SPP ELECTROMAGNETIC TRANSIENT (EMT) MODEL REQUIREMENTS

For Inverter-Based Resource Interconnection

Revision 1

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REVISION HISTORY

VERSION NUMBER		AUTHOR	CHANGE DESCRIPTION	COMMENTS
Draft		DAB	Initial Draft	For RR 430 approval
Revision 0	1/21/2022	DAB	Revised and Finalized for Customer Use	To be implemented in DISIS 2018, Phase 2
Revision 1	3/10/2023	DAB	Added Attachments 1 and 2	PSCAD Model Test Checklist & Model Supplier Checklist

SPP Electromagnetic Transient (EMT) Model Requirements

Inverter-Based Resource (IBR) response to a disturbance can be much faster than that which is shown in standard positive sequence dynamic studies. To capture these responses, Electromagnetic Transient (EMT) studies are necessary. SPP's Generator Interconnection (GI) department will be performing these studies using PSCAD™ software when screening studies reveal further analysis of weak grid conditions is needed.

To perform these studies, EMT models for IBRs are required from the GI interconnection customer. The IBR models shall be compatible with the PSCAD™ simulation tool as described throughout this document and must comply with the listed model requirement features with respect to accuracy, usability, and efficiency. The customer shall adhere to these requirements when constructing, assembling, testing, and submitting the PSCAD™ model. Any deviations shall be documented and explained and will be subject to review.

The GI customer's PSCAD™ model shall be submitted to SPP no later than 15 months prior injection of power into the SPP Transmission System.

Model Accuracy Features

For sufficient accuracy, the model provided by the customer for each facility shall:

1. *Represent the full detailed inner control loops of the power electronics.* The model cannot use the same approximations classically used in transient stability modeling, and must fully represent all fast inner controls as implemented in the real equipment. Models which embed the actual hardware code into a PSCAD component are currently wide-spread, and this is the type of model required.[1,2]
2. *Represent all control features pertinent to the type of study being done.* Examples include external voltage controllers, customized PLLs, ride-through controllers, SSCI damping controllers, etc. As in accuracy feature 1, actual hardware code is required for control and protection features. Operating modes that require system specific adjustment must be user accessible.
3. *Represent plant level control.* Power Plant Control (PPC) representation must be included which represents the specific controllers used in the plant. Plant controllers must be represented in sufficient detail to accurately represent short term performance, including specific measurement methods, communication time delays, transitions into and out of ride-through modes, settable control parameters or options, and any other specific implementation details which may impact plant behavior. Generic PPC representations are not acceptable unless the final PPC controls are designed to exactly match the generic PPC model. If multiple plants are controlled by a common controller, or if the plant includes multiple types of IBRs (e.g. Hybrid BESS/PV) this functionality must be included in the plant control model. If external or multiple voltage control devices (e.g. STATCOM) are included in the plant, these should be coordinated with the PPC.
4. *Represent all pertinent electrical and mechanical configurations* such as filters and specialized transformers. There may be other mechanical features such as gearboxes, pitch controllers, or others

[1] The model must be a full power transistor (eg. IGBT) representation (preferred), or use an average source representation that approximates the actual IBGT switching but maintains full detail in the inner controls, and maintains DC side protection features. Models manually translated block-by-block from MATLAB or control block diagrams may be unacceptable because the method used to model the electrical network and interface to the controls may not be accurate, or portions of the controls such as PLL circuits or protection circuits may be approximated or omitted. Note that firmware code may be directly used to create an extremely accurate PSCAD model of the controls. The controller source code may be compiled into DLLs or binaries if the source code is unavailable due to confidentiality restrictions.

It is not recommended to assemble the model using standard blocks available in the PSCAD master library, as approximations are usually introduced, and specific implementation details for important control blocks such as PLLs may be lost. In addition, there is a significant risk that errors will be introduced in the process of manually assembling the model. For this type of manually assembled model, (not using a direct "real code" embedding process), extra care is required, and validation is required.

[2] Model standards are under development which define appropriate ways to wrap .dll based control code into PSCAD models. Model writers are directed to IEEE/Cigre WG to develop a DLL standard for controller models.

which must be modelled if they impact electrical performance within the timeframe of the study. Any control or dynamic features of the actual equipment which may influence behavior in the simulation period which are not represented or which are approximated must be clearly identified.

5. *Have all pertinent protections modeled in detail for both balanced and unbalanced fault conditions.* Typically this includes various OV and UV protections (individual phase and RMS), frequency protections, DC bus voltage protections, converter overcurrent protections, and often other inverter specific protections. Any protections which can influence dynamic behavior or plant ride-through in the simulation period must be included. As in accuracy requirement 1 and 2, actual hardware code is required for these protection features.
6. *Be configured to match expected site-specific equipment settings.* Any user-tunable parameters or options must be set in the model to match the equipment at the specific site being evaluated, as far as they are known. Default parameters are not appropriate unless these will match the configuration in the installed equipment.

Model Usability Features

In order for study engineers to perform system studies and analyze results, the model provided for each facility shall:

7. *Have control or hardware options that are accessible to the user.* Although plant must be configured to match site specific settings as far as they are known, parameters pertinent to the study must be accessible for use by the model user. Examples of this could include protection thresholds, real power recovery ramp rates, frequency or voltage droop settings, voltage control response times, or SSCI damping controllers.[3] Diagnostic flags (e.g. flags to show control mode changes or which protection has been activated) should be visible to aid in analysis.
8. *Be accurate when running at a simulation time step of 10 µs or higher*. Often, requiring a smaller time step means that the control implementation has not used the interpolation features of PSCAD, or is using inappropriate interfacing between the model and the larger network. Lack of interpolation support introduces inaccuracies into the model at larger simulation time-steps. In cases where the power transistor (e.g. IGBT) switching frequency is so high that even interpolation does not allow accurate switching representation at 10 µs (e.g. switching frequency greater than 40 kHz), an average source approximation of the inverter switching may be used to allow a larger simulation time step.
9. *Operate at a range of simulation time* steps. The model must not be restricted to operating at a single time step, but must be able to operate within a range (e.g. 10 µs – 20 µs)
10. *Include documentation and a sample implementation test case.* Test case models must be configured according to the site-specific real equipment configuration up to the Point of Interconnection. This would include (for example): aggregated generator model, aggregated generator transformer, equivalent collector branch, and main step up transformers, gen tie line, power plant controller, and any

[3] Care must be taken to ensure that any user-settable options are not changed in a way that is not implementable in the real hardware, and that any selectable options are actually available at the specific site being considered. Discussion is recommended with the manufacturer prior to any changes being made in model configuration.

other static or dynamic reactive resources. Test case must use a single machine infinite bus representation of the system, configured with an appropriate representative SCR[4]. Access to technical support engineers is desirable.

11. *Have an identification mechanism for configuration.* The model documentation must provide a clear way to identify the specific settings and equipment configuration which will be used in any study, such that during commissioning the settings used in the studies can be checked. This may be control revision codes, settings files, or a combination of these and other identification measures.
12. *Accept external reference variables.* This includes real and reactive power ordered values for Q control modes, or voltage reference values for voltage control modes. Model must accept these reference variables for initialization, and be capable of changing these reference variables mid-simulation, i.e. dynamic signal references.
13. *Be capable of initializing itself.* Once provided with initial condition variables, the model must initialize and ramp to the ordered output without external input from simulation engineers. Any slower control functions which are included (such as switched shunt controllers or power plant controllers) must also accept initial condition variables if required. Note that during the first few seconds of simulation (e.g. 0-2 seconds), the system voltage and corresponding terminal conditions may deviate from nominal values due to other system devices initializing, and the model must be able to tolerate these deviations or provide a variable initialization time.
14. *Have the ability to scale plant capacity.* The active power capacity of the model must be scalable in some way, either internally or through an external scaling component[5]. This is distinct from a dispatchable power order, and is used for modeling different capacities of plant or breaking a lumped equivalent plant into smaller composite models.
15. *Have the ability to dispatch its output to values less than nameplate.* This is distinct from scaling a plant from one unit to more than one, and is used for testing plant behavior at various operating points.
16. *Initialize quickly.* Model must reach its ordered initial conditions as quickly as possible (for example <5 seconds) to user supplied terminal conditions.

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[4] Representative SCR should reflect approximate N-1 interconnection SCR where possible, especially if the system is expected to be weak. If the system strength is not known, using a relatively low SCR in the test system, such as 2.5, may help to avoid issues during study phases.

[5] A free publicly available scaling transformer suitable for this purpose is available in the E-Tran library.

Study Efficiency Features

In order to improve study efficiency and model compatibility the following efficiency features are required. Note that no feature should compromise model accuracy.

17. The model must be compatible with Intel Fortran compiler versions 15 and higher.
18. The model must be compatible with PSCAD version 4.6.3 and higher.
19. The model must support multiple instances of its own definition in the same simulation case.
20. The model must support the PSCAD™ "timed snapshot" and "multiple run" features.
21. The model must support the PSCAD™ "multiple run" feature.
22. The model must not use or rely upon global variables in the PSCAD™ environment
23. The model must not utilize multiple layers in the PSCAD™ environment, including "disabled layers"
24. The model must be compiled with Visual Studio 2015 or newer

Attachment #1: PSCAD Model Test Checklist for Reviewing Model Submissions

Purpose

This document is a test checklist intended for use by engineers who are reviewing model submissions to ensure core model accuracy, performance, and usability features specified in the model requirements document are observed. These procedures cannot ultimately prove that the model is compliant with all requirements, as black box models usually conceal the details of the equipment controls and protection. It is recommended that the equipment manufacturer supply additional confirmation that the model meets each individual requirement.

The tests outlined here are considered "basic", and may be supplemented by more rigorous testing, including various fault types, depths, and durations, as well as more extensive protection testing and benchmarking against phasor models. This document is not intended to be a guide for thorough benchmarking between PSCAD, PSS/E, and actual equipment, and is subject to revision as the state of the art in EMT modeling evolves.

Model test Summary	
SPP Study ID:	
SPP Interconnection Customer ID	
Model Test date:	
Manufacturer:	
Equipment type: (eg. PV or Wind)	
Equipment version:	
Documentation file:	
Model Files supplied:	

Model Review Procedure and Checklist

		Yes/No	Comments
Vendor and site specific model verification			
1a	The Vendor's name and the specific version of the model must be clearly observable in the .pscx PSCAD case.		
1b	Documentation and supporting model filenames must not conflict with model version shown in the .pscx case file.		
1c	Model is supplied with a test circuit which is configured for the site specific application.[6]		
"Real Code" model verification			
2a	Controls are black-boxed, and no PSCAD master library control blocks are visible within control circuits.[7] If the model is not based on "real code", a separate validation report is required showing model comparison against hardware tests.[8]		
Model usability verification			
3a	Model uses a timestep greater than 10 µs[9]		
3b	Model allows a variation in simulation timestep		
3c	Model compiles using Intel Fortran compiler versions 15 or higher.		
3d	Model initializes in 5 seconds or less with a POI level SCR of 2.5[10]. Real power, reactive power, and RMS voltage should reach steady state by this time.		
3e	Model allows multiple instances of itself to be run together in the same case[11]		
Model electrical configuration verification			
4a	Plant level electrical single line diagram (SLD) is included.		

[6] The test circuit must model all relevant electrical components of the plant and contain a system equivalent. Parameters will be assumed to be site-specific, unless there are obvious indications otherwise, such as an incorrect grid base frequency.

[7] Black-boxing of controls to a high level does not guarantee that real-code is embedded into the model, however the visibility of PSCAD master-library control blocks in the inner control loops (PLL, inner current controllers, etc.) suggest that the model is generic in nature. Model documentation may contain information on use of real-code in the model.

[8] If models are not "real code" models, all aspects of the controller operation are required to be validated by utilizing a "hardware in loop" platform or other hardware test systems. Model must not be validated against other software models. Validations must include control responses to various types of faults, changes in power and voltage references, changes in system frequency, testing frequency response in sub and super-synchronous ranges, and testing of protection operation. Tests must also be performed under a variety of system strengths, including very weak systems. Other tests may also be required. The validation report is required along with any model updates that result from the more rigorous validation tests.

[9] Models with timesteps less than 10 µs may be acceptable in situations where a small timestep does not significantly increase the runtime of the total simulation

[10] For all tests where an SCR of 2.5 is specified, this may be replaced with an SCR equal to that of the POI under contingency conditions if this is known.

[11] Depending on specific application and whether E-Tran Plus for PSCAD is allowed to be used to overcome the limitation, this requirement may be waived.

4b	Generator step-up transformer(s) included, with impedance between 5 and 10% on generator base, and matches SLD.[12]		
4c	Lumped collector equivalent(s) included, with total charging equal to between 0.5 and 5% of plant rating, and matches SLD.[9]		
4d	Substation transformer(s) included, rated appropriately for plant size, and impedance between 6 and 12% on transformer base, and matches SLD.[9]		
4e	Model can be scaled to represent any number inverters/turbines, either using a scaling transformer or internal scaling.		
4f	All external devices included in the plant (such as STATCOMs) include appropriate models.		
Plant controller verification			
5a	Model includes power plant controller (PPC)		
5b	PPC accepts an external active power setpoint.		
5c	PPC accepts a voltage setpoint.		
5d	PPC has a mechanism to implement a settable voltage droop.		
5e	Overall plant responds to frequency changes by increasing or decreasing its active power as appropriate. This may be accomplished either at an inverter level or via the PPC.[13]		
5f	Model initializes to the setpoints specified in the PPC. If droops or deadbands are utilized, the initial values may differ from the setpoints.[14]		
5g	If external voltage control devices (STATCOM/DVAR, SVC, MSCs) are included in the plant, ensure that the voltage control of these devices is coordinated with the PPC, with no potential for VAR looping or oscillations.		
Basic performance verification[15]			
6a	Instantaneous voltage and current waveforms have minimal distortion, and no oscillations are observed.		
6b	Model is able to ride-through and recover from a temporary (no line outage or drop in SCR), 6-cycle, zero-impedance, three-phase fault at the high side of the station transformer, with a POI level SCR of 2.5.[9]		

[12] Impedance range is for sanity checking only. Impedances outside this range may be allowed.
[13] Non-compliance with this item may not require model revision as frequency response may not be required in PSCAD models in some instances. In this case, a description of the under/over frequency response capabilities of the actual equipment must be provided by the manufacturer.
[14] If voltage control with droop is implemented, it is preferred that the PPC model requests an initial Q value to match the voltage setpoint. If no initial Q is requested, the voltage setpoint can be biased by the initial Q before it is sent to the PPC. If a non-zero deadband is included in the voltage controller, the deadband can also be considered in the voltage setpoint sent to the PPC.
[15] Performance testing is recommended with a POI level SCR of 2.5 as this is a representative system condition seen during weak system studies. Testing may be performed at higher SCRs if the stable operating SCR of a model is known to be above 2.5.

6c	Model responds to a step change in PPC voltage setpoint, reaching 90% of the new value between 1 and 10 seconds in a test system with POI level SCR of 2.5. [9]		
6d	Model responds to a step change in PPC active power setpoint, reaching 90% of the new value between 1 and 10 seconds in a test system with POI level SCR of 2.5. [9,16]		
Basic protection verification[17]			
7a	Protection settings are implemented. These could be available as inputs in the model, or hard-coded in the black-boxed controls. [18]		
7b	Option to disable protection models is present.[19]		
7c	Model trips or blocks when terminal voltage rises above 1.3 pu for 1.5 second.[20]		
7d	Model trips or blocks when terminal voltage falls below 0.2 pu for 1.5 second.[20]		
7e	Model clearly displays trip / diagnostic signals indicating the status of all pertinent protection elements		
Documentation			
8a	Model documentation states compliance with SPP EMT Model Requirements[21], or is supplied with a completed PSCAD Model Requirements Supplier Checklist.		
8b	Model documentation includes instructions for setup and running of the model, including the recommended range of simulation time steps. Documentation must give a clear description of trip / operation code signals produced by model.		

[16] Different response time criteria may apply depending on specific SPP sub-region.
[17] There are many protection functions which must be modelled and these basic tests will not be proof that these functions are modelled.
[18] If settings are not visible in model or documentation, verification that protection settings are implemented in the PSCAD model must be received from the manufacturer.
[19] Non-compliance may not require model revision as many studies do not require testing with protection settings disabled.
[20] Non-compliance with this item must result in verification of protection settings implementation from the manufacturer, as some models may have capabilities beyond what is listed here.
[21] Non-compliance may be waived in systems which do not require compliance with the model requirements document.

Attachment #2: PSCAD Model Requirements Supplier Checklist

Purpose

This document is a model requirements checklist which must be completed by the supplier of the model and submitted with each PSCAD model. Generic testing of the model may be done using the Model Test Checklist (Att. 1), which can be used as a reference.

The model supplier must review every item in the checklist and indicate compliance with each item. If the supplied model does not meet any given requirement, an explanation of the deficiency must be provided in the comments column.

Model Submission Summary (to be completed by model supplier)	
SPP Study ID:	
SPP Interconnection Customer ID	
Primary contact information for model related questions:	
Secondary contact information for model related questions:	
Manufacturer:	
Equipment type: (e.g. PV or Wind)	
Equipment version:	
Documentation file(s):	
Model Files supplied:	

Model Requirements Checklist		Referenced Requirement Number	Model Complies? (Yes/No)	Comments
1	*Model Accuracy Features*			
1.1	Power electronic controls are modelled by interfacing with actual firmware code from the inverter (“real code” model), or includes detailed validation report. [22]	1,2		
1.2	Operating modes which require system specific adjustment are accessible.	2		
1.3	Plant level controller is included.[23]	3		
1.4	Model is capable of controlling frequency[24]	2,3		
1.5	Includes pertinent electrical and mechanical features, such as gearboxes, pitch controllers, or other features which impact the plant performance in the simulation period.[25]	4		
1.6	All protections which could impact ride-through performance are modelled in detail.	5		
1.7	Model is configured for the specific site being evaluated, as far as is known.	6		
2	*Model and Project Documentation*			
2.1	Model includes documentation.	7		
2.2	Documentation includes instruction for setup and running the model. The Vendor’s name and the specific version of the model must be clearly observable in the .pscx PSCAD case. Documentation and supporting model filenames must not	7		

[22] If models are not “real code” models, all aspects of the controller operation are required to be validated by utilizing a “hardware in loop” platform or other hardware test systems. Model must not be validated against other software models. Validations must include control responses to various types of faults, changes in power and voltage references, changes in system frequency, testing frequency response in sub and super-synchronous ranges, and testing of protection operation. Tests must also be performed under a variety of system strengths, including very weak systems. Other tests may also be required. The validation report is required along with any model updates that result from the more rigorous validation tests.

[23] If the plant is part of a multi-plant control scheme, a description of the overall scheme must be provided, and corresponding PPC models must be configured to control multiple plants accordingly.

[24] Frequency control model requirements may vary by SPP region. Example response time may be less than 10 seconds.

[25] Simulation period may vary depending on the model use, but 10 seconds of simulation following an event such as a fault is a typical period.

	conflict with model version shown in the .pscx case file.			
2.3	Model is supplied with a sample test case including site specific plant representation.	7		
2.4	Plant single line diagram is provided, and aligns with model	7		
2.5	Model documentation provides a clear way to identify site-specific settings and equipment configuration.	8		
3	*Model Usability Features*			
3.01	Control or hardware options are accessible to the user as applicable.	9		
3.02	Diagnostic flags are visible to the user.	9		
3.03	Model uses a timestep greater than 10 µs.	10		
3.04	Model allows a range of simulation timesteps (ie. not restricted to a single timestep).	11		
3.06	Model accepts external reference variables for active and reactive power and voltage setpoint, and these may be changed dynamically during the simulation.	12		
3.07	Model is capable of initializing itself.	13		
3.08	Active power capacity is scalable.	14		
3.09	Active power is dispatchable.	15		
3.10	Model reaches setpoint P, Q, and V in 5 seconds or less	16		
3.11	Model compatible with Intel FORTRAN version 12 and higher.	17		
3.12	Model compiles using PSCAD version 4.5.3 or higher.	18		
3.13	Model supports multiple instances of its own definition in a single PSCAD case.	19		
3.14	Model supports PSCAD “snapshot” feature.	20		
3.15	Model supports the PSCAD “multiple run” feature.	21		
3.16	Model does not use PSCAD global variables.	22		
3.17	Model does not use PSCAD layer functionality	23		