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Verification of PSCAD® Simulation Results using Small Signal Stability Analysis

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This article presents a portion of an unstable PSCAD® simulation case that was forwarded to the PSCAD® support team by a PSCAD® user. When we encounter unstable simulation results as shown in Figure 1, the inclination is to suspect numerical issues associated with the simulation engine/model. Our experience is that, in most cases, the system studied itself is unstable and the PSCAD® result is in fact correct.

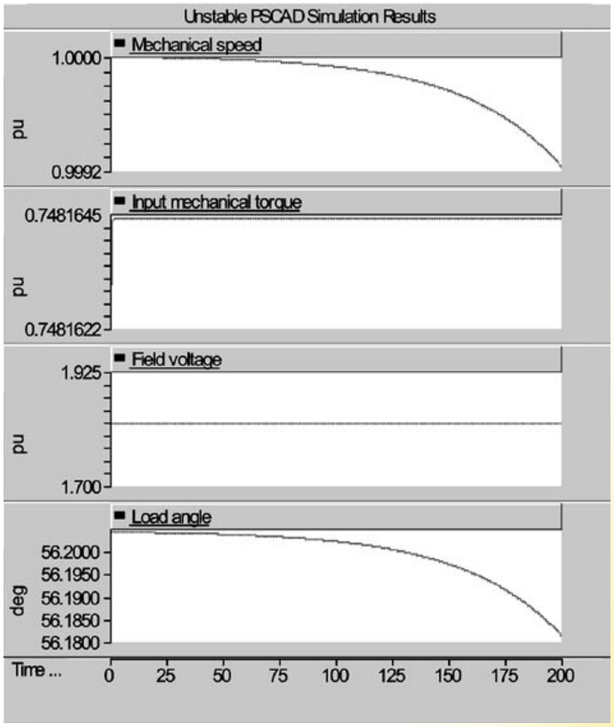

Figure 1 Simulation results showing an unstable synchronous machine operation.

To illustrate this by example we use the simple case shown in Figure 2. In this simple example, the PSCAD® user attempted to model a single machine feeding a resistive load. Further, as a simplification, the user decided not to model the governor, turbine, and the excitation system. However, the reference settings of the field voltage and turbine torque have been correctly calculated for the desired steady state condition (V = 1.0pu, P = 0.712pu, and Q = 0).

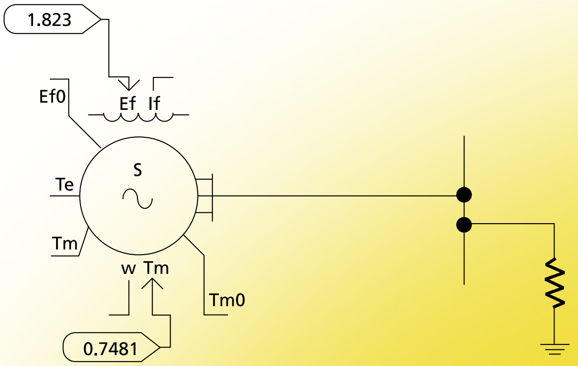

Figure 2 Synchronous machine connected to a pure resistive load.

With typical stability (small signal) studies, you would expect this system to behave in a stable manner. In contrary, PSCAD® results of the simulation given in Figure 1 show that the system is unstable. In order to understand the cause of instability, we performed a small signal stability study using the standard representation of the synchronous generator model used in stability programs. The eigenvalues of the system shown in Table 1 indicate that this system is stable. Based on this analysis, one would be tempted to conclude that the PSCAD® simulation, which shows the system to be unstable, is erroneous.

Eigenvalues	Frequency (Hz)	Damping Ratio
-28.1294 + 0i	0	1
-20.9247 + 0i	0	1
-0.7139 ± 0.2274i	0.0362	0.9528
-0.0009 + 0i	0	1

Table 1 Eigenvalues for the system shown in Figure 2.

One important distinction between the rotating machine models used in EMTDC™ and those used in standard stability analysis programs is that the stator winding flux transients are not modelled in the latter. To elaborate this further the differential equation for the voltage of d-axis 'winding' used in the two types of models is listed below.

Stability-type programs $$v_d = R_s.i_d - \lambda_q.w_r$$

EMT type programs $$v_d = R_s.i_d + \frac{d\lambda_d}{dt} - \lambda_q.w_r$$

The next step of verification is to investigate whether the contradicting outcomes of the PSCAD® and small signal stability analysis is due to the absence of stator winding flux transient terms in the voltage equations of the small signal stability model.

A small signal stability model was formulated with the stator flux terms included and the eigenvalues calculated for this model are given in Table 2. The real, positive eigenvalue clearly indicates that the system has an unstable mode that is non-oscillatory (zero imaginary part). This prediction agrees with the PSCAD® result of Figure 1.

An eigenvalue analysis can be performed beyond the calculation of eigenvalues to investigate the participation of state variables in system modes (eigenvalues). This analysis showed that the generator speed and the d-axis flux terms participate most in the unstable mode (_ = 0.0717). This reveals that the absence of stator flux terms in the simple model was the cause for the discrepancy.

Eigenvalues	Frequency (Hz)	Damping Ratio
-2111.5175 ± 312.5725i	49.7475	0.9892
-28.0767 + 0i	0	1
-20.853 + 0i	0	1
-0.7612 ± 0.3926i	0.0625	0.8888
0.0224 + 0i	0	-1

← There is an unstable mode

Table 2 Eigenvalues for the system shown in Figure 2 with the stator flux transients included in equations.

A PSCAD® simulation and a small signal analysis were then performed for the above system with the excitation system and the governor modelled for the synchronous machine. The results are shown in Figures 3 and 4. It can be seen that, the waveforms produced using the two methods agree very well.

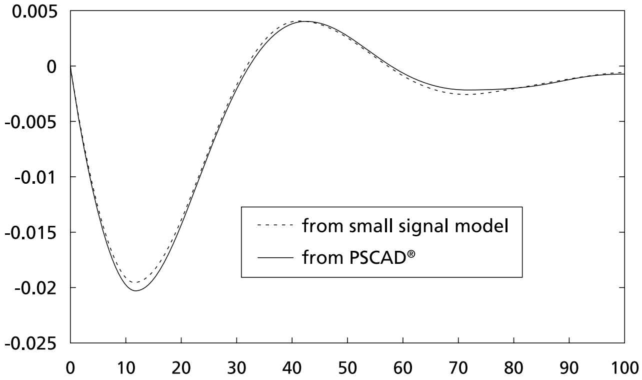

Figure 3 Rotor speed (deviation) for a 2% step change of the exciter reference voltage.

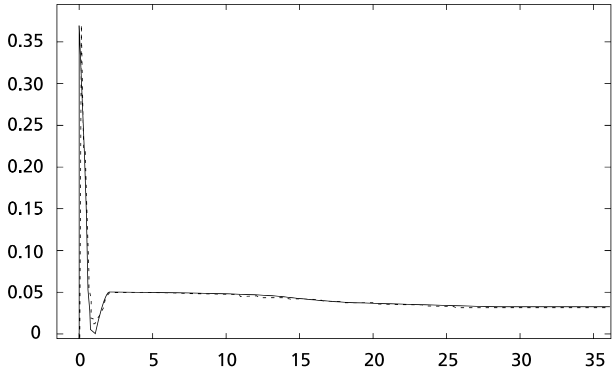

Figure 4 Field voltage (deviation) for a 2% step change of the exciter reference voltage.

In general, it is not advisable to oversimplify models when PSCAD® simulations are performed. The case presented in this article is a good example where the oversimplification of models by removing generator controllers and simplifying the load representation led to a misleading situation.

Vehicle Modelling with PSCAD® for All-Terrain Vehicles

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Figure 1 Commercially available ATV.

As oil prices rise and reductions in greenhouse emissions are being called for, it seems that there is more and more interest in the development of hybrid-electric and pure electric vehicle technologies. The overall increase in efficiency of these vehicles over their purely internal combustion engine powered counterparts is seen as one way of reducing greenhouse gas emissions. Manufacturers and researchers are working hard at developing technologies that will be more environmentally friendly without affecting the overall performance. One such project currently being undertaken is the development of a pure electric all-terrain vehicle (ATV) at the University of Manitoba.

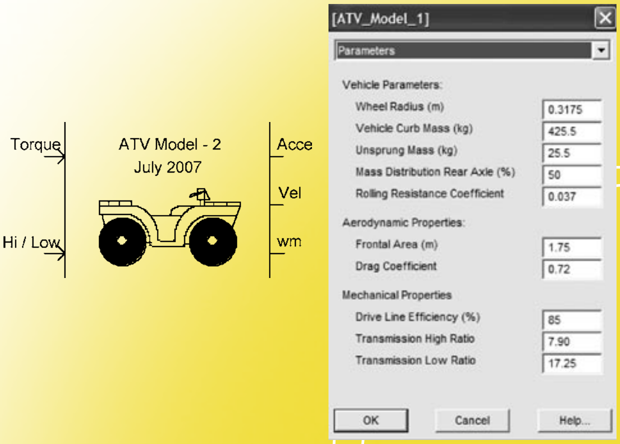
ATVs such as the one shown in Figure 1 are used extensively for recreation and field work. Further to their popularity as rugged high performance vehicles for exploring hard-to-reach areas, they find numerous applications among farmers and park officers who use them for short trips involving excessively wasteful engine idling. To eliminate this wasteful idling, the development of an electric version is being undertaken.

The electronic converters used in electric drive trains consist of fast switching high-power static switches. The fast switching generates high frequency transients that propagate through the electrical and mechanical systems having effects on the acceleration, speed and torque profiles of a vehicle. Most vehicle power train simulation software today does not have the ability to run with time steps in the microsecond range as is required to observe the electrical transients that result from high frequency converters. In order to analyze the effects of such transients, an accurate model of the mechanical system of an ATV has been developed within PSCAD®.

Having the mechanical model allows for the simulation of all the forces, internal and external, acting on the vehicle. These forces include aerodynamic forces, rolling resistance, road grade changes, terrain changes, mechanical efficiency and different traction modes. The simulation of these mechanical disturbances combined with the transients generated by the electronic converter system assists with the overall design stage of the vehicle. Multiple drive train components and parameters can be tried and optimized as well as the tuning of control parameters, well before the implementation stage.

Model Details Figure 2 demonstrates the mechanical model of the ATV which is fundamentally a detailed load model that accepts the drive torque as an input and calculates all opposing forces acting on the vehicle and returns the speed as its output. It has been designed in such a way so that it interfaces directly with the existing motor models found in the PSCAD® library.

The parameters of the model are broken into three categories, general, aerodynamic and mechanical properties. The general parameters allow for entering details such as the vehicles mass and wheel radius. The aerodynamic properties allow for changes in the frontal area and drag coefficient and finally, the mechanical properties account for gear reduction ratios and mechanical losses. The environmental variables such as wind velocity, road grade and ground type (i.e. asphalt, earth road, ice) can be made available to the model for additional model precision. All individual forces can be monitored and recorded if desired including the tractive force, the aerodynamic drag, the rolling resistance, road grade and accelerating force.



Vehicle Parameters:
Wheel Radius (m) 0.3175
Vehicle Curb Mass (kg) 425.5
Unsprung Mass (kg) 25.5
Mass Distribution Rear Axle (%) 50
Rolling Resistance Coefficient 0.037

Aerodynamic Properties:
Frontal Area (m) 1.75
Drag Coefficient 0.72

Mechanical Properties
Drive Line Efficiency (%) 85
Transmission High Ratio 7.90
Transmission Low Ratio 17.25

Figure 2 The ATV load model, component graphics (left), dialogue box (right).

As an ATV is subjected to more and different terrain types than a typical on-road vehicle, the selection of different ground types will affect the rolling resistance coefficient as well as the maximum tractive force that can be applied on the particular ground type selected. The model determines the amount of wheel slip and effects on the velocity based on the ground type selected. As most commercially available ATVs have the ability to switch between 2 and 4-wheel drive modes, the model includes this option. Not only does modelling 4-wheel drive allow for the distribution of tractive force to both axles, accordingly reducing the wheel slip, it also accounts for further losses in the mechanical system when engaged, allowing for more authentic simulation results.

Preliminary simulation results of the mechanical model were compared with results from the manufacturer of the commercial ATV being converted and correspond well. The overall PSCAD® simulation case includes the permanent magnet motor model from the library with the parameters selected to match a PMS-150 permanent magnet motor manufactured by PERM. The voltage sources are controlled by means of a torque vector control scheme, whose controllers were optimized using the non-linear simplex routine found in the library.

Figure 3 demonstrates the torque waveforms for the optimized controller. As the mechanical model is considerably slower than the converter, the waveforms of the requested and actual torques follow very closely.

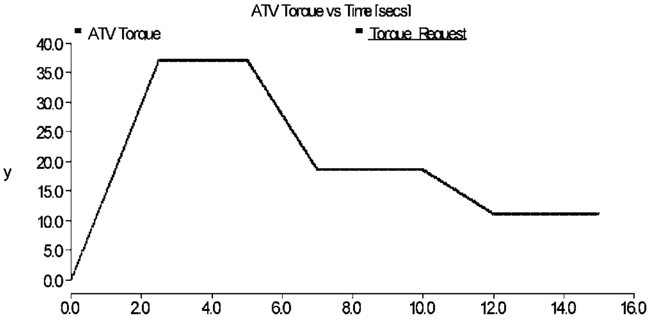


Figure 3 Torque waveform for the optimized controller.

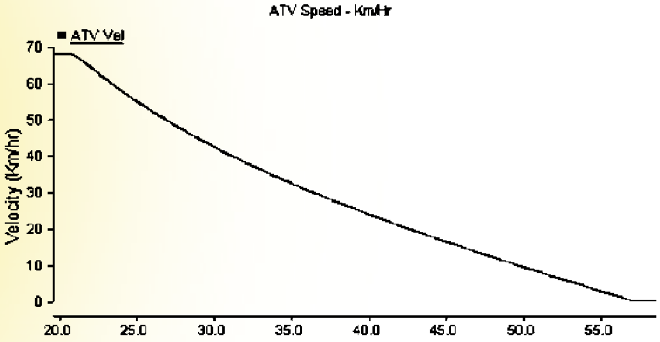


Figure 4 Coast down test on asphalt.

To demonstrate the effects that a change in terrain type can have on an ATV, Figure 4 demonstrates a coast down test from top speed on asphalt with a duration until stopped of 37 seconds and Figure 5 demonstrates the same coast down test this time on gravel with a duration until stopped of 27 seconds. The change is due to the increase in rolling resistance between asphalt and gravel. By keeping the torque constant at a constant speed the change in rolling resistance can be observed by changing only the terrain type. Figure 6 demonstrates the decrease from a steady state of 63.8km/hr to 53km/hr when the ground type is changed from asphalt to an earth road.

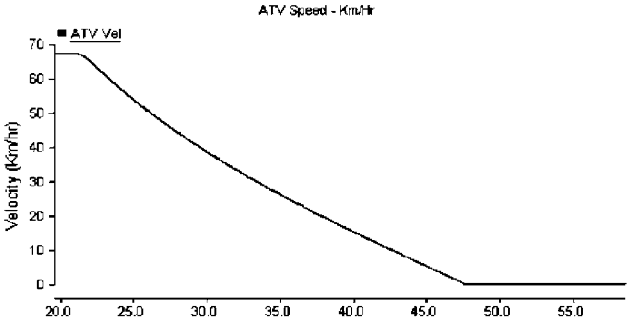


Figure 5 Coast down test on gravel.

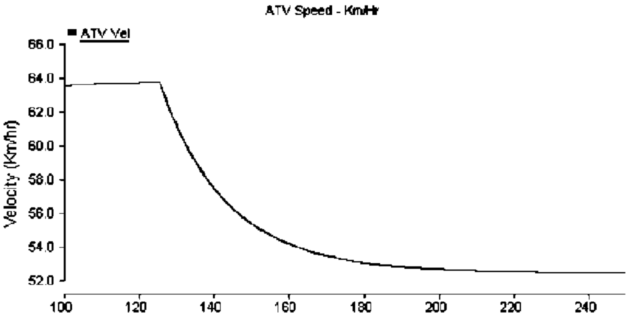


Figure 6 Effects of a step change in terrain type.

In summary, including detailed mechanical load models of vehicle can help not only with parameter determination such as top speed, power and energy requirements. The detailed modelling can also help determine the most appropriate component selection to achieve the projects requirements. Selection and tuning of the control algorithms before the prototyping and implementation stages of the project can also be done all within a single simulation environment, saving both valuable time and dollars.

How the PSCAD® Support Desk can Help You!

PSCAD® Technical Support Desk, Manitoba HVDC Research Centre

When you require assistance with PSCAD® where do you go? Some answers to commonly asked questions can be found in the existing database of frequently asked question (FAQs) through our website (*www.pscad.com*) and Forum (*bb.pscad.com*). We encourage users to utilize these resources for speedy solution to some questions. Some additional resource information is available in:

- PSCAD® On-line help file
- PSCAD® User's Guide and EMTDC™ User's Guide
- PSCAD® Application Guide *www.pscad.com*

However, when you need additional assistance, please contact the PSCAD® Technical Support Desk.

The PSCAD® Technical Support Team is comprised of Applications Engineers and PSCAD® Instructors who are engineers, many with master and doctorate degrees. They have years of experience working with PSCAD® and performing power system simulations for research and industry. This team of experts is committed to assisting new and experienced users of PSCAD®. They work to ensure Users understanding of the program features, as well as, to effectively find solutions to problems. The support team strives to provide responses that are clear, accurate, and timely.

When is PSCAD® Support available? The PSCAD® Support Desk is staffed from 8:30 am to 4:30 pm Monday to Friday Central Time (CDT) and answers a wide variety of PSCAD® questions from basic to complex, generally within one working day.

How to request support The most efficient means of requesting support is to issue a Support Petition Request directly from PSCAD®, rather than e-mailing to support directly. A Support Petition Request will automatically contain important information regarding your PSCAD® version, compiler and license data appended to the request. This automatically generated information enables the support team to minimize the need for 'back-and-forth' communications, which can be cumbersome across the different time zones. A Support Petition Request is created by: selecting Help on the Main Menu bar, then Support Request…

What Help Desk Support *is* and what Help Desk Support *is not* The PSCAD® support team provides support to all users with active warranty or maintenance. However, priority is given to users with full commercial PSCAD® Pro licenses with active maintenance. For more information about the PSCAD® maintenance program, please contact *sales@pscad.com*.

PSCAD® Support mandate is to solve PSCAD® issues including PSCAD® behaviours and addressing potential functionality or modelling difficulties which may arise. For service beyond this, the Manitoba HVDC Research Centre is pleased to offer engineering services on a contract basis. This may include developing new models or modifying existing ones, training, as well as, performing studies. Please contact *sales@pscad.com* for more information.

PSCAD® Support does not solve engineering problems, nor solve class assignments for student users. In addition to questions, the support desk welcomes and tracks suggested improvements for PSCAD® with our development processes. We appreciate and encourage PSCAD® user feedback.

For prompt support:

- Do use paid email accounts rather than hotmail accounts. Email spam filters often sort out hotmail resulting in delay or omission of these support requests. Use hotmail at your own risk.
- Do identify yourself, your organization/company, and the PSCAD® license number;
- Do indicate what version of PSCAD®, the Fortran compiler and the operating system;
- Do give a complete step-by-step and repeatable description of your issue and a copy of the PSCAD® case file if possible.

For Licensing issues please send:

- the Lmgrd-log.txt file from the machine running the License Manager
- all the PscadLmgr.txt files from the machine having problems running PSCAD®.

The Manitoba HVDC Research Centre strives to make PSCAD® the simulation tools of choice and to provide excellent customer service. Comments and feedback, both positive and negative from PSCAD® users are highly valued. We look forward to hearing from you.

Transient Recovery Voltage Assessment for 138kV Breakers with the New Addition of a Wind Farm

Zheng Zhou, Xuegong Wang and Paul Wilson, Manitoba HVDC Research Centre

Due to rapid growth of power network, increased short circuit current level could reach and possibly exceed the capability of existing breakers. Manitoba HVDC Research Centre performed an assessment study of existing breakers to guarantee the breakers can operate safely at present and also in the future. A new 70.5MW wind farm generation plant is being proposed west of the substation. This wind farm will be connected to a 138kV transmission line. With the new addition of the wind farm, one concern is that the short circuit current growth may exceed the capabilities of electric equipment in the substation. A study and breaker evaluation were required to affirm that the two 138kV breakers at the substation will be adequate to withstand the Transient Recovery Voltage (TRV) created by the proposed wind farm generation. The main objective of this study is to investigate the interconnected power system around the substation and determine if the TRV exceeds the breaker ratings. This power system will be studied to determine the worst case TRV, and to recreate the system operating condition. The purpose of TRV study is to identify if the breaker ratings for TRV are exceeded for power system operations.

Circuit breakers can fail to interrupt fault current when the power system connected has transient recovery voltage characteristics that exceed the rating of the circuit breaker. Transient Recovery Voltage is the voltage across the opening contacts of a fault-interrupting circuit breaker immediately after the arc is extinguished. The actual shape of the transient is determined by the connected lumped and distributed inductive and capacitive parameters defined by the connected bus equipment. For successful interruption, the breakdown voltage of the interrupting medium must always exceed the recovery voltage. If the TRV peak value is above the breaker rating, the increasing TRV to the gap will re-strike the arc and break down the interrupting medium. If the withstand boundary of the circuit breaker is exceeded, either a different circuit breaker should be used, or the system should be modified in such a manner as to change its TRV characteristics. The addition of capacitors to a bus bar or line is one method that can be used to improve the recovery voltage characteristics of the system.

The investigation was carried out by digital simulation using PSCAD®/EMTDC™ V4.2 to analyze TRV waveforms. Based on the output, the peak values and the Rate of Rise of the TRV (RRRV) can be determined. These values were compared with breaker rating calculated by IEC standard 62271-100. Since the breaker interrupting current in the substation is in the range of 1.8~5.1kA, which is much smaller than the rated breaker interrupting current 40kA, the two parameters representation of TRV envelope with 10% and 30% of interrupting ratings is used. Figure 1 shows a two-parameter envelop of TRV, where uc is the reference voltage (TRV peak value) in kV; t3 is the time to reach uc in µs. RRRV which is uc/t3, is a method to quantify TRV and is an important factor in switchgear application. It is a measure of circuit severity from a switchgear point of view.

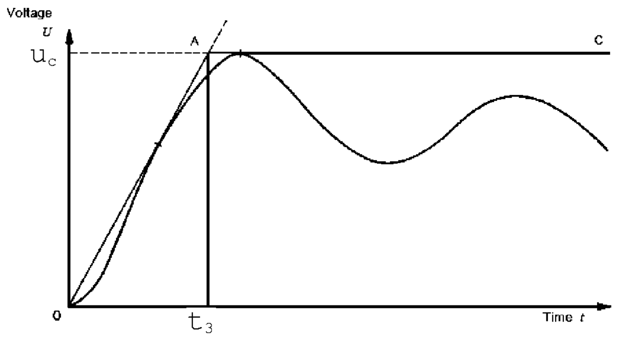


Figure 1 TRV envelops by two parameters (referenced IEC 62271-100).

Substation Power System Modelling

To perform a TRV study in digital simulation, the first step is to build up the power system model of the study subject. The detailed representation of the substation and nearby power system is required. On site measurements were carried out to get the data of the substation layout. Load flow and fault analysis raw and sequence data files in PSS/E data format were also used to determine the equivalent circuit of the external power network. A special software tool called E-TRAN is used to convert PSS/E power flow raw data file to

PSCAD® case file. It also does the system reduction and finds the equivalent circuit for a specified part of the power system.

Power System Description The substation consists of two 138kV transmission in-feeders through two ASEA HLR 145 breakers 725W and 725E to a common bus. A transformer converts the 138kV to 13.8kV of distribution level and provides power supply for a residential area. The substation is connected to the power network through the 138kV transmission systems. The original load flow file has 1800 buses; we select 38 buses which forms the interconnected power system. Two wind farm generation plants are tapped on to the west of the substation. Networks further away from the substation are represented by equivalent circuits. The following sections give the details of data calculation and the study model set-up.

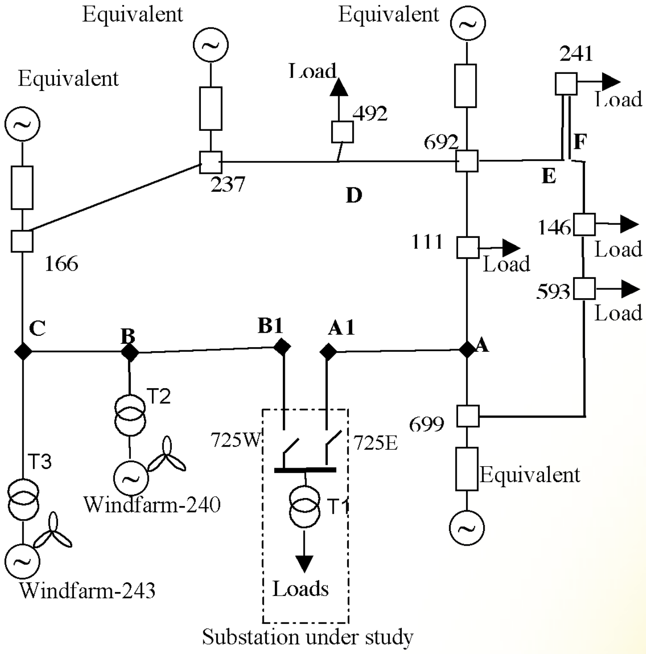


Figure 2 Substation interconnected electric system simplified schematic.

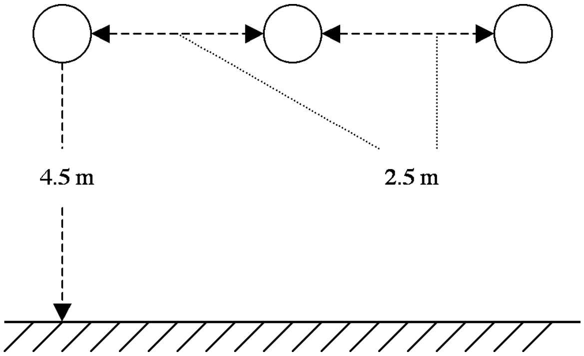


Figure 3 North and South bus-bar layout.

Substation Bus-Bar and Feeder cables There are total of 11 sections of bus-bar connecting breakers, disconnecting switches and transformers. The length of the sections varies from 4.94 to 10.25 meters. The bus-bars are constructed of 3 inch (0.0762 meter) pipe. The measurement and layout of the bus-bar is shown in Figure 3. There are 4 parallel feeder cables with length of 32 meters at the substation. In the TRV simulation study, the feeder cable is represented by lumped L-C circuit, cable resistance was ignored. The capacitance of the feeder cable was estimated, where the typical capacitance values for 15kV power cables of 500MCM is 0.86μf/mile. The total capacitance of the 4 parallel 32 meter cable is C-cable = 0.0684μf.

Substation Transformers Transformers have strong influence on fast surges due to the dominant bushing and winding capacitance. However, the transformer capacitances are often difficult to determine. Transformer capacitance is represented by CH, CL (capacitance winding to ground) and CHL (capacitance winding to winding). Normally, the CL and CHL are greater than CH, simply because high voltage calls for more separation between windings and between windings and core. Test results in Manitoba Hydro and reference show that roughly CL is three times larger than CH and CHL is four times larger than CH. A reference presents a detailed method to determine transformer capacitance. IEEE working group provides the value of the total capacitance to ground of the highest voltage windings on a per phase basis.

Effective Equipment Stray Capacitance In the calculation of TRV, proper representation of the stray capacitances of the substation is important in some situations. Accurate information on the inductance of apparatus is given by the manufacturer, but little or no information is given on the effective capacitance of apparatus. The effective capacitance values of various pieces of equipment are obtained from the recommended values in IEEE Standard C37.011-1994. These capacitances represent breakers, disconnect switches, transformers, surge arrestors, etc., from 50pF to 600pF.

Wind Farm Generators Due to the fast transient of TRV, the induction generators in the two wind farms are modelled as voltage sources with sub-transient impedance. The dynamics of the wind turbine and its controls are ignored since they are too slow to react in the fast TRV transients measured normally in microseconds. There are 47 induction generators at wind farm-243. The parameters of the generator are obtained from the data sheet provided by the manufacturer. The actual transient reactance of the induction machines of the wind farm was calculated based on the equation by Prabha Kundur, which is:

$$X_s^{'} = \omega_s \left(L_{ss} - \frac{L_m^2}{L_{rr}} \right) \qquad (1)$$

Where $L_{ss} = L_s + L_m$ and $L_{rr} = L_r + L_m$

From (1) the transient reactance of the wind farm generator is calculated as $X_s^{'} = 0.294pu$. The equivalent generator of wind farm-243 is solved by a solved power flow solution; the terminal conditions of the wind farm-243 are obtained. Similar treatment was also applied to wind farm-240.

System Equivalence The external network viewing at the boundary buses 166, 237, 692 and 699 is represented by Thevenin equivalent network. The equivalent network is obtained based on the base case of PSS/E raw data file, using E-TRAN data conversion program. The parameters of the equivalence are internal impedance of R and X and the terminal conditions such as terminal voltage and real and reactive power.

Model Validation After setting up the system in PSCAD®, the model was validated with a load flow condition provided by the system operator and fault current calculations by PSS/E. The load flow condition is also the initial operating point for the TRV analysis.

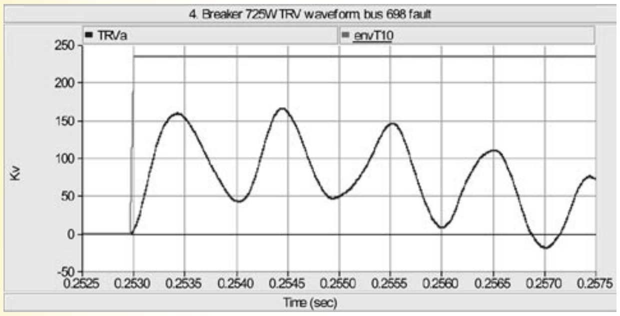


Figure 4 The TRV characteristic waveform of breaker 725W in Case 4.

TRV Simulation and Discussion

In order to obtain sufficient resolution in the output, a 0.5μs time step was used for the TRV simulations. The TRV waveform is measured by voltage meters at both sides of the breaker, then the difference is plotted to get the instantaneous TRV voltage waveform. To examine the worst TRV condition, three-phase ungrounded faults were applied at different locations in the power system. Faults were applied in the substation at the bus-bar and the load side. Also faults were applied outside substation at remote locations and the system side of the substation. The switching operations of the two 138kV breakers at the substation vary at different fault conditions. The combination of the fault locations and breaker operations result in total 15 test cases. The TRV waveforms of the first open-pole contact are plotted against the rated breaker TRV capability envelope. Here we present the TRV waveforms for case 4 in Figure 4. The figure has two plots, one is the actual TRV curve of the first open-pole of the breaker; the other one is the TRV capability envelope. From the simulation results, we observed the following:

1. The peak TRV values are in the range of 25~195kV. The allowable TRV peak value from the manufacture and IEC standard 62271-100 are 235~237kV. So the actual TRV peak values of the two 138kV breakers at the substation, are well below the peak TRV capability value.

2. The actual RRRV of the two 138kV breakers in the substation are in the range of 0.08~0.85kV/μs, which are much smaller than the RRRV capability (5~7kV/ μs). They are even smaller than the most severe RRRV (2kV/μs) at rated interrupting current of 40kA. The TRV stresses do not exist in the substation.

3. Fault current level at the substation increase only slightly. The addition of a new wind farm does not cause major impact on the 138kV breakers at the substation under study.

Please contact *info@pscad.com* for a complete version of this technical paper including all references.

Analysis of Field and Corona Effects of High Voltage Transmission Lines

Wujun Quan, Xuegong Wang, Paul Wilson, Manitoba HVDC Research Centre

Evaluation of field and corona effects is an important consideration when designing new transmission lines, reinforcing existing lines, and converting HVAC to HVDC lines or vice versa. A powerful software tool for analysing field and corona effects of HV transmission lines has been under development in the Manitoba HVDC Research Centre since early 1980s. Developments and improvements continue to be implemented. The field and corona effects program examines all the environmental impacts of AC, DC, or AC/DC hybrid HV lines, including audible noise, radio interference, corona loss, and electro-static and magnetic fields. For HVDC lines, distributions of ionized fields, ion charges, and ion currents are easily computed at any height above ground.

Numerical experiments are conducted based on the Manitoba Nelson River HVDC lines, for which long-term monitoring has been performed. The line configuration is shown in Figure 1, and Table 1 lists two different operating voltages at the four poles, for which the measured results with the wind speed less than 1m/s are available.

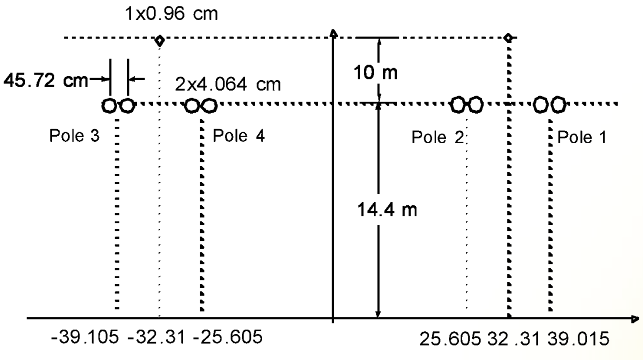


Figure 1 Geometry of the Manitoba Nelson River HVDC Transmission Lines.

	Pole 1	Pole 2	Pole 3	Pole 4
Case 1	-450	450	-450	0
Case 2	-440	440	-470	470

Table 1 Operating voltages in kV for two cases considered.

Numerical experiment – Case 1 In this case, the pole 1 and pole 2 constitute a bipolar scheme while the pole 3 is a monopolar scheme with the pole 4 being a sky wire. The AN profiles evaluated at ground level by using BPA and IREQ empirical formulas are shown in Figure 2, and the measured fair weather L_{50} values are also plotted for a comparison.

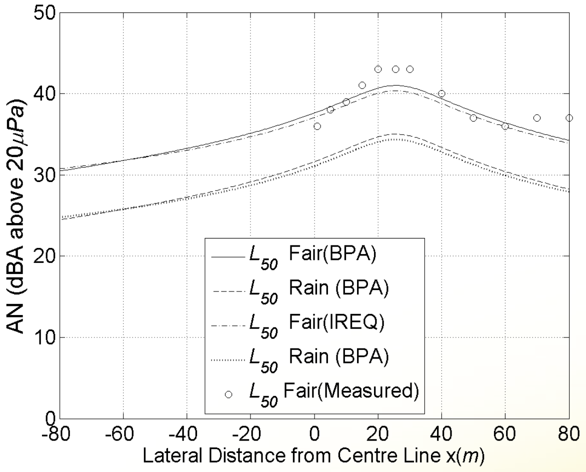


Figure 2 AN profile at ground level for Case 1.

Figure 3 shows the RI profiles at frequency 834kHz, computed at ground level with generation functions (GF) developed by HVTRC and IREQ. The measured results are also plotted for a reference. An excellent agreement between predicted and measured results is observed.

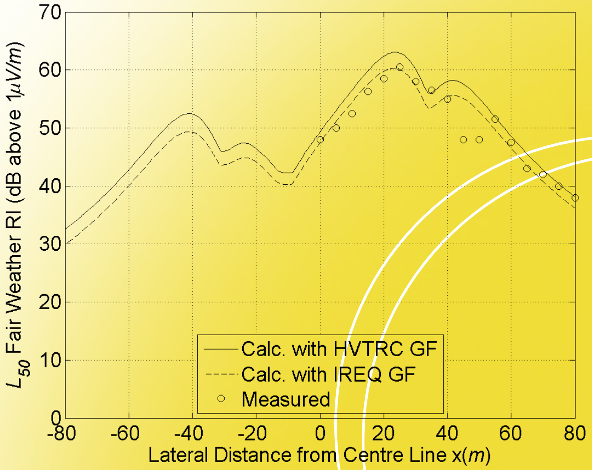


Figure 3 RI profile at ground level and frequency 834kHz for Case 1.

> *…powerful software for analysing field and corona effects is under development…*

Static electric fields and ionized fields evaluated at ground level, along with the measured data, are shown in Figure 4, and the calculated results of ion current and ion charge densities at ground level are depicted in Figure 5, where the measured ion currents are also given as a reference. The computed results agree well with the measured ones.

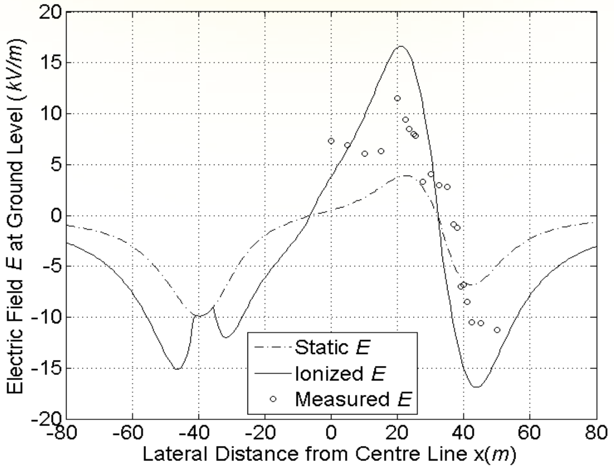


Figure 4 Electric field profile at ground level for Case 1.

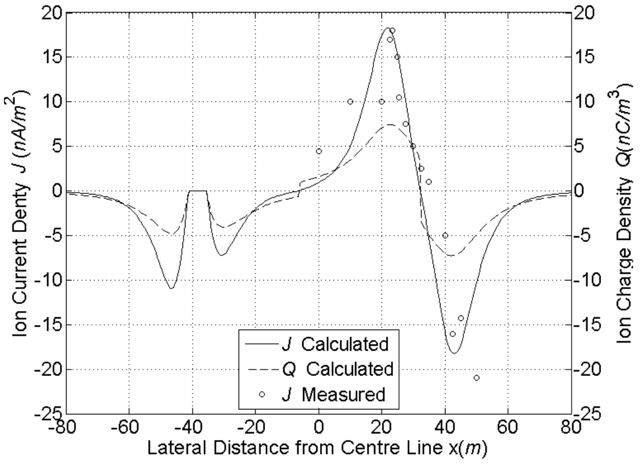


Figure 5 Ion current and charge densities at ground level for Case 1.

Case 2 This case describes a normal operation condition near the full voltages of Nelson River HVDC lines. Figure 6 shows the RI profiles at frequency 834kHz at ground level, computed with GF developed by HVTRC and IREQ. Also, the results obtained by using the BPA analytical method is plotted as a reference.

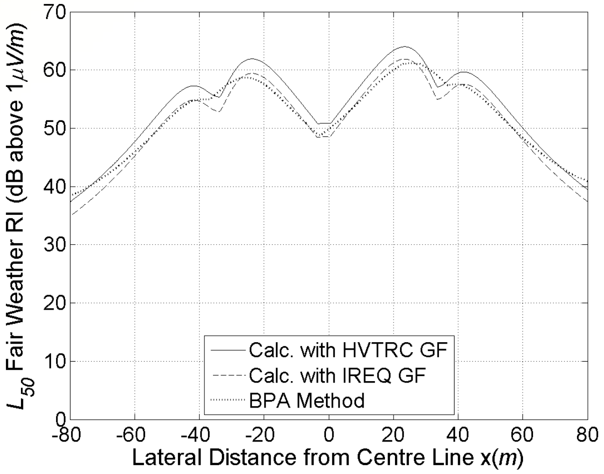


Figure 6 RI profile at ground level and frequency 834kHz for Case 2.

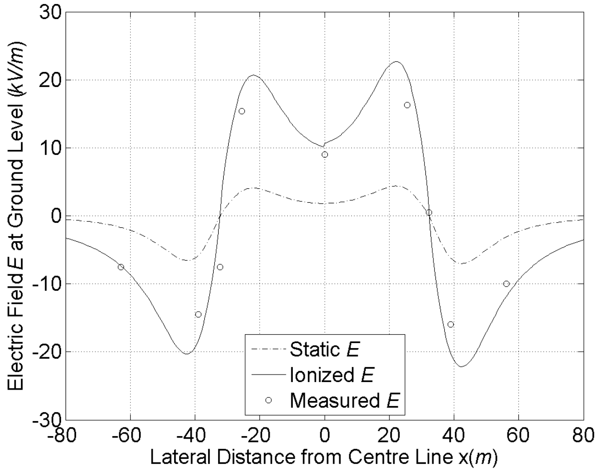


Figure 7 Electric field profile at ground level for Case 2.

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The static electric and ionized fields evaluated at ground level are shown in Figure 7, where the ionized fields are compared with the measured data. The computed results of ion current and charge densities at ground level are plotted in Figure 8 and the measured ion currents are shown for the purpose of comparison.

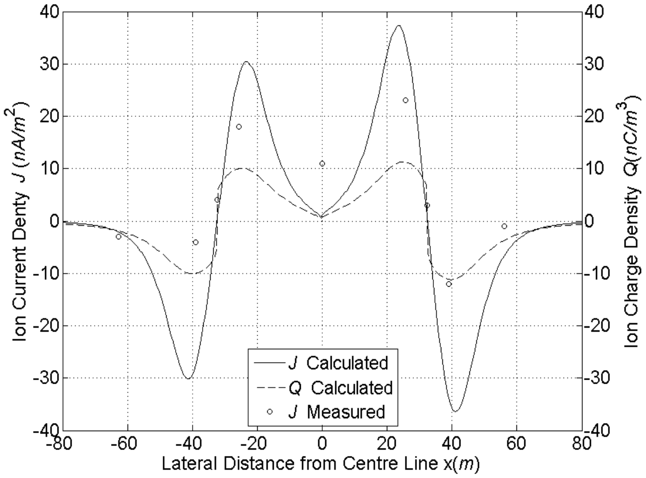

Figure 8 Ion current and charge densities at ground level for Case 2.

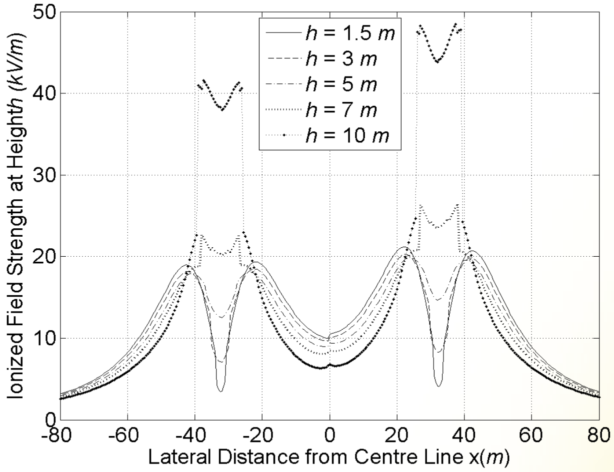

Figure 9 Ionized electric field profile at various heights *h* above ground for Case 2.

The ionized fields can be evaluated at different heights by simply changing an input parameter. Figure 9 shows ionized filed computed at various heights, namely h = 1.5, 3, 5, 7, 10 meters above ground.

In conclusion, rich empirical formulas for the analysis of AN and RI (GF) are implemented for users to select, and a rigorous analytical method is employed to compute RI of HV power lines. An efficient new algorithm has been implemented recently for a solution of non-linear equations resulting from the ionized field problems under the Deutsch's assumption. Computational experiments performed for the Manitoba Nelson River HVDC lines show that this software tool can be effectively used for a quick prediction of field and corona effects of HV transmission lines.

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