



**December 2011 Issue...**

- 1** Modeling Current Transformer (CT) Saturation for Detailed Protection Studies
- 6** The Wound Rotor (WR) and Squirrel Cage (SQ) Induction Machine Models in the PSCAD® Library
- 9** New PT Connections
- 11** Meet the Team!
- 12** PSCAD® 2012 Training Sessions

## Modeling Current Transformer (CT) Saturation for Detailed Protection Studies

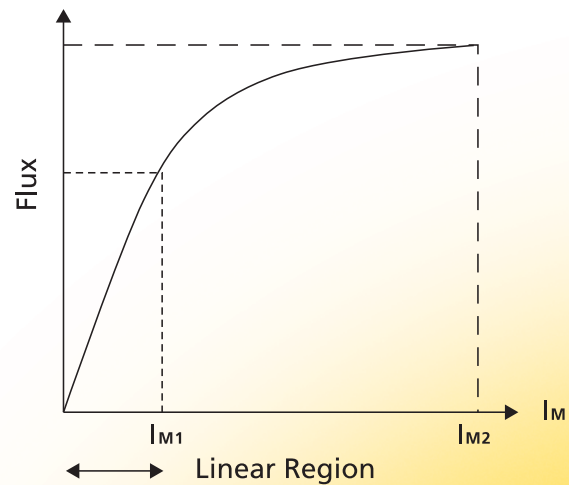
*Dr. Dharshana Muthumuni, Lisa Ruchkall, and Dr. Rohitha Jayasinghe, Manitoba HVDC Research Centre*

**The PSCAD® Master Library contains a number of models that could be used for detailed protection system analysis.** The most important of these models are the current transformer models. Current transformer saturation is associated with many protection problems encountered in power systems. CT saturation is a complex phenomenon and accurate modeling in a simulation environment is challenging. The models available in PSCAD® are based on the advanced mathematical models proposed by Jiles and Atherton and commonly referred to as the 'Jiles-Atherton theory of Ferromagnetic hysteresis.'

These developed models have been extensively tested with field recordings in collaborations with CT, relay and protection equipment vendors.

This case is used to illustrate the effects of CT saturation. The key parameters that impact CT saturation are discussed in an effort to guide PSCAD® users who may use this model for their simulations.

**General Theory** The magnetic characteristic of the CT is shown in Figure 1 (hysteresis not shown). In the linear region, the CT will behave almost like an ideal ratio changer. That is, the CT secondary current is an identical but scaled down replica of the primary current. However, If the CT saturates, more current is required to magnetize the core and as a result the secondary current ( $I_s$ ) available as inputs to the relay



**Figure 1**  $I_M$ -Flux curve

may not be an identical scaled down replica of the actual primary current ( $I_p$ ). This can lead to protection issues and should be given due consideration.

**System Overview** The AC system shown in Figure 2 consists of two 230 kV, 60 Hz Thevanin voltage sources, a 75 MVA load and three 230 kV transmission lines (125 km, 75 km and 200 km). A single phase (Phase A) to ground fault is applied between the first two transmission lines.

**Current Transformer Saturation** CT saturation can be explained using the simplified equivalent circuit shown in Figure 3.

In the linear region of operation, magnetizing current ( $I_{M1}$ ) is very small and hence  $I_P - I_M$  is approximately equal to  $I_P$ . Thus  $I_S$  would be a scaled down version (by a factor of  $N$ ). If the CT saturates, the magnetizing current increases ( $I_{M2}$ ). As a result, only a part of  $I_P$  is available for transformation to the secondary. In this simulation case, a fault is simulated on the transmission line and the CT is at the end of the line (where  $I_{abc}$  is measured).

**Note:** Figure 4 shows how the CT model is used in PSCAD®. Note also that the input primary current ( $I_{abc}$ ) is in kilo amps and the secondary current ( $I_{sabc}$ ) is in amps. The CTs are modeled as (independent) blocks and do not have to be connected to the electric circuit.

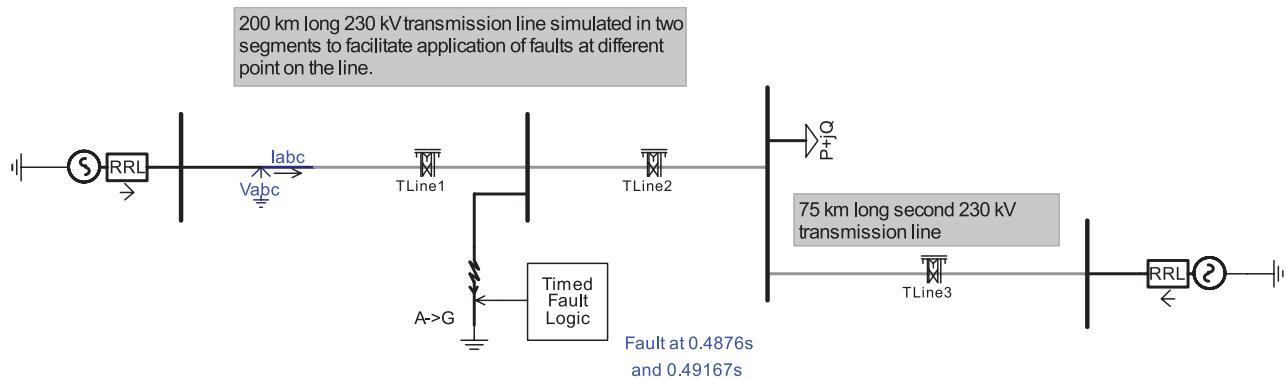
This representation is valid since the CT is essentially a short circuit (in series) from the primary power system network perspective.

**Key Parameters Impacting CT Saturation**

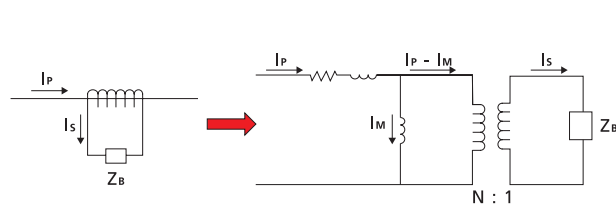
The following can have a significant impact on CT saturation and should be given due consideration in a simulation study:

- 1) DC offset in the primary side fault current.
- 2) Remnant flux on the CT prior to the fault (if any).
- 3) Secondary side impedance including those of the relay, connecting wires and CT secondary impedance - this parameter plays a major role in the level of saturation the CT will be subjected to.

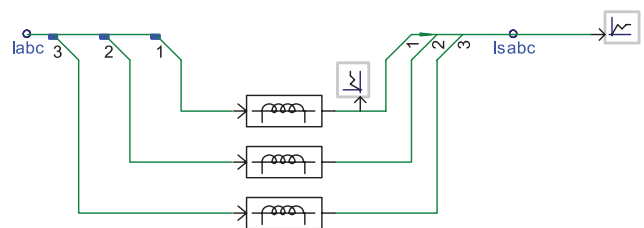
Illustrative simulation results are presented in the following sections to highlight some of the key points.



**Figure 2** AC system model



**Figure 3** Schematic representation of CT (left) and the simplified equivalent circuit (right)



**Figure 4** CT PSCAD® implementation

## Impact of DC offset in the primary fault current...

**Case 1 – Impact of DC offset in the primary fault current:** The point on the voltage wave form at the instant of the fault determines the level of the DC offset in the primary current. The maximum DC offset will occur when the fault is applied at a voltage minimum ( $t=0.49167$  s). The results in Figure 5a occur when the DC offset is significant.

As can be seen, the DC offset causes the flux (Figure 5b) to be driven down and into saturation. The CT has saturated after about two cycles. The reduction of the secondary current is evident from Figure 5a.

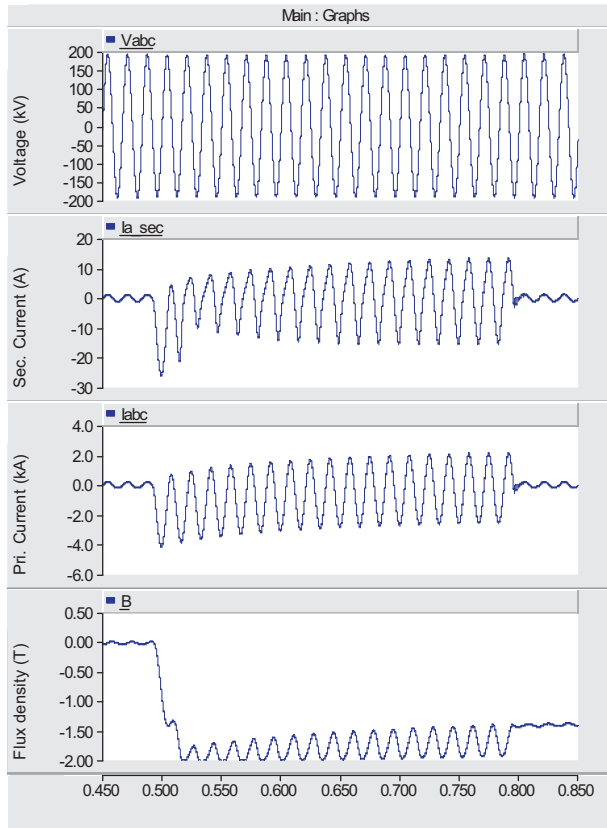


Figure 5a DC offset present

The simulation results in Figure 5b demonstrate a situation when there is no DC offset (fault is applied at  $t=0.4876$  s, voltage maximum). As can be seen, the CT does not go into saturation and only a small amount of magnetizing current is required to magnetize the core. Therefore, the secondary current is an exact but scaled down replica of the primary current.

In Figure 5a also note the remnant flux in the CT core once the fault is cleared. Effects of remnant flux will be discussed in Case 2.

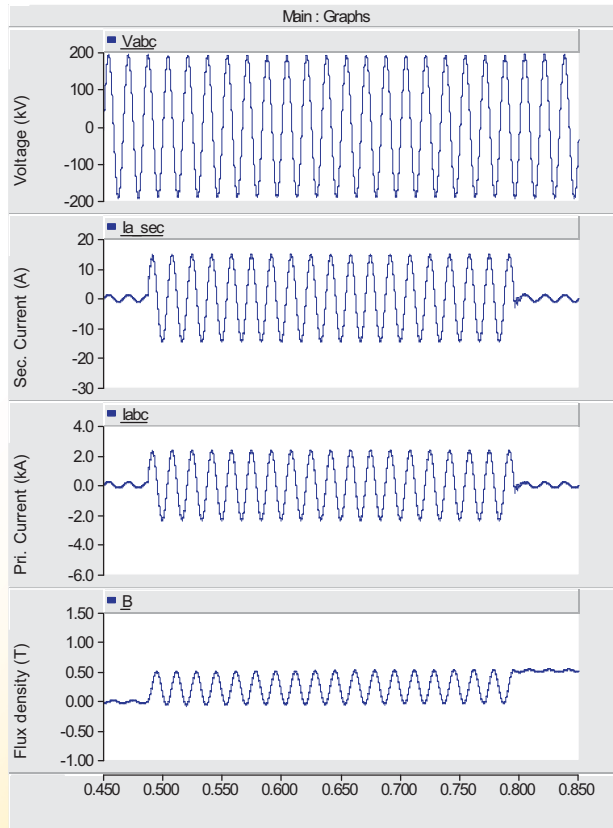
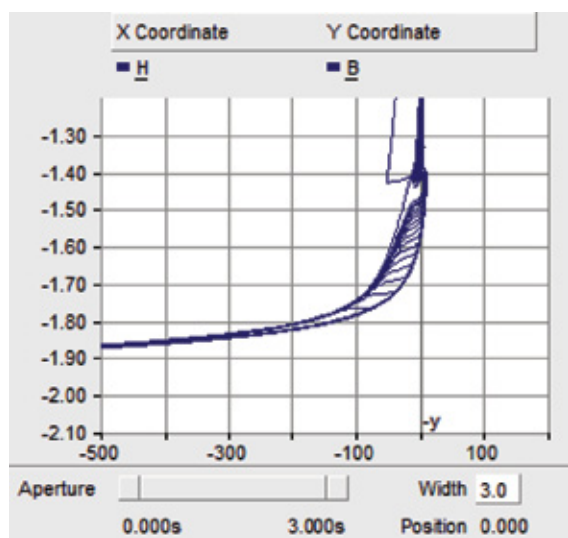


Figure 5b No DC offset present

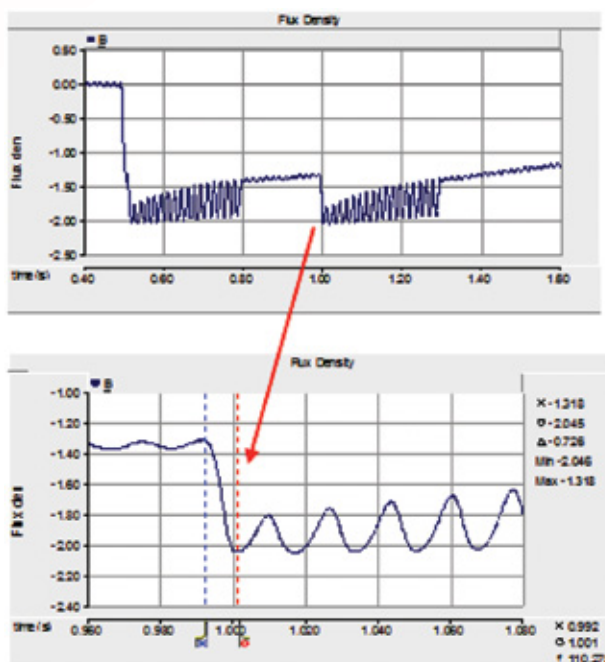
**Note:** the B-H loop trajectory of the CT during the fault is shown in Figure 6. The formation of the minor B-H loops and hysteresis are accurately modeled based on the Jiles-Atherton theory of ferromagnetic hysteresis. Such detailed representations of the CT behavior are necessary for detailed protection system analysis, such as:

- CT response during auto reclose
- Protection schemes with CTs operating in parallel
  - 6 CTs in parallel in a three-phase transformer differential scheme
  - 3 CTs in parallel in an earth fault relay scheme
  - CT connections in generator protections



**Figure 6** B-H loop trajectory

**Case 2 – Reclosing the line while the fault is still present (auto reclose):** In the first fault event, saturation had taken approximately two cycles. If the line is reclosed while the fault is still present, the CT may saturate much faster due to the presence of the remnant flux. This is demonstrated in Figure 7. As can be seen, the saturation occurs in approximately half a cycle, possibly before the relay had time to respond.

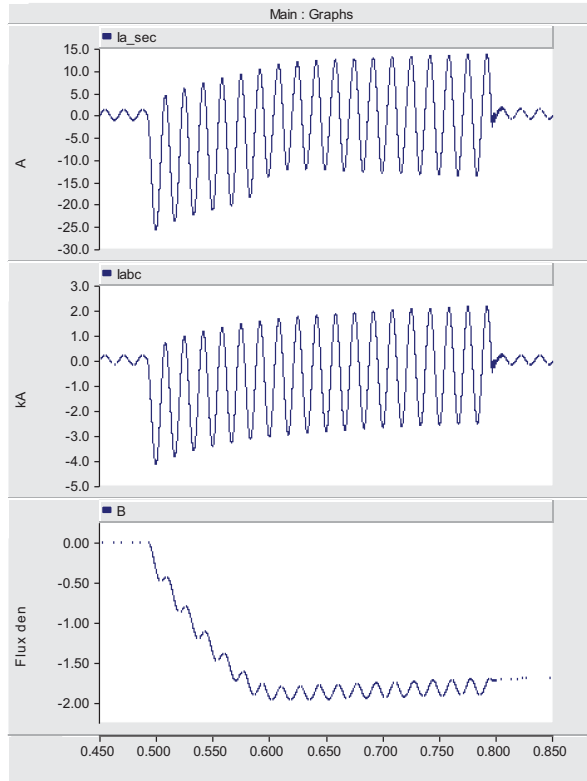


**Figure 7** Case 2 results

*The response of one CT may impact the behaviour of the other and should be appropriately modeled...*

**Case 3 – Effect of the secondary impedance:** The CT secondary side burden impedance has a significant impact on CT saturation. In Case 1, the burden was set to 2.5  $\Omega$ . The results shown in Figure 8 were obtained by reducing the burden to 0.5  $\Omega$  in the simulation. As can be seen from the results, the flux is not driven down as far. It also takes a longer time for the CT to become saturated (approximately 6 cycles).

**Note:** The CT model used in the example case is that of a single CT operating independently of any other CTs in the protection scheme. In general, a protection scheme may have a number of CTs operating in parallel. The response of one CT may impact the behaviour of the other and thus, should be appropriately modeled. Contact the PSCAD® Technical Support Team for more information on specific models.



**Figure 8** Case 3 results

# The Wound Rotor (WR) and Squirrel Cage (SQ) Induction Machine Models in the PSCAD® Library

Dr. Dharshana Muthumuni, Manitoba HVDC Research Centre

The induction machine models are two of the most widely used components from the PSCAD® Master Library. The PSCAD® library has two induction motor models:

- 1) Squirrel cage induction machine model representing a double cage design – (SQ).
- 2) Wound rotor induction machine model – (WR).

The Technical Support Team receives questions from our users as to which model they should use to represent a set of specific data provided by the equipment vendor. The goal of this technical note is to provide the necessary information to help PSCAD® users when faced with such questions.

Mathematically, the SQ cage machine can be represented by the WR machine. The WR model could also be used to represent a double cage SQ machine. The two examples below will describe relevant data entry considerations and also compare results for validation purposes.

The simple simulation case shown below is used to highlight the key points. A SQ machine and a WR machine with comparable parameters (identical ratings and data) are connected to the same supply source (60 Hz, 0.69 kV).

**Example 1: Modeling a single cage induction machine** The SQ cage machine model or the WR machine model may be used to represent a single cage (SQ) machine (IM\_study\_01.pscx).

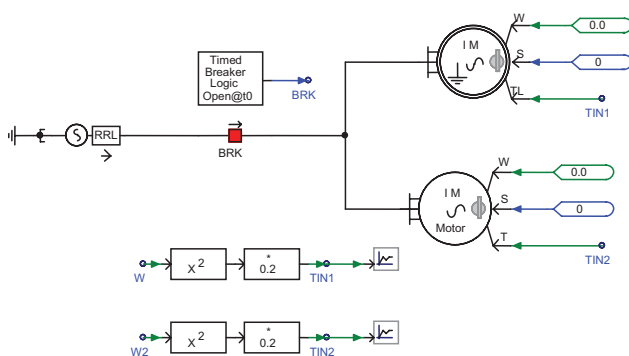


Figure 1 Circuit diagram (WR – top, SQ cage – bottom)

The equivalent circuit of a double cage design (as implemented in PSCAD®) squirrel cage machine is shown below in Figure 2.

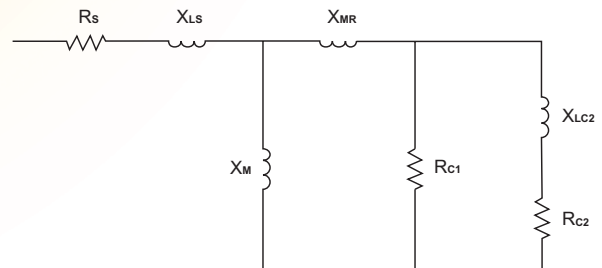


Figure 2 SQ cage (double cage) equivalent circuit

The equivalent circuit of a wound rotor machine model (single rotor winding) is shown in Figure 3.

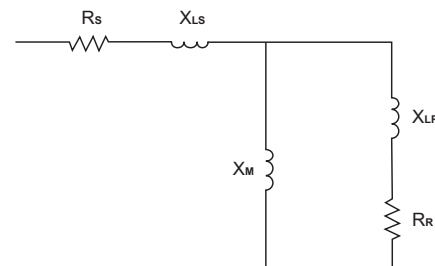


Figure 3 WR IM (single winding) equivalent circuit

To use the SQ cage machine model to represent a single cage machine:

- Make the ‘second cage resistance’ ( $R_{C2}$ ) and the ‘second cage unsaturated reactance’ ( $X_{LC2}$ ) relatively large (compared to the other leakage inductances/resistances). In this case, the values used are  $R_{C2}=5$  PU and  $X_{LC2}=5$  PU, which is much larger than  $R_{C1}=0.0507$  PU and  $X_{MR}=0.091$  PU.
- Give the SQ cage ‘rotor unsaturated mutual reactance’ ( $X_{MR}$ ) the same value as the WR ‘rotor leakage reactance’ ( $X_{LR}$ ).

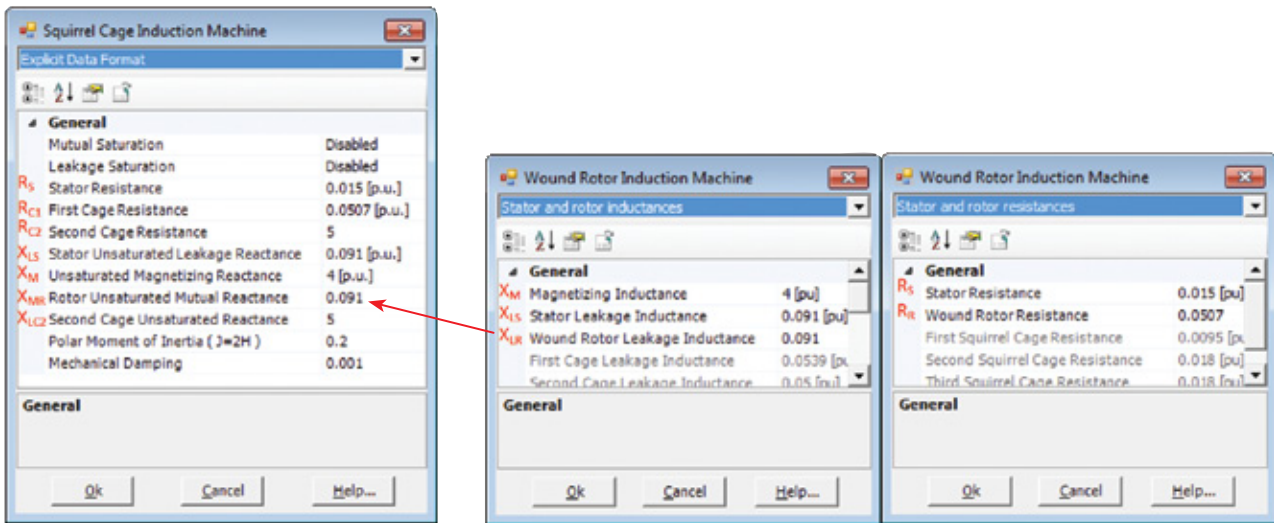


Figure 4 SQ cage and WR setup configuration

Figure 4 shows the data entry for the SQ cage (left) and WR models (right). By using equivalent values, both models show comparable behaviour (Figure 5) and represent a single cage machine design.

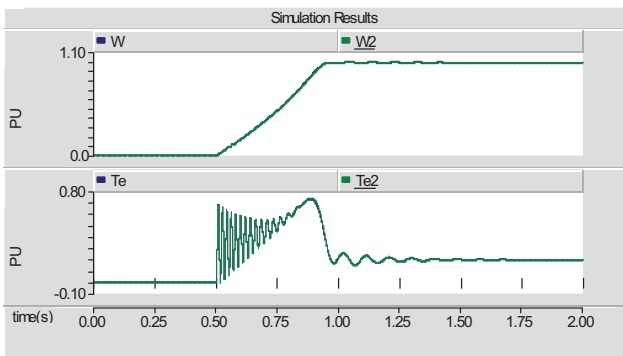


Figure 5 Simulation results (IM\_study\_06\_a.pscx)

The simulation results shown in Figure 5 show that the speed ( $W - WR$ ,  $W2 - SQ$  cage) and torque ( $T - WR$ ,  $T2 - SQ$  cage) of both machines are identical. Thus, any one of the induction machine models may be used to represent a single cage induction machine.

**Example 2: Modeling a double cage induction machine.** The WR machine model can be set up to represent a double cage SQ cage machine (IM\_study\_02.pscx).

In the WR model, select the “No. of Rotor Squirrel Cages = 1”, as shown in Figure 6. The equivalent circuit representation is as in Figure 7.

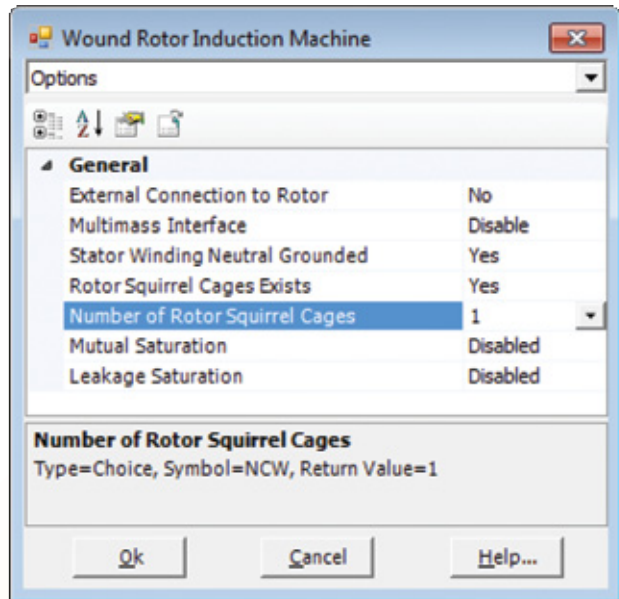


Figure 6 WR configuration

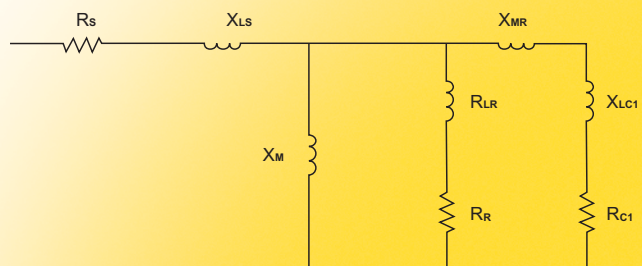


Figure 7 WR IM (No. of rotor squirrel cages = 1) equivalent circuit

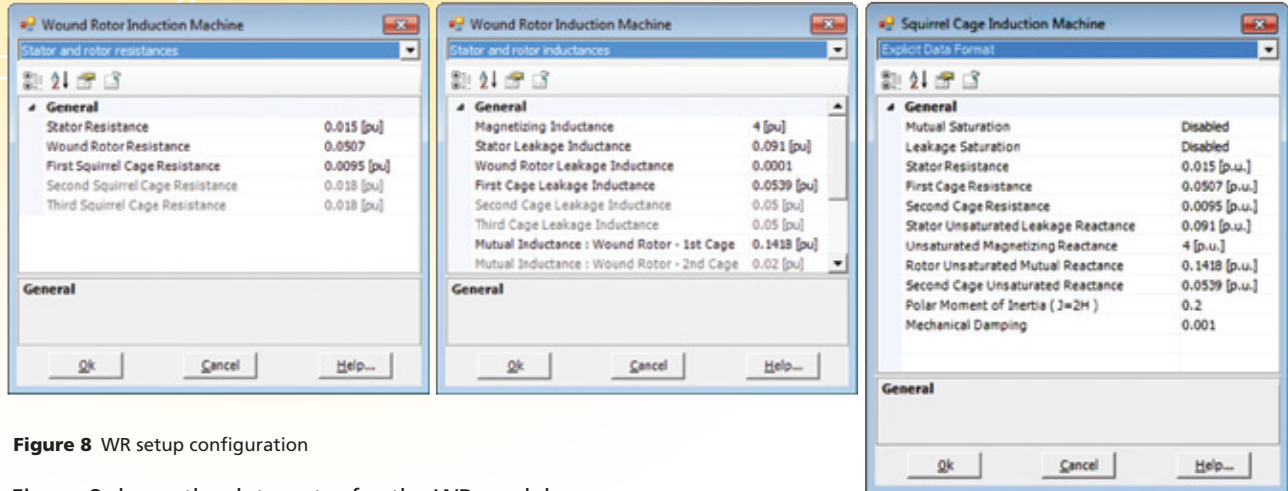


Figure 8 WR setup configuration

Figure 8 shows the data entry for the WR model. With the appropriate data, the SQ cage and WR machine models will give identical results (Figure 9).

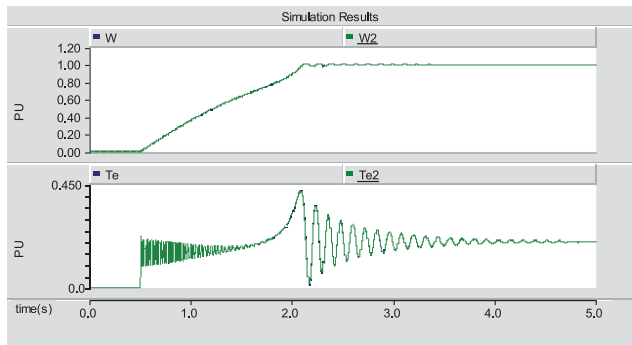


Figure 9 Simulation results (IM\_study\_06\_b.pscx)

*A SQ cage and WR machine model deliver equivalent results when configured properly...*

**Conclusions** As can be seen from the results, a SQ cage and WR machine model deliver equivalent results when configured properly. Hence, a SQ cage machine model can be accurately represented using a WR machine model. *PSCAD® users are encouraged to use the WRIM model due to its more conventional and straight forward parameter configuration.*

**PSCAD® Cases:**

IM\_study\_01.pscx and IM\_study\_02.pscx



# New PT Connections

Dr. Namal Fernando, Manitoba Hydro

**Background** *Generator and transformer protection upgrade at Seven Sisters generation station.* There are six units and the existing electromechanical relays are being replaced with multi-functional digital relays. The project includes replacement of line end potential transformers; the existing two potential transformers (i.e. open delta with phase B grounded) are being replaced with three potential transformers (grounded wye). There is only one synchronizing system for all six units. Incoming voltage reference is line voltage; phase AB with B at ground potential.

**Problem** Since the new design includes three potential transformers with neutral grounded, we could not connect directly to the existing synchronizer system. The existing system is based on phase B at ground potential and common to all the units, whereas the units with the new protection design will have neutral point grounded (i.e., for units with new protection design, the phase B is no longer at ground potential).

**Solution** Install an isolating transformer between the line voltage AB and the incoming voltage input to the synchronizer system.

**PSCAD® Application** It is well known that PTs should be connected in correct phase sequence. While the correct connections can be determined through simple hand calculations by constructing relevant phasor diagrams (Figure 1), this is not always straightforward.

There are many instances where incorrect connections have caused unit tripping at the commissioning and testing stage. This could create a headache for all involved and the consequences can be significant. PSCAD® provides a simple and efficient way to verify the new connections. We used a simple PSCAD® simulation circuit to verify that the PT connections corresponding to the running and incoming voltages to the synchronizer are connected properly.

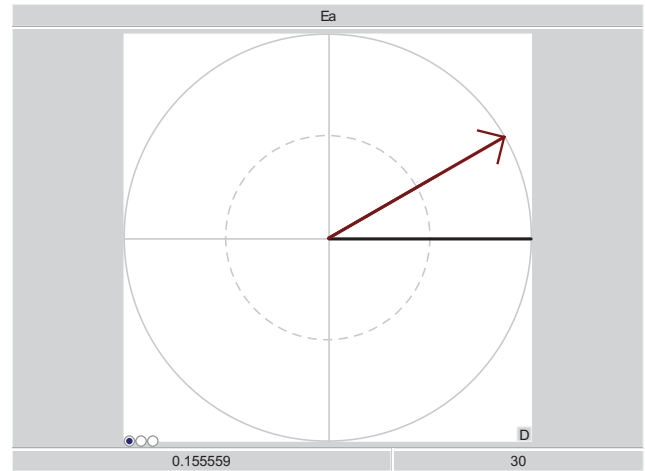


Figure 1 Phasor diagram

The PSCAD® case used for the study is shown in the figure below. The simulation is not complex. However, we find this to be a useful engineering application. The schematic diagrams are shown in Figures 2 and 3.

The important data for this simulation is just the PT voltage (turns) ratios. Other details, such as saturation, etc. are not important for this basic analysis.

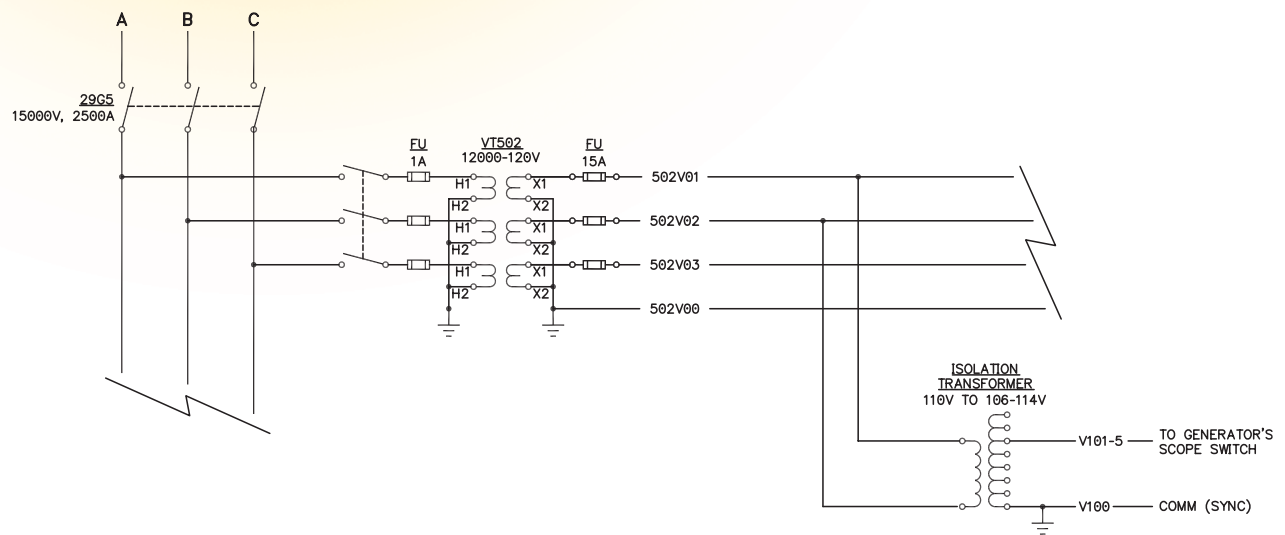


Figure 2 New PT connection

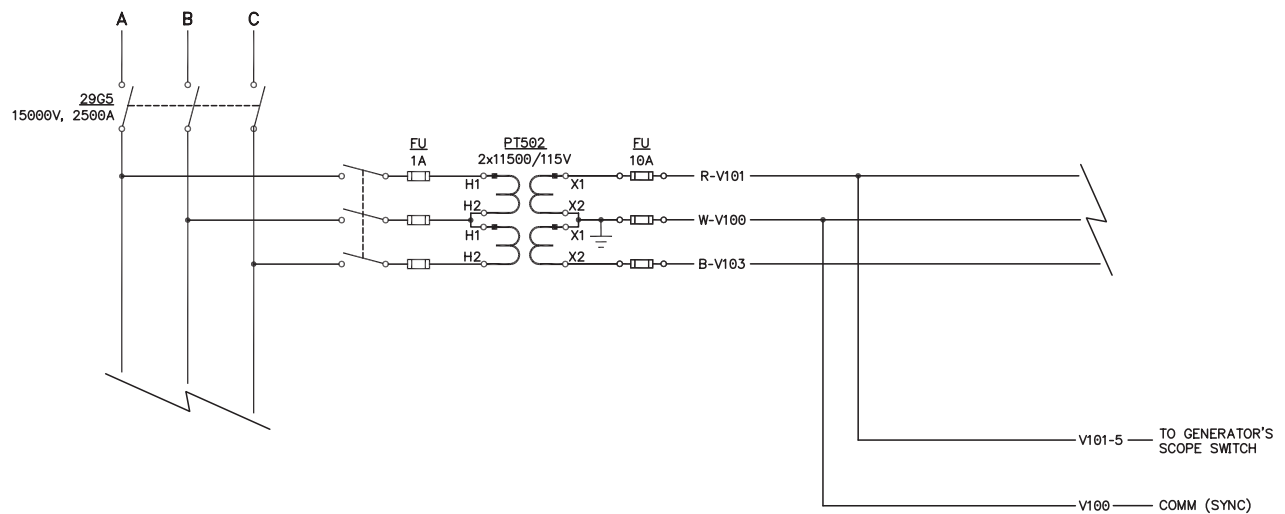


Figure 3 Old PT connection

## Meet the Team!

*Manitoba HVDC Research Centre*

**The Manitoba HVDC Research Centre prides itself on its excellent customer support and service.**

Our success is a direct result of our client focused efforts. We are committed to providing our clients with the best possible support to ensure optimum success with our products and services. "Meet the Team" will be a regularly published addition to the *Pulse* Newsletter to introduce our experienced team members. This publication features Juan Carlos Garcia Alonso and Arash Darbandi; just a few of the dynamic staff members we are fortunate to have at the Manitoba HVDC Research Centre (MHRC).



### **Juan Carlos Garcia Alonso, P.Eng.**

*Power System Simulation & Studies Engineer*

Juan Carlos (JC) received his Electrical Engineering degree from the National University of Colombia, Bogota, Colombia in 1996 and subsequently received his M.Sc. degree from the University of Manitoba, Canada. He designed power transformers with Pauwels Transformers in Winnipeg and in 2006 joined the MHRC. JC participates in various engineering service projects in the areas of insulation coordination, VSCs, protection and superconductive magnetic devices, among others. His main focus during this period has been writing new models for magnetic simulation with PSCAD®

JC can be found enjoying his favourite outdoor activities, such as rock climbing, canoeing and hiking.



### **Arash Darbandi**

*Engineering Application Specialist*

Arash received his Electrical Engineering degree from the University of Manitoba, Canada in 2010 and is currently pursuing his M.Sc. at the same university. In his short time here with us, Arash has improved the line feature software of our Ice Vision system and developed a new algorithm to improve the existing software. Arash assisted with the Line Fault Locator (LFL) product by developing new factory acceptance tests for the LFL, improving software quality and performance. Arash is currently involved with the battery re-purposing research project developing a power electronic grid interconnection and a reactive power study. He is also performing reactive power studies in different plants, as well as providing recommendations to clients to improve their system performance.

Arash enjoys a healthy and active lifestyle, volunteering with the University of Manitoba Satellite team as their Technical Coordinator, and travelling internationally to experience culture and cuisine.

## Expanding Knowledge

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

### Fundamentals of 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

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!

January 11–13, 2012

### 2012 PSCAD® and RTDS Asia Conference

[www.nayakpower.com](http://www.nayakpower.com)

Bangalore, India

January 18–22, 2012

### Elecrama–2012

[www.elecrama.com/elecrama2012/index.aspx](http://www.elecrama.com/elecrama2012/index.aspx)

Mumbai, India

January 24–26, 2012

### DistribuTECH Conference & Exhibition

[www.distributech.com/index.html](http://www.distributech.com/index.html)

San Antonio, Texas, USA | Booth #4541

March 27–30, 2012

### 2012 PSCAD European User Group Meeting

[training@pscad.com](mailto:training@pscad.com)

Castelldefels, Spain

June 3–6, 2012

### AWEA Windpower 2012 Conference & Exhibition

[www.windpowerexpo.org](http://www.windpowerexpo.org)

Atlanta, Georgia, USA | Booth #7513

August 27–31, 2012

### CIGRE Session 44 and Technical Exhibition

[www.cigre.org/gblevents/sessions.asp](http://www.cigre.org/gblevents/sessions.asp)

Paris, France

More events are planned!

Please see [www.pscad.com](http://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](http://www.pscad.com) for more information about course availability.

April 17–19, 2012

### Fundamentals of PSCAD® and Applications

May 15–17, 2012

### HVDC Theory and Controls

September 11–13, 2012

### Fundamentals of PSCAD® and Applications

September 18–20, 2012

### Wind Power Modeling & Simulation using PSCAD®

November 27–29, 2012

### HVDC Theory and Controls

All training courses mentioned above are held at the Manitoba HVDC Research Centre Inc. Winnipeg, Manitoba, Canada  
[training@pscad.com](mailto:training@pscad.com) [www.pscad.com](http://www.pscad.com)

Please visit Nayak Corporation's website [www.nayakcorp.com](http://www.nayakcorp.com) for courses in the USA.

**For more information on dates,  
contact [training@pscad.com](mailto:training@pscad.com) today!**