Tuning IBR Plant EMT Models for Interconnection Requirements

ESIG – 2026 Spring Technical Workshop

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Outlines

- Introduction
- Roles and Responsibilities
- Challenges and Risks
- EMT vs RMS: Implications for Model Tuning
- Conclusion

Introduction

Introduction

- EMT models are used to demonstrate compliance with interconnection and dynamic performance standards (e.g., LVRT, HVRT, FRT).
- They are often the only practical tool for observing, configuring, and tuning plant response to large disturbances—especially ride-through behavior.

Introduction

- For owners and developers: A model that is not properly developed and tuned can lead to costly delays in interconnection approval.
- For grid operators: A model that “passes” but does not reflect real plant behavior creates a false sense of compliance—and a real risk to grid reliability

- **Commercial Operation Date:** Within 60 days prior to the commercial operation date (COD), the interconnection customer shall submit documentation that demonstrates that the as-built equipment and parameterization matches the dynamic models used during the study process (i.e., *model verification*). This may include, but is not limited to, the following: screenshots, photos, inverter or power plant controller (PPC) control mode and protection settings, nameplate data, etc. If any equipment does not match the models submitted at signing the GIA, the interconnection customer shall submit an updated set of models and an updated model quality and performance test report.
- **Surplus and Replacement Interconnection Requests:** The requirements listed above are applicable to Surplus and Replacement interconnection requests at the time of

[16] An incomplete model package submittal may impact the timeline of SCT approving the readiness of an IBR plant for Commercial Operation.

MISO

Southern Company

Roles and Responsibilities

Roles and Responsibilities

Grid Operator
Defines performance and compliance tests and criteria.

OEM
Provides EMT model and tuning support.

Consultant
Performs simulations, identifies gaps, and refines models.

Roles and Responsibilities: Grid Operators

- ISO-NE

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4.4 Test 4 - Voltage Reference Step Change

This test evaluates the IBR plant's dynamic performance to a step change in the plant controller's[9] voltage reference.

4.4.1 Test Description

A positive and a negative step change between 1% and 3% is applied such that the inverter and PPC[10] do not reach a reactive power or voltage limit. If the plant operates with a voltage droop, the droop value (percentage) is assumed larger than the applied voltage reference change; otherwise, a smaller step change may need to be used. The GENCLS model should be used in PSSE for the infinite bus dynamic model, and an equivalent model should be used in PSCAD.

Table 7 Voltage Reference Step Change Test

Test No	Minimum Simulation Time (s)	SCR and X/R	Initial Active Power at POI (MW)	Initial Reactive Power at POI (MVAR)	Simulation Tool	Acceptance Criteria
4a	30	SCR=3, X/R=10	Pnet	~0	PSSE and PSCAD	**Dynamic Performance** The dynamic performance required in response to a change in voltage control reference is provided in Table 8. Any deviation from the performance target must be accompanied by adequate technical rationale. **Benchmarking Performance** The dynamic performance between PSSE … fullest extent possible, particularly for act… POM.
4b	30	SCR=10, X/R=10	Pnet	~0	PSSE and PSCAD	

[9] The device regulating the active or reactive power at the POI, which can be the PPC, a supplementary dynamic reactive device, or a HVDC converter.

[10] A PPC regulates and controls the networked inverters, devices, and equipment at an IBR plant to meet specified set points and change grid paramete

Table 8 Reactive Power- Voltage Performance[11] for Voltage Reference Step

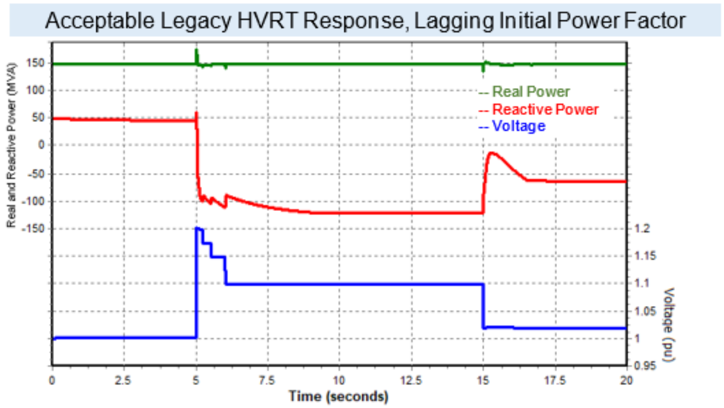
Parameter[2]	Performance Target	Notes
Reaction Time	< 200 ms	
Maximum step response time	< 10 seconds	The response time can be adjusted to allow for a stable and damped response. That is, if it is shown that for the applicable IBR plant and the given grid to which the IBR plant is connected, a stable response requires a response time that marginally exceeds the recommended response time, then this is preferred to provide a stable and damped response.
Damping[12]	Damping Ratio of 0.3 or higher	

Roles and Responsibilities: Grid Operators

- ERCOT

The following criteria apply to both the "preferred" and "legacy" HVRT tests:

- During the high voltage transient, the model should provide a fast dynamic response to absorb reactive power. The resource should be absorbing a significant amount of reactive power at the POI during the high voltage transient, and ideally within 0.5 seconds of the transient inception.
- For 1.1 pu sustained POI voltage, the AVR should move the resource towards nearly full reactive absorbing (significantly leading).
- Real power should be sustained during high voltage condition. A modest real power reduction (typically 5% of Pmax or less) may be acceptable to accommodate greater reactive power absorbed for sustained POI voltages in the range of 1.05 pu to 1.10 pu provided real power fully recovers when POI voltage returns to normal operating range (0.95-1.05 pu).
- An explanation, including a reference to any exempt status per ERCOT Nodal Operating Guide Section 2.9.1, shall be provided for models which indicate that the unit trips or fails to meet any of the above performance criteria.



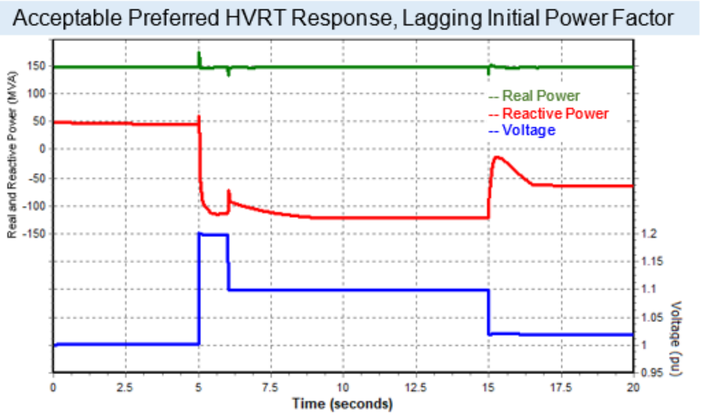
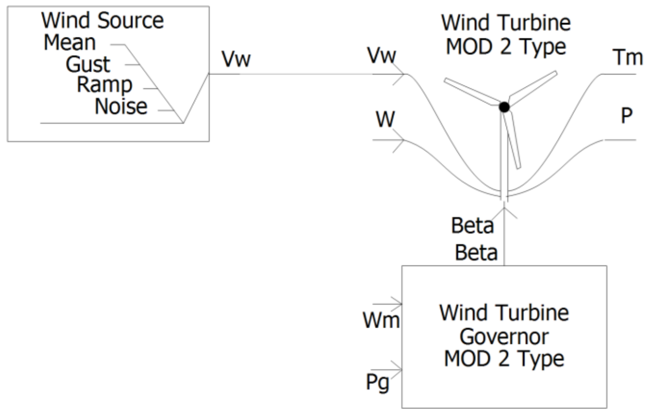


Illustration of an acceptable HVRT response. Real power is maintained and there is a good Reactive power response for voltage support: There is a large amount of reactive absorption during the high voltage transient, followed by the AVR responding to the sustained 1.1 pu POI voltage.

Roles and Responsibilities: OEMs

- Provide EMT unit-level models.
- Equipment Configuration – Who Sets the Parameters?
  - Default settings aligned with grid requirements/industry standards.
  - Site-specific parameters.



Wind Energy Associated Models
(source, governor, turbine)

Roles and Responsibilities: Consultants

- Build plant-level EMT models
- Run compliance studies and tune models to meet requirements
- Flag non-compliance when issues cannot be resolved by tuning—findings may lead to OEM model fixes or firmware updates

Compliant
The model passes and is accurate

Non-Compliant
Equipment or design limitations.

False Compliance
Compliant in model but not in field.

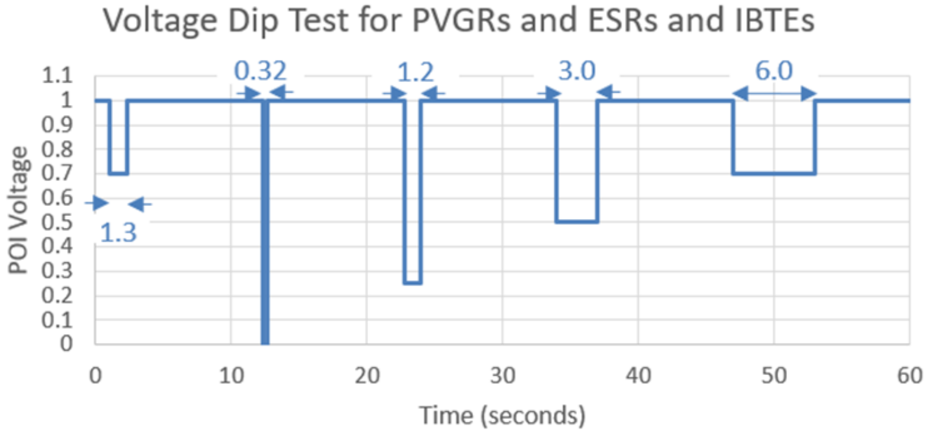
Challenges & Risks

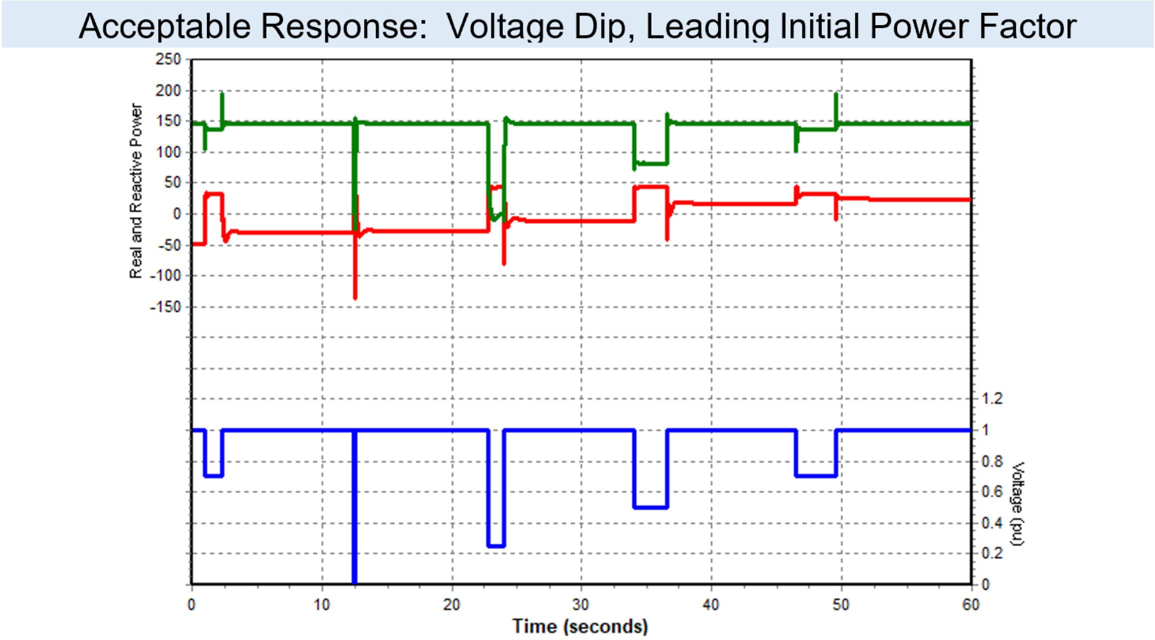
EMT-Based Compliance: Challenges & Risks

- **Tension between requirements:** tuning for one requirement may cause the model to fail another.
- **Equipment and project design limitations:** not all inverters, turbines, or PPCs can meet every grid requirement.
- **Model assumptions and simplifications:** can lead to false compliance.
- **Black-box models:** require iterative testing and expert judgment to uncover control issues and interpret unexpected behavior.

Challenges & Risks: Tension Between Requirements

- ERCOT: low voltage ride-through (reactive vs active current)





Example of acceptable response to the "voltage dip" profile. Real power is observable when the applied voltage dip is 0.5 pu and higher and fully recovers between disturbances when the voltage returns to 1.0 pu. Reactive power injection is observable for the non-zero voltage dips. The transient spikes are numerical and can be ignored.

- During the voltage dips:
  - The model shall inject active current for POI voltage dips of 0.5 and higher.
    - Injections of significantly reduced active current for voltage dips 0.5 pu and 0.7 pu should be accompanied by increased reactive current.
  - Reactive current injection at the POI shall be observable immediately or very shortly after a non-zero voltage dip is applied.

Challenges & Risks: Tension Between Requirements

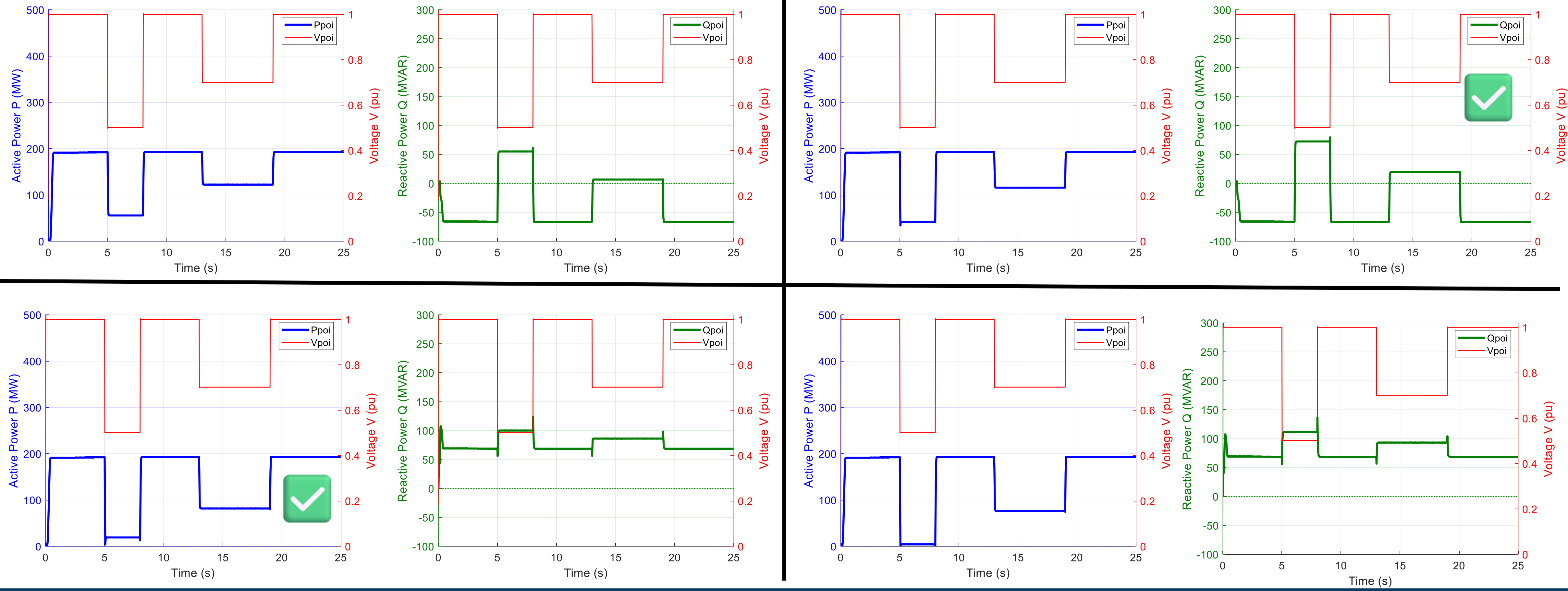
Common Inverter VRT Logic: Pre-fault Reactive Current Considered ($I_q = I_{q0} + K\Delta V$)

K=3

K=4

Leading

Lagging

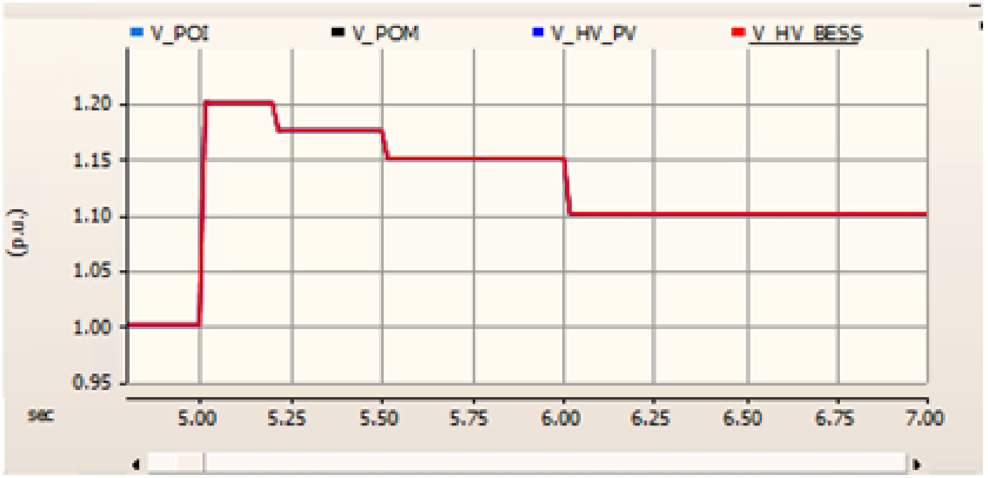


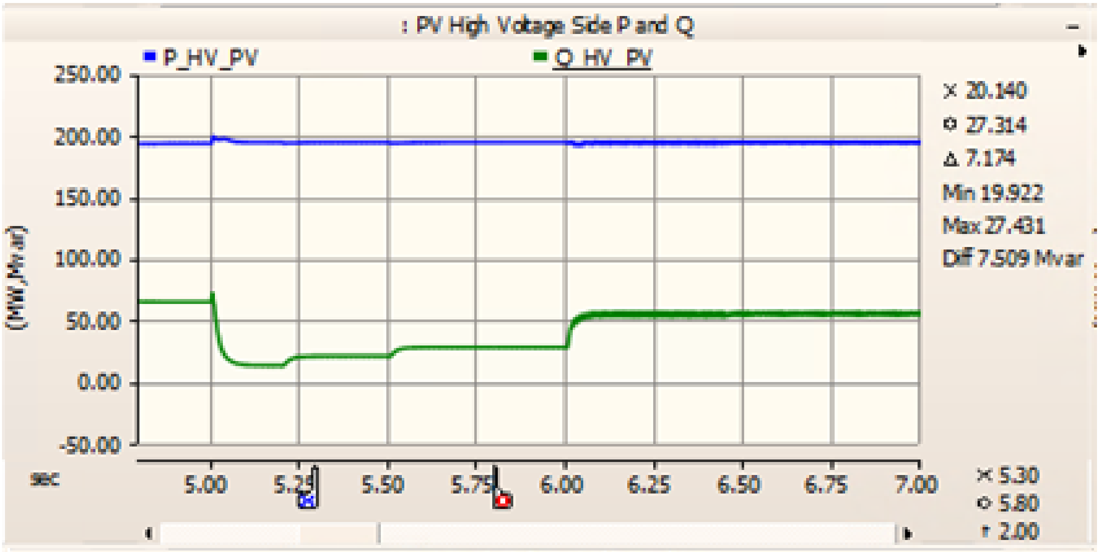
Challenges & Risks: Equipment Limitation

- ERCOT: high voltage ride-through (reactive power)

During the high voltage transient, the model should provide a fast dynamic response to absorb reactive power. The resource should be absorbing a significant amount of reactive power at the POI during the high voltage transient, and ideally within 0.5 seconds of the transient inception.

- Projects with Cap banks?





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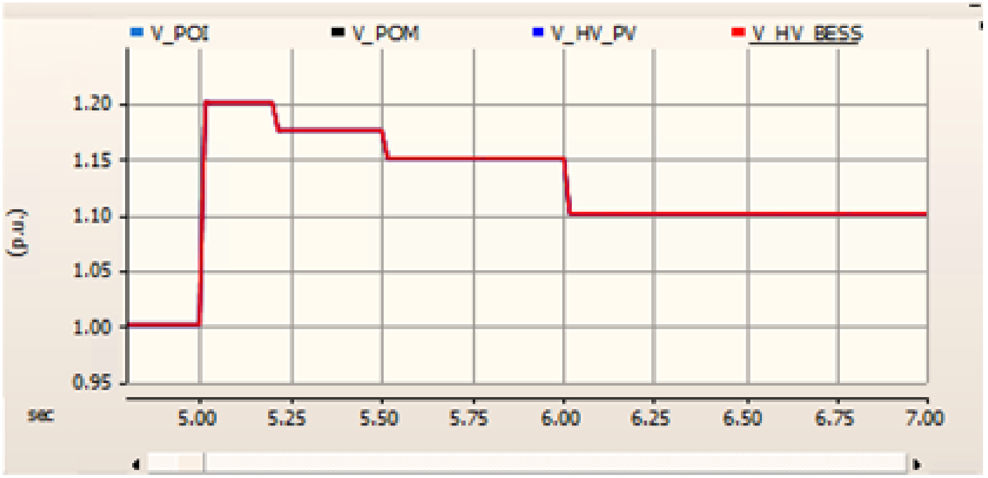
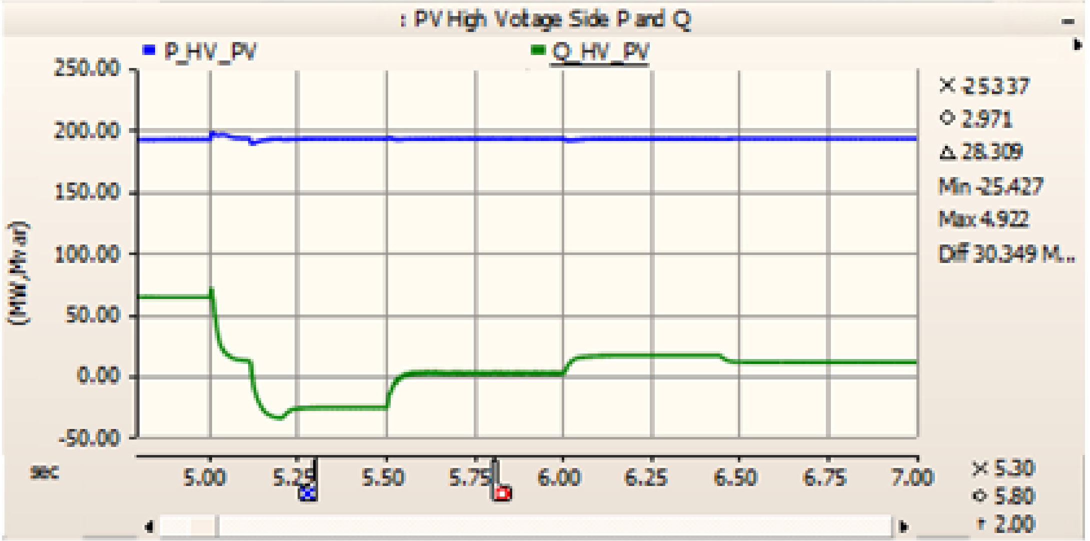
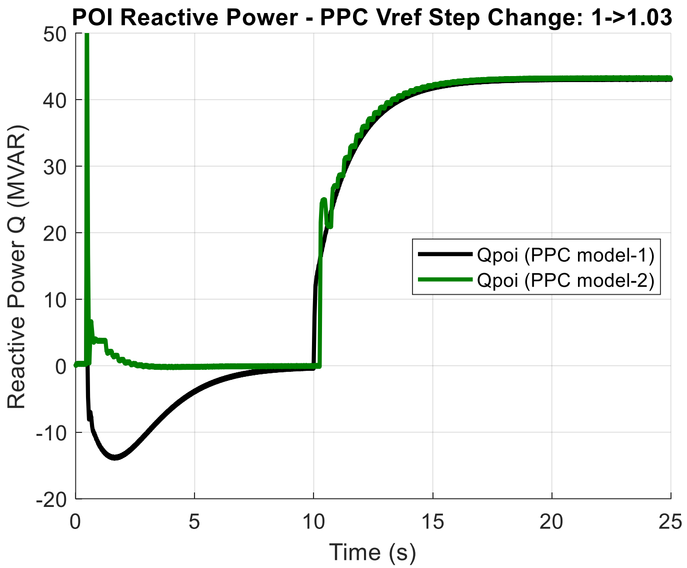


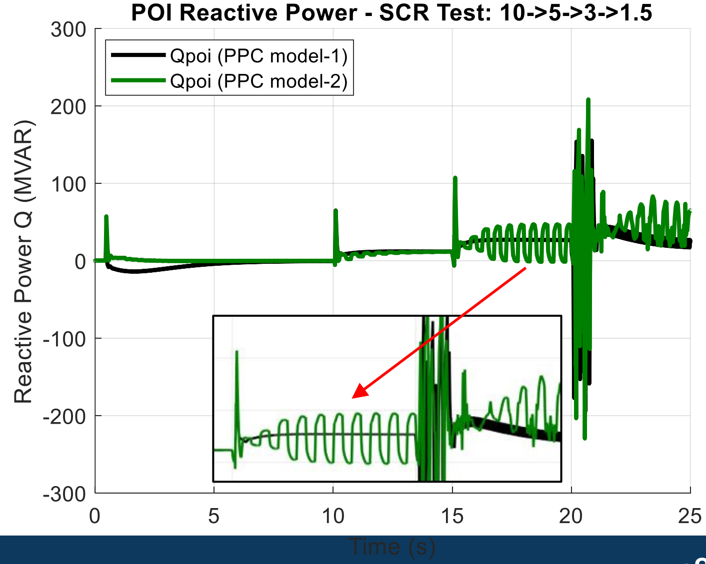


- Projects with Cap banks?
  - Improve inverters ride-through control (schedule constraints)
  - Trip Cap banks

Challenges & Risks: False Compliance

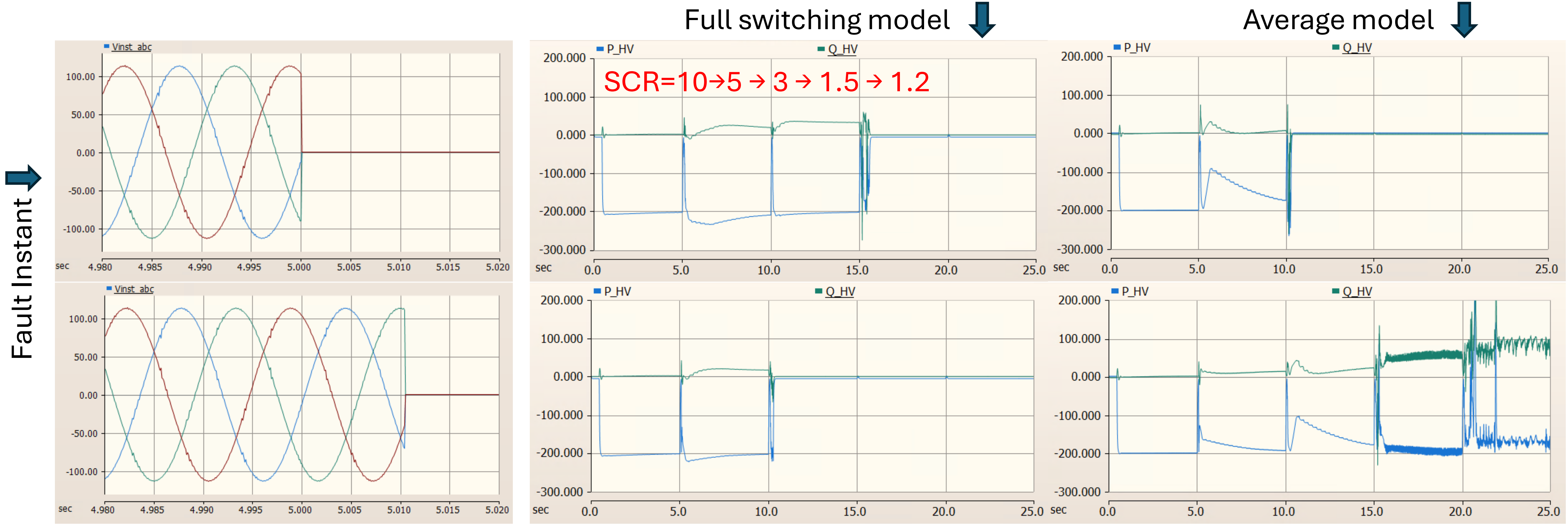
- EMT models may falsely show compliance if they omit or simplify dynamics, e.g., discrete updates or communication delays.
    - EMT models show fast, smooth responses
    - Actual control system may lag or destabilize
- Same PPC, two EMT model revisions. The latest revision includes a new parameter: "inverter write rate."





Challenges & Risks: False Compliance

- Minor simulation details (e.g., fault inception time or inverter model representation) can change compliance outcomes.



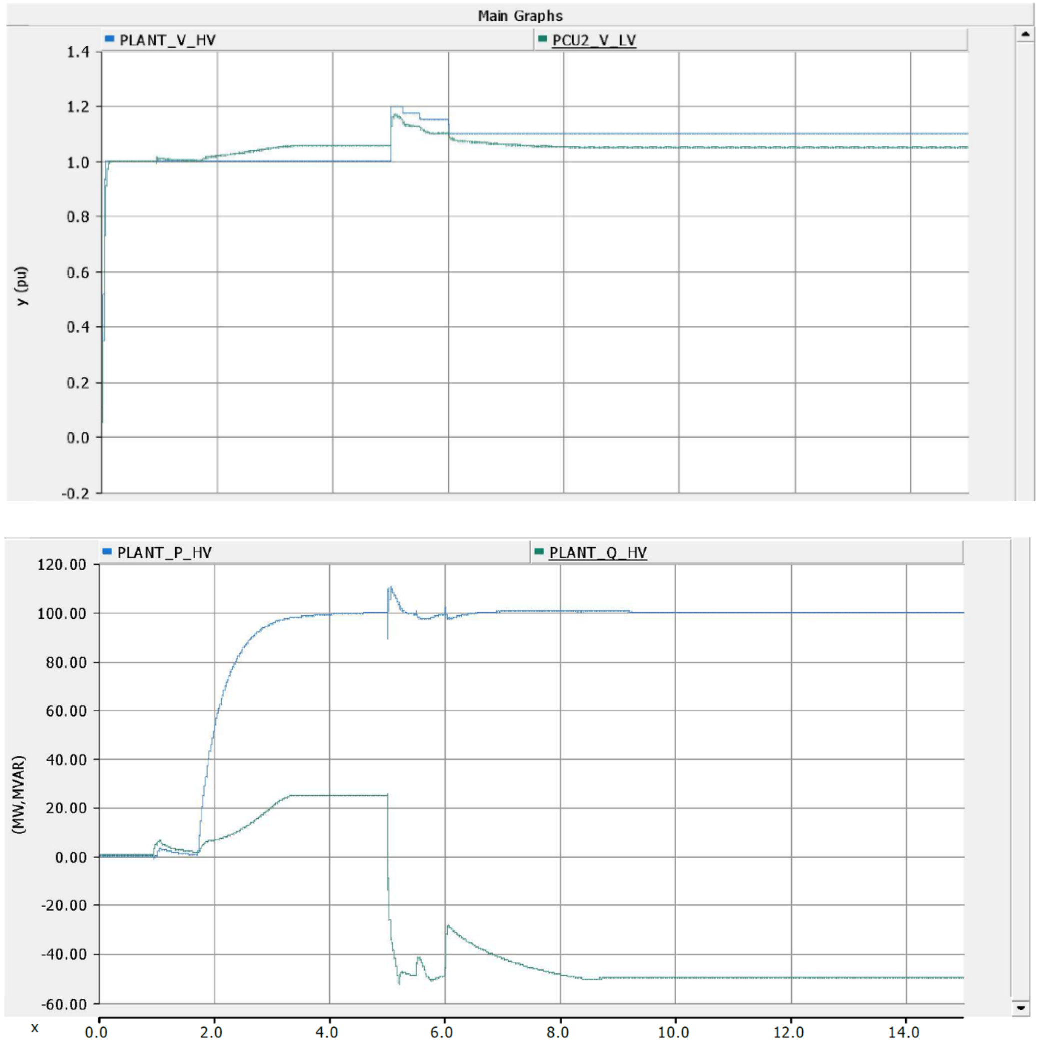
Challenges & Risks: False Compliance

- Model uses local Q(V) control; on-site inverters follow PPC Q commands.

```
# Reactive power as a function of voltage
[redacted]_VARCTLVOL
```

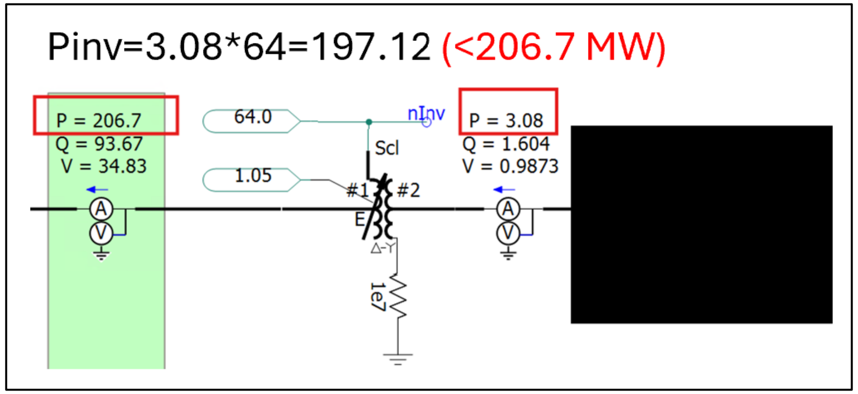
[redacted] **Voltage-dependent reactive power Q(*U*)**

[redacted]



Challenges & Risks: Black-Box Models

- Bugs or errors may appear as:
  - Unexpected responses.
  - Non-physical behavior.



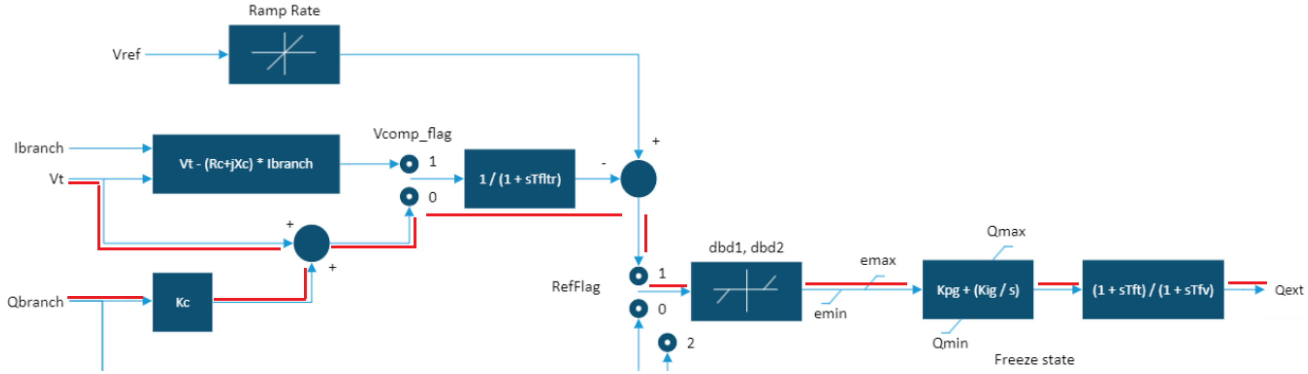
EMT vs RMS: Implications for Model Tuning

EMT vs RMS: Implications for Model Tuning

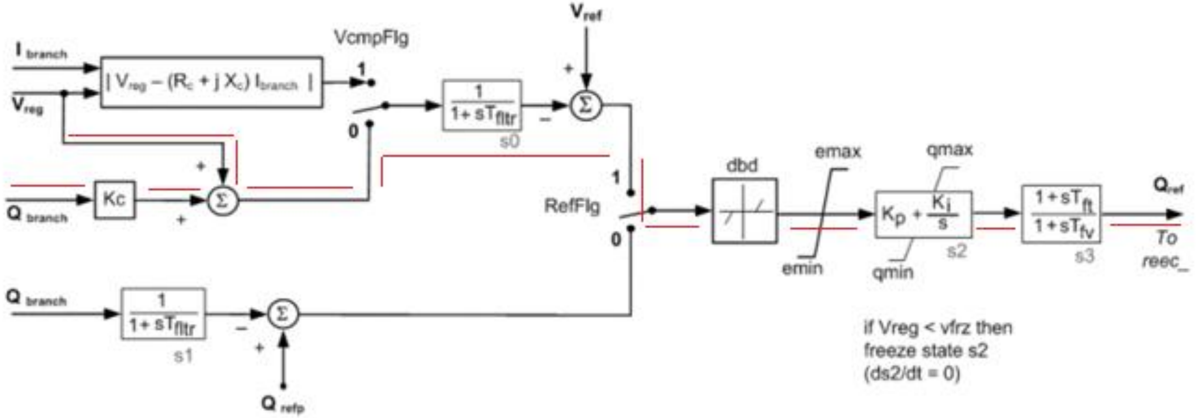
- RMS models are still the primary tool for large-scale planning and interconnection studies.
- Benchmarking EMT vs RMS helps:
  - Identify limitations of RMS models (especially generic models)
  - Improve confidence in system-wide RMS studies

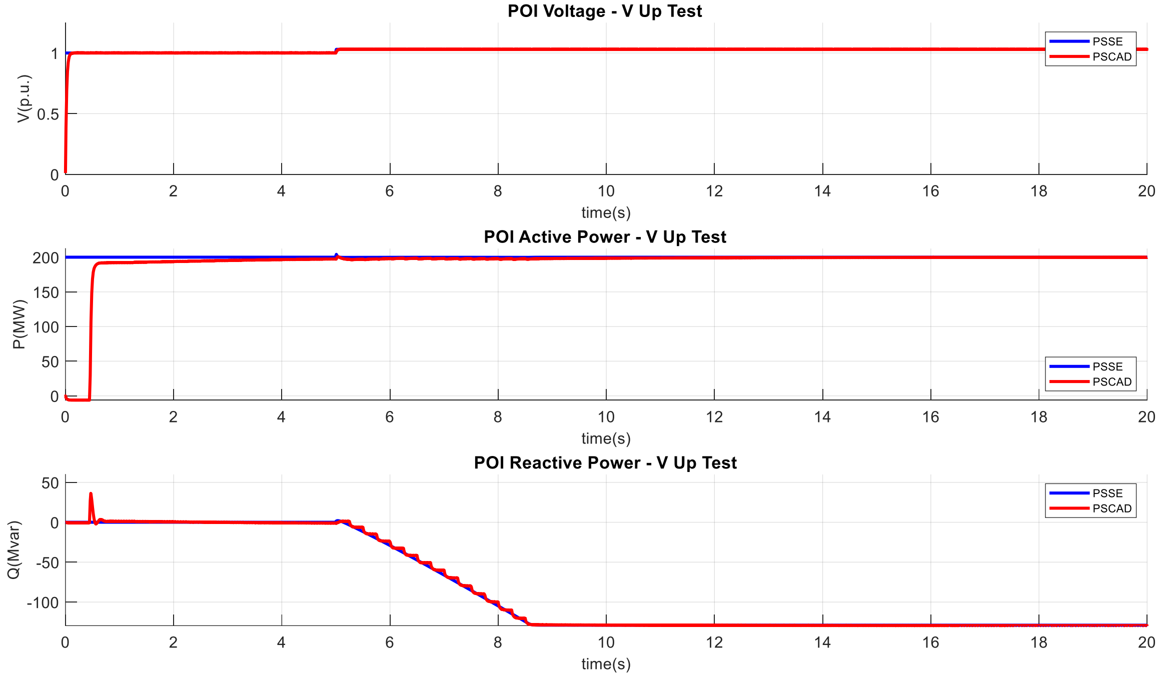
EMT vs RMS: Implications for Model Tuning

Site PPC



REPCA: Generic PPC Model





EMT vs RMS: Implications for Model Tuning

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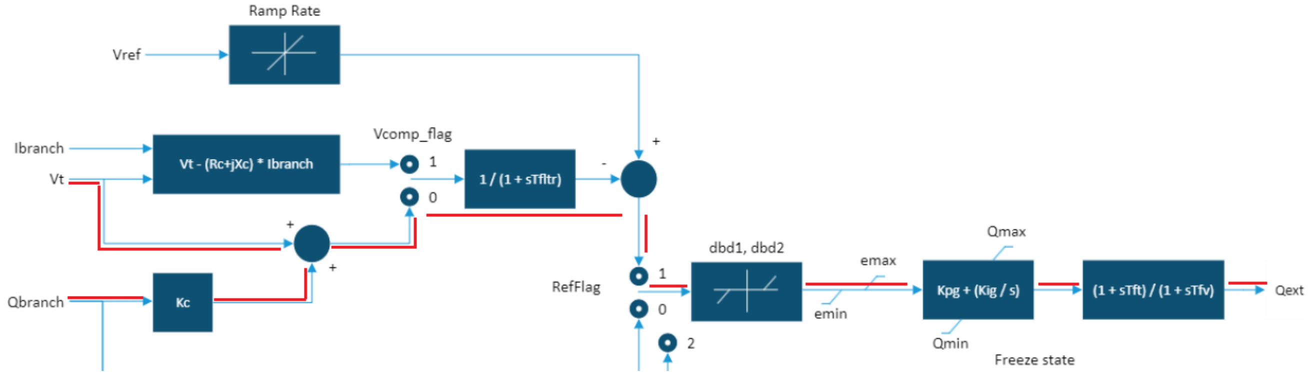

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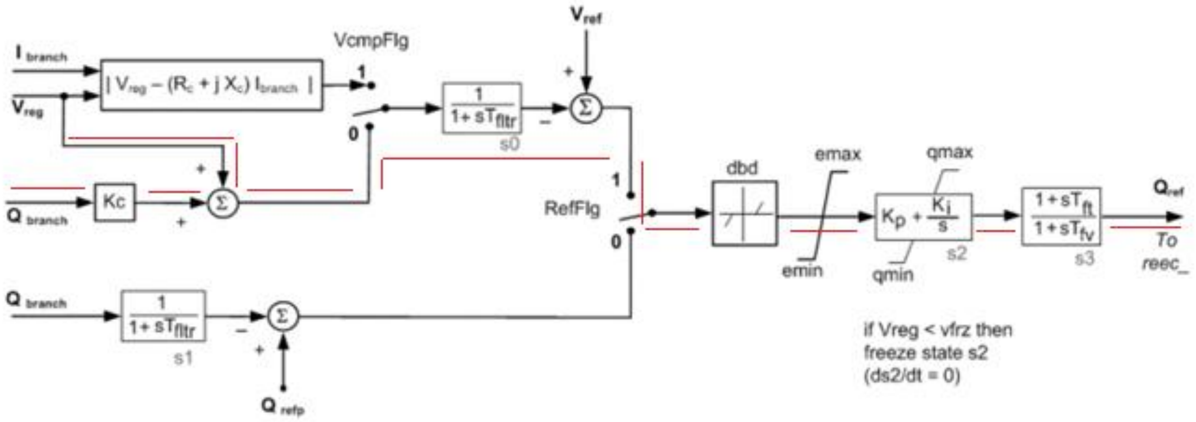
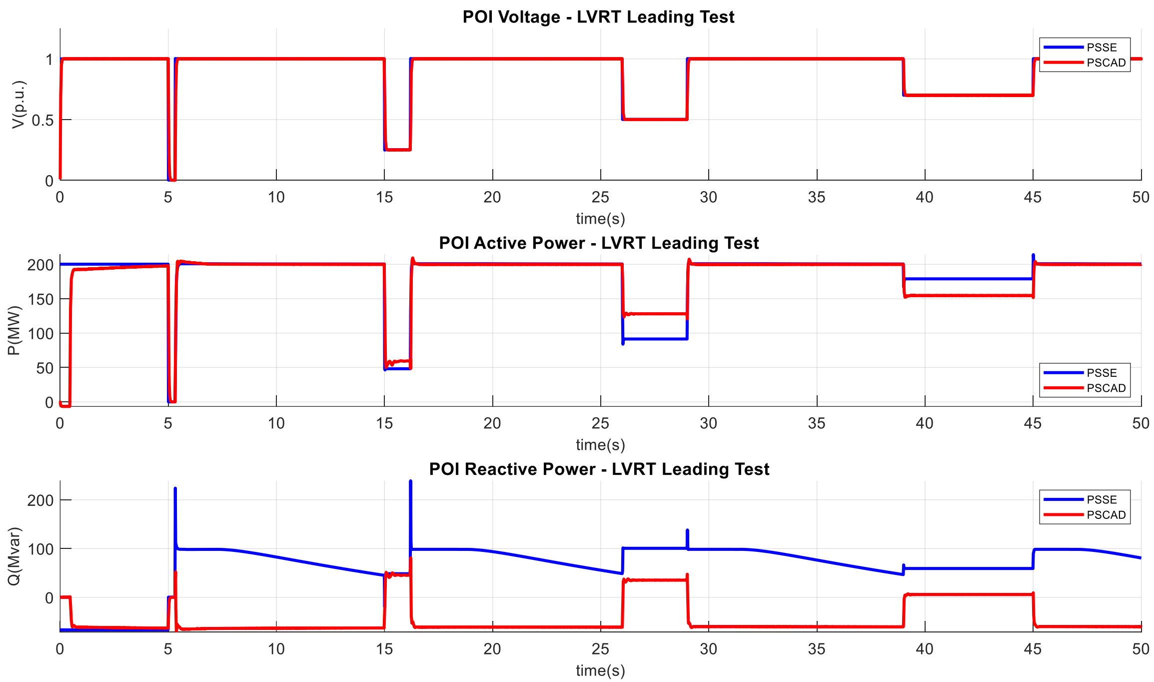
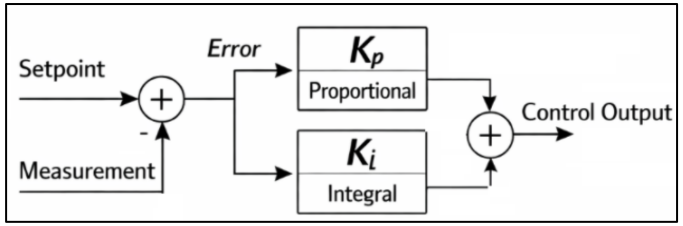
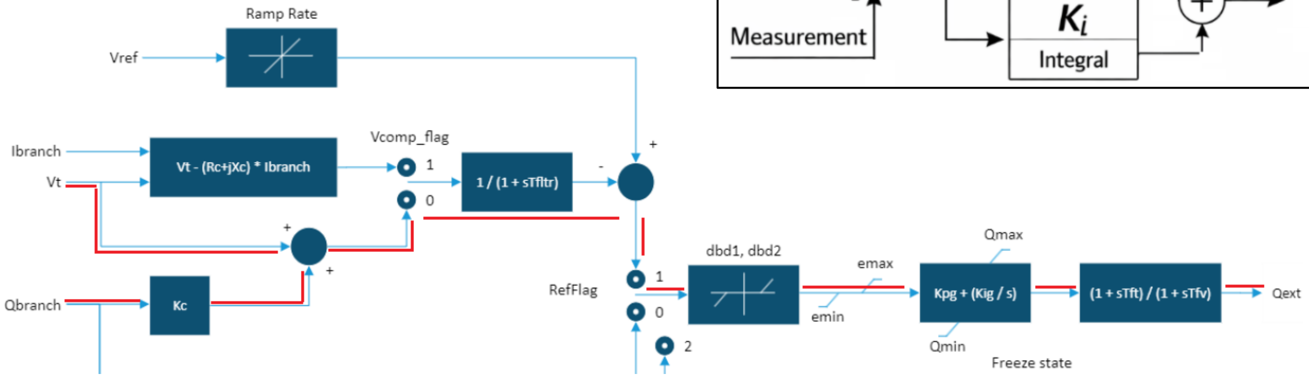




EMT vs RMS: Implications for Model Tuning



Site PPC



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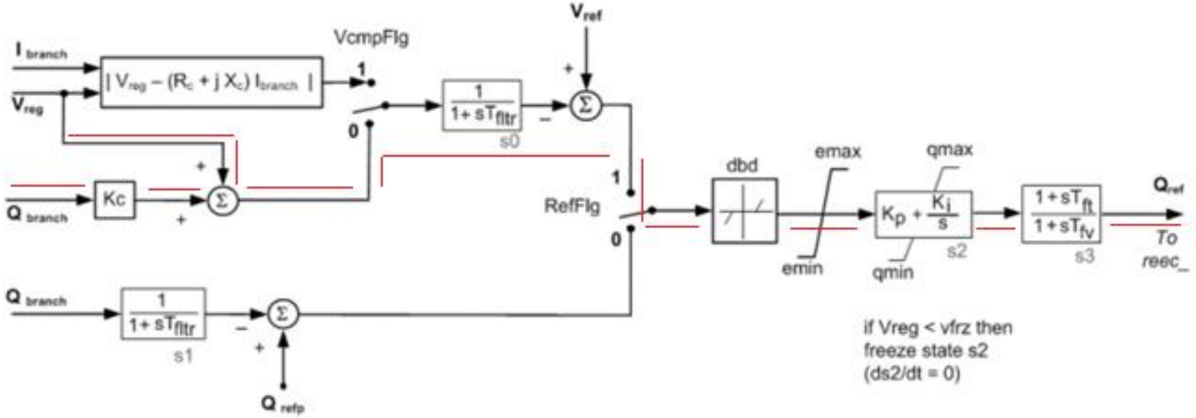

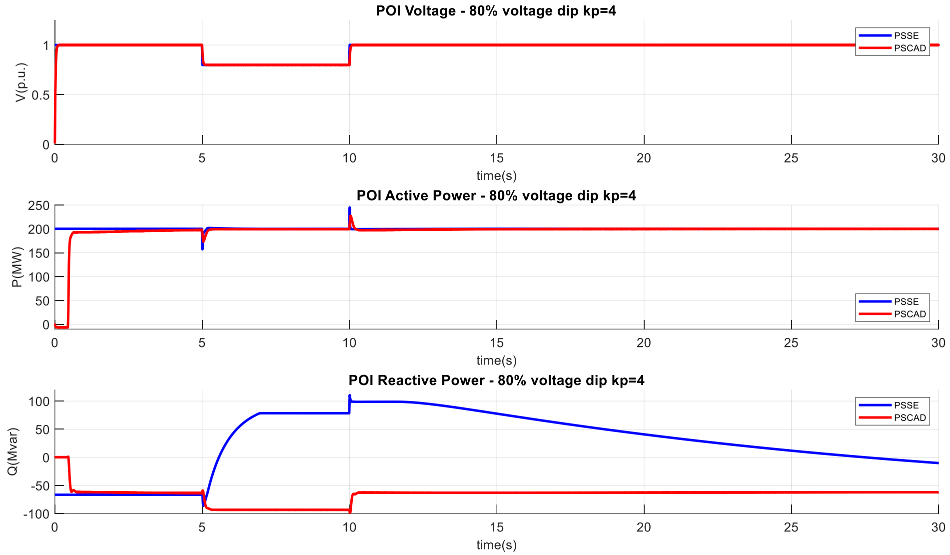

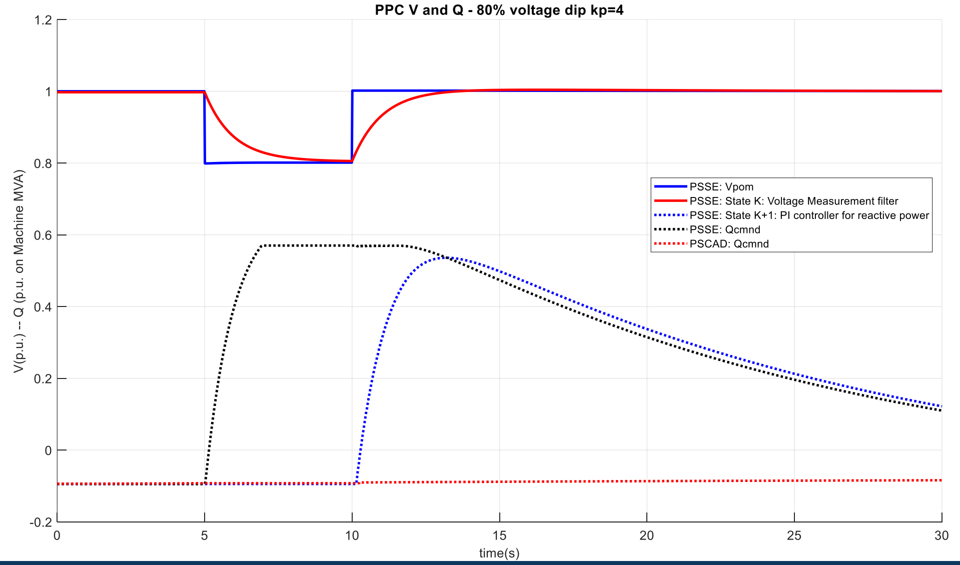

Conclusion

Conclusion

- Project compliance matters—it is essential for ensuring grid reliability.
- EMT models are the primary tool for demonstrating compliance, so accuracy matters just as much as tuning to pass performance tests.
- But getting there (an accurate and compliant model) is not always straightforward—resolving modeling challenges takes close collaboration among consultants, OEMs, grid operators, and project developers.

Thank You!