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Vacuum Circuit Breaker Model in PSCAD®/EMTDC™

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This application note presents a Vacuum Circuit Breaker (VCB) model and its implementation in PSCAD®/EMTDC.™ This model investigates the ability of the breaker on current chopping before current zero, its dielectric withstand for TRV (Transient Recovery Voltage) and high frequency current quenching for re-ignition across the breaker contacts.

The VCB is modelled by the use of the standard PSCAD® single phase breaker model with its ability to change electrical switching status by controlling the breaker parameter BRK.

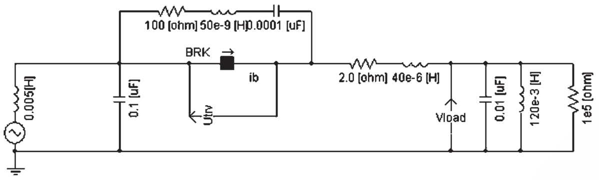

Figure 1 The test circuit for the VCB in PSCAD®

To simulate current chopping and re-ignition, a simple single phase test circuit is established. The circuit is representing a single phase transformer which is switched off by the VCB.

A circuit breaker's breaking sequence is activated by opening the breaker mechanically. This is accomplished by an impulse train that freezes at the instant of the mechanical opening of the breaker. This is the starting point for separation of the contacts. A generally accepted approximation for contact separation in VCBs is constant speed during the first millimetre of separation.

An arc is developed between the contacts and the current continues to flow until the pre-set chopping level is reached. This pre-set level is highly dependent of the contact material in the VCB. When the chopping takes place, BRK changes status from closed to open and the current is forced to zero. The energy preloaded in the inductance surrounding the breaker is transferred to capacitance in the circuit.

The response from the circuit is a TRV that increases between the contacts. If the mechanical opening time t_{open} is close to t_{chop}, the contact separation will be only slight at the chopping instant. Hence, the voltage withstand which has been built up between the contacts is not high enough to ensure current interruption. When the TRV reaches the voltage withstand characteristics, a re-ignition occurs between the VCB contacts.

When the high frequency current is close to zero, the VCB has the ability to break the current. The slope at current zero is measured and compared to the current quenching capability that has been developed between the contacts. If the current slope is less than these particular characteristics, the current is quenched. The resulting TRV is very fast rising and reaches the electrical withstand characteristics quickly. As a result, a new re-ignition takes place between the contacts and a high frequency current starts to flow. This sequence is repeated until the TRV does not reach the electrical withstand characteristics.

Dielectric and Quenching Capability Calculation

The withstand voltage is a function of the contact distance. It can be considered to be linearly dependent for the first millimetre of the contact separation. That implies that this capability is also a function of the speed at contact opening. The dielectric withstand capability for one circuit breaker may vary with a normal distribution and a particular standard deviation.

After re-ignition, a high frequency current flows through the circuit breaker. The resulting arc can be extinguished when the slope of the current is lower than the so called critical current slope, a parameter that is hard to determine. In this model, the quenching capability dielectric strength as measured by Glinkowski et al [1] is used.

The statistical mean values are used in this circuit breaker model. The tested circuit breakers test data are grouped into three levels: High, medium, and low dielectric and quenching ability.

U_b / di / dt	A_a [V/s]	B_b [V]	C_c [A/s2]	D_d [A/s]
High	1.7E7	3.40E3	-3.40E11	255.0E6
Medium	1.30E7	0.69E3	0.32E12	155.0E6
Low	0.47E6	0.69E3	1.00E12	190.0E6

Based on the constants, the mean values of the dielectric characteristic and quenching critical slope can be calculated by:

$$U_b = A_a \cdot (t - t_{open}) + B_b$$

$$\frac{di}{dt} - C_c \cdot (t - t_{open}) + D_d$$

The withstand voltage U_b and the critical slope of the arc quenching capability di/dt are calculated in this section using: A_a=1.7e7, B_b=3.4e3, C_c=-3.4e11, and D_d=255e6. If the circuit breaker statistical distribution is to be studied, details on this matter are explained in [2].

The Vacuum Breaker Probability of Reigniting

The VCB has a probability of reigniting when certain operating and circuit parameters are met [3]. The parameters are: The interrupted current is less than 500 to 600 A, the breaker contacts must part 0.5 ms to 1 ms before current zero with a speed of 1 m/s, and the TRV must rise faster than the breakdown strength of the vacuum gap.

Conditions for Opening of the Switch and the PSCAD® Implementation

The conditions for opening the switch according to Glinkowski et al [1] are:

- The instant of opening should be greater than a pre-set value of t_{open}.
- The switch is closed.
- The actual current is less than the chopping current.
- The derivative of the high frequency current at current zero is not higher than the calculated quenching capability.

For creating these conditions, a number of different parameters had to be calculated in PSCAD® The models in the CSMF part of the Master Library can be used for such calculations. Some representative calculation blocks are shown in the figures below.

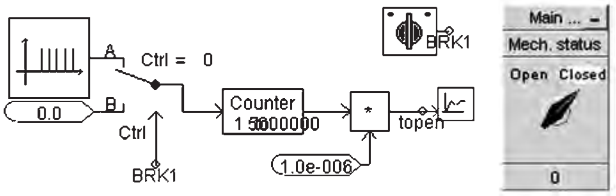

Figure 2 The t_{open} parameter is the instant when the circuit breaker mechanical opening takes place. The pulse train is frozen at $t = t_{open}$. Mechanical opening is initiated by the Mechanical status switch.

The Vacuum Circuit Breaker is an important circuit component in the medium voltage system due to its low maintenance cost and low environmental impact.

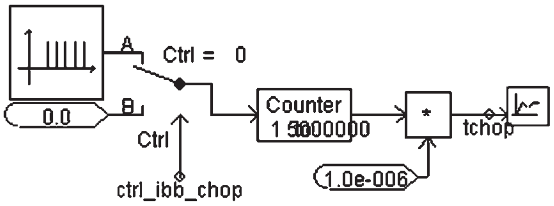

Figure 3 The *tchop* is the instant of current chopping. The pulse train is frozen at *t*= t_{chop}.

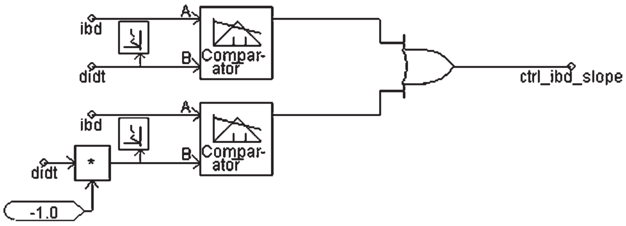

Figure 4 The current slope *ibd* is compared with the current quenching capability *di/dt*. When the current slope is less than the quenching capability, parameter *ctrl_ibd_slope* =1 else 0.

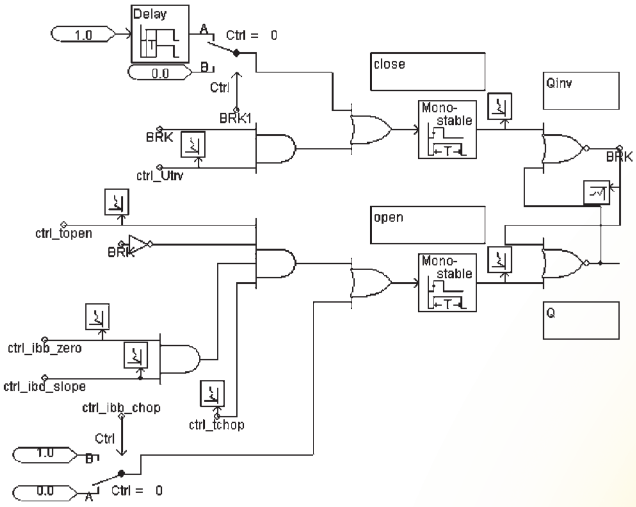

Figure 5 The conditions for opening and closing of the breaker are run through Monostable Multivibrators and a standard Set and Reset latching circuit. The BRK status parameter is now reflecting the electrical status of the vacuum breaker.

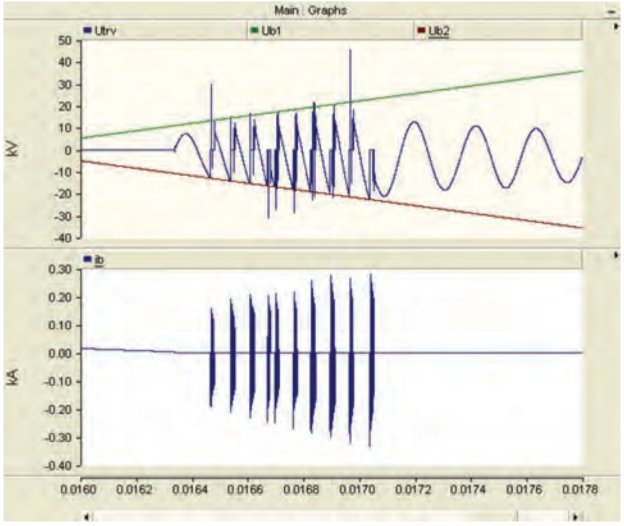

Figure 6 Typical simulation results.

Typical Simulation Results

The number of repeated reignitions depends on many factors; the most important is arcing time (i.e. the voltage withstand which has built up between the contacts when the *Utrv* starts to oscillate). It also depends on the chopping level (i.e. the energy that is transferred from the inductance to the capacitive elements and the breaker characteristics).

For more details as well as for a more complete report, contact the Manitoba HVDC Research Centre or the author directly at *olof@karlenengineering.se*

References

[1] Mietek T. Glinkowski, Moises R. Guiterrez, Dieter Braun, "Voltage Escalation and Reignition Behaviour of Vacuum Generator Circuit Breaker During Load Shedding."

[2] Popov Marjan, PhD "Thesis Switching Three-Phase Distribution Transformers with a Vacuum Circuit Breaker" ISBN 90-9016124-4.

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Single Phase Auto-reclosing and Secondary Arc Considerations

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Shan Jiang, Dharshana Muthumuni (Manitoba HVDC Research Centre)

Single Phase to Ground (SLG) is the most common fault in power transmission systems. Single phase auto reclosing is used to improve system stability, power transfer, reliability, and availability of a transmission line during a single phase to ground fault [1].

Soon after the fault, the two line end breakers will open (faulted phase only in this case) to isolate the fault. However, the other line (un-faulted phases) are still energized. There is inductive and capacitive coupling between the faulted line and the healthy phases, as well as between other conductors of parallel circuits (i.e. double circuit lines). This coupling has two effects [1]:

1. It feeds and maintains the fault arc.
2. As the arc current becomes zero, the coupling causes a recovery voltage across the arc path. If the rate of rise of recovery voltage is too great, it will reignite the arc.

The arc on the faulted phase after the two line end breakers open is the secondary arc. Recovery voltage is the voltage across the fault path after the extinction of the secondary fault arc and before re-closure of the circuit breakers.

Auto re-closing will be successful only if the secondary arc has been fully extinguished by the time the breakers are re-closed. The duration of the secondary arc depends on many factors. The main factors are: arc current, recovery voltage, arc length, as well as external factors, such as wind. When transmission lines are compensated with line end reactors, the secondary arc extinction can be improved by placing a suitably sized neutral grounding reactor (NGR) on the neutral of the line reactors [1]-[3].

DAR Engineering has designed a number of NGR's for EHV transmission lines in the Gulf region. Once the NGR parameters are determined, detailed electromagnetic transient simulations are carried out on PSCAD®/EMTDC™ to verify the insulation requirements of the NGR and to estimate the secondary arc extinction times under different system operating conditions. Such information is essential to properly design the single phase auto re-close relay settings.

The Line End and Neutral Grounding Reactors (NGR) in EHV Transmission Lines The NGR is used to cancel the capacitive component of the secondary arc current [1]. In order to cancel the capacitive current, the inductive and capacitive branches must resonate. Installation of this reactor is effective when lines are transposed.

Estimation of NGR based on the 'Shunt Compensation Degree' The NGR value can be estimated based on the following design equations (see [2] for details):

$$Xn = \frac{B1 - B0}{3F \bullet B1 \bullet (B0-(1-F)-B1)}$$

Where:
B1: positive sequence line susceptance (Siemens);
B0: zero sequence line susceptance (Siemens);

$F = \frac{Br}{B1} = \frac{1}{B1 \bullet Xr}$: shunt compensation degree.

Xr: equivalent reactance of the line reactor.
Xn: equivalent reactance of the NGR
Note 1: B1 and B0 are known from transmission line characteristics and are outputs from the PSCAD line constants program.

Estimation of NGR based on the Basic Insulation Level (BIL) requirements BIL is also a consideration when selecting the NGR. Because the higher neutral BIL level requires special design and more insulation for the line reactor, the cost of the line reactor and neutral reactor increases. If this is the NGR design criteria, the minimum acceptable BIL for the neutral point can be calculated by [4]:

$$BIL\_N = \frac{Xn}{Xn + Xr} \bullet BIL\_Ph$$

Where:
BIL_N: Basic Impulse Insulation Level for the NGR.
BIL_Ph: Basic Impulse Insulation Level of the phase.
For a 400 kV system, the BIL of the neutral point of the line reactor typically is less than 350 kV.

Once the value of the NGR is decided (based on either of the two methods above), detailed simulations (PSCAD®/EMTDC™) can be carried out to determine the secondary arc characteristics.

The Simulation Model The secondary arc extinction time and the recovery voltages are influenced by the following factors:

- Fault locations on line
- Number of reactors (and NGR) in service
- 'Initial' arc length
- Transmission line characteristics and transposing

Arc Model The arc model used in this PSCAD®/EMTDC™ study is based on the model proposed in [5]. The following parameters that influence the arc extinction time are inputs to this mathematical model.

- Initial arc length (Larc)
- Magnitude of the primary arc (Ip)
- Magnitude of the secondary arc (Is)

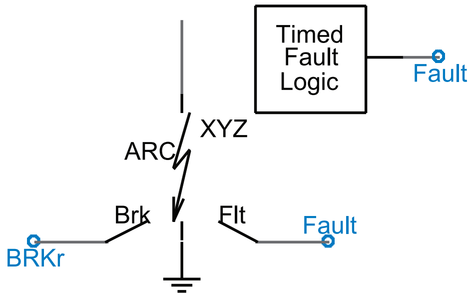


Figure 1 PSCAD® arc model

Initial Arc Length (Larc) The initial arc length influences the secondary arc extinction time. As time progresses, the arc elongates from this initial length until it is finally extinguished. Since the exact value of the initial arc length is not a precisely known quantity, simulations may have to be carried out for different practical values (i.e. 2 m, 4 m and 6 m) before reaching conclusions on relay settings.

Magnitude of the Primary Arc (Ip) This is the magnitude of the fundamental component of the single line to ground fault current at a specific fault location. This value can be calculated from fault studies or through a PSCAD® simulation itself. To calculate this value from the PSCAD® circuit, the fault is assumed to be solid with zero arc resistance.

Magnitude of the Secondary Arc (Is) This is the magnitude of the fundamental component of the single line to ground fault current at a specific fault location after opening the two line end breakers. This value can be calculated from fault studies or through a PSCAD® simulation itself. To calculate this value from the PSCAD® circuit, the fault is assumed to be solid with zero arc resistance. Once the two breakers are open, the phase coupling sustains the fault current.

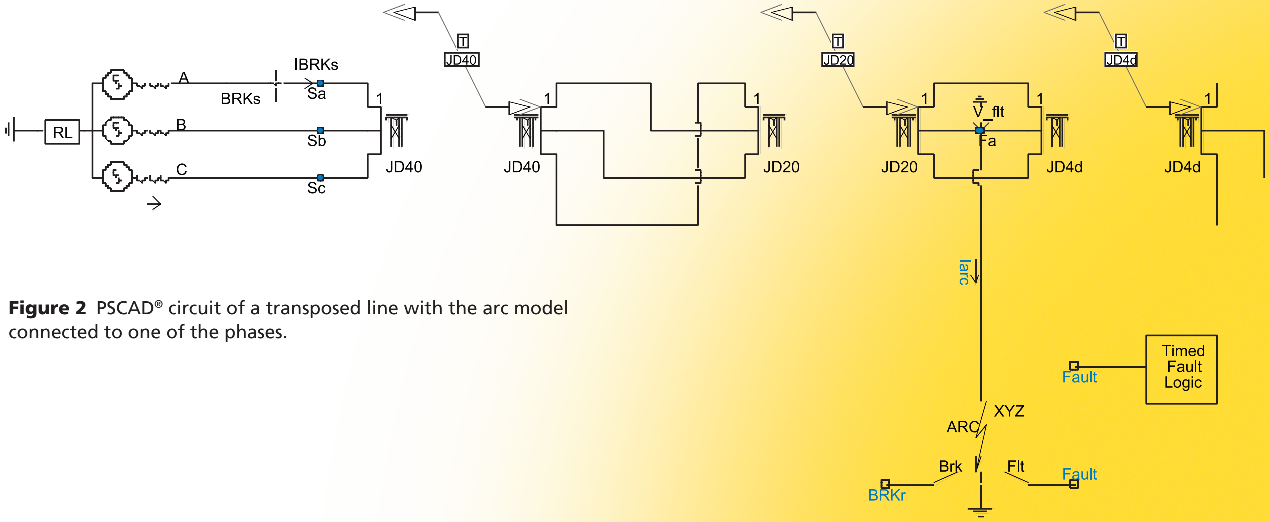


Figure 2 PSCAD® circuit of a transposed line with the arc model connected to one of the phases.

Simulation Results The extinction time and the recovery voltage under various system operating conditions for faults on a 400 kV / 350 km (approximately) double circuit line are presented in this section to illustrate typical results that can be expected.

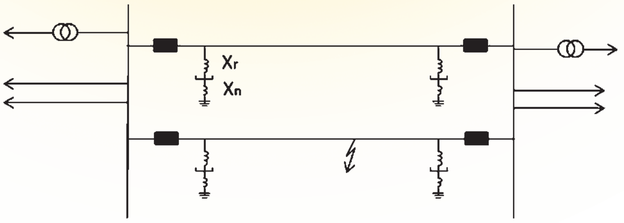
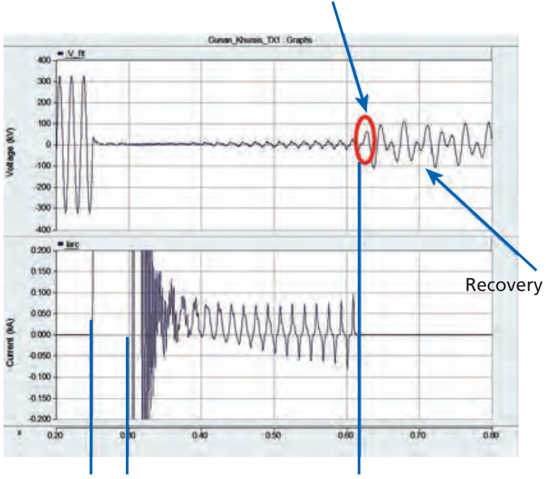


Figure 3 System operating with all reactors at the line end substations.

Fault Location		Bus A	Mid-point
Magnitude of the primary arc (Ip) (kA)		15.2	5.2
Magnitude of the secondary arc (Is) (A)		45	37
Extinction time (s)	Larc = 2.0m	0.17	0.14
	Larc = 4.0m	0.14	0.12
	Larc = 6.0m	0.12	0.12
Recovery voltage (kV)	Larc = 2.0m	46	36
	Larc = 4.0m	45	30
	Larc = 6.0m	63	33

Table 1 Arc extinction time and recovery voltage at different fault locations under different assumed initial arc length values.

First peak of the recovery voltage

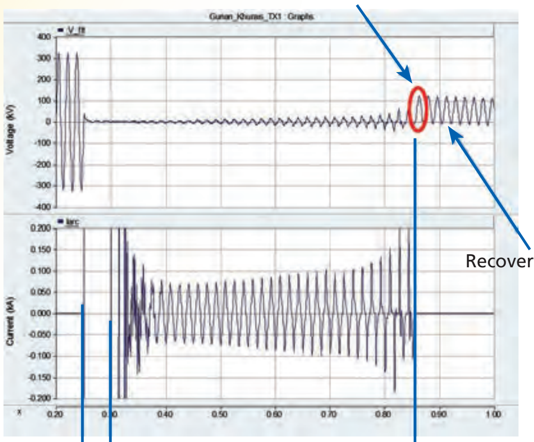


Recovery Voltage

Fault occurs Breakers open Arc extinguishes

Figure 4 Typical recovery voltage (top) and secondary arc current (bottom) with the line reactor and the NGR in service.

First peak of the recovery voltage



Recovery Voltage

Fault occurs Breakers open Arc extinguishes

Figure 5 Typical recovery voltage (top) and secondary arc current (bottom) without the line reactor and NGR

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[1] E. W. Kimbark, "Suppression of Ground-Fault Arcs on Single-Pole Switched EHV Lines by Shunt Reactors," IEEE Transactions on Power Apparatus and Systems, vol PAS-83, pp. 285-290, March/April 1964.

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[4] M.R.D.Zadeh, Majid Sanaye-Pasand, Ali Kadivar, "Investigation of Neutral Reactor Performance in Reducing Secondary Arc Current,k" IEEE Transactions on Power Delivery, vol. 23, no. 4, Oct 2008.

[5] "Improved Techniques for Modelling Fault Arcs on Faulted EHV Transmission Systems," A.T. Johns et.el. IEE Proceedings, Generation, Transmission and, Distribution, Vol. 141, No.2, March 1994.

Kinetic Turbine Power Converter

Farid Mosallat, Manitoba HVDC Research Centre

Kinetic Hydropower is one of the emerging technologies in the alternate-energy power generation sector. Kinetic Hydropower plants employ submerged turbine-generator sets to convert the energy of flowing water into electricity. The produced power is then used to supply islanded loads or is injected into the grid where a utility network is nearby.

Kinetic Turbines can be deployed in tidal flows or in high-velocity rivers. In river applications, a Kinetic Turbine is submerged and anchored at suitable locations along rivers where natural land topography restricts the flow, resulting in high local velocities. The initial installation cost and deployment time of a Kinetic Turbine is relatively small, since it does not require significant infrastructure, such as a dam or a powerhouse. Therefore, such setups can be relatively inexpensive and are expected to have minimal environmental footprint.

Harnessing of the energy in water currents is similar to converting the wind energy into electricity. In contrast to wind, however, water flow variations are steadier and more predictable. Moreover, the density of water is over 800 times larger than that of air. This effects a vast difference between power densities of flowing water and wind. For instance, the power density of water flowing at 4m/s, an upper range for rapid water currents, corresponds to that of a hurricane.

In order to study the feasibility and cost-effectiveness of the Kinetic Hydro technology in Canadian rivers, a Kinetic Turbine research platform has been designed and constructed with a maximum rated power of 60kW. This project is sponsored by Manitoba Hydro and involves researchers from NSERC Research Chairs in Alternate Energy and Power Systems Simulation at the University of Manitoba. Manitoba HVDC Research Centre has been a key partner in this initiative.

The turbine-generator is mounted on a pontoon boat to provide accessibility over the course of the study (Figure 1). In the final design, the floating platform is not required. The turbine-generator can be submerged and anchored with virtually no visual footprint.

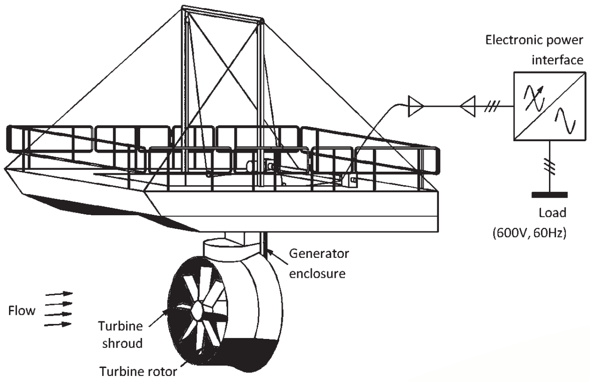

Figure 1 Schematic diagram of the Kinetic Turbine platform

Compact and lightweight generators are desirable in river Kinetic Turbines to avoid complications in the supporting structure design and installation. Significant size and weight savings can be achieved using a generator with higher nominal frequency such as 250Hz – 600Hz. A 3-phase high-frequency permanent-magnet synchronous generator (PMSG) was selected for this platform. At normal water velocities of 2m/s – 3m/s, the PMSG produces voltages in the range of 230V – 560V, 250Hz – 600Hz.

The generator output is transmitted to the shore over a cable link. In a Kinetic Turbine application, the generator output fluctuates due to uncontrollable variations of the flow. Power electronic converters are commonly used to interface the generator and the load system and supply the load with regulated voltage and frequency. The electronic power interface for this project was designed and constructed at the power electronics laboratory of the Manitoba HVDC Research Centre. It consists of two back-to-back voltage-sourced converters (VSCs) and the associated filters, switchgear, protection and control system (Figure 2).

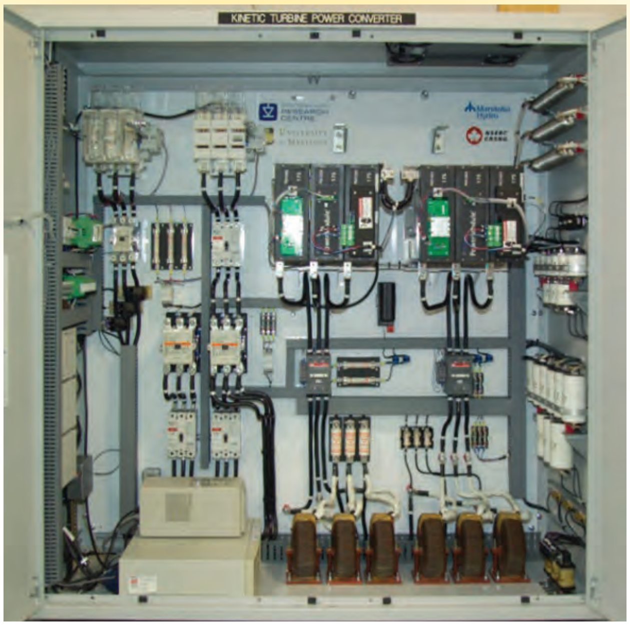

Figure 2 The Kinetic Turbine power converter constructed at the Manitoba HVDC Research Centre.

The generator-side converter rectifies the generator output and provides a regulated dc voltage. The load-side converter then transforms the dc voltage into ac and supplies the load system with a controlled voltage at 600V and 60Hz. PSCAD®/EMTDC™ was used in the design stage to validate the component ratings and the control strategy performance (Figure 3).

The power converters are based on the power electronics building blocks (PEBB) concept. This technology allows for the rapid implementation of different topologies and control schemes. The VSC converters are PM1000 PowerModule® series from American Superconductor.™ They are rated at 175kVA, 660Vac, 1200Vdc.

Figures 4 (a) and (b) show a schematic diagram of the control system structure and the HMI screen, respectively. The human-machine interface (HMI) and the digital control system were implemented using LabVIEW™ and LabVIEW™ Real-Time from National Instruments.™

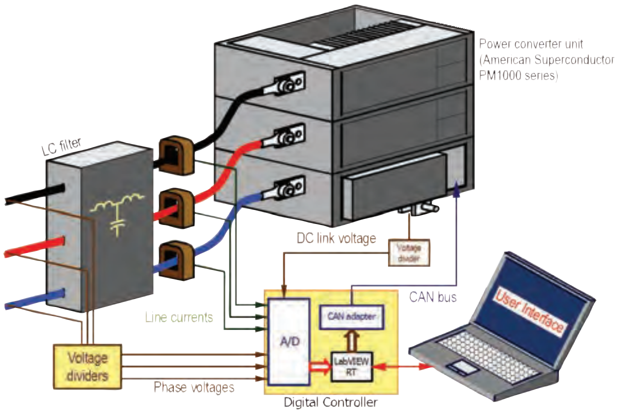

Figure 4(a) Schematic diagram of the control system

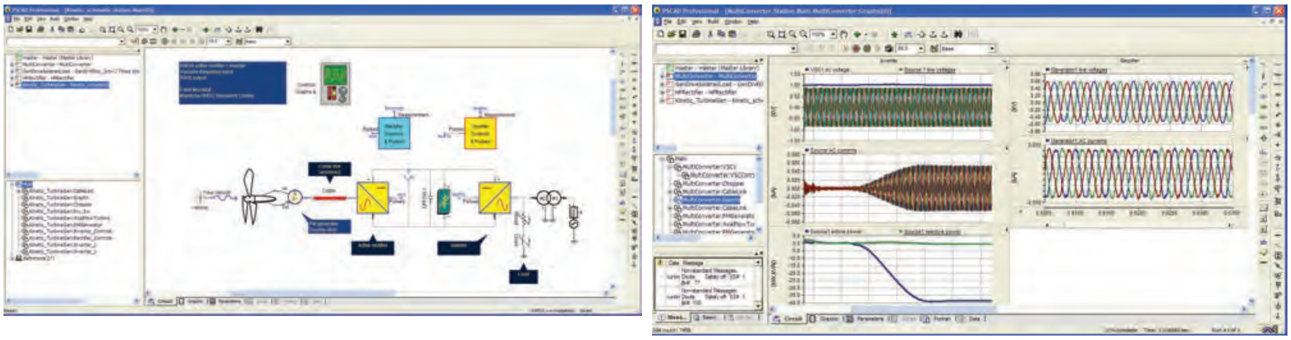

Figure 3 The PSCAD® model implemented for designing the Kinetic Turbine Power Converter.

Kinetic Turbines seem promising for many remote communities in the vicinity of high-velocity rivers, which do not have access to the grid and are currently powered by fossil-fuel-driven generators.

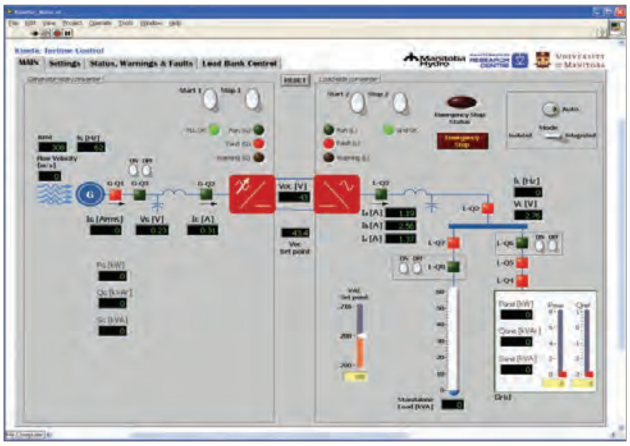

Figure 4(b) User interface screen

The unit is capable of supplying standalone loads with fixed voltage and frequency, or injecting the power to the utility system. In the design of the unit, appropriate control and protection measures were taken and Manitoba Hydro's regulations for distributed generation interconnection were observed.

The Kinetic Turbine research platform has been installed on the Winnipeg River at Pointe du Bois in Manitoba, Canada. The commissioning and performance tests will be completed in the fall of 2011.

Kinetic Turbines seem promising for many remote communities in the vicinity of high-velocity rivers, which do not have access to the grid and are currently powered by fossil-fuel-driven generators. This aspect of the Kinetic Hydropower applications is the main focus of this ongoing research initiative. The results obtained from field operation and experiments will help evaluate the use of Kinetic Turbines in rivers, with a view to the commercialization of this technology as a green source for electric power generation for remote communities in Canada and worldwide.

2010 PSCAD® User Group Meeting

Manitoba HVDC Research Centre

The Manitoba HVDC Research Centre, in collaboration with Cedrat S.A of France, and INDIELEC of Spain, would like to thank participants who attended the PSCAD® European Users Group Meeting held in Castelldefels, Spain on June 15 & 16, 2010 at the Gran Hotel Rey Don Jaime.

New and existing users of PSCAD® participated in two (2) days of meetings and tutorials comprised of presentations by guest speakers and a variety of PSCAD® users' presentations on a wide range of practical applications of PSCAD® from both a commercial and academic perspective. The agenda also included presentations and discussions with the PSCAD® development and support team.

We were privileged to have distinguished guest speakers, Dr. Hermann Dommel, of the University of British Columbia, and Garth Irwin of Electranix Corporation, providing insight into transients and their use, history and current applications. If you are interested in more information about the presentations and discussion at the EUGM, visit *www.pscad.com/news* or contact us at *info@pscad.com*

Due to the overwhelmingly positive feedback and support from attendees… we are doing it again. Look for more information about the 2011 User Group Meeting to be held in Barcelona, Spain, November 2011. More information to come! If you are interested in participating as a presenter, please email us at *info@pscad.com* We look forward to seeing you this fall in Spain!

2010 PSCAD® User Group Meeting 15 & 16 June 2010, Spain *(inset photo from UBC files: Dr. Hermann Dommel)*

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PSCAD		Last Post
General Discussion General dialog regarding the PSCAD software product.	Threads: 145 Posts: 417	PSCAD X4, ETRAN, Jimester by ramnath Today 07:45 AM
Beta Products Issues peratining to beta testing and the beta product.	Threads: 6 Posts: 8	PSCAD GPU Computing Support by Craig Muller 12-22-2009 02:39 PM
Installation and Setup Issues regarding the installation and setup of PSCAD, including Fortran compiler and MATLAB interface.	Threads: 3 Posts: 6	PSCAD 4.2.1 interface with... by IGeorge Yesterday 01:40 PM
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Applications of PSCAD		Last Post
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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, modeling and advanced topics. *Duration: 4–5 Days*

AC Switching Study Applications in PSCAD®
Fundamentals of switching transients, modeling 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*

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

Lightning Coordination & Fast Front Studies
Substation modeling 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*

Machine Modeling including SRR Investigation and Applications
Topics include machine equations, exciters, governors, etc., initialization of the machine and its controls to a specific load flow. Also discussed are typical applications and SSR studies with series compensated lines as the base case. *Duration: 2 Days*

Modeling and Application of FACTS Devices
Fundamentals of solid-state FACTS systems. System modeling, control system modeling, converter modeling, and system impact studies. *Duration: 2–3 Days*

Transmission Lines & Applications in PSCAD®
Modeling of transmission lines in typical power system studies. History and fundamentals of transmission line modeling, discussion on models, such as Phase, Modal, Bergeron and PI in terms of accuracy, typical applications, limitations, etc., example cases and discussion on transposition, standard conductors, treatments of ground wire, cross-bonding of cables, etc. *Duration: 3 Days*

Wind Power Modeling and Simulation using PSCAD®
Includes wind models, aero-dynamic models, machines, soft starting and doubly fed connections, crowbar protection, low voltage ride through capability. *Duration: 3 Days*

Connect with Us!

May 5–7, 2011
China EPower
www.epower-china.cn
Shanghai New International Expo Center, China
Booth #5E01

May 22–26, 2011
Wind Power 2011 Conference & Exhibition
www.windpowerexpo.org
Anaheim Convention Center, California, USA
Booth #555

June 14–17, 2011
IPST
http://ipst2011.tudelft.nl
Delft University, The Netherlands

More events are planned!
Please see *www.pscad.com* for more information.

PSCAD® Training Sessions

Here are a few of the training courses currently scheduled. Additional opportunities will be added periodically, so please see *www.pscad.com* for more information about course availability.

March 1–3, 2011
Fundamentals of PSCAD® and Applications

May 3–5, 2011
HVDC Theory and Controls

September 20–22, 2011
Fundamentals of PSCAD® and Applications

September 27–29, 2011
Wind Power Modeling using PSCAD®

November 22–24, 2011
HVDC Theory and Controls

All training courses mentioned above are held at the Manitoba HVDC Research Centre Inc.
Winnipeg, Manitoba, Canada
training@pscad.com *www.pscad.com*

Please visit Nayak Corporation's website *www.nayakcorp.com* for courses in the USA.

For more information on dates, contact **training@pscad.com** *today!*

If you have interesting experiences and would like to share with the PSCAD® community in future issues of the *Pulse*, please send in your article to *info@pscad.com*

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Pulse is distributed free of charge and is posted electronically at *www.hvdc.ca* If you would like to receive a copy of *Pulse*, please send us an email to *info@hvdc.ca* Articles and submissions addressing the use of PSCAD® in the real world are always welcome.