EMT Model Testing & Intake

ELECTRANIX
SPECIALISTS IN POWER SYSTEM STUDIES

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EMT Model Intake

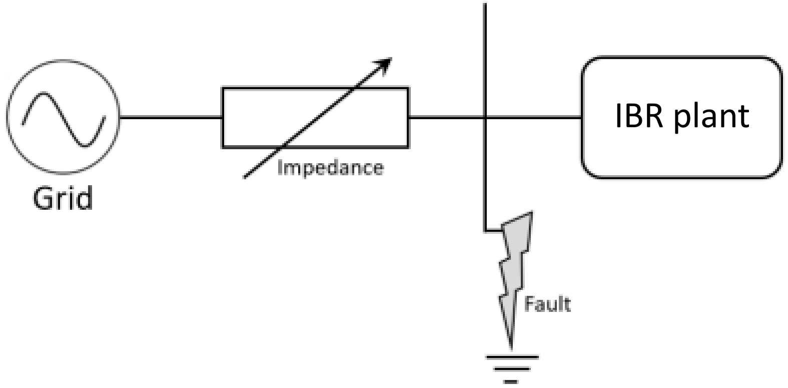
- Why collect and check EMT models?
  - High quality, well verified models needed for EMT studies
  - Lack of usability - > challenging or impossible to use in study
  - Lack of accuracy -> inaccurate studies (limited value)
  - Lack of basic performance -> likely won’t work well in a system study
- Should you collect models for all plants, even if not under study?
  - Yes! insurance for when you need to include that plant in a future study
  - difficult to get accurate models for plants after COD

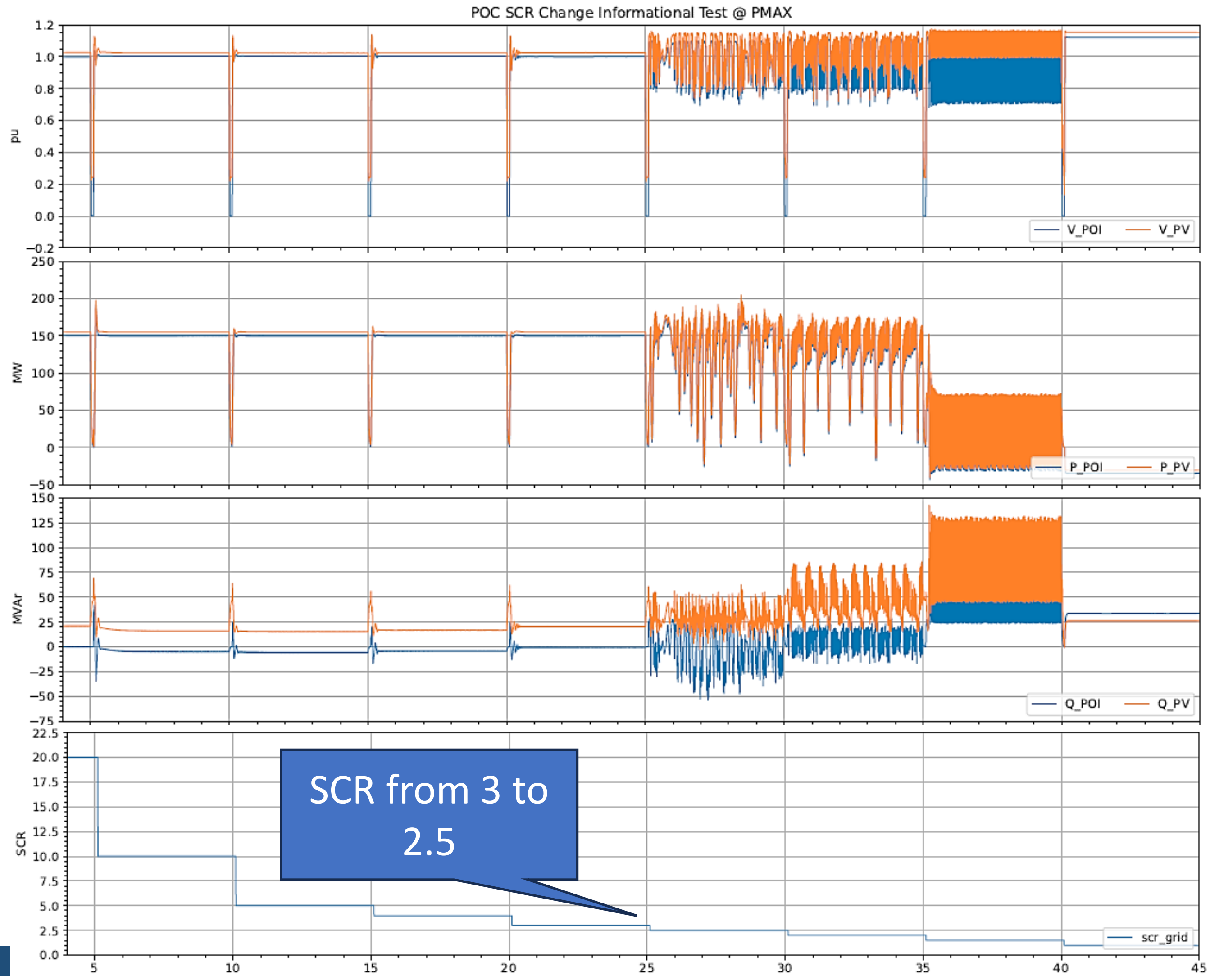
EMT Model Intake – Model Requirements

- Process that must include:
  - EMT model requirements
    - **Accuracy**: Is it detailed and correct? Validated?
    - **Usability**: Does it function within a study context?
    - **Site-specific**: Does it represent the equipment being used?
    - Documentation
  - **Performance Testing**: Is the plant likely to conform with basic performance needs for the system? (Note that usually a full study is the final arbiter of "acceptable performance")
  - Documentation
- May include:
  - Benchmarking between EMT and RMS models
  - Testing of specific capability (e.g. GFM)

EMT Model Intake – Performance Testing

- Tests may include:
  - Fault ride-through and recovery
  - Voltage / Frequency, Phase-jump, and RoCoF ride-through
  - Voltage / Frequency support verification
  - Weak-system performance testing
  - Specific capability testing (e.g. GFM)





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Terminology & timelines note

- Late 2000's – present: Electranix Model Requirements (EMR)
  - Earlier versions emphasis on model accuracy & usability, with basic performance tests (i.e. check 3LG FRT at SCR 3) added later
  - Rev 13 (2025) performance tests roughly match proposed 2800.2 SG3 (~50 tests)
- 2020: ERCOT MQT (Model Quality Testing)
  - Accuracy emphasis plus some ERCOT-specific performance requirements
- 2022: IEEE 2800-2022 Appendix G EMT Dynamic Modelling Requirements
- Draft IEEE 2800.2 Terminology:
  - Design Evaluation: Tests plant model against many IEEE 2800 performance requirements. Should not replace EMT interconnection study (if warranted), but likely the only EMT study that most plants get
  - MQT: Preliminary check on model accuracy and basic performance
- Many others along the way
- Today's Landscape?

Electranix Model Requirements Walkthrough

Model Accuracy Features

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.[2,3]

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.

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 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 controller is controlling multiple types of resources (eg. Hybrid BESS/PV), this 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. All plant level communication delays should be included in the model, including transport delays, measurement delays, delays due to bus (eg. MODBUS) communication, sample and hold logic at the inverter or the PPC, and any other delay that may influence overall plant response in the time-frame of the study.

Electranix Model Requirements Walkthrough

D. *Represent all pertinent electrical and mechanical configurations*. This includes any filters and specialized transformers (including grounding transformers). Mechanical features such as gearboxes, pitch controllers, PV panel dynamics, DC bus controllers, must be modelled if they impact electrical performance within the timeframe and electrical purview of the study. An infinite voltage source on the DC side is generally not acceptable. Battery resources must include the capability to represent the full range of state-of-charge levels. PV and wind resources must have capability to represent full range of active power availability. Any control or dynamic features of the actual equipment which may influence behaviour in the simulation period which are not represented or which are approximated must be clearly identified.

E. *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/current protections, converter overcurrent protections, and often other inverter specific protections. Any protections which can influence dynamic behaviour or plant ride-through in the simulation period must be included. If there are mechanical limits which influence ride-through, such as thermal protection of wind turbine crowbar functions, these should be included in the model. Actual hardware code is recommended to be used for these protection features.

F. *Be configured to match expected site-specific equipment settings.* Any user-tunable parameters or options must be set in the model to match the equipment at the specific site being evaluated, as far as they are known. Default parameters are not appropriate unless these will match the configuration in the installed equipment.

Electranix Model Requirements Walkthrough

Model Usability Features

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

G. *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.[4] Diagnostic flags (eg. flags to show control mode changes or which protection has been activated) should be visible to aid in analysis.

H. *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[2].

I. *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)

J. *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[5]. Access to technical support engineers is desirable. Additional detail on required documentation and test case is described in PSCAD Model Test Checklist (Appendix A).

Electranix Model Requirements Walkthrough

K. *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, and tie these model parameters to as-left hardware settings at commissioning. This may be control revision codes, settings files, or a combination of these and other identification measures.

L. *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.

M. *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.

N. *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. 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.

EMR Performance Tests

- Based on IEEE 2800 requirements
- Recommend using a moderately weak SCR (e.g. 2.5) for most tests

[5] 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.

Performance Tests

- Initialization (flat run)
  - Check that plant can initialize correctly for all considered initial conditions
  - Check Pmax, Pmin, possibly Qmax, Qmin

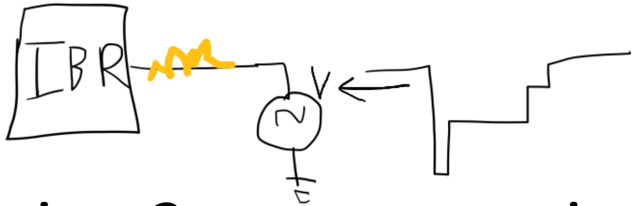
EMR

Table 1: Initialization Tests

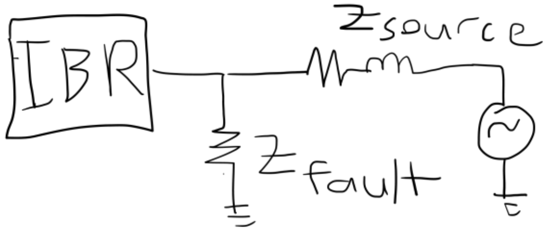
Test #	Test Description				Success Criteria
	Test duration [s]	Test Type	Active Power	Reactive Power	
1-1	20	Flat Run	Pmax[17]	0	Reach steady state within 5s
1-2	20	Flat Run	Pmin	0	Reach steady state within 5s

Performance Tests
Low-voltage ride through (fault tests)

- Option 1: zero-impedance infinite bus, play in ride-through curve
  - Tests exact limits, but grid model unrealistic



- Option 2: use source impedance and fault impedance as voltage divider
  - Less precise POI voltage, allows for testing with non infinite source



V_IBR ~ = 0.5 when Zsource = Zfault

IEEE 2800:

Table 11 —Voltage ride-through requirements at the RPA for IBR plants with auxiliary equipment that cause ride-through limitations[89]

Applicable voltage (p.u.) at the RPA	Operating mode/response	Minimum ride-through time (s) (design criteria)
V > 1.20	May ride-through or may trip	NA
V > 1.10	Mandatory operation	1.0
V > 1.05	Continuous operation[90]	1800
V < 0.90	Mandatory operation	3.00
V < 0.70	Mandatory operation	2.50
V < 0.50	Mandatory operation	1.20
V < 0.25	Mandatory operation	0.16
V < 0.10	Permissive operation[91]	0.16

Table 12 —Voltage ride-through requirements at the RPA for IBR plants without auxiliary equipment that cause ride-through limitations

Applicable voltage (p.u.) at the RPA	Operating mode/response	Minimum ride-through time (s) (design criteria)
V > 1.20	May ride-through or may trip	NA
V > 1.10	Mandatory operation	1.0
V > 1.05	Continuous operation[90]	1800
V < 0.90	Mandatory operation	6.00
V < 0.70	Mandatory operation	3.00
V < 0.50	Mandatory operation	1.20
V < 0.25	Mandatory operation	0.32
V < 0.10	Permissive operation[91]	0.32

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Table 2: Balanced Fault Ride-through Tests

Test #	Test Description					Success Criteria
	Fault duration [s]	Fault type	Fault impedance Zf	Active Power	Reactive Power	
2-1	0.16	3PHG	Zf=0	Pmax[17]	0	Ride Through
2-2	0.16	3PHG	Zf=0	Pmax[17]	Qmin	Ride Through
2-3	0.16	3PHG	Zf=0	Pmax[17]	Qmax	Ride Through
2-4	2.50	3PHG	Zf=Zs	Pmax[17]	0	Ride Through
2-5	2.50	3PHG	Zf=Zs	Pmax[17]	Qmin	Ride Through
2-6	2.50	3PHG	Zf=Zs	Pmax[17]	Qmax	Ride Through

Table 3: Unbalanced Fault Ride-Through Tests

Test #	Test Description					Success Criteria
	Fault duration [s]	Fault type	Fault impedance Zf	Active Power	Reactive Power	
3-1	0.16	2PHG	Zf=0	Pmax[17]	0	Ride Through
3-2	0.16	2PHG	Zf=0	Pmax[17]	Qmin	Ride Through
3-3	0.16	2PHG	Zf=0	Pmax[17]	Qmax	Ride Through
3-4	0.16	1PHG	Zf=0	Pmax[17]	0	Ride Through
3-5	0.16	1PHG	Zf=0	Pmax[17]	Qmin	Ride Through
3-6	0.16	1PHG	Zf=0	Pmax[17]	Qmax	Ride Through

Performance Tests
Low-voltage ride through (fault tests)

- Response during low-voltage:

IEEE 2800:

Table 13—Voltage ride-through performance requirements

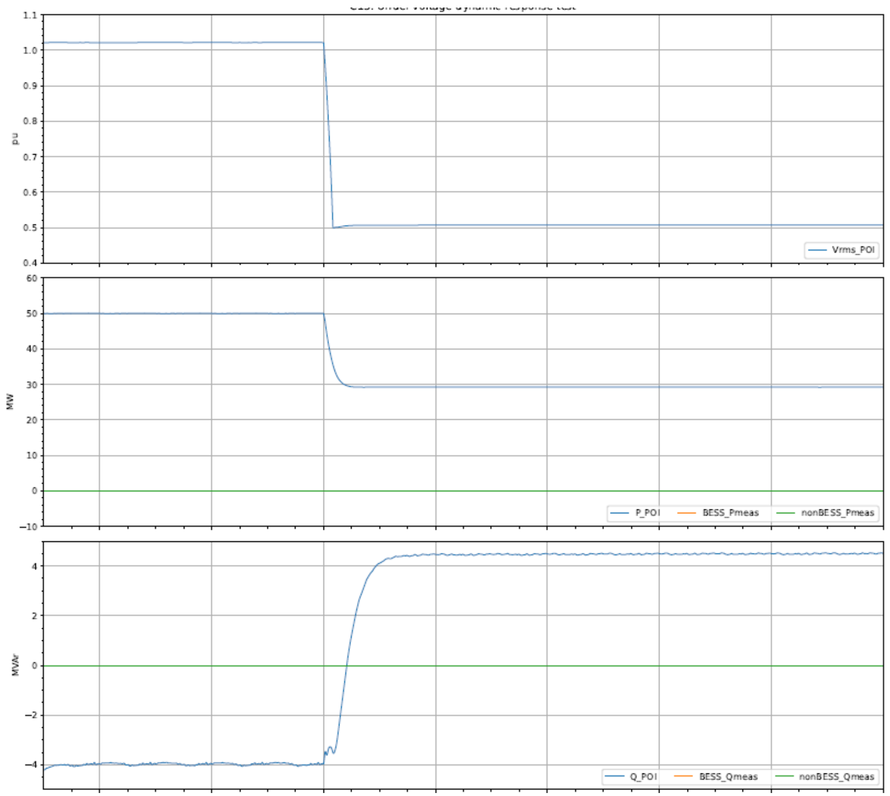
Parameter	Type III WTGs	All other IBR units
Step response time[b, c, d]	NA[a]	≤ 2.5 cycles
Settling time[b, c, d]	≤ 6 cycles	≤ 4 cycles
Settling band	−2.5%/+10% of *IBR unit maximum current*	−2.5%/+10% of *IBR unit maximum current*

[a] The initial response from the type III WTG is driven by machine characteristics and not the control system. DC component, if present, has an impact on response, which is driven by machine parameters and time of fault occurrence. Even though the control system takes an action, it cannot control machine's natural response. As such, defining response time for type III WTGs is not necessary.

[b] System conditions may require a slower response time, or *IBR units* may not be able to meet response times noted in this table for certain system conditions. If so, greater response time and *settling time* are allowed with mutual agreement between an *IBR owner* and the *TS owner*.

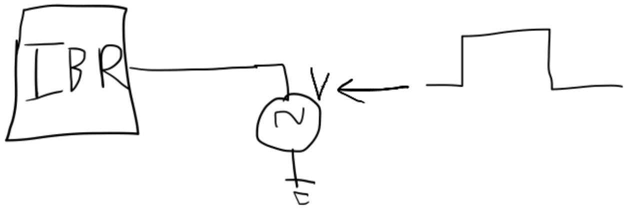
[c] The DFT with a one-cycle moving average window is used to derive phasor quantities such as active, reactive, positive-sequence, negative-sequence currents, etc. The time delay required for the DFT measurements is included in the *step response time* and *settling time* specified in this table.

[d] The specified *step response time* and *settling time* applies to both 50 Hz and 60 Hz systems.



Performance Tests
High-voltage ride through

- Infinite bus play-in ride-through curve



- Alternatives?

IEEE 2800:

Table 11 —Voltage ride-through requirements at the RPA for IBR plants with auxiliary equipment that cause ride-through limitations[89]

Applicable voltage (p.u.) at the RPA	Operating mode/response	Minimum ride-through time (s) (design criteria)
V > 1.20	May ride-through or may trip	NA
V > 1.10	Mandatory operation	1.0
V > 1.05	Continuous operation[90]	1800
V < 0.90	Mandatory operation	3.00
V < 0.70	Mandatory operation	2.50
V < 0.50	Mandatory operation	1.20
V < 0.25	Mandatory operation	0.16
V < 0.10	Permissive operation[91]	0.16

Table 12 —Voltage ride-through requirements at the RPA for IBR plants without auxiliary equipment that cause ride-through limitations

Applicable voltage (p.u.) at the RPA	Operating mode/response	Minimum ride-through time (s) (design criteria)
V > 1.20	May ride-through or may trip	NA
V > 1.10	Mandatory operation	1.0
V > 1.05	Continuous operation[90]	1800
V < 0.90	Mandatory operation	6.00
V < 0.70	Mandatory operation	3.00
V < 0.50	Mandatory operation	1.20
V < 0.25	Mandatory operation	0.32
V < 0.10	Permissive operation[91]	0.32

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Table 4: Over-Voltage Ride-Through Tests

Test #	Test Description				Success Criteria
	Duration [s]	Grid Voltage at POI (use infinite source at POI)	Active Power at POI	Initial Approx. Reactive Power at POI	
4-1	1	1.2 pu	Pmax	0	Ride Through
4-3	1	1.2 pu	Pmax	Qmax	Ride Through

Performance Tests
Steady-State Voltage Response Test

IEEE 2800:

Table 5—Performance target range

Parameter	Performance target	Notes
Reaction time	< 200 ms	
Maximum *step response time*	As required by the *TS operator*	The slowest response shall be tuned based on the *TS operator* requirements for response time and stability given the anticipated range of grid strength, other local voltage control devices, and *overshoot* requirements. The *step response time* may typically range between 1 s and 30 s. Any switched shunts or LTC transformer tap change operation needed to restore the dynamic reactive power capability in Figure 8 shall respond within 60 s.
Damping	Damping ratio of 0.3 or higher	Damping ratio, indicative of control stability, depends on grid strength.

Table 5: Voltage Reference Step Change Tests

Test #	Test Description: Event	Test Description: Active Power at POI	Test Description: Initial Approx. Reactive Power at POI	Success Criteria
5-1	Relative V (or Q or PF)[1] reference change as per Figure 1	Pmax	0	Step Response < 10s
5-2	Relative V (or Q or PF)[1] reference change as per Figure 1	Pmin	0	Step Response < 10s

[1] Will be based on reactive power control method

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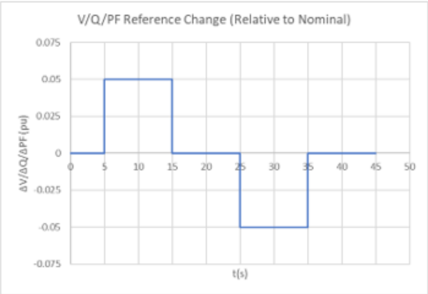
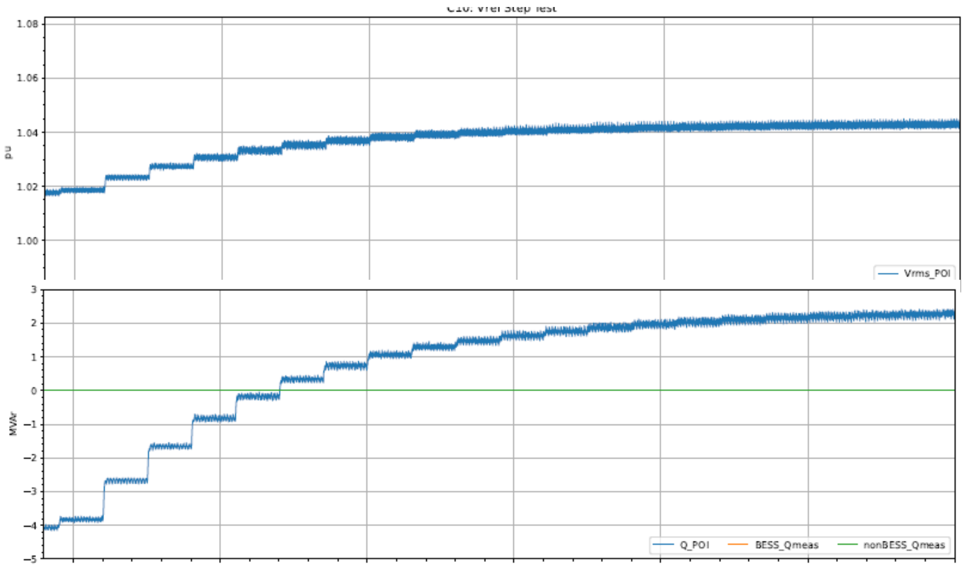


Figure 1: Relative voltage reference step change



Performance Tests
Power Reference Step Test

EMR

Table 6: Active Power Reference Step Change Tests

Test #	Test Description			Success Criteria
	Event	Active Power at POI	Initial Approx. Reactive Power at POI	
6-1	Active Power controller reference change as per Figure 2	Pmax	0	Plant Responds Appropriately

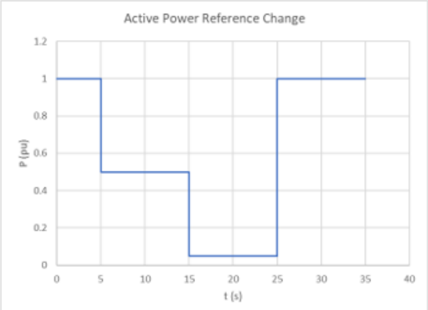


Figure 2: Active power reference step change

No time requirement in IEEE 2800

Performance Tests
Grid Frequency Response Test

IEEE 2800:

Table 8—Parameters of active power-frequency response dynamic performance for *IBR plant*

Parameter	Units	Default value	*Ranges of available settings*	
			Minimum	Maximum
Reaction time	Seconds	0.50	0.20 (0.5 for WTG)	1
Rise time	Seconds	4.0	2.0 (4.0 for WTG)	20
Settling time	Seconds	10.0	10	30
Damping ratio	Unitless	0.3	0.2	1.0
Settling band	% of change	Max (2.5% of change or 0.5% of ICR)	1	5

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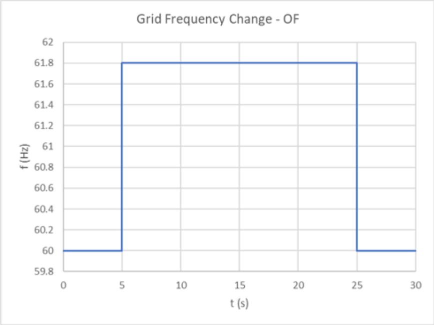
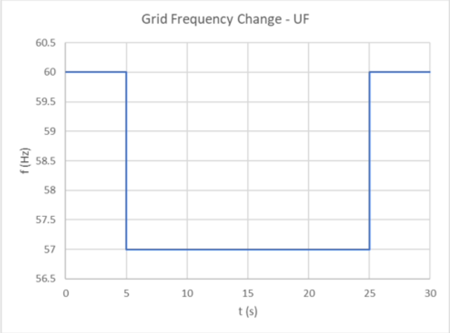
Table 7: Grid Frequency Response and Ride-through Tests

Test #	Test Description			Success Criteria
	Event	Active Power at POI	Initial Approx. Reactive Power at POI	
7-1	Grid Frequency Change as per Figure 3	Pmax	0	Ride-through, Appropriate response per IEEE 2800 Table 8
7-2	Grid Frequency Change as per Figure 3	Pmin	0	Ride-through, Appropriate response per IEEE 2800 Table 8
7-3	Grid Frequency Change as per Figure 4	Pmax	0	Ride-through, Appropriate response per IEEE 2800 Table 8
7-4	Grid Frequency Change as per Figure 4	Pmin	0	Ride-through, Appropriate response per IEEE 2800 Table 8





Performance Tests
Grid Phase Angle Step Tests

IEEE 2800:

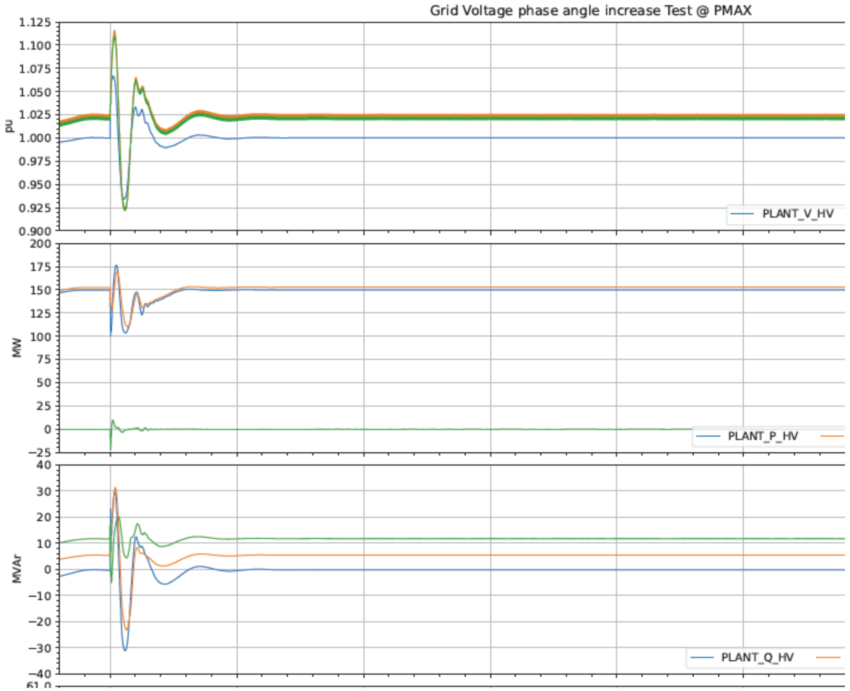
7.3.2.4 Voltage phase angle changes ride-through

The *IBR plant* shall ride through positive-sequence phase angle changes within a sub-cycle-to-cycle time frame of the *applicable voltage* of less than or equal to 25 electrical degrees.[116]

EMR

Table 9: Grid Voltage Phase Angle Change Ride-through Tests

Test #	Test Description			Success Criteria
	Event	Active Power at POI	Initial Approx. Reactive Power at POI	
9-1	Grid voltage angle change equal to +25°	Pmax	0	Ride Through
9-2	Grid voltage angle change equal to -25°	Pmax	0	Ride Through
9-3	Grid voltage angle change equal to +25°	Pmin	0	Ride Through
9-4	Grid voltage angle change equal to -25°	Pmin	0	Ride Through



Performance Tests
SCR Change Test (informational, to a degree)

EMR

Table 10: POC SCR Change Informational Tests

Test #	Test Description: Event	Test Description: Active Power at POI	Test Description: Initial Approx. Reactive Power at POI	Success Criteria
10-1	Short Circuit Ratio (SCR) of the plant at POC is changed as per Figure 6. 3LG Z=0 fault is applied at each SCR transition. Time between transitions may be extended to allow stabilization.	Pmax	0	For informational purposes only (not pass/fail) Plant should show stable operation until SCR = 2.5 and is unlikely to show stable operation as SCR approaches 1[1]

[1] valid only for grid following inverters

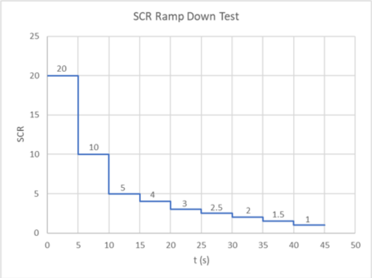
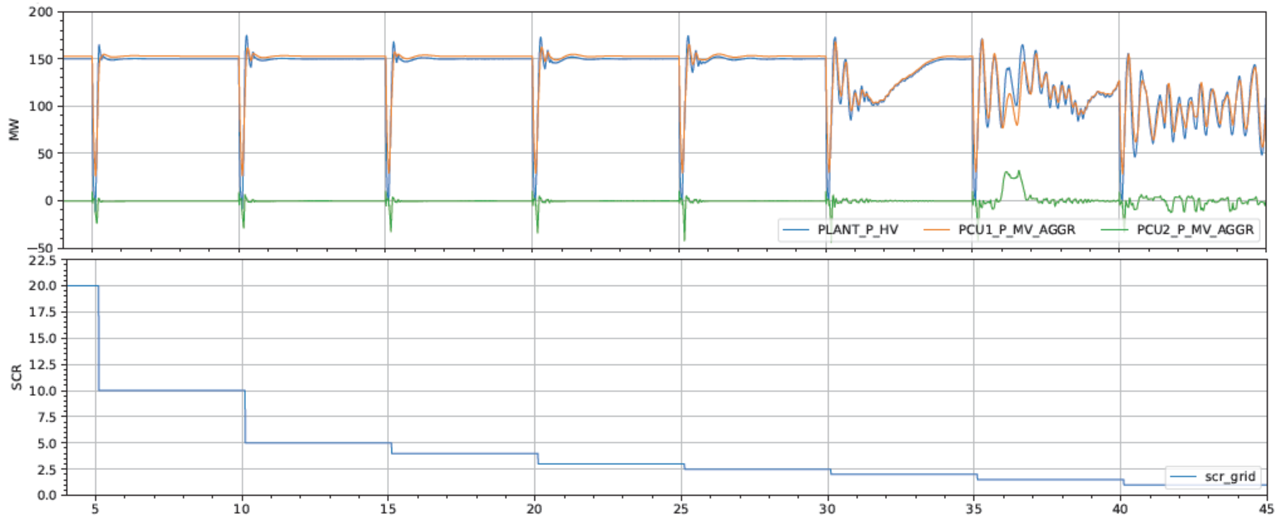


Figure 6: POC SCR change



No such requirement in IEEE 2800

Protection Inclusion Test

EMR

Table 12: Voltage Protection Inclusion Tests (Note that these tests only indicate that the model has protectio included, and may vary according to equipment capability)

Test #	Test Description			Success Criteria
	Event	Active Power at POI	Initial Approx. Reactive Power at POI	
12-1	Grid Voltage step as per Figure 9	Pmax	0	Inverter Trips
12-2	Grid Voltage step as per Figure 10	Pmax	0	Inverter Trips

No such requirement in IEEE 2800

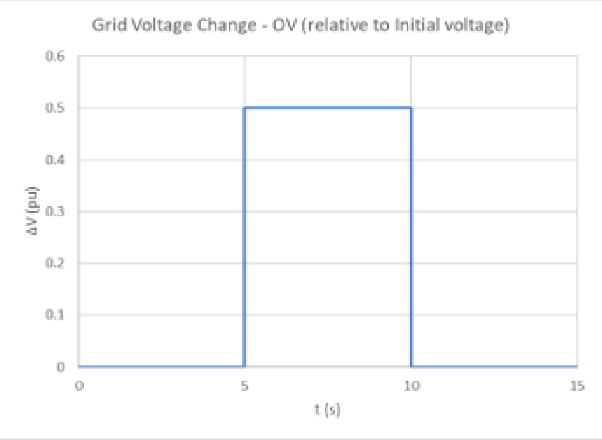


Figure 9: Grid voltage change - OV

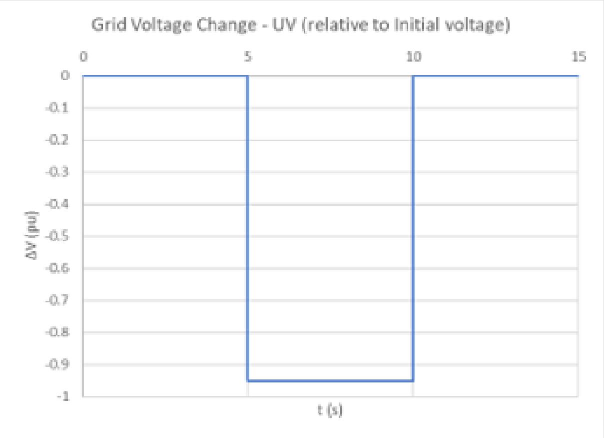
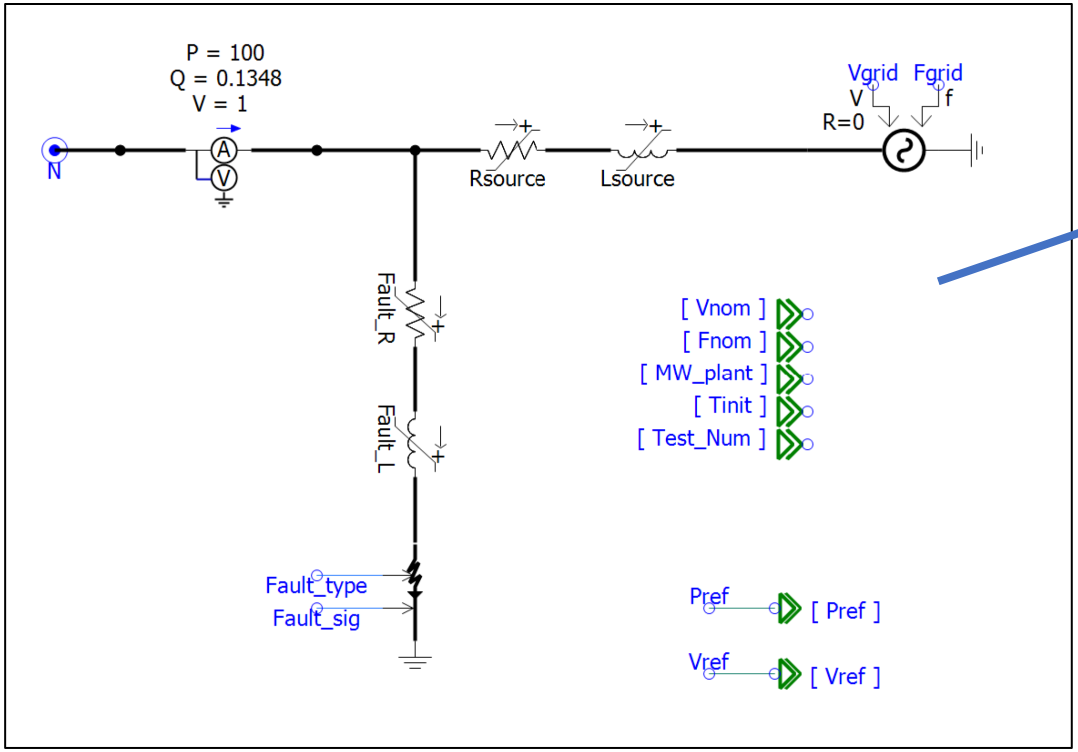
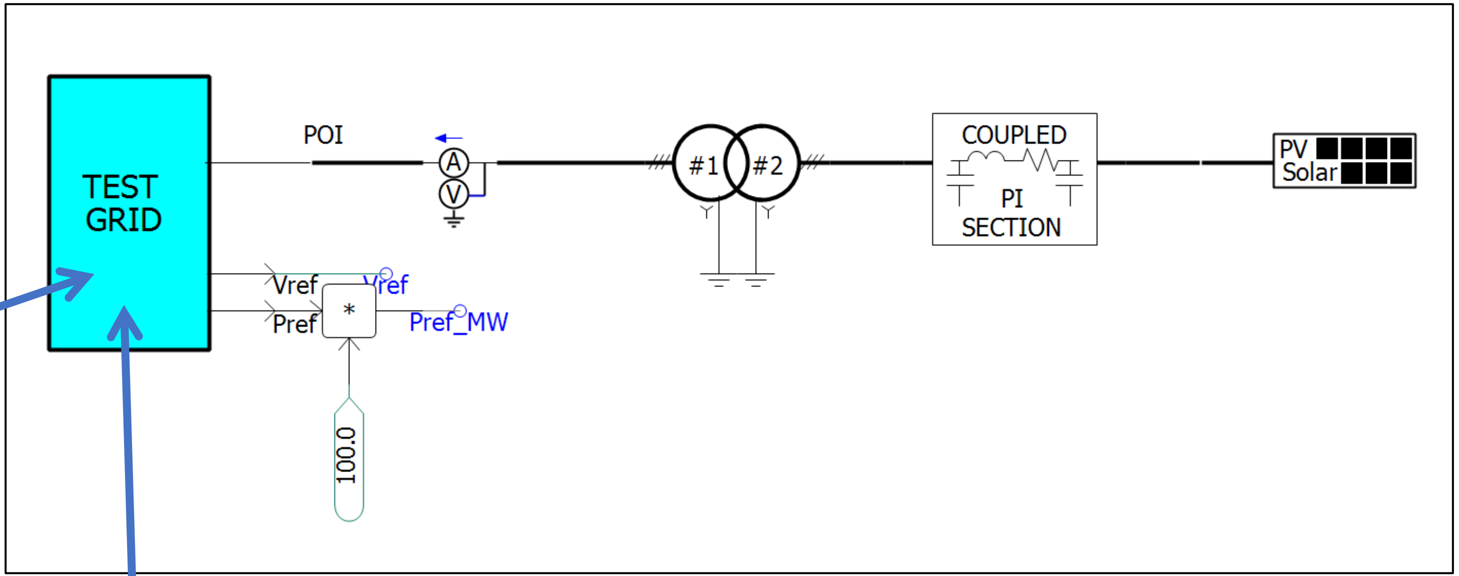
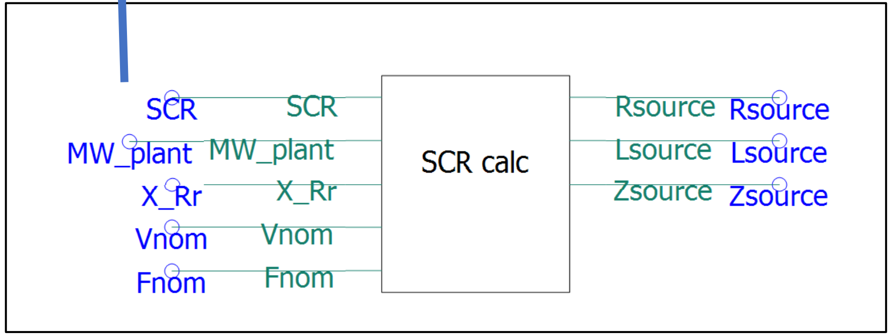


Figure 10: Grid voltage change - UV

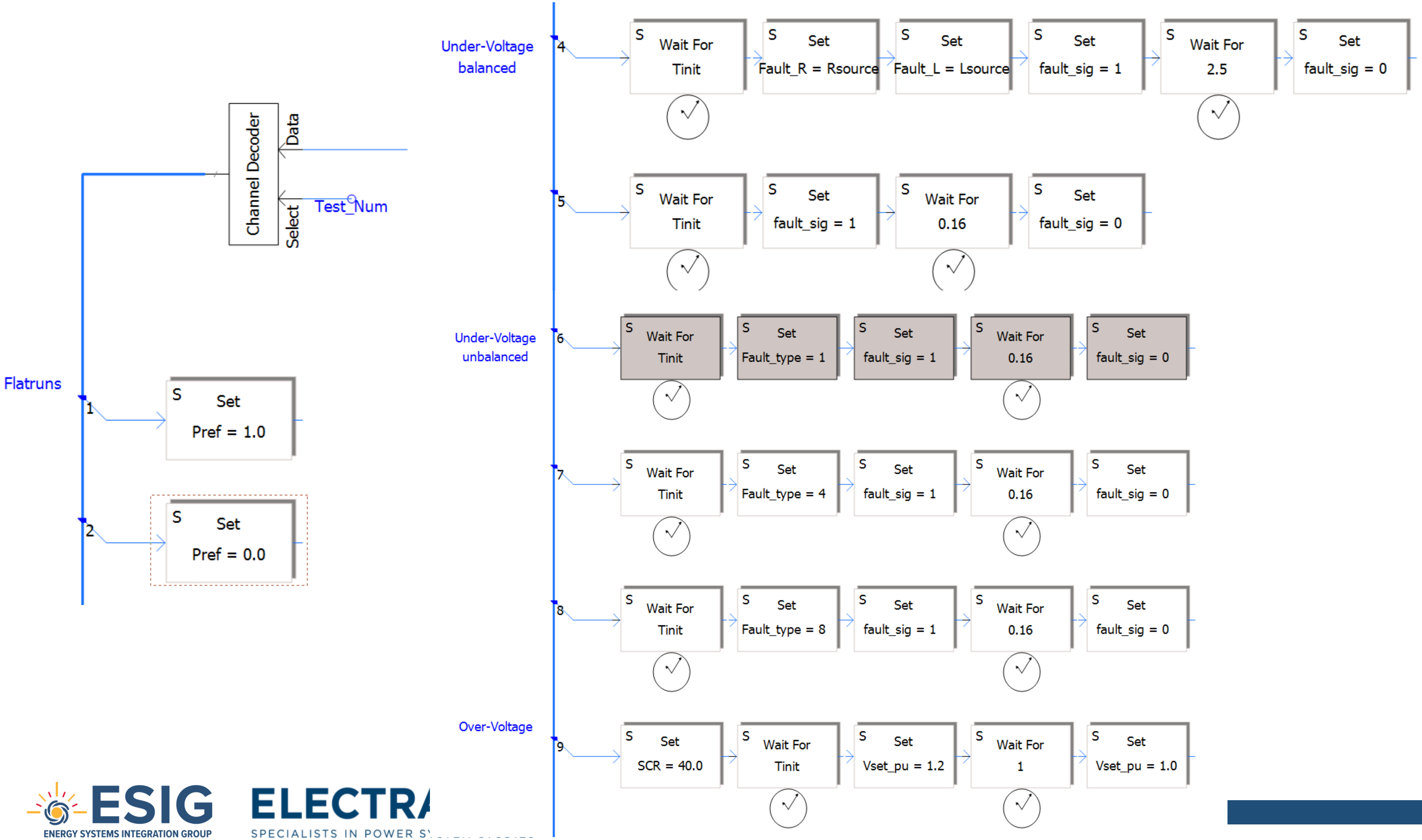
Basic Test Component



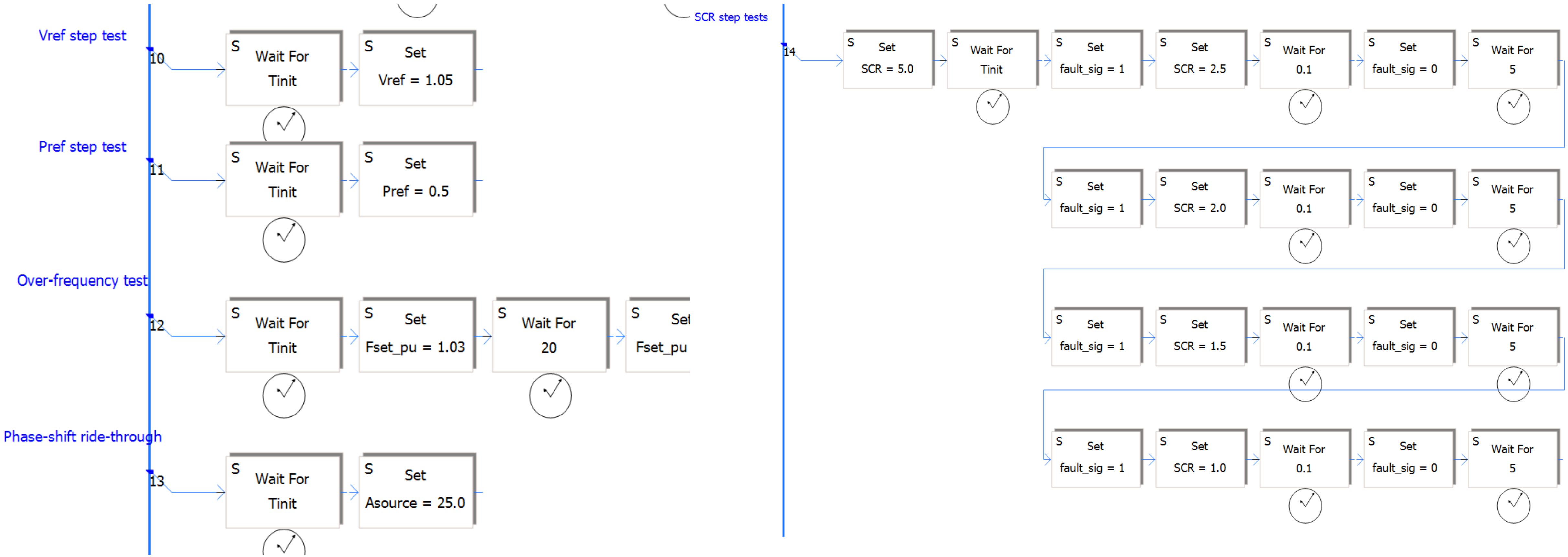




Basic Test Component



Basic Test Component

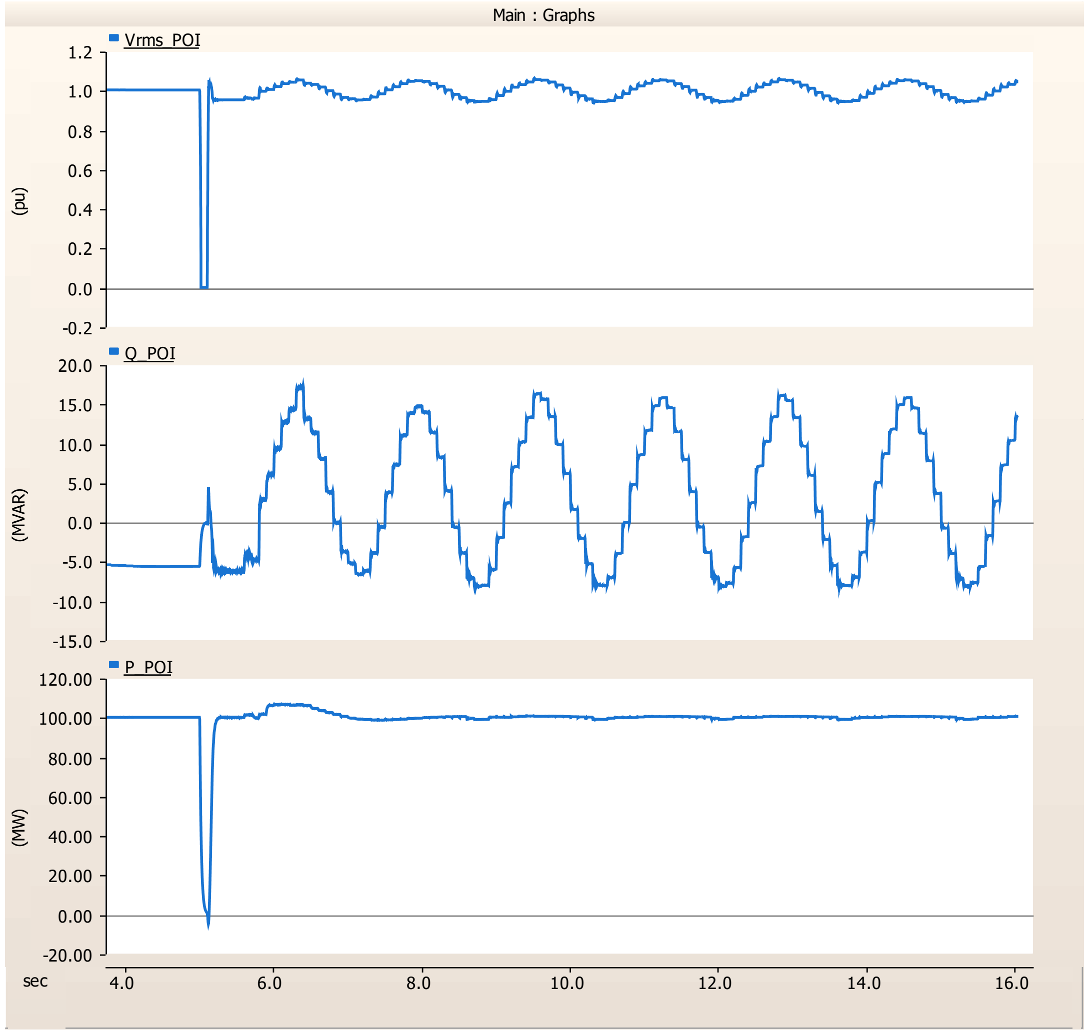


Basic Test Component – Add More Detail?

- Initialization
  - Back calculate voltage source V, angle based on P, Q, V at POI
  - Calculate Vref needed for a given POI V, Q
  - Use fast tap-changer to properly initial tap (if no load-flow solution available)
- Standardized and detailed plotting
  - Terminal and POI quantities
  - Various sequence components, harmonic components, etc.
- Dedicated external automation. May include automated post-processing for success criteria (reporting), automated benchmarking with other simulation platforms, etc.

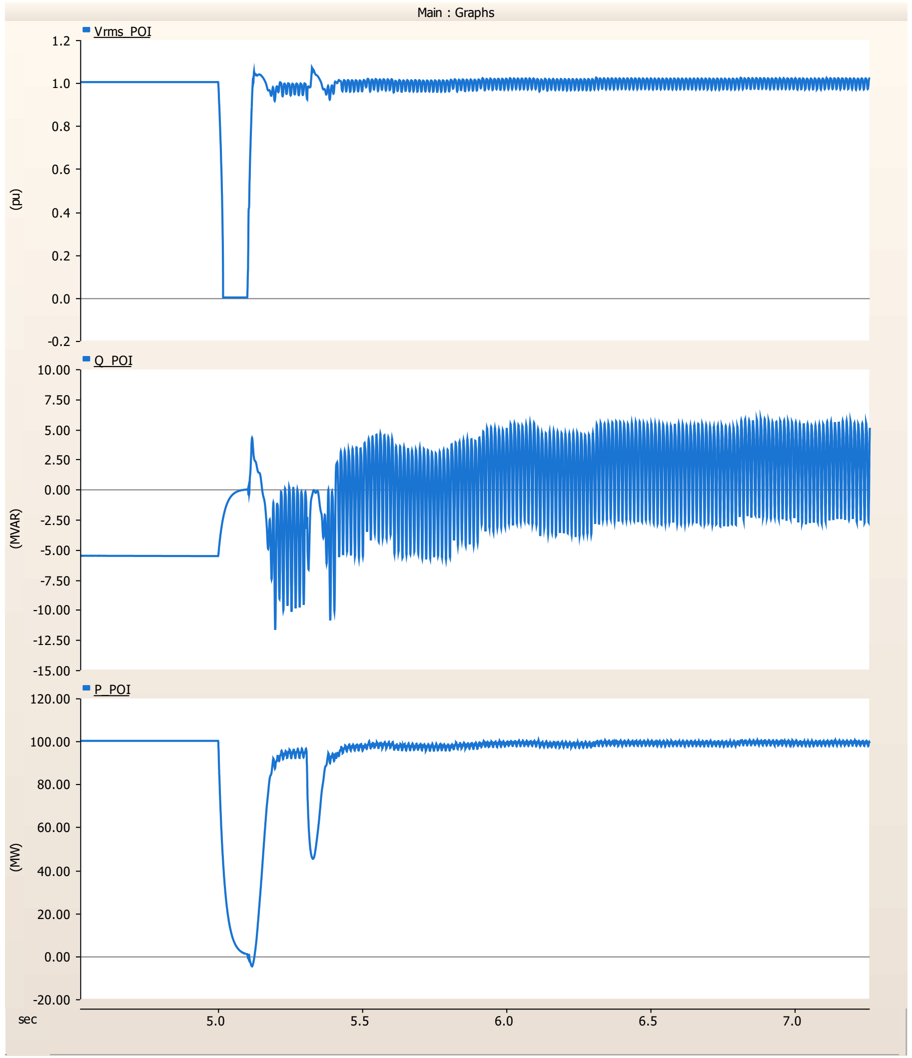
Workshop – IBR Performance Issues Example #1

- Root Cause?
- Fix?



Workshop – IBR Performance Issues Example #2

- Root Cause?
- Fix?



Workshop – IBR Performance Issues Example #3

- Root Cause?
- Fix?