AECOM

EMT and RMS Model Requirements

Findings on concerns raised by the AEMC

June 2017

EMT and RMS Model Requirements

Report Information

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Executive Summary

The AEMC is currently consulting on a request for rule change requiring the submission of EMT type models as part of AEMO's Generating System Model Guidelines[1] and has sought AECOM's opinion on the following key areas:

- Cost of development of EMT type models
- Confidentiality issues associated with sharing of EMT type models with other proponents
- Brief review of international requirements around EMT type models
- AECOM experiences with projects in the NEM requiring EMT type models

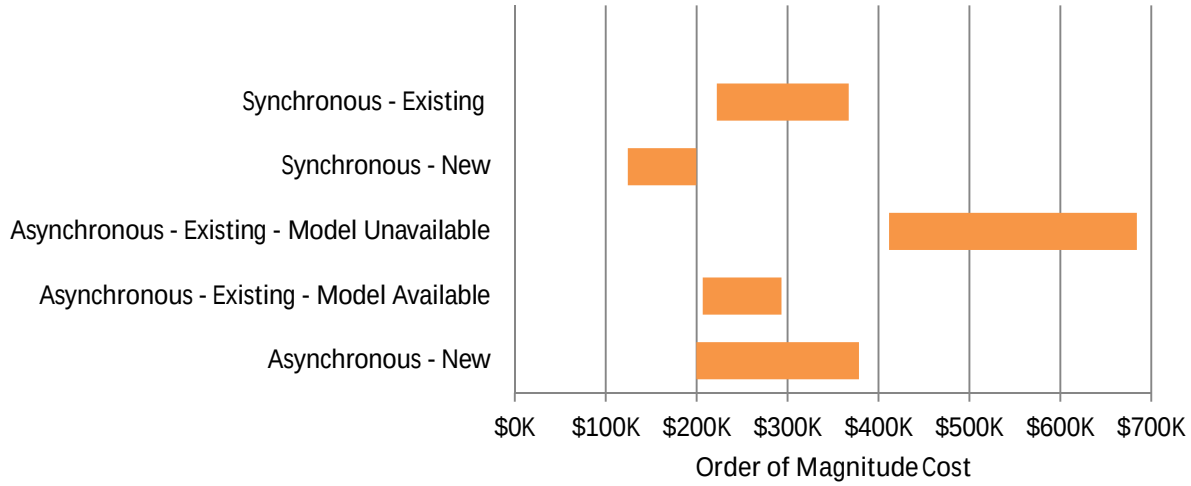
The National Electricity Market is seeing a significant uptake of renewables and with this a shift in the generation technology mix from synchronous rotating machines to power electronic connected generators such as wind, solar PV and battery storage. Power electronics connected generation present a new challenge in that their performance is governed primarily by the converter controls as opposed to the electro-mechanical characteristics as found in synchronous machines.

EMT type model development costs

Development costs of EMT type models depend on many factors including the technology type as well as whether the generating system is either new or existing.

AECOM have provided order of magnitude costs for EMT type model development based on AECOM's experience as per Figure 1 with further details provided in Section 2.0.

Figure 1 Order of magnitude costs for EMT type model development



** Order of Magnitude cost estimate is to a range of ±50% as defined in AECOM's Estimate Guidelines.*

With regards to synchronous generators, it isn't entirely clear if detailed and validated EMT type models of this technology provide any additional value with regards to the problems to be assessed, hence it would be prudent to understand if these models are required as it could entail substantial cost for existing proponents (especially given the number of existing synchronous generators in the NEM).

[1] Generating System Model Guidelines - ERC0219 http://www.aemc.gov.au/Rule-Changes/Generating-System-Model-Guidelines#

Confidentiality issues associated with EMT type models

Both EMT and RMS type models contain proprietary information relating to an OEM's generating equipment. RMS models provided to AEMO and other proponents under the Rules are governed by strict confidentiality requirements. This same process is expected to be applied to EMT type models.

Encryption is utilised to protect confidential information in models (a process referred to as 'black boxing'). A complete black box only shows inputs and output of a model and no ability to see or tune parameters within the model. Where tuning of the model is required however, it is possible for suppliers to provide a slightly more flexible black box model which provides the user with access to the model parameters (only) for the purposes of tuning.

One of the concerns raised was the ability of third parties to back-calculate information captured in encrypted models, thus compromising the intellectual property of OEMs. AECOM were unable to substantiate this or find demonstrated examples of this occurring.

AECOM has consulted with a couple of key suppliers under anonymity as part of this work.

International Trends Relating to EMT type Models

A brief review of international trends has revealed explicit requirements for EMT type models primarily within BC Hydro and Hydro-Quebec in Canada. Encryption or 'black-boxing' of models is seen as a method for maintaining confidentiality of an OEM's intellectual property.

It is noted however that the process adopted overseas such as in the US and Canada is largely different to the process applied in the Australian NEM. In the US and Canada, the NSP or network operator typically carries out interconnection studies such that models and / or confidential data is not typically made available to third parties.

Comparison of EMT type Models against RMS type Models

Where there is a requirement to provide RMS & EMT type models, there may be a requirement to compare the performance of these two models in order to identify which model is best suited for a particular assessment. OEM's of these technologies are of the view that the in the context of comparing the two models, the EMT models are the more accurate.

Clarity and/or guidance should be provided regarding the use of the most appropriate model depending on the application and how the results of the comparison of the model results should be utilised.

1.0 Introduction

1.1 Acronyms

The following acronyms are used throughout this report.

Table 1 List of acronyms

Acronym	Definition
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
EMT	Electro Magnetic Transients
HVDC	High Voltage Direct Current
NEM	National Electricity Market
NSP	Network Service Provider
OEM	Original Equipment Manufacturer
PSCAD	Power Systems Computer Aided Design. Software package utilised to carry out EMT type studies
PSS/E	Power Systems Simulator for Engineering. Software package utilised to carry out RMS type studies.

1.2 Project Background

On 1 November 2016, the AEMO submitted a rule change request to the AEMC seeking to broaden the scope and increase the level of detail of model data that AEMO may request from the registered participants.

Upon receipt of the rule change request, the AEMC conducted a public consultation on the rule change request to seek stakeholder submissions. Stakeholder submissions contained responses to six key issues raised by AEMC in their consultation paper.

AEMC have engaged AECOM to provide an independent opinion with regards to some of these items.

1.3 Purpose of this Report

The purpose of this report is to present the AEMC with an independent opinion relating to a few of the items raised, in particular the following:

1. Order of magnitude costs for the development of EMT type models
2. Confidentiality issues associated with the distribution of EMT type models
3. A brief summary of international trends relating to the requirements for EMT type models
4. Provide commentary on AECOM's experience associated with EMT type modelling on recent projects

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2.0 EMT Model Development costs

2.1 General

Under the rule change request, AEMO proposed to expand the application of its obligation by broadening its scope requiring the provision of more detailed EMT type models from generators in certain situations. AEMC have identified that there may be substantial costs for generators, if they are required to provide more detailed model data to AEMO under the proposed rule.

In the rule change request, AEMO estimated the cost of developing an EMT type model to be approximately AUD75,000 per generating system, however it isn't clear what the basis is for this estimate, or if it includes any testing to validate the model (in the factory or on site). It is likely that this cost would be significantly higher in practice.

The stakeholder responses on the compliance cost were not consistent and varied substantially from one another. As such, AEMC consider that an independent opinion is essential to produce more realistic estimates of likely cost to develop EMT type models for new and existing plant; both synchronous and power electronics connected.

Based on the discussions with a few key OEMs of power electronics based asynchronous generators and its past experience of carrying out RMS type model development and post installation generator testing and model validation work, AECOM have estimated the order magnitude cost to develop EMT type models for different technology types under a range of scenarios. These cost estimates as well as the details of the criteria and assumptions used in the estimation are discussed under the following subsections.

2.2 Criteria, Assumptions and Cost Estimates

As discussed with the AEMC, AECOM have provided order of magnitude costs for the following five (5) scenarios depending on the technology type. All costs quoted below are in Australian dollars.

Table 2 Generating System Types Considered

Generating System	Status
Asynchronous	New
	Existing – Model available
	Existing – Model is not available
Synchronous	New
	Existing generator

2.2.1 New Asynchronous Generating Systems

In case of a new asynchronous generating system, for example solar photovoltaic (PV) or wind turbine, connecting into the NEM, in the first instance, the developer will have to coordinate with the OEM to establish whether there is an EMT type model already available for the type of asynchronous generator proposed in the project. In contrast, this assessment only considers cases where there is no existing EMT type model available and where development of a new EMT type model is necessary.

AECOM had informal discussions with some key technical experts from one solar PV inverter manufacturer and one HVDC inverter manufacturer. Both parties indicated practically the same process for the development of EMT type models for their power electronics based plant. This process is summarised in the flow chart in Figure 7.

Both parties have indicated that the process is likely to take between six months to one year.

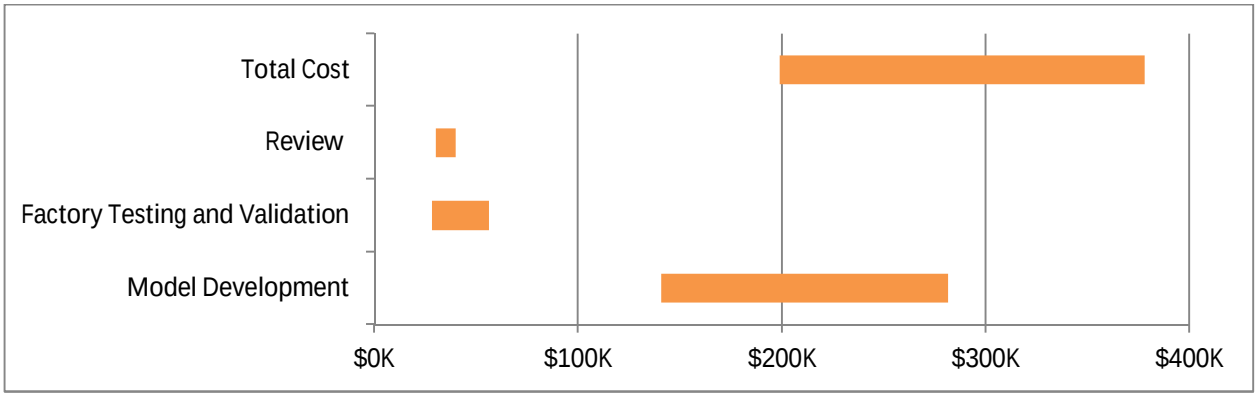
AECOM have used the following criteria to estimate the cost of developing an EMT type model for a new asynchronous generating system. The estimates are based on a range of industry rates for labour and equipment sourced from various AECOM contracts over the last few years.

- A development engineer works on the assignment for six months to one year full time equivalent.
- An experienced engineer spends three to four weeks full time equivalent on the assignment reviewing the work.
- The development engineer's time includes the time spent on factory testing and validation.
- The effort required in developing a complete EMT type model of the particular generating system and control parameter tuning to achieve specific generator performance is excluded. This is typically performed during grid connection studies before determining a set of generator performance standards for the specific generating system. The tuned EMT type model of the complete generating system may then be required to be submitted to the relevant NSP and AEMO.

AECOM also notes that the effort required to develop a Type 3 wind turbine generator (Doubly Fed Induction Generator) model may be more than that required to develop a Type 4 wind turbine generator (Full Converter) model. However, the cost of developing a Type 3 wind turbine generator EMT type model is not expected to be more than the higher end of the estimated cost.

AECOM's cost estimate for developing an EMT type model for a new asynchronous generating system is illustrated in Figure 2.

Figure 2 Order of magnitude* cost estimate for developing an EMT type model for a new asynchronous generating system



** Order of Magnitude cost estimate is to a range of ±50% as defined in AECOM's Estimate Guidelines.*

2.2.2 Existing Asynchronous Generating System

2.2.2.1 An EMT type Model is available from the OEM

For some of the existing asynchronous generating systems, the case may be, there could be an EMT type model already available from the OEM for the specific generating unit type and for the specific firmware version used in the control systems. In this case, the proponent will have to tune the model parameters so that the complete generating system model demonstrates the same behaviour as the physical plant. This requires testing of the physical generating system and subsequent model validation. In AECOM's opinion this testing and model validation process may be extensive when compared to the post installation testing and model validation process currently used to derive RMS type models.

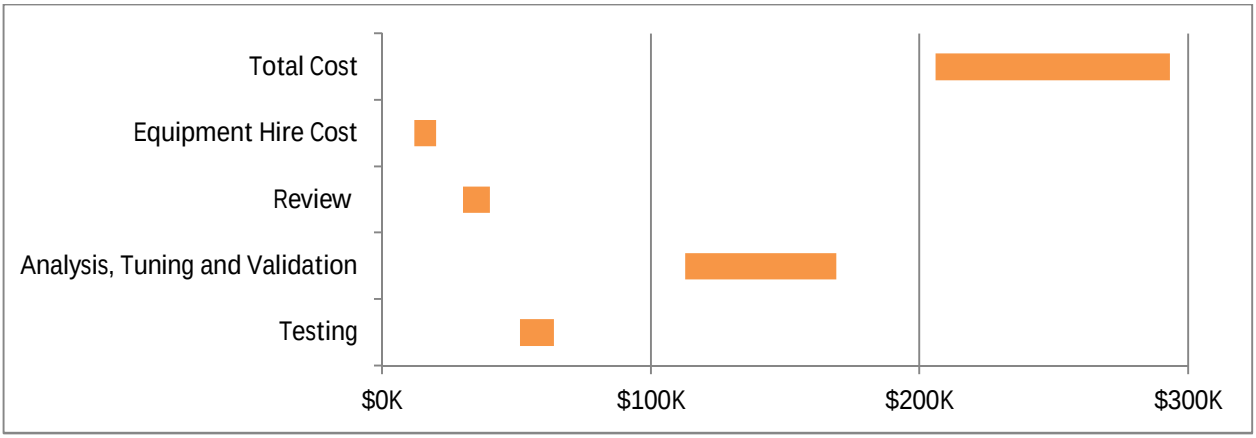
AECOM have used the following criteria to estimate the cost of developing a complete EMT type model for this type of existing asynchronous generating systems.

- An EMT type model is already available from the OEM for the specific generating unit type and for the specific firmware version used in the control systems.
- Two test engineers carry out testing on the generating system for 20 to 25 business days full time equivalent.

- A power system study engineer works on the test results analysis, model parameter tuning and validation four months to six months full time equivalent.
- An experienced engineer spends three to four weeks full time equivalent on the assignment reviewing the work.
- The power system study engineer's time includes the time spent on liaising with the OEM on model set-up and parameter tuning.
- The cost of hiring test equipment is included.
- The cost associated with loss of revenue due to periods of generating system shut down or dispatching at a level below the maximum capability for specific types of testing is excluded.
- The labour cost of generator's own technical staff assisting in the testing work is excluded.

AECOM's cost estimate for developing an EMT type model for an existing asynchronous generating system of this type is illustrated in Figure 3.

Figure 3 Order of Magnitude* cost estimate for developing an EMT type model for an existing asynchronous generating system – EMT type model is available from OEM



** Order of Magnitude cost estimate is to a range of ±50% as defined in AECOM's Estimate Guidelines.*

2.2.2.2 An EMT type Model is not available from the OEM

In contrast to the above, there may be a case where there is no EMT type model available from the OEM to match with the specific generator unit type or the specific firmware version used in the control systems. In this case, the generator developer will have to request the OEM to develop an appropriate EMT type model for them.

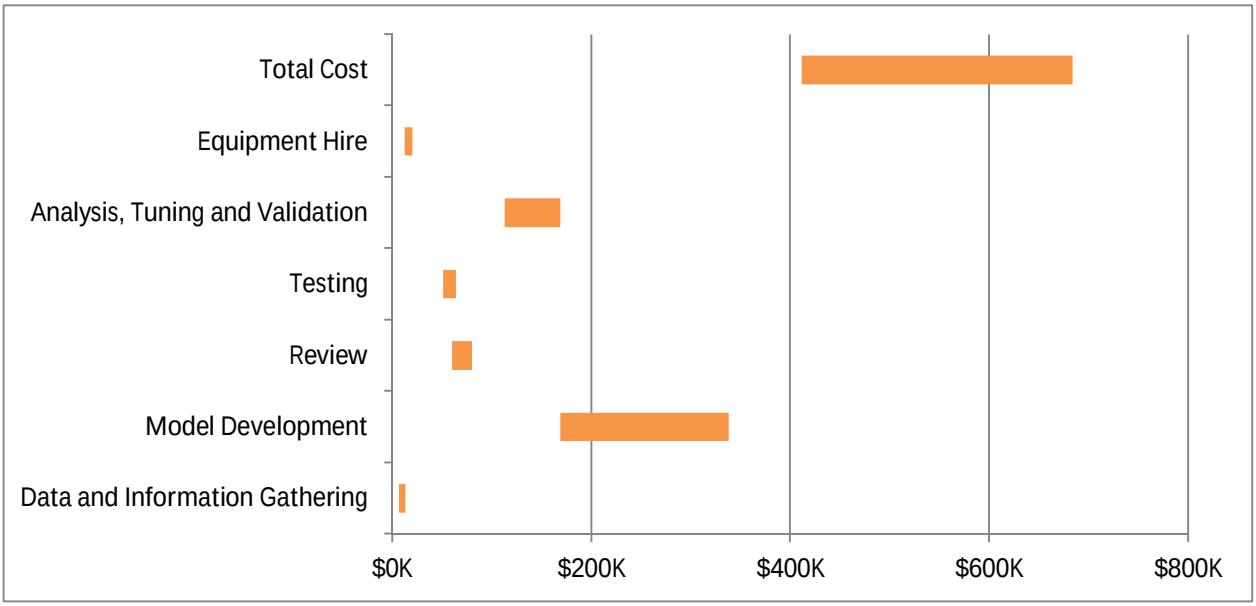
AECOM have used the following criteria to estimate the cost of developing a complete EMT type model for this type of existing asynchronous generating systems.

- A research and development engineer from the OEM spends five to ten days full time equivalent in the generating site to gather data and information related to the generating units and the control systems.
- A development engineer of the OEM works for six months to one year full time equivalent on developing an EMT type model of the generating unit and the associated control systems.
- An experienced engineer from the OEM spends three to four weeks full time equivalent on the assignment reviewing the work.
- Two test engineers carry out testing on the generating system for 20 to 25 business days full time equivalent.

- A power system study engineer works on the test results analysis, model parameter tuning and validation four months to six months full time equivalent.
- An experienced engineer spends three to four weeks full time equivalent on the assignment reviewing the work.
- The cost of hiring test equipment is included.
- The cost associated with loss of revenue due to periods of generating system shut down or dispatching at a level below the maximum capability for specific types of testing is excluded.
- The labour cost of generator's own technical staff assisting in the testing work is excluded.

AECOM's cost estimate for developing an EMT type model for an existing asynchronous generating system of this type is illustrated in Figure 4.

Figure 4 Order of Magnitude* cost estimate for developing an EMT type model for an existing asynchronous generating system – EMT type model is not available from OEM



** Order of Magnitude cost estimate is to a range of ±50% as defined in AECOM's Estimate Guidelines.*

2.2.3 New Synchronous Generating Systems

This assessment only considers cases where there is no existing EMT type model available from the OEM and where development of a new EMT type model is necessary.

In AECOM's opinion, the EMT type models of synchronous machines are rather standard and there is not much effort required in developing machine models. These machine models are readily available in EMT software packages such as PSCAD/EMTDC.

The effort is only required to develop the control system models, i.e. Automatic Voltage Regulator/Exciter, Turbine/Governor and Power System Stabiliser of the generating system. It is likely that for new control systems, the design details such as the block diagrams and transfer functions are available with the OEM. These details become the basis for developing EMT type models for the control systems.

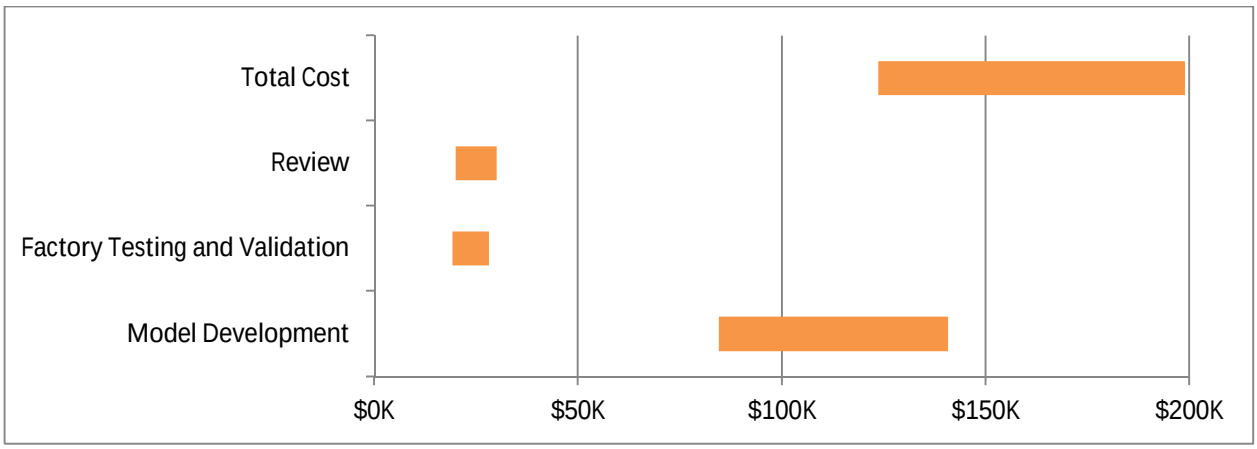
AECOM have used the following criteria to estimate the cost of developing an EMT type model for a new synchronous generating system.

- A development engineer from the OEM works on the assignment for four months to six months full time equivalent.
- An experienced engineer spends two to three weeks full time equivalent on the assignment reviewing the work.

- The development engineer's time includes the time spent on factory testing and validation.
- The effort required to develop a complete EMT type model of the particular generating system and control parameter tuning to achieve specific generator performance is excluded. This is typically performed during grid connection studies before determining a set of generator performance standards for the specific generating system. The tuned EMT type model of the complete generating system may then be required to be submitted to the relevant NSP and AEMO.

AECOM's cost estimate for developing an EMT type model for a new synchronous generating system is illustrated in Figure 5.

Figure 5 Order of Magnitude* cost estimate for developing an EMT type model for a new synchronous generating system



** Order of Magnitude cost estimate is to a range of ±50% as defined in AECOM's Estimate Guidelines.*

2.2.4 Existing Synchronous Generating Systems

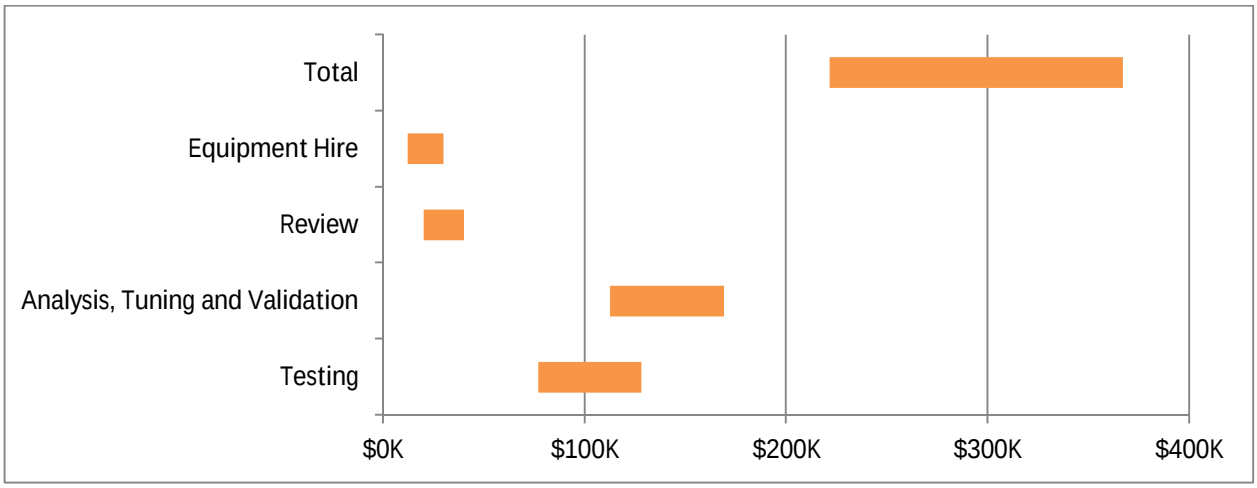
Most of the existing synchronous generating systems in the National Electricity Market (NEM) are more than ten years old and it is highly unlikely that the OEMs of these equipment and control system hardware had developed any EMT type models at that time. Thus, in most cases, extensive testing, analysis and benchmarking may be required to derive an acceptable EMT type model for these type of existing synchronous generating systems.

AECOM have used the following criteria to estimate the cost of developing a complete EMT type model for this type of existing synchronous generating systems.

- Two test engineers spend 10 to 20 days full time equivalent in the generating site to gather data and information related to the generating units and the control systems.
- Two test engineers carry out testing on the generating system for 20 to 30 days full time equivalent.
- A power system study engineer works on the test results analysis, model parameter tuning and validation four months to six months full time equivalent.
- An experienced engineer spends two to four weeks full time equivalent on the assignment reviewing the work.
- The cost of hiring test equipment is included.
- The cost associated with loss of revenue due to periods of generating system shut down or dispatching at a level below the maximum capability for specific types of testing is excluded.
- The labour cost of generator's own technical staff assisting in the testing work is excluded.

AECOM's cost estimate for developing an EMT type model for an existing synchronous generating system is illustrated in Figure 6.

Figure 6 Order of Magnitude* cost estimate for developing an EMT type model for an existing synchronous generating system



** Order of Magnitude cost estimate is to a range of ±50% as defined in AECOM's Estimate Guidelines.*

It can be seen that much of the cost of developing an EMT type model for an existing synchronous generating system comes from testing and validation.

Based on the information that AECOM have reviewed in the given timeframes, it isn't clear if detailed and validated EMT type models of synchronous generators add additional value in terms of assessing some of the issues associated with connecting asynchronous generators such as wind and solar PV. The EMT type model of the synchronous generator under fault conditions and voltage disturbances is likely to behave in a similar manner as the RMS type model of the same generator.

An alternate method and more economical way to address this issue may be (where appropriate for the particular assessment) to model the synchronous generating systems in an RMS type software platform and the power electronics based asynchronous generating systems in an EMT type software platform and then use some form of hybrid simulation interface between the two software platforms. This type of co-simulation module is already available in PSS/E (RMS type tool) enabling hybrid simulations to be performed with PSCAD/EMTDC (EMT type tool).

3.0 Confidentiality Issues Related to EMT type Models

3.1 General Background

In the consultation paper on National Electricity Amendment (Generating System Model Guidelines) Rule 2017[2], AEMC have raised the following questions on third party disclosure of EMT type models.

- Should third parties have access to EMT type models?
- What information should be made available to third parties?
- Would encryption of this data provide sufficient protection to address issues related to commercial sensitivity of the data?

AEMC raise these questions as AEMO's rule change request[3] does not propose any changes to the third party disclosure clauses of the National Electricity Rules (NER) and it may be that the conditions for providing registered participants with EMT type models would be the same as those that currently apply to RMS type models. The current conditions that apply to RMS type models are; the information must be provided to registered participants in compiled, encrypted or secured form, unless the original provider of the model has consented otherwise in writing and the recipients must treat the information as confidential.

Based on the above, AEMC consider that it is necessary to assess whether EMT type models are likely to be more commercially sensitive than an RMS type model and whether current encryption requirements can provide adequate protection.

AECOM have carried out a review of the process currently applied to RMS type models and a high level assessment of the capability of the PSCAD/EMTDC software package (An EMT type tool used by AEMO) to encrypt information. The details and the findings of the review are discussed under the following sections. AECOM have also had informal discussions with a few key wind turbine generator and solar PV inverter OEMs to understand their concerns related to potential disclosure of intellectual property in providing encrypted black-box EMT type models to third parties. Their opinions are also summarised at the end of this section.

3.2 Existing Process Applied to RMS type Models

As part of the connection process set out in S5.2.4 of the NER[4], connecting generators are required to submit a model package that represents the structure and performance of the generating plant to AEMO and the connecting NSP.

This includes the following information with sufficient details for AEMO and NSPs to perform static and dynamic simulation studies.

- a set of functional block diagrams, including all functions between feedback signals and generating system output;
- the parameters of each functional block, including all settings, gains, time constants, delays, deadbands and limits;
- the characteristics of non-linear elements; and
- model source code associated with the model in an unencrypted form.

AEMO's Generating System Model Guidelines (effective from 29th February 2008)[5] describe the above dynamic models as transient stability models. They are positive sequence RMS type models that define the electromechanical and control system performance of the plant within a generating system under steady state and disturbance conditions.

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[2] AEMC 2017, Generating System Model Guidelines, Consultation Paper, 15 March 2017, Sydney.
[3] AEMO, October 2017, Electricity Rule Change Proposal – Rule Change Submission for Revision of AEMO's Generating System Model Guidelines.
[4] National Electricity Rule Version 91, Chapter 5, 2 May 2017
[5] AEMO Generating System Design Data Sheets and Generating System Setting Data Sheets, 29 February 2008.

Under the current rules for RMS type models in PSS/E, the model source code of the RMS type models is only submitted to AEMO and is treated as confidential information. Registered participants are only permitted to request the encrypted RMS type model and data previously submitted to AEMO by other generators in order to carry out their own power system studies. Network Service Providers are also only permitted to request encrypted model data for their planning and operational studies from proponents.

At present, the majority of OEMs write the RMS type model source code in FORTRAN or FLEX programming languages based on the functional block diagrams that describe the generating system. This model source code is then compiled to produce a model file in binary encrypted format. The native model source code is only submitted to AEMO. Only the compiled encrypted model source code is available on request to Network Service Providers and third party registered participants from AEMO.

This process has been in place for more than a decade and the author is unaware of any concerns from OEMs with regards to releasing their RMS type encrypted models to third parties.

This may suggest that OEMs have trusted this process to provide an adequate level of protection for their intellectual property in the RMS type models. It may also be the case that RMS type models are reduced order models and even in model source code format do not have the level of details found in an EMT type model that is closely mapped to the physical implementation of the modelled system.

3.3 Black-Boxing Process in PSCAD/EMTDC

Due to the tight timeframe requirement of the initial opinion to the AEMC, AECOM have only considered the encryption (i.e. black-boxing) capability of PSCAD/EMTDC software package. PSCAD/EMTDC is a widely used tool among utilities, manufacturers, consultants, military and academic institutions to study the Electromagnetic Transients (EMT) in the power system.

EMTDC (which stands for Electromagnetic Transients including DC) is an electromagnetic transient program which can represent and solve differential equations of electromagnetic and electromechanical systems in the time domain. Solutions are calculated based on a fixed time step. The program structure of EMTDC also allows for the creation and analysis of control systems independent or in conjunction with the electromagnetic or electromechanical systems.

PSCAD is the graphical user interface to the EMTDC solution engine. PSCAD enables the user to schematically construct a circuit, run a simulation, analyse the results, and manage the data in a completely integrated, graphical environment.

According to information published by the Manitoba HVDC Research Centre[6], the developers of PSCAD/EMTDC, black-boxing allows the model developer to design their control system schematically, and then quickly collapse it into a pre-compiled, binary version, thereby protecting any intellectual property invested in the design, before distributing the model to clients.

AECOM perceive that the sensitivity and intellectual property issues associated with the EMT type models primarily relate to the control and protection systems of the generating units, particularly the asynchronous power electronics connected generators. These control and protection systems differ from one manufacturer to the other and dictate the major performance characteristics of non-synchronous power electronics connected generating systems. As such, there is major interest among OEMs to limit the disclosure of the intellectual property related to these systems that could compromise their competitive advantage. Other than the control and protection systems of the generating units, AECOM are of the understanding that the actual primary power electronic hardware system models are not confidential information and OEMs do not have any particular concerns about this information not being encrypted.

The PSCAD/EMTDC user guide states that black-boxing feature does not support any electrical components at present (purely protection and controls only) and that future versions are expected to support electrical systems. However, as highlighted above, AECOM are of the understanding that this is not seen as a major disclosure of the intellectual property.

[6] PSCAD User's Guide Version X4 (4.6.0), Manitoba HVDC Research Centre.

Once the black-boxing procedure is performed on a schematically designed control system in PSCAD, it generates FORTRAN source code specifically formatted to be used as an external file. This process effectively conceals the graphical design of the circuit, hiding the contents within the external source code. The normal procedure used by the OEMs is to compile this external source code into an object (*.obj) file or a static library (*.lib) before it is supplied to the third party, providing protection for the intellectual property.

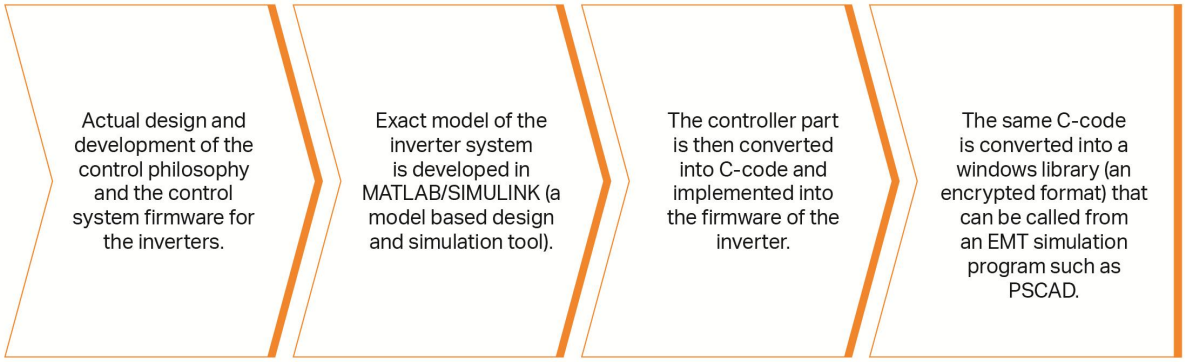
There are concerns among some OEMs that due to the level of detail found in EMT type models, providing such models to third parties even as black-box compiled format may offer the third parties the opportunity to back solve and thereby disclose the intellectual property.

However, once a control system model is black-boxed, the details are completely concealed and not observable by its user. Thus, without an associated transfer function block diagram representation of the black-boxed model, it is not reasonably practical for any third party to back solve and derive the native model source code. Therefore, AECOM are of the opinion that the risk of back solving black boxed models is extremely low. Based on the research carried out by AECOM, we are not aware of any instances where back solving has been applied to obtain confidential information.

3.4 EMT type Model Development Procedure Used by OEMs

AECOM had informal discussions with a few key technical personnel from OEMs of power electronics based asynchronous generators to gain an appreciation of the procedure used to develop an EMT type model. Generally, the process involves the steps illustrated in Figure 7.

Figure 7 The EMT type model development process used by OEMs



As it is the same C-code implemented in the firmware of the inverters that is used to develop the EMT type controller part, this EMT type model preserves the same degree of detail as the actual controller. It may be this reason that OEMs of power electronics based asynchronous generators are reluctant to distribute these EMT type models to third parties, even in encrypted format.

3.5 Summary of Concerns Raised by OEMs

During the discussions with the Original Equipment Manufacturers of power electronics based asynchronous generators, it was noted that all parties treat the EMT type models as highly sensitive confidential information. At least one manufacturer indicated that they are only comfortable in supplying the EMT type models only to AEMO and network service providers and not that keen on supplying the same to third party registered participants. The other manufacturers indicated that they are prepared to supply the models to third parties with a Non-Disclosure Agreement signed.

The Original Equipment Manufacturers' main concern on confidentiality issue originates from the process involved with development of EMT type models. As described in Section 3.4, the EMT type model preserves the same degree of detail as the actual physical controller. The manufacturers' argument is that supplying an EMT type model to a third party registered participant even in encrypted black-box format may potentially lead to revealing their intellectual property to other competitors. The basis for this argument is that even a black-box model offers the user to visualise and manipulate some parameters while some parameters are hard-coded into the model and together with the EMT

type model user manual, an experienced research and development engineer from a competitor may be able to reverse engineer the model.

4.0 International Trends Relating to EMT type Models

With regards to the request for EMT models in the international context, AECOM focussed on those countries that had specific requirements for EMT models.

The findings are provided below, with the key finding being that Canada (Hydro-Québec and British Columbia have explicit requirements for EMT type models.

4.1 Trends in the United States

AECOM originally focussed on identifying any requirements for EMT models in the Texas region (ERCOT). In the absence of being able to identify any definitive ERCOT requirements in the timeframes, it was found that the requirements for EMT models appear to be focussed primarily on identifying issues associated with Sub Synchronous Resonance (SSR) of renewable generating systems interfacing with series compensated lines.

> *"The Facility Study may include electromagnetic transient simulation if deemed necessary. As mentioned in Chapter 5, subsynchronous interactions may be an issue for installations near series-compensated lines. Wind and solar plant manufacturers are encouraged to develop detailed electromagnetic transient models. However, it is not recommended to modify FAC-001[7] to address electromagnetic transient modelling at this time. The models are not widely available and the technical issues requiring such modelling are not continent-wide.[8]*

Although it wasn't identified that connection standards be modified to request EMT models (in the context of SSR), there have been issues on the ERCOT system associated with control system instability. A particular case was a relatively large wind farm connecting to the ERCOT system some time prior to 2012 where weak network conditions would results following the loss of adjacent transmission lines. Although it isn't presently clear if ERCOT require the provision of EMT type models, the importance of such models in identifying control system instability can be seen[9].

4.2 Canadian trends

4.2.1 Hydro-Quebec

Hydro-Québec detail specific requirements for Wind generation in a supplement to their technical requirements which cover requirements for EMT type models[10] as of October 2005.

These models are required up front in order to commence studies (usually carried out by the network services provider).

Some of the requirements of the detailed EMT model are noted below:

- *Unlocked and be readily usable with EMPTWorks.*
- *Represent the wind turbine and equipment with a control system (SVC, STATCOM etc)*
- *Include an adequate representation of any power electronics with which the WTG is equipped*

[7] North American Electric Reliability Corporation (NERC) - FAC-001 - Facility Connection Requirements
[8] 2012 Specialist Assessment – Interconnection Requirements for Variable Generation, September 2012 North American Electric Reliability Corporation (NERC)
[9] Voltage control challenges on weak grids with high penetration of wind generation: ERCOT experience, July 2012, SH Huang, J Schmall, J Conto, J Adams .
[10] TECHNICAL REQUIREMENTS FOR THE CONNECTION OF GENERATION FACILITIES TO THE HYDRO-QUÉBEC TRANSMISSION SYSTEM, Supplementary requirements for wind generation, revised October 2005

The OEM is allowed to 'black box' or encrypt models in order to preserve confidentiality, however this requires 'approval' from the network service provider. It isn't clear to what extent the NSP allows/doesn't allow black-boxing of the model.

4.2.2 British Columbia

Similar to Hydro-Quebec, BC Hydro requires detailed three-phase EMT type models in PSCAD or EMTDC[11].

Some of the main points of the requirements are stated below:

- Model must be in a proven EMTP (electromagnetic transients program), specifically PSCAD/EMTDC
- Models should be for each proposed WTG type and collector network
- Include any static or dynamic VAR compensating components such as STATCOMs or SVCs
- Shall be provided for the purposes of Interconnection Impact Studies
- The model shall be available to study engineer designated by BC Hydro, whether this is the utility, consultant, or manufacturer (with the understanding that a Non Disclosure Agreement may be required).
- The model is not intended to be made "public".

BC Hydro states that Black Box type encrypted models are acceptable provided some inputs/outputs are available to be analysed as part of the studies.

It is noted that there is a detailed section (Appendix 1) of the BC Hydro document which sets out the information required from the EMT model. It isn't clear what level of testing or proving of the model is required to demonstrate its accuracy.

The requirements covered in Appendix 1 of the BC Hydro document are reproduced below.

Essential Requirements

- *Detailed modelling of the main components, the controls, automatic voltage regulations, and protections must be included.*
- *Blade/pitch controller is to be included.*
- *The ride-through capability is to be modelled.*
- *The model is to be capable of correctly reproducing the short circuit fault current contribution.*
- *The model must be suitable for modelling open circuit, short circuit, balanced and unbalanced faults in the grid, including steady state & dynamic simulations.*
- *The model should be available in the latest version of PSCAD and should support Compaq Fortran 90 V6.6.*
- *The model must be capable of representing a single unit and should be adaptable to represent any reasonable number of identical units with a minimum of effort.*
- *It must be possible to run a simulation with a case containing more than one PSCAD model, where, for example, one model might represent a cluster of wind turbine generators connected to one branch of a WGF.*
- *The model should support the "snapshot" feature in PSCAD to allow the simulation to be saved and restarted at any point in time.*

[11] BC Hydro for Generators, 60kV to 500kV Technical Interconnection Requirements For Power Generators , Rev 1.4 June 2, 2014

- *The model must come with documentation to explain the assumptions and basic operation of what is being modelled as well as a user manual.*
- *Model validation documents comparing the PSCAD model response to real system measurements must be provided.*
- *The control of internal and external shunt capacitor banks, as required by the overall controller, is to be included.*
- *A correctly functioning PSCAD case including the WGF model connected to a simple AC system must be provided.*

Non-essential Requirements:

- *Switching-based model (for doubly fed, SVC and converter based models) for harmonic/power quality studies must be provided.*
- *Blade dynamics (i.e. inertia of blades, gearbox, etc.) should be modelled for torsional interaction/dynamic studies.*

5.0 Requirement for EMT and RMS type models

5.1 General

The requirement for EMT and RMS type models stems from the fact that RMS models are not sufficiently detailed enough in order to identify some of the problems associated with integrating inverter connected generation. In the context of wind and solar PV, EMT models are intended to identify control related interactions, especially during weak network conditions.

Feedback from OEMs regarding model accuracy (wind and solar PV generators) is that an EMT model provides the most accurate representation of the generating system. However it isn't clear when EMT models should be used and when RMS models should be used given that most studies are currently completed by AEMO in PSS/E (an RMS tool).

AECOM's understanding based on recent projects is that the following all have an influence in terms of identifying whether a RMS model should be used over an EMT model.

- Strength of the system where the generator is connecting (as measured by Short Circuit Ratio and X/R)
- OEM knowledge and understanding of the suitability of their equipment to operate in a weak network (ability to tune performance of their equipment to deal with some of the challenges associated with weak grids)
- Availability of accurate models of the wider network to carry out EMT based assessments. Assessment of performance of a generating system is highly dependent on interactions with other generators and/or network equipment

Based on AECOM's review of information, there isn't a precedence set in terms of which model should be used in which application and this could result in confusion, cost and/or schedule risk if the requirements of proponents are not clear.

Furthermore, the requirement for pre-validation of models[12], could add significant up front cost and time for proponents.

[12] Rule Change Request: Generating System Model Guidelines, AEMO comments, AEMO 12 April 2017

5.2 Comparison of models

It is understood that there may be a requirement to carry out a comparison between the two models in the different simulation environments in order to understand the appropriateness of the various models for different scenarios.

The requirements, based on AECOM's understanding appear to have evolved in the following sequence:

1. Requirement for EMT models
2. Demonstrate that EMT models accurately reflect the equipment to be connected. This has in some cases required factory based testing (pre-validation as stated by AEMO in their rule change request)
3. Benchmarking the RMS and EMT models to see alignment of results (or otherwise) for various scenarios.

Clarity and/or guidance would be required regarding the use of the most appropriate model depending on the application and how the results of the comparison of the model results should be utilised. Although this is beyond the scope of this report, it may not be clear when EMT models should be used and when RMS models should be used.