EVERSOURCE MODEL AND TECHNICAL DATA REQUEST LIST FOR AFFECTED SYSTEM OPERATOR (ASO) TRANSMISSION STUDIES

In preparation for conducting the ASO studies, Eversource would like to provide customers with the list of technical information that will be needed in advance so that customers can begin pulling this information together. All data below will need to be received for each project before the ASO study can commence. It is assumed that all the DER included in the ASO transmission studies are non-FERC.

The modeling and data requests are for studies to support the ISO-NE Level 0 and Level 3 Proposed Plan Application (PPA).

All applications that are greater than 1MW **must provide** a fully working PSCAD model and the following inverter modeling information.

- A stamped one-line diagram, including total project size, GSU information, inverter manufacturer, inverter model name, version, number of inverters and kW rating.
- Presence of 32 or 32R Directional Power Relay to be included in one-line diagram if project has an export or import limit.
- Description of the Battery Energy Storage System (BESS) if the project includes any BESS.
    - If the project includes both BESS and PV how are the BESS and PV connected (AC coupled, or DC coupled)?
    - Can the BESS charge from the grid?
    - Energy Storage System (ESS) Questionnaire, if not submitted with application in powerclerk. A sample ESS questionnaire is included in **Appendix F**: Energy Storage System (ESS) Questionnaire.
- Fully functional PSCAD models of the projects are required. PSCAD model requirements are included in the attached **Appendix C**: PSCAD Model Requirements for the Eversource ASO Study.
- The inverter's frequency and voltage relay trip settings must meet the requirements found in the attached ISO-NE Default New England Bulk System Area Settings Requirement in **Appendix D**: ISO-NE Default New England Bulk System Area Settings Requirement.
- The PSCAD Model supplier checklist is included in **Appendix E**: PSCAD Model Checklist.

EVERSOURCE DATA AND MODEL REQUEST TO SUPPORT ISO-NE LEVEL 0 PPA APPROVAL

1. PROJECT PHYSICAL INFORMATION

- Stamped project one-line diagram (must include inverters)

2. PROJECT MARKET INFORMATION

- Project projected in-service date.
- Project will indicate if it will be a Settlement Only Generator (SOG) or if it intends on participating in the ISO-NE market as a Generator in accordance to ISO-NE designation in OP-14[1].

EVERSOURCE DATA AND MODEL REQUEST FOR STUDY TO SUPPORT ISO-NE LEVEL 3 PPA APPROVAL

1. **PROJECT PHYSICAL INFORMATION**
    - Stamped project one-line diagram (must include inverters)

2. **PROJECT MARKET INFORMATION**
    - Project projected in-service date
    - Project will indicate if it will be a Settlement Only Generator (SOG) or if it intends on participating in the ISO-NE market as a Generator in accordance to ISO-NE designation in OP-14[1].

3. **PROJECT TECHNICAL INFORMATION**
    - Conductor type and distances in mile between inverters/GSUs (collection system)
    - Conductor type and length of dedicated feeder to POI in miles (generator tie-line)
    - Generator step-up (GSU) transformer size (MVA), impedance (%Z), saturation data, winding configuration and X/R ratio
    - GSU transformer number of taps and per unit size of each (typical is +/-2 steps, each at 2.5% or, 0.95, 0.975, 1.0,1.025, 1.05 per unit)
    - Comprehensive project inverter modeling information
        - Description of the Battery Energy Storage System (BESS) if the project includes any BESS.
            - If the project includes both BESS and PV how are the BESS and PV connected (AC coupled, or DC coupled)?
            - Can the BESS charge from the grid?
        - Inverter manufacturer, inverter model name, version and kW rating.
    - Fully functional PSCAD models of the projects are required. PSCAD model requirements are included in the attached **Appendix C**: PSCAD Model Requirements for the Eversource ASO Study.
    - Volt-Var feature enable in the PSCAD model only: Volt-Var feature needs to be enabled/modeled in the project’s PSCAD model. Projects located where the positive sequence resistance from the substation to the point of interconnection is more than 0.0845 ohms, should utilize default volt-var settings given below, or as advised in the system impact study reports. For projects in close proximity to the substation (with a positive sequence resistance less than 0.0845 ohms), it is crucial to adhere to the 'recommended settings' outlined below to ensure proper coordination with the substation LTC

Recommended Volt-VAR Settings		
Parameter	**Default Setting – Source R1 > 0.0845**	**Alternate Setting – Source R1 < 0.0845**
V_{ref}	1.0	1.03
V_1	0.92	0.95
Q_1	25% of nameplate kVA rating, injecting	25% of nameplate kVA rating, injecting
V_2	0.98	0.98
Q_2	0	0.0
V_3	1.02	1.03
Q_3	0	0.0
V_4	1.08	1.05
Q_4	25% of nameplate kVA rating, absorbing	25% of nameplate kVA rating, absorbing
Open Loop Response Time	5s	5s

- The inverter's frequency and voltage relay trip settings must meet the requirements found in the attached ISO-NE Default New England Bulk System Area Settings Requirement in **Appendix D:** ISO-NE Default New England Bulk System Area Settings Requirement
- The PSCAD Model supplier checklist is included in **Appendix E**: PSCAD Model Checklist**.**
- Project inverter modeling information **(>1MW and <5MW only)**
  - Eversource to use the DER_A PSSE inverter stability model
- Project inverter modeling information **(≥5MW projects and single or multiple projects sharing the same POI)**
  - Datasheet and manual
  - Reactive capability curve and/or data tables necessary to create the capability curve when the project output is a maximum (Pmax)
  - Equivalent collection system impedance (per-unit quantity on 100MVA system base)
  - Generator tie-line impedance (per-unit quantity on 100MVA system base)
  - Stability model in PSS/E standard library model format. Note ISO-NE does not accept user- written models.
  - The following PSSE v34 standard library renewable energy system models shall be used to represent the transient stability of inverter-based DER's
  - Renewable Energy Generator/Converter Model: REGC_B
  - Renewable Energy Electrical Model: REEC_D
  - Centralized Plant Controller Model: REPC_A (for standalone PV, BESS and PV+DC coupled BESS), PLNTBU1 + REAX4BU1 (for PV+AC coupled BESS and hybrid-projects which include multiple technologies controlled by a single plant controller)

Project Type	**PSS/E Model Required**				
	REGC_B	**REEC_D**	**REPC_A**	**PLNTBU1**	**REAX4BU1**
Solar PV Only	X	X	X		
BESS Only	X	X	X		
PV+DC-Coupled BESS	X	X	X		
PV+ AC-Coupled BESS	X	X		X	X

  - Stability models must consist of the types listed in the latest version of the NERC List of Acceptable Models for Interconnection-Wide Modeling, as required by the ISO

New England Compliance Bulletin MOD-032 dated September, 2022[2]. The NERC list of Acceptable Renewable Energy Resource Models as of June 8, 2021 is listed in **Appendix A**: NERC List of Acceptable Renewable Energy Resource Models as of 06/08/2021.

- The PSS/E stability model parameters are listed in **Appendix B**: PSS/E Stability Model Parameters**.**
- The stability model must include accurate voltage and frequency control parameters if the voltage and frequency control functions of the model are enabled according to DER planning's requirement.
- A benchmarking report between PSSE and PSCAD is required. Benchmarking requirements are included in the attached **Appendix G.**

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[1] ISO New England Operating Procedure No. 14 - Technical Requirements for Generators, Demand Response Resources, Asset Related Demands and Alternative Technology Regulation Resources

[2] https://iso-ne.com/static-assets/documents/2015/06/iso_new_england_compliance_bulletin_mod_032.pdf

Appendix A: NERC List of Acceptable Renewable Energy Resource Models as of 06/08/2021

The most-up-to-date list of NERC Acceptable Models can be found at: https://www.nerc.com/pa/RAPA/ModelAssessment/Documents/Acceptable%20Models%20List%E2%80%8B.xlsx

Appendix B: PSS/E Stability Model Parameters

REGC_B Model Parameters - Model parameters are specified in per unit of machine MVA base

Parameter	Typical Values or range of value*	Description	Notes
RateFlag	0 or 1	0: rate limit on active current, 1: rate limit on active power	
PQFlag	0 or 1	PQ priority Flag; 0: Q priority, 1: P priority	PQFlag value must match the PQFlag value used in the REEC_D Model
Tg	0.02	Tg (sec), Converter time constant (> 0)	
Tfltr	0.02	Tfltr(sec), Voltage filter time constant	
Iqrmax	1 - 999	Iqrmax (pu/s), Upper limit on rate of change for reactive current (> 0)	DER are not allowed to control voltage in PSSE stability model. Hence, parameters are not relevant
Iqrmin	-1 - -999	Iqrmin (pu/s), Lower limit on rate of change for reactive current (< 0)	
rrpwr	Inverter Specific	rrpwr (pu/s), ramp rate for real power increase (or decrease for the case of battery in charging mode) following a fault (> 0)	This must be set to inverters actual ramp rate and must be at least 2 pu/s as per IEEE 1547 standard.
Te	0.01	Te (s), time constant to model inner control loops	
Imax	1.0 – 1.5	Imax (pu), Maximum current rating of the converter (> 0)	Imax value must match the Imax value used in the REEC_D Model

* Typical Values are provided only for reference purposes and should not be interpreted as values that must be strictly used

REEC_D Model Parameters - Model parameters are specified in per unit of machine MVA base

Parameter	Typical Values or range of value*	Description	Notes
PFFlag	0 or 1	PFFLAG: • 1 if power factor control • 0 if Q control (which can be controlled by an external signal)	Must be set to 0 when using a plant controller model
VFlag	0 or 1	VFLAG: • 1 if Q control • 0 if voltage control	This flag is irrelevant when QFLAG is set to 0
QFlag	0 or 1	QFLAG: • 1 if voltage or Q control • 0 if constant pf or Q control	Must be set to 0 as DER's are not allowed to control voltage under normal operating conditions
PFlag	0 or 1	PFLAG: • 1 if active current command has speed dependency • 0 for no dependency	Must be set to 0 as there is no speed dependency
PQFlag	0 or 1	PQFLAG: • 1 for P priority • 0 for Q priority	PQFlag value must match the PQFlag value used in the REGC_B Model
VcmpFlag	0 or 1	PQFLAG: • 1 for current compensation • 0 for reactive droop compensation	This flag is irrelevant when QFLAG is set to 0
Vdip	<0.88	Vdip (pu), low voltage threshold to activate reactive current injection logic	
Vup	>1.1	Vup (pu), Voltage above which reactive current injection logic is activated	
Trv	0.02	Trv (s), Voltage filter time constant	
dbd1	-0.1 - 0	dbd1 (pu), Voltage error dead band lower threshold (≤0)	Inverter specific values to be used if inverter provides dynamic voltage support in the low voltage mandatory operation region
dbd2	0 - 0.1	dbd2 (pu), Voltage error dead band upper threshold (≥0)	
Kqv	Inverter Specific	Kqv (pu), Reactive current injection gain during over and undervoltage conditions	

Parameter	Typical Values or range of value*	Description	Notes
Iqh1	1	Iqh1 (pu), Upper limit on reactive current injection Iqinj	
Iql1	-1	Iql1 (pu), Lower limit on reactive current injection Iqinj	
Vref0	0	Vref0 (pu), User defined reference (if 0, model initializes it to initial terminal votlage)	
Iqfrz	0	Iqfrz (pu), Value at which Iqcmdbl (value of Iqcmd before limit) is held for Thld seconds after a voltage dip is over	
Thld	0	Thld (s), Time for which Iqcmdbl is frozen after the voltage dip is over	
Thld2	Inverter Specific	Thld2 (s) (≥0), Time for which Ipcmd and Ipmax are frozen after the voltage dip is over	
Tp	0.02	Tp (s), Filter time constant for electrical power	Inverter Specific
Qmax	0.4 - 1	QMax (pu), Maximum value of the signal Qext or Vext	Qmax and Qmin should be reflective of DER reactive power capability
Qmin	-1 – - 0.4	QMin (pu) Minimum value of the signal Qext or Vext	
VMAX	Controller Specific	VMAX (pu), Maximum limit for voltage control	These values are irrelevant when QFLAG is set to 0
VMIN	Controller Specific	VMIN (pu), Minimum limit for voltage control	
Kqp	Controller Specific	Kqp (pu), Reactive power regulator proportional gain	
Kqi	Controller Specific	Kqi (pu), Reactive power regulator integral gain	
Kvp	Controller Specific	Kvp (pu), Voltage regulator proportional gain	

Parameter	Typical Values or range of value*	Description	Notes
Kvi	Controller Specific	Kvi (pu), Voltage regulator integral gain	
Vbias	0	Vbias (pu), User-defined bias (normally 0)	
Tiq	0.02	Tiq (s), Time constant on delay for block s4	
dPmax	0 - 999	dPmax (pu/s) (>0) Power reference maximum ramp rate	
dPmin	-999 - 0	dPmin (pu/s) (<0) Power reference minimum ramp rate	
PMAX	1	PMAX (pu), Maximum power limit	
PMIN	0 (PV)/ -1 (BESS)	PMIN (pu), Minimum power limit	
Imax	1.0 - 1.5	Imax (pu), Maximum limit on total converter current	Imax value must match Imax parameter in the REGC_B model
Tpord	0.02	Tpord (s), Power filter time constant	
Vq1 – 10	Inverter Specific	Vq1 - 10 (pu), VDL table vq-iq pair (voltage)	
Iq1 – 10	Inverter Specific	Iq1 - 10 (pu), VDL table vq-iq pair (current)	
Vp1 – 10	Inverter Specific	Vp1 - 10 (pu), VDL table vp-ip pair (voltage)	
Ip1 – 10	Inverter Specific	Ip1 - 10 (pu), VDL table vp-ip pair (current)	
rc	N/A	rc (pu), Current compensation resistance	Parameter is irrelevant since QFLAG is set to 0
Xc	N/A	Xc (pu), Current compensation reactance	
Tr1	N/A	Tr1 (s), Time constant for reactive current compensation	
Kc	N/A	Kc, Reactive current compensation gain	
Ke	0 - 1	Ke, Scaling on Ipmin, (0 for generator, 0<Ke≤ 1 for storage)	
Vblkl	0.5	Vblkl (pu), Voltage below which converter will block	Trigger momentary cessation when voltage drops below 0.5 pu

Parameter	Typical Values or range of value*	Description	Notes
Vblkh	1.1	Vblkh (pu), Voltage above which converter will block	Trigger momentary cessation when voltage crosses 1.1 pu
Tblk	0.1	Tblk (s), time for which converter will remain blocked after voltage is within the range Vblkl < Vt_filt < Vblkh	Converter deblock delay after exiting momentary cessation

* Typical Values are provided only for reference purposes and should not be interpreted as values that must be strictly used.

REPC_A Model Parameters - Model parameters are specified in per unit of machine MVA base

To be used for stand-alone PV, BESS and DC coupled PV+BESS

Parameter	Typical Values or range of value*	Description	Notes
Bus Num		Bus number for voltage control; local control if 0	Set to 0 to maintain specific reactive power for constant power factor at the generator terminal
Branch Bus Num From		Monitored branch FROM bus number for line drop compensation (if 0 generator power will be used)	
Branch Bus Num To		Monitored branch TO bus number for line drop compensation (if 0 generator power will be used)	
Branch Ckt Id		Branch circuit id for line drop compensation	
VCFlag	0 or 1	VCFlag: • 1 with line drop compensation • 0 with droop if power factor control	Irrelevant if RefFlag is 0
RefFlag	0 or 1	RefFLAG: • 0 Q control • 1 voltage control	Set to 0 for Q control to maintain the generator reactive power from the power flow case resulting in constant power factor at the generator terminal
Fflag	1	Fflag: • 0 disable • 1 enable control	Must be set to 1 to enable frequency control

Parameter	Typical Values or range of value*	Description	Notes
Tfltr	0.02	Tfltr, Voltage or reactive power measurement filter time constant (s)	
Kp	Controller Specific	Kp, Reactive power PI control proportional gain (pu)	
Ki	Controller Specific	Ki, Reactive power PI control integral gain (pu)	
Tft	0	Tft, Lead time constant (s)	
Tfv	0.02	Tfv, Lag time constant (s)	
Vfrz	< 0.9	Vfrz, Voltage below which State s2 is frozen (pu)	
Rc	0	Rc, Line drop compensation resistance (pu)	Parameters are irrelevant if RefFlag is set to 0
Xc	0	Xc, Line drop compensation reactance (pu)	
Kc	Controller Specific	Kc, Reactive current compensation gain (pu)	
emax	999	emax, upper limit on deadband output (pu)	
emin	-999	emin, lower limit on deadband output (pu)	
dbd1	-0.01	dbd1, lower threshold for reactive power control deadband (<=0)	
dbd2	0.01	dbd2, upper threshold for reactive power control deadband (>=0)	
Qmax	0 – 0.4	Qmax, Upper limit on output of V/Q control (pu)	
Qmin	-0.4 - 0	Qmin, Lower limit on output of V/Q control (pu)	
Kpg	Controller Specific	Kpg, Proportional gain for power control (pu)	
Kig	Controller Specific	Kig, Integral gain for power control (pu)	
Tp	0.02	Tp, Real power measurement filter time constant (s)	

Parameter	Typical Values or range of value*	Description	Notes
fdbd1	-0.0006	fdbd1, Deadband for frequency control, lower threshold (specified as per unit frequency deviation) (<=0)	36mHZ standard dead band (36mHz/60Hz)
fdbd2	0.0006	fdbd2, Deadband for frequency control, upper threshold (specified as per unit frequency deviation) (>=0)	36mHZ standard dead band (36mHz/60Hz)
femax	999	femax, frequency error upper limit (pu)	
femin	-999	femin, frequency error lower limit (pu)	
Pmax	1	Pmax, upper limit on power reference (pu)	
Pmin	0 or -1	Pmin, lower limit on power reference (pu)	Set 0 for non-BESS, non-AC coupled BESS Set -1 for BESS, AC coupled BESS
Tg	0.02	Tg, Power Controller lag time constant (s)	
Ddn	Controller Specific	Ddn, reciprocal of droop for over-frequency conditions (pu)	Standard droop setting is 5%. Set as 20
Dup	Controller Specific	Dup, reciprocal of droop for under-frequency conditions (pu)	Standard droop setting is 5%. Set as 20

* Typical Values are provided only for reference purposes and should not be interpreted as values that must be strictly used.

PLNTBU1 Model Parameters - Model parameters are specified in per unit of system MVA base

PLNTBU1 model to be used in conjunction with REAX4BU1 model for AC couples PV+BESS.

Parameter	Typical Values or range of value*	Description	Notes
Bus Num		Bus number for voltage control; local control if 0	Set to 0 to maintain specific reactive power for constant power factor at the generator terminal
Branch Bus Num From		Monitored branch FROM bus number for line drop compensation (if 0 generator power will be used)	

Parameter	Typical Values or range of value*	Description	Notes
Branch Bus Num To		Monitored branch TO bus number for line drop compensation (if 0 generator power will be used)	
Branch Ckt Id		Branch circuit id for line drop compensation	
VCFlag	0 or 1	VCFlag: • 1 with line drop compensation • 0 with droop if power factor control	Irrelevant if RefFlag is 0
RefFlag	0 or 1	RefFLAG: • 0 Q control • 1 voltage control	Set to 0 for Q control to maintain the generator reactive power from the power flow case resulting in constant power factor at the generator terminal
Fflag	0 or 1	Fflag: • 0 disable • 1 enable control	Must be set to 1 to enable frequency control
Tfltr	0.02	Tfltr, Voltage or reactive power measurement filter time constant (s)	
Kp	Controller Specific	Kp, Reactive power PI control proportional gain (pu)	
Ki	Controller Specific	Ki, Reactive power PI control integral gain (pu)	
Tft	0.01	Tft, Lead time constant (s)	
Tfv	0.02	Tfv, Lag time constant (s)	
Vfrz	< 0.9	Vfrz, Voltage below which State s2 is frozen (pu)	
Rc	0	Rc, Line drop compensation resistance (pu of SBASE)	Parameters are irrelevant if RefFlag is set to 0
Xc	0	Xc, Line drop compensation reactance (pu of SBASE)	
Kc	0	Kc, Reactive current compensation gain (pu)	
Emax	999	Emax, Upper limit on deadband output (pu)	
Emin	-999	Emin, Lower limit on deadband output (pu)	
dbd1	-0.01	DBD1, Lower threshold for reactive power control deadband (<=0)	

Parameter	Typical Values or range of value*	Description	Notes
dbd2	0.01	DBD2, Upper threshold for reactive power control deadband (>=0)	
Qmax	0 - 0.4	Qmax, Upper limit on output of V/Q control (pu)	
Qmin	-0.4 - 0	Qmin, Lower limit on output of V/Q control (pu)	
Kpg	Controller Specific	Kpg, Proportional gain for power control (pu)	
Kig	Controller Specific	KIG, Integral gain for power control (pu)	
Tp	0.02	TP, Real power measurement filter time constant (s)	
Fdbd1	-0.0006	FDBD1, Deadband for frequency control, lower threshold	36mHZ standard dead band (36mHz/60Hz)
Fdbd2	0.0006	FDBD2, Deadband for frequency control, upper threshold	36mHZ standard dead band (36mHz/60Hz)
Femax	999	FEMAX, Frequency error upper limit (pu)	
Femin	-999	FEMIN, Frequency error lower limit (pu)	
Pmax	Project Specific	PMAX, Upper limit on power reference (pu)	Must be greater of either PV or BESS MVA rating on 100MVA base
Pmin	Project Specific	PMIN, Lower limit on power reference (pu)	Set 0 for non-BESS, non-AC coupled BESS Set -1 for BESS, AC coupled BESS
Tg	0.02	TG, Power Controller lag time constant (s)	
Ddn	Controller Specific	DDN, Reciprocal of droop for over-frequency conditions	Standard droop setting is 5%. Set as 20
Dup	Controller Specific	DUP, Reciprocal of droop for under-frequency condition	Standard droop setting is 5%. Set as 20
MVA_P		MVA_P, Plant Controller MVA base - (Note 1)	If set to 0, model parameters are assumed on 100MVA base

* Typical Values are provided only for reference purposes and should not be interpreted as values that must be strictly used.

REAX4BU1 Model Parameters

To be used for AC coupled BESS projects and model parameters are in per unit of machine MVA base.

Parameter	Typical Values or range of value*	Description	Notes
Bus Num		Bus Number at which the Plant controller Model is attached	
Tw1	Inverter Specific	Tw1 (s), Measurement time constant	
Kw1		Kw1 (pu on MBASE), Gain for signal in reactive path	
Kp1		Kp1 (pu on MBASE), Gain for signal in real path	
Wmax		Wmax (pu), Maximum value of W01	
Wmin		Wmin (pu), Minimum value of W01	
Pmax	1	Pmax (pu), Maximum value of P01	
Pmin	0 or -1	Pmin (pu), Minimum value of P01	Set 0 for PV Set -1 for BESS

* Typical Values are provided only for reference purposes and should not be interpreted as values that must be strictly used.

Voltage and Frequency Protection Model Settings

The following trip setting parameters are explained in more detail in the Default New England Bulk System Area Settings Requirements in **Appendix D**: ISO-NE Default New England Bulk System Area Settings Requirement.

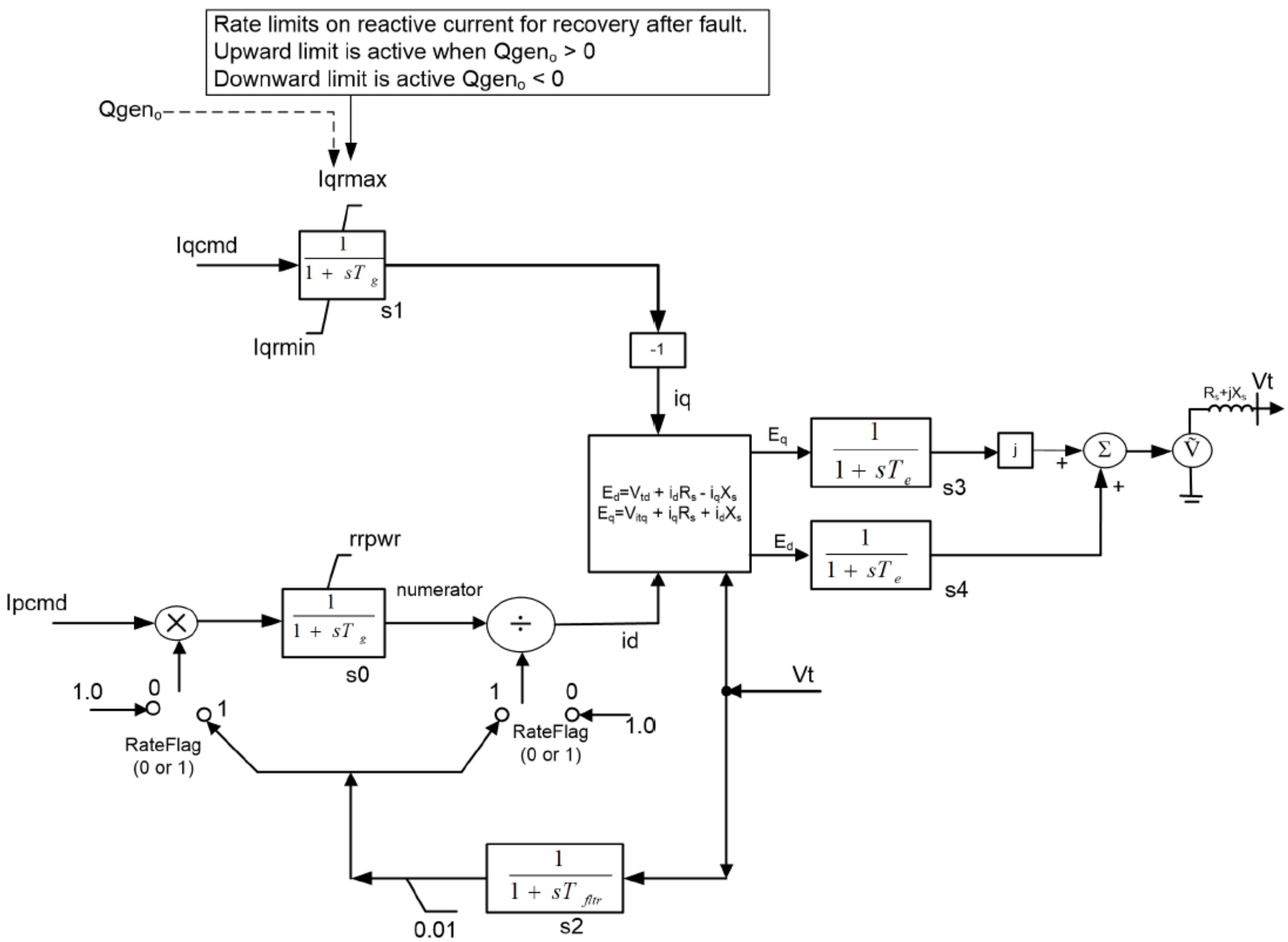
Parameter	Model	Value	Description
VL	VTGTPAT	0	Over voltage trip setpoints
VU		1.2	
TP		0.16	
VL	VTGTPAT	0	
VU		1.1	
TP		2	
VL	VTGTPAT	0.88	Under voltage trip setpoints
VU		999	
TP		3	
VL	VTGTPAT	0.5	
VU		999	
TP		1.1	
FL	FRQTPAT	0	Over frequency trip setpoints
FU		62	
TP		0.16	
FL	FRQTPAT	58.5	Under and over frequency trip setpoints
FU		61.2	

Parameter	Model	Value	Description
TP		300	
FL	FRQTPAT	56.5	Under frequency trip setpoints
FU		999	
TP		0.16	

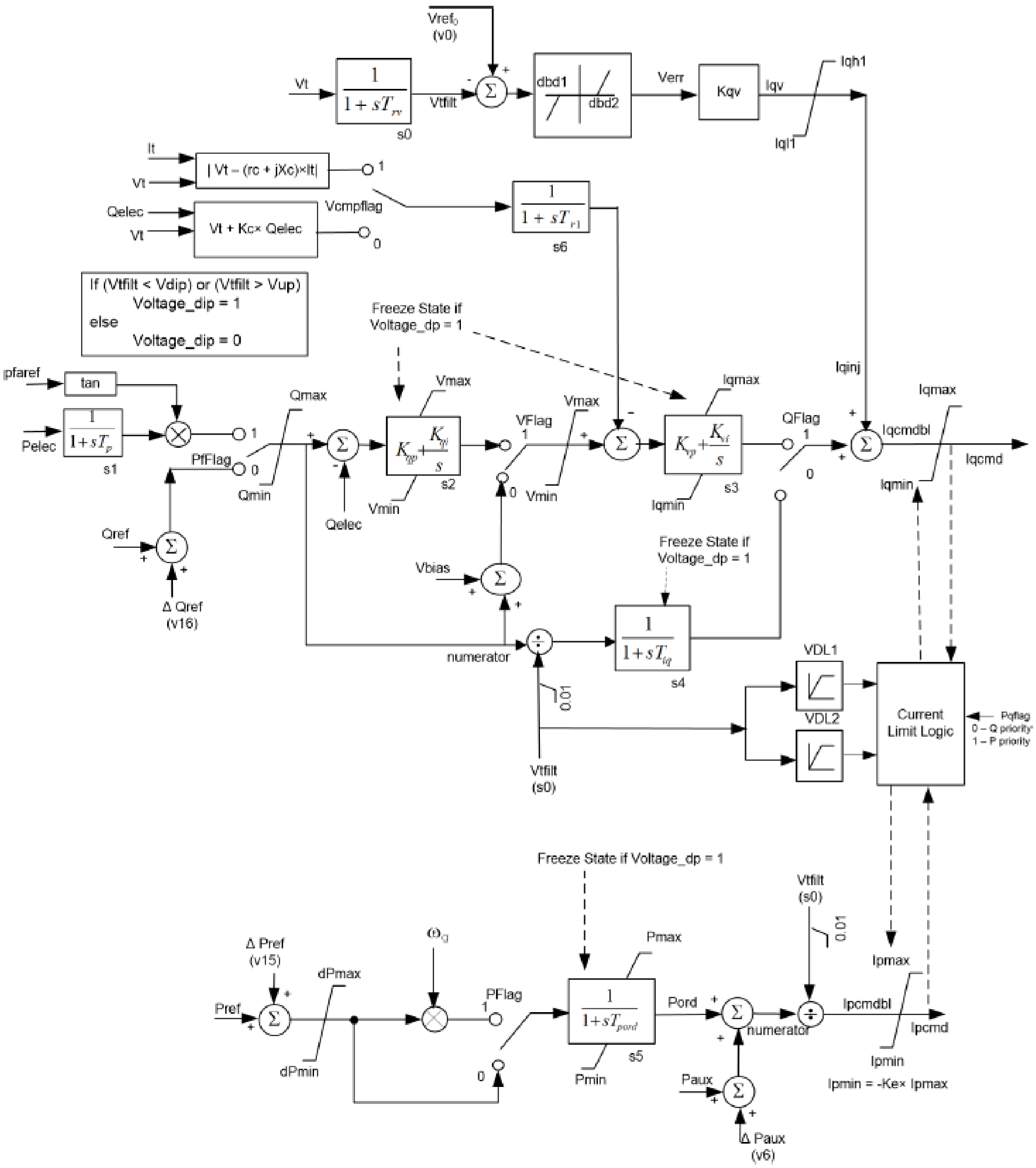
PSS/E Stability Model Block Diagrams

All block diagrams shown below originated from the PSSE Model Library.

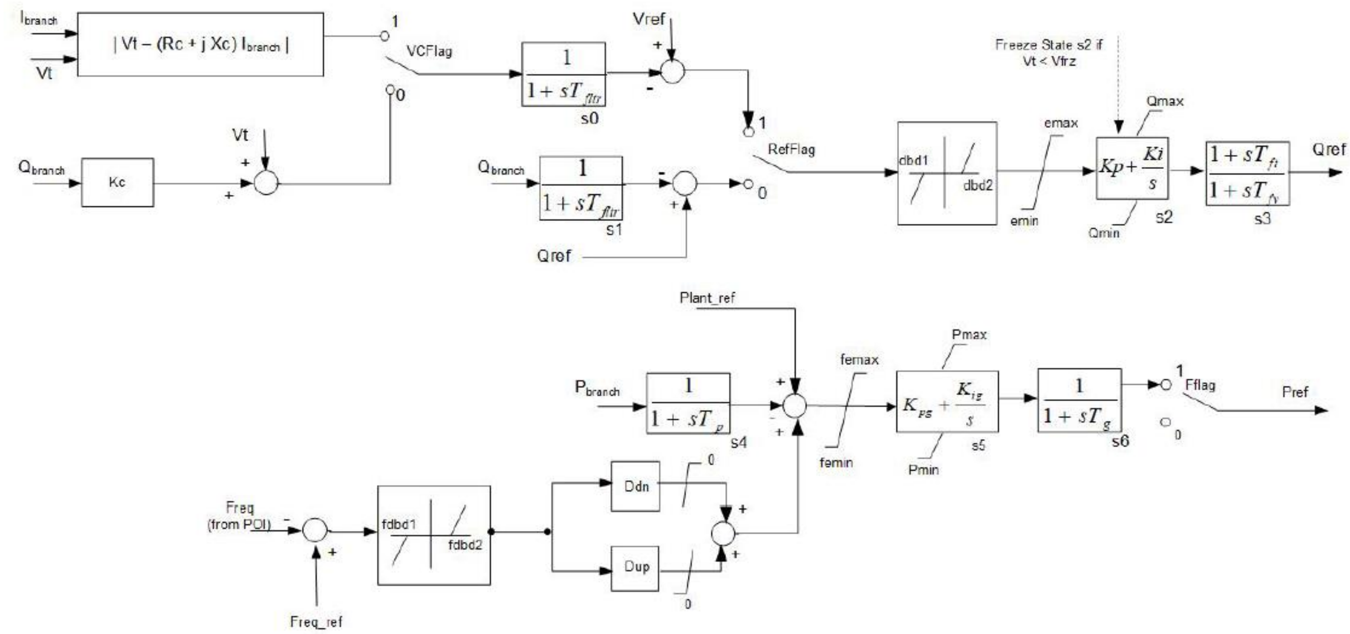
REGC_B Model Block Diagram



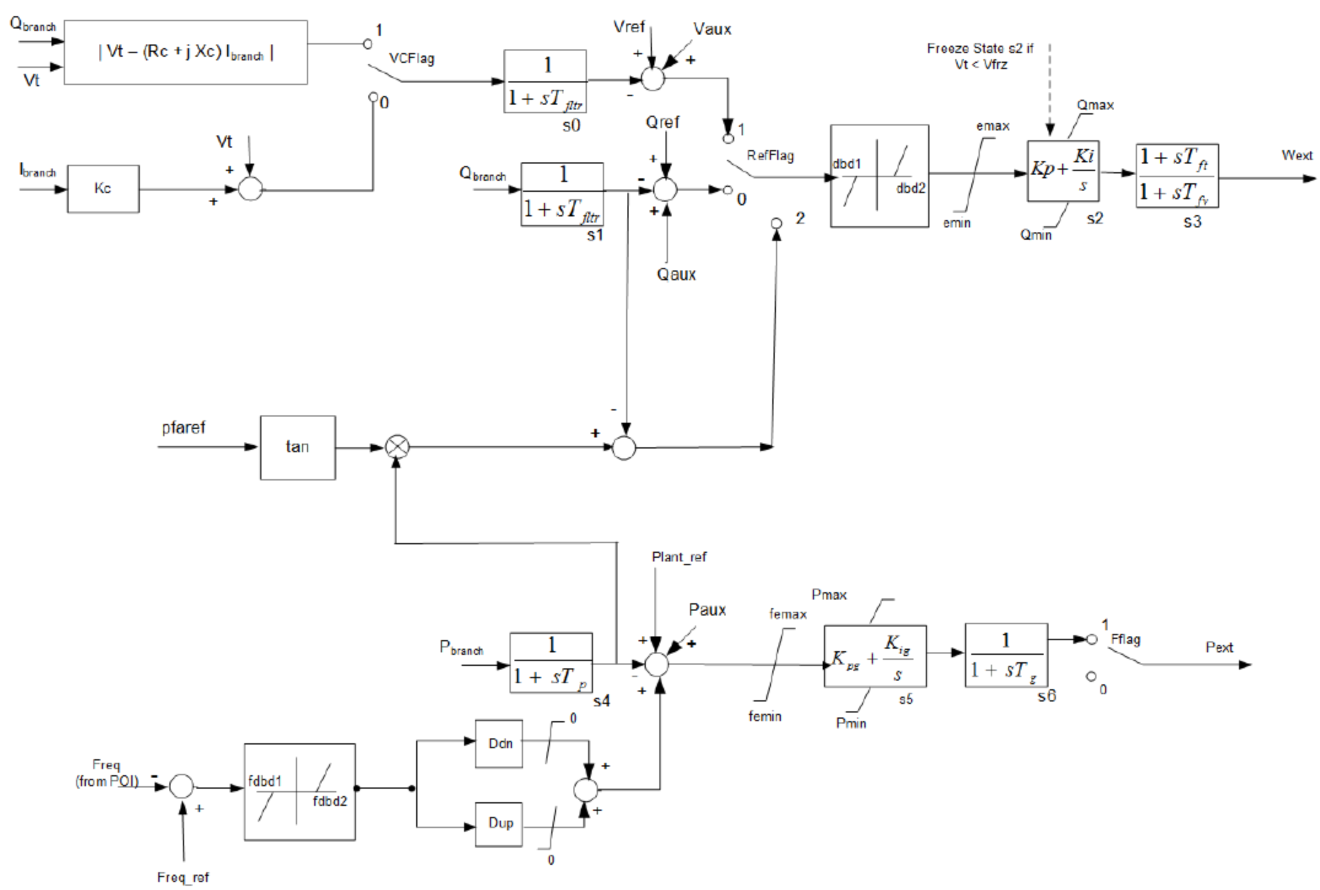
REEC_D Model Block Diagram



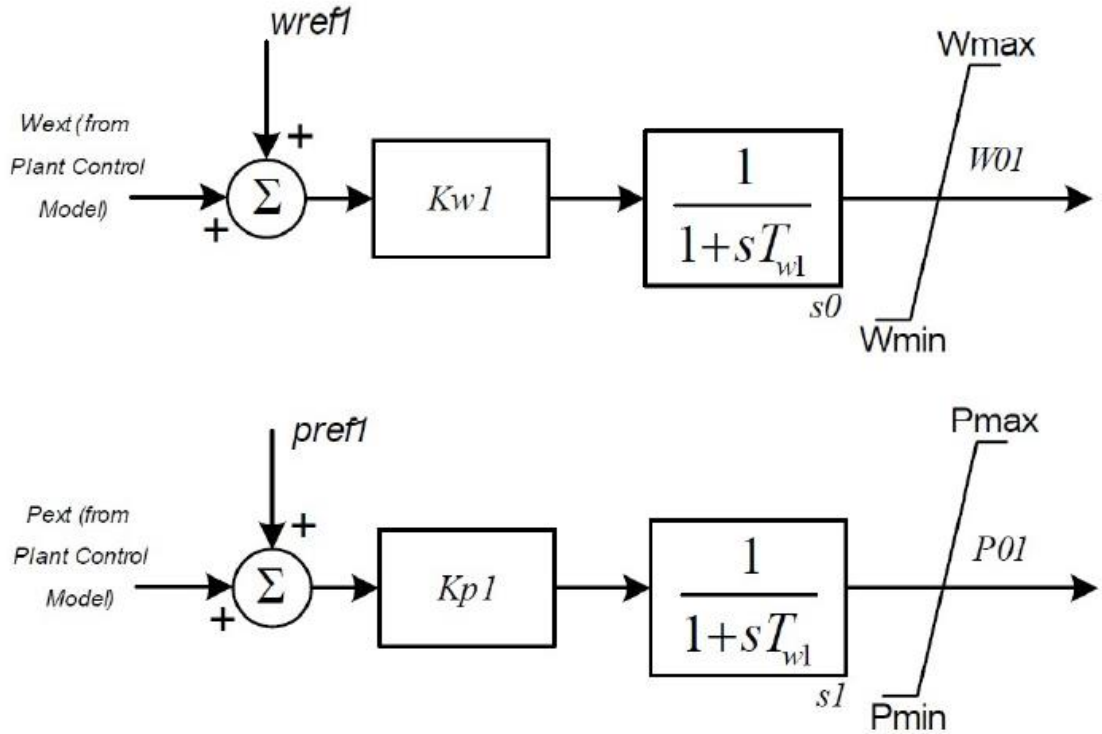
REPC_A Model Block Diagram



PLNTBU1 Model Block Diagram



REAX4BU1 Model Block Diagram



Appendix C: PSCAD Model Requirements for the Eversource ASO Study

General:

1. The developer/manufacturer of each DER project is responsible for providing a PSCAD model of the DER inverter, that meets all requirements listed in this document.

2. It is strongly encouraged that the developer of the DER project require the manufacturer to provide this PSCAD model of the inverter.

3. The developer/manufacturer is responsible for developing the “test case” referred to in Section ***Inverter Model Usability Features requirement,*** paragraph “**I**” of this document.

4. In addition to the PSCAD model for the inverter itself, the developer must provide the following data for the rest of the facility:

   a. Single line diagram of the facility
   b. Winding configuration of GSU transformer (e.g. 0.6/13 kV transformer on each inverter)
   c. Impedance of GSU transformer with MVA Base
   d. GSU Transformer Saturation Data
   e. Whether or not GSU is included in inverter PSCAD model
   f. Winding configuration of Plant transformer (e.g. 13 kV/34 kV transformer if one exists)
   g. Impedance of Plant transformer with MVA Base
   h. Shunt capacitor size (MVAr) and number (if any)
   i. DVAR size (MVAr) and number (if any)
   j. Controller details for DVAR and Shunt Capacitor coordination (if any)

Inverter Model Accuracy Features:

This section is based on ‘PSCAD Model Requirements Rev 12’ by Electranix Corporation and is modified by Eversource.

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 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 required type of model.[4,5]

[4] The model must be a full power transistor (eg. IGBT) representation (preferred), or use an average source representation that approximates the 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 should 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.

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

B. *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 and others. As in point A, actual hardware code is required to be used for most control and protection features. Operating modes that require system specific adjustment must be user accessible.

C. *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 behaviour. 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 (eg. Hybrid BESS/PV) this functionality must be included in the plant control model. If supplementary or multiple voltage control devices (eg. STATCOM) are included in the plant, these should be coordinated with the PPC.

D. *Represent the volt-var control (DERs >= 5MW) in the plant level control.* DERs greater than 5 MW need to have the volt-var scheme enabled. The volt-var scheme must be represented in the Power Plant Control (PPC) block for the plant and not in the individual inverters of the plant. This will ensure that the requirements are met at the high side of GSU or at the POI. Appropriate volt var settings based on the positive sequence impedance from the feeder head needs to be implement.

E. *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.

F. *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. Actual hardware code is recommended to be used for these protection features.

G. *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 may not be appropriate unless these will match the configuration in the installed equipment.

Inverter Model Usability Features:

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

H. *Have control or hardware options which are pertinent to the study accessible to the user.* Although plant must be configured to match site specific settings as far as they are known (see point F above), 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.[6] Diagnostic flags (eg. flags to show control mode changes or which protection has been activated) should be visible to aid in analysis.

I. *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 (eg. IGBT) switching frequency is so high that even interpolation does not allow accurate switching representation at 10 µs (eg. switching frequency greater than 40 kHz), an average source approximation of the inverter switching may be used to allow a larger simulation time step[4].

J. *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 (eg. 10 µs – 20 µs)

K. *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, main plant transformers, gen tie line, power plant controller, and any 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[7]. Access to technical support engineers is desirable. Additional detail on required documentation and test case is described in PSCAD Model Test Checklist **Appendix E**: PSCAD Model Checklist.

L. *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.

M. *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, ie. dynamic signal references.

N. *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 (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.

O. *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[8]. 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.

P. *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 behaviour at various operating points.

Q. *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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[6] 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.

[7] 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.

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

Study Efficiency Features:

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.

- **R.** Model must be compatible with Intel Fortran compiler versions 15 and higher.[9]
- **S.** Model must be compatible with PSCAD version 4.6.3 and higher.
- **T.** Model must support multiple instances of its own definition in the same simulation case.
- **U.** Model must support the PSCAD “timed snapshot” feature accessible through project settings.
- **V.** Model must support the PSCAD “multiple run” feature.
- **W.** Model must not use or rely upon global variables in the PSCAD environment.
- **X.** Model must not utilize multiple layers in the PSCAD environment, including ‘disabled’ layers.
- **Y.** Model must be compiled with Visual Studio 2015 or newer[10]

[9] Models compiled using PSCAD with Intel Fortran 12 or 14 will use Visual Studio 2010 or 2013 which may cause compiler conflicts when those models are used in combination with models built with Intel Fortran 15 and newer. If Intel Fortran 12 or 14 support is required, it is recommended to compile both an Intel Fortran 12 to 14 model and an Intel Fortran 15 and newer model for maximum compatibility.

[10] Older models which were compiled using Intel Fortran 12 may not be compatible with Visual Studio versions 2015 or newer. In this case older versions of Visual Studio may be needed.

Appendix D: ISO-NE Default New England Bulk System Area Settings Requirement

The ISO-NE Default New England Bulk System Area Settings Requirements can be found here: https://www.eversource.com/content/docs/default-source/builders-contractors/ISO_NE_Default_NE_Bulk_System_Area_Settings.pdf

Appendix E: PSCAD Model Checklist

This document is a model requirements checklist which must be completed by the supplier of the model and submitted alongside each PSCAD model. Model suppliers 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 must be provided in the comments 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: (eg. PV or BESS)	
Equipment version:	
Documentation file(s):	
Model Files supplied:	

Model Requirements Checklist		Reference	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)	A,B		
1.2	Operating modes which require system specific adjustment are accessible.	B		
1.3	Plant level controller is included according to inverter model accuracy features.[11]	C		
1.4	Model is capable of controlling frequency[12]	B,C		
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.[13]	D		
1.6	All protections which could impact ride-through performance are modelled in detail and adhrere to ISO-NE Default Bulk System Area Settings Requirement.	E		
1.7	Model is configured for the specific site being evaluated, as far as they are known.	F		
2	*Model and Project Documentation*			
2.1	Model includes documentation.	J		
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 conflict with model version shown in the .pscx case file.	J		
2.3	Model is supplied with a sample test case including site specific plant representation.	J		
2.4	Plant single line diagram is provided, and aligns with model	J		
2.5	Model documentation provides a clear way to identify site-specific settings and equipment configuration.	K		

3	*Model Usability Features*			
3.01	Control or hardware options are accessible to the user as applicable.	G		
3.02	Diagnostic flags are visible to the user.	G		
3.03	Model uses a timestep greater than 10 µs.	H		
3.04	Model allows a range of simulation timesteps (ie. not restricted to a single timestep).	I		
3.06	Model accepts external reference variables for active and reactive power and voltage setpoint, and these may be changed dynamically during the simulation.	L		
3.07	Model is capable of initializing itself.	M		
3.08	Active power capacity is scalable.	N		
3.09	Active power is dispatchable.	O		
3.10	Model reaches setpoint P, Q, and V in 5 seconds or less	P		
3.11	Model compatible with Intel FORTRAN version 15 and higher.	Q		
3.12	Model compiles using PSCAD version 4.5.3 or higher.	R		
3.13	Model supports multiple instances of its own definition in a single PSCAD case.	S		
3.14	Model supports PSCAD "snapshot" feature.	T		
3.15	Model supports the PSCAD "multiple run" feature.	U		
3.16	Model does not use PSCAD global variables.	V		
3.17	Model does not use PSCAD layer functionality	W		
3.18	Model is compiled using MS Visual Studio v.2015 or newer	X		

[11] 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.
[12] Frequency control model requirements may vary by region. Example response time may be less than 10 seconds.
[13] 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.

Appendix F: Energy Storage System (ESS) Questionnaire

The ESS Questionnaire can be found here:
https://www.eversource.com/content/docs/default-source/builders-contractors/ESS_Questionnaire.xlsx

Appendix G: Benchmarking reports for DER projects >=5MW

Benchmarking- Compare the voltage, active power (P), and reactive power (Q) at the terminal bus of the project and the point of interconnection (POI) bus for the following tests. All tests will be conducted using a generic source impedance for testing, flat-run and ringdown tests should be performed with a short-circuit ratio (SCR) of 2.5 and an X/R ratio of 10. If the inverter failed to initialize properly using SCR of 2.5, document the minimum SCR required for proper initialization. Over-frequency, Under-frequency, Over-voltage, Under-voltage tests should be performed with a high SCR (eg. 1000) in order to maintain voltage at the specified magnitudes and durations.

Flat Run Test: Run the project at its maximum output in both PSSE and PSCAD software under normal conditions, with the POI frequency set at 60Hz and voltage at 1 per unit (p.u.). The inverter is expected to run at rated output to the end of the simulation.

Ringdown Test: Initiate the simulation at normal conditions, with the POI frequency set at 60Hz and POI voltage at 1 p.u. Simulate a three-phase fault at the project's POI bus, lasting for 6 cycles, starting at 10 seconds. Continue the simulation until 30 seconds. The inverter should enter momentary cessation during the fault, then resume output with a stable, adequately damped response.

Over-frequency Test: Begin the simulation at normal conditions with 1.0 p.u. rated output, with the POI frequency set at 60 Hz (1 pu) and POI voltage at 1 p.u. Increase the frequency to 60.3Hz (1.005 pu) at the project's POI bus, starting at 10 seconds. Maintain the frequency at 60.3Hz (1.005 pu) and continue the simulation until 30 seconds. The inverter is expected to reduce output by about 5% within margin of error during the over-frequency test. Refer to Table 1 for the time and frequency test points mentioned for Over-frequency test. Refer to Figure 1 for the expected active power response of the project.

Under-frequency Test: Start the simulation at normal conditions with 0.8 p.u. rated output, with the POI frequency set at 60Hz (1 pu) and POI voltage at 1 p.u. Decrease the frequency to 59.7 Hz (0.995 pu) at the project's POI bus, starting at 10 seconds. Maintain the frequency at 59.7 Hz (0.995 pu) and continue the simulation until 30 seconds. The inverter is expected to increase output by about 5% within margin of error during the under-frequency test. Refer to Table 2 for the time and frequency test points mentioned for Over-frequency test. Refer to Figure 2 for the expected active power response of the project.

Over-Voltage Test: Commence the simulation at normal conditions, with the POI frequency set at 60Hz and POI voltage at 1 p.u. Simulate an over-voltage event of 1.2 pu at the project's POI bus for 0.15 seconds starting at 10 seconds. Then decrease the voltage to 1.125 p.u. at the project's POI bus for 1 second and then further decrease the voltage to 1.08 p.u. at the POI bus for the next 10 seconds. Finally, bring the voltage at the POI down to 1 pu until 30 seconds. The inverter is not expected to trip when the voltage is 1.2 pu at the POI and is expected to enter momentary cessation when the voltage is between 1.2 pu and 1.1 pu. Finally, it is expected that the inverter would resume normal output when the voltage drops further to 1.08 pu at the POI and continue normal output when the voltage at the POI comes back to 1 pu for the rest of the simulation. For inverter reactive power response, it is expected that the reactive power output in PSSE will be zero throughout the duration of the test. In PSCAD, the project is expected to absorb 25% of nameplate KVA rating according to the Volt-Var feature requirement when the POI voltage is outside the maximum voltage of the appropriate volt-var curve. It is also expected that the volt-var response time would be 5 seconds. Refer to Table 3 for the time and voltage test points mentioned for Over-Voltage test. Refer to Figure 3 for the expected reactive power response (not including transients) of the project in PSSE and PSCAD simulations.

Under-Voltage Test: Start the simulation at normal conditions, with the POI frequency set at 60Hz and POI voltage at 1 p.u. Simulate an under-voltage event (0.45 p.u.) at the project's POI bus for 1 second, starting at 10 seconds. Then, increase the voltage to 0.55 p.u. at the POI bus for 1.5 seconds, followed by an increase to 0.9 p.u. at the POI bus for the next 10 seconds. Finally, bring the voltage at the POI down to 1 pu until 30 seconds.. The inverter is expected to enter into momentary cessation when the voltage is at 0.45 pu and then resume output when the voltage increases to 0.55 pu. Finally, the inverter should operate continuously at normal output when the voltage increases to 0.9 pu and then further to 1 pu. For inverter reactive power response, it is expected that the reactive power output in PSSE will be zero throughout the duration of the test. In PSCAD, the project is expected to provide 25% of nameplate KVA rating according to the Volt-Var feature requirement when the POI voltage is outside the minimum voltage of the appropriate volt-var curve. It is also expected that the volt-var response time would be 5 seconds. Refer to Figure 4 for the expected reactive power response (not including transients) of the project in PSSE and PSCAD simulations respectively.

For the battery energy storage system (BESS) project, the above tests need to be performed in both discharging and charging modes.

The expected acceptable benchmarking results should demonstrate a reasonable match between the voltage (V), active power (P), obtained from both PSSE and PSCAD simulations. Reactive power (Q) values will differ between PSSE and PSCAD for voltages outside the voltage deadband of the volt-var curve. The PSSE model needs to be at unity power factor at POI at all times, whereas the PSCAD model needs to be at unity power factor under normal conditions but respond to voltage deviations outside the deadband according to appropriate volt-var curve modeled in the power plant controller.

Table 1:Test Points for Over-Frequency Test

Time (seconds)	F (Hz)	F (pu)
0	60	1
10	60	1
10	60.3	1.005
30	60.3	1.005

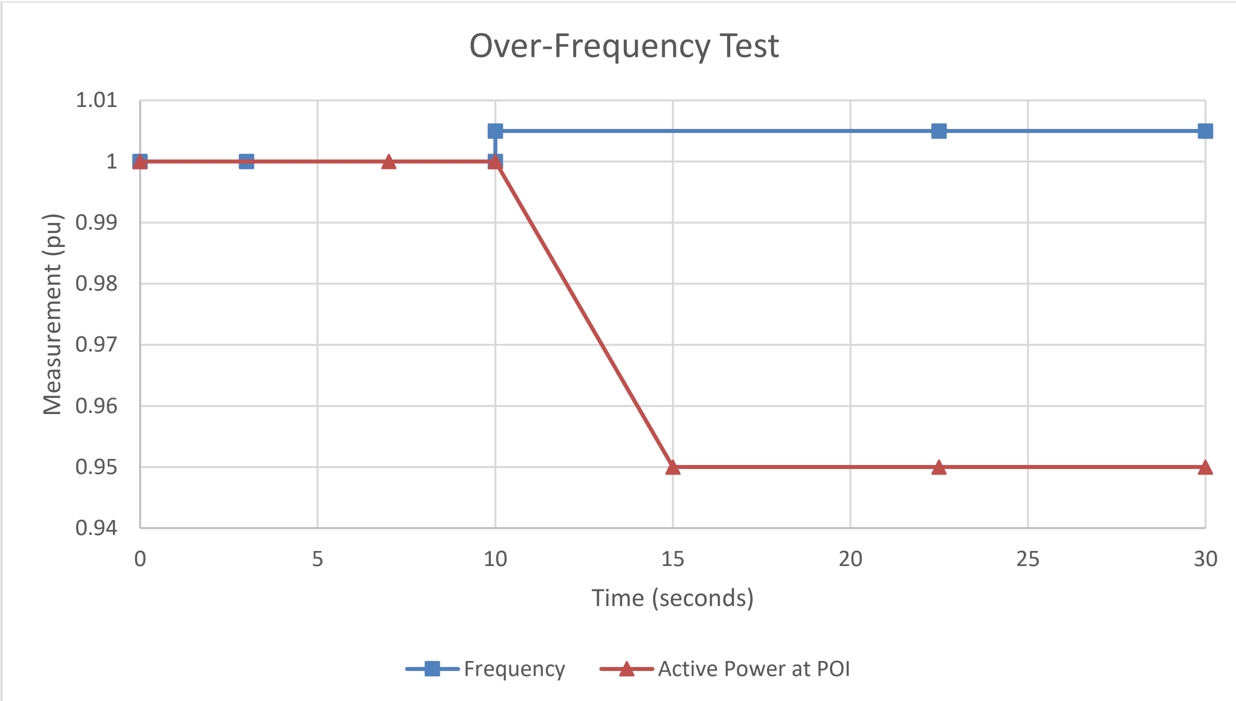

Figure 1: Expected Active Power Response to Over-Frequency Conditions

Table 2: Test Points for Under-Frequency Test

Time (seconds)	F (Hz)	F (pu)
0	60	1
10	60	1
10	59.7	0.995
30	59.7	0.995

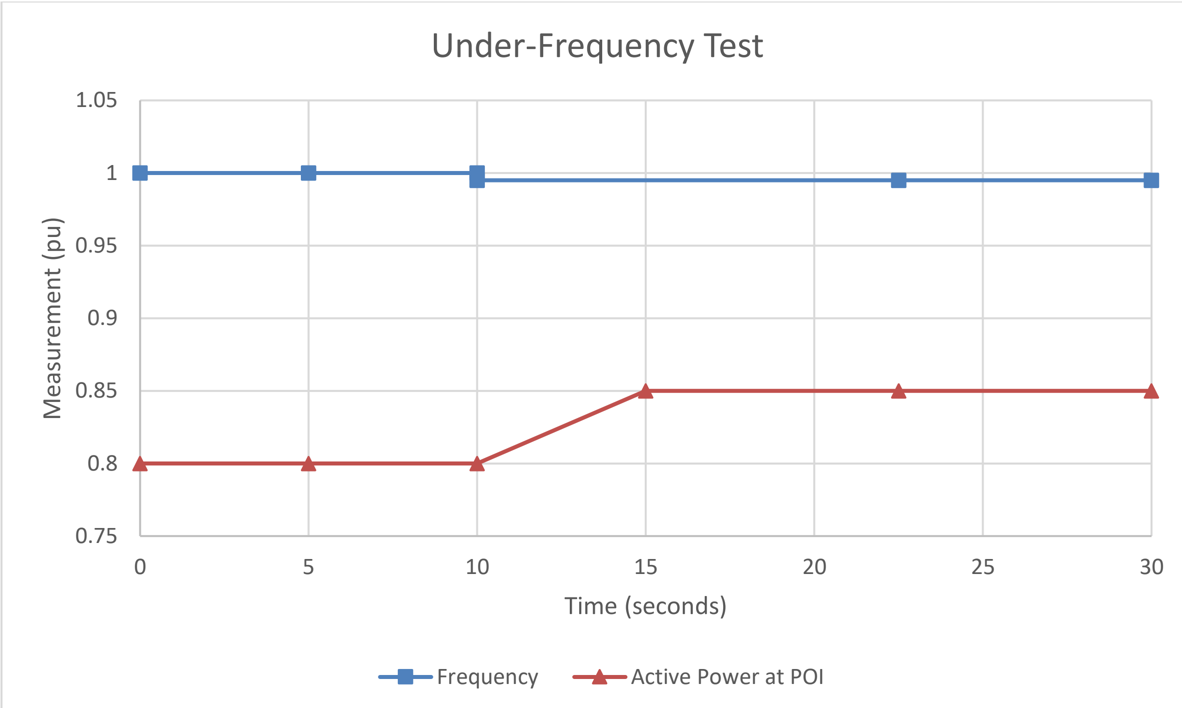

Figure 2: Expected Active Power Response to Under-Frequency Conditions

Table 3: Test Points for Over-Voltage Test

Time (seconds)	POI Voltage (pu)
0	1
10	1
10	1.2
10.15	1.2
10.15	1.125
11.15	1.125
11.15	1.08
20.15	1.08
20.15	1
30	1

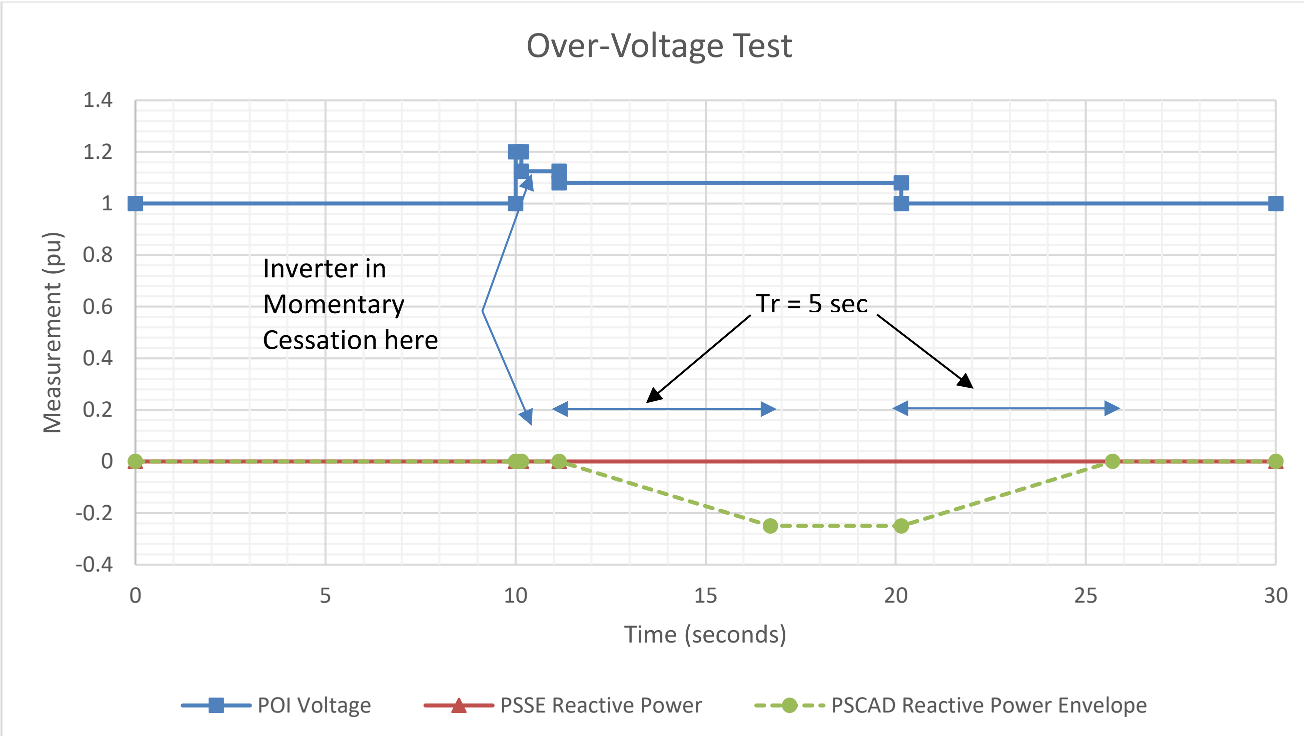

Figure 3: Expected Reactive Power Responses for Over-Voltage Test

Table 4: Test Points for Under-Voltage Test

Time (seconds)	POI Voltage (pu)
0	1
10	1
10	0.45
11	0.45
11	0.55
12.5	0.55
12.5	0.9
22.5	0.9
22.5	1
30	1

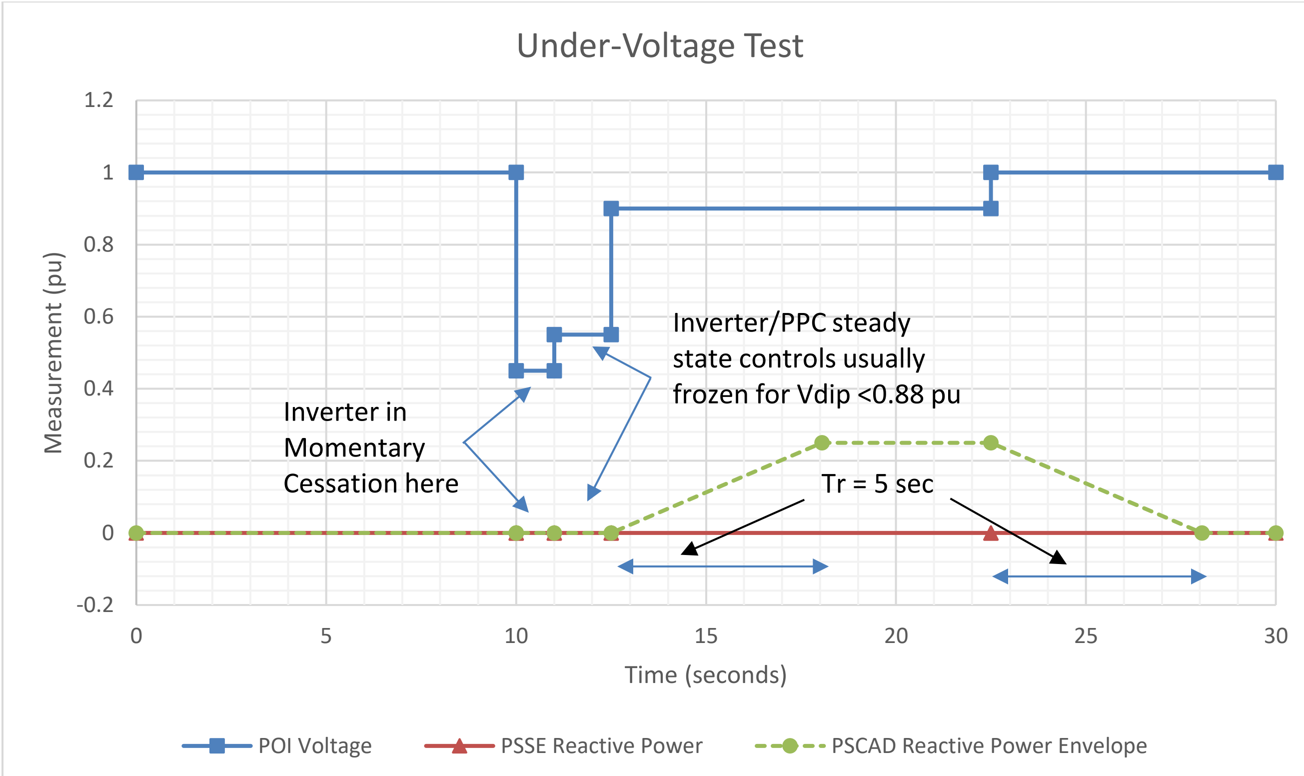

Figure 4: Expected Reactive Power Responses for Under-Voltage Test

Justification for not modeling volt-var control in PSSE

1. The volt-var control is usually regarded as a type of steady state voltage support mechanism and is not considered as dynamic voltage control since the response time is in the order of seconds to minutes[1]. The higher versions of PSSE (i.e v35) also have provisions of modeling volt-var explicitly only in the steady state generator model. Further, the longest duration disturbance in the PSSE stability studies are usually breaker failure contingencies which have a clearing time of around 17-20 cycles or around 0.33 seconds. After the disturbance, the voltage normally comes back within the deadband range in the simulation. Now, the volt-var open loop response time for projects required by Eversource is 5 seconds. Thus, the volt-var action will not be significant in the PSSE stability simulations. It will be more conservative to restrict the projects to unity power factor and not provide any type of voltage support during disturbances.
2. Volt-var modeling using only the REPCA module and the VDL table in the REECD module is not possible for projects which are close to the substation since those projects are required to have asymmetric volt-var curve. Symmetric volt var curve modeling is possible by setting droop in the REPCA module. However, the drawback is the reactive power Q at the PCC/POI would not be zero when the voltage is within deadband and the project will absorb reactive power from the system to meet the reactive power requirements of the inverter GSU and the collector system. Eversource preference is to have projects, which are greater than 5 MW, to be at unity power factor at the PCC/POI. This is also in good standing with 1547 where the applicable voltages are measured at the RPA which is usually the PCC/POI.
3. For projects with asymmetric volt-var curve requirements, the voltage PI controller and reactive PI controller (Coordinated V-Q control) can be used along with the VDL table in the REECD module with the measured voltage compensated to the POI to model the volt-var curve. The valid flag combinations to model the volt-var control (which may include the REPCA module as well) are provided in some NERC[2] and WECC[3] references. With proper parametrization, Q = 0 is achievable at the POI when the voltage is within deadband.

[1] Technical Report PES-TR67.r1, 'Impact of IEEE 1547 Standard on Smart Inverters and the Applications in Power Systems', Prepared by the IEEE PES Industry Technical Support Leadership Committee, August 2020.
[2] Technical Workshop, 'Inverter-Based Resource Performance and Analysis', NERC IRPT Meeting, February 2019.
[3] California ISO, 'Dynamic Model Review Guideline for Inverter Based Interconnection Requests', June 2, 2021

However, the issue with this modeling method is that usually provides faster response time than the prescribed open loop response time of 5 seconds. It can be quite difficult to meet the open loop response time and maintain stable operation by tuning the Kp and Ki parameters of the PI controllers. Thus, this modeling may also not be an accurate representation of the volt-var function in the field which would usually have a longer response time to voltage deviations.

4. Modeling volt-var control in PSCAD will still provide visibility into any issues with this type of control during EMT studies.