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## Manitoba HVDC Research Centre Celebrates 25 Years of Research and Innovation

**The Manitoba HVDC Research Centre celebrated its 25th anniversary on November 17th, 2006.**

A gala reception at the Centre's office was enjoyed by over 90 friends and employees. Paul Wilson, Managing Director of the Centre, opened the celebration with a presentation on the history of the Centre. Al Snyder, Vice-President of Manitoba Hydro, offered congratulations on behalf of the Centre's parent company. Guests were encouraged to tour the facility and participate in presentations on some of the ongoing work of the Centre.

Presentation topics included the PSCAD® Development, Support Service available for PSCAD® clients, Real Time Playback (RTP), Ice Detection Research, Power Electronic Building Blocks Research, and Environmental Monitoring Research. If you are interested in learning more about any of these topics or other research and engineering projects currently on-going at the Centre, please contact [info@pscad.com](mailto:info@pscad.com)



**Left to Right** The gala reception, guests participating in presentations, the Manitoba HVDC Research Centre staff.

# Application of AC or DC Staged Line Fault Test

Dr. David Jacobson, Manitoba Hydro  
 Mr. Dan Kell, Transgrid Solutions, Winnipeg, MB  
 Mr. Randy Wachal, Manitoba HVDC Research Centre

In the mid 1980's, during the commissioning of Manitoba Hydro's Nelson River HVDC system it was common utility practice to perform DC and AC line fault tests. For a line fault test, a length of wire (usually NiCr) would be dropped or swung onto an energized line producing a transmission line fault. As well as being very interesting to watch, these faults were invaluable tools in optimizing and ensuring the control and protection systems worked properly. The long history of Nelson River HVDC system's fault performance confirms that this commissioning method really worked.

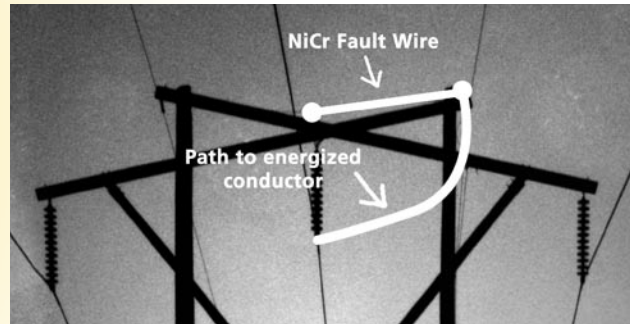
Since the 1980's, there has been increased reluctance to subject the operating power system to the harsh reality of an induced fault test. Is a line fault test justified and under what circumstances? Good question.

Manitoba Hydro recently commissioned a -20/75 Mvar (150 MVar 10 second) SVC at Ponton, Manitoba. This SVC is located near the midpoint of a transmission path from northern to southern Manitoba. Although classical voltage control or regulation is an advantage of this SVC, the main justification for the project was increased AC system stability allowing higher north to south power flows on an existing 230kV transmission line. The fast response of the SVC for an AC fault and Supplementary Damping Control function permits this increased power flow, while ensuring system stability.

These conditions can be accurately modelled using simulation tools such as PSCAD® and RTDS®. So what is the need or justification for a live, harsh and potentially damaging AC staged fault test? Validation of simulation models ultimately are performed by comparison with events that occur on the system. The main advantage of performing a staged fault test, instead of waiting for one to naturally occur, is that it provides invaluable data for this real world versus simulation comparison. The risk is mitigated because commissioning experts and extra recording equipment are available (at site) during a controlled test.

The AC system configuration is also well documented during a controlled test. The fault data collected

Figure 1 An Example of a Staged Line Fault Test



provides an excellent benchmark validation of both the SVC control modelling and the AC collector system modelling. Once a validated system model is provided, an increased level of confidence can be achieved when this model is used in the future to evaluate events and faults which have not occurred yet.

The initial comparisons of field results were close to the simulation results but did reveal some differences in the initial 500 msec following the application of single line to ground fault. Discussion with the manufacturer helped to modify our detailed SVC PSCAD® control model. The revised PSCAD® model now has a better match with the recorded field data and confirms the PSCAD® AC system and PSCAD® SVC simulation results closely replicate the transient performance. This validation increases confidence in future performance studies that will be performed using the associated PSCAD® AC system and SVC detailed models, confirming the value of performing staged line fault tests.

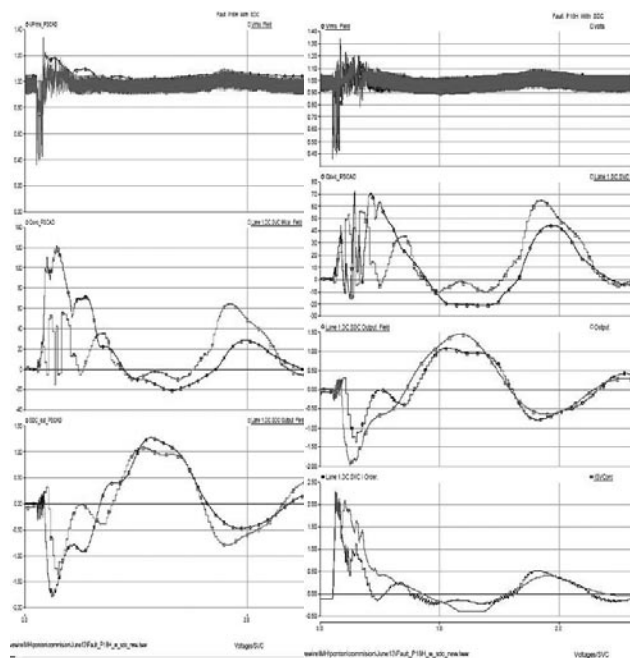


Figure 2 Ponton AC Fault Induced Test results: June 12, 2006. 230 kV Line P18H B phase was faulted, two towers outside Ponton Station.

# Digital Switching Schemes in PSCAD® Space-Vector Modulation

Mr. Ali Mehrizi-Sani (Graduate Research Assistant) and Dr. Shaahin Filizadeh, The University of Manitoba

**The Challenge** Among the most-used power electronic converters are Voltage-Sourced Converters (VSCs). VSCs are used in both high-power apparatus (in power-conditioning application: UPFC and STATCOM), and low-power apparatus (hybrid vehicles). In either case, the basic function of VSC is to convert a DC voltage to an AC, sinusoidal, three-phase voltage of controllable frequency, phase angle, and amplitude.

VSCs come in a number of configurations. The number of switches in each leg determines the resemblance of the staircase-shaped output waveform to an ideal sinusoidal waveform. In a two-level VSC, the output voltage is a sequence of positive and negative pulses. VSCs with higher number of levels, which increases the complexity of the control scheme, have corresponding level of pulses to better approximate a sinusoidal waveform. For the sake of simplicity, we confine ourselves to two-level converters.

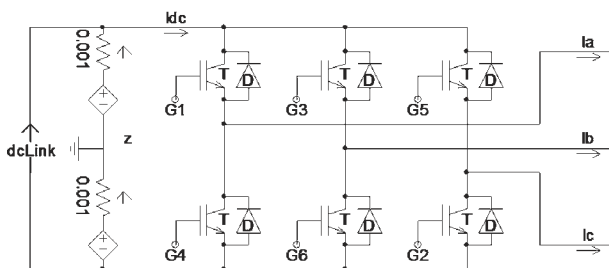


Figure 1 A three-leg, two-level VSC model in PSCAD®

Because of the nature of VSCs' output, which is comprised of a number of pulses, the control techniques used to generate the voltage are called Pulse-Width Modulation (PWM) schemes. A conventional PWM schemes such as sinusoidal PWM (SPWM) determines the turn-on and turn-off instants of each power electronic switch, hence forming the aforementioned pulses. An alternative method called Space-Vector Modulation (SVM), however, solely determines the duration of each pulse, leaving room for carefully engineering the actual turn-on and turn-off instants. This extra degree of freedom can be used to modify harmonics and/or reduce losses.

In SVM, instead of controlling each switch independently (as is done in SPWM), the converter is successively placed in one of the eight states determined by on/off state of switches. Using Park's transformation, each state translates into one vector as shown in Figure 2.

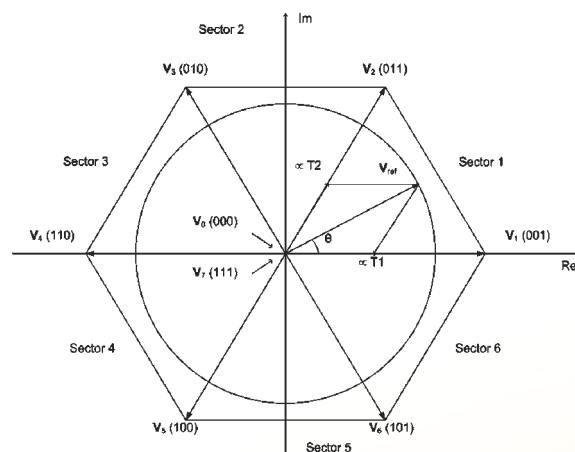


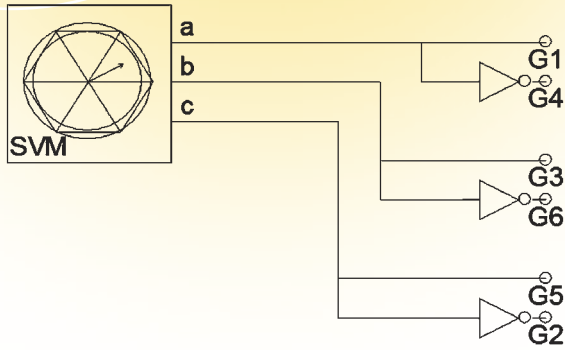
Figure 2 Six active space-vectors and two zero space-vectors in SVM.

By selecting the sequence of states and their time-shares, SVM is able to construct the output voltage with desired parameters.

**The Project** The PSCAD®/EMTDC™ program is used to implement the SVM controller as a new component shown in Figure 3. The project, started in September of 2005, is carried out by Mr. Ali Mehrizi-Sani, a graduate student at the University of Manitoba working under the supervision of Prof. Filizadeh. The project is supported in part by the Manitoba HVDC Research Centre.

**The Process** The developed model is able to generate firing pulses for the linear range as well as overmodulation range of modulation. The model also possesses advanced features such as overmodulation compensation techniques to virtually increase the linear range of operation.

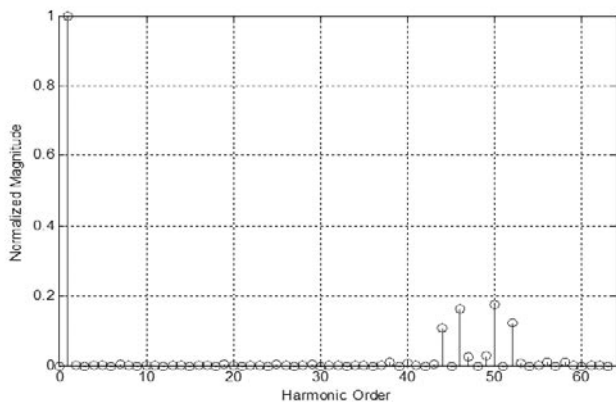
Two simulation cases are used to show the component operation in linear and overmodulation regions, with modulation indices,  $m$ , of 0.8 and 1.2, respectively.



**Figure 3** The PSCAD® Component.

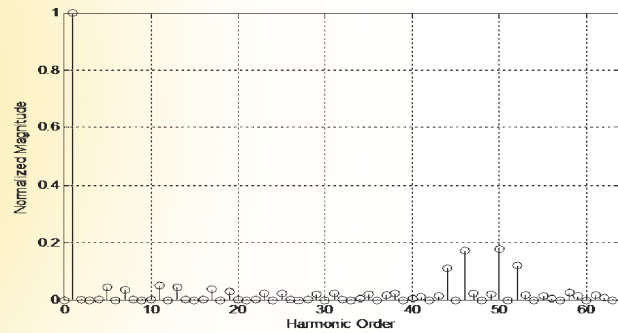
For the purpose of harmonic performance demonstration, Weighted Total Harmonic Distortion (WTHD) for the first 63 harmonic components is calculated.

Generated waveforms have a fundamental frequency of 60Hz. Sampling frequency is chosen to be 48 times fundamental frequency. Because of symmetric firing-pulse generation, even and triple-n harmonics are absent in the line voltage. For  $m$  equal to 0.8 (linear region) measured WTHD is 1.58%. For  $m$  equal to 1.2 (overmodulation region) measured WTHD is 1.69%. In both cases, WTHD is quite acceptable. Harmonic spectra for linear and nonlinear operations are shown in Figure 4 and Figure 5, respectively. Line currents are shown in Figure 6 and Figure 7. Simulation results confirm that generated voltages show complete symmetry with acceptable harmonic performance.



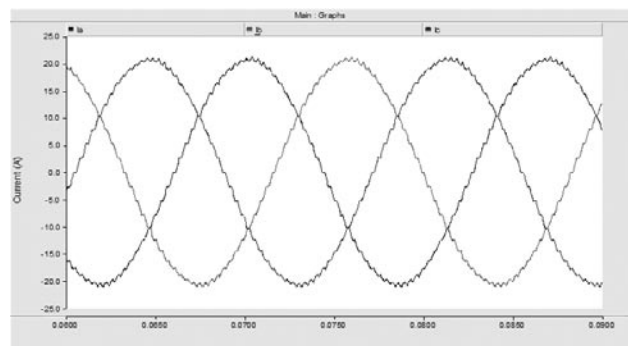
**Figure 4** Harmonic spectrum for the first 63 harmonics for  $m = 0.8$ .

**Figure 5** Harmonic spectrum for the first 63 harmonics for  $m = 1.2$ .

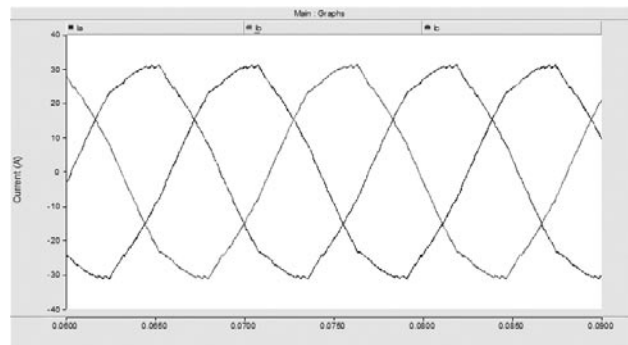


**The Benefit** The model implements space-vector modulation in PSCAD®/EMTDC™ program. While SPWM is simply based on comparison of two sets of waveforms, implementation of SVM requires writing the appropriate code. The developed component is of fundamental value because not all PSCAD® users are necessarily familiar with FORTAN programming language. The component saves PSCAD® users from the hassle of reinventing the wheel and provides a ready-to-go component with built-in options for implementing different SVM strategies.

With the provision to accept dynamically-changed SVM parameters, the user is able to do parametric studies (probably using the Multiple-Run component), which may be used to study the degree of the effect of different parameters such as sampling frequency and vector arrangement on the performance. The model can be also readily used for transient simulation of SVM-controlled VSCs used in power systems or industrial drives. This enables investigation of SVM operation in the context of a power system.



**Figure 6** Line currents for  $m = 0.8$ .



**Figure 7** Line currents for  $m = 1.2$ .

# Hardware-in-the-Loop Test Platforms

Farid Mosallat, Manitoba HVDC Research Centre in collaboration with The University of Manitoba

## Digital simulation tools can virtually simulate any real system, provided a proper mathematical model of the physical system is available.

A common notion among some experts suggests that traditional software-based simulation is unable to exactly replicate real operational conditions. This is not an accurate conclusion. If the system is modelled precisely and all elements of the system are considered in the overall model, the simulation output will be identical to the response of the real system. However, in many situations, building precise models of sophisticated pieces of equipment may be very difficult. The studied component often contains manufacturer-specific structure and for developing a model, some functional details of the device may not be accessed.

## One now must make a choice between the following options:

*Approximate the Device Operation* This may provide a quick estimate but it may also result in unreliable or inaccurate simulation results.

*Investigate if the Manufacturer-specific Information may be attained,* This may require extensive effort and may not be possible at all. If a detailed model is developed, including this comprehensive model may result in reduced simulation speed.

*Include Physical Hardware in the Simulation* Performing the simulation including a physical device rather than a model may provide the most efficient and effective simulation. However, the device must be available for testing. This method is also valuable when initial tuning of a device is required before installation in the field.

There will be a time and place when each of these options is the valid choice. Where approximations are not acceptable and manufacturer-specific data is unavailable, hardware-in-the-loop (HIL) could be considered as the solution.

In HIL technique, physical hardware interacts with a software-based simulation model of the rest of the system (e.g. a power system), running in real-time. If the rest of the system is modelled accurately, the combination of the real hardware and the modelled system will behave as though the physical device is operating in the real world. In this way, it is possible to test and tune the physical apparatus prior to deploying it in the field. Therefore, on one hand, there is no need to model complicated hardware elements, and on the other hand, risk of destructive errors in the installation and commissioning stages can be minimized.

**HIL Schemes** Real-time operation is essential in this type of simulation and test. Since real equipment responds and operates in real-time, the modelled portion of the system shall be simulated in real-time as well; otherwise, the results of the test will be meaningless. The best platform for running an HIL simulation case is a real-time digital simulator (RTDS®). The real-time simulator runs the digital model of the power system, to which, the hardware is connected. This configuration is shown in Figure 1.

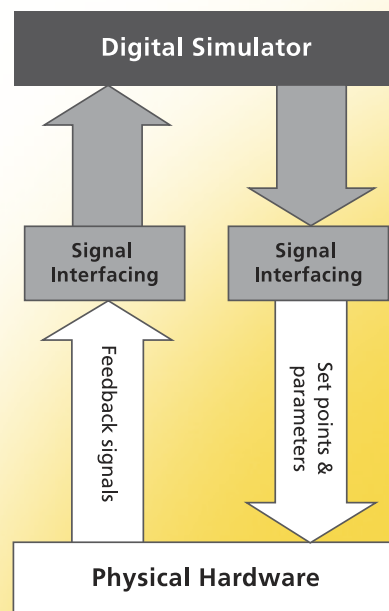
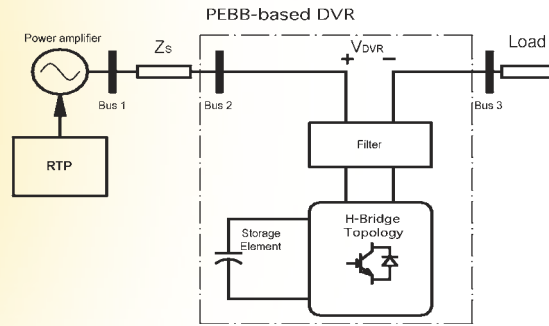


Figure 1 General layout of a Hardware-in-the-Loop test platform, using a digital simulator.

**Figure 2** PEBB-based cascade DVR



The simulated model interacts with the real hardware through a set of input and output signals. The input signals received by the real-time simulator reflect the operating conditions of the physical apparatus, while the output signals generated by the simulator represent the response of the simulated segment of the system to the operation of the device. The exchanged signals and parameters have to be conditioned through signal interfacing modules before being transmitted. The interfacing modules could be analog-to-digital (A/D) or digital-to-analog (D/A) converters, communications links, or plain passive circuits for transforming signal levels.

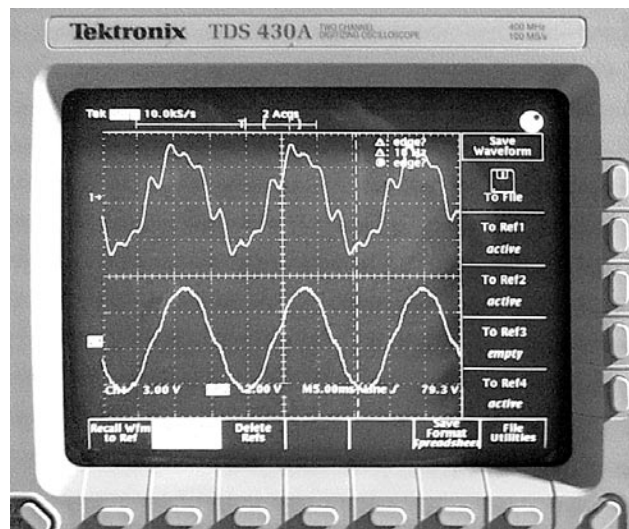
As an example, the AVR (automatic voltage regulator) of a synchronous generator can be tested and tuned using this method. The simulation case will contain EMT (Electromagnetic Transient) models of the power system and the generator. The real-time simulator will transmit the required signals (such as generator terminal voltage) to the AVR and receive the output of the AVR as the controller reaction. Thus, the AVR can be tested and tuned before in-the-field commissioning stage. This is called closed-loop testing.

In some cases, the model does not require feedback from the hardware, or its behaviour is not affected by the response of the real device. In such cases, open-loop testing can be applied. A real-time playback (RTP) replaces the real-time simulator, the system is modelled using offline simulation tools such as PSCAD<sup>®</sup>/EMTDC<sup>™</sup> and the results are uploaded into the RTP. RTP plays back the recorded waveforms in real-time and applies the output signal(s) to the real hardware. This approach is less expensive and can provide the same results and accuracy where open-loop testing is required (i.e. no real feedback signals). Where closed-loop testing (including feedback) is required, real-time simulation technique is the only option.

Figure 2 demonstrates Power-HIL testing of a PEBB-based cascade dynamic voltage restorer (DVR), carried out at Manitoba HVDC Research Centre PEBB lab. All circuit components are real elements.

The RTP represents the voltage source at Bus 1. The output of the RTP is amplified by a power amplifier and applied to the circuit. Control algorithm of the PEBB module was verified and enhanced using this scheme.

Figure 3 shows operation of the DVR as an active filter to remove harmonic distortion from the source voltage (upper waveform) and provide a sinusoidal waveform at Bus 3 (lower waveform).



**Figure 3** Harmonic cancellation using the DVR shown in Figure 2.

#### References

- [1] Farid Mosallat, "PEBB: Building Blocks of Power Electronics" The University of Manitoba, See *Pulse* Spring 2006 issue, 2.
- [2] H. Al-Hadidi, "Minimum Power Operation of Cascade Inverter Based Dynamic Voltage Restorer for Power Quality Improvement", *Ph.D. Thesis*, Department of ECE, The University of Manitoba.



## Bitwise and Byte Foolish

*An Editorial by Craig Muller, PSCAD® Development Team*

**The world of power systems software is vertical and conservative. Its roots continue to pull from work written up to three decades ago.**

In software terms these are enormous time frames, spanning operating systems, hardware platforms and a vast number of standards in software architecture. It has often been said that the one good thing about software standards is there is never a shortage of choice. These choices compete for their opportunity to be the next big thing and more often than not get relegated to the dusty bookshelves of history, only be amusing for the technical archeologists who study their curious offerings and wonder "what were they thinking?". On occasion, one of these technologies survives the battle to prevail as the 'de-facto' standard in the industry. For software vendors, especially those that have short life cycles, the competing 'newbie' can be a daunting reality that haunts their offerings and begs the question, "have I made the right choice?" in using the technology.

Powers Systems Software is quite another animal altogether. Long shadows cast by originators of tools keep these kinds of software tools strongly entrenched in the strategies of the past. Heavy investment in training for the occasional user and the long term investment of the expert in the 'black art' of making these tools jump through flaming hoops means that companies are not so ready to switch the way they use the tool for the promise of new abilities.

This conservative nature does have its advantages, and for the development group there is relief. Since new technologies are very slow to adopt, spared is the team from a stray bullet that otherwise force a restructured version to be built with little or no new features added in the process, simply to switch technology baselines. Instead of this, an established tool or technology has already proven itself to be effective and the vendor decision to adopt it can be made without the fear of some future bitwise bloodletting. The flipside to this conservative approach means that new adoption often creates a significant shift in the patterns of work, something the black artisans do not want since they are comfortable in

the existing structures. Change cannot be ignored, this would be byte foolish, so it must be planned into the work with care to ensure that the old will function while transition to new offers enough benefit to overcome the negative perceptions and create 'neo-cons' of the skeptical elements in the user base. This time has arrived for our team.

The response is targeted and specific. Our goals in the PSCAD® Development team are to move the product from the traditional hand rolled data storage methods to database integration under .NET tools. The adoption of XML in all means of storage and transfer under common standard and reuse of schematic models was the focus of 2006. New alphas under test have been very solid, embracing the reliability of established libraries in the Common Language Runtime (CLR).

This year the focus is integration of multiple solution solvers under a single environment. The development is shifting from a traditionally 'flat earth' EMT centered approach to a system or database centered approach 'neXus'. This means solvers become the consumers and producers of the information in the database able to share and utilize each other for a better overall approach to simulation and problem solving. In the final phase of development, the pieces will be coupled together under a single 'world view' approach pulling together the detail and network based schematics under a single geographic navigator using real GIS coordinates. It is an ambitious effort, and the development group is making great progress towards making it a reality. Much is still unknown, and this is normal when building something completely new, but the search for standards is bearing fruit in many unexpected ways. I suppose we are working to be the next "disruptive innovation", and so we should.

The next year will be exciting indeed with new tools and solvers coming online in a greatly expanded graphical environment. I expect no dust to settle on this book for some time to come. The archeologists will just have to dig elsewhere.

## Expanding Knowledge

The following courses are available, as well as custom training courses - contact [sales@pscad.com](mailto:sales@pscad.com) for more information.

### Introduction to PSCAD® and Applications

Includes discussion of AC transients, fault and protection, transformer saturation, wind energy, FACTS, distributed generation, and power quality with practical examples. *Duration: 3 Days*

### Advanced Topics in PSCAD® Simulation Training

Includes custom component design, analysis of specific simulation models, HVDC/FACTS, distributed generation, machines, power quality, etc. *Duration: 2-4 Days*

### HVDC Theory & Controls

Fundamentals of HVDC Technology and applications including controls, modelling and advanced topics. *Duration: 4-5 Days*

### AC Switching Study Applications in PSCAD®

Fundamentals of switching transients, modelling issues of power system equipment, stray capacitances/inductances, surge arrester energy requirements, batch mode processing and relevant standards, direct conversion of PSS/E files to PSCAD®. *Duration: 2-3 Days*

### Machine Modelling including SRR Investigation and Applications

Includes machine equations, exciters, governors, initialization of the machine and its controls to a specific load flow, typical applications, SSR studies with series compensated lines as the base case. *Duration: 2 Days*

### Distributed Generation & Power Quality

Includes wind energy system modelling, integration to the grid, power quality issues, and other DG methods such as solar PV, small diesel plants, fuel cells. *Duration: 3 Days*

### Wind Park Modelling

Includes wind models, aero-dynamic models, machines, soft starting and doubly fed connections, crowbar protection, low voltage ride through capability. *Duration: 3 Days*

### Industrial Systems Simulation & Modelling

Includes motor starting, power quality, capacitor bank switching, harmonics, power electronic converters, arc furnace, protection issues.

*Duration: 1-2 Days*

### Lightning Coordination & Fast Front Studies

Substation modelling for a fast front study, representing station equipment, stray capacitances, relevant standards, transmission tower model for flash-over studies, surge arrester representation and data. *Duration: 2 Days*

### Modelling and Application of FACTS Devices

Fundamentals of solid-state FACTS systems. System modelling, control system modelling, converter modelling, and system impact studies. *Duration: 2-3 Days*

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