Appendix C-1

Electromagnetic Transient Modeling Requirements

In support of an Interconnection Request (IR) all equipment-level Electromagnetic Transient (EMT) models must be supplied by the respective Original Equipment Manufacturers (OEM) and combined into a plant-level model[1] by the Interconnection Customer (IC). These models must meet the requirements included in this checklist Sections A, B and C. Each checklist must be accompanied with an equipment Model Quality Attestation[2] (e-MQA) that is submitted by the respective OEM. Additionally, for each IR, the IC shall submit a single plant-level Model Quality Attestation (p-MQA)2 above that covers all equipment-level EMT models and other equipment[3] within the plant.

For the EMT models to be usable by ISO-NE, they must be in a format usable by the PSCAD™/EMTDC™ simulation tool. Any requirement within the checklist that is not met shall be documented with sufficient technical justification and will be subject to review.

Model Quality Attestation (MQA)[4]

Each IR (for which an equipment-level EMT model is provided) must be accompanied by an equipment Model Quality Attestation (e-MQA) from the respective OEM and a plant-level Model Quality Attestation (p-MQA) from the IC. An e-MQA and/or p-MQA shall be provided any time significant changes are made to the model[5] that may affect the performance of the plant. An e-MQA and p-MQA form is provided in Appendix C-1A and Appendix C-1B.

1 A combination of system components (e.g. transformers, cables, auxiliary devices etc.) and unit-level models provided by the inverter and plant-level controller OEMs to represent the expected behavior of the equipment

2 https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline-EMT_Modeling_and_Simulations.pdf

3 Examples of equipment include, but are not limited to, the following: gen-tie line, main power transformers, collector system, generator step-up transformer, coupling or scaling transformers, static reactive power devices, and any other equipment necessary

4 MQA must be provided for the Planned, As-Purchased and As-Built project

5 Significant changes include, but are not limited to, make and model of inverter or controller including software version, control parameters, plant configuration

Checklist for EMT Model

The following model submission summary table and model requirement checklist shall be submitted for each equipment-level EMT model.

EMT Model Submission Summary	
Interconnection Request ID	
Submission date	
Revision Number	
Equipment OEM	
OEM Contact for model related questions	
Technology type (eg. Wind, Solar, BESS, Fuel Cell etc.)	
Equipment Type[6]	
Equipment Model	
Hardware Firmware Version	
EMT Model Release Version and Date	
Model Documentation file(s) (Model User document etc.)	
Model Files supplied (e.g. DLL, lib, obj, txt, etc.)	

[6] Examples of equipment include, but are not limited to, the following: inverter models, plant-level controllers, dynamic reactive power devices, HVDC and any other applicable equipment

A. Model Accuracy Features [7]

In order to be sufficiently accurate, the model provided for each facility shall:

Requirement	Description	Y/N	Provide details if requirement not met or not applicable
1	Represent the full detailed inner control loop of the power electronics. Models 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 manually translated block-by-block from MATLAB or control block diagrams are unacceptable.A full power transistor (e.g. IGBT) representation is the preferred model. Models must embed the actual hardware code into a PSCAD component[8].		
2	An average source representation is strongly discouraged. However, if an average source representation is utilized (e.g., switching frequency greater than 40 kHz), it shall maintain full detail in the inner controls and DC side protection features. Sufficient technical justification must be provided on the usage of an average source representation.		
3	DC side protections, and any current, power or energy limitations that could affect plant ride-through shall be represented in the model. Modelling the DC side with an ideal voltage source is not acceptable if such a representation prevents the possibility of protection operation during external system events.		
4	Represent all pertinent control features as they are implemented in the real controls (e.g. customized PLLs, ride-through controllers, etc.) using actual hardware code.		
5	Represent Power Plant Controller (PPC) as implemented in the real controls and represent the specific controllers used in the plant. This includes automatic voltage regulation, specific measurement methods, and transitions into and out of ride-through modes among others. Generic PPC representations are not acceptable.		

[7] The ISO-NE acknowledges the Electranix Technical Memo which was used to develop ISO-NE's EMT model requirements: http://www.electranix.com/wp-content/uploads/2022/09/PSCAD-Model-Requirements-Rev.-12-Sept-2022.pdf

[8] The controller source code may be compiled into DLLs or binaries if the source code is unavailable due to confidentiality restrictions

Requirement	Description	Y/N	Provide details if requirement not met or not applicable
6	Communication and sample and hold delays between PPC and inverter must be modeled.		
7	Represent common plant controller functionality if there are multiple plants using the same technology or multiple technologies (eg. Hybrid BESS/PV). If supplementary or multiple voltage control devices (eg. STATCOM) are included in the plant, these should be coordinated with the PPC.		
8	Represent Sub Synchronous Oscillation (SSO) mitigation and/or protection including the ability to enable and disable SSO mitigation/protection, if applicable.		
9	Represent shunt capacitor and reactor banks and any dynamic reactive devices. The controls should be modeled if the equipment dynamically responds within 10 seconds following a disturbance.		
10	Represent all pertinent electrical and mechanical configurations, such as filters and specialized transformers. Mechanical features (such as gearboxes, pitch controllers, etc.) should be included in the model if they affect electrical performance. Any control or dynamic features of the actual equipment that may influence behaviour in the simulation period (up to 30 second post-disturbance) but are not represented or are approximated must be clearly identified.		
11	Have all pertinent protections modeled in detail for both balanced and unbalanced fault conditions. Typically, this includes various over-voltage and under-voltage protections (individual phase and RMS), frequency protections, DC bus voltage protections, and overcurrent protection among others. Any protection, which can influence dynamic behavior or plant ride-through in the simulation period (up to 30 second post-disturbance), must be included.		
12	Accurately reflect behavior throughout the valid (MW and MVAR) output range from minimum power through maximum power.		

Requirement	Description	Y/N	Provide details if requirement not met or not applicable
13	Model main power transformer[9] (MPT) and generator step up saturation based upon transformer test reports available. If such data is not available, reasonable approximate data for transformer saturation shall be used and documented[10].		
14	Include detailed representation of any hardware or software filters for the wind turbine controllers, if necessary		
15	The specific implementation of frequency measurement equipment should be modeled. If actual equipment model is not available, a smoothed master library FFT or master library PLL shall be used.		
16	Be configured to match planned (or installed) site-specific equipment settings[11]. Any user-tunable parameters or options must be set in the model to match the equipment at the specific site being evaluated. It is unacceptable to use default parameters.		

B. Model Usability Features

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

Requirement	Description	Y/N	Provide details if requirement not met or not applicable
1	Have pertinent control or hardware options accessible to the user (e.g. adjustable protection thresholds, real power recovery ramp rates frequency or voltage droop settings, voltage control response time).Diagnostic flags (e.g. flags to show control mode changes or which protection has been activated) should be accessible to facilitate analysis and should clearly identify why a model trips during simulations.		

9 The MPT is the power transformer that steps up voltage from the collection system voltage to the nominal transmission/interconnecting system voltage for dispersed power producing resources.

10 Data includes magnetization model, magnetizing current, air-core reactance, knee voltage of winding-limb, loop width and any other relevant information

11 If POI SCR is unknown at the time of model submission, it is recommended to parametrize to a POI level SCR of 3 and X/R of 10 as an approximate representation of a weak system. If studies show a SCR lower than 3, additional model tuning may be required

Requirement	Description	Y/N	Provide details if requirement not met or not applicable
2	Be capable of accurately running for a time step of 10 µs or higher and not be restricted to operating at a single time step but within a range (eg. 10µs - 20 µs).Models requiring a smaller time step may mean that the control implementation has not used the interpolation features of PSCAD[12] or is using inappropriate interfacing between the model and the larger network. Smaller time step will be considered on a case-by-case basis.		
3	Be capable of initializing itself. Models shall initialize and ramp to full 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[13].		
4	Accept external reference values. This includes real and reactive power reference values (for Q control modes), or voltage reference values (for V control modes) and utilize a single parameter for adjusting real power, and separately, a single parameter for adjusting voltage setpoints. Model must accept these reference variables for initialization, and be capable of changing these reference variables mid-simulation, i.e. dynamic signal references.		
5	Allow protection models to be disabled. Many studies result in inadvertent tripping of converter equipment, and the ability to disable protection functions temporarily provides study engineers with valuable system diagnostic information.		
6	Allow the active power capacity of the model to be scaled. This is distinct from a dispatchable power order and is used for modeling different plant capacities (e.g. if a portion of the plant is offline).		
7	Allow the plant to be dispatched at any output within its operating range. If a minimum output is required, sufficient technical justification shall be provided. 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.		

12 If power transistor switching frequency prevents accurate switching representation at 10 µs using interpolation, an average source approximation may be used. See Section A, Requirement 2 for more details.

13 Note that during the first few seconds of simulation (eg. 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.

C. Model 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. The model shall:

Requirement	Description	Y/N	Provide details if model does not meet requirements
1	Be compatible with Intel Fortran compiler versions 15 and higher and be compiled with Visual Studio 2015 or newer.		
2	Be compatible with PSCAD version 4.6.3 and higher.		
3	Initialize to user defined terminal conditions within five seconds of simulation time		
4	Support multiple instances of its own definition in the same simulation case.		
5	Support the PSCAD "snapshot" and "multiple run" feature.		
6	Allow replication in different PSCAD cases or libraries through the "copy" or "copy transfer" features.		
7	Not use or rely upon global variables in the PSCAD environment and not use multiple layers in the PSCAD environment, including 'disabled' layers		
8	Inform the user through messages to the progress output device when the system conditions are beyond plant operational limits or otherwise not consistent with valid operating conditions for the plant.		
10	Show error/status codes[14]		
11	Clearly identify the OEM's EMT model release version and the applicable corresponding hardware firmware version.		

[14] Only those error/status codes which translate into a distinct electrical system response at the low voltage terminals of the unit, for example, normal, fault, stop, low or high voltage ride-through activation, unstable mode identification

D. Accessible Parameters

All models shall allow modification to parameters typically requiring site-specific adjustments. Where applicable, these include:

- All applicable set-points including but not limited to(shall be adjustable before and during a simulation run):
  - Active and Reactive power
  - Voltage and Frequency
  - Power Factor
- Deadband, droop, delays (including communication delays) and slow outer loop controls for any applicable control system such voltage and frequency control
- Active power ramp rate adjustment
- Voltage and frequency protection settings
- Fault ride through activation and deactivation thresholds
- Active and reactive current injection/absorption settings during a fault
- Number of in-service inverters which can be adjusted before and during a simulation run
- Other parameters such as PI gains for inner/outer current/voltage control loops (including PLL, DC link current and voltage control, and any other control loops which can have an impact on system performance)

E. Model Documentation

At a minimum, the EMT model document shall include the following:

1. The specific equipment model(s) for which the provided document is valid
2. Detailed description of all control schemes that respond to voltage or frequency disturbances on the system. These include but not limited to:
   a. Voltage and frequency control
   b. Power factor and/or reactive power control

c. Priority modes and controls including description of voltage and frequency ride-through characteristics such as activation/deactivation thresholds, control mode during ride through etc.

d. Protection schemes and settings for (but not limited to):

   i. Over-and-under-voltage protection

   ii. Over-and-under-frequency protection

   iii. Inter-trip or runback protection scheme

   iv. Any other relevant protections (e.g. frequency rate of change protections)

3. A table of all user-definable settings and status code outputs, range of acceptable values for each user-modifiable variable and a description of each entry's function. An image of the of model instance corresponding to the table must also be provided.
4. A table of all signals fed to the Power Plant Controller such as feedback from inverter, grid measurements, reference set-points etc., parameter unit (specify the base of all per unit parameters) and a description of each entry's function
5. A table of all trip signals and a description of each entry

Appendix C-1A

Equipment Model Quality Attestation (e-MQA) Form

Respective OEM must complete the follow equipment Model Quality Attestation (e-MQA) form

Equipment Model Quality Attestation	
Interconnection Request ID	
Point of Interconnection	
Technology type (Wind, Solar, BESS, Fuel Cell etc)	
Equipment Type[15]	
Equipment OEM	
OEM Attester (Name)	
Equipment Model	
Equipment Software version	
Date of Attestation (mm/dd/yyyy)	
Attestation Revision Number	

Please provide any additional comments here including list of changes since last revision.

Attester Signature

I hereby certify that, to the best of my knowledge, the equipment-level Electromagnetic Transient (EMT) model provided in support of Interconnection Request _____________ has been parametrized to be site specific and meets the requirements listed in Appendix C.

15 Examples of equipment include, but are not limited to, the following: inverter models, plant-level controllers, dynamic reactive power devices, HVDC and any other applicable equipment

Appendix C-1B

Plant-level Model Quality Attestation (p-MQA) Form

The Interconnection Customer (IC) must complete the following plant-level Model Quality Attestation (p-MQA) form

Plant-level Model Quality Attestation			
Interconnection Request ID			
Technology type (Wind, Solar, BESS, Fuel Cell etc)			
Point of Interconnection (POI)			
SCR at POI[16]			
IC Attester (Name)			
Date of Attestation (mm/dd/yyyy)			
Attestation Revision Number			
Equipment OEMs	**Equipment Type[17]**	**Equipment Model**	**Hardware Firmware version**

Please provide any additional comments here including list of changes since last revision.

Attester Signature

I hereby certify that, to the best of my knowledge, the plant-level Electromagnetic Transient (EMT) model provided in support of Interconnection Request _____________ has been parametrized to be site specific and meets the requirements listed in Appendix C.

16 If POI SCR is unknown at the time of model submission, it is recommended to parametrize to a POI level SCR of 3 and X/R of 10 as an approximate representation of a weak system. If studies show a SCR lower than 3, additional model tuning may be required

17 Examples of equipment include, but are not limited to, the following: gen-tie line, main power transformers, generator step-up transformer,inverter models, plant-level controllers, dynamic or static reactive power devices, HVDC and any other applicable equipment