Central Maine Power Inverter-Based Distributed Energy Resource - Source Requirement Documentation

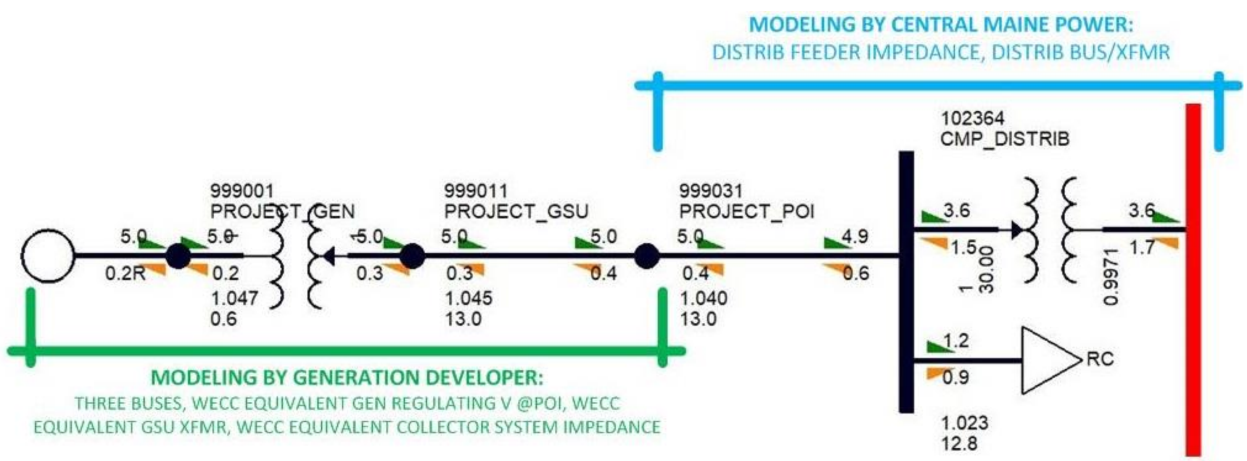
This document is applicable to all inverter-based Distributed Energy Resource (DER) generation connected to the sub-transmission and distribution systems of Central Maine Power (CMP). Testing of equipment will be to the requirements outlined below, and as applicable, follow up on modal accuracy and consistency may be required.

1. PSS/E Steady-State Modeling

The Project's Developer must provide to CMP a PSS/E version 33 **AND** version 34 RAW data file including three (3) buses representing the project up to its Point of Interconnection (POI) (an example is depicted in Figure 1 - Steady-State Model Representation below):

1. A bus representing the low side voltage of the inverters,
2. A bus representing the high side of the equivalent project transformer to distribution feeder voltage,
3. and a bus representing the POI of the Project on the distribution feeder.
4. Bus numbers should be easily discernable from the other parameters in the dynamic's models—suggested bus numbers to be used would be six digits, and above 990000

Figure 1 - Steady-State Model Representation



The steady-state representation of inverter-based DER model must meet the following requirements:

a. Should be set regulating the POI bus voltage (assume 1.04 per unit for the initial submittal—the distribution study analysis will determine the actual setting).
b. Set Pmax to the maximum gross generation from the Project, matching that of the Interconnection Request

c. Set Qmax and Qmin to the maximum capacitive and inductive reactive capability of the equivalent generator when operating at Pmax output
d. If the Project is a Battery Energy Storage facility, a separate generator model with negative Pmax representing charging mode (with Qmax/Qmin at this negative Pmax) should be added to the RAW data file. Use generator ID "G" for the generation mode and "L" (load) for the charging mode.
e. Include the equivalent GSU transformer
f. Include the equivalent collector system line impedance from the high side of the GSU transformer to the Project's POI
g. If the Project has any notable station service to model, include a load at the bus where the station service is expected to be served.

At any point in time, CMP may ask for a newer PSS/E version of the steady state model, or certification that the provided file represents the project correctly in a newer version.

2. PSS/E Dynamics Modeling

The Project's Developer must provide to CMP a PSS/E version 33 **AND** version 34 DYR file representing the dynamics modeling for their project.

The inverter-based DERs dynamic model must be from the standard library models of PSS/E, per Appendix B of **ISO New England Planning Procedure 5-6**. User written models will not be accepted by CMP.

Key dynamic modeling considerations to note:

1. Specific inverter-based DER settings are provided in Section 5 below which must be met at a minimum.
2. Per Section II of **ISO New England Operating Procedure 14**, a Generator (5 MW or larger) must keep and maintain an automatic voltage regulator (AVR) unless granted an exemption.
    a. Also per Section II of **ISO New England Operating Procedure 14**, a Generator with a capability of ten (10) MW or greater must maintain a "functioning governor" which includes hardware or software that provides autonomous frequency-responsive power control.
3. At all times the most stringent SRD requirements between CMP and ISO New England's **Source Requirement Document** must be adhered to.
4. If the Project is a Battery Energy Storage facility, a separate DYR file model would be required for the charging mode "L" generator.
5. CMP's review of data and testing regimen for reporting to ISO New England will include relevant parts of the attached ISO New England **Model Testing Requirements for Model Submittals** document. The Developer and their engineering team may consider choosing to perform some preliminary testing of their modeling in advance of submitting data to CMP, to help reduce the chance of possible model performance problems in CMP's testing.

At any point in time, CMP may ask for a newer PSS/E version of the stability model, or certification that the provided file represents the project correctly in a newer version.

3. Short-Circuit Modeling

The Project's Developer must provide CMP an ASPEN OneLiner CHF file that represents the short circuit characteristics of the project.

The inverter-based DERs short circuit model must adhere to **ISO-NE Planning Procedure 5-6**, **ISO-NE Operating Procedure 16** and **NERC TPL-001** requirements

Furthermore, all Type 4 inverters must be modeled as a Voltage Controlled Current Source (VCCS) in line with ISO-NE OP16 Attachment K. It is expected that any applicable inverter-based DER includes a completed Inverter Generator Short Circuit Data Worksheet (included in Attachment K) with any model submission.

4. PSCAD Modeling

The Project's Developer must provide CMP a PSCAD PSCX file that meets the source requirements within this document and are able to be benchmarked against the stability model provided. The stability model should as closely as possible mimic the PSCAD model such that there is not significant re-work of either inverter-based DER modeling. Appendix 1 should be completed by developer and provided to CMP with model submission.

4.1. For the model to be sufficiently accurate, it must:

A. *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 should 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 recommended type of model.[1]

B. *Represent all control features pertinent to the type of study being done.* Examples include external voltage controllers, plant level controllers, customized PLLs, ride-through controllers, SSCI damping controllers and others. As in point A, actual hardware code is recommended to be used for most

[1] The model must be a full IGBT representation (preferred) or may use an average source representation that approximates the IGBT 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.

control and protection features. Operating modes that require system specific adjustment should be user accessible. Plant level voltage control should be represented along with adjustable droop characteristics. If multiple plants are controlled by a common controller, or if the plant includes multiple types of IBRs (eg. Hybrid BESS/PV) this functionality should be included in the plant control model.

C. *Represent all pertinent electrical and mechanical configurations*. This includes any filters and specialized transformers. There may be other mechanical features such as gearboxes, pitch controllers, or others which should 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 should be clearly identified.

D. *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 should be included. As in point A, actual hardware code is recommended to be used for these protection features.

E. *Be configured to match expected site-specific equipment settings.* Any user-tunable parameters or options should be set in the model to match the equipment at the specific site being evaluated, as far as they are known. Default parameters may not be appropriate.

4.2. Model Usability Features

In order to allow study engineers to perform system analysis using the model, the PSCAD model must:

A. *Have control or hardware options which are pertinent to the study accessible to the user.* Although plant should be configured to match site specific settings as far as they are known (see point E above), parameters pertinent to the study should 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.[2] Diagnostic flags (eg. flags to show control mode changes or which protection has been activated) should be visible to aid in analysis.

B. *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 IGBT switching frequency is so high that even interpolation does not allow accurate switching representation at 10 µs (eg. 40 kHz), an average source approximation of the inverter switching may be used to allow a larger simulation time step[1].

[2] Care should 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 available at the specific site being considered. Discussion is recommended with the manufacturer prior to any changes being made in model configuration.

C. *Operate at a range of simulation time* steps. The model should not be restricted to operating at a single time step but should be able to operate within a range (eg. 10 μs – 20 μs)

D. *Have the ability to disable protection models.* 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.

E. *Include documentation and a sample implementation test case.* Test case models should 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, main step up transformers, gen tie line, and any other static or dynamic reactive resources. Test case should use a single machine infinite bus representation of the system, configured with an appropriate representative SCR[3]. Access to technical support engineers is desirable.

F. *Have an identification mechanism for configuration.* The model documentation should 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.

G. *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 should accept these reference variables for initialization and be capable of changing these reference variables mid-simulation, (i.e. dynamic signal references).

H. *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) should also accept initial condition variables if required. 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 should be able to tolerate these deviations or provide a variable initialization time.

I. *Have the ability to scale plant capacity.* The active power capacity of the model should be scalable in some way, either internally or through an external scaling transformer[4]. 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.

J. *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.

K. *Initialize quickly.* Model must reach its ordered initial conditions as quickly as possible (for example <5 seconds) to user supplied terminal conditions.

[3] 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.

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

4.3. Study Efficiency Features

In addition, the following elements are required to improve study efficiency, model compatibility, and enable other studies which include the model to be run as efficiently as possible. If these features are not supported, additional discussion is required:

L. Model should be compatible with Intel Fortran compiler versions 12 and higher.
M. Model should be compatible with PSCAD version 4.6.3 and higher.
N. Model supports multiple instances of its own definition in the same simulation case.
O. Model supports the PSCAD "timed snapshot" feature accessible through project settings.
P. Model supports the PSCAD "multiple run" feature.
Q. Model does not use or rely upon global variables in the PSCAD environment.
R. Model should not utilize multiple layers in the PSCAD environment, including 'disabled' layers.

5. Source Requirement Document

This Source Requirement Document applies to all inverter-based generation connected to the sub-transmission and/or distribution system of Central Maine Power. All such inverter-based generation must meet the ride through, and trip requirements set forth within this document.

All applicable inverter-based applications shall:

- be certified per the requirements of UL 1741 SA as a grid support utility interactive inverter
- have the voltage and frequency trip settings
- have the abnormal performance capabilities (ride-through)
- comply with other grid support utility interactive inverter functions statuses

5.1. Certification per UL 1741 SA as grid support utility interactive inverters

In the interim period while IEEE P1547.1 is not yet revised and published, certification of all inverter-based applications:

a. shall be compliant with only those parts of Clause 6 (Response to Area EPS abnormal conditions) of IEEE Std 1547-2018 (2nd ed.)1 that can be certified per the type test requirements of UL 1741 SA (September 2016). IEEE Std 1547-2018 (2nd ed.) in combination with this document replaces other Source Requirements Documents (SRDs), as applicable;

5.2. Voltage and frequency trip settings for inverter-based applications

Applications shall have the voltage and frequency trip points specified in Table 1 - Inverters' Voltage Trip Settings and Table 2 - Inverters' Frequency Trip Settings below.

5.3. Abnormal performance capabilities (ride-through) requirements for inverter-based applications

The inverters shall have the ride-through capability per abnormal performance category II of IEEE Std 1547-2018 (2nd ed.) as shown in Table 3 - Inverters' Voltage Ride-Through Capability and Operational Requirements and Table 4 - Inverters' Frequency Ride-Through Capability.

The following additional performance requirements shall apply for all inverters:

a. In the Permissive Operation region above 0.5 p.u., inverters shall ride-through in Mandatory Operation mode, and
b. For voltages below 0.5 p.u. inverters shall ride-through in Momentary Cessation mode with a maximum response time of 0.083 seconds.

Consistent with IEEE Std 1547-2018 (2nd ed.) the following shall apply:

a. DER tripping requirements specified in this SRD shall take precedence over the abnormal performance capability (ride-through) requirements in this section, subject to the following:

1. Where the prescribed trip duration settings for the respective voltage or frequency magnitude are set at least 160 ms or 1% of the prescribed tripping time, whichever is greater, beyond the prescribed ride-through duration, the DER shall comply with the ride-through requirements specified in this section prior to tripping.
2. In all other cases, the ride-through requirements shall apply until 160 ms or 1% of the prescribed tripping time, whichever is greater, prior to the prescribed tripping time.

b. DER ride-through requirements specified in this section shall take precedence over all other requirements within this SRD with the exception of tripping requirements listed in item a. above. Ride-through may be terminated by the detection of an unintentional island. However, false detection of an unintentional island that does not actually exist shall not justify non-compliance with ride-through requirements. Conversely, ride-through requirements specified in this section shall not inhibit the islanding detection performance where a valid unintentional islanding condition exists.

5.4. Other grid support utility interactive inverter functions statuses

Other functions required by UL 1741 SA shall comply with the requirements specified in Table 5 - Grid Support Utility Interactive Inverter Functions Status. For functions not activated by default, the inverter is compliant if tested to the manufacturers stated capability.

5.5. Definitions

The following definitions which are consistent with IEEE Std 1547-2018 (2nd ed.) and UL 1741 SA shall apply:

cease to energize: Cessation of active power delivery under steady state and transient conditions and limitation of reactive power exchange. This may lead to momentary cessation or trip.

clearing time: The time between the start of an abnormal condition and the DER ceasing to energize the utility's distribution circuit(s) to which it is connected. It is the sum of the detection time, any adjustable time delay, the operating time plus arcing time for any interposing devices (if used), and the operating time plus arcing time for the interrupting device (used to interconnect the DER with the utility's distribution circuit).

continuous operation: Exchange of current between the DER and an EPS within prescribed behavior while connected to the utility's distribution system and while the applicable voltage and the system frequency is within specified parameters.

mandatory operation: Required continuance of active current and reactive current exchange of DER with utility's distribution system as prescribed, notwithstanding disturbances of the utility's distribution system voltage or frequency having magnitude and duration severity within defined limits.

momentary cessation: Temporarily cease to energize the utility's distribution system while connected to the utility's distribution system, in response to a disturbance of the applicable voltages or the system frequency, with the capability of immediate restore output of operation when the applicable voltages and the system frequency return to within defined ranges.

Table 1 - Inverters' Voltage Trip Settings

Shall Trip Function	Required Settings		Comparison to IEEE Std. 1547-2018 (2nd ed.) for Category II		
	Voltage (p.u. of nominal voltage)	Clearing Time (s)	Voltage	Clearing Time (s)	Within ranges of allowable settings?
OV2	1.20	0.16	Identical	Identical	Yes
OV1	1.10	2.0	Identical	Identical	Yes
UV1	0.88	2.0	Higher (default is 0.70 p.u.)	Much Shorter (default is 10 s)	Yes
UV2	0.50	1.1	Slightly higher (default is 0.45 p.u.)	Much longer (default is 0.16 s)	Yes

Table 2 - Inverters' Frequency Trip Settings

Shall Trip Function	Required Settings		Comparison to IEEE Std. 1547-2018 (2nd ed.) for Category II		
	Frequency (Hz)	Clearing Time (s)	Frequency	Clearing Time (s)	Within ranges of allowable settings?
OF2	62.0	0.16	Identical	Identical	Yes
OF1	61.2	300.0	Identical	Identical	Yes
UF1	58.5	300.0	Identical	Identical	Yes
UF2	56.5	0.16	Identical	Identical	Yes

Table 3 - Inverters' Voltage Ride-Through Capability and Operational Requirements

Voltage Range (p.u.)	Operating Mode	Minimum ride-through time (s) (design criteria)	Maximum response time (s) (design criteria)	Comparison to IEEE Std. 1547-2018 (2nd ed.) for Category II
V > 1.2	Cease to Energize	N/A	0.16	Identical
1.10 < V ≤ 1.20	Mandatory Operation	2.0	N/A	Identical
0.88 ≤ V ≤ 1.10	Continuous Operation	Infinite	N/A	Identical
0.5 ≤ V < 0.88	Mandatory Operation	2.0	N/A	See footnote a
V < 0.5	Momentary Cessation	1.1	0.083	See footnote b

The following requirements shall apply for all inverters in addition to the abnormal performance category II of IEEE Std 1547-2018 (2nd ed.):

a. For voltages between 0.5 p.u. and 0.88 p.u., inverters shall ride-through in mandatory operation mode.
b. For voltages below 0.5 p.u., inverters shall ride-through in momentary cessation mode with a maximum response time of 0.083 seconds

Table 4 - Inverters' Frequency Ride-Through Capability

Frequency Range (Hz)	Operating Mode	Minimum ride-through time (s) (design criteria)	Comparison to IEEE Std. 1547-2018 (2nd ed.) for Category II
f > 62.0	No ride-through requirements apply to this range		Identical
61.2 < f ≤ 61.8	Mandatory Operation	299	Identical
58.8 ≤ f ≤ 61.2	Continuous Operation	Infinite	Identical
57.0 ≤ f < 58.8	Mandatory Operation	299	Identical
F < 57.0	No ride-through requirements apply to this range		Identical

Table 5 - Grid Support Utility Interactive Inverter Functions Status

Function	Default Activation State
SPF, Specified Power Factor	OFF (OFF and operating at unity PF. OR set to ON with unity PF.
Q(V), Volt-Var Function with Watt or Var Priority	OFF (Default value: 2% of maximum current out per second
SS, Soft-Start Ramp Rate	ON
PW, Freq-Watt Function OFF	OFF

6. Appendix 1 - PSCAD Model Requirements Developer Checklist

This document is a model requirements checklist which should be completed by the supplier of the model and submitted alongside each PSCAD model. This document accompanies the "**Error! Reference source not found.**" document above (PMR), which should be used for further reference to describe the requirements associated with each point. Generic testing of the model may be done using "**Error! Reference source not found.**", which may be used as a reference.

Model supplier must review every item in the checklist and indicate compliance for each item. If the supplied model does not meet any of the requirements an explanation of the deficiency should be provided in the comment's column.

Model Submission Summary (to be completed by model supplier)	
Submission date:	
Project Name:	
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		PMR Reference	Model Complies? (Yes/No)	Comments	Applicability
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.	A, B			Model should include a detailed representation of the actual inverter controls, but real code/validation report requirement may be waived for DER inverters
1.2	Operating modes which require system specific adjustment are accessible.	B			Likely not applicable for DER
1.3	Plant level controller is included.[5]	B			We should ask for them to supply this but it would not have substantial impact to PSCAD study as the DER inverters should be in constant Q/PF control
1.4	Model is capable of controlling frequency[6]	B			May not be required of DER at this time. Even if it is required, it wouldn't have substantial impact on PSCAD studies as we typically don't study loss of large load/generation
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.[7]	C			Required
1.6	All protections which could impact ride-through performance are modelled in detail.	D			Required
1.7	Model is configured for the specific site being evaluated, as far as they are known.	D			Site specific inverter & other relevant controllers (such as PPC model) is required. A single model submission may

[5] If the plant is part of a multi-plant control scheme, a description of the overall scheme should be provided, and corresponding PPC models should be configured to control multiple plants accordingly.
[6] Frequency control model requirements may vary by region. Example response time may be less than 10 seconds.
[7] 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.

					be adequate to model all projects which are using the same inverter model and configuration
2	Model and Project Documentation				
2.1	Model includes documentation.	E			Required
2.2	Documentation includes instruction for setup and running the model.	E			Required
2.3	Model is supplied with a sample test case including site specific plant representation.	E			see note on 1.7 above
2.4	Plant single line diagram is provided, and aligns with model	E			May be helpful
2.5	Model documentation provides a clear way to identify site-specific settings and equipment configuration.	F			Required
3	Model Usability Features				
3.01	Control or hardware options are accessible to the user as applicable.	A			Required
3.02	Diagnostic flags are visible to the user.	A			May be waived on a case-by-case basis
3.03	Model uses a timestep greater than 10 µs.	B			Highly recommended but may be waived on a case-by-case basis
3.04	Model allows a range of simulation timesteps (ie. not restricted to a single timestep).	C			Highly recommended but may be waived on a case-by-case basis
3.05	Protection model may be disabled for troubleshooting	D			May be waived on a case-by-case basis
3.06	Model accepts external reference variables for active and reactive power and voltage setpoint, and these may be changed dynamically during the simulation.	G			At a minimum, the inverter model needs to have the capability to have a variable power and reactive power setpoint accessible
3.07	Model is capable of initializing itself.	H			Required
3.08	Active power capacity is scalable.	I			For DER inverters, it is often preferable to receive a single inverter model and then the study engineer can apply the scaling externally
3.09	Active power is dispatchable.	J			Required
3.10	Model reaches setpoint P, Q, and V in 5 seconds or less	K			Required (for DER, only P & Q setpoints are relevant)

3.11	Model compatible with Intel FORTRAN version 12 and higher.	L			Required
3.12	Model compiles using PSCAD version 4.5.3 or higher.	M			Required
3.13	Model supports multiple instances of its own definition in a single PSCAD case.	N			May be waived
3.14	Model supports PSCAD “snapshot” feature.	O			May be waived
3.15	Model supports the PSCAD “multiple run” feature.	P			May be waived
3.16	Model does not use PSCAD global variables.	V			May be waived, depending on extent of use
3.17	Model does not use PSCAD layer functionality	W			May be waived, depending on extent of use