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MANITOBA·HVDC RESEARCH CENTRE

2006 Spring Issue...

Manitoba HVDC Research Centre Receives Prestigious NSERC Award

Canada's largest science and engineering granting agency, the Natural Sciences and Engineering Research Council (NSERC), presented the University of Manitoba (UofM) and partners Manitoba HVDC Research Centre and RTDS Technologies Inc. with a national Synergy award for excellence in innovation at an awards ceremony on October 19, 2005 at the Halifax World Trade and Convention Centre.

"The 2005 NSERC Synergy Awards for Innovation celebrate the very best Canadian achievements in R&D collaboration between universities and industry," said the Honourable David L. Emerson, Minister of Industry and Minister responsible for NSERC. "Collaborations such as these are responsible for new products, new services and new ways of doing things. They make this country one of the worlds most innovative and ensure our future prosperity and quality of life."

Six partnerships were singled out for national prizes. The university leaders in the winning collaborations each receive a $25,000 NSERC research grant. The University of Manitoba, Manitoba HVDC Research Centre and RTDS Technologies were honoured for their development and commercialization of state-of-the-art technologies for power systems simulation and the creation of an outstanding body of dedicated, highly trained professionals and leaders in the field. The award commemorates approximately 30 years of collaborative development between the parties which has created a new industry in real time transients power system simulation.

The products of the Manitoba HVDC Research Centre (PSCAD™/EMTDC™ simulation software) and RTDS Technologies (RTDS™ – Real Time Digital Simulator) are now marketed around the world and comprise approximately 90% of the real time transient simulation market.

The University of Manitoba is second only to the University of British Columbia in terms of the number of Synergy awards won since such recognition began. Of the eight awards won by the University of Manitoba, the Department of Electrical & Computer Engineering have received three. This emphasizes the tradition in Manitoba of partnering with its academic research institutes to deliver innovative and commercially viable technology products.

Left to Right Dr. Joanne C. Keselman (UofM), Dr. Nigel Lloyd (NSERC Canada), Rick Kuffel (RTDS Technologies), Paul Wilson (Manitoba HVDC Research Centre) and Dr. Ani Gole (UofM).

PEBB: Building Blocks of Power Electronics

Farid Mosallat, The University of Manitoba

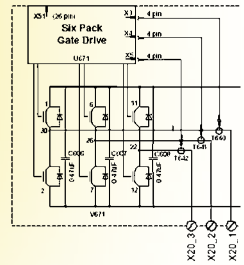
During the commissioning of a container crane, IGBT failure damaged an 110kW AC motor drive. This left a 20', 40-ton container precariously suspended 32' in the air. After replacing the 250-pound power electronic converter and lowering the suspended load, I asked myself, "How could this be made easier?" My question was answered four years later.

Today's modern electrical installations increasingly rely on power electronic converters. However, this dependency can bring a few disadvantages, particularly maintenance and spare part management. Currently, end users may have to store numerous and expensive power electronic converters in their spare part stock. Moreover, manufacturers are continuously upgrading their products and the equipment being used today may not be supported by the producer in the future.

The Potential of PEBB PEBB can offer flexibility at design and commissioning stages; since control engineers can configure the converters based on application needs and apply required modifications even during the commissioning phase. Furthermore, it can also offer compatibility and hence, less dependence on vendors for maintenance or spare parts. PEBB is transforming the perspective of power electronics in the same way that PLCs (Programmable Logic Controller) and industrial PCs revolutionized industrial automation.

PEBB producers have different definitions of the idea. Some of them have adopted a Lego-structured scheme. They provide their PEBBs as standard blocks containing power electronics with corresponding controls. Several such blocks can be combined to build converters of higher rated power. Some manufacturers define PEBB as only the power electronic basic core including the solid-state switches and DC bus elements. Firing of the switches is performed by means of very fast controllers, which can be configured to meet application requirements. Each approach has its advantages and disadvantages.

Figure 1 ABB PEBB Converter Configuration



PEBB Research in Progress At the Manitoba HVDC Research Centre, exploration of the PEBB concept has begun as a research project in collaboration with the University of Manitoba. Products of two manufacturers are being inspected in this study in order to find out how they fit the term PEBB with the introduced concept. To determine this, research should be carried out. Figure 1 shows a portion of a converter configuration using the ABB PEBB apparatus under study. Figure 2 depicts how PEBB is applied to the design of industrial systems, such as a two-stage DVR.

Every experimental case is first simulated using PSCAD™. In the developed model, the converter, electrical sources and targeted loads are modelled using circuit structure and values of the actual system elements. Then, the required control system is added to the model, the case is simulated and the controller parameters are properly adjusted. After obtaining appropriate results from the simulation, the control strategy is uploaded to the PEBB controller using the software provided by the manufacturer. Ultimately, the experiment is performed using actual components.

Several objectives are achieved in this manner. In addition to investigation of different PEBB equipment, accuracy of PSCAD™ simulations can be confirmed. The results obtained from the experiments will also be used for the improvement of EMTDC™ models and can help with the development of new EMTDC™ models and components.

The Future for PEBB The PEBB apparatus will later be utilized in a more sophisticated project, in order to form a versatile scalable platform for implementation of various electrical systems that involve power electronics, such as HVDC systems, wind turbines, FACTS devices, variable-speed drives or any other type of custom converter. In addition to serving as a research lab, such a facility will be able to provide technical consulting services to different clients who need practical results which verify simulation outputs of their design.

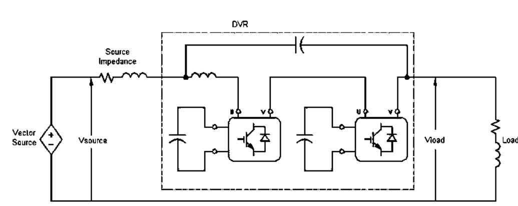


Figure 2 Dynamic Voltage Restorer (DVR) – Two Stage

Comparison of Field and Simulation Switching Overvoltages

Kanchit Ngamsanroaj & Suthep Chimklai (EGAT, Thailand)
Worawit Tayati (Chiang Mai University, Thailand)

Switching operations in power networks are common causes of transient disturbances. Depending on the network configuration and the characteristics of the switching condition, these transients can cause not only undesirable effects on the switched load, but also on the entire network. The Electricity Generating Authority of Thailand (EGAT) has used the PSCAD™ simulation software to predict the behaviour of their 500kV system in response to switching operations. To validate the simulation models, actual field test switching overvoltage readings have been compared to the simulation results. The operational results of the actual equipment also include the line energizing events to determine the magnitude of the switching surge.

Switching Surge Study The EGAT 500kV transmission system as illustrated in Figure 1, consists of single-circuit and double-circuit 500kV lines of more than 2,600km. To meet growing electrical demands, EGAT is planning to construct more 500kV transmission lines and substations which will connect to the existing system. Since the magnitude and wave shape of switching voltages are important factors in determining the efficient operation of extra-high-voltage (EHV) equipment and transmission lines, it was necessary to conduct a switching surge study to cover all switching conditions on the system.

Energizing a transmission line is a common study conducted using electromagnetic transients simulation. When the line is energized, the incident and multiple reflected waves on the line will cause overvoltages. The purpose of the simulation is to be sure that there will be no flashovers when the line is energized. Often, surge arresters are used to hold the switching overvoltages to an acceptable level. As such, a simulation study is also employed to size the surge arresters and to be sure their energy absorption capability is not exceeded when the line is energized. The breakers used for energizing the line may also have insertion resistors. Typically, the size of the insertion resistor is from 300 to 600 Ω, and the resistor is inserted 5 to 10 ms before the main contacts are closed. With insertion resistors, the overvoltages are reduced as compared

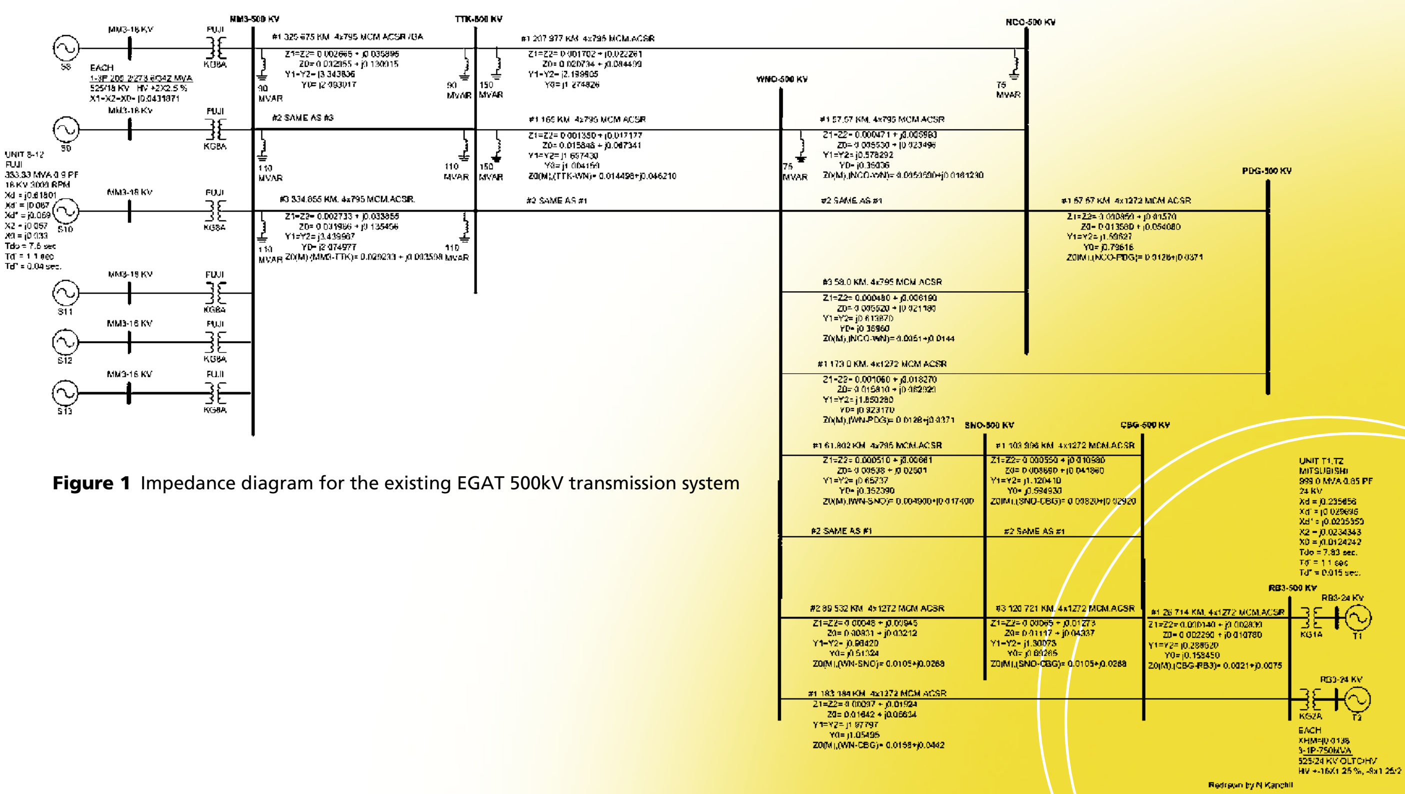


Figure 1 Impedance diagram for the existing EGAT 500kV transmission system

Some utilities are discontinuing the use of insertion resistors, relying instead on surge arresters to limit the overvoltages.

to the overvoltages experienced without insertion resistors. However, a breaker with insertion resistors is complicated and can cause maintenance problems. Electromagnetic transients simulation programs are almost exclusively used when studying power frequency phenomena in systems. The accuracy of the results obtained depends on the accuracy of the system model as well as on the accuracy of the available input data. Comparisons between field tests and simulation results provide a direct way to validate the accuracy of the representation of the system model. However, field tests require resources as well as network outages which may affect the supply reliability. In many cases, field tests cannot be conducted due to operational limitations.

Studying the EGAT 500kV Network The system adopted for the PSCAD™ simulation study represents the EGAT 500kV network. This network consists of 8 nodes and 20 lines. Two main groups of generating stations are located at the two extreme nodes as shown in Figure 1. Due to the system availability and stability, the scope of field tests was defined to line energization with all protection. Therefore, four lines to Tha Tako were considered. The first two were Mae Moh 3 – Tha Tako circuit number 1, and number 2. Next was Nong Chok – Tha Tako, and in the fourth field test, the Wang Noi – Tha Tako circuit number 1 was included. Tha Tako was the receiving end for each test, while the remainder of the system was in service.

At the boundary of the simulation study, the external grid was represented by the positive/zero sequence equivalent circuit impedances. A generator is represented by the constant electromotive force connected in series with the subtransient impedance. For the study of switching overvoltage on the energized line, overvoltages occurring within the feeding network are not high enough to cause magnetic saturation in transformers and shunt reactors. During line energizing, the circuit breaker closes at one end, with the other end open for the weak system condition, while in the remainder of the system, all circuit breakers are closed.

Results of the Study During the simulation studies, recorded field test results were used to calibrate the simulation model and the associated parameters. Although detailed simulation studies had preceded the field tests, further precautionary measures are employed to protect the system equipment from being damaged by switching overvoltages.

Simulations were conducted for multiple scenarios to determine the equipment characteristics and operating procedures required to energize each line with acceptable peak overvoltages. Various system conditions were studied for a number of switching events. During the field tests, the receiving end voltage waveforms were recorded. There was strong agreement between recorded field test results and the simulation waveforms and the simulation study had the identical system configuration as the field test. The voltage waveforms are almost identical, further confirming the accuracy of the simulation model and parameters used. To view the detailed field test overvoltages to simulation model waveform comparisons please refer to the full paper, *Comparison of Field and Digital Simulation Results of Switching Overvoltages in the EGAT 500kV Transmission System*, on *Paper Trail* at the PSCAD™ Forum at *http://bb.pscad.com*

Advancements in simulation techniques increase the complexity and potential value of the studies, but this is of little practical use without accurate 'input' data related to the transient behaviour of actual system elements. The energizing of an unloaded transmission line can cause a higher overvoltage in the power system. However, there are many factors which impact the level of overvoltage experienced, as well as numerous methods to control the higher overvoltages. Due to the statistical characteristics of model variables, it is necessary to calculate overvoltage values by employing statistical methods.

The following simulation results have been carried out using the following methods:

- Varying the closing phase angle to determine which closing phase angle can cause the highest overvoltage value
- Adapting the mean closing time while performing the statistical calculation from the phase angle which can cause the highest value of overvoltage
- Compare the cases where protective devices were in place and where they were not in place.

The results of switching overvoltages obtained when the various 500kV lines were energized with all protective devices in service are shown in Figure 2. The voltages are the maximum recorded with each study case having 200 statistically controlled closings.

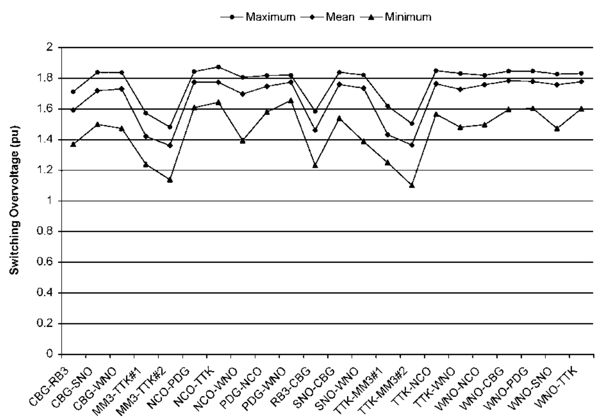


Figure 2 Maximum overvoltage for line energization

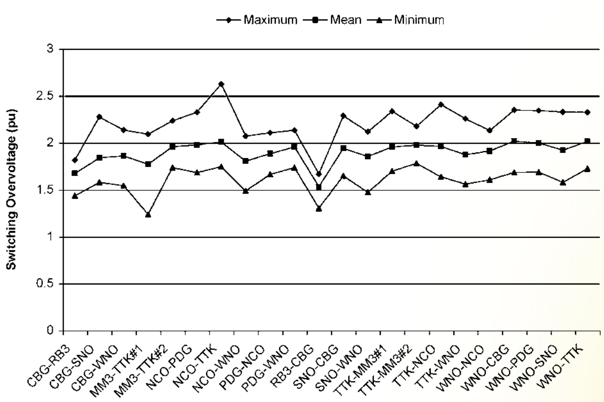


Figure 3 Maximum overvoltage for line energization without any protective devices in service.

Figure 3 depicts the results from the same simulation study but without deploying any protective devices.

It is determined from this study that the maximum overvoltage reached approximately 2.66pu with no protective devices installed. And, with all protective devices deployed, the highest overvoltage will be at the level of 1.84pu.

Summary Switching operations are not always planned events. Some disturbances may cause a switching operation during a period of very light load. The response of a very lightly loaded system is nearly the same as the response of an unloaded system. Therefore, for ease and simplicity, switching overvoltage investigations are usually made with no load represented on the system. Switching operations on an unloaded system will produce the most severe, but not overly pessimistic, transient overvoltages.

Energizing transient overvoltages are investigated statistically. Feeder energization remains in the network for the period of analysis. For each energization, 200 statistical switching operations are made, each statistically controlled with respect to source bus driving voltage and with the three circuit breaker poles closing randomly with respect to each other, but within specific closing times. It has been validated through these studies that the voltage waveform results obtained from the PSCAD™ system model are very close to the actual field results.

The results of these studies provide EGAT with information on the confidence limits of computed switching surges using the PSCAD™ simulation software. This will facilitate future studies. The results provide a reference for further investigation of the transient performance of the existing EGAT 500kV system.

The authors acknowledge the contribution of Luechai Suraphongphan for his valued support.

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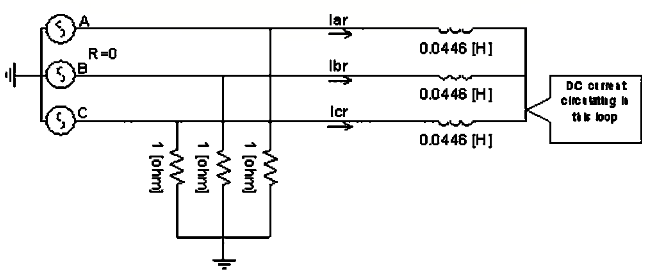
For a copy of the full paper, *Comparison of Field and Digital Simulation Results of Switching Overvoltages in the EGAT 500 kV Transmission System,* (including the full reference list and detailed field test to simulation waveform comparisons), please visit *Paper Trail* on the PSCAD™ Forum at *http://bb.pscad.com*

Interesting Problems: The Importance of Ramp-up Time Selection

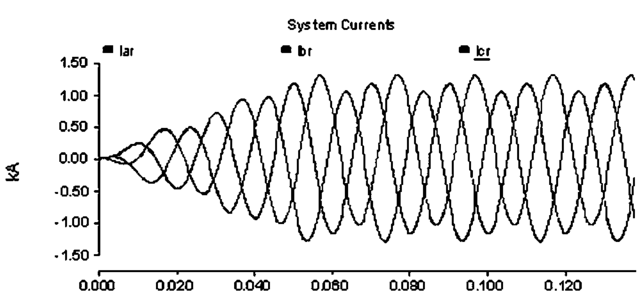
John Nordstrom & Rohitha Jayasinghe, Manitoba HVDC Research Centre Inc.

This problem illustrates that even the selection of an input parameter as simple as the source 'voltage ramp-up time,' is important and can have unexpected results on a simulation. This particular case was sent to the PSCAD™ Support Desk by a user in Finland in June of 2005.

The circuit illustrated below consists of infinite bus source set to 20kV, 50Hz with a voltage ramp-up time of 0.05s. The load consists of an ungrounded, star-connected balanced inductive load, along with a star-connected, balanced resistive shunt.



When the case is run, the seemingly balanced system appears to have unbalanced currents flowing in the inductive load.



This 'imbalance' is actually caused by a DC current circulating in the phase B to C loop. This DC current adds to the phase B current Ibr and subtracts from phase C current Icr. Phase A current Iar remains unaffected.

It turns out that the circulating DC current is a direct result of the ramp-up time selected for the source, which can be described mathematically as follows:

The current in the inductive loop following ramp-up is given by:

$$i = \frac{V}{\tau \cdot L} \int_0^{\tau} t \cdot \sin(\omega t + \alpha) \cdot dt$$

Where,
V = source voltage
L = total loop inductance
ω = frequency
α = initial phase
τ = voltage ramp - up time

Solving the integral:

$$i = \frac{V}{\omega L} \cos(\omega\tau + \alpha) + \frac{V}{\omega^2 L} \frac{\sin(\omega t + \alpha) - \sin(\alpha)}{\tau}$$

The second term in the equation above represents the DC component of the inductive current. Therefore, in order for the DC component to fall to zero at steady-state:

$$\omega\tau = 2n\pi \rightarrow \tau = \frac{n}{f} \text{ where, } n = 1, 2, \ldots\infty$$

For a 50Hz system, this means that the ramp-up time should be selected as 0.02, 0.04, 0.06, etc. seconds. If not, a DC component will initially be present (as it is in this case with t = 0.05s), and due to the lack of any resistance in the loop, will continue critically damped for the remainder of the simulation run.

In order to avoid this unwanted initial DC component, a ramp-up time divisible into the period of the fundamental frequency should be selected.

Conductor Icing Detection with Vision Recognition Technology

Pei Wang & Norm Tarko, Manitoba HVDC Research Centre

Manitoba Hydro transmission systems are prone to icing due to the adverse weather conditions, especially in rural areas. Depending on wind speed, ambient temperature and amount of precipitation, ice accretions on conductors can vary in geometric shapes and types. The accumulation of ice on conductors will add both static and dynamic loads to the structure, which may lead to damaged overhead lines and towers. The consequences can be catastrophic, including expensive repair costs and/or electrical outages for residents and businesses for an extended period.

In order to reduce icing damage, Manitoba Hydro has developed an Ice Storm Management Program responsible for ice detection and dispatch of resources for ice removal. Present ice detection devices used by Manitoba Hydro measure ice accumulation on a sensing probe. If the ice accumulation exceeds a preset threshold, an alarm signal will be activated. Field personnel will then be dispatched for icing assessment through visual inspections of the ice on the line using binoculars. Thus, decisions on icing status are subjective and based on human experience.

Early & Accurate Detection A new ice detection system based on advanced vision recognition technology is in development at the Manitoba HVDC Research Centre. This research work is funded by the Manitoba Hydro R&D Board and is a cooperative effort between the University of Manitoba and Manitoba HVDC Research Centre with the support of hydro engineers and staff. The new system detects ice accumulation directly on conductors providing accurate visual information, such as ice thickness and shape. Operation of the new system features automation and real-time, enabling early icing detection and assisting in more cost effective decisions.

Phase I development work was performed in the 2004 fiscal year. To verify the developed ice detection algorithm, laboratory testing was carried out with different types and shapes of ice accretions formed on sample conductors in a controlled environment. The results demonstrate that application of vision recognition to ice accretion detection is technically feasible. A typical ice profile detected is shown in Figure 1.

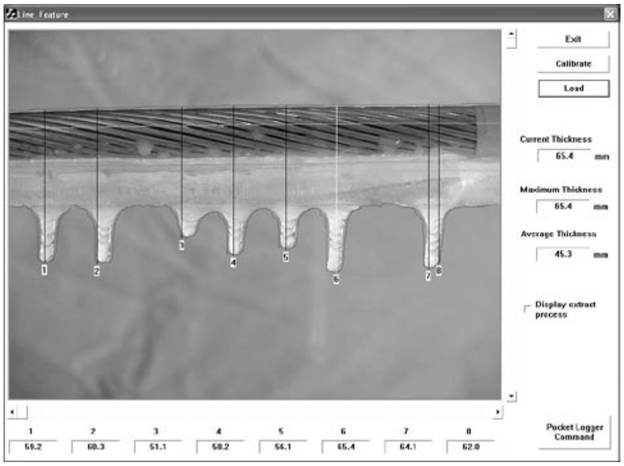


Figure 1 Detection of irregular shaped ice

Phase II of the research work is still in progress. A prototype of the ice detection system suitable for harsh environment operations has been developed. The system is deployed at the HVDC Research Centre outdoor test line as shown in Figure 2. Two weatherproof boxes are included: one houses the main control system and the other for image capture and wireless communications. Field data is being collected to validate performance of the new ice detection system.

Figure 2 The outdoor test site

Multiple Module Instances

Craig Muller, PSCAD™ Development Manager, Manitoba HVDC Research Centre Inc.

One question that commonly comes up when using PSCAD™ for large systems: "Why am I not able to create multiple instances of my circuit module?" All User Defined Components (UDC) are capable of producing FORTRAN code that is compiled into the simulation. The original text file definition for the UDC allowed users to create component instances in the circuit schematic as inline code. In this context, the corresponding FORTRAN code is expanded inline with the rest of the components as part of a larger subroutine. In the first 2 Unix versions of the software, all components were expanded inline into a single subroutine call and thus only a single FORTRAN file was compiled into the simulation.

The third generation of the software introduced the concept of a hierarchy in the simulation design. This gave the ability to define a component and its source code as a collection of other component instances in a circuit schematic. This created an extended UDC definition that included all the schematics, commonly referred to as a module. These schematics operate as an alternate to scripted code provided in the original definition. When compiled, each module provides information to construct FORTRAN code, branch information and establishes a unique data space for all the components in the schematic. The inline code is thus reduced to subroutine call wherever the module instance is created. This structure can be nested for as many levels as desired, forming an hierarchy of files rather than a flat single file approach.

It will not be long until Beta versions of the software become available. There are many interesting challenges ahead.

In the design, some components perform specific roles in tracking and maintaining simulation data. One of those components is called the recorder or more cryptically the programmable gain block (pgb). Since these components are responsible for holding the data for a memory store in the instanced module, if another module is instantiated, another instance of the recorder storage is required to hold the additional data. Since only one UDC and its schematic exist, there are no additional storage locations for additional instances. For this reason, modules cannot be instantiated more than once. If another were required, then the work around is to copy the UDC and rename it to another unique name. This enforces another recorder is available for storage.

Situation When one is working with larger systems, often smaller parts of the system are broken down into modules. This allows the circuit to be more readable and also allows signals to be created that are local to that circuit module only. Sometimes when a module needs to be duplicated, the natural response is to copy and paste that module in the same fashion as would be done with a simple component type. This action is disallowed. If multiple copies of the same module were allowed, then each copy would end up referencing memory in the same fashion. From a circuit design, it is expected that one should be able to produce many instances of the same component, even if that component is a module. Ultimately, that circuit design must be converted into subroutines that run the simulation.

This requirement is not a simple one, since the objects that manage data must be capable of many sets of data, one for each instance of the component in the system. Every time the user enters a module, the software must context switch from one data set to another. This means the data set under control or in graphs must be displayed based on the current context; otherwise you would not see the correct data for that component. Since there is no mechanism to assign separate memory spaces to each instance, the code will ultimately fail.

At this time, if a copy of a module is required, then the definition of that module must be duplicated and given a separate name. This will create the necessary memory space to allow the system to behave as if it had multiple instances. When you edit them however, they will be treated as separate circuits with no relationship between them.

This will give others the opportunity to test the new architecture and help define the future of the tool as a whole.

Prototypes From a user standpoint, if the simulation operates as expected, the precise implementation is not too important. There are some real reasons to do a full implementation. The full implementation has distinct advantages for several reasons:

- Only a single method is created for control dynamics. This means that arrays of modules can be created without increasing the number of FORTRAN files to build into the simulation. This greatly reduces the memory requirement and time to compile the simulation
- Multiple data spaces (one for each instance) enable the application to attach a set of parameters that can be variables between instances. This is just like what is currently done with simple components. This gives the user dynamic control over the instance.
- Much larger systems can be constructed using multiple module instances, since the application needs to create only a single module in memory (since they are all the same) and bind the instance to a unique data set. This is especially important when considering future modelling of large systems used in power flow studies (10000+ buses).

Prototypes of a multi-module instance (MMI) version of the software have been created and are being tested in-house. They have demonstrated the capability of the concept as both efficient and effective. Managing MMI at a user level can be tricky, since you must always consider what the component context is to understand where the data is coming from. Development of an interface that is clear and concise will take some effort, but the potential for large systems is great. In addition, the development of a control system can be done by assembling primitives into modules, then reusing these modules many times over with no overhead cost, since only one subroutine is created for all.

Research Scholars *Juan Carlos Garcia Alonso, MSc. (left), new Power Systems Engineer with the PSCAD™ Support team, greets Fernando Martínez Cárdenas (right), Professor at the Instituto Technologico de Morelia, Mexico and PhD candidate at Universidad Michoacana de San Nicolás de Hidalgo. Professor Martínez is the latest in a long line of research scholars to visit the Manitoba HVDC Research Centre. He will be applying PSCAD™ to develop a machine model for the simulation of winding faults and he will be working with the University of Manitoba and RTDS Technologies Inc. to analyse the capabilities of RTP and the RTDS™ on advanced testing applications.*

Wind Farm Transformer Inrush Studies

For further information please contact: Dr. Kenneth Smith or Mr. Roddy Wilson of Mott MacDonald Transmission and Distribution, Glasgow, UK at Kenneth.Smith@mottmac.com or Roddy.Wilson@mottmac.com

In a typical UK wind farm, a series of radial 33kV collector circuits run from the main switchboard and link together individual wind turbine generator transformers (WTG). At the design stage, it is necessary to determine the maximum number of WTG transformers that can be energized simultaneously from the 33kV system. One of the factors to be considered is the voltage dip experienced at the point of common coupling (PCC) or interface between the electrical system of the wind farm and the utility company. The UK standard applied is the Electricity Council's Engineering Recommendation P28, which allows a 3% voltage dip. This article describes wind farm transformer inrush analysis studies the Glasgow based power systems consultants Mott MacDonald have undertaken using PSCAD™ to demonstrate compliance with P28.

Transformer Inrush When a transformer is energized, it may draw a high magnitude transient current from the supply causing a temporary voltage dip. This current, characterized as being almost entirely unidirectional, rises abruptly to its maximum value in the first half-cycle and then decays until the normal steady-state magnetizing conditions are reached. The magnitude and duration of the inrush current depends upon the following, all of which can be represented using a PSCAD™ model as follows:

- The point on the voltage wave at the instant the transformer is energized (i.e. switching angle)
- The impedance of the supply circuit
- The value and sign of the residual flux linkage in the core
- The non-linear magnetic saturation characteristic of the core.

Transformer Modelling The transformer model adopted for these studies is the 'classical' transient model in which each phase of the transformer is represented by a separate single-phase transformer model with no coupling between phases and magnetic core saturation is represented by a current source. Saturation is modelled on the LV winding closest to the transformer core, and flux linkage is calculated as the integral of the winding voltage. The magnetizing current represented by the current source, is related to the flux linkage by a non-linear characteristic that can be partially derived from measurements taken during a no-load (open circuit) test. Above the saturation flux density of the core material, the slope of the flux linkage/magnetizing current curve tends towards the saturated air cored inductance of the winding. This can be calculated from the winding geometry.

Figure 1a shows the variation in peak inrush current with different switching angles predicted for a 1.5MVA, 33/0.69kV, 6.0% impedance transformer when energized from a very strong 33kV source. This study includes core residual flux and as shown in (1b) and (1c), the least favourable switching angle of zero degrees causes the phases with maximum residual flux linkage to be pushed further in saturation and generates the highest inrush current of 440A.

Case Study: 33kV Grid Connection The wind farm is comprised of 15 wind turbines connected via a 33kV collector network to the main wind farm 33kV switchboard. The individual WTG transformers are 33/0.69kV, 1.5MVA units, as described above. The PCC with the utility system is at the end of a 10km overhead line. The fault levels (rms break) at the PCC are: three-phase 6.81kA and line-ground 2.22kA.

Studies indicate that when a single 1.5MVA transformer is energized, the peak current is 407A. This is less than the 440A predicted for this rating of transformer when energized against the strong source discussed above due to the higher impedance of the lower fault level source. For this wind farm configuration, no more than three WTG transformers should be energized simultaneously to ensure that the maximum voltage drop of 3% imposed at the PCC by P28 is never exceeded. If four units are energized simultaneously, an analysis with different switching angles shows that there is a 44% probability of the voltage dip at the PCC exceeding the 3% limit.

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Figure 1a-c Study results for 1.5MVA, 33/0.690kV, 6.0% Dy11 WTG transformer.

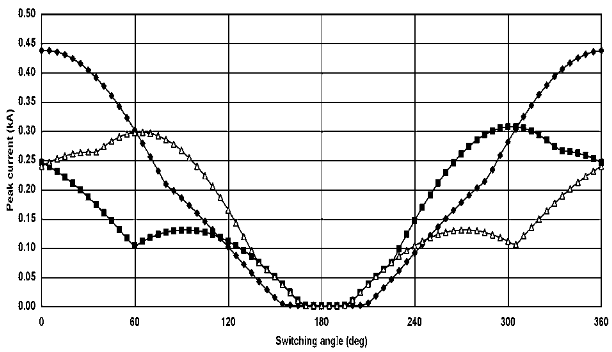

Figure 1a Variation of peak current with switching angle.

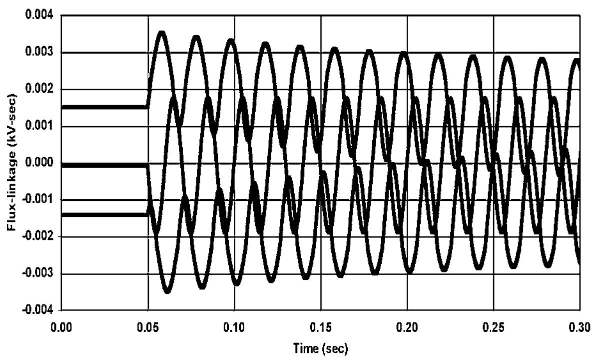

Figure 1b Instantaneous winding flux linkage switching at zero degrees.

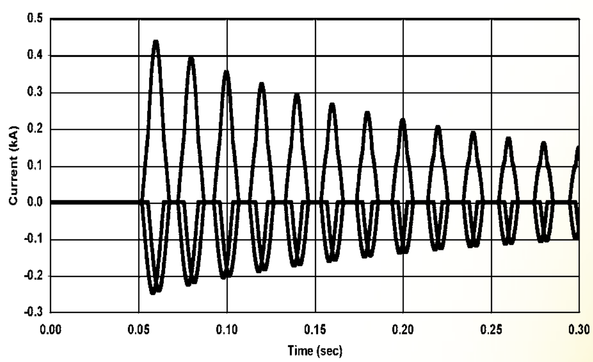

Figure 1c Instantaneous currents switching at zero degrees.

Conclusions Mott MacDonald routinely use PSCAD™ models to determine the transient inrush current and system voltage drop caused when energizing WTG transformers. Examples presented demonstrate that the impact of point on wave switching, core residual flux linkage and transformer core saturation can be included in the PSCAD™ model. Study results for a small wind farm with a rural 33kV grid connection voltage are presented which indicate that for this installation, no more than three WTG transformers should be energized simultaneously to ensure compliance with P28. This has a direct impact on the number and placement of sectionalizing switches required on the 33kV collector network which link the 15 turbines to the main wind farm switchboard. Similar studies have been successfully completed for numerous other wind farm installations.

Expanding Knowledge

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