MANITOBA·HVDC RESEARCH CENTRE

Manitoba HVDC Research Centre

The Manitoba HVDC Research Centre (MHRC) provides innovative products and services to the global power industry

MHRC is the world leader of power system simulation innovation and applied services. MHRC's mission is to create advanced technologies and applied solutions for the power systems industry. With expertise in power systems, MHRC provides a comprehensive array of engineering solutions and services. MHRC believes it's important to contribute to the industry through fostering new ideas and technologies through collaborative global partnerships.

MHRC's mission is to pioneer innovative technologies for the global electric power industry and Manitoba Hydro by supplying power system simulation tools, applied research, and engineering services.

Software Products

PSCAD

PSCAD™ - The Professionals' Choice for Power System Simulation
PSCAD is a fast, accurate, and easy-to-use power system simulator for the design, analysis, optimization, and verification of power systems and power electronic controls. When used with the EMTDC transient simulation program, PSCAD provides a rich set of tools and models for complete and accurate analysis of electrical systems. With limitless applications, PSCAD has become the visual design tool of choice for commercial, industrial, and research organizations worldwide.

The PSCAD Technical Support Team assists with software related issues and can guide users through complex studies and applications.

Engineering Services

Consulting Services
MHRC offers our clients advanced engineering solutions and supports users around the world, including equipment vendors and utilities. MHRC is recognized as a world leader in electrical power simulation, applied power systems analysis, and related technologies. MHRC's engineering team consists of multi-disciplined power systems engineers and simulations specialists who provide clients with an array of services in the following areas:

- Detailed electro-magnetic transient studies and custom model development
- Load flow and fault analysis
- Project Management
- Harmonic analysis and risk/reliability analysis
- Training and research services for power systems

PSCAD is the tool of choice for electromagnetic transient studies. In addition to PSCAD, MHRC also develops specialized in-house software and hardware for harmonic analysis, reliability and risk analysis, corona and field effects, and real-time testing of protective and control devices.

ENGINEERING CONSULTING

Capabilities

June 2014

PSCAD

EMTDC

Visual Simulation for Power Systems

MANITOBA·HVDC RESEARCH CENTRE

PSCAD X4: New and Enhanced Features

The Manitoba HVDC Research Centre (MHRC) is now offering the newest and most powerful version of PSCAD™ software.

The software development team at MHRC has made significant improvements to the structure and abilities of PSCAD v4.2.1 to include highly requested features by PSCAD users. PSCAD X4 represents a complete overhaul of the internal architecture of the software. With the new architecture comes a multitude of new features and functionalities that were previously not possible.

The following features are found exclusively in PSCAD X4 and subsequent versions.

Multiple Instances Modules (MIM)

- Users are now able to copy and paste modules easily and may even store modules in library projects and for use in multiple case projects, just like any other component.
- Circuits can now be duplicated inside modules and instantiated. This allows for decreased duplication.
- Modules may now possess parameters, which can be used to pass data in and out of modules without the need for connection ports.

Module Blackboxing

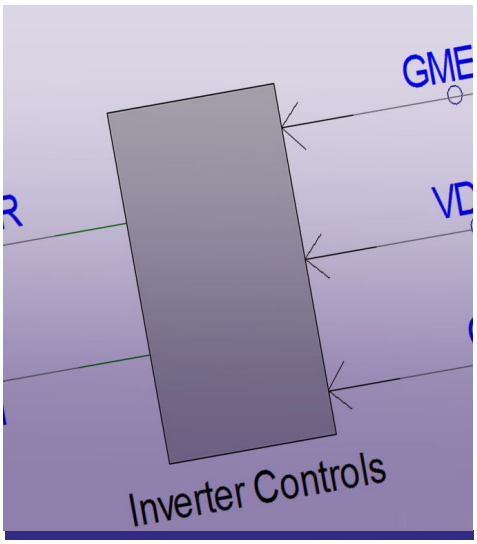
- This feature converts any control system module into an equivalent, non-module component, complete with generated source files and/or compiled binary files.
- Blackboxing allows users to design their systems graphically and black box the system, thereby protecting their intellectual property when distributing their models to clients.

Simulation Sets and Parallel EMTDC Runs

- Users can simultaneously launch and run multiple EMTDC simulations.

Upgraded Free Fortran Compiler

- GNU Fortran 77 compiler has been replaced with the modern GFortran 95.



Blackboxing allows users to design their systems graphically, and then quickly black box the system.

MHRC is committed to providing its clients with the best training. Whether you are a new or experienced user, a team of experts at MHRC can tailor a course that fits your needs.

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Training Course Listing

The Manitoba HVDC Research Centre (MHRC) is committed to providing general power system and PSCAD™ specific training programs, which include practical case studies and interactive workshops, to aid in each client's understanding.

Course Topics

Applications of PSCAD & Transient Studies | 3 Days

This course covers the fundamentals applicable to the study of electromagnetic transients in electrical networks. A number of application areas such as AC transients, fault and protection, transformer saturation, wind power, FACTS, power quality, as well as other power system topics are discussed with practical examples serving to illustrate the subjects. Several case studies will be applied in detail to highlight practical situations encountered by engineers.

Applications of PSCAD in Power Systems including Switching & Lightning Induced Transients for Insulation Coordination | 2 Days

This course covers the electromagnetic transient studies that are required to determine the insulation levels and ratings of substation equipment. Specific topics include the following: selection of surge arrester (ratings and position) to protect substation equipment from lightning and switching surges, development of the system model for switching frequency overvoltage studies and estimation of 'failure rates, lightning overvoltage studies - representation of station equipment, line segments and towers for a lightning overvoltage study, circuit breaker TRV, and capacitor switching transients.

HVDC Control & Project Management | 3-5 Days

This course covers the fundamentals of HVDC transmission in electrical networks, including HVDC transmission system concepts, components, equipment and their characteristics and their controls. The concepts presented are reinforced with several PSCAD simulation workshops. Case studies will be applied in detail to highlight practical situations encountered by engineers in the field.

Modeling & Applications of FACTS Devices | 3 Days

This course covers the fundamentals of solid-state FACTS systems, system modeling, control system modeling, converter modeling, and system impact studies.

A variety of power system, PSCAD, and custom training courses are offered by MHRC. Training programs offered will assist all clients in fulfilling their learning objectives, whether attendees are beginners or experts.

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Course Topics Continued...

Wind Power Modeling & Studies Using PSCAD | 3 Days
This course covers the fundamentals of wind power and its integration into the electric grid. The vital role electromagnetic transient program based simulation plays in a wide range of wind integration aspects is highlighted and discussed in the classroom. Several case studies are applied in detail to highlight practical situations encountered by engineers. Course attendees are able to experiment with case studies in an interactive hands-on workshop environment using PSCAD simulation software.

Configuring Transmission Lines with PSCAD | 1 Day
This course is designed to help remove the uncertainty when modeling transmission systems. Attendees will touch upon important mathematical concepts, including frequency and time-domain theory, then move on to practical selection of model types, an explanation of important model parameters, and troubleshooting. Using PSCAD, course attendees will then apply their newly learned modeling skills to several real-world applications.

Advanced Topics in PSCAD Simulation | 2-4 Days

Attendees can request more detailed coverage of specific topics or phenomena of interest. This includes custom, client-specific component design and assisting users with the analysis of specific simulation models. Topics may include HVDC/FACTS, distributed generation, machines, power quality and others.

Other Available Courses

- AC Switching Study Applications in PSCAD
- Distributed Generation & Power Quality
- Lightning Coordination & Fast Front Studies
- Machine Modeling including SRR Investigation and Applications
- Modular Multilevel Converter – Voltage Source Converter Fundamentals

Custom Training Courses

MHRC offers custom courses designed to meet clients' specific requirements. Often the most effective and productive use of time and money is receiving the training that meets clients' needs in regards to content, schedule and location. Dedicated course material can be provided through custom training programs, which can be delivered to groups or individuals.

Individualized Training

MHRC also takes training one step further to work alongside clients as they build PSCAD system cases, prepare data, run cases, analyze results and draft recommendations this highly specialized one on one training allows clients to have a deep and thorough knowledge of PSCAD and its applications.

Course Particulars

Instructor
Course instruction will be provided by one of our many simulation and application experts. CV's available upon request.

Classroom Size
By striving to keep classroom sizes small, there is ample opportunity for questions and discussions among the students and the instructor.

Training Location
Courses can be provided at MHRC's Winnipeg location, or an instructor can provide training at clients' desired location.

For more information about our training courses, please contact us.

The Manitoba HVDC Research Centre is the world leader in power system simulation, innovation, and applied services. Our expertise provides a comprehensive array of engineering products and solutions. We foster new ideas and technologies through collaborative partnerships globally.

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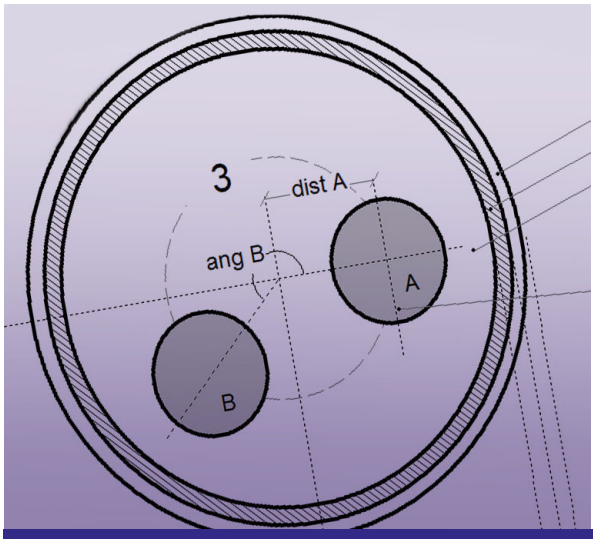
Transmission Line/Cable Mutual Coupling

- This feature enables users to mutually couple individual line or cable segments that possess identical lengths.
- Multiple segments can be merged into a single right-of-way without affecting the individuality of the each segment.
- Large transmission system right-of-ways (i.e. greater than six conductors) may be easily combined without elaborate connections using interface components.
- Multiple line segments may be placed between two buses and then coupled together without being concerned about dimension mismatch errors.



A pipe-type (or multi-core) cable model has been added. This cable may contain up to 3 inner cables and can exist with other coaxial cables in the same right-of-way.

PSCAD X4 can be used in parallel with PSCAD v4.2.1, enabling users to migrate cases forward at their convenience.

Multiple Workspaces

- The ability to load any number of workspaces means that users can create and store sets of projects that are all related to a single study. Users who are working on multiple studies simultaneously may simply open the corresponding workspace and all related projects will automatically appear ready for use.

Enhanced and Updated Line Constants Program

- Two unique DC correction algorithms have been added, which ensures perfectly accurate DC parameters in time domain simulations.
- If there are two ground wires in a tower, each wire may now be entered with its own unique parameters.
- Users may now select which conductors are to be eliminated (not just the outer layer).

Many New Master Library Models Included

- New multiple run component allows for additional data recording.
- Discrete Wavelet Transformation (DWT)
- Saturable reactor
- Spark gap
- Two new auto transformer models

For more information about PSCAD, please contact us.

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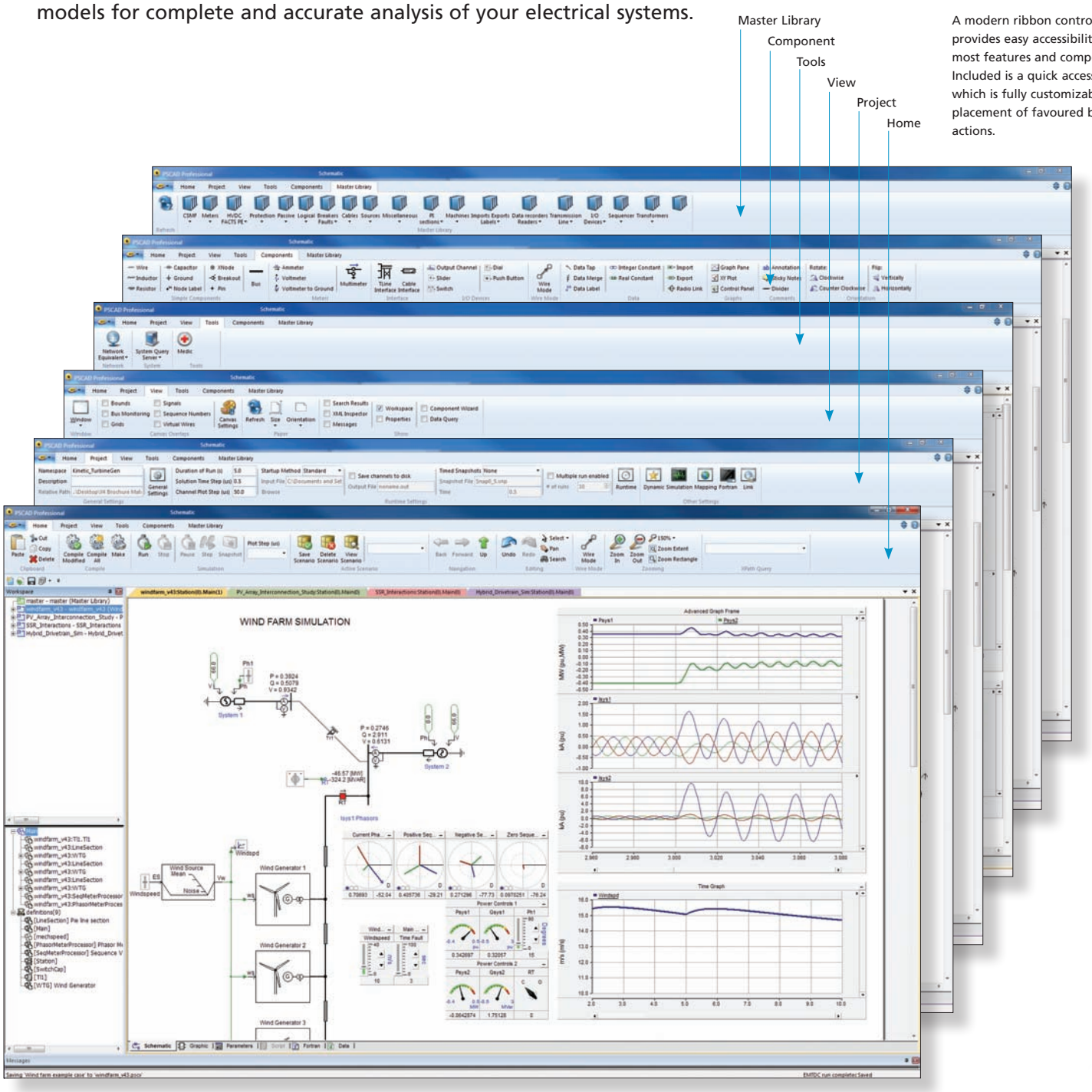
The Professionals' Choice for Power System Simulation...

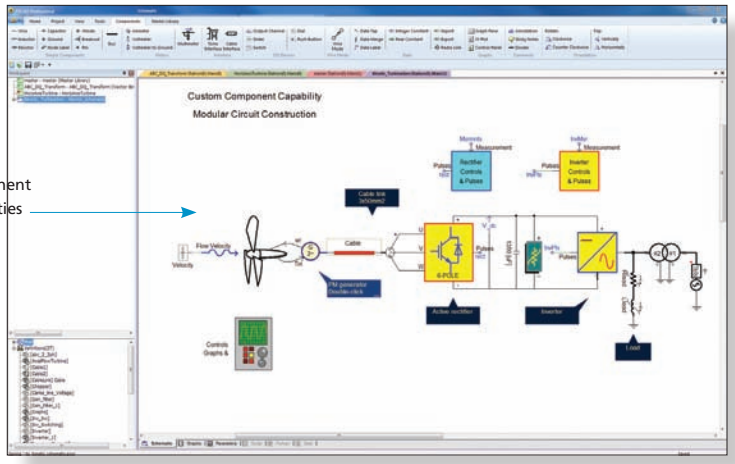
PSCAD is a fast, accurate, and easy-to-use power system simulator for the design, analysis, optimization and verification of power systems and power electronic controls. PSCAD, with the EMTDC™ transients simulation program, provides a rich set of tools and models for complete and accurate analysis of your electrical systems.



A modern ribbon control bar provides easy accessibility to most features and components. Included is a quick access bar, which is fully customizable for placement of favoured button actions.

Modern application framework has improved the working environment by providing customizable docked windows, as well as window pinning and hiding. A new tabbed document interface (TDI) enhances convenience in project navigation. Revamped component wizard and search interfaces provide more flexibility in creating new components and project searching.

Custom component design capabilities

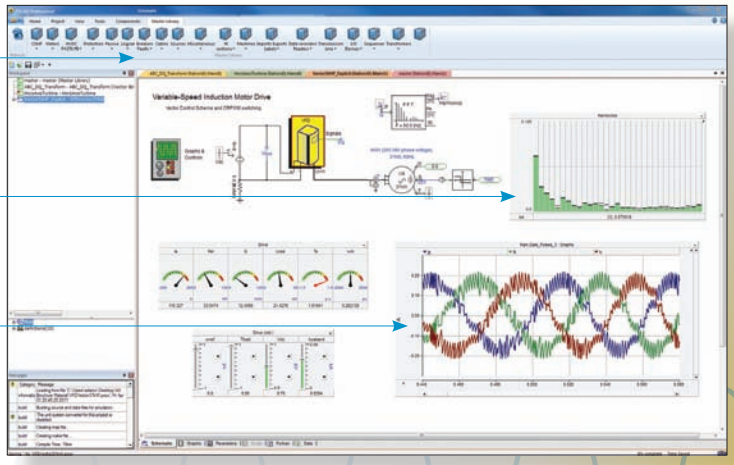


Online Controls

Comprehensive, extensively validated master library

Polymeter

Overlay Graph



Limitless Applications

A product of 30 years of power systems simulation research, PSCAD has become the visual design tool of choice at commercial, industrial, and research organizations worldwide. Applications include:

- AC transients and insulation coordination studies including TOV, TRV, lightning and VFT, line and equipment switching
- HVDC interconnection studies (conventional as well as VSC based)
- Modeling and assessment of FACTS based solutions SVC, STATCOM, TCSC, and other
- Wind energy system design and integration Fault ride-through, control and protection performance, SSR concerns
- Power quality studies that include a wide spectrum of harmonics
- Protection and control system design, optimization, and validation studies
- and much more...

Advanced Display Techniques

With its complete set of controls and control logic, PSCAD provides the end-user with the ability to interact with their power systems models.

As a simulation runs, users can dynamically control events and input data, and have the ability to record and display output using advanced plotting techniques. PSCAD users gain a better understanding of complex systems, which results in optimal designs.

Dedicated Support Team & Help Desk

PSCAD's dedicated technical support team consists of highly qualified professional engineers and technology specialists with expertise in different areas of simulation.

This team helps with software-related issues, guiding users on complex studies and applications, and offering users a wide range of application examples.

www.pscad.com

MANITOBA·HVDC RESEARCH CENTRE

Since 1993, PSCAD™ has been the professionals' choice... 35,000+ users in 80 countries.

World-leading Power System & Engineering Services

The Manitoba HVDC Research Centre is dedicated to pioneering innovative technologies for the global electric power industry by supplying power system simulation tools, applied research, and engineering services. We foster strategic partnerships, and collaborate with leading researchers and industry associations.

The Manitoba HVDC Research Centre is a division of Manitoba Hydro International Ltd., a wholly-owned subsidiary of Manitoba Hydro, Canada's 4th-largest electrical utility.

1981	Non-profit research company founded	
1983	EMTDC used for commercial application	EMTDC
1993	PSCAD v.2 for Unix commercially available	PSCAD v.2
1994	RTDS Technologies Inc. founded	RTDS Technologies
1999	PSCAD v.3 (Windows version)	PSCAD EMTDC
2000	Centre becomes a subsidiary of Manitoba Hydro	Manitoba Hydro
2003	PSCAD v.4 released	PSCAD v.4
2009	Centre becomes division of Manitoba Hydro International Ltd.	Manitoba HYDRO INTERNATIONAL
2010	PSCAD X4 released	PSCAD X4

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CIRCLE

Contents

Company Overview

Manitoba HVDC Research Centre

The Manitoba HVDC Research Centre (MHRC) is a world leader in electrical power simulation, applied power systems analysis, and related technologies. Located in Winnipeg, Canada, we develop and market a variety of products including PSCAD™/EMTDC™, a renowned power system simulation software. Additional innovative technologies to improve transmission system efficiency are offered by MHRC, including our Line Fault Locator and Ice Vision Systems. Both of these products are designed to improve the transmission system efficiency.

We offer our clients an experienced team of engineer professionals that have a wide range of experience providing solutions to the global power industry. Our unique expertise includes engineering studies, equipment specifications, and maintenance and system operation. MHRC has leading experts in the field of HVDC who were a part of the millstone-recognized Nelson River project for Manitoba Hydro and Bipole I and II.

We provide comprehensive training for PSCAD™ as well as a variety of power system courses and custom training. Other services offered by MHRC include maintenance and support, laboratory testing and research opportunities.

Founded in 1981, MHRC is a division of Manitoba Hydro International Ltd., a wholly-owned subsidiary of Manitoba Hydro.

For more information please visit www.hvdc.ca.

Manitoba Hydro International Ltd.

Manitoba Hydro International Ltd. provides professional consulting, operations, maintenance and project management services to energy sectors world-wide, either exclusively or through partnerships. MHI Ltd. is a leader in power system research and development providing leading edge products and services to the electrical power system industry.

Manitoba Hydro

Manitoba Hydro is a provincial Crown Corporation, providing electricity to over 532,000 customers throughout Manitoba and natural gas service to over 264,000 in various communities. With over 6,000 employees, Manitoba Hydro currently holds assets approaching $13 billion, with $2.4 billion in annual revenues. It is one of the largest energy utilities in Canada involved in the planning, design, construction, operation, and maintenance of all elements of power infrastructure.

Manitoba Hydro pioneered the development of HVDC technology building and maintaining two HVDC bipoles. Bipole 1 is +/- 463.5 kV, 2000 Amperes, 900 kilometers in length, in service since 1973. Bipole 2 is +/- 500 kV, 2000 Amperes, 950 kilometers in length, in service since 1978. Generating over 32 billion kilowatt hours annually the infrastructure also includes fourteen hydroelectric generating stations, two thermal generating stations, wind farms and over 11,700 kilometers of transmission lines and 72,000 kilometers of distribution lines.

A 500 kV HVAC interconnecting transmission line between Winnipeg and Minneapolis was established in 1979 providing a third interconnection to the United States (U.S.A.). This line more than doubled Manitoba Hydro's power exchange capability with the U.S.A. In 2010 – 2011 Manitoba Hydro's export sales totaled $398 million to North American markets which include over 35 utilities and marketers in the mid-western U.S.A., Ontario, and Saskatchewan.

Manitoba Hydro takes a proactive approach to protecting the environment and is ISO 14001 registered. The corporation is capable of executing any type and size of transmission, substation, or distribution project. For more information please visit www.hydro.mb.ca.

Engineering Service Capabilities of the Manitoba HVDC Research Centre

As the developer of the world-renowned PSCAD™ software, MHRC offers our clients advanced engineering solutions and supports users around the world, including equipment vendors and utilities. With over 100 years of combined experience, we are recognized as a world leader in electrical power simulation, applied power systems analysis, and related technologies. Our engineering team consists of multi-disciplined power systems engineers and simulations specialists who provide clients with an array of services in the following areas:

- Load flow and fault analysis
- Detailed electro-magnetic transient studies and custom model development
- Project Management
- Harmonic analysis and risk/reliability analysis
- Training and research services for power systems

PSCAD™ is our tool of choice for electromagnetic transient studies and we utilize other leading commercial software packages for loadflow and stability studies. In addition to PSCAD™, MHRC also develops specialized in-house software and hardware for harmonic analysis, reliability and risk analysis, corona and field effects, and real-time testing of protective and control devices.

Scope of Engineering Services

MHRC Engineering Services offers knowledge, expertise and solutions for the global power industry, including Power System Studies and Project Management Services.

Load flow, Stability and PSCAD™/EMTDC™ (Electromagnetic Transient) Study

- Power flow and transient stability analysis for interconnected power systems, such as equipment addition, transfer capability, AC contingency, transmission feasibility studies, etc.
- HVDC, SVC, FACTs and wind farm integration/interconnection and feasibility studies
- Project management, including technical review and on-site commissioning of SVC, HVDC and other power electronics related equipment
- Power system transient studies including TOV, faults, re-closure, in-rush and out-rush evaluation, and ferroresonance for equipment specifications
- Wind farm integration studies, Sub-synchronous resonance (SSR/SSTI) studies, including Breaker TRV and Switching transients
- Insulation coordination and lighting studies
- Power system protection and relay settings
- Effects of DC currents and geomagnetically induced currents on power systems and inrush effects
- Power quality analysis and improvement, including harmonic impedance analysis, motor starting, voltage sags and swells, non-linear loads, such as arc furnaces and flicker analysis, etc.
- Distribution system design, including transient overvoltage, with custom power controllers and distributed generation
- Relay testing (waveforms) and detailed analysis of the CT/VT/CCVT responses and their impact on operation.

Specialized Power System Study:

- Transmission line field effects and corona analysis using FACE software for both HVDC and AC systems

- Power system harmonic analysis using the Frequency Domain Harmonics Analysis Program (FDHAP) for AC, HVDC and hybrid systems
- Power system reliability and calculation of LOLE and ENS indices using sequential Monte Carlo analysis with the RISK_A program

Project Management:

- Development of advanced power system simulation models including custom machines, transformers, non-linear loads, power electronics and FACTS devices

Overall HVDC Capabilities

Our highly experienced, multi-disciplinary team of experts provides specialized engineering solutions for the HVDC power system community worldwide. As leading experts in the field of HVDC, we offer comprehensive global services for HVDC transmission. Being a subsidiary of Manitoba Hydro, one of Canada's largest utilities, we were key participants in the landmark HVDC transmission projects of Nelson River Bipole I and II. The two Bipoles have the capability of transmitting 3 654 MW at +/- 500 kV and over 1 800 km of HVDC transmission line. The HVDC system provides over 75% of the energy generated so it is critical that its reliable and available.

Our unique team of experts specializes in providing unique services and has the international experience and expertise to perform a wide variety of HVDC services. With over 40 years of design, owner, maintenance and operating experience, we offer customized and reliable solutions in the field of HVDC transmission. Over the years, we have gained a comprehensive experience and knowledge of the industry, including the capability to do system studies, prepare required specifications, perform HVDC planning and feasibility studies, and provide operations and commissioning consulting services around the globe.

Our Worldwide expertise in the area of HVDC transmission includes:

- conceptual system design studies
- equipment specifications and commissioning
- harmonic analysis and risk/reliability
- HVDC interconnection studies
- modeling and assessment of FACTS based solutions for power system operation
- bid evaluations
- factory acceptance testing
- operations and maintenance studies
- back-to-back HVDC projects
- converter station life assessments
- converter transformer analysis
- ground electrode investigations
- medium voltage DC (MVDC) investigations

Our team has HVDC transmission experience applicable to every stage and type of your project, from multi-year projects to specialized studies.

Our Project experience around the globe includes:

HVDC Support

Our team has provided HVDC support for a multitude of new projects. We apply a unique perspective to assist clients throughout the process of acquiring HVDC technology and during the life cycle of the station. Our design review experience includes Protection and Control, Transformers, Reactors, Thyristor Valves, cooling systems, and AC remedial action schemes.

HVDC Projects

MHRC has completed several HVDC projects to assist with the studies, construction, and factory acceptance testing (FAT). Our factory testing extends to DC control and protection, transformers, reactors, and valves. Our team assists through the project in areas of supervision and system operation. We have also provided maintenance program implementation, procedures, commissioning and support services.

Life Extension and Life Assessment

We have conducted several life assessments of HVDC stations which included converter transformers, smoothing reactors, valves, equipment testing, HVDC controls, and post commissioning services.

HVDC Specification Bids and Tender Evaluations

MHRC has the expertise in providing support to clients evaluating HVDC specification bids and tenders. Our team, generally in close contact with the project owners, is available to answer technical questions throughout the bid process, review supplier specifications for equipment manufacturing, and negotiate with preferred suppliers to arrive at a final contract. We approach this area from a project life cycle perspective to provide technical support throughout the entire HVDC project.

Ground and Sea Electrode Studies

MHRC has performed studies for the investigation of new ground electrodes in HVDC projects, replacement and upgrade of electrodes, and high level design of the electrode line and underground cables.

HVDC Simulation Studies

We have a wide array of in-house tools and capabilities to support a variety of simulation studies, including:

- VSC MMC Model Development
  - Develop models for new HVDC schemes based on the new multi-level voltage source converter technology. The models developed are used to perform system level feasibility studies, evaluation of protection and control schemes, AC system requirements, equipment ratings, and project cost.
- Energy Integration
  - Studies for the integration of renewable resources using multi-terminal HVDC, VSCs and FACTS, as well as series compensation technologies.
- PSCAD Simulation Studies
  - PSCAD™, developed by the Manitoba HVDC Research Centre, is the tool of choice for all major HVDC vendors.
- RTDS Simulation Studies
  - Provide clients with support and advice on real-time electromagnetic transient simulations.
- Field and Corona Effects (FACE) HVDC Calculations
  - We developed a study tool to perform field and corona effects on high voltage power lines. It has been used to perform a number of field and corona effect studies.

HVDC Training

Our specialized HVDC Theory & Controls training program has been well-received by vendors, utilities, and academic institutions worldwide. This course covers the fundamentals of HVDC technology and their applications. Topics covered included HVDC fundamentals, controls, modeling, and advanced topics, including HVDC implementation and maintenance issues for HVDC systems.

Past and Present Projects

The Manitoba HVDC Research Centre has a highly experienced team of multi-disciplined power systems engineers and simulation specialists.

The following is a list of past and current projects undertaken by our team:

HCB – HVDC Owners Engineer for Valve Overcurrent Study – Mozambique

The HVDC Transmission project was built in the early 1970's and is +/-533 kV 1 800 Amperes. In 2005, MHI was a sub-contractor to NIPPON KOI to do an assessment of the Generating Station, Converter Station and Mozambique portion of the HVDC line for the government of Mozambique to purchase the system from the government of Portugal.

In 2007, the sale of the system between Mozambique and Portugal was finalized, and MHI was contracted to provide quarterly monitoring of project operations and maintenance. MHI was also contracted as the technical advisor on all aspects of the operations and maintenance, including training, legal, accounting, operations, maintenance, and refurbishment. An MHI operations person has been located at Songo for the past 4 years.

In addition, MHI prepared the technical specifications for three 533 kV and 1800 Amperes converter transformers, two 533 kV smoothing reactors and associated DCCT and DC lightning arrestor. An option in the specification is the possible upgrade to +/- 600 kV and 3300 Amperes.

MHI was also contracted to study the removal of the over-current diverters. The diverters were designed to protect the thyristor valves but are causing failures in the converter transformers. MHI did PSCAD™ studies and arranged for the testing of the Thyristors at Dynex Semiconductors in the UK.

Our work also includes reviewing the technical reports and requirements from other consultants regarding the refurbishment, upgrade, or a Greenfield option. Additionally, MHI is doing a life assessment and refurbishment plan for their converter transformers and smoothing reactors.

Confidential Project - HVDC Link

MHRC has a contract to assist a Client with an HVDC link. The work consists of reviewing supplier specifications for the manufacturing of the equipment and providing technical assistance throughout the entire HVDC project, as required.

Confidential - Studies under Master Services Agreement

Under Master Services Agreement, MHRC provides engineering services from specification, negotiation, design reviews, construction supervision, commissioning to in-service, as required for several projects including a Controls Replacement and Synchronous Condenser.

Confidential –HVDC Link – 500 kV

We were awarded a contract to assist a Client with a HVDC link. This link is a 500 kV mono-pole, 1000 MW and 350 kilometers long. The work consists of reviewing supplier specifications for the manufacturing of the equipment and providing technical assistance throughout the entire HVDC project, as required.

Transelec – Risk Analysis and Operations and Maintenance Study – Chile

MHI was contracted to do a risk analysis for a +/- 500 kV, 1100 MW and 750 kilometers long HVDC transmission line with 150 kilometers of undersea cable. A comprehensive risk analysis was completed for the HVDC system and the AC collector system to evaluate the owners risks associated with various aspects of this project. In addition, a comprehensive study of the operations and maintenance costs, including staffing, accommodations, equipment and tools was provided for the 40 year life of the project.

LADWP Sea Electrode and Electrode Line Study – United States of America

MHRC was sub-contracted for the replacement and upgrade of a Converter Station electrode line and sea electrode. MHRC is doing the system studies and interaction from nearby AC lines as well as the high level design of the electrode line and the underground cables.

Confidential –Back-to-Back HVDC Project – United States of America

The contract was to assist the client with the studies, construction, factory testing, supervision, commissioning and operation of their DC back-to-back system for two inter-ties.

MHRC provided the following services:

- PSCAD™ bases studies
- Factory Testing of DC control and Protection
- Factory Testing of Transformers
- Factory Testing of Reactors
- Factory Testing of Valves
- Commissioning
- Construction Inspection and Equipment Testing
- Operations Engineering and Support Services
- Maintenance Program Implementation, Procedures and Support Services
- POST Commissioning Voltage Flicker Assessment

ESBI Alberta Ltd. – 500 kV AC/DC Transmission Line Options Study – Canada

MHRC was contracted by ESBI Alberta Ltd. to perform an assessment of DC transmission technologies applied to upgrading major transmission of the Alberta interconnected electric system.

Specifically, MHRC carried out the following work related to a base case of 500 kV AC transmission facilities between Edmonton and Calgary:

- Preliminary Design of Transmission Options for Study
- Determine Equipment Ratings and Conductor Sizes

Confidential – FACE HVDC Calculations – Finland

The contract was to perform the analysis of the field and corona effects for the HVDC overhead transmission lines in Finland.). The analysis covered eight different possible cases as outlined by the client.

Note: MHI has developed a study tool to perform field and corona effects on HV lines. It has been used to perform a number of field and corona effect studies.

The ETI – UK (2010)

This project was carried out for the Energy Technologies Institute (The ETI) in the UK as part of a subcontract to Mott MacDonald. One of the goals of this study was to examine issues in 400 kV AC grid reinforcement for the United Kingdom for the integration of renewable resources using multi-terminal HVDC, VSCs and FACTs as well as series compensation technologies.

Polarconsult Alaska, Inc. – Low Voltage DC Single Conductor Earth Return – United States of America

A contract has been awarded to assist in the development of a pilot project to demonstrate the feasibility of Single Wire Earth Return (SWER) HVDC to remote northern communities. MHRC provided subject matter expert support on integration of a novel HVDC system for distribution. Project Phase 2 is completed and the installation of Phase 3 pilot is currently underway.

Confidential –Life Assessment – United States of America

Under this study, MHRC did a life assessment on the Converter Transformers, Smoothing Reactors and HVDC controls. This was an update on the 2006 life assessment report.

STRI Sweden – Modelling of Multi-Terminal VSC South West Link – Sweden

This project involves the detailed PSCAD™ model development of a five terminal HVDC (proposed) scheme based on the new multi-level voltage source converter technology. Significant research and development effort from MHI and the University of Manitoba resulted in a novel simulation technique that would enable simulation of this technology in an EMT (PSCAD™) environment. The models developed will be used to perform system level feasibility studies, evaluation of protection and control schemes, AC system requirements, equipment ratings and project cost.

ENMAX – HVDC System Impact Study

System impact study based on PSS/E (on Enmax facilities) to identify the impact of two new HVDC links being implemented in the Alberta power system. MHI engineers utilized ‘customized’ HVDC models in PSS/E to obtain accurate results.

Tri-State G&T – Tri-State Converter Transformer Analysis – United States of America

Under this project, MHRC did an analysis to Tri-State Converter Transformer for refurbishment or replacement. The deliverables included two reports, one on operations and maintenance and one on recommendations for replacement.

Manitoba Hydro – AC Collector System and HVDC Links – Manitoba, Canada

Most of the project team of Manitoba Hydro International Ltd. (MHI) have personal experience with Manitoba Hydro's Northern AC Collector System and the AC to DC system interactions. This includes the planning studies through to 35 years of operations and maintenance issues. This unique experience gives insight into problems encountered, their resolution and avoidance of the same problems in this project.

HVDC Transmission Project for Leading US Wind Turbine Manufacturer – United States

This project is to provide engineering advice and studies for a 3500 MW 500 kV HVDC Transmission project including integration into the rectifier and inverter systems. The wind generation is based on back-to-back VSC technology. However, the bulk power transmission is proposed to be via a conventional line commutated HVDC bi-pole link. MHI is performing the necessary studies to indemnify the technical challenges associated with this novel proposed system.

AMPRION – VSC HVDC North South Link Interconnection

The North South link is landmark project were the emerging MMC –VSC technology is to be utilized for the HVDC converters. In addition to performing conceptual system studies, MHI also developed and provided the detailed MMC-VSC simulation modules based on published modeling methods developed internally.

Confidential Project

Under a subcontract, MHRC provided technical advice on the environmental and social aspects of a 500 kV 1000 MW HVDC transmission line.

Hatch – Nalcor Lower Churchill Project, DC 1240 – HVDC and AC Lines Proximity Analysis

The principle objectives of WTO DC 1240 were to determine potential line candidate configurations and any required mitigation measures to ensure acceptable performance of the integrated HVDC and AC Systems; to identify the minimum separation distance between the HVDC and AC, and confirm the

suitability of the existing right-of-ways for the proposed HVDC transmission lines.

MHI consulted Hatch and assisted with:

- Identifying potential hybrid line sections along the proposed HVDC transmission line route
- Investigation of field and corona effects for the potential hybrid lines and determination of suitable candidate line configurations;
- Investigation of steady state and transient coupling issues;
- Reviewing qualitatively potential impact on existing AC system protections;
- Reviewing other factors which can influence the determination on minimum separation requirements between HVDC and AC lines

Transmission Company of Nigeria (TCN) – Nigeria

TCN is in the process of upgrading transmission capabilities from 5000 MW to 10,000MW by 2017. MHRC is the expert consultant leading variety of system studies. Some of tasks MHRC has performed are:

- Conversion of the existing base cases power flow model to PSS/E format,
- Validate the converted base cases with the help of TCN system operation and system planning department,
- Append the validated base cases with details of potential upgrades which expand transmission capability from 5000 MW to 10000 MW,
- Perform system studies for various load\generation scenarios to identify, additional system upgrades, the project priority based on the future needs, transfer limits considering hydro –thermal coordination.

Rwanda Economic Dispatch Study

Power generation in Rwanda is expanding rapidly as result of ‘take or pay’ agreements offered to the private investors to develop power generation based on renewable as well as naturally available fossil fuels in Rwanda. An economic dispatch study was performed to project the total operating cost for future years and hence to determine the appropriate combination of ‘take or pay’ generation and generators own by the government.

Panama – Study and Design of SVC Substations Llano Sánchez and Panama II (2013)

From 2012 to 2015, an 815-MW increase of hydroelectric power is expected from the western Panamanian region. Due to this planned increase, ETESA has

determined it necessary to strengthen the support of reactive power of the system to meet the voltage levels established by the transmission regulators.

ETESA has contracted MHI to perform the study and design of additional static reactive power compensators in substations – Llano Sánchez and Panama II.

MHI has developed a 4-phased approach to provide the following services, specified under the contract:

Phase 1 – Electrical studies

- Electrical studies will be performed in static and transient regimes to determine the needs and limitations of the system, and the correct sizing of the static reactive power compensators (SVC).

Phase 2 – Engineering and basic design

- The design of the SVCs will reflect the results of the studies from phase 1 and will reveal the optimal solution for the system, taking into account the costs and benefits from an economic perspective and quality of performance.

Phase 3 – Preparation of tender documents

- This service includes, but is not limited to, technical specifications, basic drawings, construction schedules, and equipment acquisition documents.

Phase 4 – Preparation of the budget document

- MHI will outline the strategic plan and parameters used for the preparation of the budget and will establish a cost estimate for the SVC substations.

Manitoba Hydro – Distribution Voltage Capacitor Switching Studies – Canada

This project was to support the energization of over 30 capacitor banks at different locations on the Manitoba Hydro 11 kV network. In addition to identifying the inrush/outrush reactor requirements, the study also investigated network resonance possibilities due to capacitor bank switching.

Manitoba Hydro – 500 kV AC Interconnection Transmission Line Protection – Canada

This protection study involves the selection and verification of the 500 kV transmission line protection on a series compensated transmission line for the Riel extension. This line is Manitoba Hydro's main export line to the United States and of critical importance. All relay settings and functions were verified

in the laboratory utilizing PSCAD™ transient models, and transients playback hardware.

Confidential – System Operational Planning Studies and Operating Area Interconnection Support – Middle East

MHI was contracted to assist a company to combine four separate regions of the country into one company for the whole country. The backbone of the system is a 380 kV AC Interconnected network. The final goal is to operate the entire system through a single unified control centre. MHI engineers are involved in a number of different key projects to assist the client in unifying their power network. In addition to engineering studies, over six engineering specialists are stationed in different regions in Saudi Arabia, providing expert guidance on operational aspects, policies and procedures.

The engineering studies to support the final objectives include the following (using PSS/E and PSCAD™):

- Studies aimed at defining operating guidelines
- Black start procedures - studies to support new black start procedures developed by MHI for the entire Kingdom
- Area interconnection studies, including load flow, stability and voltage control
- Tie line transfer limits
- TOV and Switching studies, network resonance studies

Confidential– Transmission Line Switching Studies – Middle East

MHI was contracted to perform switching studies to identify undesirable conditions in the high voltage network due to switching events including the switching of line end reactors.

The project includes approximately 25 separate studies at selected substations (includes over 20 double circuit lines/ cables):

- Breaker TRV considerations during reactor switching
- Breaker TRV during station faults, remote faults and short line faults
- Temporary overvoltage (TOV) conditions and mitigation methods

- Secondary fault arc studies to support single pole auto reclose, as well as identify neutral grounding reactor (NGR) requirements
- Ferro-resonance studies
- Network frequency scan studies to identify network resonance points
- Switching overvoltage studies
- Temporary overvoltage studies

Confidential – Transfer Limits Study – Middle East

Operational limits for power transfer between interconnected areas in the clients' network were estimated for different seasons. These transfer limits consider static and dynamic limitations of the system. In addition, sensitivity of transfer limit to identified crucial devices such as availability of generators for voltage support and congestion management was identified. This information helps system operator to adjust inter-area transfer to a safe level based on the availability of resources.

Confidential - Under Frequency and Under Voltage Studies - Middle East

System studies to determine relay settings considering the interconnected operation.

Confidential - Steady State Over Voltage Mitigation Studies - Middle East

Validation of generator reactive power capabilities and updated the operational planning system models. These updated system models (PSS/E based) were the used to study over voltage issues observed in the system and subsequently overvoltage mitigation measures were proposed.

GCCIA Interconnection Voltage Control and HVDC Performance Studies – Middle East

Under this project MHI responsibility was to study the back to back HVDC link in the GCCI system and identify its unused reactive power absorption capability to mitigate overvoltage issues observed during low power transfer conditions.

Bayswater Thermal Generation Station – Bayswater Protection Investigation – Australia

This project goal was to review the protective relaying settings and installed current transformers of the thermal units located at the Bayswater GS in Australia, Australia's largest thermal generating station. The entire plant was modeled, including detailed models of the CTs in order to determine the effects of saturation on the protective relays due to through faults. CT saturation was present in several operational situations and relay settings were revised to improve performance and recommendations made to replace older CTs.

Pacific Gas & Electric Company – Los Banos-Gates 500kV Transmission Project – United States of America

This 500 kV AC protection, line switching, TOV, TRV and capacitor switching study was to support the Path 15, 500 kV line from Los Banos to Gates:

- Several thousand simulation cases were generated and captured for verification of protection operations during factory and field acceptances tests
- Breaker TRV studies
- Several switching studies were also performed to size outrush and inrush reactors for the new associated 230 kV capacitor banks as part of this project (inrush/outrush reactors/switching, MOV sizing)
- TOV and Switching studies

Confidential– Voltage Flicker Study – United States of America

MHRC modeled a distribution network feeding an arc furnace. The high levels of voltage flicker observed in the field were reproduced in the model. Then a STATCOM based solution involving a novel auxiliary control loop was designed by the study team.

Voltage flicker reduction was demonstrated and the STATCOM rating required for different clicker reduction levels were identified for equipment rating design. The applicability of a battery energy storage based solution was also investigated.

A detailed battery energy storage device model was implemented in PSCAD™ and the model was validated against manufacture provided performance data of waveforms.

Altanano Arc Furnace Study for an installation in South America

MHRC modeled an AC system network feeding an arc furnace. The high levels of voltage flicker observed in the field were reproduced in the model. A STATCOM based solution involving a novel auxiliary control loop was designed by the study team. Voltage flicker reduction was demonstrated and the STATCOM rating required for different clicker reduction levels were identified for equipment rating design.

Confidential – Insulation Coordination Studies

MHRC performed Insulation Coordination Studies, including SOV, TOV, and Lightning Studies for a 2-phase project for a Client to support the development of the insulation design of a new high-capacity, high-efficiency 345 kV transmission line.

Black & Veatch – TRV and Insulation Coordination Switching Studies

MHRC provided insulation coordination studies aimed at identifying the severity of overvoltages that can appear at the transformer terminals and other electrical equipment in the station due to system events. In addition to identifying the severity of overvoltages, the study also verified the adequacy of protection devices to protect critical equipment.

Electrical Consultants Inc. (ECI) – TRV and Lightning Studies

MHRC was contracted by ECI to provide engineering assistance on technical studies, including TRV and Lightning studies, at four new substations in the United States.

ENMAX – Insulation Coordination and Breaker TRV Studies

MHRC has conducted several insulation coordination studies for ENMAX, including Temporary Over Voltage (TOV), Switching Over Voltage (SOV), and Lightning Over Voltage studies on a number of substations. The studies included the development of a network model in PSCAD.

Manitoba Hydro – Northern Collector Switching Studies

Under this project, MHRC performed Temporary Over Voltage (TOV) studies to facilitate the new proposed expansions to the Northern Collector System AC network. These expansions are in view of the proposed new Bipole 3 HVDC transmission expansion. The main objective of the study was to perform Switching Studies under different conditions and configurations; in particular the system responses related to the transformer energization, faults clearing and potential system resonance. PSCAD formed the basis for the TOV investigations.

Electric Arc Furnace Projects - EAF Model Development for PSCAD

Manitoba HVDC Research Centre is the developer of PSCAD™ /EMTDC™ program. This program is the industry standard for EAF, flicker and harmonic studies. The EAF model that is available in PSCAD™ format was developed by the company. It has been used by our worldwide clients. We have conducted research and development efforts on developing this mathematical model.

EAF Study Technical support to PSCAD clients

We have provided technical support and guidance to a significant number of PSCAD™ users on performing EAF related studies. The clients include equipment vendors, consultants and utilities.

- Assist in validating the overall system model required for a flicker /harmonic study.
- Adjusting the arc furnace parameters to match field recordings.
- Flicker mitigation strategies including FACTS solutions.

Other HVDC Projects

- Highgate Back to Back HVDC Converter Station Life Assessment Study
- Alaska HVDC SWER Project. This project is to study a 50 kV HVDC Single Wire Earth Return Network feasibility.
- Oklaunion HVDC Converter Station Life Assessment Study
- Eddy County HVDC Converter Life Extension Study (in 2004 and in 2011)
- CU HVDC Converter Station Life Assessment Study
- Tri-State Converter Transformer Life Assessment Study

SVC and FACTS Related Projects

- Ponton SVC - Engineering studies and project management services to support Manitoba Hydro's Ponton SVC
- Birchtree SVC (Manitoba) - Technical evaluations and development of specifications and assistance in factory acceptance tests
- Lanfine SVC (Alberta) – Technical evaluations and development of specifications

- Tri-State Utility - Commissioning expertise for Clapham SVC with Electranix

- Clapham SVC - Engineering studies to investigate the voltage flicker issues experienced in the town of Clapham (USA) and to identify an SVC based mitigation. The electric power to the Clapham town was transmitted by a weak 345 kV system. The fluctuating load at a large industrial plant was causing flicker issues. A PSCAD™ based model was used to simulate the flicker problem. The model was validated by comparing the simulation results with actual filed recordings. A SVC based solution was proposed is is now successfully implemented.

- Public Utilities New Mexico - Blackwater HVDC Station refurbishment study with HEG

Sub Synchronous Resonance (SSR) Related

- Development of PSCAD™ based models, application examples and application notes for SSR analysis. MHI expertise is constantly sought by the PSCAD™ user community: https://PSCAD™.com/resource/File/Application_notes/Application_Note_-_Investigating_Possible_Induction_Generator_Effects_Due_to_SSR_-_no_background_colour.pdf)

- Provide technical support to users of PSCAD™ on SSR studies. The clients include equipment vendors, consultants, utility engineers and researchers.

    a. development and validation of a detailed turbine shaft model to include up to 100 rotating masses.

    b. development of a mass-shaft system for a special application where the turbine sections were on either side of the generator.

- SSR investigation of a thermal generation unit connected to a series compensated system (Black and Veatch). This study includes PSCAD™ based studies, as well as mathematical analysis of the shaft-mass system to identify mechanical resonance frequencies.

- Ontario Power Authority - Perform due diligence review of SSR requirements for 500 kV transmission line with Electranix.

- SSR screening guidelines and training for power system operators concerned with SSR issues due to extensive wind

generation interconnections (Texas, USA - 2011).

Wind Integration Related Studies

- Primrose Wind Power Development Ltd. - technical review for a wind farm proposal
- Confidential - Wind Farm studies – This study involved the modeling and analysis of voltage harmonic distortions at the transmission sub station near a wind farm. Field harmonic recordings were used to tune and validate the model. The harmonic distortions were calculated based on IEEE guidelines. Mitigation methods based on passive filters (tuned to around the 5th harmonic) were proposed.
- St. Kitts Wind farm study
- Buffalo Gap (Texas) wind farm studies – This study involved the modeling and analysis of voltage harmonic distortions at the transmission sub station near a wind farm in Texas, USA. A novel method was proposed to model the harmonic injection. In the proposed method the actual harmonic current profile of the harmonic generating equipment as provided in the data sheets were utilized in the model. The harmonic distortions were calculated based on IEEE guidelines.
- Wind Energy Transmission Texas
- Sharyland Utilities

Sub-Synchronous Resonance Studies & Expertise

Rewarded a joint contract with a USA company, MHRC provided a leading US system operator training and technical assistance in detection and analysis of SSR and SSCI risk in the operator's bulk electric system. This project included the following:

- Review and assess the technical analysis provided regarding SSR and SSCI risks to particular units and grid locations
- Provide quality assurance and quality control on issues related to modeling and anslysis of SSCI
- Deliver a set of guidelines associated with modeling requirements and SSCI screening methodology
- Provide technical support and training courses

Alstom Renewables Espana – Wind Turbine Model Development

In close collaboration with the R&D Grid Integration Department at Alstom, in Barcelona, MHRC worked on the development of a PSCAD model of the ECO110 60Hz DFIG wind turbine including all its capabilities. This model can be easily adapted to the other ECO100 platform wind turbines to perform grid integration studies.

RWE NPower – Wind Energy Offshore Power System Analysis

MHRC was contracted to determine the feasibility of connecting 1200 MW offshore platforms by means of 220 kV export cables for RWE in the UK. A variety of studies were undertaken to determine the feasibility of connecting the proposed wind generation to the 400 kV National Grid. The overall project included: load flow study, losses study, short circuit study, and transient studies.

Studies Based on PSCAD™ and PSSE Simulations

- Manitoba Hydro Rolling Mill Voltage Flicker Studies - Engineering studies to investigate the voltage flicker issues experienced at the Manitoba rolling mill due to the operation of an ARC furnace. A STATCOM based mitigation method was investigated.

- Arc Furnace/Industrial Load Related Voltage Flicker Studies - Engineering studies to investigate the voltage flicker issues experienced due to nonlinear loads. Numerous mitigation methods were studied and proposed to clients.

Out of Step Relay Studies

- Manitoba Hydro 500 kV line protection studies (series compensated line)

- OOS studies were done to support the interconnection of four independent operating areas in the Middle East through series compensated lines

    - PSSE based system studies to identify relay settings

    - TRV studies to verify the breaker capability

- Southern Operating System (SOA) Out of Step relay studies were performed in the Middle East

HV Substation Physical Verification Studies and Electrical Analysis

Engineering studies and physical inspection and testing to identify the root cause of transformer bushing failure at a thermal generating station. The studies included:

- TOV and switching
- Resonance and Ferro resonance
- GIS very fast transients
- Generator black start related transients and overvoltage issues

Switching and Insulation Coordination Studies for Major Equipment Vendors and Contractors to Support High Voltage Substation Design

- Over six insulation coordination and switching studies performed for vendors over the past year.

TRV Studies to Support the Installation of Series Line Reactors

Series reactors (while not common) are sometimes required on high voltage transmission lines for fault current limiting, as well as transient stability improvement purposes. Series reactors present a challenging situation with regards to the circuit breaker TRV. Since series reactor installations are not common, each situation must be carefully evaluated considering the location of breakers, CCVTs and other main station equipment. MHI engineering experts have been sought by a number of PSCAD™ software customers to perform the required TRV studies:

- Red Electrica De Espana 345 kV series reactor TRV study. MHI designed the TRV limiting capacitors that would be required for this installation.

Additional Projects

- Fortis, B.C. - Generation Resource Adequacy Study
- Confidential Project - Prepare Lifetime Extension Guidelines for HVDC Systems IEEE Committees and CIGRE Working Groups
- Lanfine SVC Installation for AE – Switching & TRV Studies of HV Circuit Breakers

MHRC is actively involved in several IEEE committee and CIGRE Working groups, including:

- Conveyor of CIGRE B4-57 Working Group – Guide for the development of models for HVDC converters in a HVDC grid - Active
- Conveyor of CIGRE B4-54 Working Group – Guide on the Life Assessment of HVDC Converter Station equipment - Active
- IEEE IEEC57.129 2007 – MHRC technical staff involved in the revision of the IEEE Standard for Converter Transformers, including VSC transformers – Starting new revision
- Vice Chair of IEEE Sub-Committee for Converter Transformers, Smoothing Reactors and Series Reactors - Active
- Chair of IEEE Sub-Committee for DC Bushings - Active
- IEEE WGI8 TF2 Chairman and contributor to Power Electronics Building Block Concepts Control Architecture - Complete
- CIGRE Working Group C4.502 – Power System Technical Performance Issues Related to the Application of Long HVAC Cables - In revision
- CIGRE Working Group C2.21 – Lessons Learnt from Recent Emergencies and Blackout Incidents - Active
- IEEE Task Force – Dynamic Average Modeling – Active

Our Team

Our team consists of highly experienced professionals, three quarters who are professional engineers and technology specialists. Many of our team members have advanced degrees and also possess a wealth of experience obtained while working on HVDC and HVAC systems at Manitoba Hydro. With a staff of over forty we offer the technical skills and expertise required to provide specialized engineering services for the global power system community.

The following is a brief outline highlighting a few members of our team. Full CVs are available for members of our team upon request.

Dharshana Muthumuni, **Ph.D., P.Eng.,** the Managing Director of Manitoba HVDC Research Centre, a division of Manitoba Hydro International Ltd. He has 20 years of experience in engineering studies using a variety of simulation products during his career including PSCAD™ and PSS/E. His expertise is regularly sought out by clients around the world for his strong and wide ranging technical knowledge on power system behavior, model development and simulation studies. He has lead the technical team to solve challenging problems including HVDC and generation interconnections, wind integration into weak grids, FACTS based solutions, SSR screening techniques and power quality and harmonics.

Dharshana has worked extensively and closely with equipment vendors to develop simulation models and techniques to address difficult interconnection problems.
Dr. Muthumuni has developed many customer custom models and developed simulations techniques for specific studies including working closely with equipment vendors to address their simulation study requirements.

In addition to his engineering study experience, Dharshana has been a key developer of the PSCAD simulation tool and has conducted training workshops on a variety of power system topics for our global clients. He has led our

engineering teams on a number of engineering study projects including the Saudi Electric Company system operation and interconnection project.

Les Recksiedler, **P.Eng., CIM.,** has over 40 years of experience and expertise in the electrical utility industry, including the station apparatus design, specifications, bid reviews, contract negotiations, design reviews , factory acceptance testing (FAT), drawing approval for construction, installation supervision, pre-commissioning, commissioning , performance testing, as-built drawings, warranty, Operations and Maintenance, and life assessment. In addition, he has over 34 years of HVDC experience in the design, modification, operations and maintenance of the Nelson River +/- 500 kV, 3 854 MW HVDC system. At MHRC, Les is specializing in HVDC Systems, Power Apparatus and Business Development. He is actively involved with IEEE Standards development and is currently co-chair of a joint IEEE/IEC Standard on DC Bushings. He actively participates on CIGRE HVDC working groups.

Bathiya Jayasekara, Ph.D., P.Eng. is a senior engineer in system planning and operational studies. He has also worked in design verification studies, custom software development for dynamic devices and tender review. His work includes system stability analysis and electro-magnetic transient analysis in both AC and DC systems. Bathiya has over 14 years of experience in engineering studies using variety of simulation tools including PSS/E, PSCAD and small signal stability analysis software. Bathiya is constantly consulted by our clients worldwide for his expert knowledge on power system dynamic performance and equipment modeling skills in PSS/E software.

His recent projects include system planning studies to support the expansion of the TCN network of Nigeria, System studies to determine the optimum size and locations of SVC's in the Panama system, Generation and HVDC interconnection impact studies in Alberta, Canada as well as transfer limit and voltage control studies for the Saudi Electricity Company system. The VAR limits determined by MHI are being utilized in SEC operational planning models.

In particular, he has involved many system interconnection studies out of which more than 10 projects involve the evaluation of impact of new HVDC and SVC system as well as identifying network facilities required to mitigation adverse impacts.

Rohitha Jayasinghe, **Ph.D., P.Eng.,** has been working for the Manitoba HVDC Research Centre for over 13 years and is the lead developer in EMTDC™ simulation engine and component models included in PSCAD™. He has extensive experience in modeling and simulations with PSCAD™ and was responsible for the design and implementation of the frequency scanning component that is now widely used in industry.

Shan Jiang, **Ph.D., P.Eng.,** is a Support and Simulation Engineer at the Manitoba HVDC Research Centre since 2010. Shan has over 10 years of

experience in the field of engineering. He received his B.Sc. and M.Sc. degrees from Chongqing University in China in 1989 and 1992 respectively, and completed his Ph.D. at the University of Manitoba in 2011. He has been involved in Power System Control and FACTS, small signal stability, model validation, and has extensive experience in power simulation software, PSCAD™.

Wujun Quan, **Ph.D., P.Eng.,** received degrees of B. Sc. (84), M.Sc. (89), and Ph.D (03). From 1987 to 1995, he worked as an electrical engineer in R&D department, Harbin Large Electrical Machinery Works Ltd., China. From 1995 to 1998, he was an RA/TA in the dept. of ECE, at the University of Manitoba. He also worked as a control system programmer/analyst in the City of Winnipeg from 1999 to 2000. Since 2000, he has been with the Manitoba HVDC Research Centre, where he is a research and studies engineer and extensively involved in the developments of PSCAD™/EMTDC™, power system reliability software (RISK_A), and the analysis tool for field and corona effects of power transmission lines (FACE).

Farid Mosallat, **Ph.D.,** has been Study Engineer at the Manitoba HVDC Research Centre since 2005. He received the B.Sc. degree from Tabriz University (Tabriz, Iran) and the M.Sc. degree from Sharif University of Technology (Tehran, Iran) in 1996 and 1998, respectively. He completed the Ph.D. degree at the University of Manitoba in 2012. Prior to joining the Centre, he worked as an Automation and Drives Engineer in the manufacturing sector, and was involved in the design, installation and commissioning of electrical distribution and control systems for material handling equipment such as shipyard cranes, and stacker/reclaimer systems.

At the Manitoba HVDC Research Centre, he has been conducting system level and ETM-type studies on the integration of HVDC VSC systems into AC networks; application of SVCs and STATCOMs in voltage flicker mitigation and power quality improvement using SVC; design and implementation of inverter-based distributed generation sources such as hydrokinetic and hybrid diesel-generator (supplemented by battery storage) systems.

He has experience in AC system performance studies, including contingency analysis and transient stability simulations. He is an expert user of PSS/E software and was a key member of the team that performed steady state, dynamic and transfer limit studies on the SEC operational study projects from 2009 – 2011.

Juan Carlos Garcia Alonso, **P. Eng., M.Sc.,** received his Electrical Engineering degree from the National University of Colombia, Bogota, Colombia in 1996. He then received his M. Sc. degree from the University of Manitoba, Canada. He worked designing medium to large power transformers with Pauwels Transformers in Winnipeg for four years between 2002 and 2006. He then joined the Manitoba HVDC Research Centre in 2006. At the Centre he has been working in various consulting projects regarding transient simulation of power

systems with PSCAD™/EMTDC™ in the areas of insulation coordination, VSC's, protections and superconductive magnetic devices, among others. His main focus during this period has been writing new models for magnetic simulation with PSCAD™.

Adam Chevrefils, **P.Eng, M.Sc.,** obtained his B.Sc. (Engineering) from the University of Manitoba, Canada (2005) and completed his M.Sc. at the University of Manitoba (2008). Since 2007, he has been employed at the Manitoba HVDC Research Centre. He was responsible for the design, simulation, implementation and the testing of an electric off-road, all-terrain vehicle and its customized power electronic drive. He has been a member of the PSCAD™ support team assisting clients all over the globe with training and application related support.

Warren Erickson **CET, CTTAM,** has 30 years' experience in working in the Electronics Maintenance Department of Manitoba Hydro. During this time he has spent 20+ years in the HVDC system working on commissioning and maintenance of HVDC equipment and complex controls systems. He received his diploma in Electronic Engineering Technology from Red River College in 1981. He was also involved in the original design and building of a HVDC Line Fault Locator System developed by Manitoba Hydro. At the Manitoba HVDC Research Centre Warren is presently responsible to carry out specialized studies and research focusing on instrumentation, measurement and monitoring technologies. Other work includes assembly of newly designed Line Fault Locator Systems and assisting with factory acceptance testing.

Lalin Kothalawala, **M.Sc., P.Eng.,** provides engineering services to a variety of clients and projects including power system simulation studies and analyses, engineering design analyses and commissioning support to the clients. He is an expert user of transmission planning tools PSS/E and PSCAD. His recent projects include system level studies for the Saudi Electricity Company system, SVC studies for Panama and transmission planning studies for Nigeria.

He was also involved in preparing bid specifications, bid evaluation criteria, project proposals, project schedules, commissioning plans and budget estimations. Additionally, Lalin involves in Factory Assessment Tests (FATs) and equipment commissioning.

Prior to joining the Manitoba HVDC Research Centre, Lalin worked as a commissioning engineer for thermal power stations and high voltage substations in Sri Lanka. He has been in the commissioning team of thermal power stations (100 MW diesel and 300 MW combined cycle) and 132 kV substations. He has been the warranty engineer for 100 MW thermal power plant and worked as the Chief operations Engineer in one of the thermal power stations he commissioned.

Kumara Kotuwage, **P.Eng., M.Sc.,** is a Technical Support and Consulting Engineer who has been working at the Manitoba HVDC Research Centre since March, 2011. He received the B.Sc. degree from University of Moratuwa (2002, Sri Lanka) and the M.Sc. degree from University of Manitoba in 2011. Prior to joining the centre, he worked as an Electrical Engineer and was involved in the product design and development of low voltage switch gears manufacturing sector. His other areas of expertise include industrial automation, electric drive systems, power electronic converters and installation of power distribution systems.

Amalnath Mani **EIT, B.Sc.,** received his Electrical Engineering degree from the University of Manitoba in 2011. Amal has been working for the Manitoba HVDC Research Centre since 2010. In his role as Technical Sales and Support Specialist, Amal supports PSCAD™ users, assisting with model development and various studies. Since his employment he has worked in both PSCAD™ and PSS/E and working on Switching studies, and Load flow for Blackstart Restoration Studies.

Arash Darbandi, **EIT, M.Sc.,** is working as an Engineering Application, EIT. He received his Electrical Engineering degree from the University of Manitoba, Canada in 2010 and currently pursuing his M. Sc. at the same educational establishment. Arash has improved the line feature software of the Ice Vision Project and developed a new algorithm to improve the existing software. He is currently working on an ElectroVaya Battery Re-Purposing Project developing a power electronic grid interconnection and a Reactive Power Study, performing reactive power studies in different plants as well as providing recommendations to clients to improve their system performance.

Jeewantha de Silva, **Ph.D., P.Eng.,** is a software and simulation development engineer at the Manitoba HVDC Research center since 2009. He received B.Sc. (Eng) degree at University of Moratuwa, Sri Lanka in 2001 and then Ph.D. from University of Manitoba, Canada in 2009 on accurate simulation of transmission lines and cables. He is involved with improving overhead transmission lines and cable models in PSCAD™. He is also involved in power system studies, support and various activities at MHRC.

Dexter Williams, **EIT, M.Sc.,** has been working as an Engineer-in-Training since December 2011 at the Manitoba HVDC Research Centre. Dexter received his M.Sc. in Electrical Engineering from the University of Manitoba in 2012. Through his education at the University of Manitoba, he also received his B.Sc. in Computer Engineering in 2009 and B.Sc. in Electrical Engineering in 2007. Dexter has designed, constructed and tested power electronic converters and PCB, as well as developed, tested, and validated embedded software. Dexter contributed to the development of system architecture for MHRC's repurposed battery project.

Anand Gole **B.Eng.,** received his Bachelor of Engineering at the University of Manitoba in 2011, with specialization in power systems engineering. He started working at the Manitoba HVDC Research Centre during a term internship and was later extended employment to assist in a number of projects. Through Anand's employment at Manitoba Hydro international, he has assisted with MHRC's direct current Line Fault Locator (dcLFL), research and assessments of Ice Vision, and the construction of PSCAD equivalent models and validation of the Frequency Dependent Harmonic Analysis Program (FDHAP) conversion program, and has conducted studies using PSS/E.

Software and Hardware Tools

The Centre uses the following analysis tools in its work:

PSCAD™ / EMTDC™

PSCAD™/EMTDC™ is the world's leading commercial electromagnetic transient simulation program developed by MHRC in 1993. EMTDC™ (which stands for Electromagnetic Transients including DC) represents and solves differential equations for the electrical power system network, as well as controls and electro-mechanical portions of the system. PSCAD™ (Power Systems CAD) is the powerful and flexible graphical user interface.

PSCAD™/EMTDC™ enables the user to schematically construct a circuit, run a simulation, analyze the results, and manage the data in a completely integrated, graphical environment. PSCAD™/EMTDC™ is used extensively in power system planning, operation, design, commissioning, preparing of tender specifications, teaching and research. Many major manufacturers use PSCAD™ as a standard tool for their model development, such as HVDC links, SVC and wind farms.

PTI PSS/E (Manitoba Hydro data only)

Developed by Power Technologies Inc., the PSS/E (V32/33) program is a commercial package for power system loadflow and transient stability analysis. This program provides steady state solutions of power networks in phasor domain, and solves differential equations for controls and electro-mechanical portions of the system. Many utilities in North America use PSS/E as a standard tool in their power system planning and operations.

RISK_A (Power System Reliability Assessment and Risk Analysis program)

Risk_A is a proven tool for reliability analysis of power systems. Based on the sequential Monte Carlo method, it produces not only values but also a histogrammed distribution of the reliability indexes, such as EENS (Expected Energy Not Served), LOLE (loss-of-load expectation), as well as the time-correlated indexes-frequency and duration of outage. Operations of spare and redundant components, as well as various outages caused by factors in real systems, such as statistical component failure, maintenance, seasonal shutdown, and aging, are taken into account. Salient features include the ability to model dynamic load distributions with any time interval, built-in substation model, and the capability to consider the capacities or transfer limits of system components. It can be effectively used for resource adequacy assessments, composite power system adequacy assessments, and the adequacy assessments of distribution systems and stations.

FDHAP (Frequency Dependent Harmonic Analysis program)

FDHAP is a frequency-domain harmonic analysis package originally developed at Manitoba Hydro, and was enhanced and performance optimized at Manitoba HVDC Research Centre. Suitable for both AC and DC studies, this program calculates magnitude and phase information of harmonics levels at defined nodes under different combinations of harmonic source injections. Some typical applications include HVDC dc-side harmonics, HVDC ac-side harmonics, frequency scan, power line carrier, voltage and current profiles along the lines and cables, filter design, telephone influence factor, etc. FDHAP is currently a standalone command line product.

FACE (Field and Corona Effect Program)

FACE is a software developed to evaluate the external effects of HV transmission lines.

It quickly evaluates corona-related parameters, such as corona loss(CL), audible noise(AN), and radio interference(RI). Empirical formulas are implemented for analysis of CL and AN, while the semi-analytical method is employed for radio interference, where generating functions obtained experimentally are utilized and a rigorous frequency domain modal analysis is employed to analyze the transmission line geometries. FACE also computes (ionized) field effects of HV transmission lines. It produces static filed profile by the methods of successive images. Ionized fields are computed under Deutsch's assumption and by implementing an efficient algorithm for non-linear two-point initial value problems. FACE is capable of analyzing AC, DC, or AC/DC hybrid transmission lines.

CYMDIST – Distribution System Analysis

The CYMDIST software performs several types of analysis on balanced or unbalanced three-phase, two-phase and single-phase systems that are operated in radial, looped or meshed configurations. The software includes a full network editor, as well as:

- Unbalanced load flow
- Comprehensive fault analysis
- Load balancing
- Load allocation/estimation
- Optimal capacitor placement

SSAT – Small Signal Analysis Tool

SSAT™ is an eigenvalue-based software tool designed for analysis of small signal stability of large complex power systems. It includes a wide number of analysis functions and productivity tools, making it ideal for investigating oscillatory behavior, and for designing and tuning controls to improve system damping.

Applications:

- Studies of low-frequency inter-area oscillations
- Analysis of local or inter-machine modes of oscillations
- Design and tuning of controls
- Investigation of the sensitivity of system parameters on modes of oscillations
- Contingencies screening to meet damping requirement
- Determination of power transfer limit to meet damping requirement

Other Divisions of Manitoba Hydro International Ltd.

Manitoba Hydro Telecom Division

Manitoba Hydro Telecom (MHT) owns, operates, and maintains the second largest data communications network in Manitoba providing business to business services for customers requiring high performance and capacity data telecommunications. Such services are delivered using Manitoba Hydro's surplus fiber optic cable infrastructure. In cooperation with our National and International partners we can help our customers connect across the globe or across the street.

MHT can also assist in business case development and analysis as well as new network design and implementation. We also have expertise available to assist with commercializing existing utility telecommunications networks to enable utilities to add new revenue streams while supporting economic development in the areas they serve.

http://www.mht.mb.ca/

Wire Services Division

Worldwide Integrated Rating Enhancement (W.I.R.E.) Services began operations in 2001 using the experience and expertise developed in applying LiDAR data to transmission line analysis and upgrade engineering solutions. Being the first utility-based company to create a business that combines LiDAR technology with utility applications, we have strengthened our knowledge and gained experience over the past decade by assisting our clients in achieving cost-effective, environmentally friendly, and energy efficient transmission line solutions.

Our services provide electric utilities a full solution package for their transmission line needs. Through our professional and highly experienced employees, we are a "one-stop shop" for transmission line modeling, thermal rating analysis, upgrade engineering, danger tree/vegetation assessments, new route surveys, design engineering, and other environmental applications.

http://www.wireservices.ca/

Manitoba Hydro International Utility Services Division

Manitoba Hydro International Ltd. (MHI) assists power utilities, governments, and private sector clients around the world in the efficient, effective, and sustainable delivery of electricity. As a wholly-owned subsidiary of one of the largest and longest-standing electric power utilities in Canada, MHI has provided utility and asset management; consulting; and training solutions to over 70 countries worldwide.

Utilizing the experience and human resources of its parent Manitoba Hydro, MHI provides electric utility expertise in the planning, design, construction, and operations management of generation, transmission, distribution, and retails sales infrastructure to its international clients. In response to current industry trends, MHI has developed specialized expertise in the areas of utility management and training services.

MHI has established itself as an ethical, environmentally responsible provider of high-quality utility services to the international power sector for over two decades.

http://www.mhius.ca/

Manitoba Hydro International Maintenance Services Division

Manitoba Hydro International Maintenance Services (MHIMS) provides safe, efficient and cost-effective electrical high voltage and natural gas services within Manitoba, Canada and throughout the world. These energy services include, but are not limited to, project and contract management services, project design, material procurement, and maintenance services.

By specializing on both natural gas & high voltage electrical construction, design and maintenance services, MHIMS can provide you with the solution you need to maximize your energy efficiency.

http://www.mhims.ca/

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Hardware Products

Specialized Tools

dcLFL - Line Fault Location System
Consisting of computer-based master stations, GPS timing units, custom wavefront detection unit electronics, and fibre optic transmitters, the dcLFL locates faults with an accuracy of ±500 meters on an overhead HVDC transmission line.

The dcLFL was originally developed to locate faults on Manitoba Hydro's Nelson River HVDC transmission lines. This system has since been successfully installed and used in a number of other countries to monitor power lines, including Malaysia, Australia, New Zealand, India, and China.

Ice Vision System
Vision recognition automatically measures ice profiles directly on overhead transmission lines. The system is very useful for assessment and prioritization of ice mitigation resources. Quick remediation saves on wear and tear of equipment under icing conditions. The system was developed in collaboration with the University of Manitoba Virtual Reality Laboratory.

Training

MHRC provides comprehensive standard or customized education and training programs to assist in building competencies within an organization. Whether clients require a one day session, or a multiple day workshop, instructors possess the knowledge and expertise to provide a unique learning experience designed to satisfy clients' objectives.

A variety of power system, PSCAD, and custom training courses are provided by MHRC. The courses below are some of the many courses that are offered through MHRC that can be customized to suit a client's needs or as is. The courses can be provided at either the client's location or within MHRC.

Some of our courses include:

- Applications of PSCAD and Transient Studies
- HVDC Theory and Controls
- AC Switching Study Applications in PSCAD
- Wind Power Modeling and Studies Using PSCAD

PSCAD continues to be the world-renowned power system simulations software release system. There are over 35,000 PSCAD licenses sold to over 1521 organizations across 80 countries.

Research and Development

Laboratory & Testing
MHRC is equipped with two laboratories used for development, prototyping, testing, validation of electronic devices, and assembling and testing large equipment.

Research Programs
MHRC performs innovative research to support and advance the power system industry. Focusing on simulation, power electronics, and instrumentation research, we strive to present industry and utilities with practical solutions.

- CEF Electrovaya Battery Re-Purposing
- Electric ATV
- Medium Voltage DC Investigation for Remote Communities
- Wavelet based Line Fault Locator

Partnerships
Through global partnerships, new ideas and technologies are continually advanced.

For more information about HVDC Centre, please contact us.

The Manitoba HVDC Research Centre started as a research company. Over the past 30 years, we have developed collaborative partnerships and innovative technologies to diversify our offerings to include a variety of products and services for the power industry.

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