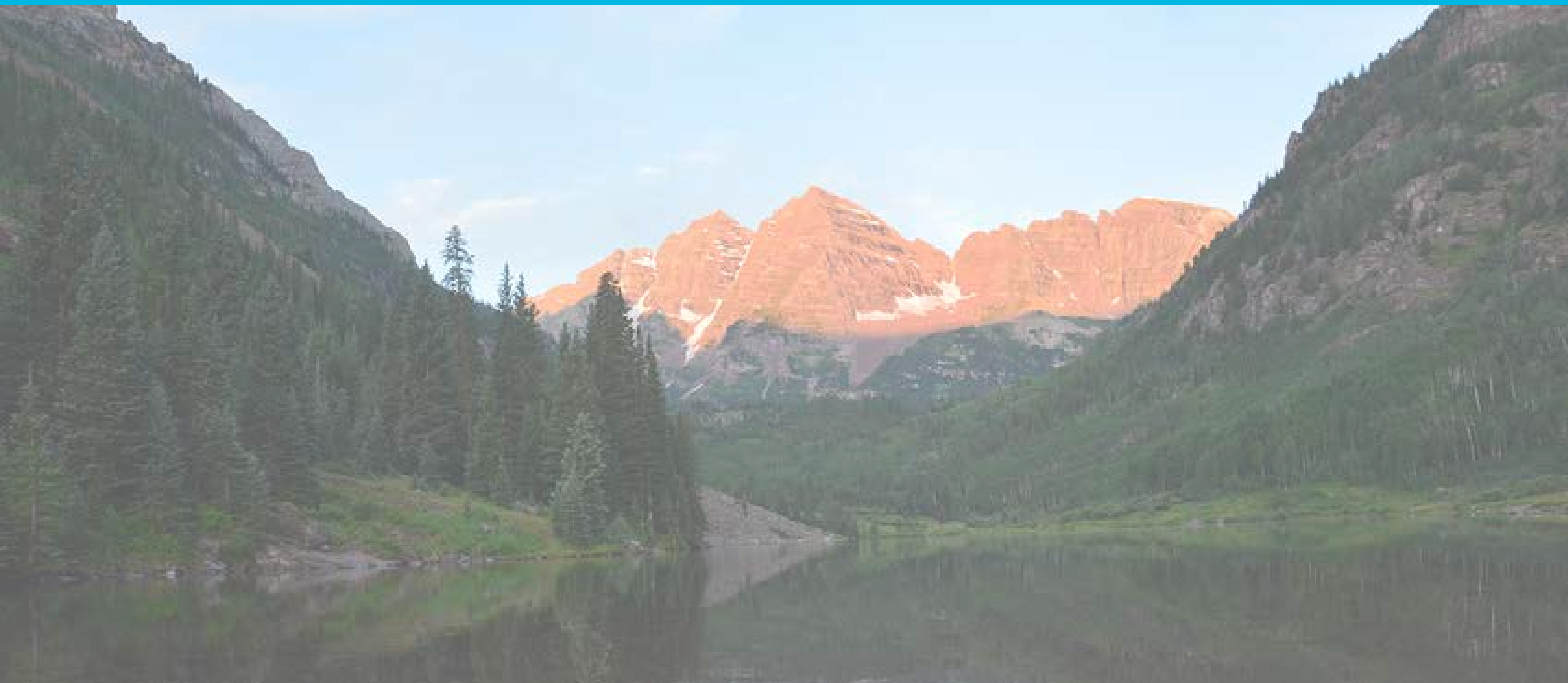
RTDS Technologies

Applications & Technology Conference

May 14, 15 & 16, 2019 • Denver, Colorado



WELCOME

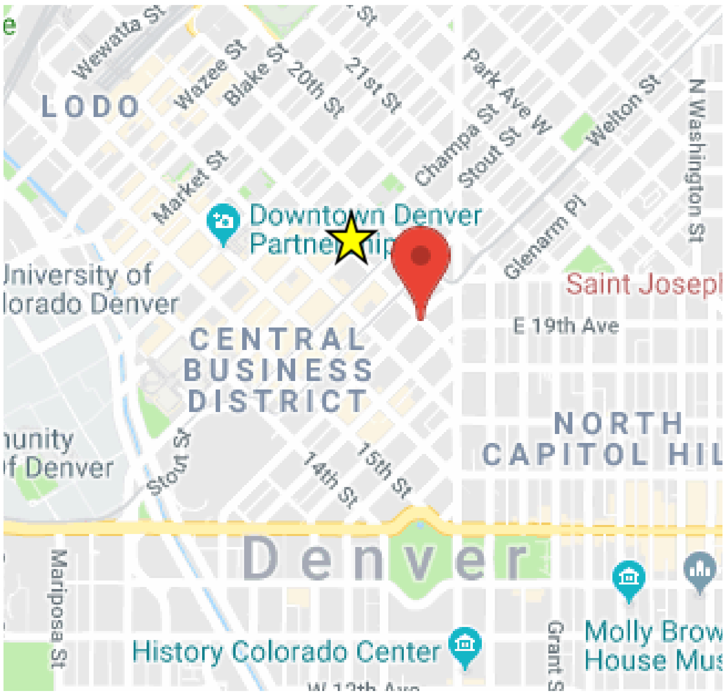
Welcome to the **2019 RTDS Applications and Technology Conference!** We are thrilled that this event continues to grow in size and in relevance to our RTDS® Simulator community. We look forward to learning about user success stories, challenges, and exciting new applications of real time simulation technology, while sharing new features and capabilities with you in order to equip you to make the most of your RTDS Simulator.

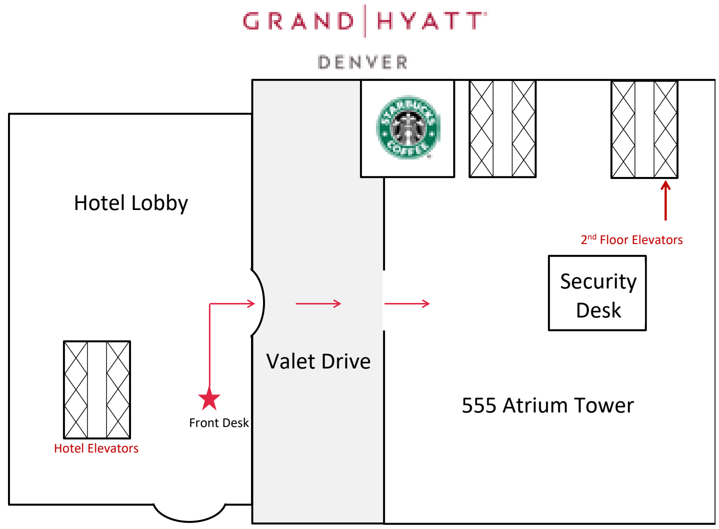
2019 marks a significant milestone – the 25th anniversary of RTDS Technologies. Looking back over decades of innovation and collaboration, we are truly amazed at how much this technology and this community have grown and evolved. The first-generation RTDS Simulator processing hardware, the TPC, was released in the early 1990s. It had a speed of 0.011 GHz and allowed a maximum of 18 nodes to be simulated on one rack. At the time, this technology was state-of-the-art, allowing engineers around the world to perform closed-loop testing with a flexible digital platform for the first time in history. Today, the capabilities of the RTDS Simulator have increased exponentially, and the role of real time simulation for power system engineers is more significant than we could have known. Looking ahead, we see an exciting future for this technology as our power system continues to change. Once a niche tool, real time simulation is now being adapted to an increasing number of grid modernization projects where its ability to efficiently and flexibly increase resilience, reliability, and grid intelligence are highly valued.

Thank you for your interest in real time simulation and your contributions to this community, and welcome to our event here in Denver. We look forward to an informative and celebratory few days.

VENUE

GRAND HYATT DENVER
1750 Welton Street
Denver, CO, USA





MEETING SPACE LOCATION

HOTEL INFO

Check In 3:00 PM

Check Out 12:00 PM

Indoor Pool

Outdoor rooftop track

Onsite restaurant

FROM THE AIRPORT

Denver Airport Rail – Travelers can use the A Line rail service from Denver International Airport to LoDo's (lower downtown) Union Station and back, courtesy of Regional Transportation District (RTD). The Denver airport rail has six stops along the way and takes approximately 37 minutes at a cost of $10.50 each way.

MEETING SPACE

Join us in the **Mt. Evans** room on the second floor in the Grand Hyatt Conference Center. Elevators are located in the Atrium Tower, across the Valet Drive from the Grand Hyatt's hotel lobby.

REGISTRATION

Tuesday: 7:30 - 8:30 AM

Wednesday: 7:30 - 8:30 AM

Mt. Evans Room (2nd floor)

PARKING

Valet parking is available at the hotel for $28.00/day or $46.00 overnight. Self-park is available at the hotel for $18.00/day.

MEALS

We will start each day with **breakfast at 7:30 AM in Pikes Peak**, which is adjacent to our meeting space, Mt. Evans room.

Lunches and coffee break refreshements will be provided daily.

MEETING WIFI

Network: Hyatt-Meetings

Password: rtds2019

PROGRAM

Tuesday, May 14

07:30 - 08:30	Registration & Breakfast
08:30 - 09:00	Welcome & Opening Remarks Rudi Wierckx, RTDS Technologies Inc.
09:00 - 09:30	*RTDS in the Dominion Energy Blackstart Study* Ren Liu, Dominion Energy
09:30 - 10:00	*Cascading Outage Analysis & Controlled Islanding on Power Systems using RTDS Simulations and Graph Theory Analysis* Rama Gokaraju, University of Sasktachewan
10:00 - 10:30	NETWORKING BREAK
10:30 - 11:00	*Using RTDS for Undergraduate Education of Engineers* Prosper Panumpabi, University of Illinois Urbana-Champaign
11:00 - 11:30	*Real Time C-HIL Implementation of 100 MVA Convertible Static Compensator (CSC) for New York Power Authority* Semih Isik & Harshit Nath, North Carolina State University
11:30 -12:00	*Analysis of NHMFL Power Supplies Upgradation using RTDS* Harsha Ravindra, Florida State University
12:00 - 1:00	LUNCH
1:00 - 1:30	*Cyber Security and the RTDS Simulator* Christian Jegues, Simulation Engineer - RTDS Technologies Inc.
1:30 - 2:00	*Cyber-Physical Resiliency Experimentation using RTDS* Venkatesh Venkataramanan, Washington State University
2:00 - 2:30	*Experiences Setting Up and Using a Cybersecurity Testbed* Yacine Chakhchoukh, University of Idaho
2:30 - 3:00	NETWORKING BREAK
3:00 - 3:30	*Real-Time Synchrophasor Applications* Clifton Black, Southern Company
3:30 - 4:00	*Latest Developments for Power Hardware in the Loop (PHIL) Simulation on the RTDS Simulator* Christian Jegues, Simulation Engineer - RTDS Technologies Inc.
4:00 - 4:30	*PHIL Testing of Integrated Supercapacitor Energy Storage System for Providing Blackstart and Wide-Area Stability Services to DER Plants* Om Nayak, Nayak Corporation & Aung Thant, Maxwell
4:30 - 5:00	*Characterizing Impacts of PHIL Interface Utilizing RTDS and Egston Compiso* Harsha Ravidra, Florida State University; Daniel Skibicki, Egston Power

PROGRAM

Wednesday, May 15

07:30 - 08:30	Registration & Breakfast
08:30 - 09:00	*A New Platform for Validating Real-Time, Large-Scale WAMPAC Systems* Steve Blair, University of Strathclyde
09:00 - 09:30	*How to Avoid Relay Misoperations due to Wrong Settings of Firmware Bugs* Juergen Holbach, Quanta Technology
09:30 - 10:00	*How SEL and RTDS Marked Historic Milestone in Power System Protection* Jordan Bell, Schweitzer Engineering Labs
10:00 - 10:15	NETWORKING BREAK
10:15 - 11:00	*New Developments & Applications in Protection and Automation* Eric Xu, Lead Simulation & Automation Engineer - RTDS Technologies Inc.
11:00 - 11:30	*RTDS Tests For Utility Protection Standards Development* Mark Xue, FlexGrid
11:30 -12:00	*Centralized Protection Approach for Interconnected Power Systems using the RTDS Simulator* Adeyemi Adewole, University of Manitoba
12:00 - 1:00	LUNCH
1:00 - 1:30	*Synchronous Condenser Controls and Protection HIL Testbed for Training, Maintenance and Operations Support* Denden Tekeste, San Diego Gas & Electric
1:30 - 2:00	*The Application of Integrated Electronic Device Protection relays in Undergraduate/Graduate Education* Doug Wagner, University of Regina
2:00 - 2:30	*Detailed AC System Modelling in RTDS* Hiranya Suriyaarachchi, TransGrid Solutions
2:30 - 3:00	NETWORKING BREAK
3:00 - 3:30	*Online HVDC Line Fault Locator Factory Acceptance Testing using RTDS.* Adam Chevrefils, Manitoba Hydro International
3:30 - 4:00	*Application of Co-Simulation Studies in Practical Power Systems* Xi Lin, Powertech Labs
4:00 - 4:30	*Faster than Real-time Co-simulation with High Performance Computing* Mayank Panwar, Idaho National Laboratory
6:00 - 9:00	*NETWORKING EVENING* *GREAT DIVIDE BREWING COMPANY* 3403 Brighton Blvd

PROGRAM

Thursday, May 16

07:30- 08:30	Breakfast
08:30 - 09:15	*Modeling and Simulation of Renewable Applications* Onyi Nzimako, Senior Applicatins Engineer, Renewables - RTDS Technologies
09:15 - 09:45	*SDG&E's Testbeds for Microgrid Controls, Distribution Protection and Automation, and Communication Schemes in RT-HIL Environment* Amin Salmani, San Diego Gas & Electric
09:45 - 10:15	NETWORKING BREAK
10:15 - 10:45	*Evaluation of Photovoltaic PV Controller Design using Controller Hardware-in-the-Loop(CHIL) Simulation* Avishek Ghosh, University of Manitoba
10:45 - 11:15	*Real-Time Electromagnetic Transient and Transient Stability Co-Simulation Model Using a Dynamic Phasor Buffer Zone* Harshani Konara, University of Manitoba
11:15 -12:00	*Power Electronic Modelling and New Substep Feature* Sumek Elimban, Lead Applications Engineer, PE & HVDC - RTDS Technologies
12:00 - 1:00	LUNCH
1:00 - 1:30	*Laboratory Setup of Modular Multilevel Converters with RTDS as Controller* Xianghua Shi, University of Manitoba
1:30 - 2:00	*Modular Multilevel Converter Control Method for High-power Applications* Mohammed Alharbi, North Carolina State University
2:00 - 2:30	*Real-time Simulation of Modular Multilevel Converter Systems for DC Grids and Hybrid AC-DC Power Systems* Gregory Kish, University of Alberta
2:30 - 3:00	NETWORKING BREAK
3:00 - 3:30	*Nelson River Bipole III HVDC Control and Protection Systems Hardware in the Loop Testing using RTDS* Chun Fang, Manitoba Hydro
3:30 - 4:00	*Data Storage & Visualization Solutions for Real Time Simulations & Experiments* Kumaraguru Prabakar, NREL
4:00 - 4:15	*RTDS Technologies Support & Latest Developments* Heather Meiklejohn, Manager, Support & Development - RTDS Technologies
4:15 - 4:45	*OPEN DISCUSSION & CLOSING REMARKS*

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Welcome & Opening Remarks

Rudi Wierckx, RTDS Technologies

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.

RTDS in the Dominion Energy Blackstart Study

Ren Liu, Dominion Energy

When a complete or partial blackout has occurred, the system operator is responsible for assessing the system condition, restoring the system based on the emergency operation procedures and re-establishing the integrity of the interconnection. This procedure is called blackstart. During the blackstart process, the system is operating in relatively weak condition, since the generation capacity is small in each blackstart path and there are plenty of different blackstart transients, such as transmission line energization, load pickup, generator synchronization, and island synchronization. In order to have a better understanding of blackstart process, dynamic behavior simulation, reply performance validation, and island synchronization are performed on the RTDS platform. In the future, RTDS will be utilized as the Real-time decision support tool for blackstart process.

Ren Liu received his B.S. degree in automation from Huazhong University of Science and Technology in 2011, his master degree in electrical engineering from Arizona State University in 2012 and his Ph.D. degree in electrical engineering from Washington State University in 2017. He currently works in Dominion Energy. His research interest includes blackstart study, battery energy storage system, microgrid, harmonic analysis, cyber-physical security of power system, and synchrophasor application.

Cascading Outage Analysis & Controlled Islanding on Power Systems using RTDS Simulations and Graph Theory Analysis

Rama Gokaraju, University of Sasktachewan

Despite layers of protection at work, power systems have experienced major blackouts due to cascading outages. Such outages can be narrowed with controlled islanding which involves two problems of "when" and "where" to island. Majority of the existing methods for "when" aspects are wide area measurement system (WAMS) based, which require system configuration or real-time computation of dynamic system equivalents. This presentation will discuss a simplified "when" approach implemented utilizing the information about which local generator out-of-step (OOS) relays tripped or not. By using local OOS protection relay trip decisions to identify the overall system instability, the methodology eliminates the need for wide bandwidth WAMS communication or the complex computation required in real-time methods to form dynamic system equivalents. The proposed methodology simplifies the communication between central "when" unit and each generator OOS protection relay by using status flags communicated between central "when" unit and each generator OOS protection relay reducing the complexity involved.

For overall controlled islanding experiment, a graph theory method is developed to find appropriate locations for "where" to separate satisfying islanding constraints such as load-generation balance, generator coherency, transmission availability, etc. Cascading outage test cases are developed in RTDS using the IEEE 39 bus system to test the proposed methodology.

Ramakrishna (Rama) Gokaraju graduated with Distinction in April 1992 from the Department of Electrical and Electronics Engineering, Regional Engineering College (National Institute of Technology), Trichy, India. He obtained M.Sc. and Ph.D. degrees in Electrical & Computer Engineering from the University of Calgary, Calgary, Canada in June 1996 and May 2000, respectively. He joined the Department of Electrical & Computer Engineering at the University of Saskatchewan as an Assistant Professor in 2003 and became a professor in 2015.

During the period 1999-2002, he worked at the Alberta Research Council, Calgary, Canada as a Research Scientist and the IBM Toronto Lab, Toronto, Canada as a Staff Software Engineer. He has held visiting professor appointments during sabbatical leaves at the University of Manitoba, Winnipeg, Canada; Power Research & Development Consultants (PRDC), Bangalore, India; University of Queensland, Brisbane, Australia; and the Indian Institute of Technology, Kanpur, India.

Dr. Gokaraju's current areas of research are in Cascading Outage Analysis, High Speed Relaying, Transient Stability Prediction and Protection, and Sustainable Energy Systems. He is a member of the J-5 Working Group ("Application of Out-of-Step Protection Schemes for Generators") of the Rotating Machinery Subcommittee, IEEE Power System Relaying Committee (PSRC). He is a registered professional engineer in the Province of Saskatchewan, Canada.

Real Time C-HIL Implementation of 100 MVA Convertible Static Compensator (CSC) for New York Power Authority

Semhi Isik & Harshit Nath, North Carolina State University

Objective: The combination of increasing electric power demand, restriction on transmission system expansion, and flexible utilization patterns for transmission network, make the development and application of power electronics-based controller for power system a high priority. Generally, Flexible AC Transmission System (FACTS) devices refer to the use of power electronics to enhance the power system performance. Voltage-Sourced Converter (VSC) based Static Synchronous Compensators (STATCOMs) are used for voltage regulation in transmission and distribution systems. Unlike PWM-controlled STATCOMs, Angle-controlled STATCOMs are switched at line frequency to limit the system losses. In recent years, angle-controlled STATCOMs have been deployed by utilities for the purpose of transmission system voltage regulation, voltage stability improvement and increasing operational functionality.

Summary: VSC consists of four three level Neutral Point Clamped (NPC) three phase inverters. Their square wave outputs are combined electromagnetically to generate a 48-pulse output voltage waveform and their DC sides are connected to a common DC-bus. The output voltages of the three level NPC poles are combined through auxiliary and shunt transformers. The primary winding of the auxiliary transformer is doubly fed open wye winding with 11.9 kV rated voltage across the winding. The secondary winding is doubly fed open zigzag winding with the same voltage rating as the primary winding i.e. 11.9 kV. The voltage across the secondary leads the primary by 30 degree. The shunt transformer aids in voltage waveform construction and serves to couple the synthesized voltage to the 345 kV transmission system. The shunt transformer has standard delta connected primary windings rated 345 kV, and open delta secondary windings rated 21.4 kV across the winding. The AC-system zero-sequence current, in case of ground faults in the AC-system, is filtered out by the primary winding delta connection. Therefore, the AC-system zero-sequence current does not flow on the STATCOM tie line. The zero angle is set to 3.75 degree to eliminate the 23rd and 25th harmonics of the NPC configuration.

Impact: CSC project is currently up and running in upstate New York. Having the actual implementation of the system in the real time based simulation allows to do any type of study faster than with offline simulations programs in case of any abnormal condition. A complex network such as CSC system is simulated using a typical timestep of 25-50 μs. Besides, switching functions can be simulated in the range of 1-4 μs.When a complete or partial blackout has occurred, the system operator is responsible for assessing the system condition, restoring the system based on the emergency operation procedures and re-establishing the integrity of the interconnection. This procedure is called blackstart. During the blackstart process, the system is operating in relatively weak condition, since the generation capacity is small in each blackstart path and there are plenty of different blackstart transients,

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such as transmission line energization, load pickup, generator synchronization, and island synchronization. In order to have a better understanding of blackstart process, dynamic behavior simulation, reply performance validation, and island synchronization are performed on the RTDS platform. In the future, RTDS will be utilized as the Real-time decision support tool for blackstart process.

Semhi Isik is currently pursuing his Ph.D. at North Carolina State University at Raleigh, NC under Dr. Subhashish Bhattacharya. He received his Bachelor's degree in Electrical Engineering from Nigde University, Turkey in 2014 and his M.Sc. thesis from NC State University in 2018. His current research is focused on Modular Multilevel Converters and on dynamic control of FACTs devices to enable large scale penetration of renewable energy resources.

Harshit Nath is currently pursuing his Ph.D. at FREEDM System Center, North Carolina State University. His adviser is Dr. Subhashish Bhattacharya. He had received his bachelor's degree in Electrical Engineering from Thapar University, India in 2015 and Master's in Electric Power System Engineering from North Carolina State University in 2017.His area of research is FACTS and its control, power system stability and grid integration of renewable systems.

Analysis of NHMFL Power Supplies Upgradation using RTDS

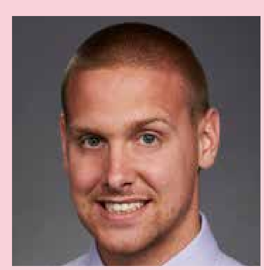
Harsha Ravindra, Florida State University

The presentation will focus on recent efforts at CAPS, FSU in modeling of the four high magnetic field strength magnet power supplies at National High Magnetic Field Lab (NHMFL). The power supplies currently operate at 650V DC, 20 kA each. NHMFL plans to operate the power supplies at 725V dc, 24 kA each in the near future. Simulation of future capabilities of power supplies as well as CHIL control of one power supply is ongoing. The power supplies are 24 pulse rectifiers with passive and active filters to keep the current supply to magnet in 10 ppm range.

Harsha Ravindra (M'13) received the M.S. degree in electrical and computer engineering from Florida State University, Tallahassee, FL, USA, in 2013. He is currently working as an Associate in Research at Center for Advanced Power Systems (CAPS), Florida State University (FSU), Tallahassee, FL. His research interests include power system, protection, transmission and distribution system modeling, renewable energy integration, MVDC systems, real-time simulation with PHIL and CHIL experiments

Cyber Security and the RTDS Simulator

Christian Jegues, Simulation Engineer, RTDS Technologies



As the modern power grid employs increasingly complex devices, operational methods, and communication networks, new methods are required in order to maintain the reliability, resiliency, and efficiency that we require from our power infrastructure. In this presentation, an example related to cyber security using the RTDS Simulator is presented.

Christian Jegues joined RTDS Technologies in 2014 after receiving his Bachelor of Science degree in Electrical Engineering from the University of Manitoba, Canada. Since joining, Christian has been involved in a wide range of tasks such as customer support, on-site commissioning and training courses, and model development. Christian has become increasingly involved in applications such as Micro-grids and Power Hardware In the Loop (PHIL) simulation. He currently holds the title of Simulation Engineer, and is a registered professional engineer in the province of Manitoba, Canada.

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Cyber-Physical Resiliency Experimentation using RTDS

Venkatesh Venkataramanan, Washington State University

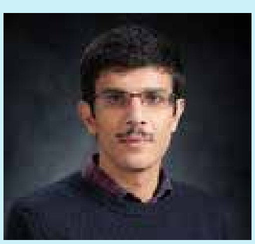
Recent cyber-attacks have been of increasing complexity and sophistication. These cyber-attacks, when targeted towards critical infrastructure such as the power grid can have a devastating impact. In order to understand the impact of cyber-attacks, it is important to consider a holistic cyber-physical system with various layers, and the data generated by them. The cyber-physical system typically consists of a physical layer, a communication layer, a management/application layer, and various devices associated with all these layers. Real-time simulation allows us to gather realistic power system data, and combine them with communication emulation to obtain cyber-physical system data. RTDS provides multiple interfaces with a variety of protocols which allows us to generate data required to compute resiliency metrics. In addition, hardware-in-loop capabilities of RTDS allows us to connect various controllers and measurement devices to emulate the real power system and test the performance of new algorithms. This talk will focus on the various interfaces used at Washington State, the projects in which the RTDS has been used, and our lessons learned.

Venkatesh Venkataramanan is a Ph.D. candidate at Washington State University. His research focuses on design and operation of resilient smart grid systems. His work involves building cyber-physical models of critical infrastructure systems, studying the impact of cyber-attacks, and designing defense mechanisms to mitigate cyber-attacks. His recent work is towards quantification of resilience. His research interests include cyber-physical systems security, data-driven quantification of resiliency, resilient systems, and smart grid modeling and control.

Experiences Setting Up and Using a Cybersecurity Testbed

Yacine Chakhchoukh, University of Idaho

The development and implementation of a power system cybersecurity testbed will be presented. The testbed is established on an isolated network with ties to an attack/defend cybersecurity lab and to a lab with a simulated control center and data analytics/visualization capability. The integration of external communication and control networks to the RTDS and the development and implementation of security policies acceptable for the university IT department will be discussed.



Yacine Chakhchoukh received the Ph.D. degree (with honors) in electrical engineering from Paris-Sud XI University (France). His industrial experience was with the French Electrical Transmission System Operator (RTE-EDF, France) where he worked for 3 years. Currently, he is an Assistant Professor at the University of Idaho. Before joining the University of Idaho, he was a project assistant professor at the Tokyo Institute of Technology (Japan) where he worked on cyber-security applied to the power systems area. He also taught and conducted research at the Technical University Darmstadt (Germany) and Arizona State University. His research interests are cyber and physical security for the smart grid, power systems control and analysis. He received the 2017 IEEE SPS Signal Processing Magazine best paper award for his work on robust signal processing and its applications to power systems (work published in 2012).

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Real-Time Synchrophasor Applications

Clifton Black, Southern Company

Synchophasors are precise grid measurements from devices called phasor measurement units (PMUs). These measurements are streamed at rates of 30 samples per second or higher, which is over 100 times faster than the traditional SCADA approach. PMUs incorporate GPS technology which permits all measurements to be time-stamped relative to a common time reference. The data are aggregated and time-aligned allowing measurements from dispersed locations to be combined to provide meaningful information about the grid. Synchrophasors can be used to develop tools that enhance the operators's ability to manage and operate the power system. Real-time applications include but are not limited to: wide-area situational awareness, oscillation monitoring, voltage stability monitoring, frequency excursion monitoring, intermittent resource integration, dynamic line ratings and congestion management, event detection and mitigation and islanding detection. These applications must be tested and validated to ensure that they will yield robust and trustworthy decision support information. One approach to such validation is the streaming of simulated synchrophasor data into these tools from a RTDS in which various grid disturbances have been modeled. One can then assess how well the applications identify and characterize these simulated grid disturbance phenomena and ensure that the relevant settings and thresholds are appropriately configured. The presentation illustrates the validation of a few of the referenced grid phenomena using the RTDS.

Clifton Black currently leads Southern Company's Grid Visualization and Analytics Center in the Power Delivery research area. In this role, he is responsible for directing internal research efforts and managing collaborative partnerships with external organizations in Grid Operations, Planning and Visualization and Distribution. His technical focus areas include situational awareness, data analytics, power system analysis, security and resiliency. Clifton began his career in Power Delivery R&D with Southern Company in 2006. Over the years, he has led and developed several research programs and projects spanning a wide range of technology areas. These include synchrophasor technology, distributed generation including energy storage, dynamic line ratings, big data analytics, stability monitoring and assessment, security and visualization. Clifton attended the University of Alabama (Tuscaloosa) where he received the BS, MS and PhD degrees in Electrical Engineering.

Latest Developments for Power Hardware In the Loop (PHIL) Simulation on the RTDS Simulator

Christian Jegues, RTDS Technologies

Power hardware in the loop (PHIL) simulation involves the real-time simulation environment exchanging power with real, physical power hardware, such as renewable energy hardware, electric vehicles, batteries, motors and loads. PHIL simulation allows for real time testing of devices in a controlled environment before they are connected to the actual physical system. The fidelity of the interface between the RTDS™ Simulator and the device under test is crucial in maintaining the accuracy and stability of the simulation results. In this presentation, the latest developments related to Power Hardware In the Loop (PHIL) Simulation on the RTDS Simulator are presented.

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PHIL Testing of Integrated Supercapacitor Energy Storage System for Providing Blackstart and Wide-Area Stability Services to DER Plants

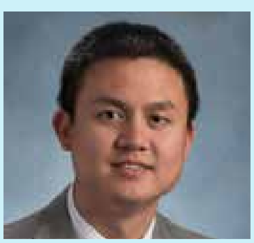
Om Nayak, Nayak Corporation & Aung Thant, Maxwell

Creating and maintaining a black-start strategy is very important for utilities. A successful strategy starts with identifying feasible power sources in feasible cranking paths. Having more such sources available at your disposal increases the flexibility, effectiveness and reliability of the strategy. Supercapacitor Energy Storage System (SESS) with its fast response time is ideally suited to provide cost competitive Watt-Hz support during the black-start sequence so that some of the existing DER plants can be made to be feasible candidates. Idaho National Lab in partnership with Maxwell Technologies initiated a DoE project to evaluate this technology. Being the first of its kind application, real-time PHIL testing was considered an essential step to validate the strategy to de-risk the investment in a field pilot. This presentation discusses the PHIL test setup with the SESS power hardware interfaced with a candidate DER plant modeled in RTDS™. The test demonstrates the effectiveness of the strategy and gives confidence to propose the field pilot. Supercapacitors are supplied by Maxwell Technologies. The converter and controls are supplied by EPC Power.

Dr. Om Nayak is the President of Nayak Corporation. He has extensive hands-on experience with RTDS and PSCAD as a developer, user and as a consultant to many utilities and industries in the US. Additionally, as a past lead developer of EMTDC (PSCAD) at Manitoba Hydro International in Winnipeg, Canada, he has in-depth understanding of electromagnetic transient simulation of power systems.

Dr. Nayak obtained his bachelor's degree from Mysore University, India and M.Sc. and Ph.D. degrees from University of Manitoba, Canada, all specializing in power systems. He is a Senior Member of the IEEE.

Nayak represents RTDS Technologies in the US and India. They also represent PSCAD, Spitzenberger and Spies Amplifiers and other complimentary simulation tools in the US and India and provide training, technical support and consulting services involving all these tools.



Aung Thant is a power systems engineer currently performing advanced architecture and designs, modeling and simulations of utility distribution level energy storage utilizing Maxwell's ultracapacitor grid modules and commercially available advanced batteries. He works with utility and C&I customers to identify the best strategic approach for their energy storage requirements, which may include a stand-alone ultracapacitor ESS or a hybrid ultracapacitor-battery ESS system.

Mr. Thant received his education from New York University – Polytechnic/Tandon School of Engineering with BSEE and MSEE degrees in electrical engineering. He joined Nayak Corporation for eight years as senior engineer where he performed electromagnetic transient studies and hardware-in-the-loop testing for North American and international utilities.

Prior to joining Maxwell in March 2018, Thant was an RTDS engineer for San Diego Gas & Electric's Distributed Energy Resources (DER) team where he applied his technical expertise to solve problems in DER integration leveraging his HIL testing and RTDS experience.

Characterizing Impacts of PHIL Interface Utilizing RTDS and Egston Compiso

Harsha Ravindra, Florida State University

This presentation focuses on characterizing PHIL interfaces utilizing RTDS and EGSTON COMPISO System Unit (CSU) as well testing the latest interface between simulator and hardware which would reduce latencies for PHIL experiments

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A New Platform for Validating Real-time, Large-scale WAMPAC Systems

Steven Blair, University of Strathclyde

Introduction: Power systems are increasingly reliant on Synchrophasor-based methods for monitoring, protection, and control. Testing of such schemes is of critical importance before they can be accepted and deployed.

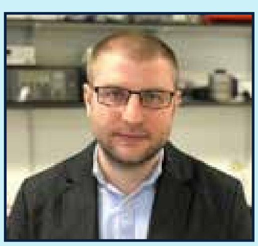
This paper describes a new platform for validating wide-area monitoring, protection, and control (WAMPAC) systems in real-time. The platform is an extension to an RTDS power system simulator, and uses the "GTFPGA" unit to generate 16 simultaneous streams of IEC 61850-9-2 Sampled Value (SV) data representing waveforms from the simulation. Each SV data stream contains three-phase voltage and current samples from four independent locations in the RTDS simulation. This is equivalent to representing data for 64 unique and distributed Phasor Measurement Units (PMUs). Each SV stream is connected to a quad-core ARM-based device (in this case, a Raspberry Pi 3 Model B+) to process the waveform data according to a software PMU signal processing algorithm – with each CPU core dedicated to implement one PMU. PMU output data is streamed from the ARM device according to the IEEE C37.118.2 standard.

High-Fidelity PMU Implementation: The PMU algorithm executed within each ARM processor core uses an adaptive filter window [1] and has been selected for to its state-of-the-art measurement performance. This platform therefore provides a convenient and cost-effective method for emulating a large number of high-fidelity PMUs that are driven by power system simulation data. The component can readily be added to existing RTDS simulations to enable WAMPAC functions. Although an RTDS can also generate multiple PMU data streams using GTNET cards, this approach is limited in the choice of PMU algorithm and the Synchrophasor dataset used (although using GTNET cards does have advantages such as greater convenience of integration within an RTDS simulation, guaranteed real-time performance, and support for other protocols).

An open source mapping of IEC 61850-7-2 to web services [2], [3] has been used to automatically create an HTTP interface for monitoring and managing each PMU. A web interface has been created to allow the PMU type (P class or M class) and reporting rate to be dynamically modified, at run-time, for different types of experiments. There is also flexibility to entirely change the PMU algorithm if required.

The platform is designed to efficiently direct SV and IEEE C37.118.2 traffic to only the correct devices, and the processor allocation on the ARM processor is strictly controlled to ensure real-time operation.

Conclusions: This development provides a new way for emulating 64 high-fidelity PMUs in large-scale WAMPAC systems, particularly for validating novel visualisation, control, and data analytics methods. The platform has already been used for validating wide-area frequency control and backup transmission system protection applications.



Steven Blair received the M.Eng. degree (with distinction) in computer and electronic systems and the Ph.D. degree in electrical engineering from the University of Strathclyde, Glasgow, UK in 2008 and 2013, respectively. Dr Blair is a Lecturer at the University of Strathclyde. He is a member of IEC Technical Committee 57 Working Group 10 and CIGRE Working Group B5.64. His research interests include power system protection, communications, measurements, power quality, and real-time simulation.

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How to Avoid Relay Misoperations due to Wrong Settings of Firmware Bugs

Juergen Holbach, Quanta Technology

Utilities developed in the past good processes and tools for the setting development task. By using standard calculation sheets that are based on a consistent setting philosophy the quality of protection settings can be guaranteed. But still, statistics show that many misoperations can be traced back to wrong settings (28%) or firmware problems (20%) [NERC Protection System Misoperations Task Force 2013]. The proposed paper reports on a project that used a real time digital simulator (RTDS™) for hardware in the loop testing to verify the correct relay settings and relay behavior on a 500 kV transmission line. During the project relay setting problems as well as firmware issues were discovered and could be resolved before the deployment of the relay scheme. The paper makes a case that hardware in the loop testing has become an economical option for the verification of the correct relay scheme behavior not only for the high end applications. This is based on the fact that automation can help during the testing and analyzing of the test results and can so lower cost and time to perform a sophisticated relay test. By evaluation the consequences of a misoperations against the cost of hardware in the loop testing, it can be shown that of hardware in the loop testing has become an economical method in the relay setting development process and verification of a correct relay application. This is particular true for utilities that own real time digital simulator hardware. The paper will discuss some of the findings and show how automation enabled the processing and reporting of over 3000 test in two week.

Dr. Juergen Holbach, Senior Director has more than 30 years of experience in design and application of protective relaying. He started his career in the development department of a German relay manufacturer and led the development project of numerical line differential relays. Juergen was one of the lead engineers on the first IEC61850 based Protection and Control, Multi-Vendor Project in the United States (500KV Bradley Station-TVA). In recent years, Juergen has been involved in several industrial and utility projects focusing on wide-area protection coordination studies, industry load shedding and islanding schemes, Real Time Digital Simulation (RTDS) testing of protection and control schemes and Power System Fault analysis

Juergen contributed to several working groups in CIGRE as well as in IEEE-PSRC and is the chairmen of the working group H5 “Common format for IED configuration data”. He is also member of the IEEE-PSRC subcommittees “Relay Practices” and “Relay communication”. He published over a dozen papers at the major relay conferences in North America and is member of the Georgia Tech Protective Relaying Conference Planning Committee.

How SEL and RTDS Marked Historic Milestone in Power System Protection

Jordan Bell, Schweitzer Engineering Labs

Public Service Company of New Mexico (PNM) has a 345 kV series-compensated transmission line that was bisected by a new substation. The location of this substation resulted in one of the new line segments being overcompensated by 170 percent. Because of this, the line protection scheme applied by PNM included both phasor-based and ultra-high-speed (UHS) protection using incremental- and traveling-wave-based principles. This marked the first time that a relay based on traveling-wave protection principles was applied to protect a high-voltage transmission line with the trip circuits live to the breakers. This event was made possible with the use of the new Traveling Wave Relay Testing (TWRT™) capability in the Real Time Digital Simulator (RTDS®).

Jordan Bell received his BSEE from Washington State University in 2006. He joined Schweitzer Engineering Laboratories, Inc. (SEL) in 2008 as a protection engineer in the SEL Engineering Services, Inc. (SEL ES) group, where he is currently a Senior Engineer and supervisor. He performs event report analysis, relay settings and relay coordination, fault studies, and model power system testing using a real-time digital simulator. He is a registered professional engineer in the state of Washington and a member of IEEE

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New Developments & Applications in Protection and Automation

Eric Xu, Lead Simulation & Automation Engineer, RTDS Technologies

A couple of new GTNETx2 components were developed to further enhance the functionality of IEC 60870-5-104 and Socket protocol. Routable GOOSE and Sampled Values based on IEC TR 61850-90-5 are introduced. GTFPGA-SV now supports Sampled Values subscription. Updates of GTSYNC on supporting IEC 61850-9-3 Power Utility Profile are reviewed, and more.

Eric Xu joined RTDS in 2009 after graduated from University of Manitoba with the Distinguished Award. Since joined, Eric has been involved in technical support, user training and GTNET component models development. Eric is a Registered Professional Engineer in the Province of Manitoba and a member of IEEE. He is also an active member of IEC Technical Committee 57 Working Group 10 which is the section working on the development of the communicationstandards for substations – functional architecture and general requirements. Eric currently serves as the Lead Simulation and Automation Engineer in the protection and automation group.

RTDS Tests For Utility Protection Standards Development

Mark Xue, FlexGrid Technologies

Every utility would love to have a set of protection standards, because standards can help utility to improve productivity and quality of engineering. After all, power system reliability can be improved with good standards. A set of protection standards include setting templates, drawings, guides, etc. A standard should be foolproof, meanwhile it needs flexibility to accommodate different applications. Modern IED relays can have thousands of settings and programmable logic to support various applications. Because of the complexity of IED relays and the applications, the development of standards is typically an evolving process. It takes years of operation experience and numerous lessons-learned to make a set of good protection standards. ElectraNET, an Australia utility has determined to develop a set of protection standards. Through a few previous projects that RTDS was used to verify protection settings, ElectraNET engineers realized the power of RTDS can help them to achieve the goal within a short period. They believe that the newly developed standards can be examined from all the angles by performing RTDS tests in the lab, without taking the risk of trial-and-error.

Two engineers spent three weeks in UNSW RTDS lab to check the transmission line protection standard package. Part of ElectraNET's network was modeled on RTDS and a few selected relays were put in the test loop. A few line protection schemes were thoroughly checked by simulating all sorts of faults and operation conditions. RSCAD script and VBA/spreadsheet were used to organize the test cases including the planned ones and the on-the-fly cases. During the tests, not only flaws in the protection scheme and settings were identified, a couple of issues with specific relay design was also found. After this test, ElectraNET engineers gained full confidence with their line protection standards.

The experience of this project may provide some help to utility engineers that wish to develop and verify protection standards using RTDS. The RTDS test experience on other protection applications will also be touched in this presentation as well.

Mark Yiyan Xue received his B.Eng. from Zhejiang University in China and M.Sc. from the University of Guelph in Canada. With 25 years technical experience in power system engineering, Mark is a protection and control specialist to service utilities and industrial customers. In the past, he had spent 8 years with American Electric Power (AEP), 3 years with GE Multilin and 10 years with ABB. Through various technical roles, Mark has built expertise in protection & control system design, transient simulations and analysis, RTDS tests, relay settings calculation, power system modelling, system integration for digital substations and software development. Mark has one US patent and presented over 10 technical papers in major relay conferences. He is a senior member of IEEE and a Professional Engineer registered in the state of Ohio, USA.

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Centralized Protection Approach for Interconnected Power Systems using the RTDS Simulator

Adeyemi Adewole, University of Manitoba

Local protective relays distributed across power systems are prone to misoperate in interconnected microgrids integrated with Distributed Energy Resources (DERs) mainly due to the changes in the power flow pattern, fault current level, and difficulty in protection coordination. This paper presents a non-traditional Centralized Intelligent Station-Level Protection (CISP) approach in the simultaneous protection of multiple electric power apparatuses in interconnected (networked) microgrids. A new dynamic Protection Zone Selection (PZS) algorithm is proposed to account for the dynamic behavior of such microgrids, various operating topologies (grid-connected and islanded modes), and various system operating scenarios. Also, three new protective relaying algorithms are proposed for the protection of the electric power apparatuses in the zones determined by the PZS algorithm. Furthermore, the PZS algorithm intelligently determines the protection zones in MATLAB using graph theory, and communicates the results to the CISP algorithms implemented in the RTDS® simulator. The inputs to the CISP algorithms are wide area IEC 61869-9 Sampled Values (SVs) from the RTDS GT-FPGA and IEC 61860 GOOSE binary signals from the GTNET card. The modified IEEE 13-node distribution feeder integrated with DERs is modelled in RSCAD and was used in testing the proposed CISP approach in real-time. Results obtained are promising and showed that the centralized protection performed its intended function.

Adeyemi Charles Adewole received his Master's and Doctorate degrees in Electrical Engineering from the Cape Peninsula University of Technology, Cape Town in 2012 and 2016, respectively.

Currently, he is a Post-Doctoral Fellow at the University of Manitoba, Winnipeg, Canada. His research interests include substation automation, power system protection, and grid integration of distributed and renewable energy systems. He is a Member of IEEE, IET, and CIGRE B5.62 and B5.64 working groups.

Synchronous Condenser Controls and Protection HIL Testbed for Training, Maintenance and Operations Support

Denden Tekeste, San Diego Gas & Electric

Worst case power system conditions are rare and dangerous to induce in the real world. Thus, the testing of the influences of synchronous condensers on the real power grid is impossible. In addition, due to the large amounts of reactive power these devices could absorb or inject into the grid at a high speed when responding to a fast system transient, the improper coordination and operation can turn a positive desirable outcome into an adverse response. An adverse response could jeopardize the system reliability. It is also important to study potential interaction between the device controller and other devices installed in the same network or in some cases in the same bus or substation. In the case of the San Diego Gas & Electric (SDG&E) synchronous condenser projects, the above-mentioned situations could be tested using the an RTDS-HIL replica controller. SDG&E has installed a total of Seven (7) 225MVA synchronous condenser. Five (5) synchronous condensers within one bus away from each other. Thereby the overall system performance of synchronous condensers can be optimized through closed-loop testing under the most realistic test conditions possible.

Denden Tekeste graduated from San Diego State University in 2010, works for San Diego Gas and Electric (SDG&E) since graduation and a licensed Professional Engineer in the state of California. He has rotated in varies department within SDG&E such as Transmission planning, Grid operation, Substation Engineering, Design construction, and he's currently the Team lead of Transmission planning- Grid Assessment group.

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The Application of Integrated Electronic Device Protection Relays in Undergraduate/Graduate Education

Doug Wagner, University of Regina

The U of R Power Systems lab, equipped with a variety of IEC 61850 compliant IED's and injection test equipment has produced a number of successful project outcomes including; GOOSE security management over wide area networks, travelling wave based protective (in collaboration with the University of Saskatchewan), islanding control and protection scenarios, NERC compliant DG protection, and generator control application, since its commissioning in 2014. The lab supports a number of undergraduate and graduate student learning objectives in addition to capstone and graduate thesis projects. Examples of these projects included:

- Generating GOOSE traffic via SEL 751A/SEL 2411 IED's, managed via two Linux interface machines, managed via a 3rd, simulating inter-station tie via SEL ICON terminals.
- Development of a travelling wave algorithm, with COMTRADE data input, to validate (through MatLAB, and in the future hardware testing) the algorithm security and dependability
- Multiple SEL 751A, controlled via SEL 2411 allowing priority load shedding under planned and unplanned islanding scenarios using sample values via IEC 61850 communications.

The next phase lab development incorporates Real Time Digital Simulation, offering exciting opportunities to further support the existing coursework, and creates an opportunity to prepare graduates to understand and engineer the new frontiers of IEC 61850 based process bus technology by understanding its performance and application.

Doug Wagner is a graduate of the Electronic Information Systems Engineering (EISE) program (1990-Distinction), prior to this, he worked 10 years in broadcast transmission technology with the Canadian Broadcasting Corporation (CBC). In 2000 Doug left the CBC, providing RF consulting services, and in 2002 joined the University of Regina as a sessional lecturer, and in 2008 became an instructor as part of the faculty at the U of R.

Since 2008 he has led the power systems curriculum at U of R, and led the implementation of the Protection lab in 2014.

Doug leads Protection and Relay Testing laboratory, funded externally through Innovation Saskatchewan with over $250,000 of technical assets, provided through ongoing partnerships with equipment suppliers, and industry/employer partners who have helped shape this facility such as RTDS, SEL, SaskPower, Siemens and Omicron.

Detailed AC System Modelling in RTDS

Hiranya Suriyaarachchi, TransGrid Solutions

Unlike the past, nearly every power system in the world today contains a large number of power electronic based devices. This makes today's power systems more complex. The dynamics of power electronic based devices are heavily dependent on their controls. Therefore, accurate modelling of these devices and studying the behaviour of the integrated system have become important. There is an increased tendency by network owners to use RTDS and control replicas to study their systems. Currently, we are developing an integrated AC network model of a large power system which is planned to be connected to multiple HVDC control replicas. This presentation will discuss the benefit to the network owners of having a detailed AC system model, and the high level methodology and the challenges faced in developing such a model.

Dr. Hiranya Suriyaarachch received the B.Sc. Engineering degree from University of Moratuwa, Sri Lanka in 2003 and M.Sc. and Ph.D. degrees from University of Manitoba, Canada in 2008 and 2014, respectively. Since 2010, he is with TransGrid Solutions where he was involved with a number of HVDC projects in North America, Europe and in Asia. He has developed dynamic network equivalent models for number of HVDC and FACTs manufacturers to perform factory acceptance testing of their equipment and currently leading the development of a network model for a 6000 bus AC system. Dr. Suriyaarachchi is actively participating in some CIGRE and IEEE working groups on VSC HVDC technology.

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Online HVDC Line Fault Locator Factory Acceptance Testing using RTDS

Adam Chevrefils, Manitoba Hydro International

MHI develops and builds an online HVDC Line Fault Locator (dcLFL) that have been installed in several projects world-wide. As part of the factory acceptance test (FAT) procedures, end-to-end system tests are performed at our lab prior to shipping the fault locators to the site. Line faults are emulated by triggering the dcLFL wave front detector modules with controlled pulses.

In the past emulated line fault tests were limited to simulating mid-line faults. Recently, those tests have been performed using hardware-in-the-loop real-time simulations on RTDS. With this technique, faults can be simulated anywhere along the line model. This successful testing has increased client confidence in the system before the hardware leaves the factory. This presentation will review the simulation approach and different modeling options that have been used during product development and FAT stages.

Adam Chevrefils M.Sc., P.Eng, is a Power Systems Simulation and Project Engineer with Manitoba Hydro International. He has over 10 years of experience in engineering studies using a variety of simulation tools including PSCAD and PSS/E and hardware development and testing.

Adam has worked extensively and closely with external clients to develop simulation models and techniques that have led to the development of new product offerings and patent applications. He has been involved in all aspects of Manitoba Hydro International, including model development, studies, education and training, marketing and product development and testing.

In his current position, Adam is part of the team responsible for the design, construction, factory acceptance testing and field commissioning of the full line of hardware products currently offered by the Manitoba HVDC Research Centre. He is also active in the research and development program leading to new and improved product offerings.

Application of Co-Simulation Studies in Practical Power Systems

Xi Lin, Powertech Labs

Co-Simulation studies aim at providing a platform to perform synchronized and real-time simulations using Electro-Magnetic Transient (EMT) simulation package and Transient Stability Assessment (TSA) tools. In this application, system is separated into an internal system (modeled in EMT) and external system (simulated in Phasor-Domain) to take advantage of the modeling capability of the EMT and TSA packages. The Co-Simulation studies offer several advantages that include performing hardware-in-loop testing with a much larger portion of the system, using detailed EMT models in a positive sequence TSA study, and capturing low-frequency oscillations in the EMT study. As a Co-Simulation platform, TSAT-RTDS Interface (TRI) has been used in several projects and applied to practical power systems and the presenter will share Powertech's experience in using TRI and provides details about the process of creation of the Co-Simulation studies. If the base power system is too large, such process typically starts with a dynamic system reduction to reduce number of buses to less than 10,000, which is a practical size for running the system in real-time in TSAT. Based on the purpose of the Co-Simulation study, the boundary between internal and external systems are determined next, which are used to develop the proper model in RTDS and determine injection points in TSAT-side of the simulation. In this process, adjustments may be made to the RTDS model to include additional dynamic details that are not available in the Phasor-Domain model. The presentation will also demonstrate a case study and discuss how the results may be analyzed.

Xi Lin received the Bachelor degree in mechanical engineering from the Tsinghua University, China in 1997 and the Master degree in electrical engineering from the Nanjing Automation Research Institute (NARI), China, in 2000. He received the Ph.D. degree in electrical engineering from the University of Manitoba, Canada in 2011. He has been with Powertech Labs Inc. in Surrey, Canada since 2007. He leads the development team of the DSAToolsTM software. His research interests include power system stability and control, power system simulation.

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Faster Than Real-time Co-Simulation with High Performance Computing

Mayank Panwar, INL

Electric grid is becoming more complex, dynamic, and less predictable due to integration of newer technologies and approaches, driven jointly by science and policy. The reducing inertia and increasingly dynamic grid have increased the risk of cascading failures, thereby compromising resiliency. From computation and controls perspective, some of the major challenges of the grid include, but are not limited to, prediction and mitigation of cascading failures, real-time adaptive methods for protection and remedial action schemes, and real-time resiliency analysis considering several multi-timescale factors. We present an approach to integrate high-performance computing and RTDS to enable faster-than-real-time co-simulation. We also present this co-simulation setup to effectively address some of the challenges and rapidly evolving needs for data-driven and learning-based methods for control.

We will present the co-simulation setup, and some results for potential applications including

i. Faster Than Real-time Prediction and Control of Cascading Failure in Electric Grids

ii. Multi-dimensional Real-time Resilience Computation and Applications

iii. Geographically Distributed Real-Time Co-simulations with HPC and RTDS

Mayank Panwar is a Research Scientist in the Power and Energy Systems department at Idaho National Laboratory. His research interests are power system modeling, real-time simulation, microgrids, and protection systems. He has a B.Tech. in electronics and instrumentation engineering from U.P. Technical University in India, and M.S. and Ph.D. degrees in electrical engineering from Colorado State University in Fort Collins, CO, USA. He is a member of IEEE PES.

NETWORKING EVENT

GREAT DIVIDE BREWING CO

Wednesday, May 15 • 6:00 PM - 9:00 PM
3403 Brighton Blvd, Denver, Co, 80216
SEE MAP ON BACK PAGE

Join us at the Great Divide Brewing Company for a fun evening together! This is a chance to unwind, get to know your fellow delegates, and enjoy games of ping pong or cornhole in the Bottling Hall! There will be brewery tours from every half hour from 6:30 - 7:30. Dinner will be served from one of Denver's famous food trucks!

This meal is complimentary. Dress code is business casual.

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Modeling and Simulation of Renewable Applications

Onyi Nzimako, Senior Applications Engineer, Renewables - RTDS Technologies

Integration of renewable energy sources is a mainstream trend around the world. Rapid technology advancements has enabled the wide spread integration of solar and wind systems to power systems traditionally characterized by conventional energy sources. This session will discuss current trends, demands and developments for real time modeling and simulation applications of renewable energy systems.

Onyi Nzimako joined RTDS Technologies in 2010 after receiving her B.Sc. degree in Electrical Engineering from the Unviersity of Manitoba, Canada. She currently holds the title of Senior Simulation Engineer, Renwable Applications and works on developing power and control system models. Her current interests are in the area of modeling renewable energy systems and Hardware in the Loop applications.

SDG&E's Testbeds for Microgrid Controls, Distribution Protection and Automation, and communication Schemes in RT-HIL

Amin Salmani, San Diego Gas & Electric

In this presentation Amin Salmani will present RTDS activities within SDG&E, which includes SDG&E's testbeds for microgrid controls, distribution protection and automation, and communication schemes in RT-HIL environment. This presentation will include in depth description of two of SDG&E's most recent projects that have taken advantage of RTDS capabilities. Furthermore, Amin will briefly introduce the rest of RTDS oriented projects with describing/showing developed testbeds at SDG&E's Integrated Test Facility (ITF).

Amin Salmani has more than 10 years of hands-on experience with solution development, evaluation, design, implementation, and advisory service in energy and power industry with a focus on power electronics applications, emerging technologies, microgrids, and battery systems.

Amin has provided consulting services to two of California's utilities (PG&E and SDG&E) and has worked for different power systems solution providers (such as Varentec Inc.). In his current role, Amin is a Principal Engineer at SDG&E.

Amin's profound insight on energy and power business and technology was acquired through handling projects for SDG&E EPIC Program and grid modernization projects as well as technology development and system integration in Varentec. Amin is Licensed Professional Engineer in the State of California and his enhanced analytical thinking and problem-solving ability is backed by a PhD in power systems (FSU, 2014) and proved by 9 registered patents and 20 technical publications.

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Evaluation of Photovoltaic PV Controller Design using Controller Hardware-in-the-Loop(CHIL)

Avishek Ghosh, University of Manitoba

Solar energy is classified as an environment friendly renewable resource that can potentially mitigate the energy crisis. Photovoltaics (PV) is an effective solar energy conversion technique which can directly transform solar energy into electricity using semiconducting materials without having any adverse effect on the environment during the conversion process. In modern day PV systems, the energy conversion and conditioning is typically achieved by a first-stage DC/DC converter sometimes referred as micro-boost cell (MBC) followed by a second-stage grid-connected inverter. The output voltage of the MBC is fixed by the DC bus hence it operates in an inverse-buck mode to control the input voltage. It implements a Maximum Power Point Tracking (MPPT) controller to ensure maximum power extraction from the PV source under all conditions. A second voltage controller maintains MBC input voltage at the maximum power point located by the MPPT controller. This work adopts a simplified approach to obtain a comprehensive small signal model of a MBC and its controllers. The designed models are verified using Controller Hardware-in- the-Loop (CHIL) method.

CHIL simulation consists of an actual control hardware being interfaced with a power stage simulated in a Real Time Digital Simulator (RTDS) environment. In this work, the power stage consisting of a PV source and MBC is simulated in RSCAD, a RTDS based interfacing software and the controller is implemented using a DSP. A digital interface using Giga-Transceiver Digital Input (GTDI) card provides the gate pulses from the actual controller to the 'virtual' converter. The dynamic behaviour of the control system is experimentally studied in both steady state and transient conditions. Following this method, PV control system designers can evaluate their controllers under different operating conditions to ensure its stability and reliability. Public utility companies can benchmark and evaluate PV control systems using CHIL simulation before any real life installation.

The presentation will demonstrate a CHIL simulation test bed using RTDS for evaluating solar MBC controllers. Moreover, design and implementation issues, system analysis and experimental results will also be discussed.

Avishek Ghosh received the B.Eng. degree in Electronics and Electrical Engineering with first class honours from the University of Glasgow, UK in 2012. He has worked in the Energy sector in India from 2012 to 2016. As a Project Engineer, he gained industrial experience in areas of manufacturing, testing and commissioning of Electrostatic Precipitator (ESP) technologies, HV Switchgears, and other substation equipments. He successfully completed his M.Sc. degree from the department of Electrical and Computer Engineering at the University of Manitoba, Winnipeg, Canada in April 2019. He is currently pursuing his PhD degree and working as a Research Assistant at the Renewable-energy Interface and Grid Automation (RIGA) Lab in the University of Manitoba. His current research interests include Wide-bandgap semiconductor device characterization, applications and Power Hardware in the Loop simulations.

Real-Time Electromagnetic Transient and Transient Stability Co-Simulation Model Using a Dynamic Phasor Buffer Zone

Harshani Konara, University of Manitoba

There is an increasing interest among utilities to perform real time simulation of large power systems. If the entire power system is simulated using real time simulators, the cost of hardware can be prohibitive to many utilities. There has been many efforts to perform real time co-simulation where the part of the network that needs to be modelled with details is modelled using Electromagnetic Transient (EMT) models while the remaining part modelled using conventional Transient Stability (TS) models. The established approach of interfacing the two networks (EMT and TS) is to have a Frequency Dependent Network Equivalent at the boundary between the EMT and TS parts of the network.

We investigated an alternative approach that eliminates the need of an FDNE. In the proposed co-simulation model the interface between the two models is a portion of the network (buffer zone) modelled using Dynamic Phasors (DP). This requires two interfaces, namely, EMT to DP and DP to TS. The challenges of interfacing EMT-DP and DP-TS and the proposed solutions will be presented. A data prediction method is used to overcome the time-step delay between EMT and DP models. Since high frequency dynamics in the TS

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part are of no interest, the TS part of the simulation uses a relatively larger time-step than DP and EMT. The challenges associated with using two different time steps will be discussed and the proposed solutions will be presented. The numerical stability and accuracy of the proposed EMT-DP-TS co-simulation tested on the IEEE 68 bus system with an LCC HVDC in-feed will also be presented to conclude that the proposed approach has the potential to replace FDNE at interfaces.

Harshani Konara graduated from the University of Peradeniya, Sri Lanka in 2012 with a B.Sc. in Electrical and Electronic Engineering. She completed her M.Sc. degree at the University of Manitoba in 2015 and her thesis project was on interfacing dynamic phasor model to RTDS simulator. She is currently working toward the Ph.D. degree at the University of Manitoba, Canada. In her Ph.D. research, she developed a real-time co-simulation model using Electromagnetic Transient model and a Transient Stability model.

Power Electronic Modelling and New Substep Feature

Sumek Elimban, Lead Applications Engineer, PE & HVDC, RTDS Technologies

Power Electronic modelling requires small time steps to accurately represent the higher frequency phenomena and circuit dynamics. The Small Time Step environment is one of the most widely used applications for the RTDS simulator. RTDS Technologies has recently released several new features to increase the power electronic simulation capabilities of the simulator. This tutorial session will go through the available resources to model power electronic based systems.

Topics include:

- Small time step enhancements
- GPES, executed on the GTFPGA unit, a flexible platform for modelling custom converter topologies at a reduced time step.
- Substep, modelling power electronic circuits with pure resistive switching which will provide clean waveforms, low losses and still maintains a very small time step to support high switching frequencies. Substep is a result of the significant increase in computing power of NovaCor.

Sumek Elimban is a Lead Applications Engineer at RTDS Technologies. He joined RTDS in 2011 after receiving his B.Sc. degree in Electrical Engineering from the University of Manitoba, where he was awarded the Engineering Gold Medal. His main role is working in the field of HVDC and Power Electronics for the RTDS Simulator. He is an active member in CIGRE, participating in WG B4. 70 Guide for Electromagnetic Transient Studies involving VSC converters and WG B4.72 DC grid benchmark models for system studies. He is a Professional Engineer in the province of Manitoba.

Laboratory Setup of Modular Multilevel Converters with RTDS as Controller

Xianghua Shi, University of Manitoba

Modularly multilevel converters (MMCs) possess many attractive advantages, including modularity, scalability and high voltage quality, and are therefore promising candidates for high-voltage direct-current (HVDC) transmission systems. Over the past decade, to improve converters' performance under different operating conditions in HVDC system, novel MMC topologies with dc-fault capability, reliability and high efficiency have been proposed and investigated primarily through simulations in the literature. However, the converter's characteristics in real-time operations need to be fully assessed before being employed in realistic applications, considering the fact that it takes a massive amount of financial and time costs to establish a mature HVDC transmission system. Therefore, real-time digital simulator (RTDS) is of significance to validate the control strategies and real-time operations for various novel MMC topologies.

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RTDS has been widely used in various applications, such as wind farm, photovoltaic system and HVDC transmission system. Conventionally, RTDS implements controlled objects with great flexibility at a minimal cost, in conjunction with controllers implemented in external components. In academic research related to MMCs, the main focus is on novel topologies and control strategies. In order to minimize the effort to develop codes for control strategies, RTDS is a good candidate to implement various controls. This is because RTDS provides extensive reliable control modules that are also visually accessible. In addition, RTDS provides a convenient debug environment, since real-time intermediate variables in control strategies can be monitored conveniently. These features of RTDS significantly facilitates the debug process of control strategies.

To conduct experimental validations of control strategies and novel MMC topologies, a laboratory setup of a 3-phase MMCs is built and controlled by RTDS. All the sampled analog and digital signals from the MMC setup are sent to RTDS using GTAI and GTDI boards via firber optic connections, and RTDS sends out gate signals using GTDO boards to all SMs in the setup. Currently, this setup only has two types of SMs, i.e., half-bridge (HB) and full-bridge (FB) submodules (SMs). Due to the modularity of MMC converters, this setup can be configurated as various MMC topologies that are composed of HB or FB SMs. In order to control the MMC hardware by RTDS, information exchange between hardware and controller is necessary. Typically, all SM capacitor voltages, three-phase currents and voltages, and dc voltage and current are required to sample and send to RTDS. Due to the employment of many SMs in MMC converters, RTDS needs to sample a large number of SM capacitor voltages. In the present setup, each GTAI board has 12 analog input channels. Therefore, a 3-phase MMC converter may require many GTAI boards, which increases the cost and footprint. In order to reduce the required number of GTAI boards, a multiplexer (IDTQS4A215) is used to sample the large number of SM capacitor voltages in a sequence. The decoding function to obtain the actual SM capacitor voltage data is implemented in a user-defined function.

We are currently investigating a MMC topology that has topologically dc-fault blocking capability – hybrid cascaded MMC (HC-MMC). This topology is composed of HB SMs in the main power stage and FB SMs in the phase limb. Some control strategies and design principles have been proposed. To validate all the investigations, the laboratory setup with 12 HB SMs per arm and 6 FB SMs per phase limb, resulting in 90 SMs for the 3-phase HC-MMC. Consequently, the HC-MMC requires 90 analog sampling channels to sample all SM capacitor voltages, and 108 digital output channels to send out gate signals. In addition, there are other sampling requirements, such as 6 samples for arm currents, 3 samples for ac-side voltages, and 2 samples for dc-side voltage and current. If no multiplexers are used, the HC-MMC needs 9 GTAI boards, and 2 GTDO boards. The required number of GTAI boards is decreased to 4 GTAI boards with a special multiplexer. This multiplexer can sample 20 SM capacitor voltages in fours groups and each group has 5 signals. The four groups of data are sampled in sequence controller by a 2-bit control signal. The computational load of controls for the 3-phase HC-MMC is distributed to 4 GPC processors. One of the four processors is responsible to implement start-up sequence, power-on self test for the converter, software protection and closed-loop control strategies. The remaining three processors have the same control tasks for three similar phases, including decoding the sampled data for SM capacitor voltage, sorting and rotating algorithm for SM capacitor voltage balancing and firing pulse output. The experimental results showed that the laboratory setup works properly with balanced SM capacitor voltages and the effectiveness of the proposed control strategies is validated.

Xianghua Shi received the B.Sc. degree in electrical engineering and automation and M.Sc. degree in power electronics and power drives from Nanjing University of Aeronautics and Astronautics, Nanjing, China, in 2011 and 2014, respectively. She is currently working toward the Ph.D. degree in electrical and computer engineering at the University of Manitoba, Winnipeg, MB, Canada. Her research interests include voltage source converters with dc fault ride-through capability, as well as controls and real-time simulation for HVDC transmission systems.

PRESENTATIONS

Thursday, May 15, 2019

Modular Multilevel Converter Control Method for High-power Applications

Mohammed Alharbi, North Carolina State University

Modular multilevel converters (MMCs) are a realistic alternative to the conventional voltage source converters for medium voltage (MV) and high voltage direct current (HVDC) applications. The number of submodules (SMs) per arm of the MMC can be as high as 512 to achieve desired high DC voltage levels required for HVDC with a very low total harmonics distortion (THD) (e.g., < 0.1%) of the MMC AC-side interface voltage. Although the low THD of the MMC output voltage with a high number of SMs is desirable, the MMC control implementation and complexity is also important to be considered for the high number of SMs. The MMC control complexity significantly increases as the number of SMs increases. Redesigning the number of SMs in MMCs also becomes quite difficult and may require significant control upgrade, which in turn also needs additional tests and validations. An MMC control methodology applicable for MV and HVDC applications is presented. The number of SMs can conveniently be increased or reduced without any significant control modifications. The proposed control method and capacitor voltage balancing (CVB) algorithm are implemented in the Real-Time Digital Simulator (RTDS) and MMC support units based on Field Programmable Gate Array (FPGA) boards. The performance of the proposed MMC control method is investigated for an MMC based multi-terminal DC (MTDC) system under various operating conditions.

Mohammed Alharbi received his B.S. degree in electrical engineering from King Saud University, Riyadh, Saudi Arabia in 2010 and his M.S. degree in electrical engineering from Missouri University of Science and Technology, Rolla, Missouri, USA in 2014. He is currently pursuing his Ph.D. degree in electrical engineering at North Carolina State University, Raleigh, North Carolina, USA. His research interests include applications of power electronics in power systems, system modeling and control of modular multilevel converters (MMC) based HVDC and MTDC systems.

Real-time Simulation of Modular Multilevel Converter Systems for DC Grids and Hybrid AC-DC Power Systems

Gregory Kish, University of Alberta

Explosive levels of research into modular multilevel converter (MMC) systems for MVdc and HVdc applications including dc grids and hybrid ac-dc power systems are currently being witnessed. The conventional MMC concept originally conceived for dc-ac conversion is being leveraged for different purposes such as dc-dc converters, multiport dc-dc hubs and multifunctional dc-dc-ac topologies. This presentation gives an overview of recent experience at the University of Alberta with RTDS NovaCor simulation of novel MMC-based topologies, including the use of GTFPGA units for (i) valve modeling, and (ii) low-level capacitor voltage balancing controls and semiconductor switches modulation. The talk will focus on the nature of the RTDS work being carried out, supported by preliminary simulation results.

Gregory Kish received the B.E.Sc. degree in electrical engineering from the University of Western Ontario, ON, Canada, in 2009, and the M.A.Sc. and Ph.D. degrees in electrical engineering from the University of Toronto, ON, Canada, in 2011 and 2016, respectively.

Since 2015, he has been an assistant professor in the energy systems group at the University of Alberta, AB, Canada. His research interests are at the intersection of power electronics and power systems, with a focus on modular converter systems for MVdc and HVdc applications, grid integration of distributed energy resources, dc grids, and hybrid ac-dc power systems. He is a member of CIGRE WG B4.76 "DC-DC converters

PRESENTATIONS

Thursday, May 15, 2019

Nelson River Bipole III HVDC Control and Protection Systems Hardware in the Loop Testing using RTDS

Chun Fang, Manitoba Hydro

The newly inaugurated Nelson River Bipole III HVDC with classic Line Commutated Converter (LCC) technology represents a significant long-term investment in reliability and security of Manitoba Hydro HVDC bulk system by providing 2000MW north-to-south transfer capacity. It originates from Keewatinohk rectifier station and terminates at Riel inverter station, which together with Nelson River Bipole I & II HVDC systems forms an electrically tightly-coupled three-bipole, multi-infeed and multi-egress topology. In such a complex operating environment, the performance of the supplied Bipole III control and protection systems would need to be evaluated and validated in the larger integrated Manitoba Hydro system to identify any adverse system interactions and prevent impacts.

Driven by the strategic plan to ensure a secure integration of Bipole III HVDC and to support ongoing operations and further HVDC refurbishments, the Manitoba Hydro Simulation Centre (MHSC) was established in 2013 and fully outfitted in 2016. As witnessed by Manitoba Hydro, the utilization of RTDS platform during Bipole III factory acceptance test (FAT) conducted by supplier has greatly reduced on-site commissioning time and associated outage costs. Prior to the final on-site commissioning, MHSC has leveraged the expertise and internally developed detailed Bipole I & II RTDS simulation models to truthfully represent Manitoba Hydro multi-infeed HVDC and functional AC systems, which is interfaced to the physical Bipole III control and protection replica units. This strategy has derived tremendous value for all stakeholders in optimization of commissioning and efficiency improvement in emerging issue resolutions to help accomplishing a timely and successful execution of Bipole III project.

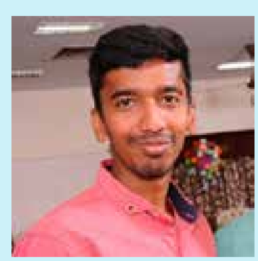
Chun Fang received his M.Sc. degree and B.Sc. degree with honor in Electrical Engineering in 2017 and 2010 respectively from University of Manitoba, Canada. He has over 10 years of industry experience working in utility sector and assumed many professional roles with various technical and mentorship capacities. Currently, he is working as AC / HVDC Control Studies Engineer at Manitoba Hydro. In the last 5 years, he has been a key contributor to the Nelson River Bipole III HVDC project, including the design and specification reviews, Factory Acceptance Test (FAT) witness, and on-site commissioning. Being the lead engineer, he has helped delivering state-of-the-art controlled switching technology for converter transformers in the first ever HVDC application. His current interests are in the area of HVDC and FACTs technologies and modelling, real-time hardware-in-the-loop applications, and probabilistic asset strategy developments.

Data storage & Visualization Solutions for Real Time Simulations & Experiments

Kumaraguru Prabakar, NREL

There are multiple challenges in performing real time simulations and real time experiments. Data storage and visualization are challenges that could be solved easily and when solved provide rich and valuable insights into the experiments. In this presentation, we will talk about National Renewable Energy Laboratories solutions to tackle these issues while running real time experiments and simulations. NREL team has made these open-source for the community to utilize with real time simulations and experiments.

Kumaraguru Prabakar is a research engineer at the National Renewable Energy Laboratory in Golden, CO. He works with the digital real time simulators at the energy systems integration facility. His responsibilities include running controller hardware-in-the-loop and power hardware-in-the-loop experiments.



PRESENTATIONS

Thursday, May 15, 2019

RTDS Support & Latest Developments

Heather Meiklejohn, Manager, Support & Development, RTDS Technologies

This presentation will focus on the Technical and Customer Support that is offered through RTDS Technologies. Recent developments within the RTDS Simulator hardware and software will also be discussed.

Heather Meiklejohn is the Manager of Support and Development at RTDS Technologies. She joined RTDS in 1996 after receiving her B.SC.E.E from the University of Manitoba.

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