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WECC

Electromagnetic Transient (EMT) Strategic Workshop

Branden Sudduth

VP, Reliability Planning and Performance Analysis

Electric Reliability
& Security for the West

November 19, 2025

<Public>

Western Interconnection: Resources At A Glance

The Western Interconnection's resource portfolio continues to transform, heavily driven by energy policy.

- 20% increase in annual demand forecasted over next decade
- 24 GW of new resources added in 2024
  - 75% of new generation was inverter-based (IBR)
- Significantly higher than 10-year annual average build rate of 7.4 GW
- Baseload generation retirements

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Inverter-Based Resource Growth

- Over past five years, installed IBR capacity has risen from 52 GW in 2020 to 100 GW in 2024. 2024 resource additions included approximately 18 GW of:
  - 8 GW solar generation, totaling 44 GW as of 2024
  - 3 GW wind generation, totaling 39.3 GW as of 2024
  - 7 GW battery storage, totaling 16.7 GW as of 2024

<Public>

Risk Landscape

The Western Interconnection's risk landscape is "everything, everywhere, all at once."

- Risks increasing in frequency and severity.
- Evolving and dynamically changing risk profiles
  - *Proliferation of IBRs*
  - *Large load interconnections*
  - *Rapid technology deployment*
  - *Extreme natural events*
  - *Energy emergencies*
  - *Security threats*
  - *Etc.*

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EMT: Changing World Requires Changing Approach to Reliability

- EMT has become ***increasingly and critically important*** for reliability
  - High IBR operating conditions
  - Low system strength conditions
  - Large IBR-based technology solutions (e.g., HVDC, large BESS and hybrid plants)
  - Large load dynamics
  - Complex controls, interactions, and stability
- Accurate models are ***essential*** to grid reliability – operate in a known operating state
- Performing EMT studies becoming ***necessary*** to ensure reliability risks are adequately addressed

<Public>

Why We're Here

To bring people together to raise awareness and to give us all an opportunity to educate/learn, share, and gather information:

- Raise awareness and gain a common understanding of the landscape, the need for EMT, existing guidance, and to learn about what's happening on the Reliability Standards front
- Give people an opportunity to learn about what others are doing and identify best practices
- Talk about the critical components of EMT and get alignment around what those critical components are (harmonization)

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WWW.WECC.ORG | (801) 582-0353

155 N 400 W, Salt Lake City, UT 84103, USA

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Workshop Kickoff and Background

Ryan Quint, PhD, PE
President and CEO
Elevate Energy Consulting

November 19, 2025

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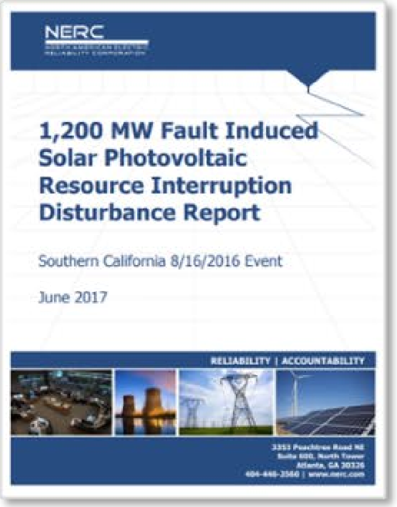
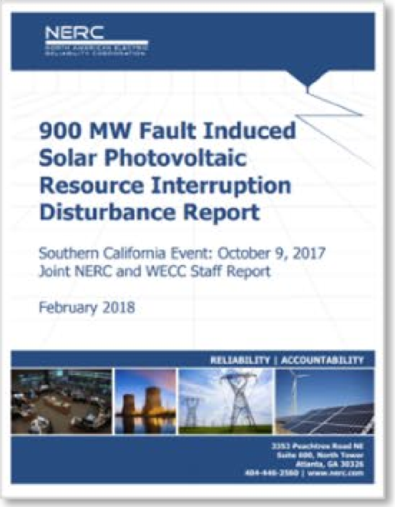
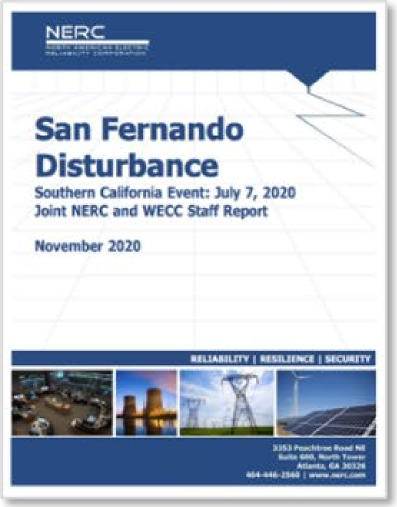
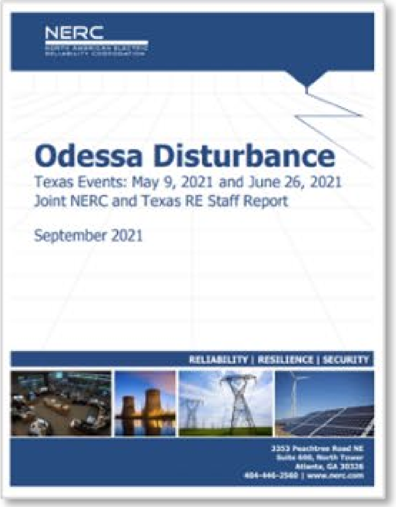
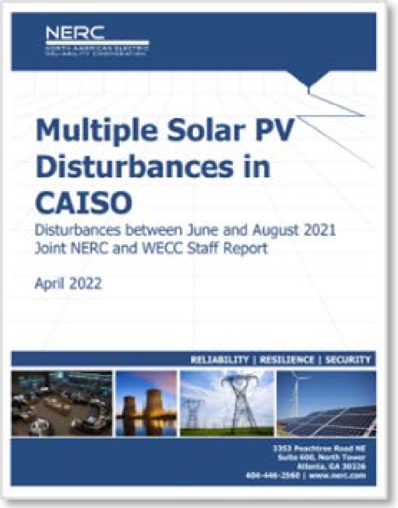

NERC
1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report
Southern California 8/16/2016 Event
June 2017
RELIABILITY | ACCOUNTABILITY

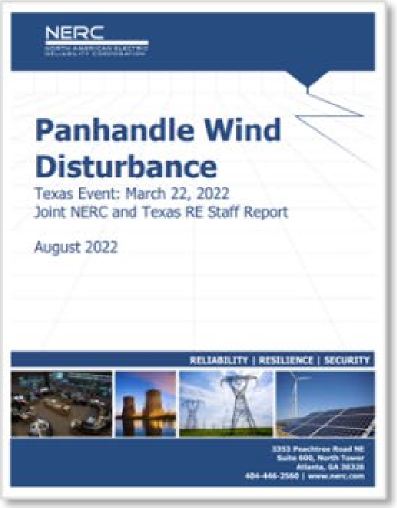

NERC
900 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report
Southern California Event: October 9, 2017
Joint NERC and WECC Staff Report
February 2018
RELIABILITY | ACCOUNTABILITY

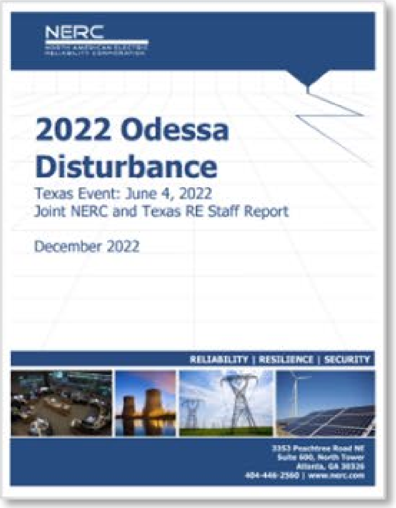

NERC
April and May 2018 Fault Induced Solar Photovoltaic Resource Interruption Disturbances Report
Southern California Events: April 20, 2018 and May 11, 2018
Joint NERC and WECC Staff Report
January 2019
RELIABILITY | ACCOUNTABILITY


NERC
San Fernando Disturbance
Southern California Event: July 7, 2020
Joint NERC and WECC Staff Report
November 2020
RELIABILITY | RESILIENCE | SECURITY


NERC
Odessa Disturbance
Texas Events: May 9, 2021 and June 26, 2021
Joint NERC and Texas RE Staff Report
September 2021
RELIABILITY | RESILIENCE | SECURITY


NERC
Multiple Solar PV Disturbances in CAISO
Disturbances between June and August 2021
Joint NERC and WECC Staff Report
April 2022
RELIABILITY | RESILIENCE | SECURITY


NERC
Panhandle Wind Disturbance
Texas Event: March 22, 2022
Joint NERC and Texas RE Staff Report
August 2022
RELIABILITY | RESILIENCE | SECURITY


NERC
2022 Odessa Disturbance
Texas Event: June 4, 2022
Joint NERC and Texas RE Staff Report
December 2022
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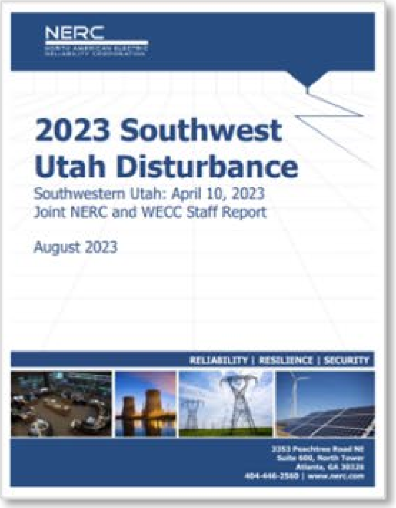
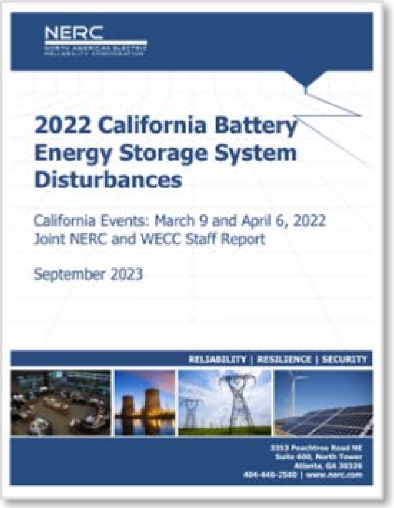

NERC
2023 Southwest Utah Disturbance
Southwestern Utah: April 10, 2023
Joint NERC and WECC Staff Report
August 2023
RELIABILITY | RESILIENCE | SECURITY


NERC
2022 California Battery Energy Storage System Disturbances
California Events: March 9 and April 6, 2022
Joint NERC and WECC Staff Report
September 2023
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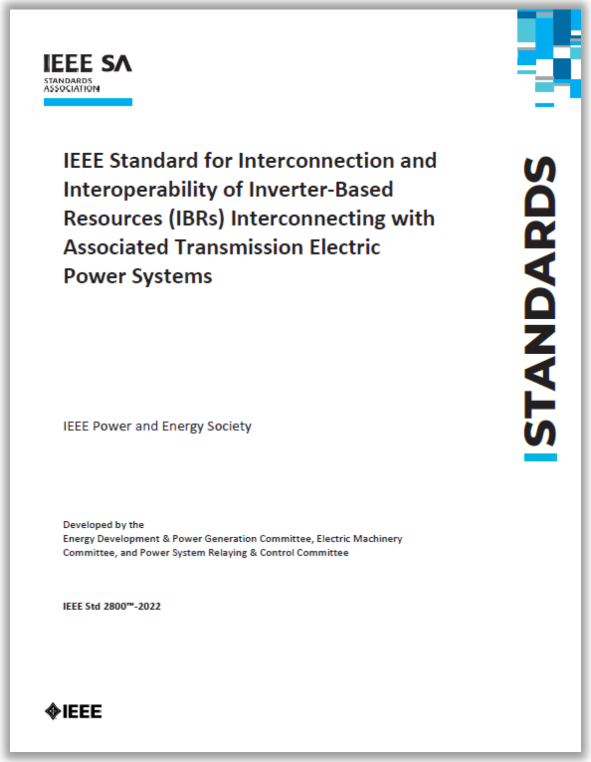


IEEE SA STANDARDS ASSOCIATION

IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems

IEEE Power and Energy Society

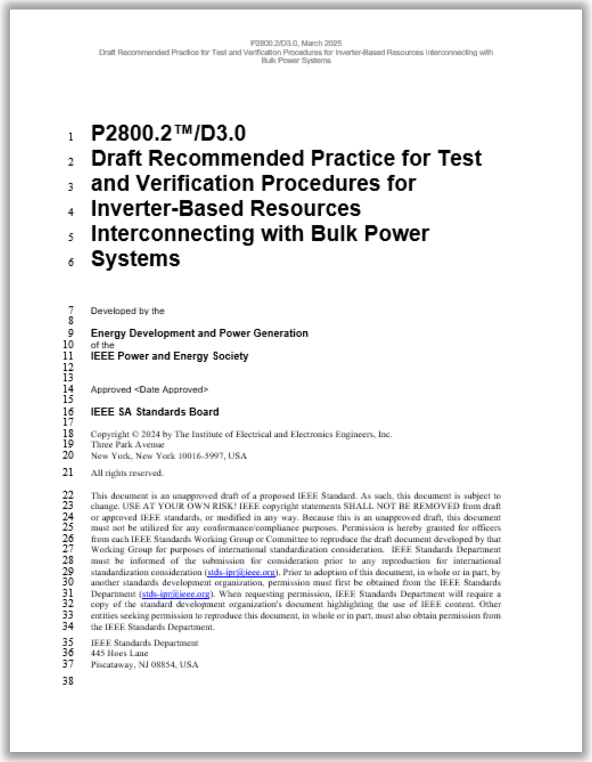
Developed by the
Energy Development & Power Generation Committee, Electric Machinery Committee, and Power System Relaying & Control Committee

IEEE Std 2800™-2022

STANDARDS

IEEE

The What



P2800.2/D3.0, March 2025
Draft Recommended Practice for Test and Verification Procedures for Inverter-Based Resources Interconnecting with Bulk Power Systems

P2800.2™/D3.0
Draft Recommended Practice for Test and Verification Procedures for Inverter-Based Resources Interconnecting with Bulk Power Systems

Developed by the

Energy Development and Power Generation
of the
IEEE Power and Energy Society

Approved <Date Approved>

IEEE SA Standards Board

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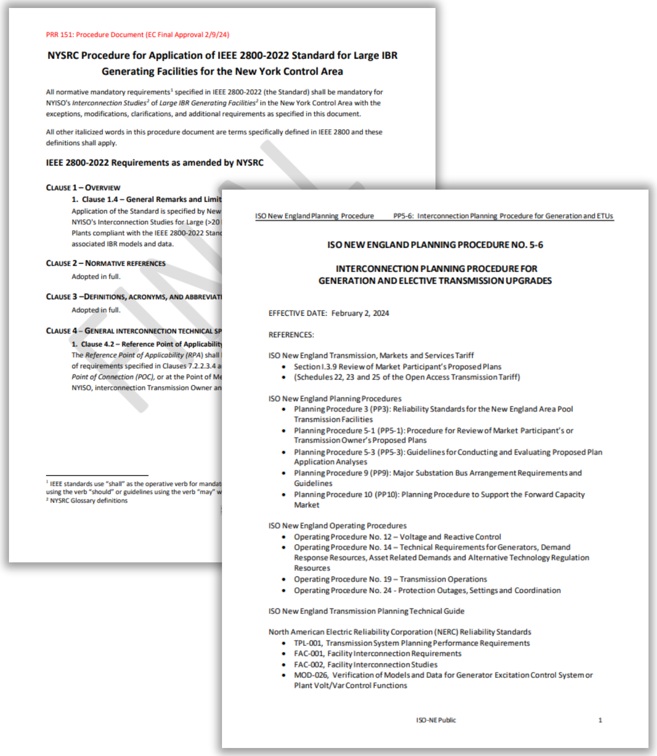

PRR 151: Procedure Document (EC Final Approval 2/9/24)

NYSRC Procedure for Application of IEEE 2800-2022 Standard for Large IBR Generating Facilities for the New York Control Area

All normative mandatory requirements[1] specified in IEEE 2800-2022 (the Standard) shall be mandatory for NYISO's *Interconnection Studies*[2] of *Large IBR Generating Facilities*[2] in the New York Control Area with the exceptions, modifications, clarifications, and additional requirements as specified in this document.

All other italicized words in this procedure document are terms specifically defined in IEEE 2800 and these definitions shall apply.

IEEE 2800-2022 Requirements as amended by NYSRC

CLAUSE 1 – OVERVIEW
1. Clause 1.4 – General Remarks and Limit
Application of the Standard is specified by New
NYISO's Interconnection Studies for Large (>20
Plants compliant with the IEEE 2800-2022 Stand
associated IBR models and data.

CLAUSE 2 – NORMATIVE REFERENCES
Adopted in full.

CLAUSE 3 –DEFINITIONS, ACRONYMS, AND ABBREVIATI
Adopted in full.

CLAUSE 4 – GENERAL INTERCONNECTION TECHNICAL SP
1. Clause 4.2 – Reference Point of Applicability
The *Reference Point of Applicability (RPA)* shall
of requirements specified in Clauses 7.2.2.3.4 a
Point of Connection (POC), or at the Point of Me
NYISO, interconnection Transmission Owner an

[1] IEEE standards use "shall" as the operative verb for mandat
using the verb "should" or guidelines using the verb "may" w
[2] NYSRC Glossary definitions

FINAL

ISO New England Planning Procedure PP5-6: Interconnection Planning Procedure for Generation and ETUs

ISO NEW ENGLAND PLANNING PROCEDURE NO. 5-6

INTERCONNECTION PLANNING PROCEDURE FOR
GENERATION AND ELECTIVE TRANSMISSION UPGRADES

EFFECTIVE DATE: February 2, 2024

REFERENCES:

ISO New England Transmission, Markets and Services Tariff
- Section I.3.9 Review of Market Participant's Proposed Plans
- (Schedules 22, 23 and 25 of the Open Access Transmission Tariff)

ISO New England Planning Procedures
- Planning Procedure 3 (PP3): Reliability Standards for the New England Area Pool Transmission Facilities
- Planning Procedure 5-1 (PP5-1): Procedure for Review of Market Participant's or Transmission Owner's Proposed Plans
- Planning Procedure 5-3 (PP5-3): Guidelines for Conducting and Evaluating Proposed Plan Application Analyses
- Planning Procedure 9 (PP9): Major Substation Bus Arrangement Requirements and Guidelines
- Planning Procedure 10 (PP10): Planning Procedure to Support the Forward Capacity Market

ISO New England Operating Procedures
- Operating Procedure No. 12 – Voltage and Reactive Control
- Operating Procedure No. 14 – Technical Requirements for Generators, Demand Response Resources, Asset Related Demands and Alternative Technology Regulation Resources
- Operating Procedure No. 19 – Transmission Operations
- Operating Procedure No. 24 - Protection Outages, Settings and Coordination

ISO New England Transmission Planning Technical Guide

North American Electric Reliability Corporation (NERC) Reliability Standards
- TPL-001, Transmission System Planning Performance Requirements
- FAC-001, Facility Interconnection Requirements
- FAC-002, Facility Interconnection Studies
- MOD-026, Verification of Models and Data for Generator Excitation Control System or Plant Volt/Var Control Functions

ISO-NE Public 1

Implementation

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- Detailed and accurate modeling
- Reflecting as-left facility settings
- Comprehensive IBR modeling req's
- Adequate proof of conformance
- Positive sequence library model
- Positive sequence user-defined model (UDM)
- Electromagnetic transient (EMT) model
- Site-specific models, verified by OEM
- Benchmarking across models
- List of unacceptable models

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Dynamic Modeling Recommendations

Recommended Modeling Practices and List of Unacceptable Models

Primary Interest Groups

This document applies to Transmission Planners (TP), Planning Coordinators (PC), and MOD-032 designees. The recommendations are also relevant to Generator Owners (GO), original equipment manufacturers (OEM), consultants, and any other organization performing bulk power system (BPS) reliability studies.

Scope and Intended Use

This document replaces the NERC Acceptable Model List, which has historically been used to establish requirements and criteria for the creation of Interconnection-wide base cases by MOD-032 designees. The intent of this paper is to provide clear and more comprehensive recommendations regarding the use of dynamic models for different types of reliability studies. This paper particularly focuses on models used for dynamic stability analyses but does incorporate recommendations for other types of studies as well. MOD-032 designees shall incorporate the recommendations contained herein for their Interconnection-wide case creation processes; TPs and PCs are strongly encouraged to review and incorporate these recommendations in their modeling and study processes.

Recommended Dynamic Modeling Practices

NERC strongly recommends the following framework for dynamic models used in BPS reliability studies:

- All models should be detailed and accurate representations of expected or as-built facilities on the BPS, including during interconnection studies and throughout the lifecycle of a project.
- It is the responsibility of each TP and PC to establish clear, consistent, sufficiently detailed, and comprehensive modeling requirements. These requirements should include model quality checks and updates when needed.
- It is the responsibility of each project developer and GO to meet the modeling requirements established by the TP and PC and to provide adequate proof of conformance to the requirements. It is the responsibility of each GO to maintain an accurate model throughout the lifecycle of the project. GOs shall notify the TP and PC of any expected changes or updates (per NERC FAC-002) for in-service equipment and submit updated models accordingly.
- All TPs and PCs should require all of the following for each generator connected (or seeking interconnection) to the BPS to ensure that sufficient models and supporting documentation are provided:
  - A positive sequence library model that is on the list of unacceptable models found in Appendix A should not be provided. This model is often used by the MOD-032 designee for Interconnection-wide base case creation, and it is often used in studies to represent facilities outside of the TP/PC study area.

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Source: NERC Recommendations

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Industry Recommendation

Inverter-Based Resource Model Quality Deficiencies

Initial Distribution: June 4, 2024

NERC has analyzed 10 large-scale disturbances on the bulk power system (BPS) that involved the widespread and unexpected reduction in output of inverter-based resources (IBR) since 2016. These 10 disturbances totaled nearly 15,000 MW of unexpected IBR output reduction with approximately 10,000 MW occurring between 2020 and 2024. The increase of IBR-related events coincides with an increase in IBR penetration across the BPS. Two contributing causes to these events are poor modeling and study practices to assess the performance of these resources.

Performing dynamic simulations of the BPS allows Transmission Planners (TP), in cooperation with Generator Owners (GO), to mitigate reliability risks before they occur. Accurate dynamic models of resources are critical to this analysis and to BPS reliability. Several of NERC's published disturbance reports included analyses of the models for the affected facilities, which revealed systemic dynamic model inaccuracies. These analyses also revealed that the models provided for conducting generator interconnection studies or other system studies failed to accurately reflect the dynamic performance of the plants. Accurate modeling of IBR facilities is critical in performing system studies to assess the reliable operation of the BPS.

This alert is being distributed to all GOs of Bulk Electric System (BES)-connected IBRs as modeling deficiencies, best practices, and recommendations are applicable across all IBR technologies. NERC encourages owners and operators of non-BES and BPS-connected IBRs to review this alert as well.

The significantly higher complexity and software-based nature of IBR modeling when compared to synchronous machine modeling necessitates an improvement in the fundamental principles of dynamic modeling to accurately capture the performance of IBR plants. This alert is also being distributed to TPs and Planning Coordinators (PC) to provide recommendations that can be implemented to strengthen current modeling practices. TPs and PCs are required to answer a set of questions in the alert system; however, only GOs of IBRs will need to complete the Data Submission Worksheet.

This alert will gather dynamic modeling information from BES-connected IBR GOs, TPs, and PCs to understand the extent of condition of dynamic modeling for IBR, which will inform what additional actions are necessary to mitigate observed deficiencies. These GOs are strongly encouraged to coordinate with their inverter- and plant-level controller manufacturers and third-party consultants to review the parameters and controls installed in the field, review and mitigate modeling deficiencies, and implement the recommendations described in this alert. The information gathered throughout this alert should also be shared and reviewed with the associated GOPs as applicable.

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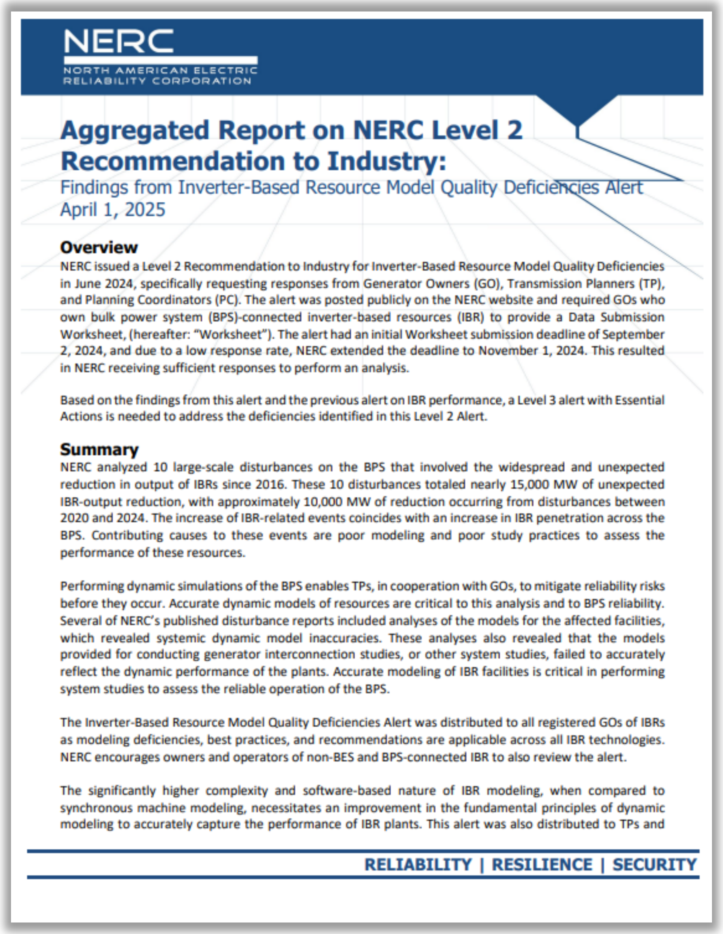
Level 2 Alert on IBR Model Quality Deficiencies (June 2024)

here



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Aggregated Report on NERC Level 2 Recommendation to Industry:

Findings from Inverter-Based Resource Model Quality Deficiencies Alert

April 1, 2025

Overview

NERC issued a Level 2 Recommendation to Industry for Inverter-Based Resource Model Quality Deficiencies in June 2024, specifically requesting responses from Generator Owners (GO), Transmission Planners (TP), and Planning Coordinators (PC). The alert was posted publicly on the NERC website and required GOs who own bulk power system (BPS)-connected inverter-based resources (IBR) to provide a Data Submission Worksheet, (hereafter: "Worksheet"). The alert had an initial Worksheet submission deadline of September 2, 2024, and due to a low response rate, NERC extended the deadline to November 1, 2024. This resulted in NERC receiving sufficient responses to perform an analysis.

Based on the findings from this alert and the previous alert on IBR performance, a Level 3 alert with Essential Actions is needed to address the deficiencies identified in this Level 2 Alert.

Summary

NERC analyzed 10 large-scale disturbances on the BPS that involved the widespread and unexpected reduction in output of IBRs since 2016. These 10 disturbances totaled nearly 15,000 MW of unexpected IBR-output reduction, with approximately 10,000 MW of reduction occurring from disturbances between 2020 and 2024. The increase of IBR-related events coincides with an increase in IBR penetration across the BPS. Contributing causes to these events are poor modeling and poor study practices to assess the performance of these resources.

Performing dynamic simulations of the BPS enables TPs, in cooperation with GOs, to mitigate reliability risks before they occur. Accurate dynamic models of resources are critical to this analysis and to BPS reliability. Several of NERC's published disturbance reports included analyses of the models for the affected facilities, which revealed systemic dynamic model inaccuracies. These analyses also revealed that the models provided for conducting generator interconnection studies, or other system studies, failed to accurately reflect the dynamic performance of the plants. Accurate modeling of IBR facilities is critical in performing system studies to assess the reliable operation of the BPS.

The Inverter-Based Resource Model Quality Deficiencies Alert was distributed to all registered GOs of IBRs as modeling deficiencies, best practices, and recommendations are applicable across all IBR technologies. NERC encourages owners and operators of non-BES and BPS-connected IBR to also review the alert.

The significantly higher complexity and software-based nature of IBR modeling, when compared to synchronous machine modeling, necessitates an improvement in the fundamental principles of dynamic modeling to accurately capture the performance of IBR plants. This alert was also distributed to TPs and

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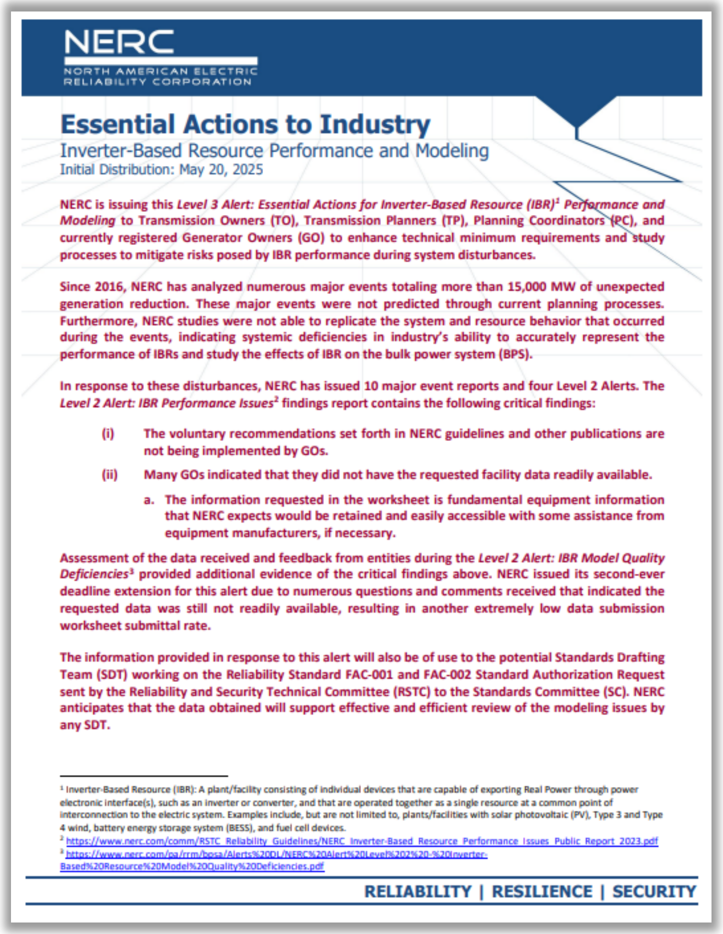
Report on Level 2 Alert on IBR Model Quality Deficiencies (April 2025)

here



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Essential Actions to Industry

Inverter-Based Resource Performance and Modeling

Initial Distribution: May 20, 2025

NERC is issuing this *Level 3 Alert: Essential Actions for Inverter-Based Resource (IBR)*[1] *Performance and Modeling* to Transmission Owners (TO), Transmission Planners (TP), Planning Coordinators (PC), and currently registered Generator Owners (GO) to enhance technical minimum requirements and study processes to mitigate risks posed by IBR performance during system disturbances.

Since 2016, NERC has analyzed numerous major events totaling more than 15,000 MW of unexpected generation reduction. These major events were not predicted through current planning processes. Furthermore, NERC studies were not able to replicate the system and resource behavior that occurred during the events, indicating systemic deficiencies in industry's ability to accurately represent the performance of IBRs and study the effects of IBR on the bulk power system (BPS).

In response to these disturbances, NERC has issued 10 major event reports and four Level 2 Alerts. The *Level 2 Alert: IBR Performance Issues*[2] findings report contains the following critical findings:

(i) The voluntary recommendations set forth in NERC guidelines and other publications are not being implemented by GOs.

(ii) Many GOs indicated that they did not have the requested facility data readily available.

a. The information requested in the worksheet is fundamental equipment information that NERC expects would be retained and easily accessible with some assistance from equipment manufacturers, if necessary.

Assessment of the data received and feedback from entities during the *Level 2 Alert: IBR Model Quality Deficiencies*[3] provided additional evidence of the critical findings above. NERC issued its second-ever deadline extension for this alert due to numerous questions and comments received that indicated the requested data was still not readily available, resulting in another extremely low data submission worksheet submittal rate.

The information provided in response to this alert will also be of use to the potential Standards Drafting Team (SDT) working on the Reliability Standard FAC-001 and FAC-002 Standard Authorization Request sent by the Reliability and Security Technical Committee (RSTC) to the Standards Committee (SC). NERC anticipates that the data obtained will support effective and efficient review of the modeling issues by any SDT.

[1] Inverter-Based Resource (IBR): A plant/facility consisting of individual devices that are capable of exporting Real Power through power electronic interface(s), such as an inverter or converter, and that are operated together as a single resource at a common point of interconnection to the electric system. Examples include, but are not limited to, plants/facilities with solar photovoltaic (PV), Type 3 and Type 4 wind, battery energy storage system (BESS), and fuel cell devices.

[2] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/NERC_Inverter-Based_Resource_Performance_Issues_Public_Report_2023.pdf

[3] https://www.nerc.com/pa/rrm/bpsa/Alerts%20DL/NERC%20Alert%20Level%202%20-%20Inverter-Based%20Resource%20Model%20Quality%20Deficiencies.pdf

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Level 3 Alert on IBR Performance and Modeling (May 2025)

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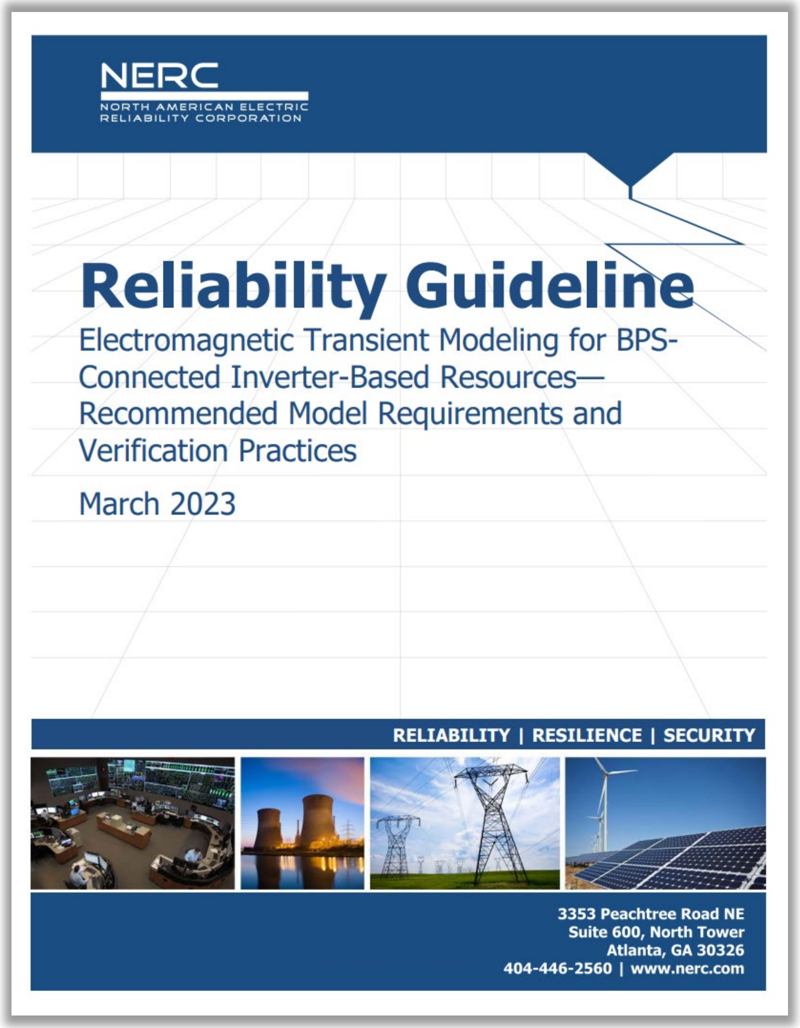
NERC Guidelines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Reliability Guideline

Electromagnetic Transient Modeling for BPS-Connected Inverter-Based Resources—Recommended Model Requirements and Verification Practices

March 2023

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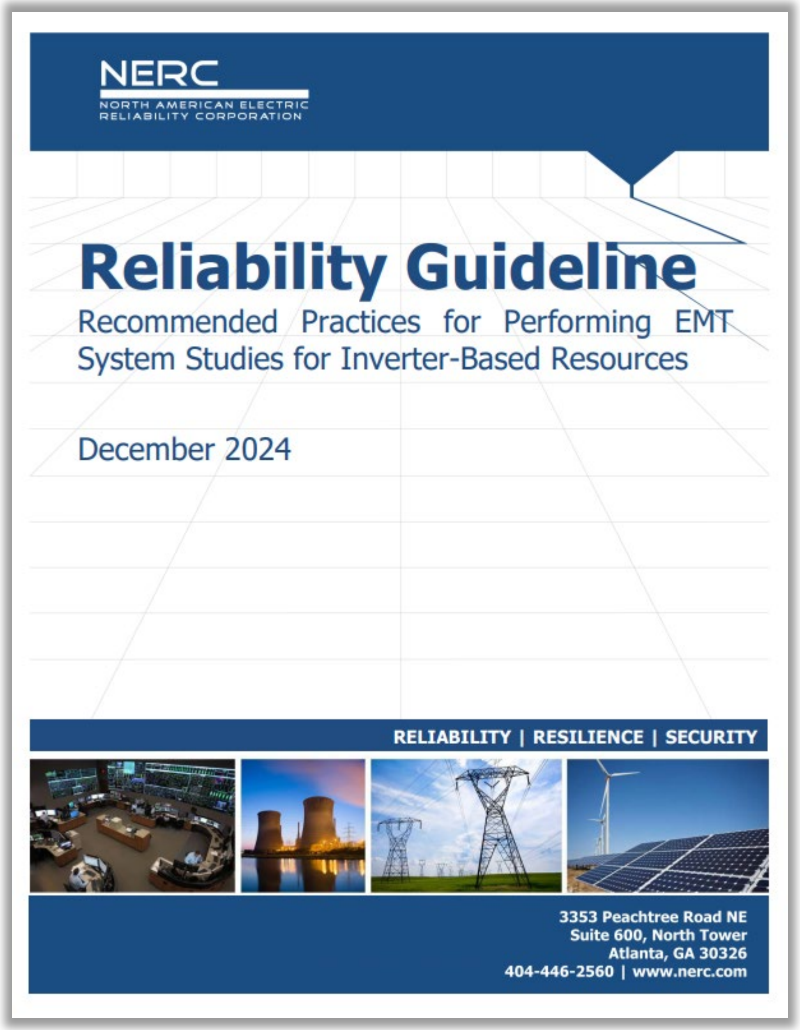
3353 Peachtree Road NE
Suite 600, North Tower
Atlanta, GA 30326
404-446-2560 | www.nerc.com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Reliability Guideline

Recommended Practices for Performing EMT System Studies for Inverter-Based Resources

December 2024

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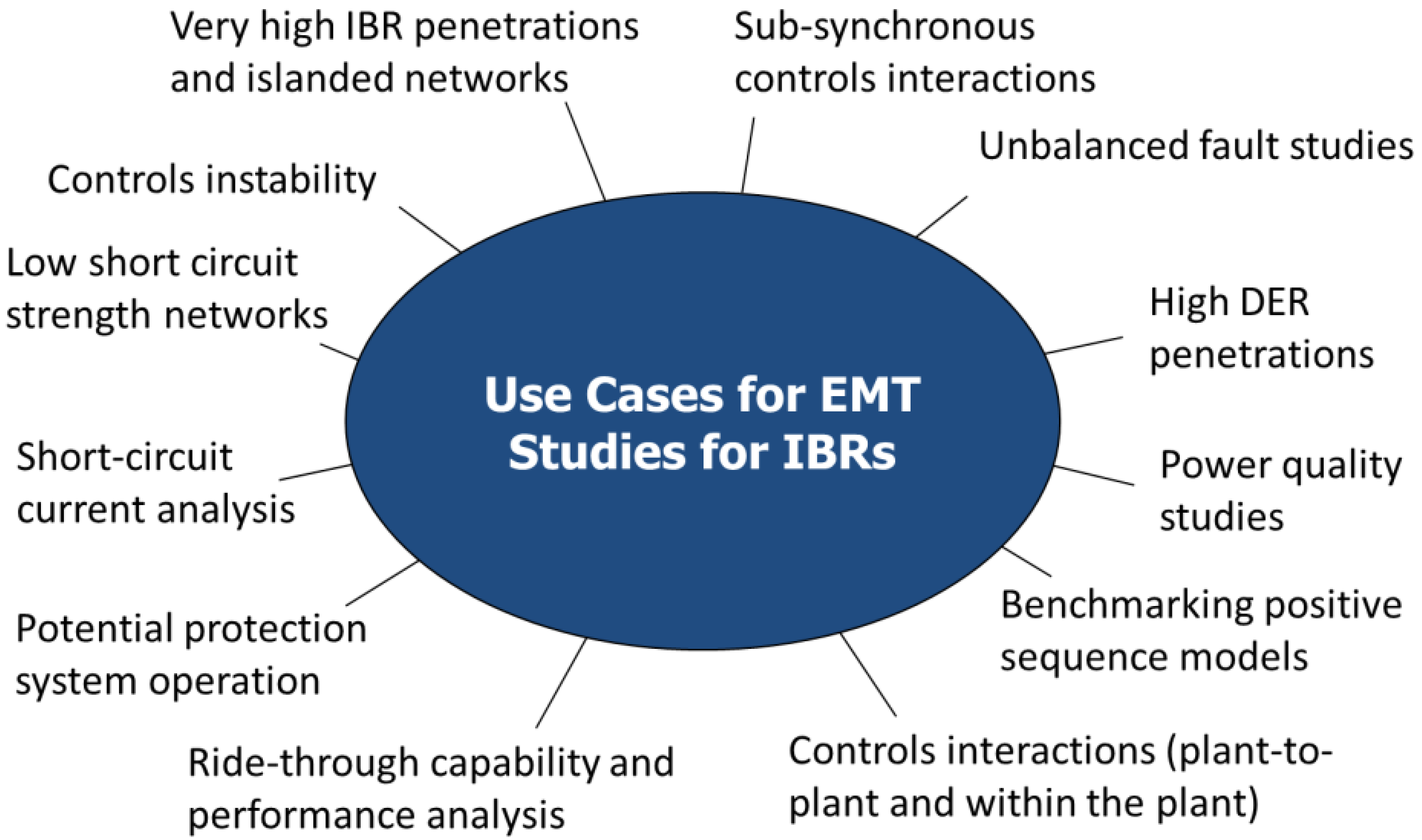

NERC EMT Guideline (2023)

Day 1—November 19, 2025

<Public>

Time (MT)	Topic	Presenters
8:00 a.m.	**Continental Breakfast and Check-in**	
8:30 a.m.	**Opening Keynote** Inventing the Future of EMT Modeling and Studies in the West	Branden Sudduth, WECC
8:45 a.m.	**Workshop Kickoff and Background** Workshop Goals, Objectives, and Background	Ryan Quint, Elevate
9:00 a.m.	**Panel 1: EMT Drivers, Needs, and the IBR Business Case** The Importance of EMT Modeling and Industry Experience Building EMT Expertise EMT Modeling and IEEE 2800-Series Interconnection Standards Overview of NERC Project 2022-04 EMT Modeling and Project 2020-06 Model Verification and Validation	Julia Matevosyan, ESIG Andy Hoke, NREL Mike Marz, ATC
10:15 a.m.	**Break**	
10:30 a.m.	**Panel 2: EMT Modeling Requirements** SRP Experience Building EMT Modeling Requirements and Gathering EMT Models from Developers EMT Models and Studies in CAISO PacifiCorp EMT Modeling Requirements	Bo Gong, SRP Ebrahim Rahimi, CAISO Rikin Shah, PAC
Noon	**Lunch**	

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Day 1—November 19, 2025

Time (MT)	Topic	Presenters
1:00 p.m.	**Panel 3: EMT Model Quality Checks and Testing—Pt. 1** Electranix Model Requirements: History and Philosophy EMT Model Quality Checks and Testing Requirements and Recommended Practices in IEEE 2800-2022 and IEEEP2800.2	Anuradha Kariyawasam, E-TRAN Julia Matevosyan, ESIG
1:45 p.m.	**Break**	
2:00 p.m.	**Panel 3: EMT Model Quality Checks and Testing—Pt. 2** Walkthrough of IBR Model Quality Testing IBR Plant Model Development and Updates EMT Model Development: IBR Plant Owner's Perspective	Kasun Samarasekera, Elevate Katie Iversen, AES Rishi Maharaj, Engie
3:15 p.m.	**Group Discussion: Prioritization, Lessons Learned, Harmonization Opportunities**	Vic Howell, WECC (moderator)
4:00 p.m.	**Adjourn**	
5:00 p.m.	**Networking Opportunity at HallPass**	(Voluntary)

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YOU'RE INVITED

HallPass @ the Gateway

Wednesday, November 19, 5:00 p.m.
53 S Rio Grande Street
Salt Lake City, UT 84101
(Voluntary Dinner)

Join your fellow workshop attendees at HallPass at the Gateway, just a short walk from the WECC office. Utah's first food hall features a fully stocked bar and a variety of fast-casual dining options, from bao buns to lobster rolls. *Participants are responsible for their own meal costs.*

Anchored by Las Vegas' SkinnyFATS, HallPass offers communal dining in a beautifully designed space with local art and an outdoor patio. Enjoy a range of delicious options, including BBQ, Greek, seafood, and desserts. Highlights include the HOG & Tradition BBQ fries, lamb and feta gyro, and creative dishes like the Cherry Popper Hamburger and "BLOT" sandwich.

Day 2—November 20, 2025

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Time (MT)	Topic	Presenters
8:00 a.m.	**Continental Breakfast**	
8:30 a.m.	**Day 1 Recap**	Enoch Davies, WECC
9:00 a.m.	**Panel 4: EMT Screening Approaches: Where and When is EMT Needed? (Presentations + Discussion)** Harmonized EMT screening and understanding what neighbor PCs are doing Early experience with EMT screening at PGE PG&E EMT Study Screen Approach SDG&E Screening Approach and Studies	 Ben Hutchins, WPP Ian Beil, PGE Sophie Xu, PG&E Hassan Baklou, SDG&E
10:15 a.m.	**Break**	
10:30 a.m.	**Panel 5: EMT System Studies: Experience, Tools, and Practices (Presentations + Discussion)** ERCOT Large-Scale PSCAD Simulations EMT Modeling and Studies Experience at Idaho Power ATC EMT Study Experience with IBRs, Data Centers, etc. From Vision to Reality: Ontario's Path to EMT Adoption	 Scott Zuloaga, Moinul Islam, ERCOT Andrés Valdepeña Delgado, IPC Mike Marz, ATC Mohamed ElNozahy, IESO
12:15 p.m.	**Lunch**	
1:15 p.m.	**Input and Feedback Session—Roadmap for the Future (Open Discussion)** Feedback and Learnings from Panel Sessions WECC's Role in Helping the West Advance EMT Modeling and Studies—Industry Feedback	 Ryan Quint, Elevate Vic Howell, WECC
3:00 p.m.	**Adjourn**	

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- Sharing insights and perspectives among diverse backgrounds
- Learning from peers and colleagues across the West
- Identifying opportunities for harmonization and establishing best practices
- Determining areas where additional education, support, or effort is needed
- Thinking about what an *“invented future”* may look like for EMT in the West

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- Invited speakers to start panels
- Extended Q&A and discussion
- Intended for ***active*** audience participation

- Build upon each other
- Respect others' ideas, opinions, and perspectives
- Think outside the box; get creative
- Have fun, enjoy the sessions
- Connect with colleagues and friends; make new ones!

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The Importance of EMT Modeling and Industry Experience Building EMT Expertise

Julia Matevosyan

Associate Director and Chief Engineer

ESIG

ESIG
ENERGY SYSTEMS INTEGRATION GROUP

11/18/2025

<Public>

Why Electromagnetic Transient (EMT) Studies?

- Previously, EMT modeling and analysis was used for specific local phenomena (lightning evaluation, insulation coordination, transformer and line energization, harmonic analysis)
- With proliferation on inverter-based resources (IBRs), FACTs devices, HVDC and power electronic interfaced loads, the dynamic behavior of power systems is becoming impacted by fast-response power electronic devices.
- New stability concerns are being observed such as e.g. sub-synchronous control interactions, particularly in weak parts of the grid with multiple IBRs. .
- Need for studies in simulation environment capable of capturing fast (sub-cycle) dynamic phenomena.
- Additionally, large disturbance events resulting in tripping of multiple IBRs have revealed another challenge, where more detailed (but also more accurate) models can help with timely detection and mitigation

<Public>

Growth of IBRs and Importance of EMT Models

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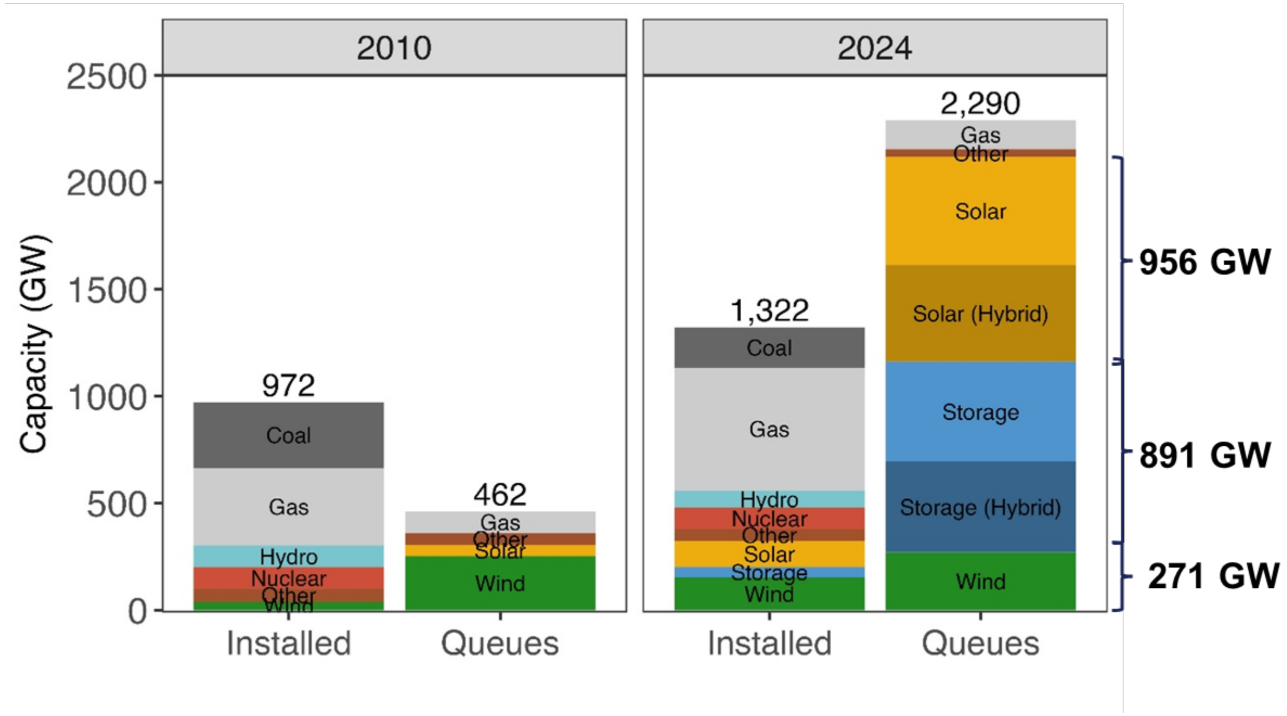
- Over 2500 GW of capacity in the U.S. queues, as of the end of 2023, majority are IBRs
- Growing need for EMT modeling as the system evolves to weaker grids and more advanced controls
- EMT models are important not just for EMT studies but for IBR conformity assessment with applicable requirements and benchmarking with PDT models
- Only a few areas in the U.S. currently are collecting EMT models during interconnection process
- Missed opportunity of post-commissioning model validation
- Manufacturers are discontinuing products or going out of business – EMT models are hard to obtain at that stage

By the time EMT study is needed collecting models is too late!!!!

Generation interconnection requests in the U.S. compared to installed capacity, 2010 and 2024



Source: LBNL, [Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection]

<Public>

How EMT is Used Today?

Questions	AEMO	ERCOT	CAISO	ISO-NE	NESO	EirGrid	Fingrid	Energinet	SvK	Amprion	50 Herz	TenneT	RTE	REE
Are EMT models required?	Yes	Yes	Yes[1]	Yes	Yes	Yes, no enforce ment	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes, in special cases
Who the requirement apply to?	All gen. > 5 MW and LLs	IBRs and LLs[2]	IBRs > 10 MVA at ≥60 kV and some SGs[2]	IBRs	HVDC and IBRs	All users of the power system	IBRs	All gen. and LLs	IBRs and some SGs[2]	IBRs, HVDC, STATCOM and LLs at ≥ 220 kV	offshore wind plants	HVDC and IBRs	IBRs and LLs	IBRs
When was the requirement introduced?	2018	IBRs[2] 2013, All 2015	2019	2014	HVDC 2010, IBRs 2022	~ 2016	IBRs[2] 2020, All 2022	~ 2016	2020	~ 2012	2019	HVDC always, IBRs 2024[3]	2019	2019
Are models for legacy plants required?	Upon request	Upon request	Yes	Upon request[4]	Req. under develop ment	Req. under develop ment	"Proxy"[5] models, built as needed	Consultants build models, as needed	Not yet	Upon request	No	Plan to start in 2024	No	Upon request
Is MQT required?	Yes	Yes	Yes	Yes	Yes	Yes[6]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Is model validation required?	Yes	Yes	Yes	No	Yes	Yes[6]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Is there "as-built" evaluation?[7]	Yes	Yes	Yes	Under develop ment	Yes	Plan to develop	Yes[6], more req. for GFM	Some validation with site tests	Yes[2]	Not yet.	Not yet	Yes	Yes, using site tests	Yes[8]
Is there model validation based on disturbance event data?	No formal process, validation with select events	No formal process, validation with select events[9]	No formal process, validation with select events[9]	Under develop ment	Under consider ation	Plan to develop	Only for hybrid plants and GFM BESSs.	No formal process, validation with select events	Yes[10]	Specific events replicated with EMT models	Not yet	No	No	No

Source: IEEE PES Power and Energy Magazine, July/August 2025

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Australian Approach to EMT modeling for IBR

Model acceptance testing	Technical performance assessment	Commissioning and compliance tests	Post-commissioning model validation
SMIB	SMIB and Wide-area	SMIB	SMIB (and wide-area)
EMT and PDT	EMT and PDT	EMT or PDT	EMT and PDT
Generator owner NSP/AEMO DD	Generator owner NSP/AEMO DD	Generator owner	Generator owner NSP /AEMO DD

IBR Plant Conformity Assessment and Role of EMT Models

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As a first step, SMIB applications can be used to assess compliance with applicable interconnection requirements, where such assessment is a common practice. The following requirements are assessed in EMT:

- Withstand capability and plant design for a range of low system strength conditions;
- Establishment of plant's LVRT and HVRT and dynamic reactive current injection capability;
- Frequency studies including susceptibility to high RoCoF and evaluation of frequency protection;
- Assessment of plant's protective functions, that may trigger on sub-cycle phenomena,
- Establishment of consecutive disturbance ride-through capability;
- Transformer energization impact;
- Short circuit current contribution for unbalanced faults;
- Switching studies of plant's reactive compensation equipment; and
- Benchmarking grid code compliance tests between PDT and EMT software.

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Key Takeaways

- EMT modeling and studies are becoming increasingly important at interconnection of IBRs.
- Vendor and site-specific high fidelity EMT models are key for obtaining meaningful and accurate study results; need for model validation, verification and quality testing
- Collecting EMT models during interconnection process is recommended; retroactive model development is challenging, time-consuming, lacks accuracy, reduces validity of study results.
- EMT models of newly-connecting plants can be used for grid code compliance assessment in a SMIB; in some areas wider-area EMT studies are needed as a part of grid impact assessment.
- Wider-area EMT studies may be useful for multiple plant control tuning in weak grids as an alternative to more costly transmission upgrades.
- Development, integration and upkeep of vendor and site-specific high-fidelity models requires continuous collaboration between OEMs, project developers and transmission system operators.
- Post-commissioning model validation is still in early stage, calls for high resolution data recording and event analysis standards (e.g. NERC PRC-028 and PRC-030 are steps in the right direction)

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EMT Modeling Working Group and Staged Approach to EMT Modeling Adoption

Upcoming MOD-026-2 R3

Stage 1
Establishing EMT Model Requirements

Stage 2
EMT Model Quality Verification

Stage 3
Plant Performance Assessment & Model Benchmarking

Stage 4
Screening and Integration in Interconnection Process

Stage 5
Conducting Interconnection and Planning Studies

NERC Std Project 2022-04 EMT Modeling Affected Standards: FAC-001, FAC-002, MOD-032, TPL-001

1st Guideline Scope

[NERC Reliability Guideline: EMT Modeling for BPS-Connected Inverter-Based Resources—Recommended Model Requirements and Verification Practices](#) *– March 2023*

2nd Guideline Scope

[NERC Reliability Guideline: Recommended Practices for Performing EMT System Studies for Inverter-Based Resources](#) *– December 2024*

Interested? Contact Aung Thant Aung.Thant@nerc.net

DOE/ESIG/ORNL Trainings –Dec 2025 and Beyond

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ESIG Electromagnetic Transient Training

WHEN: December 16 - 19, 2025

WHERE: Texas RE's Rio Grande Room, Austin, Texas

MORE DETAILS: This 3-day in-person training is intended to enhance the knowledge and ability of the current workforce through coursework focused on performing EMT simulations in the current interconnection and planning paradigm. Training participants will learn practical methods and best practices that can be leveraged into enhanced study practices across the industry. These training modules will focus on the expected day-to-day needs of engineers performing EMT analysis as well as managing EMT study practices within their organization.

MORE INFO- EMT TRAINING

Thanks to Texas Reliability Entity for hosting at their facilities!

More EMT Training Opportunities in 2026

- EMT training SPP and their stakeholders, Date: Feb 2026
- Enhanced online version of Dec 2025 EMT training, Date: Feb 2026
- EMT training for practicing engineers, Date: Aug 2026
- EMT getting-started training, online, Date: Sept 2026
- EMT model quality testing and benchmarking training, online, Date: November 2026
- Deeper-dive EMT Training, Date: December 2026

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Additional Resources

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- ERCOT Model Quality Guide - (scroll down to Guides, download Model Quality Guide .zip, go to START HERE file for further directions, including links to open-source PMView and DMView tools for Model Quality Testing (in PSCAD and PSS/E respectively))
- Direct link to PMView https://sites.google.com/view/pmview/home (with video tutorials on PMView and PSCAD Model Tests)
- ERCOT Dynamic Working Group Procedure Manual – includes everything related to dynamic model requirements, including specific model tests and examples of acceptable / unacceptable behavior
- AEMO Dynamic Modeling Requirements Guides

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Additional Resources

ESIG

ESIG i2X FIRST website: https://www.esig.energy/i2x-first-forum/

i2X INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

ESIG Tutorial: Electromagnetic Transient Analysis Simulation Tools, March 2024

ESIG Fall Technical Workshop, October 2024

Session 8A: EMT Practices and Applications

Session Chair: Julia Matevosyan, Chief Engineer, ESIG

- EMT Practices in ONS
  Bruno Pestana Rosa, Electrical Studies Engineer, Planning Department, ONS
- EMT Practices in ISO-NE
  Brad Marszalkowski, Supervisor of Resource Integration, ISO-NE
- EMT Studies: Industry Uptake and How to Make Them More Manageable
  Andrew Isaacs, Vice President, Electranix (Canada)
- NERC EMT Task Force Update
  Aung Thant, Engineer, Inverter-Based Resource Specialist, NERC

EMT MODEL REQUIREMENTS REV. 13 FEB 2025

Model Requirements Rev. 13

Date: February 2025
Prepared By: Electranix Corporation

This document includes the following attachments:
Attachment #1: PSCAD Model Test Checklist for Reviewing Model Submissions

Revision 13 Notes (Changes from rev. 12):

Entire document	Editorial changes and clarifications in tables, figures and test names
Attachment 2	Attachment 2: Supplier compliance checklist removed
Requirements C,D,E,K	Additional clarity/focus on DC bus and energy source modeling, thermal protections, PPC delays, and as-left setting verification and associated model or documentation checks.
Footnote 2	Additional clarity on average source model features.
Requirement Y	Additional requirement for 32 and 64 bit Intel compiled models
Test list	Additional test measuring reaction time, and to check whether PPC/inverter comm delays are included
Test list	Clarified "Pmax" should be both charging and discharging for BESS systems.
Test list	Minor adjustments and fixes to existing tests, including adding ROCOF to frequency step test, reducing magnitude of voltage step test, additional operating points, and reduction in duration for LL fault test.

Contributors include: Andrew L. Isaacs, Lukas Unruh, Garth Irwin, Kasun Samarawickrama, Anuradha Kariyawasam

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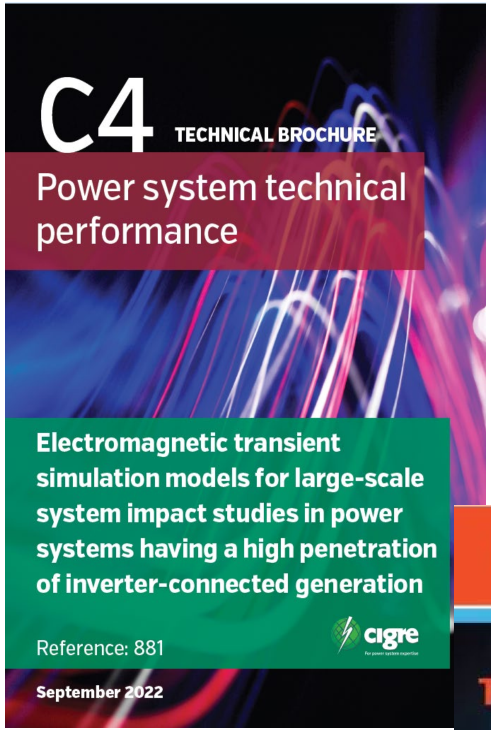

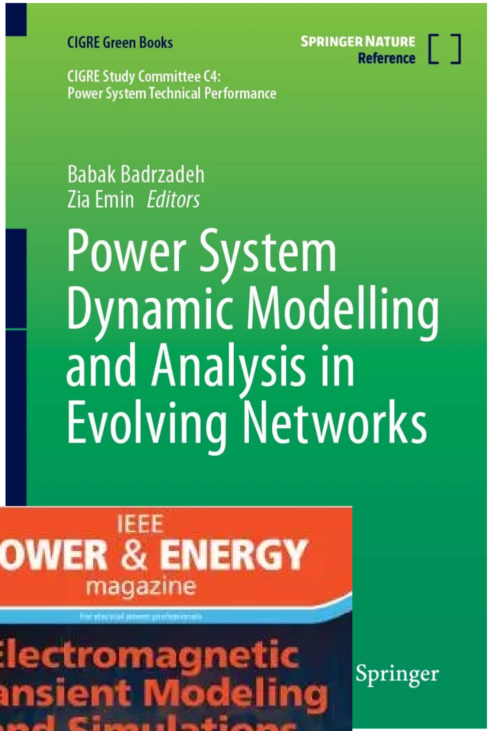

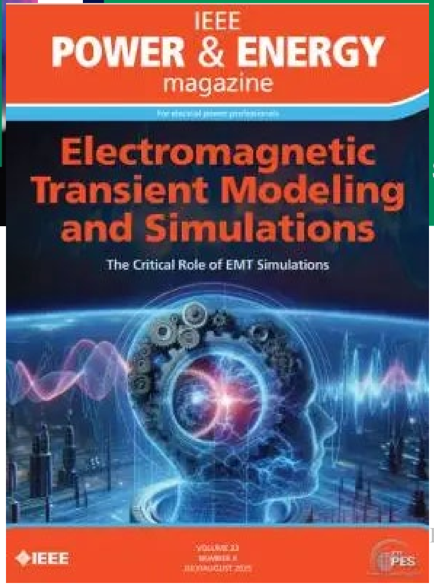

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THANK YOU

Julia Matevosyan

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EMT Modeling and IEEE 2800-series Interconnection Standards

Presented to WECC Strategic Workshop on EMT

ANDY HOKE, P2800.2 WG CHAIR
MANISH PATEL, SECRETARY
JENS BOEMER, BOB CUMMINGS, DIVYA CHANDRASHEKHARA,
JULIA MATEVOSYAN, MAHESH MORJARIA, STEVE WURMLINGER, VICE CHAIRS

November 19, 2025

Some content derived from IEEE 2800 WG and Jens Boemer, 2800 WG Chair

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Standards in the IEEE 2800 series

Standard	Status	Role of EMT modeling
IEEE **2800**-2022: Interconnection requirements for IBRs on the BPS	Published, adopted by a few dozen entities and counting	Requires IBR owner to provide EMT model upon request
IEEE P**2800.2**: Assessing conformity to 2800	At 90% approval in 2nd ballot. Publication expected Q1 2026	Relies heavily on EMT modeling: • Type tests to validate EMT model • EMT model validation procedures • Plant-level EMT tests • EMT model validation against commissioning tests
IEEE P**2800.1**: Recommended specifications for **grid-forming** IBR equipment	• Expect PAR approval next month • **Kickoff meeting December 15**	Will rely exclusively on EMT model for conformity assessment: • Time-domain EMT tests • Frequency-domain EMT tests

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What does IEEE 2800 say about EMT modeling?

- Clause 10 (Modeling data):
  - Mentions that all models including EMT make approximations
  - "Upon request from the TS operator and TS owner, the **IBR owner <u>shall</u> provide**:"
    - "**verified… EMT model**" (among other models)
    - "**Documentation detailing development process and verification of these models**"
  - List of "common practices to develop verified models" including:
    - "non-aggregated EMT model" may be verified against type tests or HIL tests
    - Other model types are verified against non-aggregated EMT model
- Informative Annex C *(Inverter stability and system strength)* mentions EMT modeling several times
- Informative Annex G *(Recommendation for modeling data)* includes a clause on EMT model data requirements
  - Recommends real code models
  - Lists EMT model usability criteria

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P2800.2 – Relationship to the IBR interconnection process

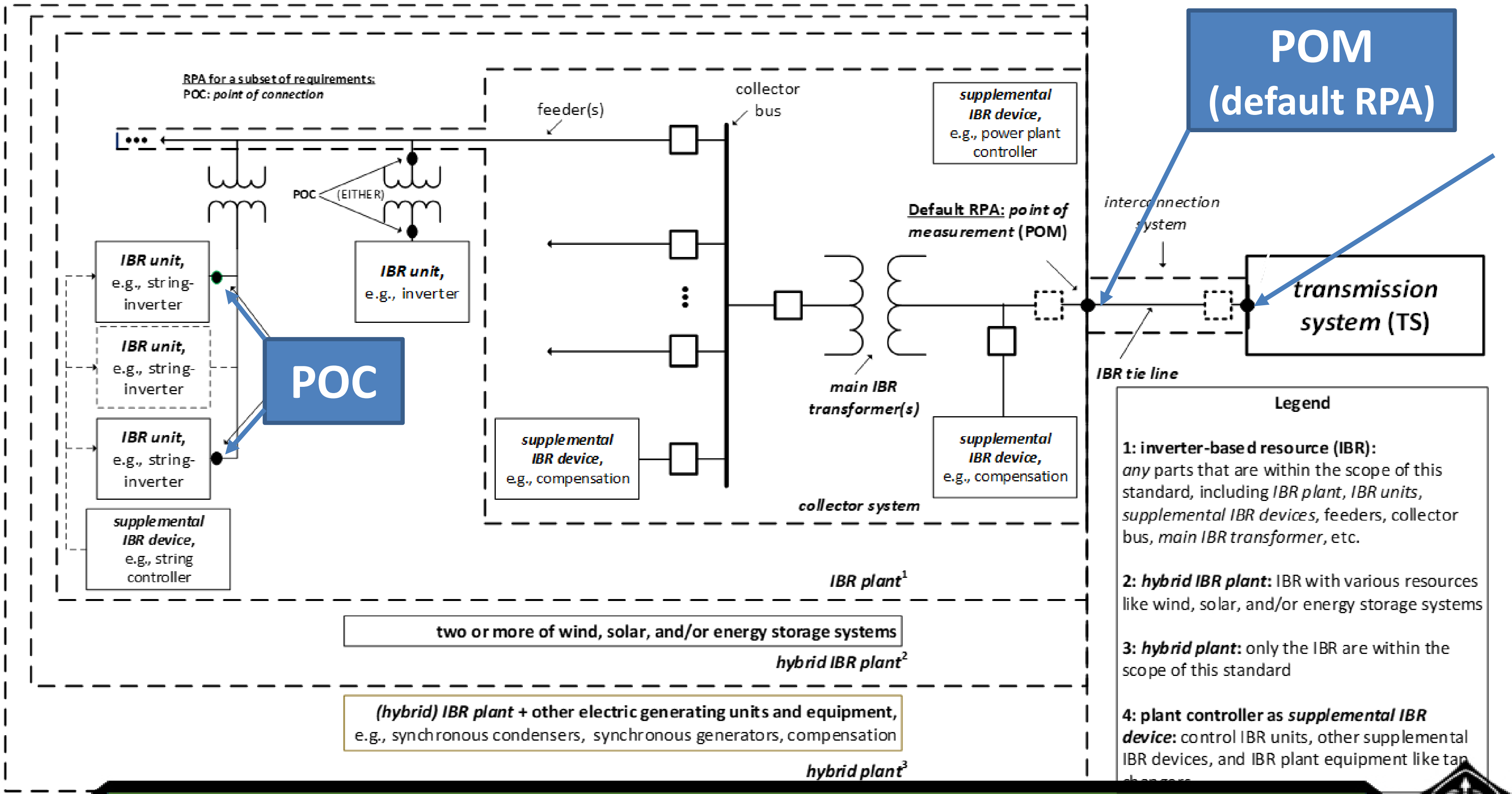
________ an interconnection process:

- P2800.2 type tests can inform interconnection process
- P2800.2 design evaluation, commissioning tests, and post-commissioning model validation can occur during interconnection process (along with other steps not in scope of P2800.2)

- Important discussions related to interconnection that do not relate to *IEEE 2800 conformance verification* can take place *primarily outside* P2800.2
- By providing standardized procedures, we are taking a major step to improve the interconnection process (without trying to fix everything)

Role of P2800.2 in IEEE 2800 Adoption

Almost all **requirements of IEEE 2800 apply at Point of Measurement (POM)** by default



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P2800.2 EMT definitions

- Looked for NERC definitions to coordinate. (Didn't find.)

electromagnetic transient model (EMT model): A software model with associated parameters that represents the physical equipment in the time domain as closely as possible in a simulation platform including a representation of all three phases of the network and can represent frequency dependence of network components in discretized differential form, as well as IBRs, controllers, and other equipment.

NOTE 1—These models have very high bandwidth of validity allowing integration time steps down to micro-seconds.

NOTE 2—The frequency dependency may be limited to a range of frequencies of interest.

NOTE 3—An *EMT model* of an *inverter-based resource (IBR)* may be an *averaged EMT model* or a *switching EMT model*.

averaged electromagnetic transient model (averaged EMT model): An *EMT model* of an IBR or other power electronic device in which the state of the power electronic switches averaged across one converter switching cycle is represented by one controlled voltage source per phase.

NOTE 1—An averaged model of the power stage can be used because switching-frequency dynamics are not usually important in studies of IBR dynamic performance.

switching electromagnetic transient model (switching EMT model): An *EMT model* of an IBR or other power electronic device in which the output of each of the power electronic switches in the converter is directly represented along with the switch control signals.

NOTE—Switching models of IBRs have been referred to in other documents as "detailed models". This term is not used here to avoid confusion with non-aggregated *IBR plant* models.

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Overview of conformity assessment steps in IEEE P2800.2

Type Tests

Lab or field tests of individual IBR unit for model verification

IBR Unit Model Validation

Based on type test data

IBR Plant Model Development

Based on validated IBR unit model(s) and balance of plant

IBR Plant Design Evaluation

Simulations to assess plant conformity to IEEE 2800

Design Evaluation

Plant construction complete

As-built Installation Evaluation

Verification of installed plant

Commissioning Tests

Partial field assessment of plant performance

Post-commissioning Monitoring

Monitoring of plant performance during grid events

Post-Commissioning Model Validation

Based on commissioning test data

Periodic Tests and Verifications

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Where is EMT modeling used in IEEE P2800.2?

IEEE PES Power & Energy Society® | IEEE

Design Evaluation

Type Tests

Lab or field tests of individual IBR unit for model verification

IBR Unit Model Validation

Based on type test data

- Unit-level EMT model should be validated against hardware tests
- Lists variables to be included in validation (P, Pref, Q, Qref, V1, V2, I1, I2, f)
- Defines qualitative validation process
- Does not include quantitative pass/fail criteria

IBR Plant Model Development

Based on validated IBR unit model(s) and balance of plant

- Table of model quality tests
- Applies to both PD and EMT models
- Discussion of non-aggregated vs aggregated EMT models

IBR Plant Design Evaluation

Simulations to assess plant conformity to IEEE 2800

- Table defining verification method for each requirement of 2800
- Preference for simple test system
- Tables of simulation tests for ride-through, P_{ref} step, PFR, FFR, phase jump, SCR change

As-built Installation Evaluation

Verification of installed plant

Commissioning Tests

Partial field assessment of plant performance

Post-commissioning Monitoring

Monitoring of plant performance during grid events

- *May* include comparison of event response to EMT model response

Post-Commissioning Model Validation

Based on commissioning test data

- Plant model params verified to match those used in Design Evaluation
- Plant model **validated against commissioning test data**

Periodic Tests and Verifications

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Type tests in IEEE P2800.2

- Primary purpose is to **validate model** of individual inverter, turbine, and plant controller against hardware tests
- Hardware tests can be in lab, field, or controller hardware-in-the-loop
- For inverters and turbines, tests include:
  - Reactive power capability
  - Voltage and reactive power control
  - Active power control
  - Frequency response and FFR
  - Voltage ride-through, including phase jump ride-through
  - Harmonics (for model creation, not model validation)
  - Protection
  - Frequency scan

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Type tests in IEEE P2800.2

- For **power plant controllers**, tests include:
  - Active power setpoint change
  - Reactive power setpoint change
  - Frequency step
  - Voltage measurement step
  - Voltage setpoint step
  - Power factor setpoint step
  - Fault response
- As with IBR unit type tests, purpose is to validate model

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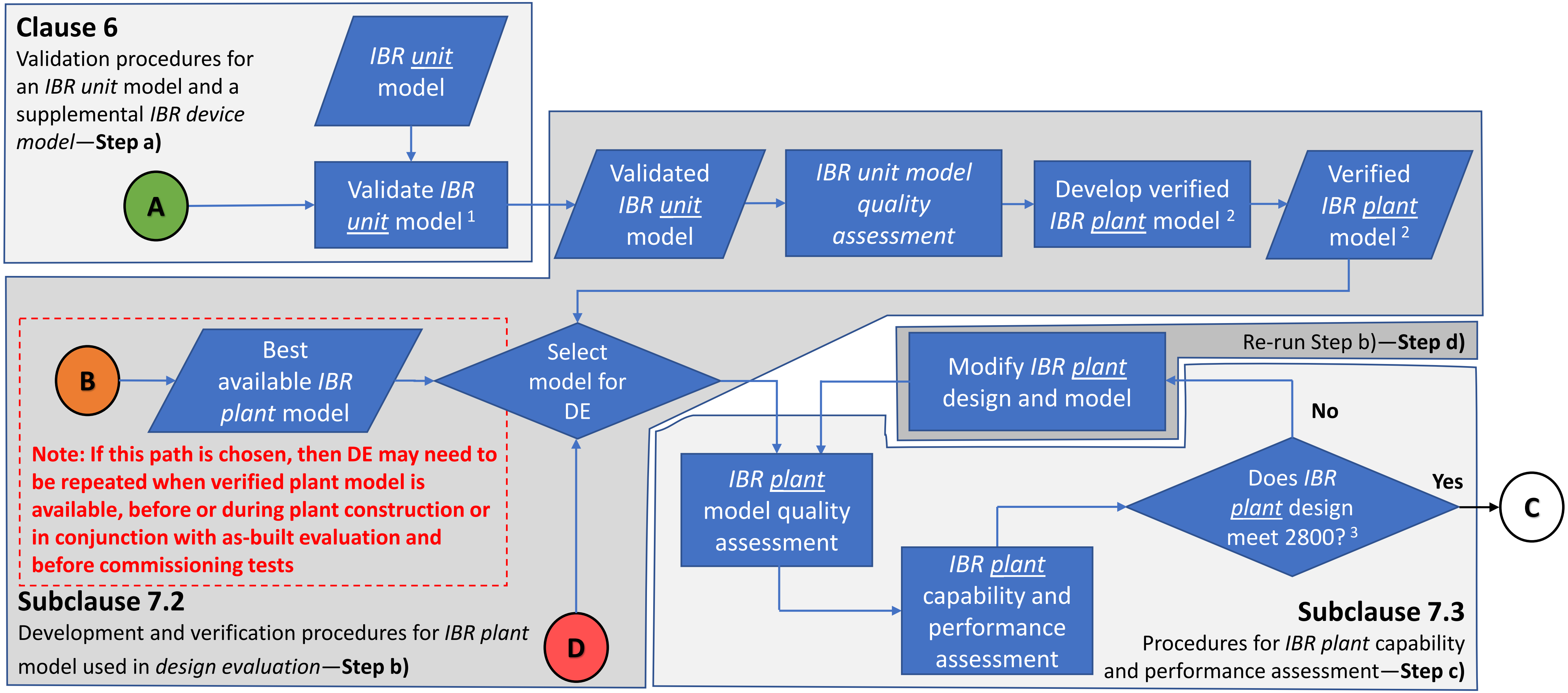

[1] Follow same procedure for validation of *supplemental IBR device* model.
[2] The verified *IBR plant* model is developed using *IBR plant* design and validated *IBR unit/supplemental IBR device* models. The plant model in this step is not validated until after commissioning.
[3] Passes *IBR plant design evaluation* steps listed in Clause 7.3.

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Table of verification methods

- Calls out EMT modeling for several requirements, especially ride through and frequency response
- Excerpt shown here

Requirement	RPA where requirement applies	Design evaluation[a]	Procedure type	*IBR plant* representation detail[b] and data[48]
Clause 5 Reactive power—voltage control requirements within the continuous operation region				
5.1 Reactive power capability	POM	R	Review of *IBR plant* design documentation, *OEM documentation* and *steady-state* power flow (or maybe PDT analysis, informed by guidance provided in Annex B, section B.3)	Aggregated model (or maybe non-aggregated model informed by guidance provided in Annex B, section B.3)
5.2 Voltage and reactive power control modes	POM	R for capability	Review of *OEM documentation*	IBR unit(s) and supplemental IBR device(s)
		R for performance of 5.2.2	PDT and EMT analysis	Aggregated model
Clause 6 Active-power—frequency response requirements				
6.1 Primary frequency response (PFR)	POC and POM	R	PDT and EMT analysis	Aggregated model
6.2 Fast frequency response (FFR)	POC and POM	R	PDT and EMT analysis	Aggregated model
Clause 7 Response to TS abnormal conditions				
7.2.2 Voltage disturbance *ride-through* requirements	POC[49]	R	Review of *OEM documentation* on capability	*IBR unit(s)* and *supplemental IBR device(s)*
		R	Review of type test results and EMT analysis	*IBR unit(s)* and *supplemental IBR device(s)*
	POM[50]	R	PDT and EMT analysis	Aggregated model
7.2.3 Transient overvoltage *ride-through* requirements	POM	R	Review of *IBR plant* design documentation and *OEM documentation*	As appropriate
7.3.2 Frequency disturbance	POM	R	PDT and EMT analysis	Aggregated model

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Model quality assessment (MQA) procedure

- Found in Annex H (normative)
- Contains step-by-step procedures for MQA of IBR unit and IBR plant models

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Tables of simulation tests

- Tables included for fault ride-through, OV ride-through, Vref step, Pref step, OF and UF ride-through, phase jump ride-through, SCR change, protection (basic).
- Most require EMT
- Balanced fault ride-through table shown as example
- Can use simple test system (voltage source behind impedance) or detailed system (model of real grid at POI)

Test #	Test Description					Success Criteria
	Fault duration [s]	**Fault type at RPA**	**Fault impedance Zf**	**Initial approx. Active Power at RPA**	**Initial Approx. Reactive Power at RPA**	
2-1	0.16	3PHG	Zf=0	ICR	0	Ride Through
2-2		3PHG	Zf=Zs[1]	ICR	0	Ride Through
2-3	0.16	3PHG	Zf=0	ICR	0.3287 x ICR injecting	Ride Through
2-4		3PHG	Zf=Zs[2]	ICR	0.3287 x ICR injecting	Ride Through
2-5	0.16	3PHG	Zf=0	ICR	0.3287 x ICR absorbing	Ride Through
2-6		3PHG	Zf=Zs[3]	ICR	0.3287 x ICR absorbing	Ride Through

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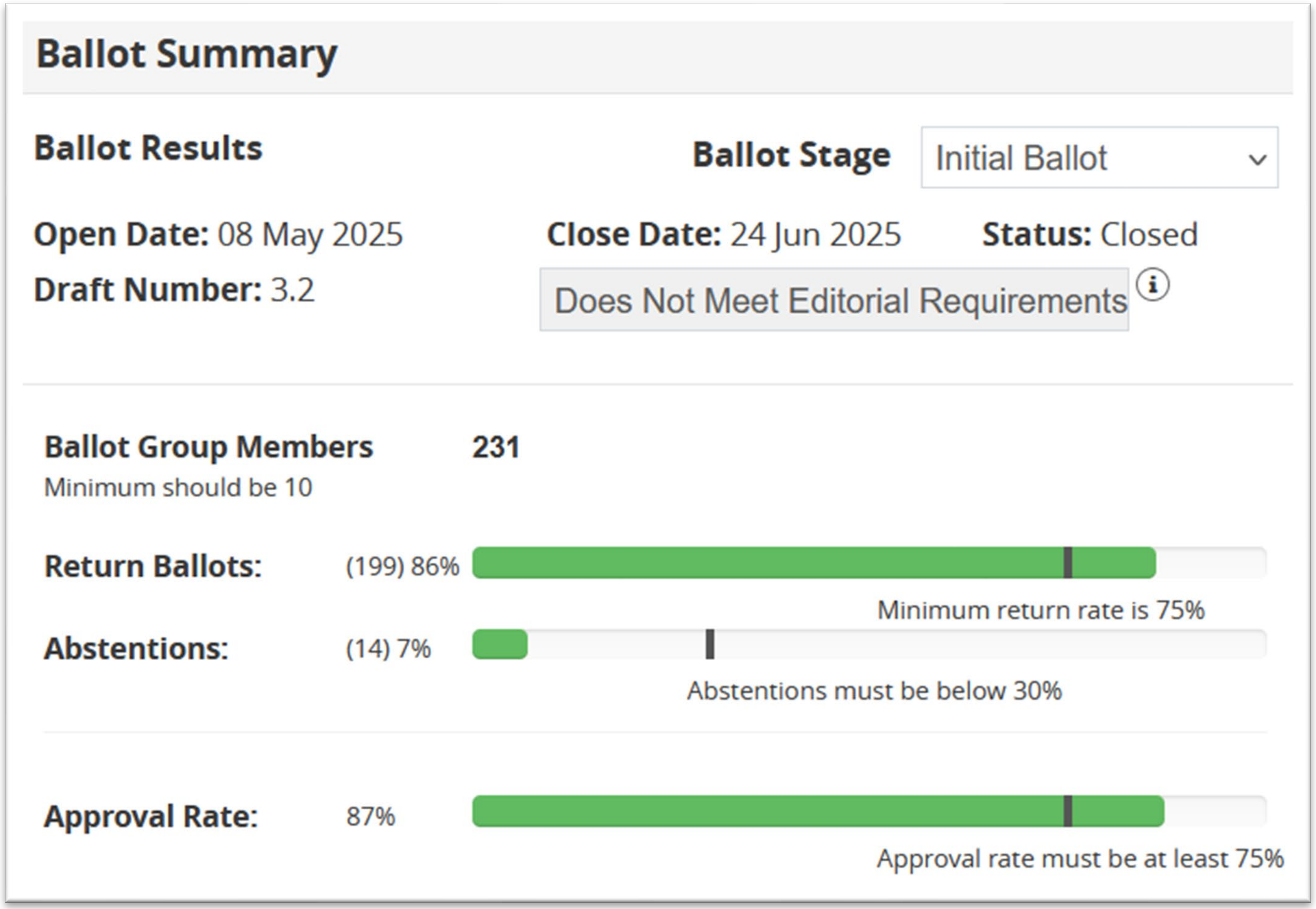
P2800.2 initial ballot results



- **87% approval**
  - **Exceeds 75% threshold to pass**
- 743 ballot comments
- 35 public comments

- Currently in 2nd ballot
- Approval now at 90%

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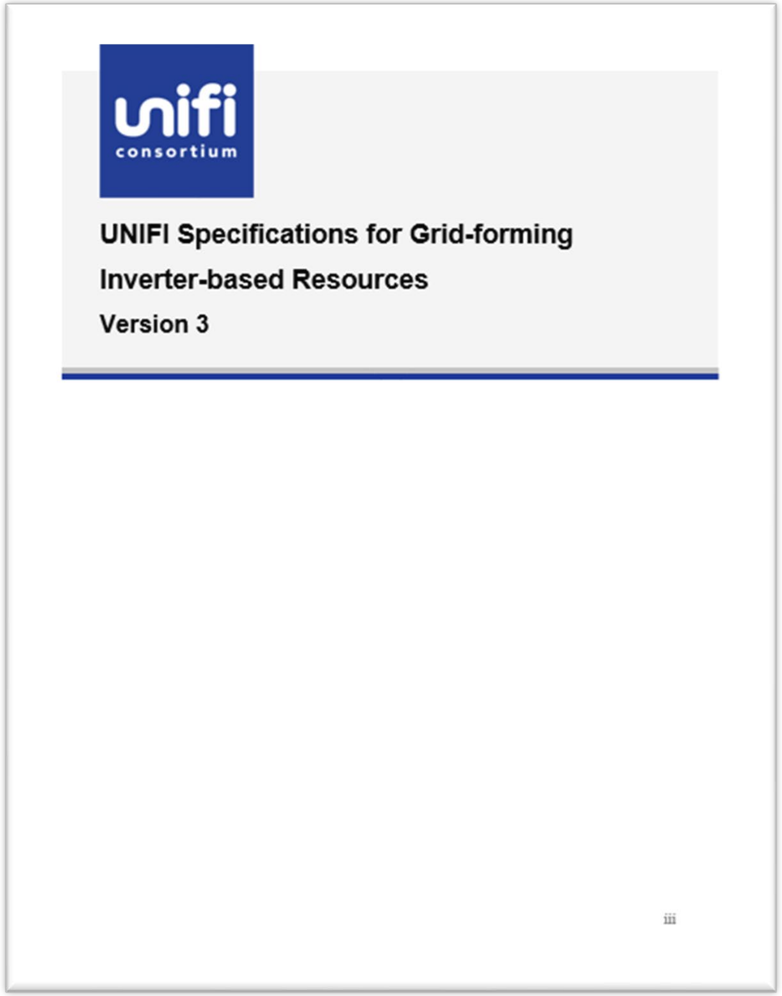
Next up: Grid-forming (GFM)

- **IEEE P2800.1** will contain recommend requirements for GFM IBR equipment
- Will start from the **UNIFI GFM Specification** Version 3 (to appear soon)
  - Version 2: https://unificonsortium.org/resources/#toc_Specifications_v2
- Three main elements:
  1. Qualitative requirements for GFM capability
  2. **Time-domain EMT tests** with quantitative pass-fail criteria (similar to ERCOT's)
  3. **Frequency-domain EMT tests** with quantitative pass-fail criteria


UNIFI Specifications for Grid-forming
Inverter-based Resources
Version 3

iii

<Public>

Save the date for next WG meeting

- P2800a: Amendment to reduce barriers to GFM
- P2800.1: Recommended requirements for GFM equipment, including EMT tests
- P2800 full revision: Incorporate industry learnings from 2800 adoption

Andy.Hoke@nrel.gov if you need the meeting invitation

<Public>

How To Express interest in IEEE myProject:

1. On the myProject Home Screen, click on "**Menu**" and then on "**Manage Profile and Interests**"
2. Click on the "**Interests**" tab, then on "**Add Groups**"
3. Find "**Inverter-Based Resources Interconnection Working Group**" under PES/EDPG, or simply search for "**IBRI-WG**" — see screenshot excerpts at right
4. Click bullet under "Groups I Am Interested In" and follow instructions on screen

Why register on MyProject?

- Receive **WG meeting invitations**
- Receive **invitation to join IEEE-SA ballot pool** when a standard under the WG goes to ballot

Why does it not show forthcoming projects P2800a, P2800 R1, and P2800.1?

- These projects are not authorized yet.
- Will appear along with existing P2800.2 project, once approved by IEEE SASB NesCom later in 2025.

Group Name	Committee	Group Type	Groups I Am Interested In
IEEE Power and Energy Society	PE	Society	
Analytic Methods for Power Systems	PE/AMPS	Standards Committee	●
Energy Development & Power Generation	PE/EDPG	Standards Committee	●
Project Administration	PE/EDPG/ADMIN	Working Group	●
Coordination Control of Full-Size Converter Based Variable Speed Pumped Storage Unit (FSC-VSPSU)	PE/EDPG/CCFV	Entity Working Group	○
...			
Wind and Solar Plant Collector Design Working Group	PE/EDPG/WSPPCD	Working Group	●
Wind and Solar Power Plant Interconnection and Design Subcommittee	PE/EDPG/WSPPID	Subcommittee	○
Inverter-Based Resources Interconnection Working Group	PE/EDPG/WSPPID/IBRI-WG	Working Group	●
Recommended Practice for Test and Verification Procedures for Inverter-based Resources (IBRs) Interconnecting with Bulk Power Systems	PE/EDPG/WSPPID/IBRI-WG/2800.2	Project/Task Group	●
Wind and Solar Plant Interconnection Test and Verification Working Group (WSPI-TV)	PE/EDPG/WSPPID/WSPI/WSPI-TV	Entity Working Group	●

IEEE PES Power & Energy Society

IEEE

<Public>

Thank You

www.nrel.gov

Contact: Andy.Hoke@nrel.gov

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NERC Standard Revisions for EMT Modeling – Projects 2022-04 (and 2020-06)

PRESENTED BY:

Michael B. Marz

Principal Engineer

American Transmission Company

WECC EMT Strategic Workshop November 19, 2025

<Public>

Background

- High IBR penetration transforming BPS
  - New issues require EMT simulation
  - TPs & PCs need accurate EMT data
  - **Studies needed to analyze system.**
- Revise NERC standards for reliability
  - TPs and PCs need models and tools to conduct reliability assessments.
  - This requires collection of accurate EMT models when needed.
  - **Studies required for compliance.**

Standard Authorization Request (SAR)

<Public>

- Project 2024-04 – “EMT Modeling” 5/15/23
  - TP/PC need models for assessments.
  - EMT model collection, review, and study.
  - FAC-002, MOD-032 and TPL-001
- Project 2020-06 - “Verification of Models and Data for Generators” 5/12/21
  - GOs - Provide verified generator models
  - TPs - Specify usability criteria for models
  - MOD-026 and MOD-027

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Standard Authorization Request (SAR)

Complete and submit this form, with attachment(s) to the NERC Help Desk. Upon entering the Captcha, please type in your contact information, and attach the SAR to your ticket. Once submitted, you will receive a confirmation number which you can use to track your request.

The North American Electric Reliability Corporation (NERC) welcomes suggestions to improve the reliability of the bulk power system through improved Reliability Standards.

Requested information			
SAR Title:	EMT Modeling		
Date Submitted:	June 8, 2022 (Revised on May 15, 2023)		
SAR Requester			
Name:	Allen Schriver, NextEra Energy (NERC IRPS Chair) Julia Matevosyan, ESIG (NERC IRPS Vice Chair)		
Organization:	NERC Inverter-Based Resource Performance Subcommittee (IRPS) (Revised by Project 2022-04 SAR DT)		
Telephone:	Allen – 561-904-3234 Julia – 512-994-7914	Email:	allen.schriver@fpl.com julia@esig.energy
SAR Type (Check as many as apply)			
☒ New Standard ☒ Revision to Existing Standard ☒ Add, Modify or Retire a Glossary Term ☐ Withdraw/retire an Existing Standard		☐ Imminent Action/ Confidential Issue (SPM Section 10) ☐ Variance development or revision ☐ Other (Please specify)	
Justification for this proposed standard development project (Check all that apply to help NERC prioritize development)			
☐ Regulatory Initiation ☐ Emerging Risk (Reliability Issues Steering Committee) Identified ☐ Reliability Standard Development Plan		☒ NERC Standing Committee Identified ☐ Enhanced Periodic Review Initiated ☒ Industry Stakeholder Identified	
Industry Need (What Bulk Electric System (BES) reliability benefit does the proposed project provide?):			
The bulk power system (BPS) in North America is undergoing a rapid transformation towards high penetrations of inverter-based resources (IBR). Transmission Planners (TP) and Planning Coordinators (PC) are concerned about the lack of accurate modeling data and the need to perform electromagnetic transient (EMT) studies during the interconnection and planning processes. The growth of inverter technology has pushed conventional planning tools to their limits in many ways. TPs and PCs are now faced with the need to conduct more detailed studies using EMT models for issues related to inverter-based resource integration. This SAR proposes including EMT models and studies in planning-related NERC Standards to ensure reliable operation of the BPS moving forward. See supporting paper[1] for more details.			

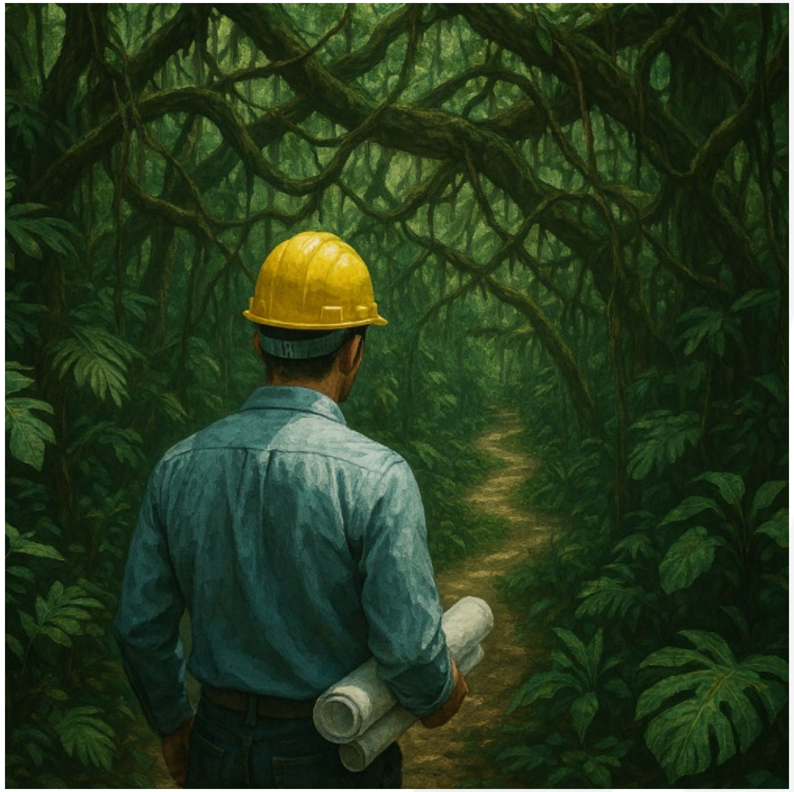
[1] IRPS Supporting Paper

RELIABILITY | RESILIENCE | SECURITY

<Public>

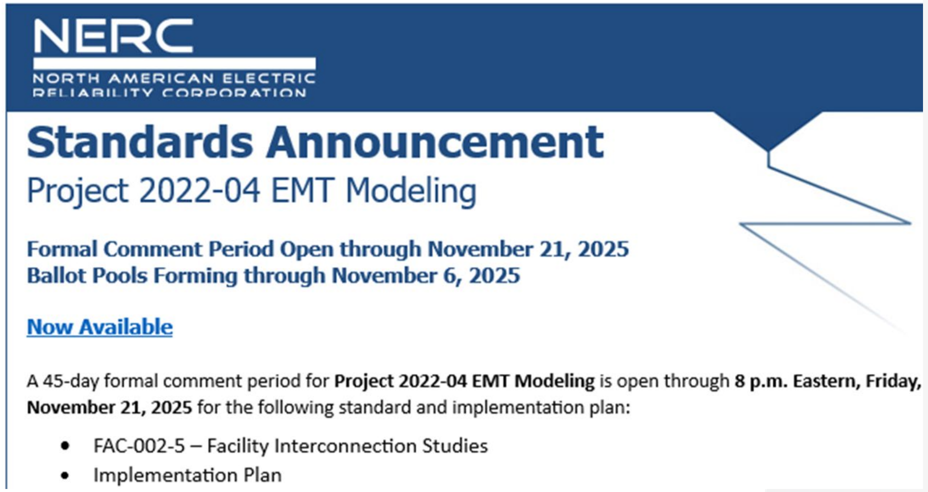
Project 2022-04 Affected Standard Changes

- FAC-002 – Facility Interconnection Studies
  - TP & PC **Jointly** Document a Process to:
    - Collect and review models
    - Determine when study necessary
      - ✓EMT, dynamics, SC and SS
  - GOs & TOs Provide Models.
- MOD-032 – Data for Modeling & Analysis
  - TPs & PCs develop modeling requirements.
  - GOs & TOs provide models to PCs & TPs.
  - PCs and TPs review models: GOs & TOs address issues
- TPL-001 or new Standard – Transmission System Performance



<Public>

Project 2022-04 Today


NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Standards Announcement

Project 2022-04 EMT Modeling

Formal Comment Period Open through November 21, 2025
Ballot Pools Forming through November 6, 2025

Now Available

A 45-day formal comment period for **Project 2022-04 EMT Modeling** is open through **8 p.m. Eastern, Friday, November 21, 2025** for the following standard and implementation plan:

- FAC-002-5 – Facility Interconnection Studies
- Implementation Plan

- FAC-002 – Facility Interconnection Studies
  - Comments through November 21.
    - Do revisions address SAR concerns?
    - Technical Rationale, Implementation Plan, etc.
- MOD-032 – Data for Planning Modeling and Analysis
  - Produced revisions last year, will revisit. Dates?
- TPL-001– Transmission System Planning Performance
  - Hardest standard to revise – new standard won’t be easy
  - Not a high priority (medium), but time running out (2026?)

<Public>

Project 2020-06 Today

- Final ballots October 24, 2025 - Approved
  - MOD-026-2 “Verification and Validation of Dynamic Models and Data
  - Implementation Plan
  - Submitted to Board of Trustees
  - Filed with regulatory atthorities
- Balloting of Verification and Validation definitions separate
  - Due to limited time for 2020-06 balloting
  - These definitions will be used for other standards

<Public>

Q&A

SRP Experience Building EMT Modeling Requirements and Gathering EMT Models from Developers

Bo Gong, PhD
Executive Engineer, SRP

WECC EMT Workshop
Salt Lake City, November 2025

Delivering water and power™

SRP's EMT Modeling and Study Evolution

- Prior to 2022, EMT studies were conducted only for special issues such as delayed zero crossing, TRV/RRRV, SSR, and switching studies.
- IBR projects were traditionally evaluated using power flow and transient stability studies
- SRP's first EMT study for an IBR project was the Bolster Energy Storage Project (25 MW Tesla BESS) in 2022
- Since then, all IBR/HVDC projects (>5 GW) have undergone EMT studies during the pre-commissioning stage.

Key Lessons from EMT modeling and study

EMT studies are essential for IBR

- Reveal reliability issues not captured by positive sequence models.

Limitation of WECC generic models

- Often fail to accurately represent project-specific dynamics.

User Defined Models (UDMs)

- Provide more accurate representation than generic models.
- Still not sufficient for capturing certain reliability issues—EMT models remain necessary.
- SRP collaborates with OEMs to develop UDMs—challenging but valuable.

EMT models: A double-edged sword

- Highly accurate and effective when properly developed and applied.
- Require rigorous verification and coordination among stakeholders.

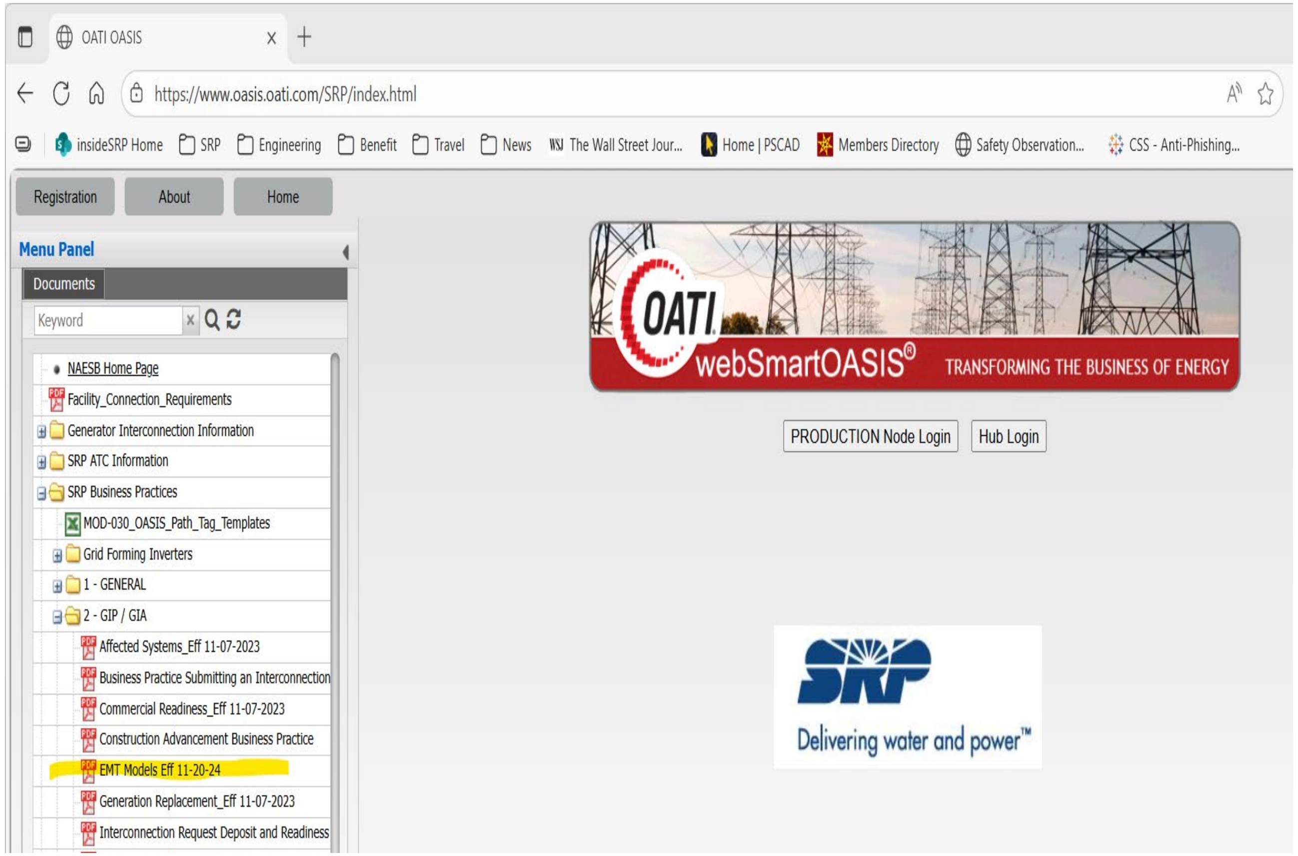
Model verification requires collaboration

- **Utilities:** Ensure accuracy and usability.
- **Developers:** Obtain utility approval and meet commissioning timelines.
- **OEMs:** Provide models and documentation while protecting proprietary data.
- **Consultants (to developers):** Configure inverters with limited insight into full system.
- **Consultants (to utilities):** Identify issues through studies but may struggle to trace root causes.

<Public>

SRP's EMT Modeling Business Practice under GIA Reform

- In 2023, SRP published EMT modeling business practice on OASIS, aligned with NERC reliability guidelines.
  - EMT models are now mandated for most IBR project types.
  - A compliance checklist holds developers accountable.
  - References include Electranix PSCAD requirements and standards from MISO, SPP, CAISO, and other utilities.
  - The 2024 update adds:
    - Benchmarking and validation requirements
    - Real-code model mandate
    - Version control
    - Impedance scan requirements



IEEE 2800 Adoption and Facility Connection Requirement Update

- EMT studies often misalign with rigid cluster timelines.
- Early-stage models may not reflect post-commissioning settings.
- Separated funding requirement outside GIP for EMT studies

- Model Acceptance → Screening → Full-scale EMT Study

- Model verification and data check
- Model validation check
- Model benchmarking check
- Model quality check
- Model performance check

Suggestions for Future Directions in the WECC Region for EMT Modeling

Questions ?

bo.gong@srpnet.com

California ISO

EMT Models and Studies in CAISO Status Update

Ebrahim Rahimi
Sr. Advisor - Transmission Planning

WECC EMT Workshop
November 19-20, 2025

Introduction

- As of 9/10/2025, 46 GW of Inverter-based resources (IBRs) are connected to the CAISO transmission system
  - In addition, 17 GW distribution connected solar
- Installed IBR capacity in CAISO system is expected to reach to ~120 GW by 2035 and ~200 GW by 2045
- NERC standards are being updated to include EMT studies in planning and interconnection studies
- CAISO started working on EMT models and studies in 2019

CAISO Approach to EMT Models and Studies

- Resource EMT Models
  - CAISO's Transmission BPM Section 10 requires all the existing IBRs to provide EMT models
  - As part of generation interconnection process (GIP), a screening analysis is performed. If a risk is identified, the Interconnection Customer is required to provide EMT model and mitigate any potential identified issues
  - If there are no risks, 12 months after going into commercial operation, all new IBRs are required to provide EMT models
- System EMT Studies
  - CAISO is developing processes and tools in preparation for NERC standards

EMT Model Reviews

- PSCAD models are reviewed with main objective being to ensure they reflect the equipment in the field (where applicable)
  - CAISO EMT Requirements: http://www.caiso.com/Documents/CaliforniaISOElectromagneticTransientModelingRequirements.pdf
  - IBR EMT Checklist: http://www.caiso.com/Documents/DataTemplateforGeneratorsinCategory1and2.xlsx
  - The checklist includes 55 questions on supporting documentation, model accuracy, usability, and performance to ensure the model meets all the requirements

1. Are the supporting documentation submitted? GO, please list the files below.
2. Does the documentation include instruction for setup and running the model?
3. Does the documentation provides a clear way to identify site-specific settings and equipment configuration?
4. Are the complete model files submitted? GO, please list the files below.
5. Is the model supplied with a sample test case including site specific plant representation?
6. Does the model schematic align with the single line diagram and include all devices from the inverters to the Point of Interconnection?
7. Does the model use the actual firmware code from the inverter for power electronic controls ("real code")?
8. If not using real code, is a model validation report included?
9. Does the model include the plant level controller? List all the plant level controller below, e.g. power plant controller, customized phase locked loop systems, ride-through controllers, sub-synchronous control interaction damping controllers, etc.
10. Does the plant level controller control generating resources other than the subject resource in this model submission?
11. Are the operating modes which require system specific adjustment accessible? Please describe how to access mode settings below.
12. Does the model include automatically controlled capacitor and reactor banks?
13. Are the transformer magnetizing curves included?
14. Does the model include pertinent electrical and mechanical features, such as gearboxes, pitch controllers, or other features which impact the plant performance in the simulation period?
15. Are all protections which could impact ride-through performance modeled in detail? Please list the protections included in the model below.
16. Has the model being validated at different operating conditions ranging from minimum power through maximum power?
17. Is the model configured for the specific site being evaluated, as far as they are known?
18. Are pertinent control or hardware options accessible to the user (e.g., adjustable protection thresholds, real power recovery ramp rates, or Sub-Synchronous Control Interaction damping controllers)
19. Are there diagnostic flags accessible? Please provide the description of the diagnostic flags below.
20. Please provide the grid strength in terms of simple short circuit ratio at POI that the model is designed for.
21. Does the model run at a time step between 10 μs to 20 μs? Please specify the time step required by the model below.
22. Is the model restricted to the time step provided above?
23. Does the model initialize itself?
24. Does the model initialize to P, Q, V setpoints in 5 seconds or less?
25. Does the model accept external reference variables for active and reactive power?
26. Could the external references be changed dynamically during the simulation?
27. Could the protection models be disabled for troubleshooting?
28. Is the active power capacity scalable?
29. Is the active power dispatchable?
30. Is the model compatible with Intel FORTRAN version 12 and higher? Please specify Intel FORTRAN version required below.
31. Does the model compile using PSCAD version 4.6.3 or higher?
32. Does the model support multiple instances of its own definition in a single PSCAD case?
33. Does the model support the PSCAD "snapshot" feature?
34. Does the model support the PSCAD "multiple run" feature?
35. Does the model support "copy transfer" feature to replicate the components in a different PSCAD case?
36. Is it true that the model does not use PSCAD layer functionality?
37. The Vendor's name and the specific version of the model should be clearly observable in the .pscx case file.
38. Documentation and supporting model filenames should not conflict with model version shown in the .pscx case file.
39. Parameters of the gen-tie line, collectors, transformers align with the PSLF models.
40. Number of inverters, inverter capacity and operating modes for voltage control and frequency control match the PSLF models.
41. Power plant controller voltage control and frequency control match the PSLF models
42. PPC accepts an external active power setpoint.
43. PPC accepts a voltage or reactive power setpoint.
44. PPC has a mechanism to implement a settable voltage droop.
45. If the primary frequency response is enabled, the plant responds to frequency changes by increasing or decreasing its active power as appropriate.
46. Model initializes to the setpoints specified in the PPC. If droops or deadbands are utilized, the initial values may differ from the setpoints.
47. If external voltage control devices (STATCOM/DVAR, SVC, MSCs) are included in the plant, ensure that the voltage control of these devices is coordinated with the PPC, with no potential for VAR looping or oscillations.
48. Protection settings are implemented. These could be available as inputs in the model, or hard-coded in the black-boxed controls.
49. Instantaneous voltage and current waveforms have minimal distortion, and no oscillations are observed.
50. Model is able to ride-through and recover from a temporary (no line outage or drop in SCR), 6-cycle, zero-impedance, three-phase fault at the high side of the station transformer, with a POI level SCR of 3.
51. Model responds to a step change in PPC voltage setpoint, reaching 90% of the new value between 1 and 10 seconds in a test system with POI level SCR of 3.
52. Model responds to a step change in PPC active power setpoint, reaching 90% of the new value between 1 and 10 seconds in a test system with POI level SCR of 3.
53. Model trips or blocks when terminal voltage rises above 1.3 pu for 1.5 second.
54. Model trips or blocks when terminal voltage falls below the protection setting for specified time period.
55. Model clearly displays trip / diagnostic signals indicating the status of all pertinent protection elements.

Lessons Learned from EMT Model Validation Process

- Obtaining EMT models for the units that are in service could be challenging. Some of the issues are:
  - Change of ownership
  - OEM not in business anymore
  - GOs not having SMEs familiar with EMT models and studies
  - It takes significant amount of time to go through the process and get a compliant EMT model
  - ...
- NERC standards requirements for EMT models and studies will provide the needed direction and focus

EMT System Studies

- CAISO is in the process of developing an EMT studies roadmap

- A pilot EMT studies of a local area is near completion
  - The required software/tools
  - The hardware requirement for sufficient computing power
  - Staff training requirement
  - Required consulting support
  - Estimate of the time required to perform the studies
  - How to identify local areas for EMT studies

- Initiated coordination with PTOs to ensure consistency and alignment

<Public>

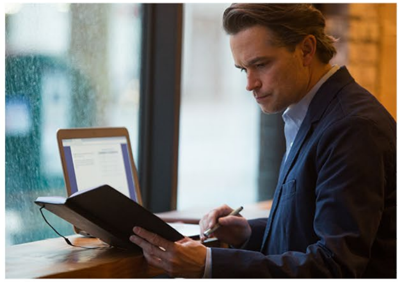
EMT Modeling Requirements

WECC Electromagnetic Transient (EMT) Strategic Workshop (November 19-20)

Rikin Shah - PacifiCorp








PACIFICORP

POWERING YOUR GREATNESS

Need for the EMTP Studies and model requirements

- Addition of Inverter Based Resources (IBR) presenting unique challenges
  - Similar kind of unique challenge observed in the past known as Sub-Synchronous Resonance (SSR) with thermal plants when series compensation inserted in line with synchronous generators
- IBR resources connected close to series compensated transmission lines introducing interactions between IBR controls and series capacitors and create low frequency oscillations and this is called Sub-Synchronous Control Interactions (SSCI)
  - LL20110705_Sub-Synchronous_Interaction.pdf (NERC Lessons Learned 2009)
- SSCI has a potential of growing over time and damaging turbines and other equipment.
- High levels of IBR resources with specific control parameters and higher levels of series compensation on the transmission system to maximize transmission capacity are the contributing factors that can potentially lead to SSCI.

Methods of SSCI Detection & Potential Mitigations

- Methods of SSCI Detection
  - Simulations: Time domain simulations with tools like PSCAD/ EMTDC to perform EMTP analysis
  - Frequency Domain Analysis: Impedance Scanning & eigen value analysis
  - Observer Based Controllers: Algorithms that are constantly observing & predicting the system state and detecting SSCI
- Methods of SSCI Mitigation
  - Thyristor controlled series compensation: Modulate the reactance to provide damping
  - NGH damping scheme: Linear resistor in parallel to the series capacitor controlled by thyristor and triggered when the SSCI currents are detected
  - SSCI damping controller: Installed at the IBR resources that actively mitigate the SSCI by adjusting control parameters
  - Bypassing the series capacitors
  - Reducing the amount of series compensation

<Public>

PacifiCorp Current Requirements related to EMTP Modeling for new IBR resources

- PacifiCorp Business Practice 84 currently guides the modeling requirements for new generators trying to interconnect to PacifiCorp's transmission system (Posted on PacifiCorp OASIS BP84.pdf)
- PacifiCorp currently requires all the new Generation Interconnection Customers trying to interconnect Inverter Based Resources (IBR) to provide the following modeling data
    - Positive Sequence Power flow Data
    - Dynamic model (WECC Generic & UDM)
    - Short Circuit Model
    - EMTP Model
- Challenges in receiving EMTP models from developers as requires model tuning and developers not having a tuned EMTP model at the starting phase of the interconnection application

Potential for Future Enhancements

- Incorporating requirements established in IEEE 2800-2022 standard
  - Requiring Model Validation Tests (MVT) from the LGIA customers
  - Incorporating guidelines developed by WIRAB into PacifiCorp modeling/performance requirements for IBR based resources
- Potential for WECC/NERC to come together and collaborate in developing standard/criteria and potential model library for transmission planners/ developers to download and perform required analysis
- Potential Challenges
  - Development of systemwide EMTP models along with computing/time requirements for this type of analysis
  - FERC timeline for reviewing and validating EMTP models provided by developers
  - Knowledgebase for this kind of special studies

Questions

Electranix Model Requirements: History and Philosophy

WECC EMT Strategic Workshop
November 19^{th} – 20^{th}, 2025

Anuradha Kariyawasam
www.electranix.com

Document History

- Started with common request from a customer’s generator owners (HECO).
- When a PSCAD model is requested from the developers… they would respond with “what do you mean?”
- Models would come in with problems, and we would revise the document over time as we found common problems that needed fixing.

<Public>

Document History

Suggested PSCAD model requirements

Date: May 31, 2013

Prepared By: Andrew L. Isaacs P.Eng.

Specific model requirements for a PSCAD study depends on the type of study being done. A study with a scope covering weak system interconnection, ride-through, voltage control and event response, and islanding performance (for example) would require a model which has the following characteristics. Such a model will also be suitable for classical PSCAD transient studies. Some specialty studies may require other features.

MUST HAVE
The model….

- Represents the full detailed inner control loop of the power electronics. The model cannot use the same approximations classically used in transient stability modeling, and should fully represent all fast inner controls, as implemented in the real equipment. It is possible to create models which embed the actual hardware code into a PSCAD component, and this is the best type of model.
- Represents all pertinent control features (eg. external voltage controllers, plant level controllers, etc). Operating modes that require system specific adjustment should be user accessible.
- Represents all pertinent electrical and mechanical configurations, such as filters and specialized transformers, gearboxes, torsional models. Model can be either a full IGBT representation, or use a voltage source interface that mimics the IGBT operation (unless harmonic studies require full representation of switching dynamics). Current source interface is not recommended.
- Has all pertinent protections modeled in detail. Typically this includes various OV and UV protections, frequency protections, DC bus voltage protections, and overcurrent protection. There may be others.
- Has control or hardware options which are pertinent to the study accessible to the user.
- Initializes as quickly as possible (<1-3 seconds) to user supplied terminal conditions.
- Is capable of running at a minimum time step of 20 us, unless specific control parameters require smaller. The smallest we have seen in terms of genuine control limits are 10 us. Most of the time, 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 higher timesteps. Depending on the size of the system being modeled in the actual study, this could be a firm requirement.
- Supports multiple instances of the model in the same simulation.
- Documentation and a sample implementation test case should be provided
- Supports the PSCAD "snapshot" feature.
- Supports the PSCAD "multiple run" feature.

NICE TO HAVE (Recommended but may not be required)
The model…

- Is compiled for both Compaq Fortran, and the most recent version of Intel Fortran. The compiler requirement depends on what other custom models are being used in the composite

system model. Sometimes flexibility for compiler options is very helpful (ie. Ability to quickly recompile models). Alternatively, the model can use DLLs which are compiler independent.

- Is written in PSCAD version 4.2.1. This older version of PSCAD is upward compatible with version 4.5, but 4.5 is not backward compatible. This can become important where many manufacturers and compilers are contributing to a composite model. This is a preferred feature, but not always required.

Where we are now..

- Current Version – Rev. 13
- Cited or used directly in many US regions
- V12 is used near verbatim into IEEE 2800, and the tests from v13 were the foundation for 2800.2 draft language.
- Which tests are better, 2800.2 or ours?
- We use this internally to test models often even when other requirements also apply

Model Requirements Rev. 13

Date: **February 2025**

Prepared By: **Electranix Corporation**

Philosophy of current release

- Types of Studies

Introduction

Specific model requirements for a PSCAD study depend on the type of study being done. A study with a scope covering weak system interconnections, ride-through evaluation, Sub-Synchronous Control Interactions (SSCI), short term[1] event response, and fast control interaction with nearby devices (for example) would require a model which has the following characteristics. Some specialty studies may require other features. Refer to

- General use with balanced set of tests, can be modified for specific system requirements

Philosophy of current release

- Informed by 2800
- Tuned and informed by hundreds of actual tests of OEM models
- All wording and footnotes are highly *intentional*, in some cases in order to fix exploits or loopholes.

[2] The model may be a full power transistor (eg. IGBT) representation, or use an average source representation that approximates the switching but maintains full detail in the inner controls, maintains DC side representation and protection features, maintains numerical stability when disconnected, and correctly mimics gate-blocking dynamics. 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.

How to use the document

- Note CC-BY “Attribution” license… means you can use and modify, but attribution is required. If this is a problem, please reach out.
- Use directly or modify, but we recommend: Only delete something if you understand the original purpose, including footnotes
- Before you add something, consider that we may have left it out for a reason.
- Any new tests should be tested against multiple real models. It is easy to cause chaos with a buggy test.
- If you want, chat with us to have us go through individual points or detail. We also teach this in courses.

Thank you!
Questions?

<Public>

EMT Model Quality Checks and Testing Requirements and Recommended Practices in IEEE 2800-2022 and IEEEP2800.2

Presented to WECC Strategic Workshop on EMT

JULIA MATEVOSYAN, IEEE P2800.2 SG5 CHAIR

IEEE P2800.2 LEADERSHIP TEAM:

ANDY HOKE, P2800.2 WG CHAIR
MANISH PATEL, SECRETARY
JENS BOEMER, BOB CUMMINGS, DIVYA CHANDRASHEKHARA,
JULIA MATEVOSYAN, MAHESH MORJARIA, STEVE WURMLINGER, VICE CHAIRS

Power & Energy Society®

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  - P2800.2 is an unapproved draft of a proposed IEEE Standard. As such, the document is subject to change, any draft requirements and figures shown in this presentation may change.
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What is Model Quality Assessment?

- **Model quality assessment** (MQA): The process of evaluating the plausibility, usability, and numeric stability of a model based on a review of model documentation, data, and simulations
- MQA is a first step to IBR plant design evaluation
- Should be performed on **validated**:
  - IBR unit model
  - Supplemental IBR device model
  - IBR plant model

  to ensure that the models perform reasonably in the software tool of choice

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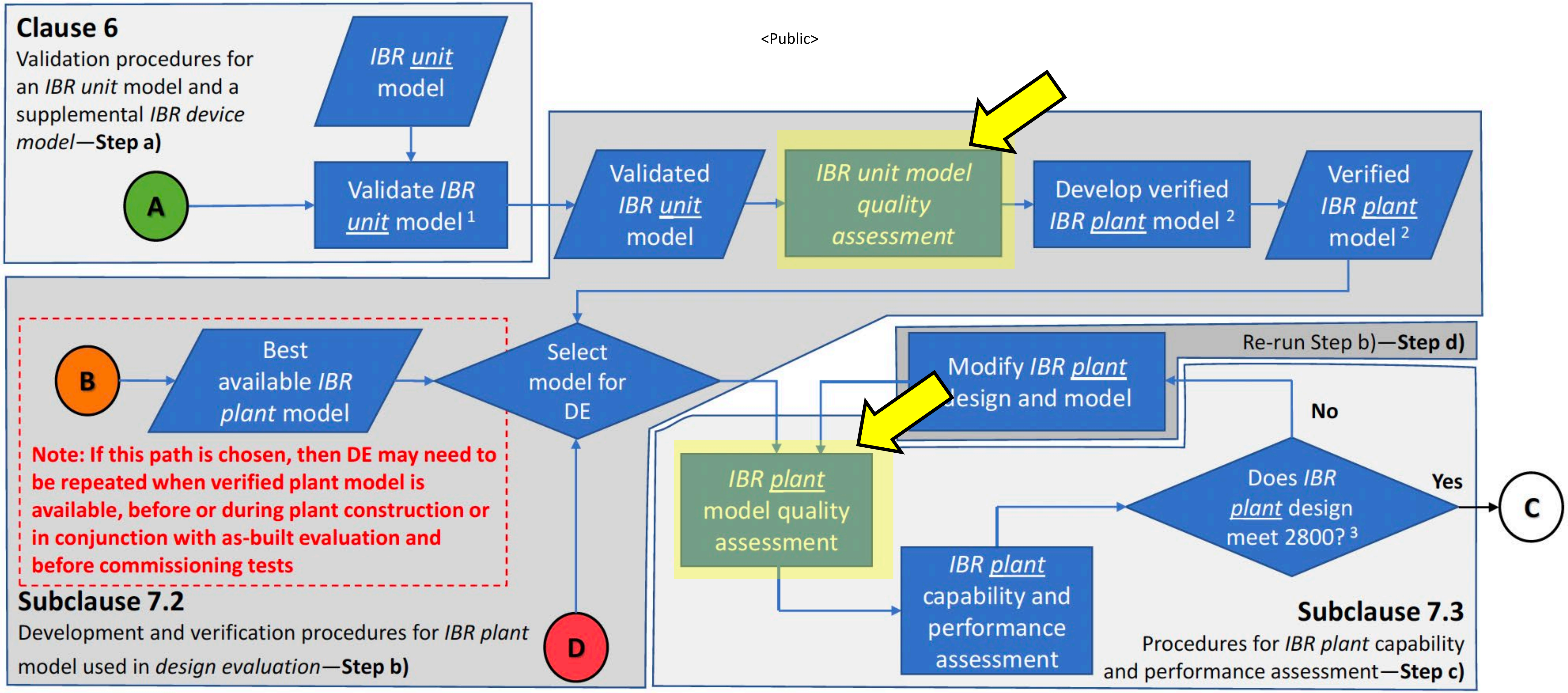
What is Model Quality Assessment?

- What MQA is not?
  - It is not model validation → applied to validated models
  - It is not assessment of performance conformity → pre-requisite for detailed conformity assessment
  - It is not model verification → applied to verified models
- Procedure found in Annex H (normative) of IEEE P2800.2, while the main document includes several reminders and clarifications in Clause 7, Design Evaluation



[1] Follow same procedure for validation of *supplemental IBR device* model.

[2] The verified *IBR plant* model is developed using *IBR plant* design and validated *IBR unit/supplemental IBR device* models. The plant model in this step is not validated until after commissioning.

[3] Passes *IBR plant design evaluation* steps listed in Clause 7.3.

<Public>

Model Quality Assessment

- Step 1: High-level sanity check of parameters
- Step 2: Perform some simple quality check simulations on PDT or EMT models to
  - Ensure that the model initializes properly in the software and for a no-disturbance run the model's output remains in steady-state and does not change noticeably nor diverge,
  - Ensure that the model responds as expected in an orderly, and well damped fashion to:
    - Voltage/reactive power/power factor reference step down and back up
    - A plant active power (MW) reference step up and back down
    - A step up and down in the network frequency to test the active power frequency response of the IBR plant, with the plant initially in a curtailed mode.
    - A normally cleared (e.g., 5 cycle duration) 3-phase to ground fault at the RPA of the plant.
    - A simulation of a back-up clearing event. First a normally cleared (e.g., 5 cycle duration) 3-phase to ground fault at the RPA, followed by a single-line to ground (SLG) fault that lingers on and is cleared after an additional e.g., 10 cycles.

<Public>

Model Quality Assessment

- Step 2 (cont.): Perform some simple quality check simulations on PDT or EMT models to
  - Ensure that the model behaves well numerically for a reasonable range of system strengths at the point of connection.
  - If OEM documentation states that protective functions are present and enabled, a series of simple tests is applied to verify that protective functions are included in the model
  - Verify that PDT and EMT models run and their performance match sufficiently over a range of time steps as mutually agreed upon by all stakeholders.

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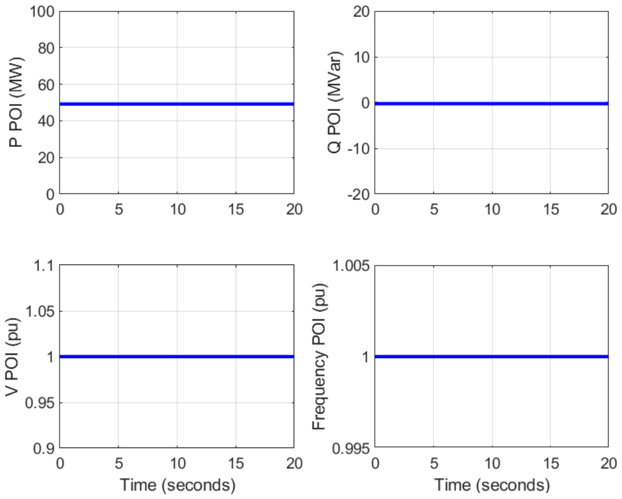
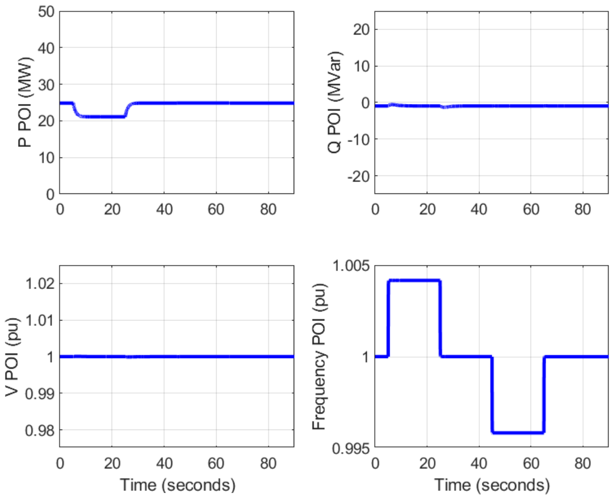
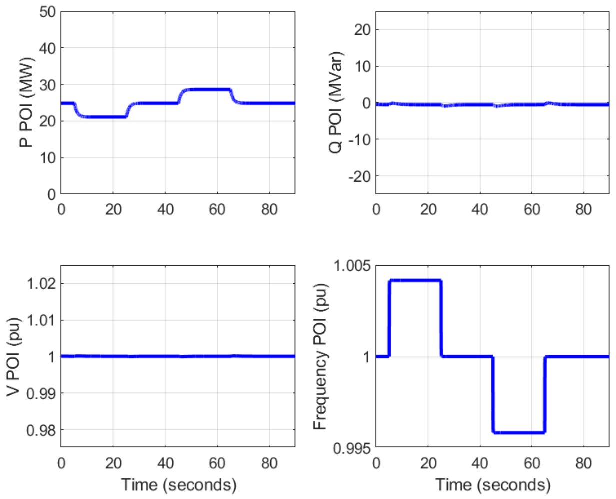
Model Quality Assessment

- Keep it simple
- Keep it focused
- Apply judgement







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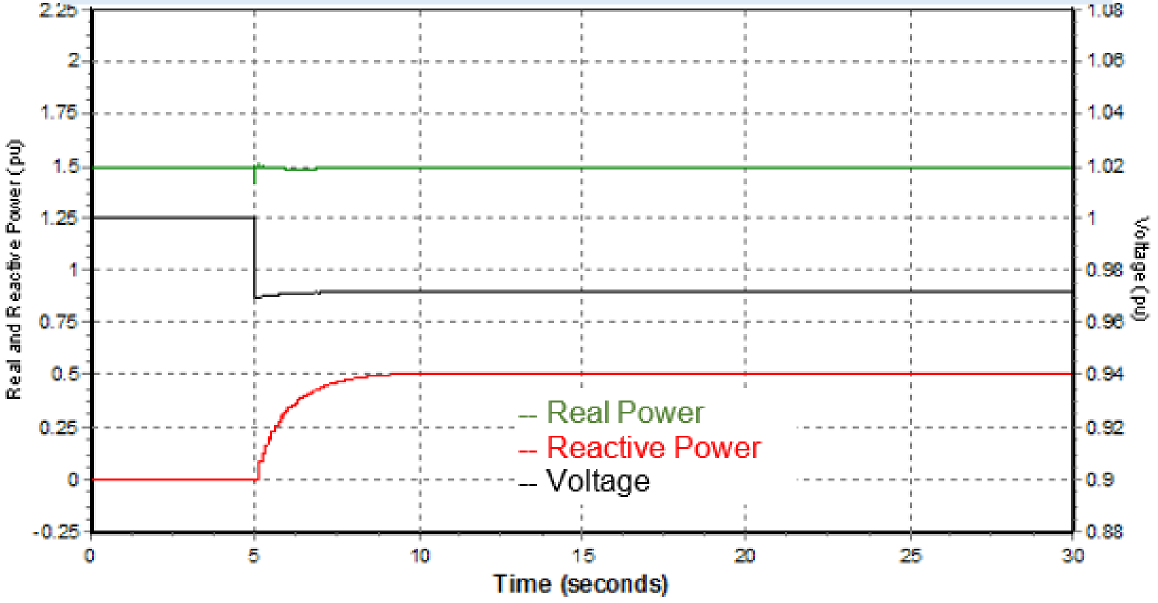
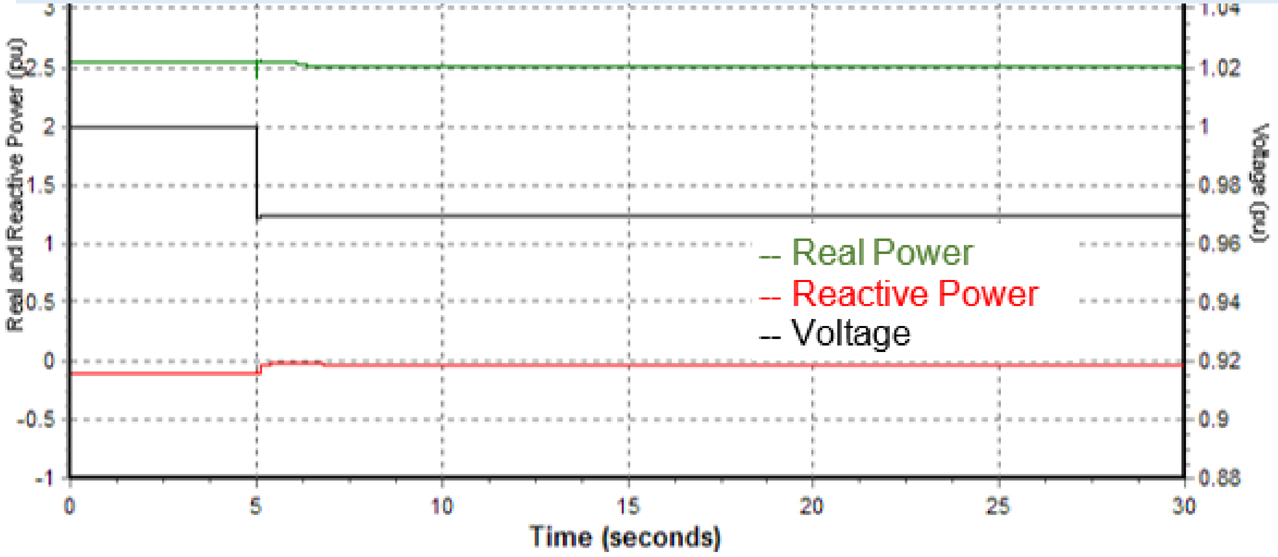
Model Quality Assessment

Acceptable Response: Small Voltage Step Down



Unacceptable Response: Small Voltage Step Down



ERCOT Dynamic Working Group Procedure Manual

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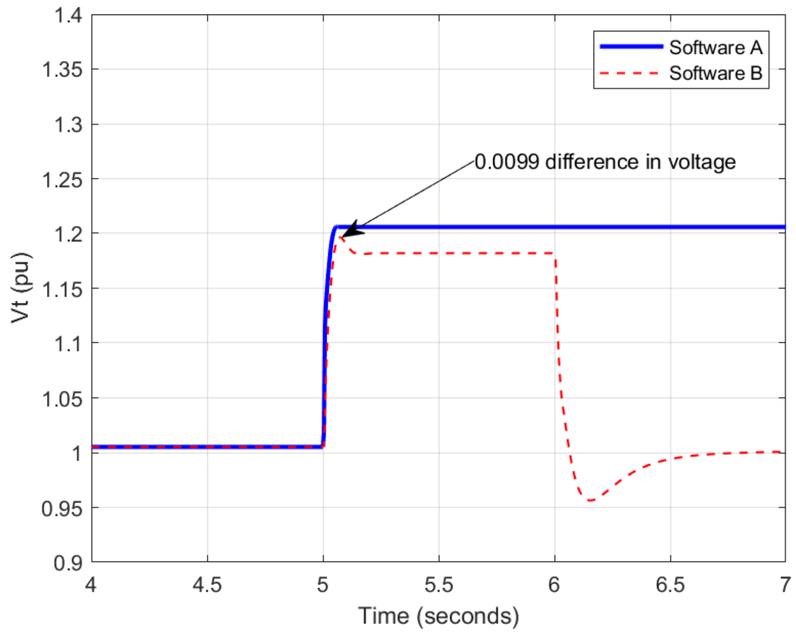
Model Quality Assessment

- Realize that the exact same model may not 100% align across software platforms due to numerical differences in solution algorithms particularly associated with the network solution (not equipment)



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Summary

- MQA tests needs to be performed
- Keep them simple and focused → is the model well behaved to move to the next step
  - Not trying to do too many things at once
- Understand differences across software platforms and do not get hung up on them

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THANK YOU

Julia Matevosyan

julia@esig.energy

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Walkthrough of IBR Model Quality Testing

Kasun Samarasekera, *Head of Power Systems Studies and Modeling*

November 19, 2025

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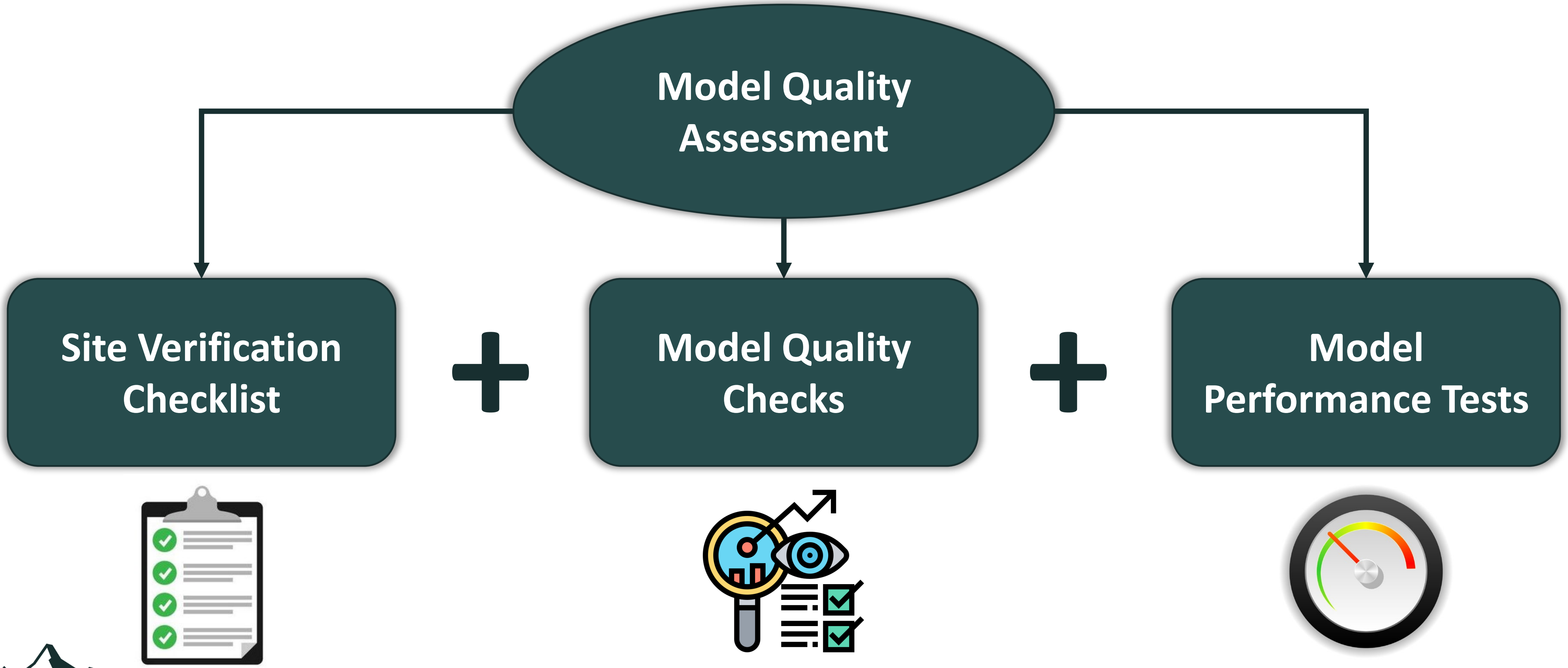

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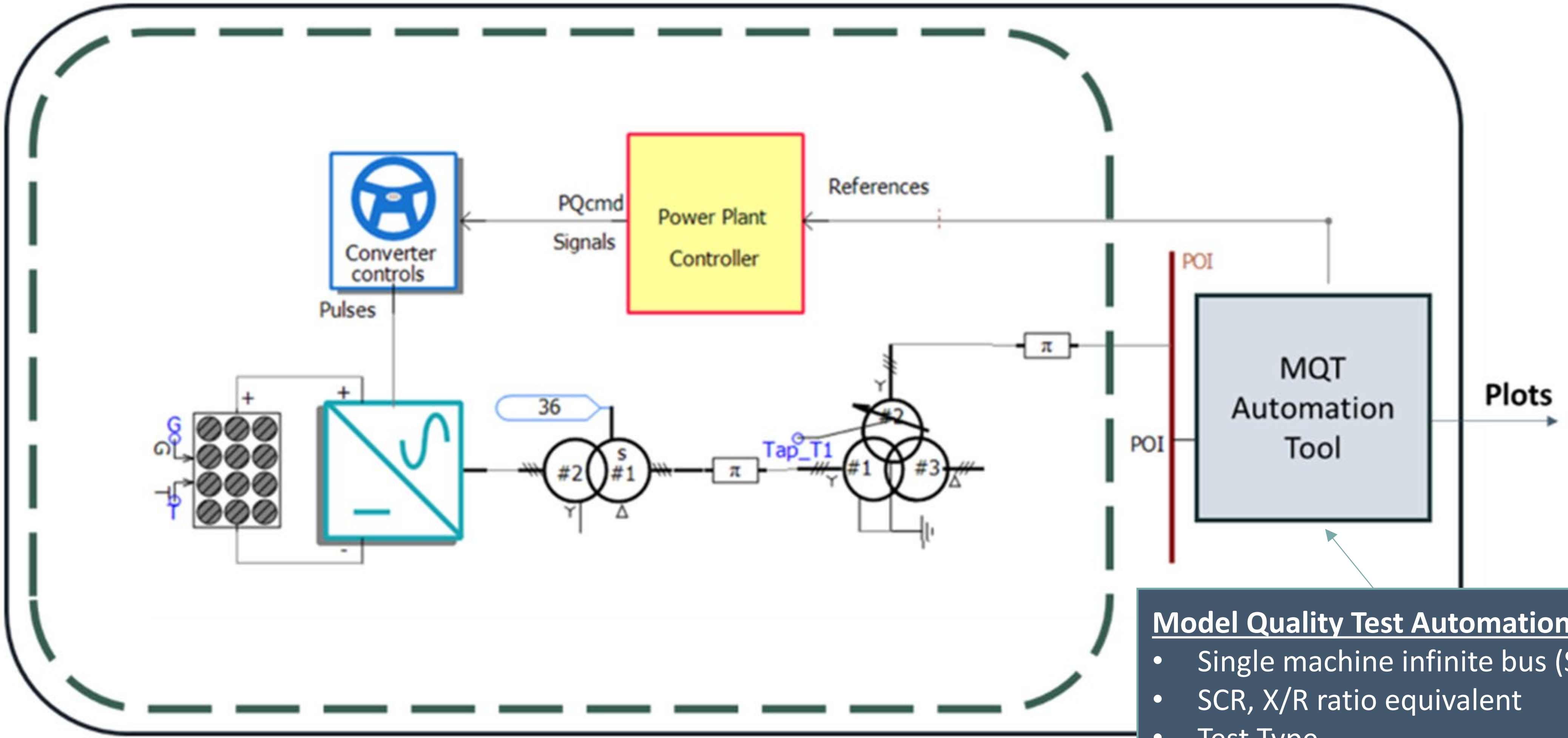

Model Quality Test Automation Config:

- Single machine infinite bus (SMIB) system
- SCR, X/R ratio equivalent
- Test Type
- Simulation test duration
- Plot definitions

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PSS®E
PSCAD
DSATools™ Dynamic Security Assessment Software

Select Simulation Platforms

TVA ISO new england ercot ieso MISO

Choose a Region

Conduct Model Performance Tests
Run all tests via web interface on virtual computers.
One click, minimize, and wait.

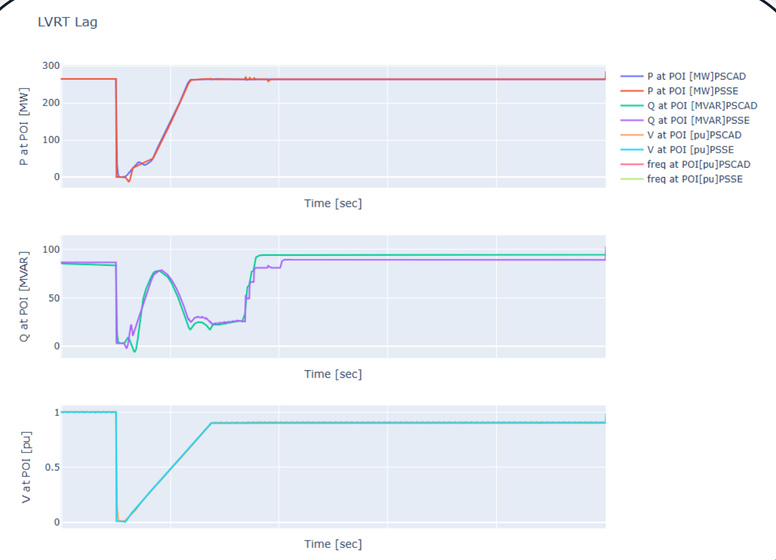
Benchmark Results
Overlay responses from each simulation model (PSSE, PSCAD, TSAT).

Compare Simulations
Automatically check conformity with requirements.
Check pre- vs. post-modification results. Tune as needed.

Compile Report
Capture simulation results and findings from all tests conducted. Standardized reporting tailored to regional requirements.

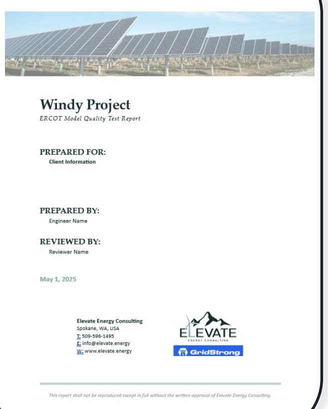
Example automation approach

Secure Virtual Computer Lab



Interactive plots with analytics built in

Standardized and Automated Reporting



GridStrong

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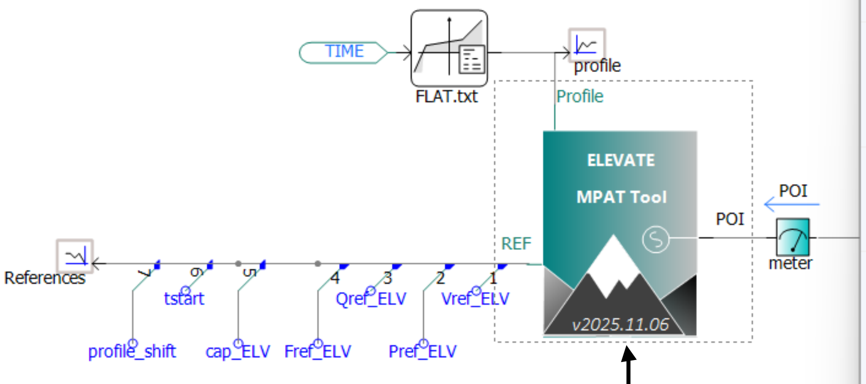
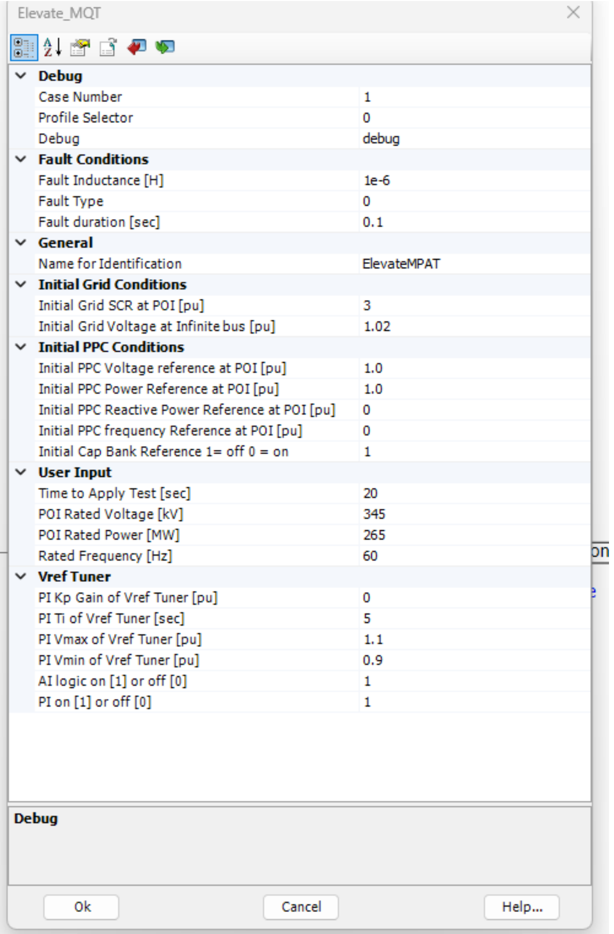
Universal MPAT Block




Elevate_MQT

Debug	
Case Number	1
Profile Selector	0
Debug	debug
Fault Conditions	
Fault Inductance [H]	1e-6
Fault Type	0
Fault duration [sec]	0.1
General	
Name for Identification	ElevateMPAT
Initial Grid Conditions	
Initial Grid SCR at POI [pu]	3
Initial Grid Voltage at Infinite bus [pu]	1.02
Initial PPC Conditions	
Initial PPC Voltage reference at POI [pu]	1.0
Initial PPC Power Reference at POI [pu]	1.0
Initial PPC Reactive Power Reference at POI [pu]	0
Initial PPC frequency Reference at POI [pu]	0
Initial Cap Bank Reference 1= off 0 = on	1
User Input	
Time to Apply Test [sec]	20
POI Rated Voltage [kV]	345
POI Rated Power [MW]	265
Rated Frequency [Hz]	60
Vref Tuner	
PI Kp Gain of Vref Tuner [pu]	0
PI Ti of Vref Tuner [sec]	5
PI Vmax of Vref Tuner [pu]	1.1
PI Vmin of Vref Tuner [pu]	0.9
AI logic on [1] or off [0]	1
PI on [1] or off [0]	1

Debug

Ok Cancel Help...

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Flat Run

Phase Jump

SCR

Model Quality Tests

HVRT and LVRT Ride Through Tests

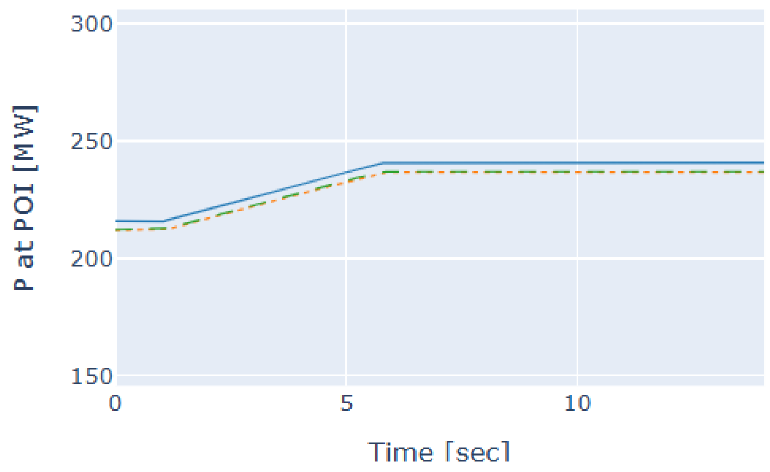
Faults

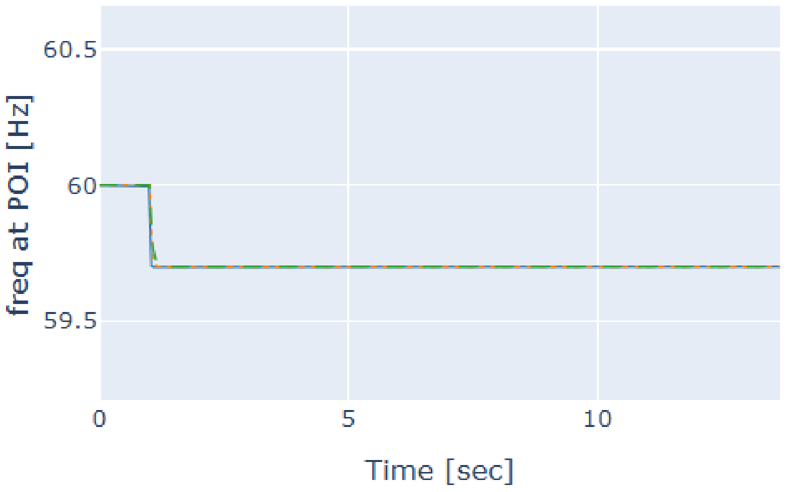
Voltage and Frequency Step up

Source: Gemini

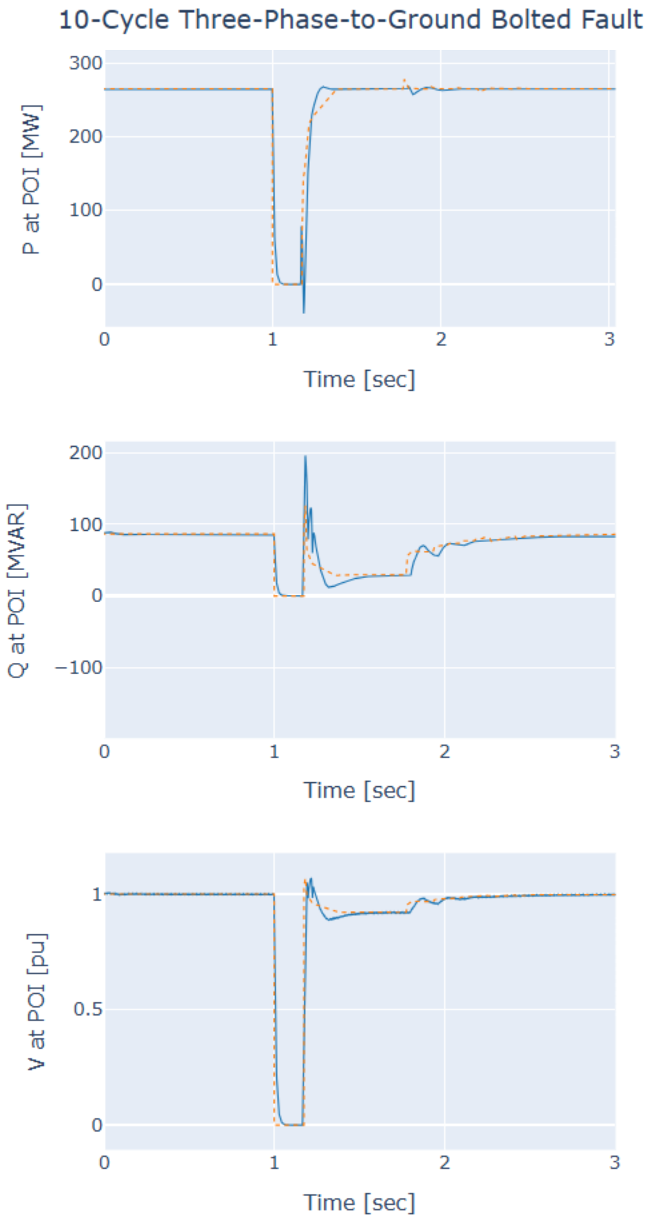
ERCOT Tests
Flat Run
Grid Voltage Down
Grid Voltage Up
LVRT Lead Legacy
LVRT Lead Voltage Dip (WGR)
LVRT Lag Legacy
LVRT Lag Voltage Dip (WGR)
HVRT Lead Legacy
HVRT Lead Preferred
HVRT Lag Legacy
HVRT Lag Preferred
Grid Freq Down no Head Room
Grid Freq Down with Headroom
Grid Freq Up no Head Room
Grid Phase Angle Up
Grid Phase Angle Down
Short Circuit Test

Grid Freq Down with Headroom





MISO Tests
Flat Run, Pmax, Qmax
Flat Run, Pmax, Qmin
Flat Run, Pmin, Qmax
Flat Run, Pmin, Qmin
10-Cycle Three-Phase-to-Ground Bolted Fault
Small Voltage Disturbance
Small Frequency Disturbance Up No Headroom
Small Frequency Disturbance Down No Headroom
Small Frequency Disturbance Up with Headroom
Small Frequency Disturbance Down with Headroom
High Voltage Ride-Through
Low Voltage Ride Through
High Frequency Ride Through
Low Frequency Ride Through
High Voltage Protection Test
Low Voltage Protection Test
High Frequency Protection Test
Low Frequency Protection Test
Short Circuit Test
Grid Phase Angle Up
Grid Phase Angle Down



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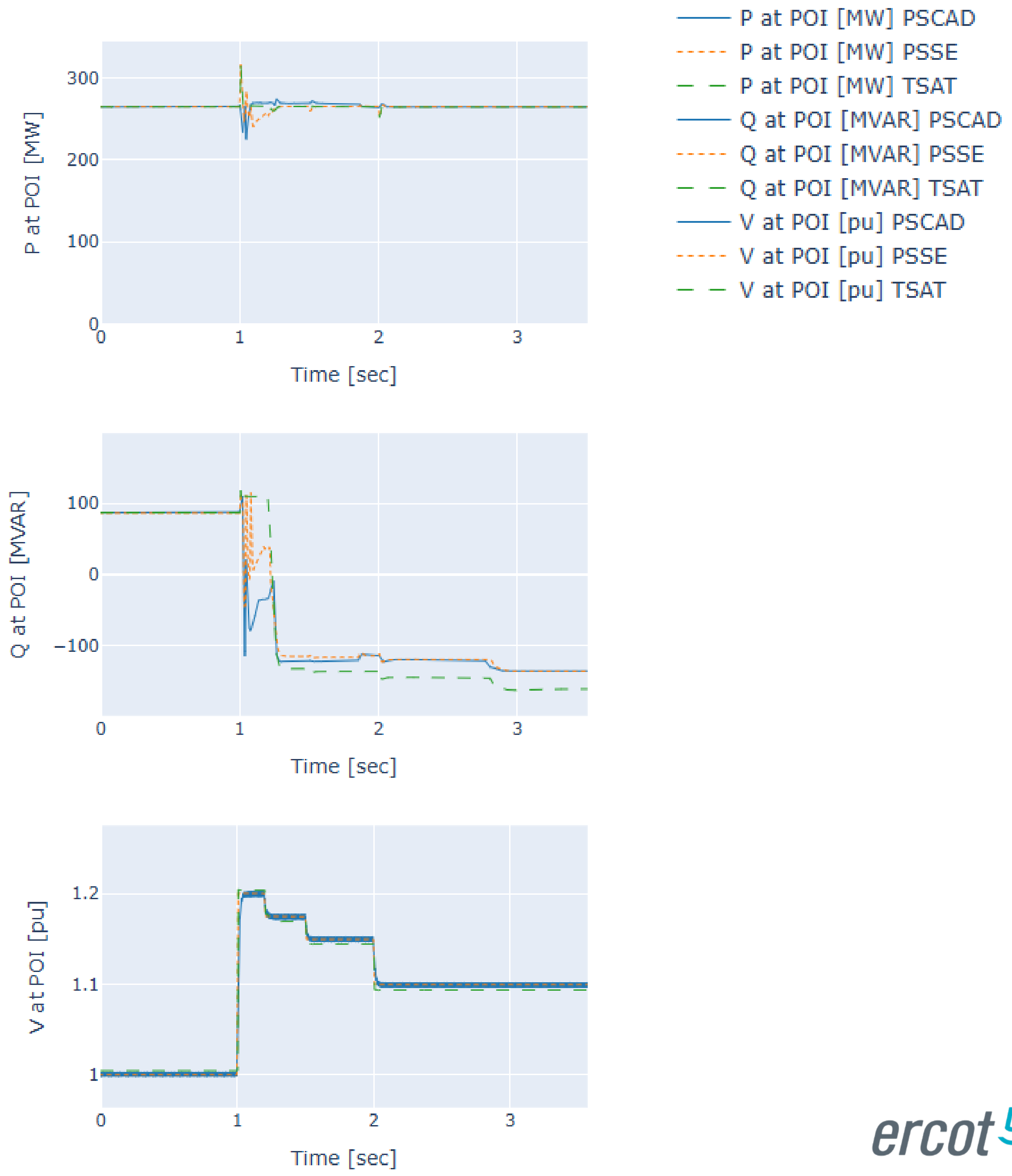
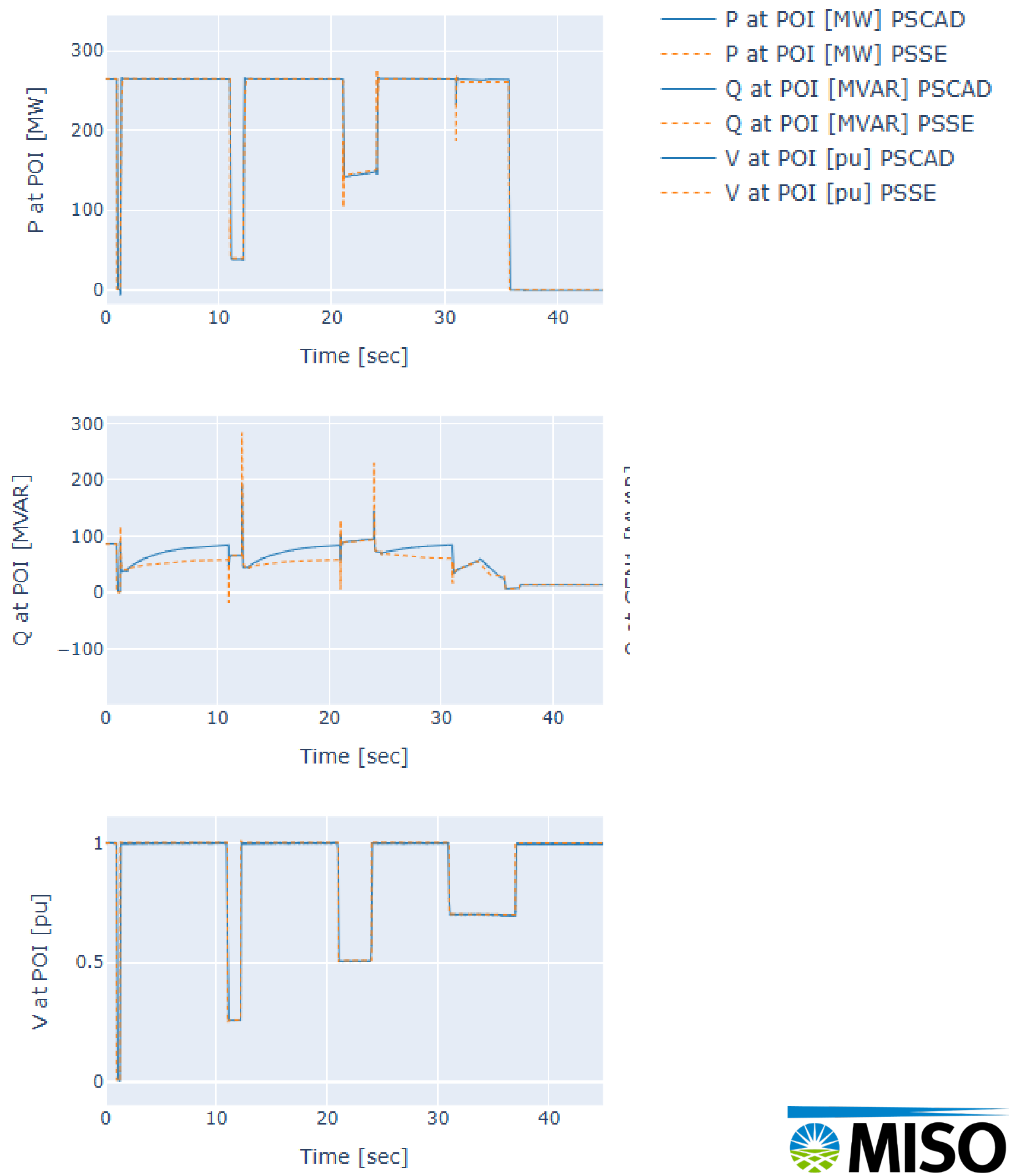
HVRT Lag Legacy



Low Voltage Ride Through



Source: Gemini

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Photo by Daniel Ziegener on Unsplash

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kasun.samarasekera@elevate.energy

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WECC EMT Workshop

Katie Iversen

Sr. Manager, Generator Modeling & Power System Studies

November 2025

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Presentation Overview

Background Information

- Project Processes & Major Stages
- Requirements
- OEM & EPC Background

EMT Modeling

- Positives
- Challenges
  - Accuracy & Responsibilities, Wastes & Illusions, Logistics

Solutions

- Partnering for Success: Help us Help You

<Public>

AES' US Businesses portfolio

14.3 GW operating

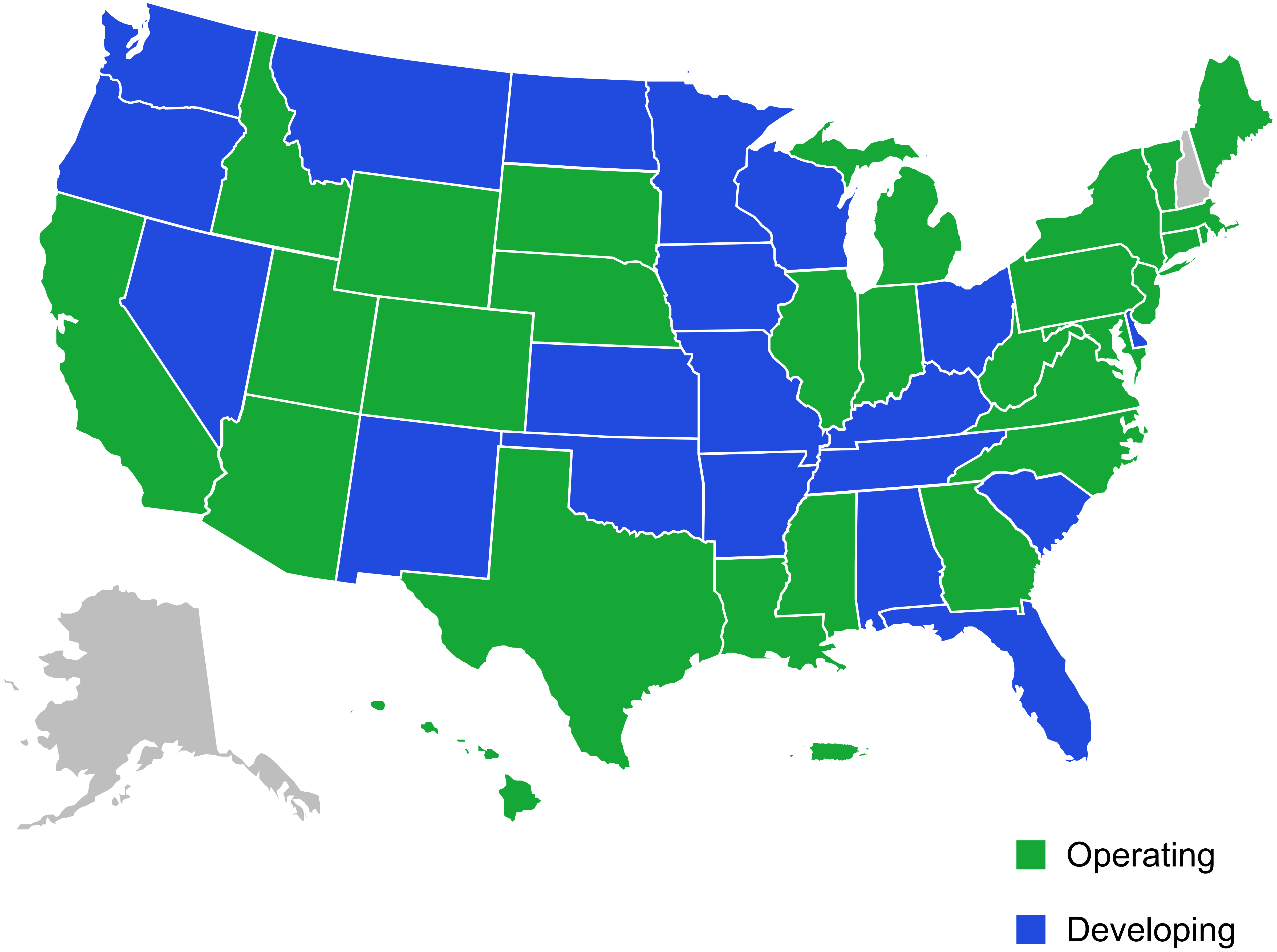
6.4 GW
solar

2.1 GW
wind

2.5 GW
battery energy storage

3.3 GW
flexible capacity

50+ GW in development



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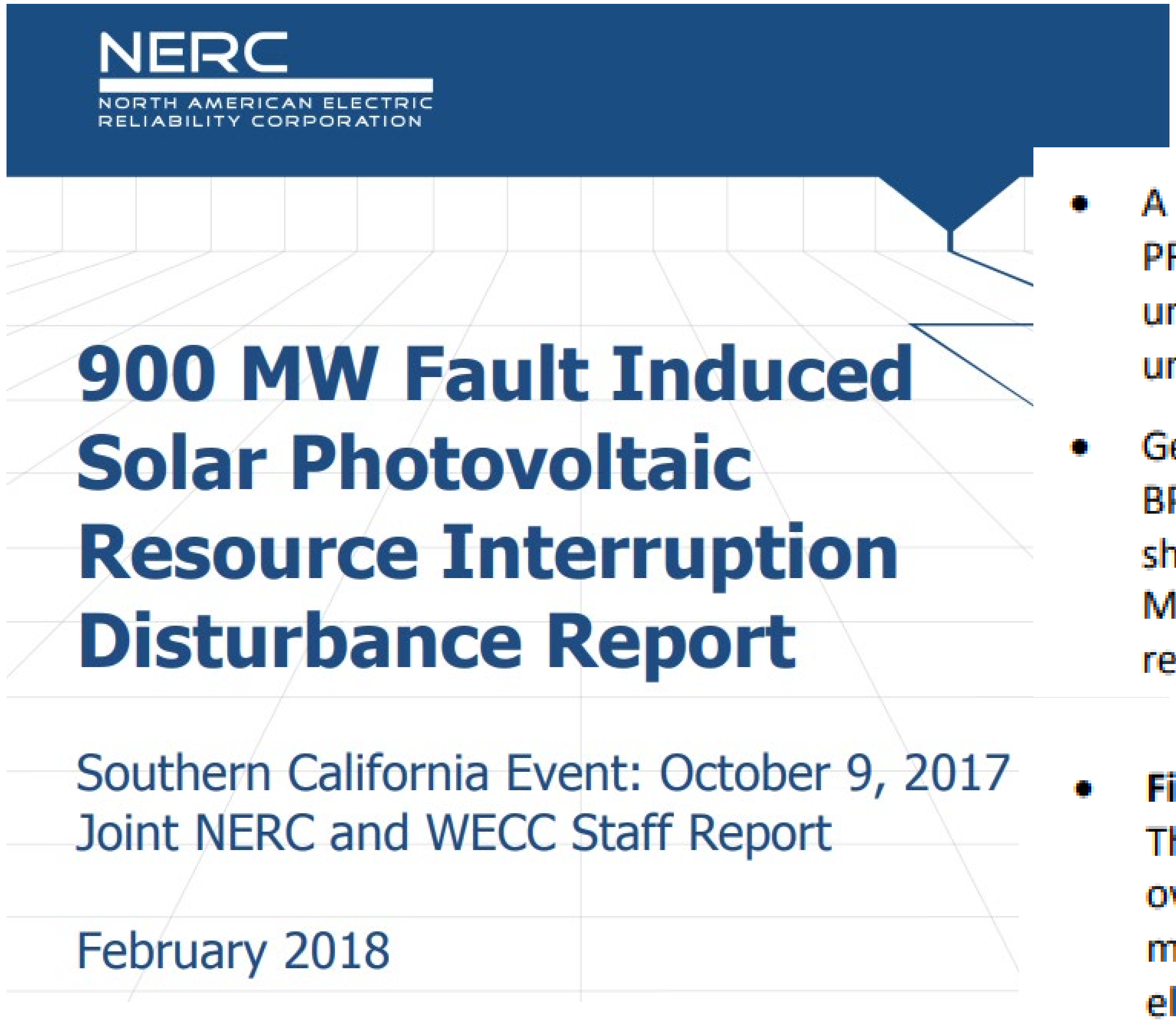
NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

900 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report

Southern California Event: October 9, 2017
Joint NERC and WECC Staff Report

February 2018

- A NERC Alert should be issued to the NERC registered GOs to ensure they understand the intent of the PRC-024-2 curve and equipment voltage protective philosophies. The purpose of the alert is to mitigate unnecessary voltage-related inverter tripping during grid disturbances, and to ensure that GOs understand how to mitigate these risks.
- Generic dynamic stability models used during the interconnection process for studying reliability of the BPS do not accurately reflect all aspects of the behavior of inverter-based resources. Model improvements should be prioritized by industry groups developing these models (e.g., WECC Renewable Energy Modeling Task Force) to ensure that stability models sufficiently reflect the behavior of inverter-based resources installed today and in the future.

- **Finding 8: Transient Interactions and Ride-Through Considerations**
  There appears to be an inter-relationship between in-plant shunt compensation, sub-cycle transient overvoltage, and momentary cessation that results in inverter tripping. While this has been observed at multiple locations for multiple events, the causes and effects are not well understood and require detailed electromagnetic transient (EMT) simulations for further investigation.

  Recommendation 8
  EMT studies should be performed by the affected GOPs, in coordination with their Transmission Owner(s) (TO(s)), to better understand the cause of transient overvoltages resulting in inverter tripping. These studies should also identify why the observed inverter terminal voltages are much higher than the voltage at the point of measurement (POM) and any protection coordination needed to ride through these types of voltage conditions.

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Project Processes and Major Stages

Development

- < 30% Design
- Low certainty, low fidelity design

Execution

- 30%+ Design
- Equipment Selection
- Commissioning & COD

Operations

- MOD-026/MOD-027
- Operational Performance
- New NERC Standards, Other Updates

Augmentations & Repowers

Interconnection Processes

FAC-002

After COD Requirements

MOD-032 R2
MOD-026, MOD-027

~~MOD-025~~

COD: PRC-019, PRC-024

Operational Changes, and Deficiencies

MOD-032 R2 & R3
MOD-026/MOD-027 R3
MOD-026, MOD-027 R4

PRC-019, PRC-024

Various Unpredictable Requests

aes

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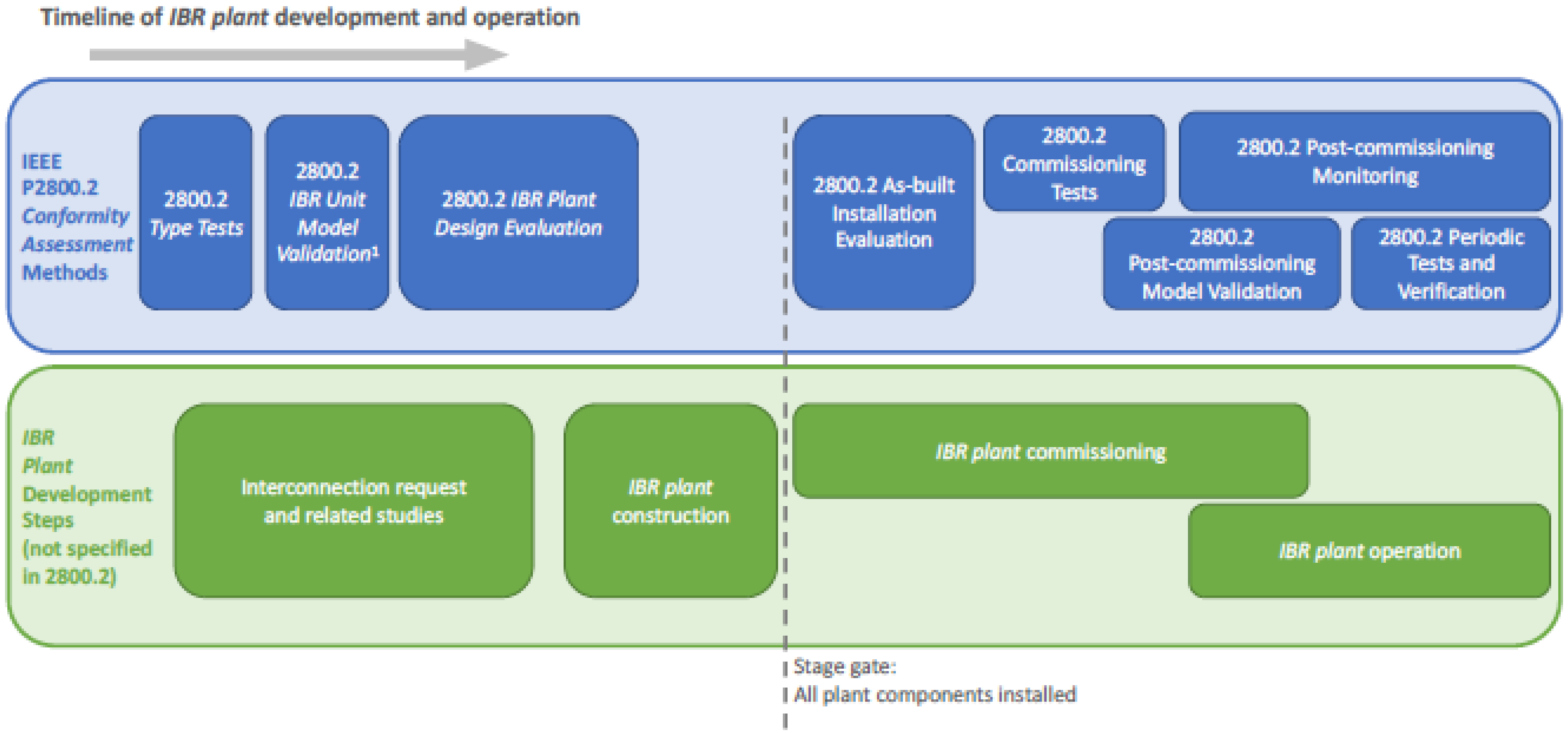

Figure 1 — Overview of *IBR plant* conformity verification sequence

[1] In addition to *IBR unit* models, models of applicable *supplemental IBR devices* such as *power plant controllers* are also validated here.

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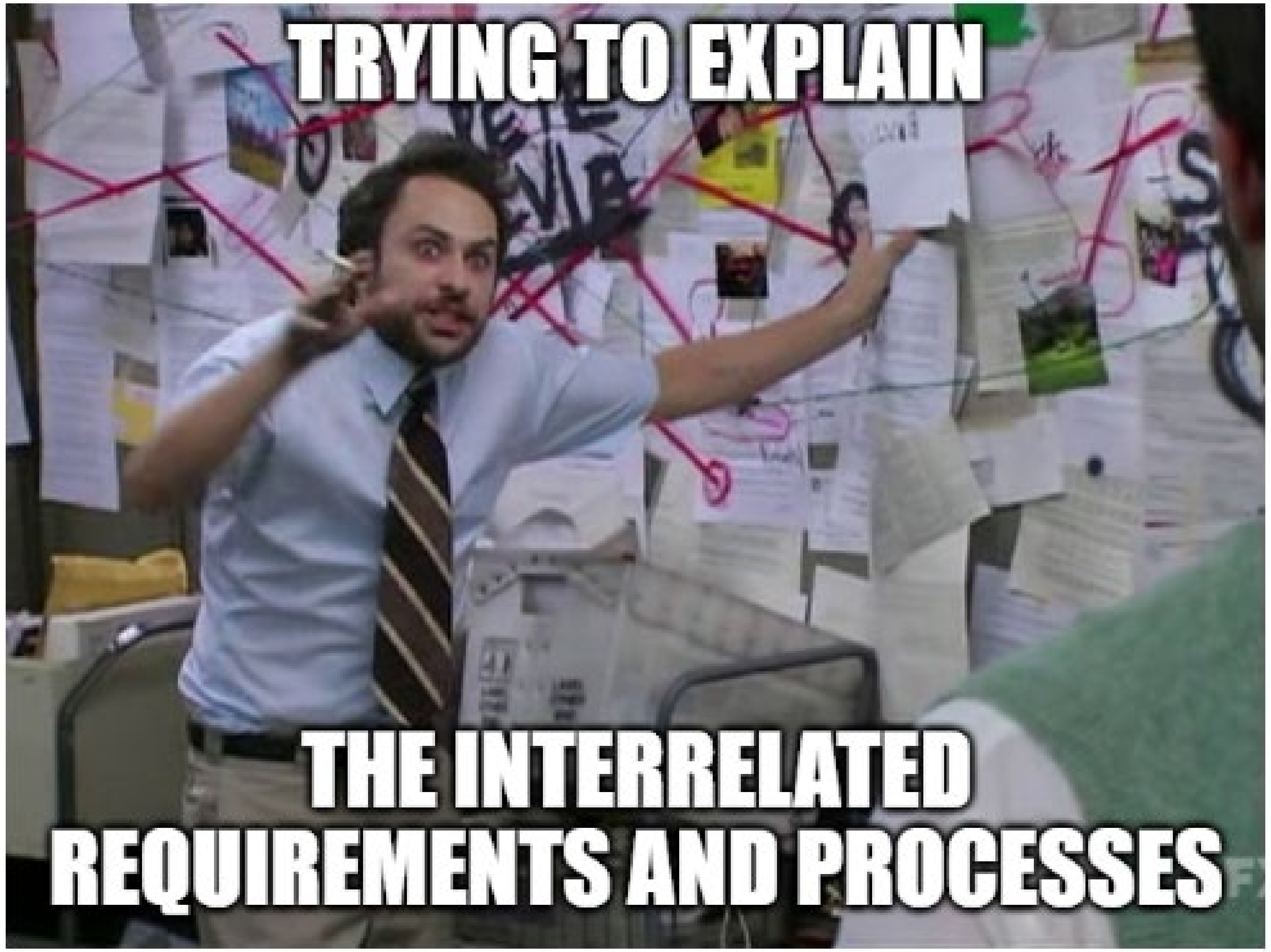
Lots of Processes



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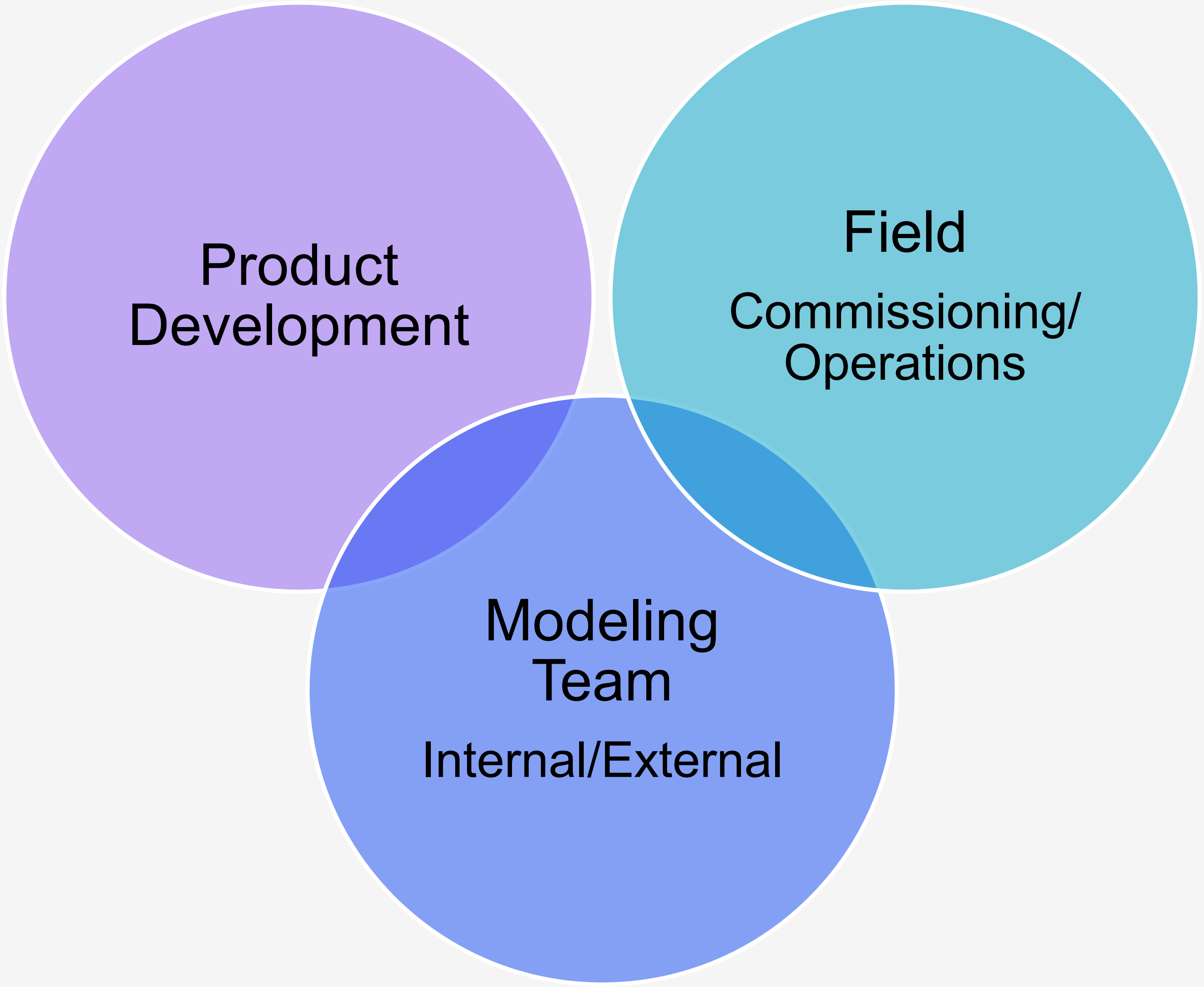

Equipment Development

- OEMs receive requirements and design equipment to meet them

Equipment Confirmation/ Model

- Confirm requirements are met as equipment is selected & model them

Confirm Requirements Met & Commission

- Confirm Requirements are met (GO/Developer Consultant)
- Commissions the plant as studied

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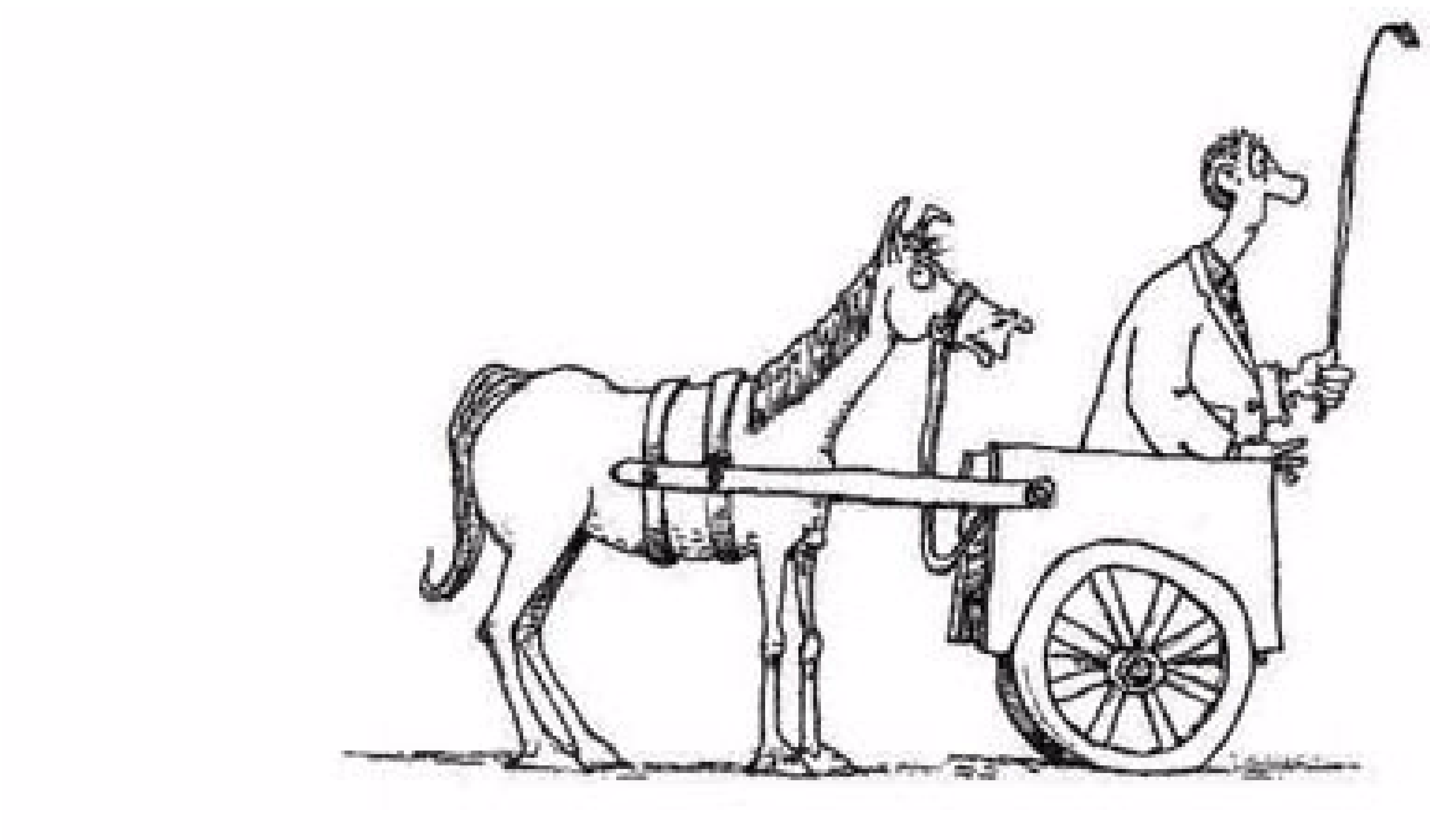
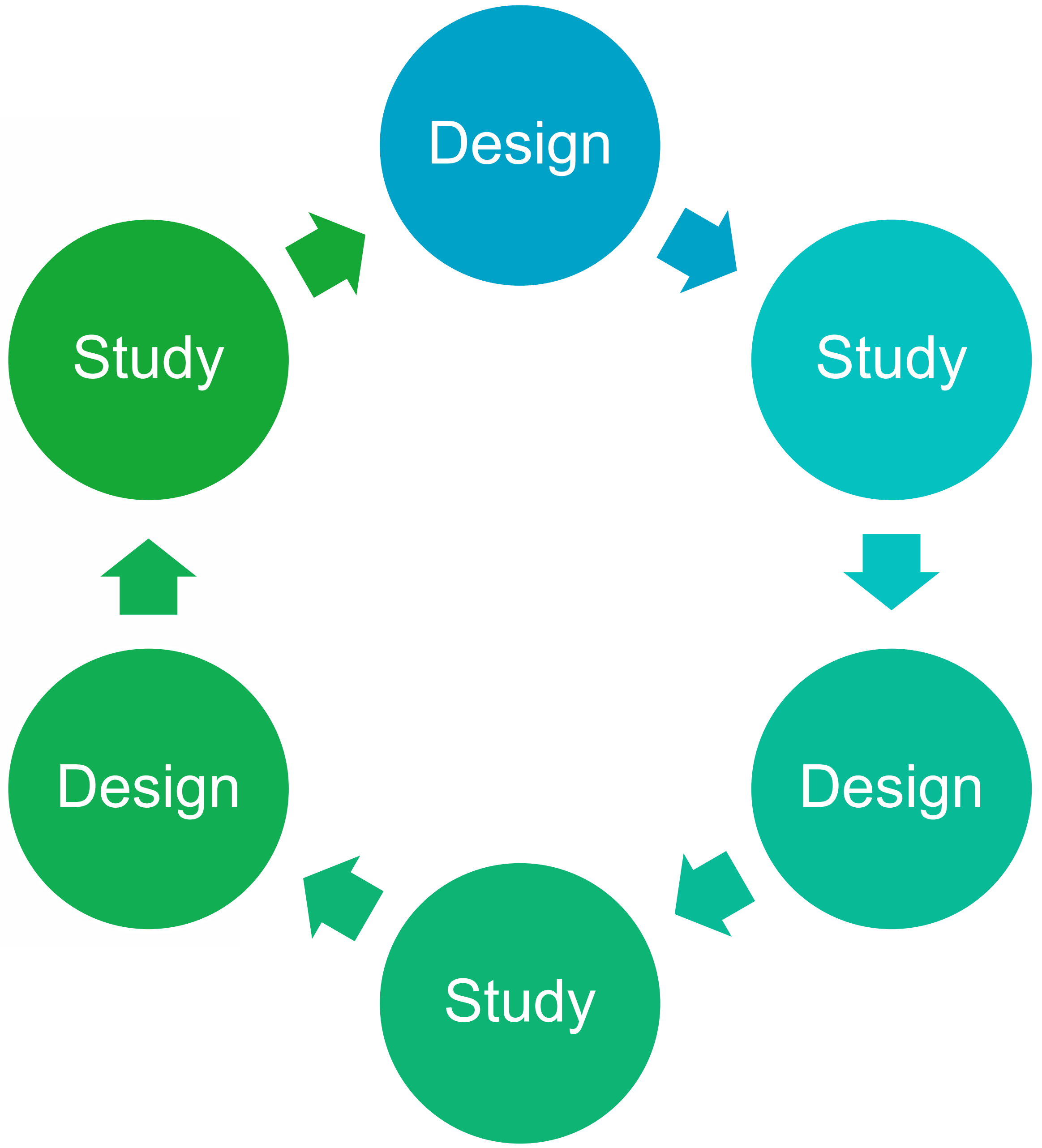
Iterative Nature with the EPC





EMT Models

Positives

- Demonstrates plant behavior that cannot be observed in the RMS domain
- Directly correlates to equipment
  - Provides valuable feedback to equipment commissioning
- Necessary for identifying and mitigating low SCR areas for both the developer, OEMs, & TP/PC
  - Evaluate where Grid Forming or other solutions are needed
- Beneficial for Event analysis

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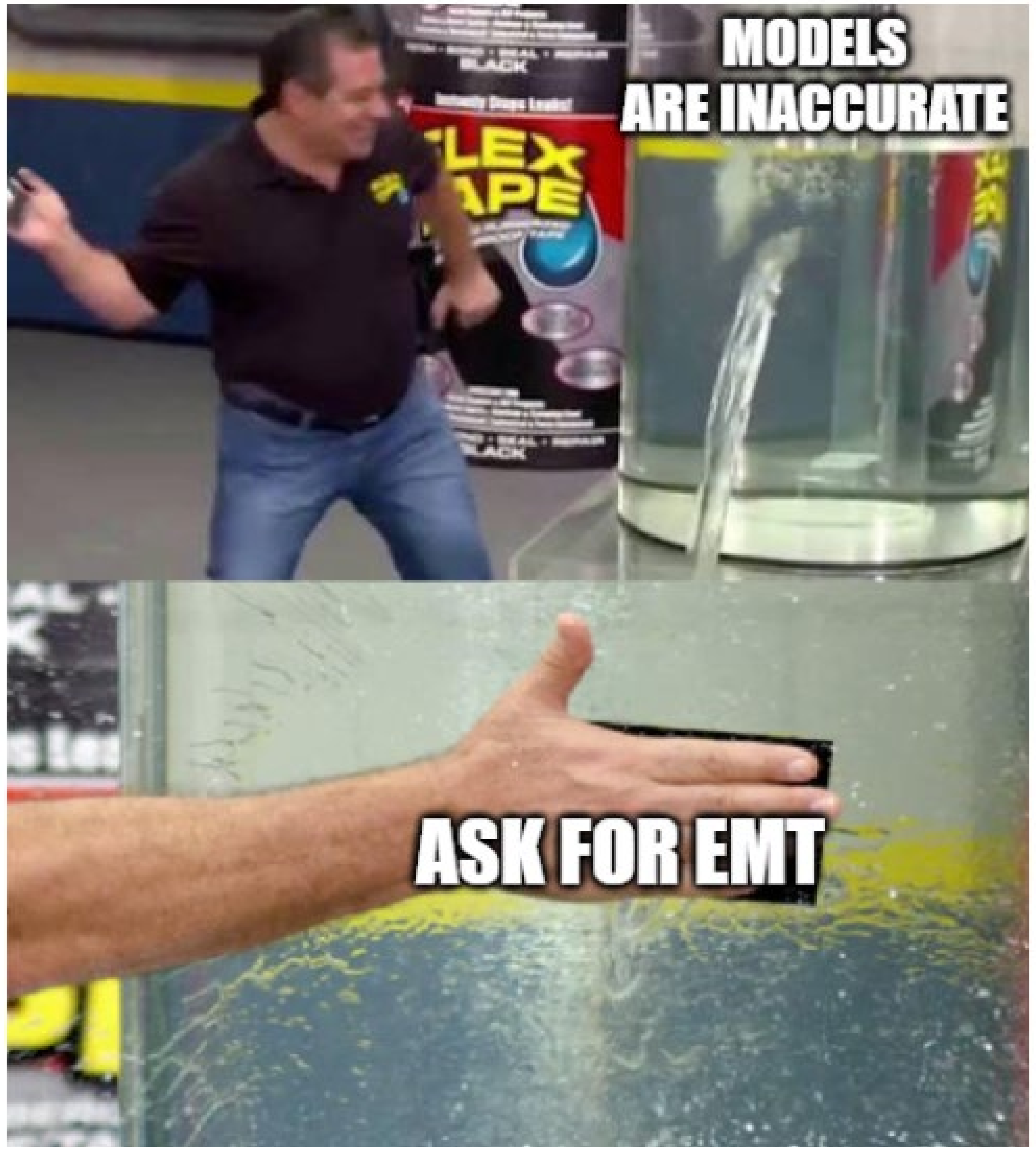
EMT Models

Accuracy & Responsibilities

- Processes/reviews incentivize inaccurate models to meet timelines
  - Accuracy requires time & collaboration
  - Equipment capabilities can be easily misrepresented to pass model tests
  - Models are mainly used by the utility, not by the developer/owner or OEM
- Model updates are seldomly met with a positive response
- Model feedback is unpredictable
- Legacy projects are not well supported

EMT Models

Wastes & Illusions



- High fidelity models of low accuracy designs creates engineering waste on all fronts
- EMT models provide an illusion of "modeling safety"
  - Inaccurate models provide little value
  - Lack of feedback or questions feeds confirmation bias
- Events are difficult to reproduce
  - Grid representation
  - Model accuracy
    - Real-code models & measurement equipment
- Area models are important to recognize EMT value
  - Grid representation and SCRs are needed

EMT Models

Logistics & Requirements

- EMT requirements of various ISOs
  - Overlapping requirements with areas of misalignment
    - Base requirements are typically Electranix's checklist
    - Additional bits from ERCOT Requirements & the NERC EMT documents
    - Individual entity adjustments
- Parallel Processes
  - Interconnection Requirements
  - NERC Requirements
    - MOD-032 R1: Copy + Paste

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Partnering for Success: Help Us Help You

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Partnering for Success: Help Us Help You

- Communicate and enforce at the right time
- Clear and standardized processes
- Focus on the impact of model updates, not on incentivizing no updates at all
- Dedicate resources to this work

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Extra slides >

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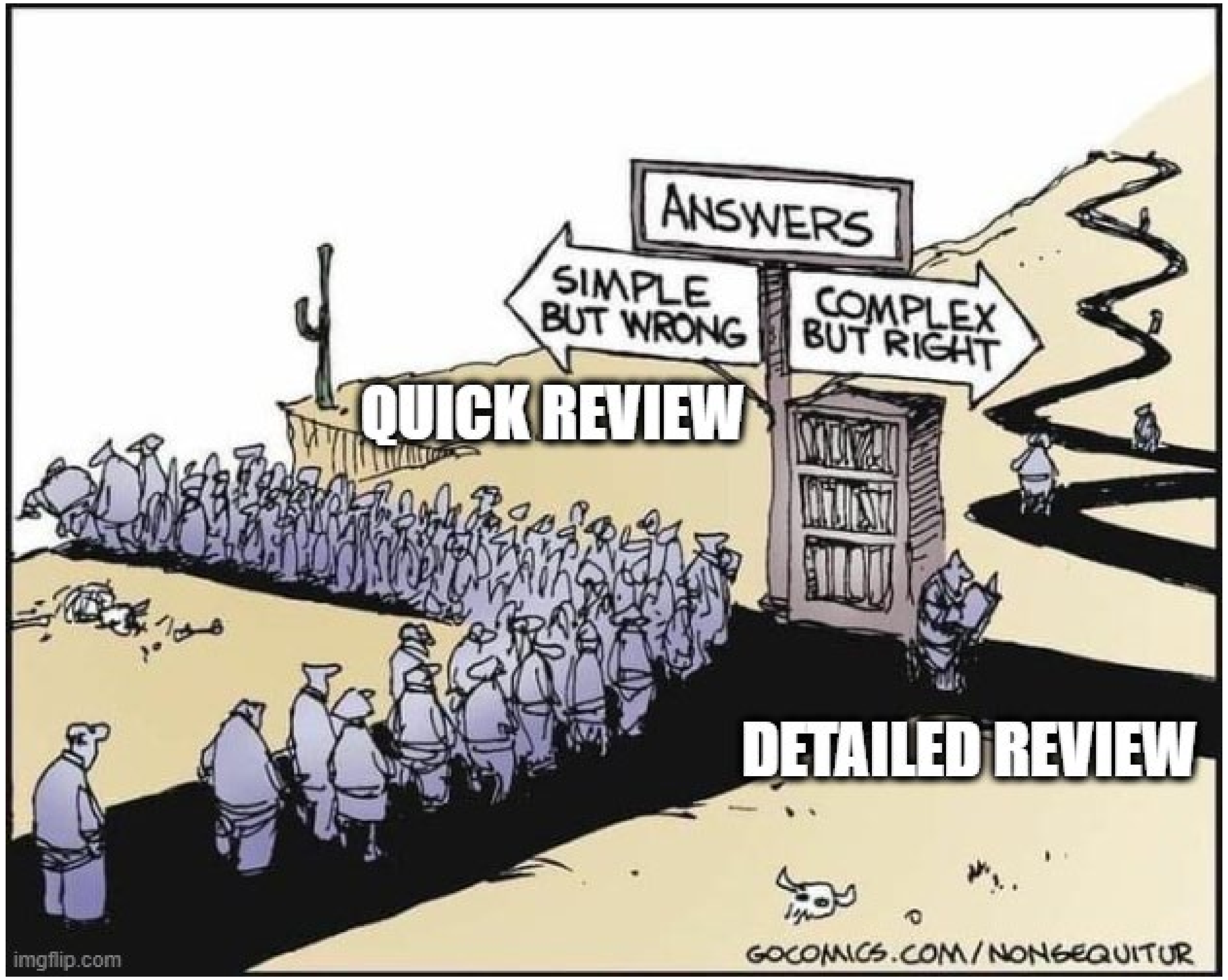
Review Processes



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Motivations & Perspectives

Transmission Planners
- Interconnection / Operations
- Steady State / Dynamic

Owners
- Execution
- Operations

OEMs
- Controller(s)
- Inverter(s)
- Turbine(s)

Developers
- Early Stages

EPCs
- Full Wrap
- Single Wrap
- Engineering Studies

Humans

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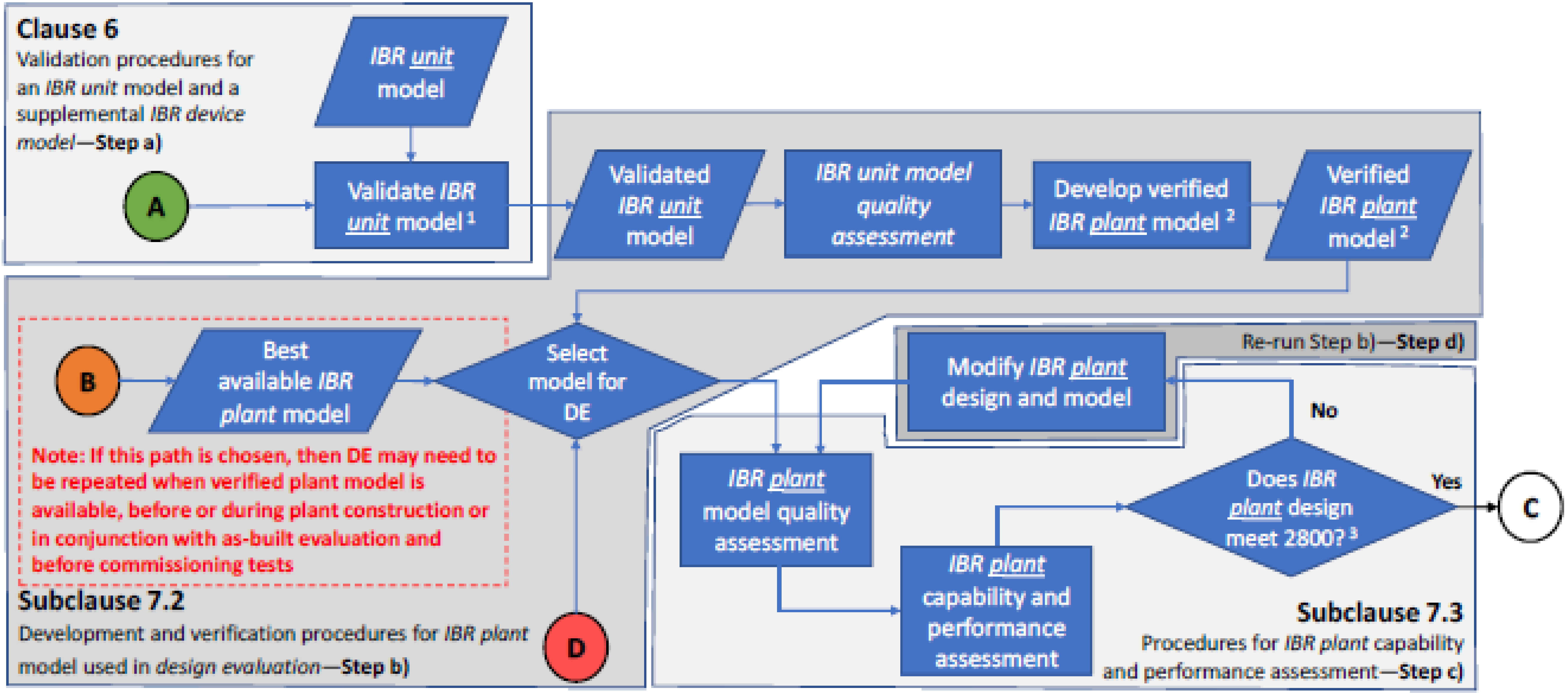

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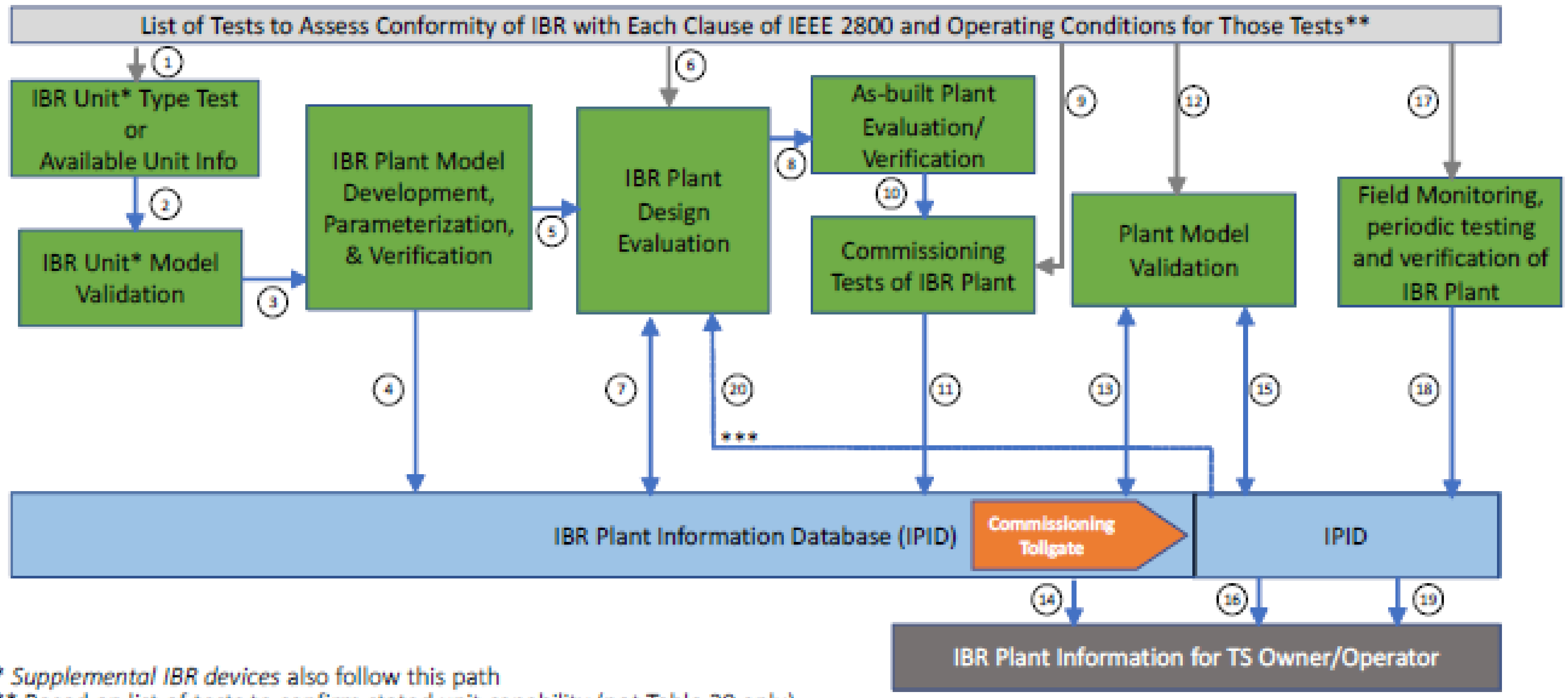
IEEE2800.2



* *Supplemental IBR devices* also follow this path
** Based on list of tests to confirm stated unit capability (not Table 20 only)
*** Design evaluation may need to be repeated if plant design changes

Figure 2—Conformance process overview showing information handoffs (see number key below)

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Partnering for Success: Help Us Help You

- Communicate and enforce models & model specifics **at the right time and to the right people**
- Promote efficiency with **clear and standardized** processes for **submittals and reviews**
- **Focus on the impact of model updates**, not on incentivizing no updates at all
- **Dedicate resources** to Transmission Planning/Modeling from **OEMs, developers, and utilities/ISOs**

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EMT Model Development
IBR Plant Owner's Perspective

Rishi Maharaj

November 19, 2025

Issues in EMT model development by GOs

- Developers/Owners are usually not employing large groups of engineers to develop and test plant models for submission. Model development is an exercise in project management and coordination of 3rd parties, which is often bounded by contractual arrangements.
- Nearly all **EMT plant model** development is in response to interconnection requirements. We are not ourselves running studies using these models.
  - EMT model development may be siloed from plant design activities, with convergence only when req's explicitly call for it (e.g. ERCOT PVR).
- "Specific overrides the general"
  - Highly prescriptive **model tests** can be perceived as overriding more general (but very important) **model or plant** requirements.
- Potential for perverse or wrong incentives in model req's.
  - The need to meet model req's can drive counterproductive actions that reduce model accuracy.
- Equal attention must be paid to how (and when) EMT models are verified vs. field settings.
  - GOs themselves can be caught off-guard by difficulties in translating OEM model parameters to the field after all interconnection studies have been completed.

Simplified project hierarchy

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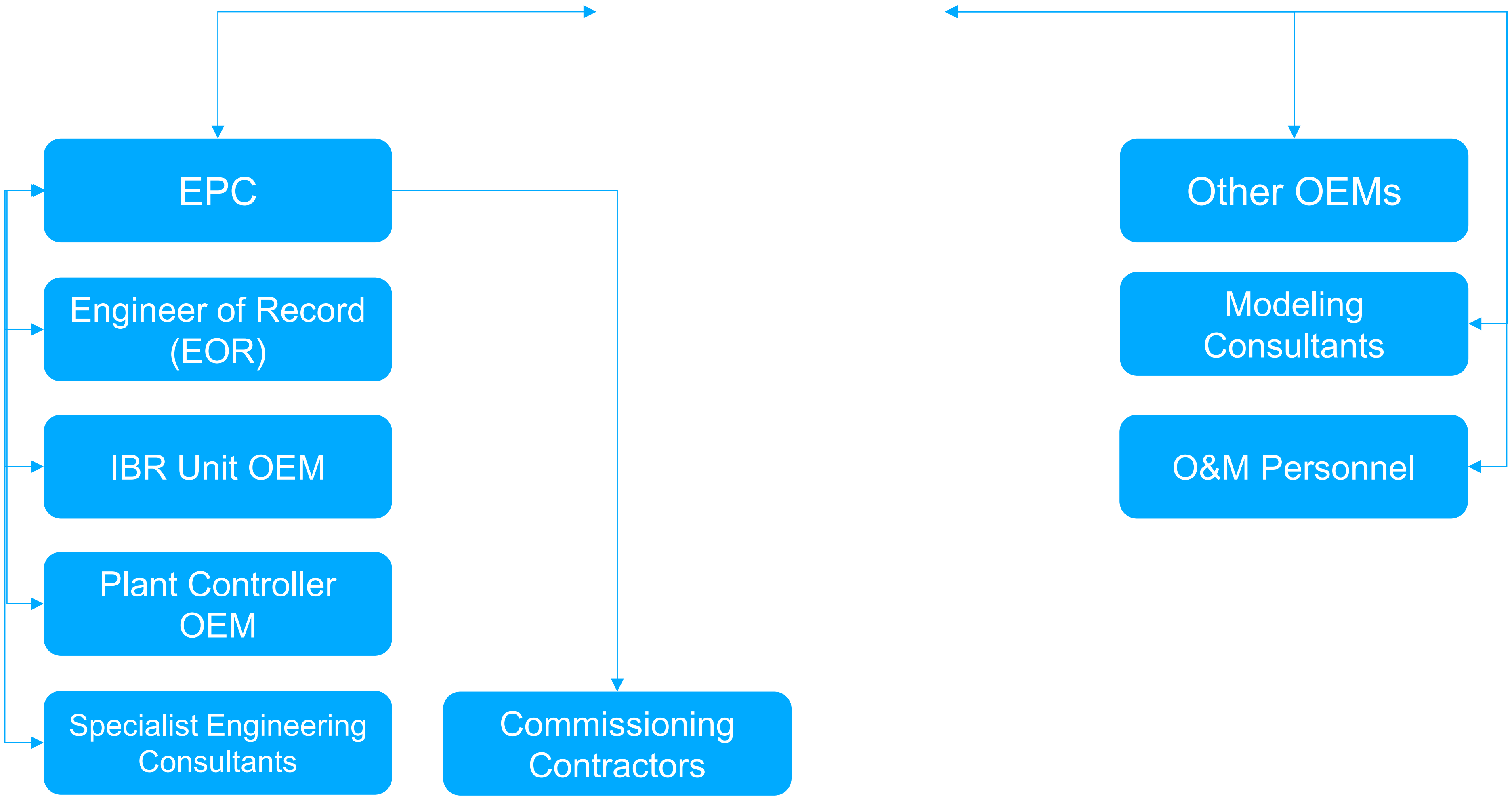


Instructive examples

<Public>

- Power plant controller (PPC) model accuracy
  - Requirement for “accurate” PPC models (general, no defined unit model validation) vs. very specific model quality test req’s.
  - Result: PPC models developed by a 3rd party to be capable of meeting the model testing requirements, without coordination with actual PPC developer. Tuned by a consultant unaware of discrepancies.
  - All model tests passed. Upon implementation of model parameters in the field (after COD), found PPC had hard-coded voltage freezer timer of **5 minutes**.
- Inverter model configured inaccurately for MQT
  - All PV/BESS inverter models from OEM X had numerical stability problems at low SCR, resulting in spurious trips of inverter SPOV protection in model quality testing.
  - Result: SPOV disabled in models to pass MQT. All model users (including owner’s consultant) unaware that SPOV cannot truly be disabled in the field.
  - After the discrepancy was discovered, OEM was able to improve the model to resolve numerical issues within 3 weeks. But by this point, inaccurate models had been submitted and approved for “as-built” by TP and used in other studies.
- Undocumented protection functions
  - Checklist requirement to “represent all protections relevant to ride-through”. No tests on model or hardware specified.
  - BESS PCS tripped on ROCOF protection in real event. Could not be replicated in EMT. Found that ROCOF protection was not modelled by OEM.

More instructive examples

<Public>

- Inverter HVRT logic “fix”
  - PV inverter’s HVRT function did not absorb sufficient Q during MQT. Issue discovered immediately before critical interconnection milestone.
  - Result: consultant bypassed inverter’s HVRT mode and set up PPC to command the required Q response, which is not possible in real plant. Passed MQT. Models approved by TP.
  - When inverter OEM later updated model to include improved HVRT response, new plant model had to be successfully benchmarked vs. approved (but fictional) model to obtain approval for update.
  - To date, OEM never actually implemented updated HVRT logic in field (still developing updated firmware).
- PPC model mismatch
  - PPC OEM’s PSCAD model included functions not present in real PPC (reactive power limiter).
  - Not discovered until after COD during implementation of “as-built” model parameters.
  - Commercial relationship between owner and OEM had already broken down.
  - Plant now stuck in limbo. May require PPC retrofit to a different OEM/model.

Final thoughts

<Public>

- Overly prescriptive model testing requirements can be counterproductive and result in compromises to model accuracy to pass the tests.
- AGIRs should leave room for engineering judgement in assessment of requirements.
- IBR plant EMT model development is an iterative process involving many participants. Developers/owners should be encouraged to transparently communicate known deficiencies to AGIRs rather than papering over them.
- Considerable complexity and effort is involved in the mapping and field implementation of model parameters. Model verification should occur early and often, not only as a final step after all studies are complete.
- Comprehensive model validation for plant controllers is essential.
- Developers/owners should “eat their own dogfood” by using their own EMT models in the design process when appropriate.

<Public>

<Public>

Day 1 Group Discussion: Prioritization, Lessons Learned, and Harmonization

Vic Howell
Director, Reliability Assessments and Modeling

Electric Reliability
& Security for the West

November 19, 2025

<Public>

Group Discussion Talking Points

- **Aligning EMT Requirements Across Utilities**
  How can Western Interconnection TPs and PCs harmonize their EMT (and positive sequence) modeling requirements, submittal formats and processes, and model quality checks/tests to reduce confusion and improve model consistency?

- **Integration with IEEE 2800 and P2800.2**
  How can IBR modeling requirements being developed per NERC FAC-002 and MOD-026 align best with IEEE 2800-2022 and IEEE P2800.2? How should utilities be thinking about aligning in these areas? When is the right time?

<Public>

Group Discussion Talking Points

- **Model Quality and Tests: Defining Minimum Acceptable Requirements**
  Based on panelist presentations and discussion, what are the minimum set of model quality and performance tests that should be adopted? Why? What challenges do we face in accomplishing uniformity and harmonization here?

- **Cross-Industry Unified IBR Modeling Requirements in the West**
  Is there opportunity to develop a unified and harmonized set of IBR modeling requirements across the West? Who is the best organizational body to accomplish such this? Recurring meetings, templates, WECC working group, etc.? What works best?

<Public>

Group Discussion Talking Points

- **Developer Pain Points and How to Reduce Friction**
  What were the key IBR developer pain points we heard and how can processes be streamlined to support improvements in this area?

- **Model Verification and Validation: What's Achievable Today**
  With the new MOD-026-2, how and when should model verification/validation be done for newly connecting IBRs? Why? How are TPs and PCs thinking about the identification of legacy IBRs for requiring EMT models be provided and verified/validated?

WECC

WWW.WECC.ORG | (801) 582-0353

155 N 400 W, Salt Lake City, UT 84103, USA

EMT IBR Screening Path of Least Time

By: Ben Hutchins, WPP

For: WECC EMT Workshop

EMT Screenings Panel, November 2025

IBR Complexity

<Public>

N: Utilities

M: Inverter Models

Ideas to Reduce Complexity

- Do like AEMO for performance criteria:
    - Have interconnection-wide (WECC) performance requirements which are *very* specific.
    - IEEE 2800, WIRAB, and BPA are making excellent progress towards this.
    - Manufacturers can then implement a "WECC v1" settings group they can advertise.

- Do like ERCOT for model screenings:
    - Post a WECC-level SMIB testbench with automated positive-sequence and EMT tests.
    - Require the interconnector to submit the testbench results early in the process, with models.

- Do like ISO-NE to ensure positive-sequence generic models are as useful as possible:
    - Require the interconnector to submit plots of the EMT and Positive-Sequence models plotted together for a variety of tests, like MOD-026/027 generator tests.

- IEEE/CIGRE Standard DLL Format, FMI/FMU Models, or Collect Model Source Code:
    - Allows you to upgrade or change simulation software in the future.

- Do commissioning tests:
    - Ensure the developer sets the same settings in the field as they submitted in their EMT models.
    - Only perform more detailed EMT simulation tests on the small number of projects moving to construction.

WPP

<Public>

Early Experience with EMT Screening at PGE

Ian Beil, PhD, PE

Manager, Transmission Planning, PGE

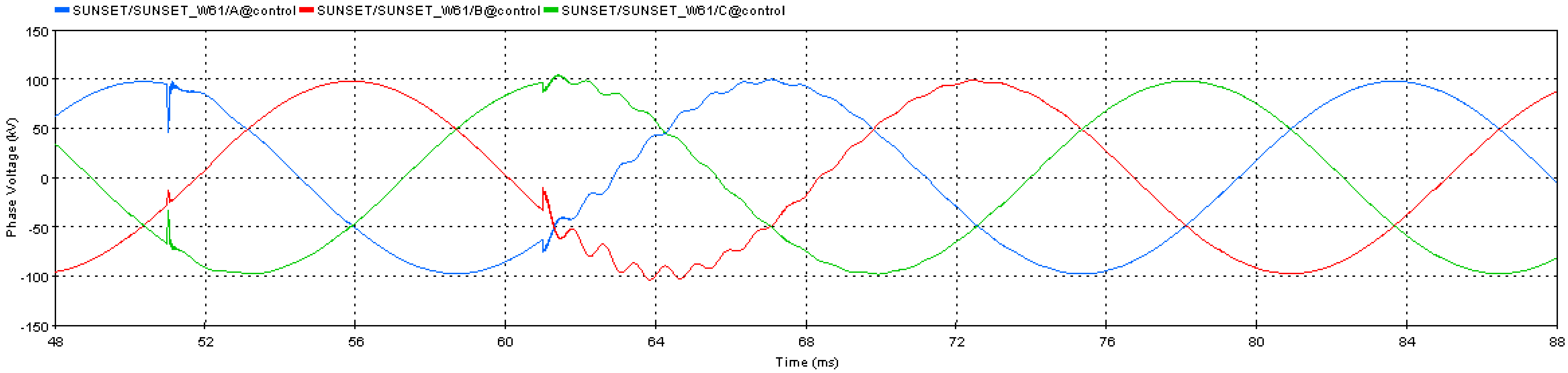
WECC Electromagnetic Transient Strategic Workshop – Nov 20, 2025

<Public>

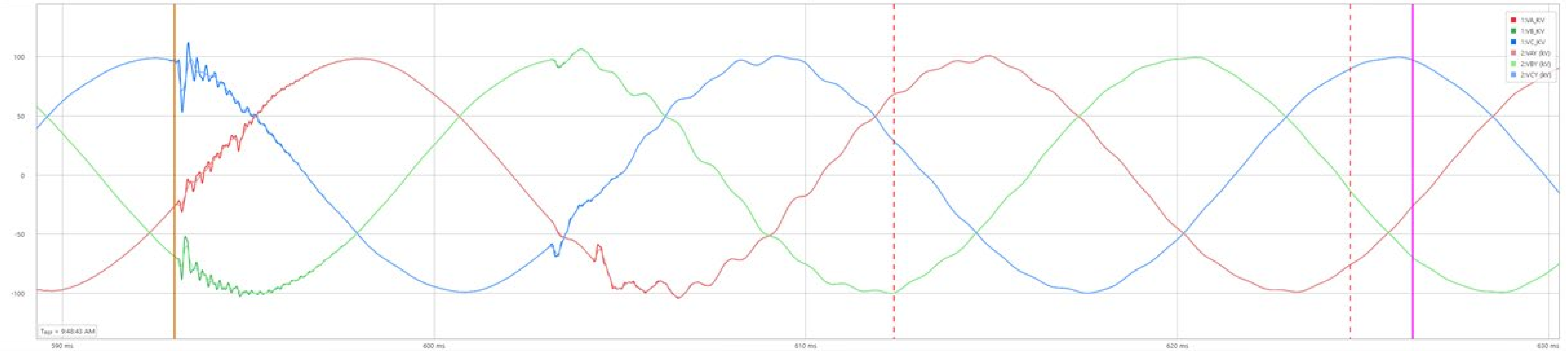
The value of EMT modeling: high resolution, high fidelity simulations

Top: EMTP Simulation

Cap Bank Switching Event



Bottom: SEL-421 Event Capture on 4/16/2021



<Public>

FERC Order 2023 Requires EMT models as part of the Generation Cluster Study Process

- Modeling: FERC adopted the NOPR proposal to require interconnection customers interconnecting nonsynchronous generating facilities to submit as part of their request: (1) a validated user-defined RMS positive sequence dynamic model; (2) an appropriately parameterized generic library RMS positive sequence dynamic model, including a model block diagram of the inverter control system and plant control system, that corresponds to a model listed in a new table of acceptable models or a model otherwise approved by WECC; and (3) **a validated EMT model, if the transmission provider performs an EMT study as part of the interconnection study process.**

Per Troutman Pepper Executive Summary of FERC Order 2023:
https://www.troutman.com/insights/troutman-pepper-summary-of-ferc-order-no-2023-on-generator-interconnection-reform/

<Public>

PGE Experience with EMT model validation

- New process during PGE's Transitional Cluster Study
- Contract EMT model validation support out to Elevate Energy
- All generators required to submit EMT models during the application window; PGE and Elevate targeted EMT validation complete by 45 days after cluster studies begin

<Public>

Cluster Study Timeline

FERC-mandated cluster study timelines are tight:

- Transitional Cluster – 300 days for both SIS and Facility study (combined effort)
- Annual Cluster Studies thereafter – 150 days for SIS portion of study

This leaves very little time to try to perform EMT studies during the Cluster process

- Risk of missed system vulnerabilities

<Public>

Thank you

<Public>

EMT Study Screening Approach
PG&E

Sophie Xu

Nov. 20th, 2025

Together, Building
a Better California

EMT Study Screening Approach

<Public>

Types of Issues:

- Positive sequence model validation: flat run, L/HVRT, weak grid performance
- Weak Grid issues
- SSR, SSO and SSCI
- Control interactions
- Impacts on existing issues, series cap changes

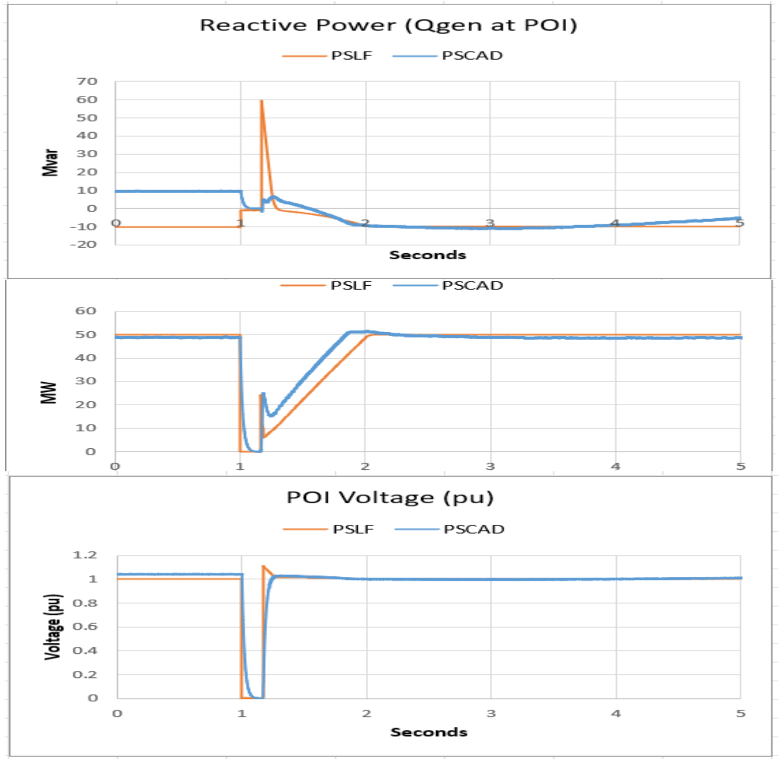
EMT Study Screening Approach - EMT Models

<Public>

Which Resources are required for EMT Model and Model Validation?

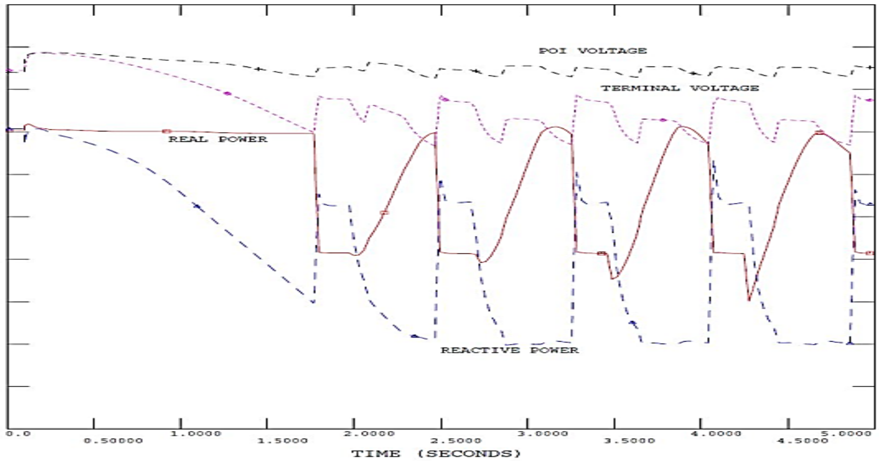
- All IBRs and FACTs devices are required to provide EMT models
- Rotating Generators (excluding hydro): radial connection via series capacitors after N-6 or less.

- Validate EMT model, flat run, LVRT
- Benchmark EMT vs PSLF models



Potential Issues:
model is not tested in the transmission network
Issues like below could be missed

LVRT Oscillation due to slow system recovery



EMT Study Screening Approach - SSR, SSO and SSCI

Screening for Potential SSR, SSO and SSCI Risks Scenarios

- 6 Switching Practice: After N-6 or less, IBR or generator or FACTs device is radially connected to the system via series capacitor(s).

- Installing or Modifying Series Capacitors

- Frequency Scan to search for scenarios for time domain EMT simulation: all contingencies and IBR/FACTs at various output levels to identify scenarios

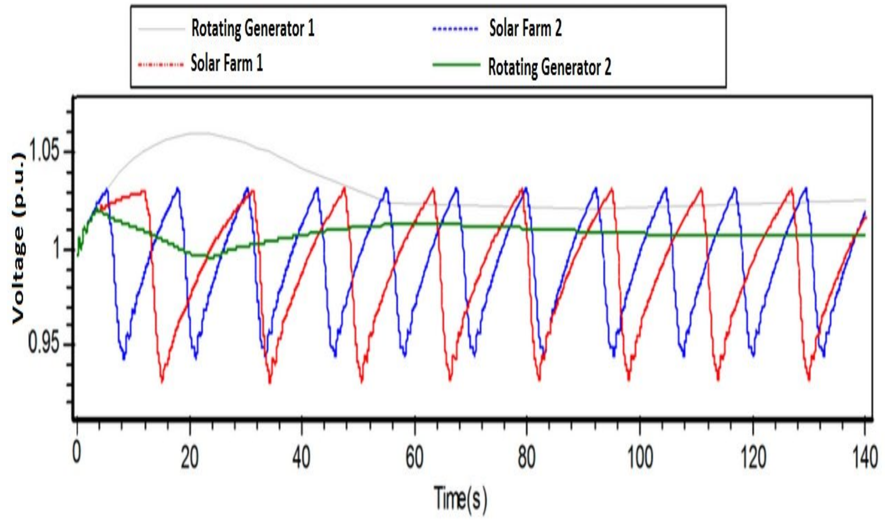
Questions: How to select base case(s) for frequency scan? System load, transfer levels, generators, etc.

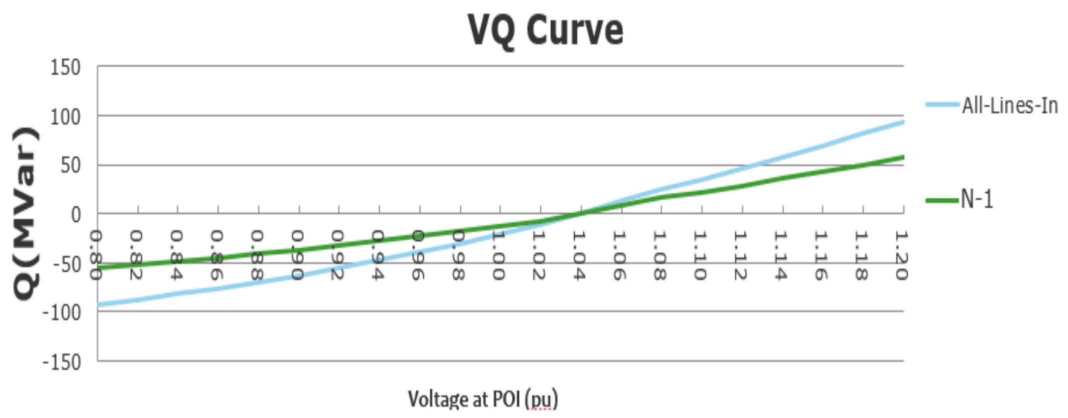
EMT Study Screening Approach - Control Interactions

Screening for Control interactions

- IBRs and/or other fast controllers such as STATCOMs sharing the same POI or are next to each other
- QV analysis can help in searching for the study scenario

Reactive Control Oscillation Caused by Control Interaction



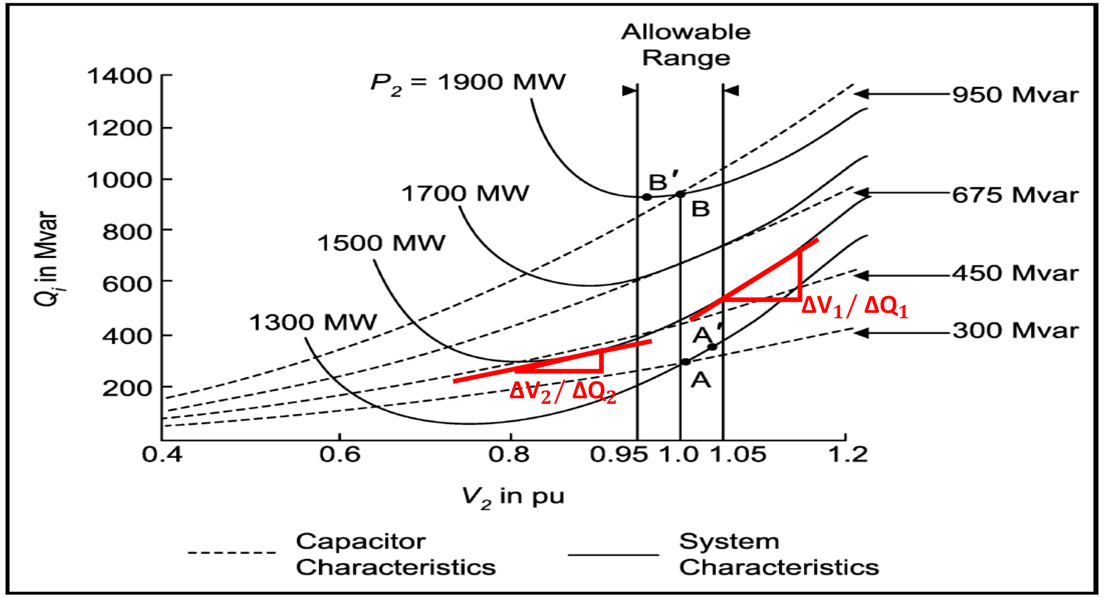


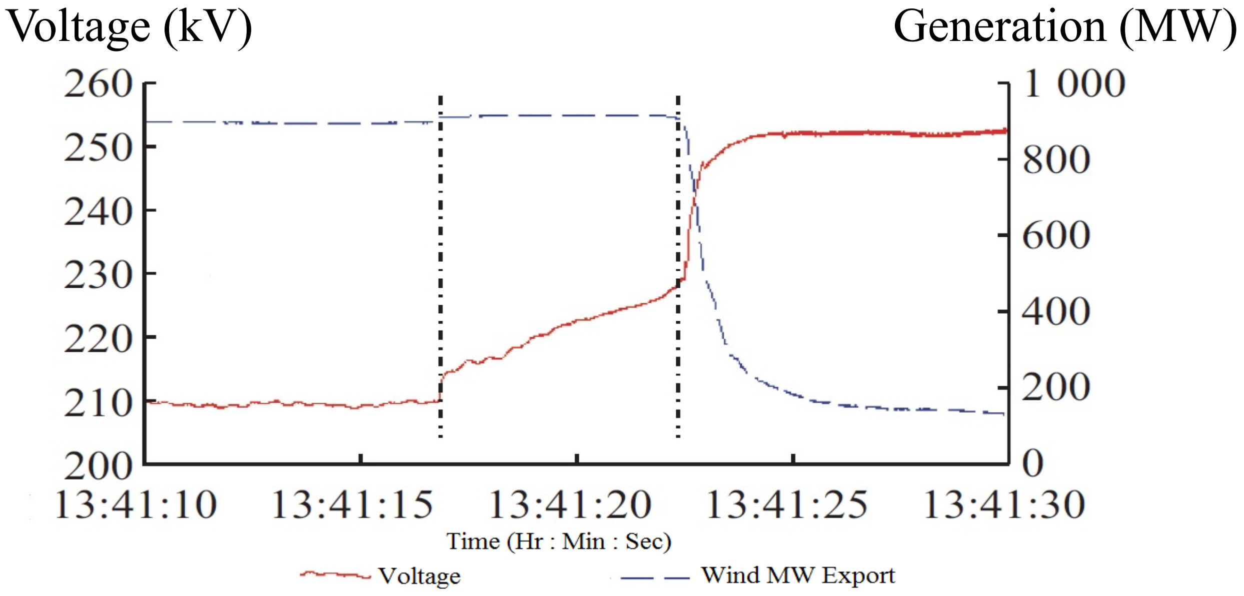
EMT Study Screening Approach - Weak Grid

Screening for Potential Weak Grid

- Short Circuit Ratio, SCR? WSCR? CSCR?
- Voltage change by switching shunt capacitor/reactor >2.5% $\Delta V \approx Isc/\Delta Q$
- QV Curves

Questions: how to select the right study scenarios to reveal unique issues?





EMT Study Screening Approach - PG&E

Questions?

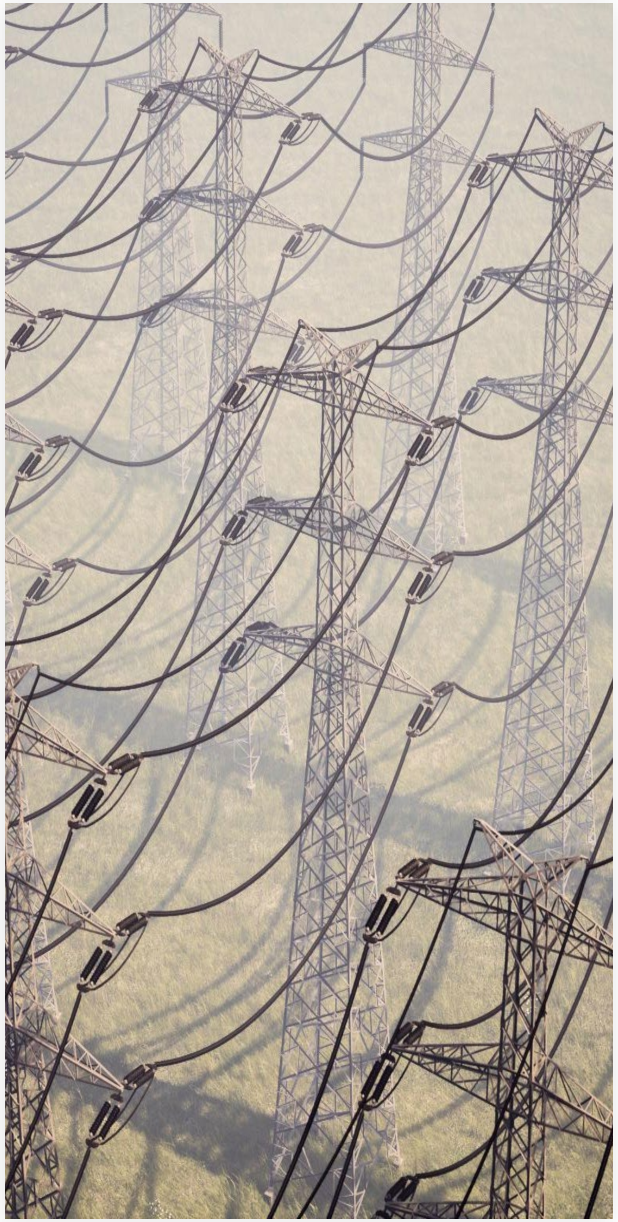
<Public>

SDG&E's Screening Criteria for SSR & SSCI Studies

Hassan Ghoudjehbaklou, PhD, PE, LSM-IEEE

Principal Engineer, Transmission Planning

San Diego Gas & Electric



Why SSR/SSCI Screening Matters

Risks of SSR and SSCI

SSR and SSCI threaten grid reliability by causing equipment damage and instability. They increase with inverter-based resources and series compensation.

ERCOT 2009 Event Example

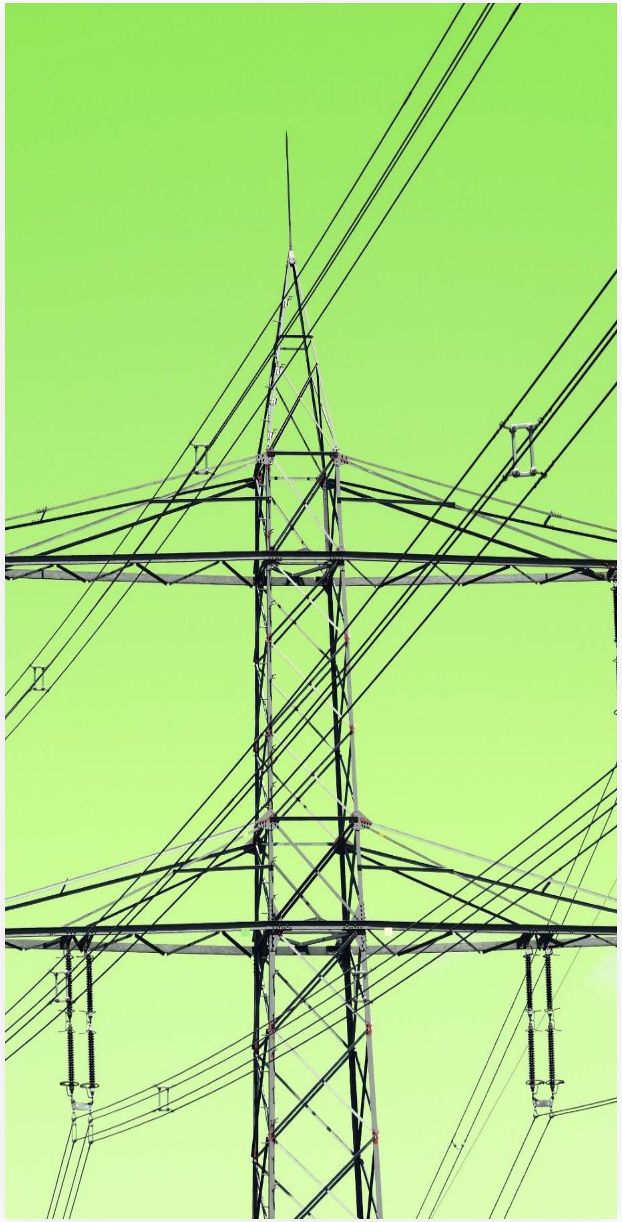
The 2009 ERCOT event showed 22 Hz oscillations causing voltage doubling and damage to wind generators and capacitors rapidly.

N-5 Contingency Screening

N-5 screening proactively identifies generators at SSR/SSCI risk under multiple outages, enhancing risk mitigation.

Planning and Reliability Benefits

Screening reduces the need for exhaustive stability and power flow studies by quickly identifying electrically weak connections through impedance-based proximity and susceptibility analysis. It flags areas where multiple contingencies (up to N-5) could lead to radialization, signaling vulnerability without requiring full-scale simulations. This targeted approach accelerates planning, optimizes computational resources, and improves reliability assessments..



Understanding Subsynchronous Oscillations (SSO)

SSR Subsynchronous Resonance

Resonance between generator torsional modes and series-compensated network

SSCI Subsynchronous Control Interaction

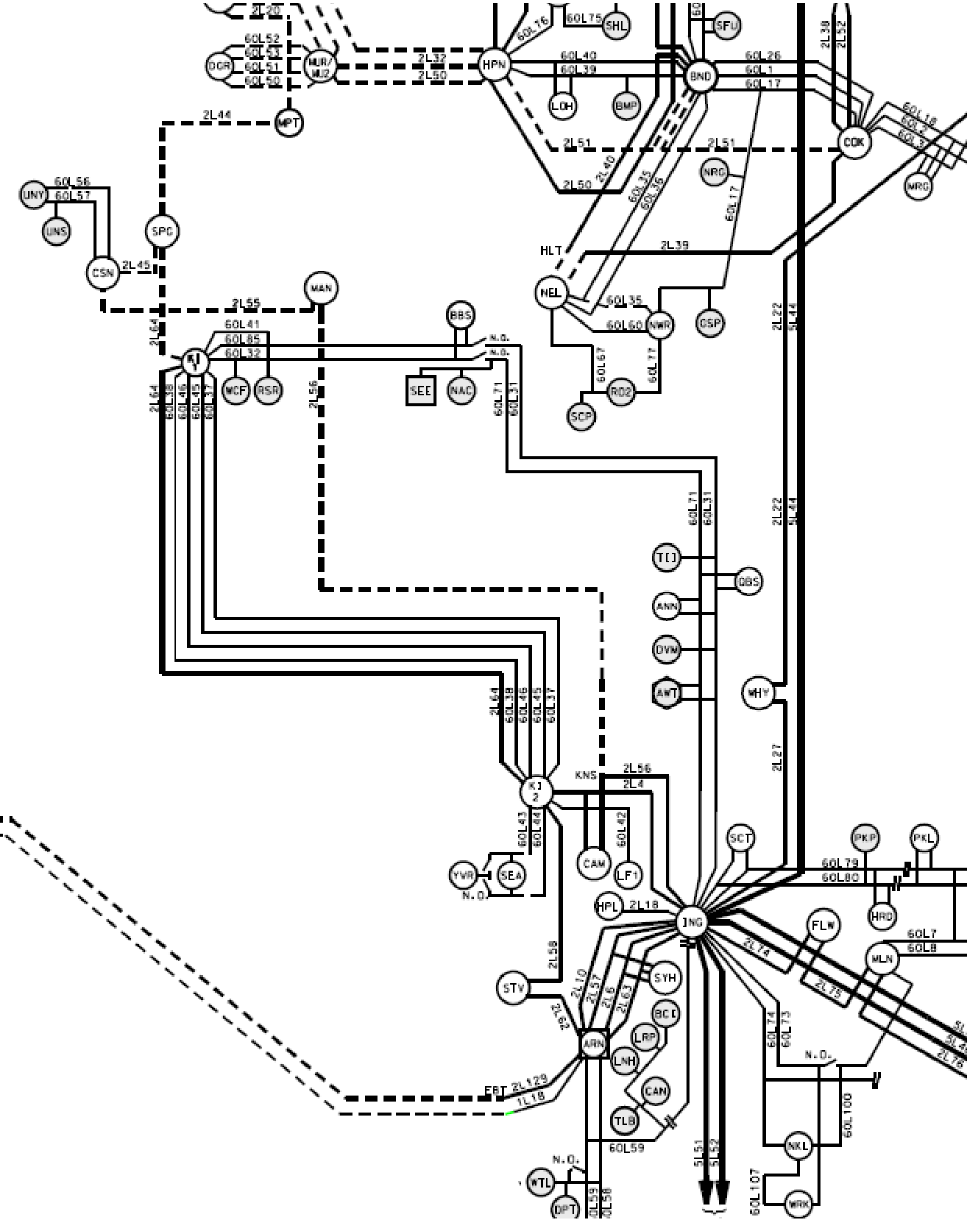
Control instability in inverter-based resources interacting with grid impedance and/or other IBRs; can occur with or without series compensation

SSTI Subsynchronous Torsional Interaction

Dynamic interaction between shaft torsional modes and network impedance

IGE Induction Generator Effect

Negative damping in induction generators under specific grid conditions



N-5 Contingency Screening Logic

Contingency Scenario Scope

Evaluates outages involving up to five transmission elements to identify risk conditions effectively.

Element Counting Criteria

Excludes generators, loads, FACTS devices, and HVDC converters; counts parallel lines and transformers as one.

Electrical Proximity Assessment

Focuses on electrical connectivity to assess network vulnerability rather than physical layout.

High-Risk Location Identification

Highlights specific critical buses and loop-ins identified as high-risk based on connectivity and impact.

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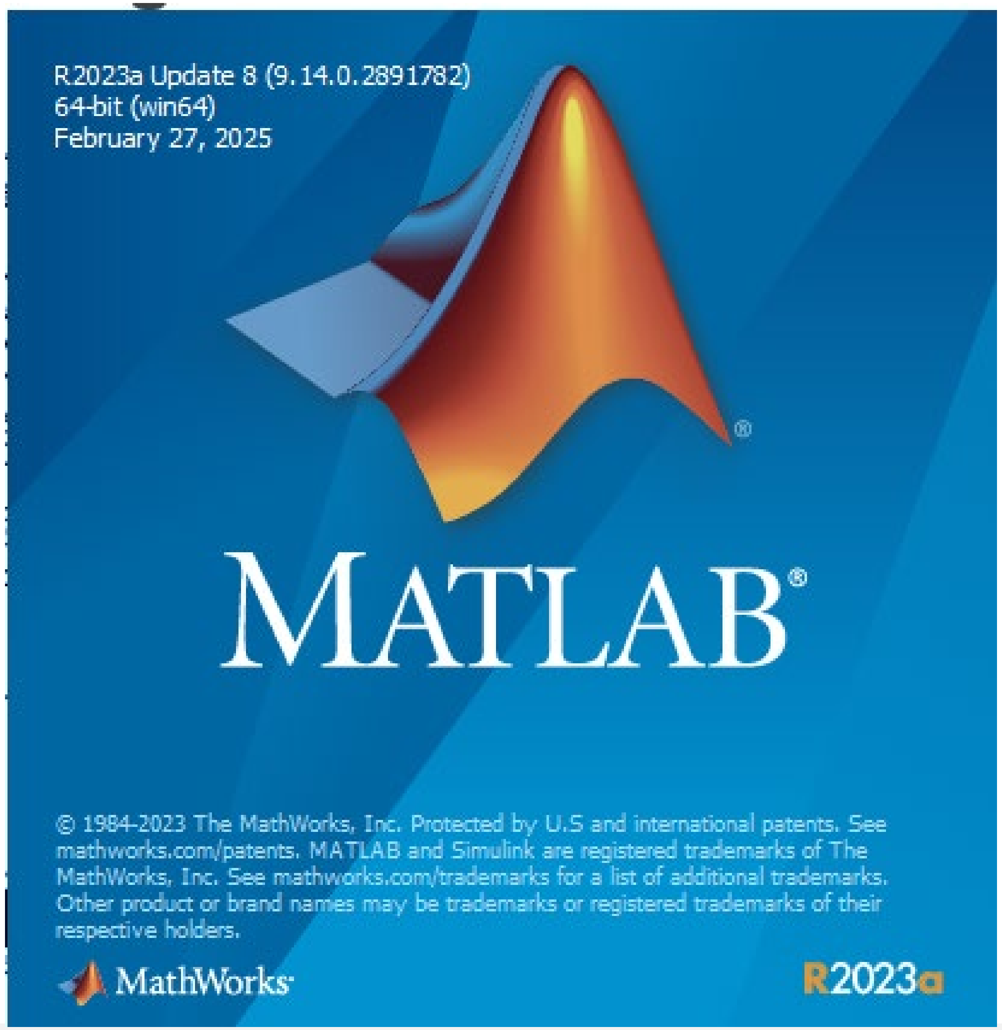
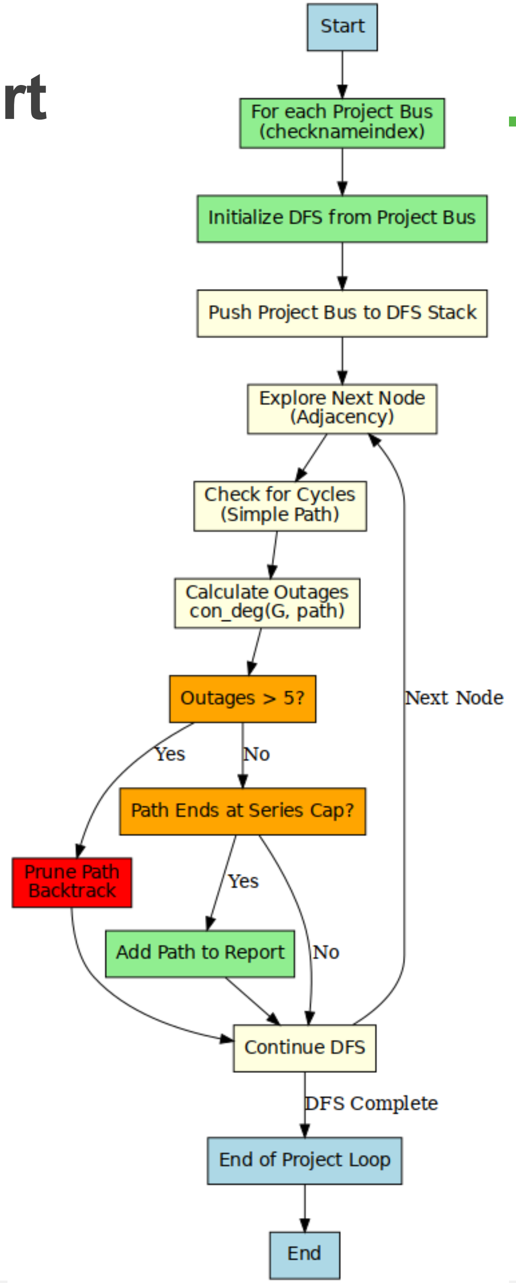
Automation of N-5 Criteria using Matlab: flow chart
Checking each project





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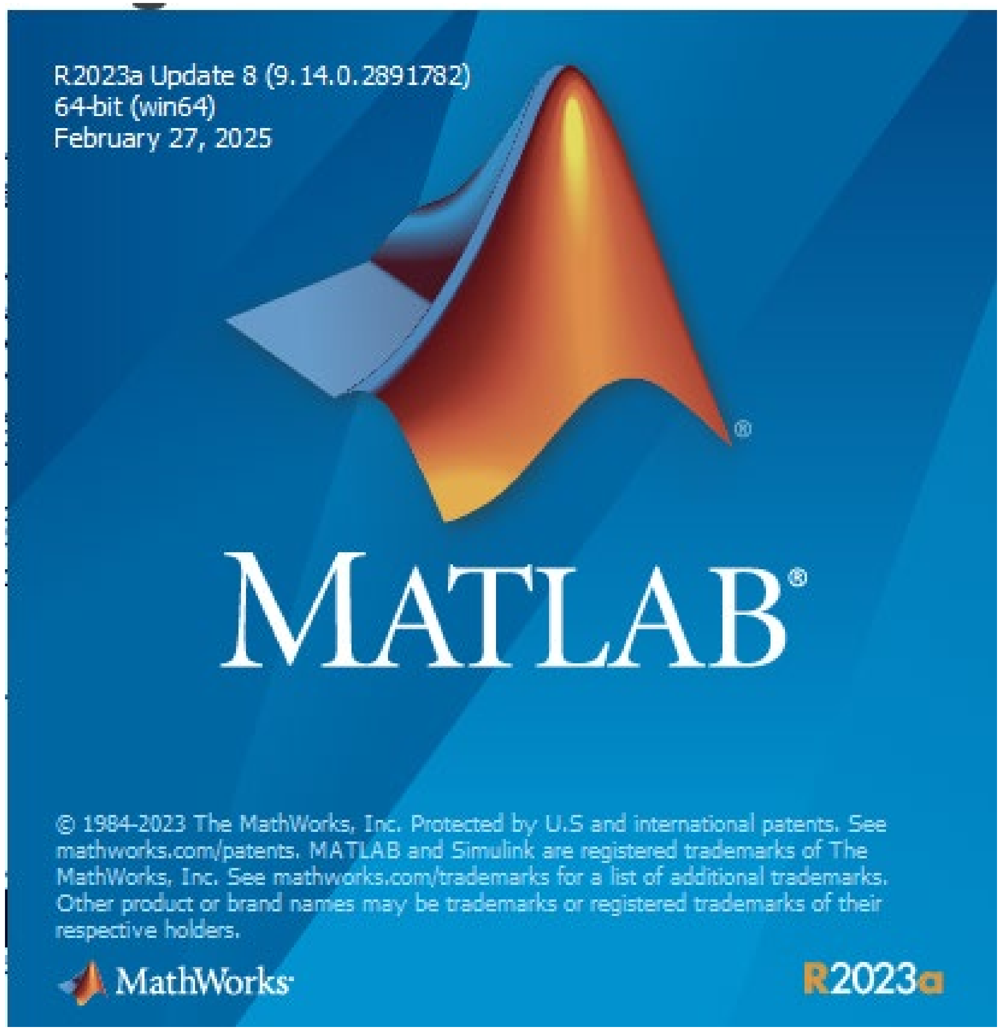
Automation of N-5 Criteria using Matlab: output Checking each project



- Sample output report:

******** Report start for Qnnnn ********

****** for path no 14 ***********

Qnnnp_HS 230   ABC GEN1_HV_ 230

ABC GEN1_HV_ 230 ABC 230

ABC 230   ABC MP 500

ABC MP 500   ABC 500

****** for path 14, # of required branch outages are 3 ***********

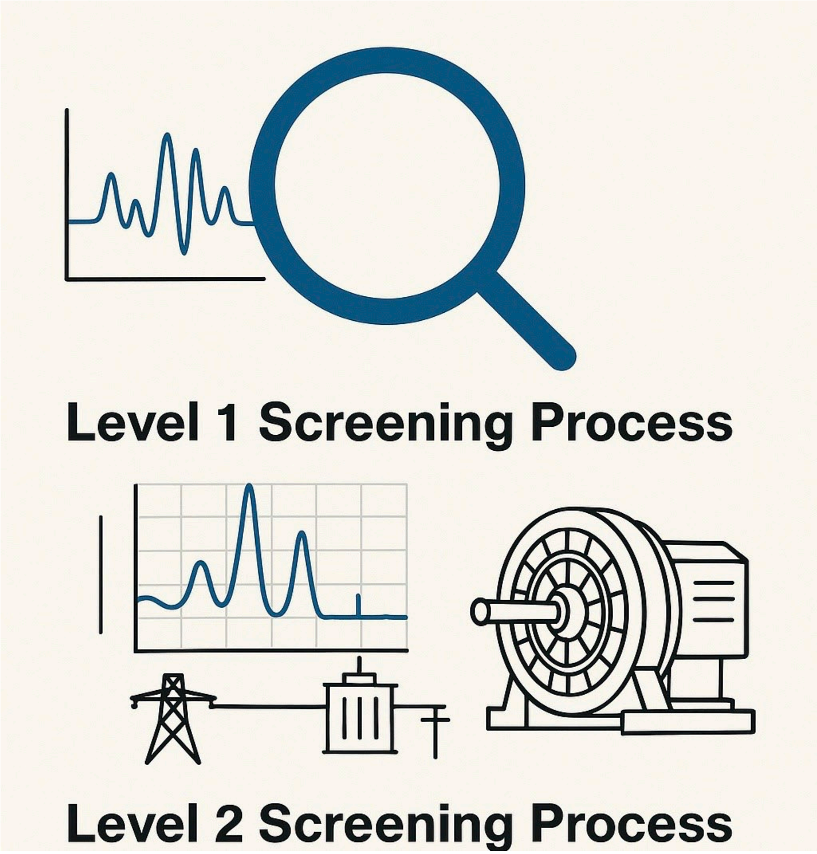
ABC GEN1_HV_ 230   Qnnnq_HV_Sta 230

ABC 230   ABC 138

ABC 230   Qnnnn_HV 230

******** Report end for Q1661 ********

Screening Methodology: Level 1 and Level 2 Screening



Level 1 Screening Process

Grid-side frequency scan injects varying frequencies into the grid to find resonant frequencies under contingency conditions.

Level 2 Screening Process

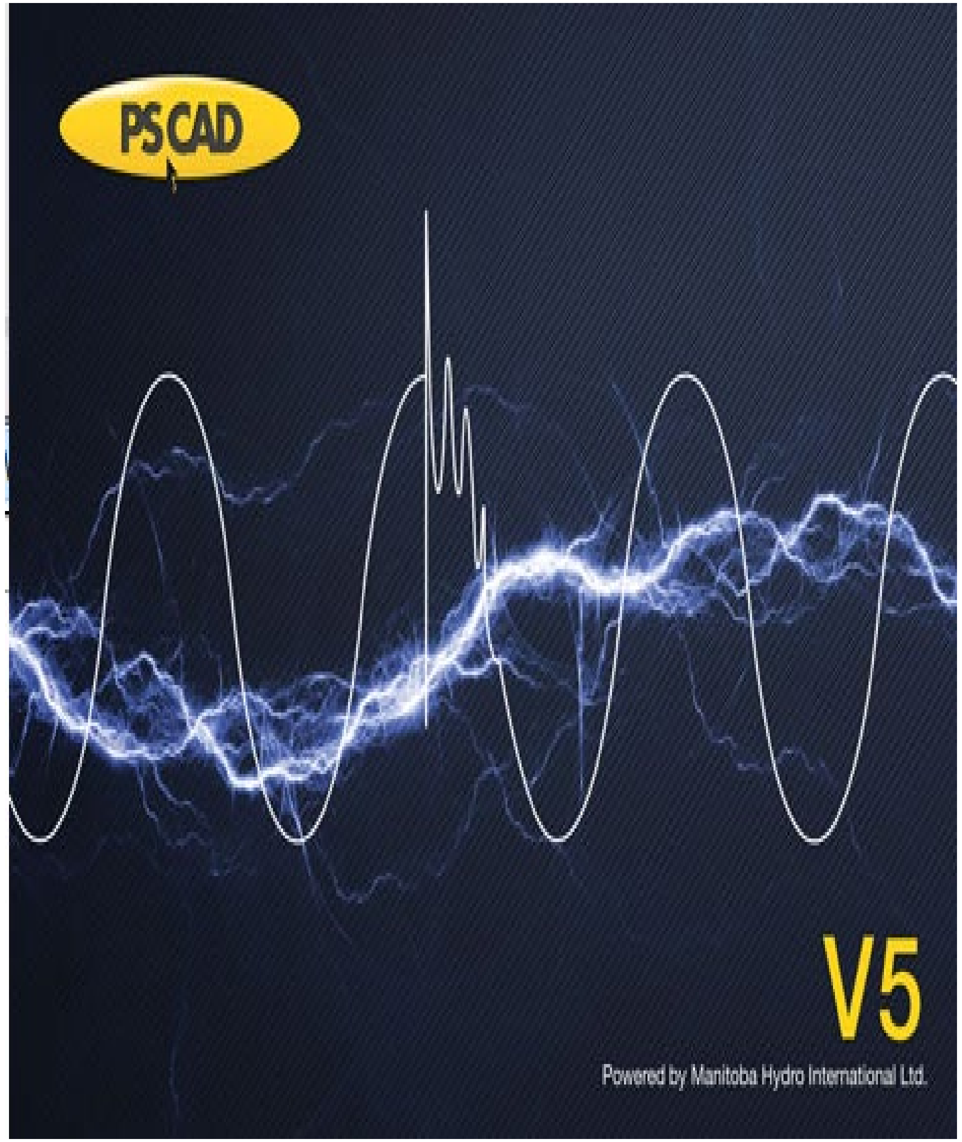
Machine-side scan uses detailed generator models to detect mechanical resonances below 60 Hz.

Risk Assessment Outcome

No resonant frequencies found means negligible SSR/SSCI risk; otherwise, a full study is required.

Screening Benefits

Staged screenings enable efficient risk identification and prioritized detailed modeling resources.



Full SSR/SSCI Study Requirements

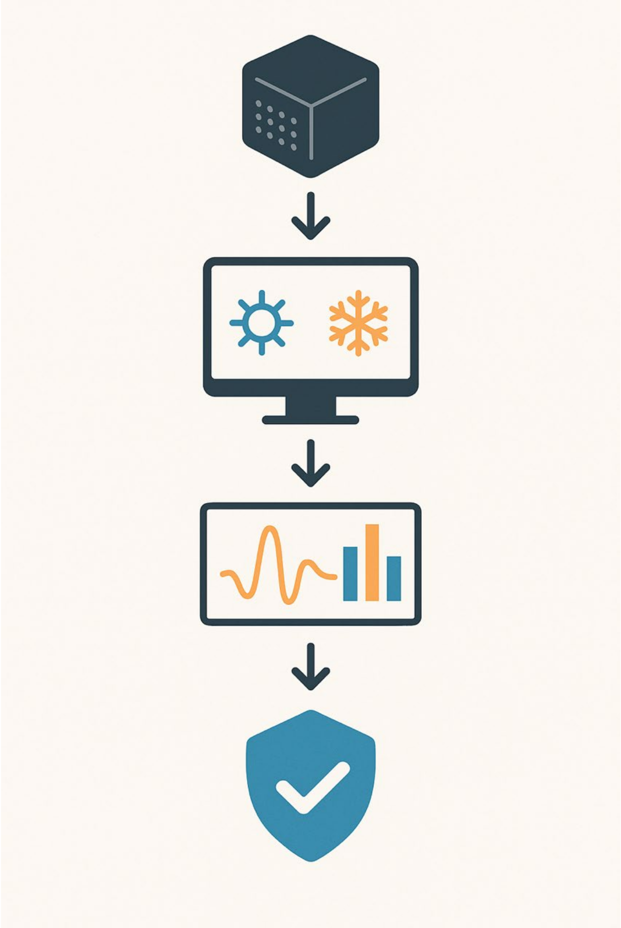
Mandatory Study Trigger
Full SSR/SSCI study is required when screenings show potential risks at Level 1 and Level 2.

Software Requirement
Studies must be performed using PSCAD software as exclusively accepted by SDG&E.

Modeling and Scenarios
Study incorporates detailed three-phase modeling, OEM black box models, and simulates summer and light load conditions.

Deliverables and Analysis
Deliverables include reproducible models, FFT oscillation analysis, damping tables, and IBR checklist compliance.

Project Execution and Case Studies



Detailed Black Box Modeling

Use OEM black box models to represent generating facilities and control systems precisely.

Simulation Conditions

Simulate both Heavy Summer and Light Load scenarios to evaluate performance under varied conditions.

FFT and Damping Analysis

Perform FFT analysis to find oscillation magnitudes and calculate damping ratios at subsynchronous frequencies.

Reproducible and Compliant Setup

Ensure results are reproducible and follow NERC inverter ramp rate guidelines including contingency simulation.

Project Milestones and Deliverables

Structured Timeline

The study process follows a clear timeline from 14 to 2 months before ISD.

Consultant Coordination

Consultants engage early with SDG&E and receive key models for study preparation.

Study Deliverables

Deliverables include PSCAD models, graphs, tables, and mitigation strategy documentation at least 6 months in advance of ISD.

Review and Replication

SDG&E reviews and replicates study results 2 months before ISD to ensure accuracy.

Case Study: Qnnnn Some Company Solar

Comprehensive SSR/SSCI Study

Study was essential due to proximity to series-compensated transmission lines. It ensured system stability and safety.

PSCAD Modeling and Simulation

SDG&E provided a backbone-reduced PSCAD model used for simulating various contingency scenarios with accuracy.

FFT Filtering and Damping Analysis

Analysis performed using FFT filtering across 1 Hz bands to identify system damping characteristics.

Stakeholder Engagement and Model Review

SDG&E reviewed model behavior and requested additional contingency scenarios.

<Public>

Regulatory Framework and GIA Milestones

GIA Study Requirements

Section A.10 of GIA specifies SSR/SSCI study requirements for interconnection.

Milestones Timeline

Appendix B sets milestones at 12, 9, and 6 months before ISD for study submissions.

Mitigation and Compliance

Mitigation is required one month before synchronization if instability is found; costs borne by IC.

Technical and Operational Challenges

Tight Timelines

Study completion and mitigation must adhere to strict deadlines for operational efficiency.

Model Validation Complexity

Ensuring model accuracy and reproducibility is critical for trustworthy study outcomes.

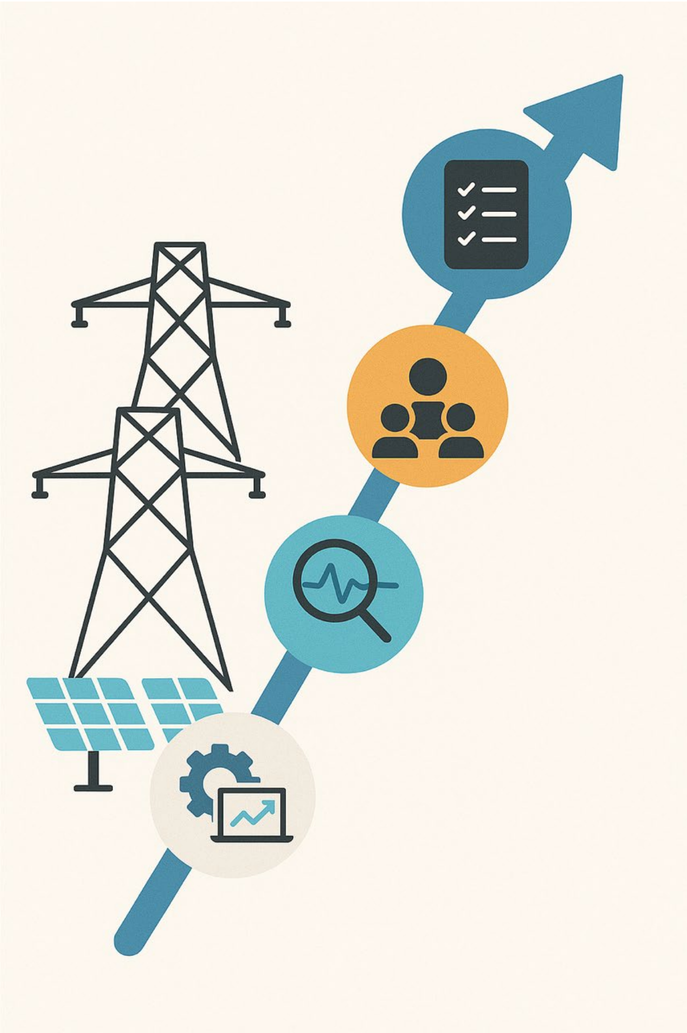
Network Topology Changes

Evolving network structures and compensation setups require continual updates and reviews.

Risk Scenario Coverage

Comprehensive identification of all plausible risk scenarios ensures grid reliability.

Recommendations for Future Improvements



Refine Screening Criteria
Improve SSR/SSCI screening accuracy by refining criteria and modeling practices for efficiency.

Strengthen Collaboration
Enhance coordination between ICs, SDG&E, and CAISO for aligned and timely execution.

Monitor Evolving Risks
Continuously track SSR/SSCI risks as grid and technology configurations change.

Invest in Advanced Tools
Adopt advanced modeling and mitigation technologies to tackle emerging grid challenges.

<Public>

Q/A
Key challenges in SSR & SSCI studies?
Most effective tools for SSR & SSCI?
Role of EMT modeling?
Managing study complexity?
Lessons from recent projects?

<Public>

Large-Scale PSCAD EMT Simulation

Moinul Islam
ERCOT Planning Engineer, Dynamic Studies

November 20, 2025

<Public>

Objective

- Development of Large-Scale PSCAD EMT simulation case for:
  - Determination of stability limit for an area with penetration of high inverter-based resources (IBRs)
  - Wide-area instability challenges associated with large power transfers
  - Sub-synchronous oscillation (SSO) study
- Test critical contingencies and benchmark the PSCAD study results against the study results in PSS/e
- The initial stage focused on developing a PSCAD study case representing an ERCOT area with significant levels of IBRs

<Public>

Motivation

- Development of large-scale PSCAD EMT simulation case
  - Increase penetration of inverter-based resources (IBRs)
  - PSCAD model of IBRs is developed from actual field settings and provides more detailed and accurate representation of the IBRs
  - Compared to typical phasor-domain simulation such as PSS/e, no numerical issue is observed in PSCAD
  - Provides more realistic results for stability issue identification and model validation
  - Identify potential cost-effective, long-term transmission improvement options for future system load and generation trends

<Public>

Transmission Interface Constraints Driven by Stability Issue

- Wide-area stability issues are observed due to large power transfers from an area with high penetration of IBRs to load centers

- To maintain the stability, ERCOT utilizes Generic Transmission Constraint (GTC*) methodology per ERCOT Nodal Protocol Section 3.10.7.6. For example,
  - West Texas Export GTC
  - South Texas Export and Import GTC

**GTC: A transmission constraint made up of one or more grouped Transmission Elements that is used to constrain flow between geographic areas of ERCOT for the purpose of managing stability, voltage, and other constraints that cannot otherwise be modeled directly in ERCOT's power flow and contingency analysis applications.*

Key Takeaway: Maintains certain megawatt power flow through GTC interface lines to maintain stability

https://www.ercot.com/files/docs/2020/10/07/05.__WESTEX_GTC_ROS_10_08_2020.pdf

Map of West Texas and South Texas Export GTC

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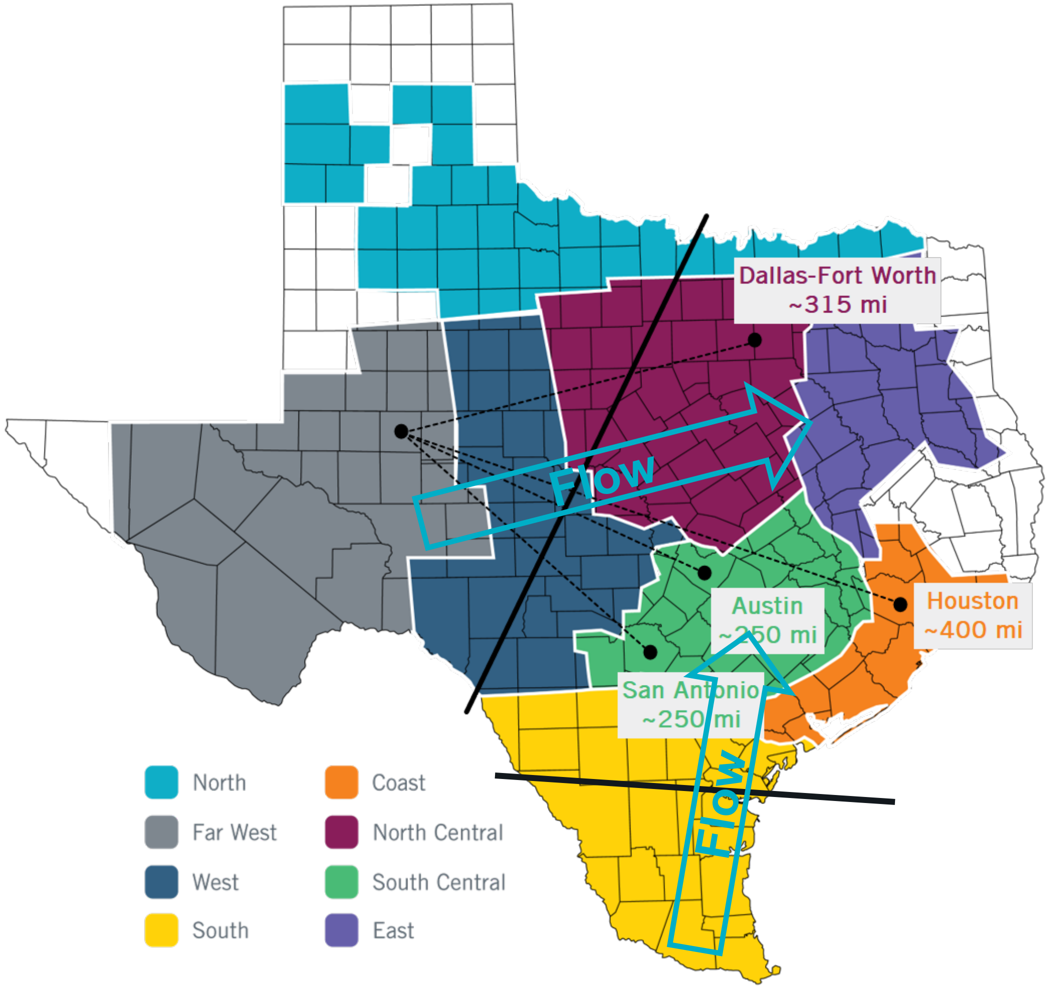


Key Takeaway: Stability issues (GTC) are driven by the large amount of power flow from West Texas and South Texas to load centers in Austin, Dallas, Houston, and San Antonio.

https://www.ercot.com/files/docs/2022/01/14/Long-Term-West-Texas-Export-Study-Report.pdf

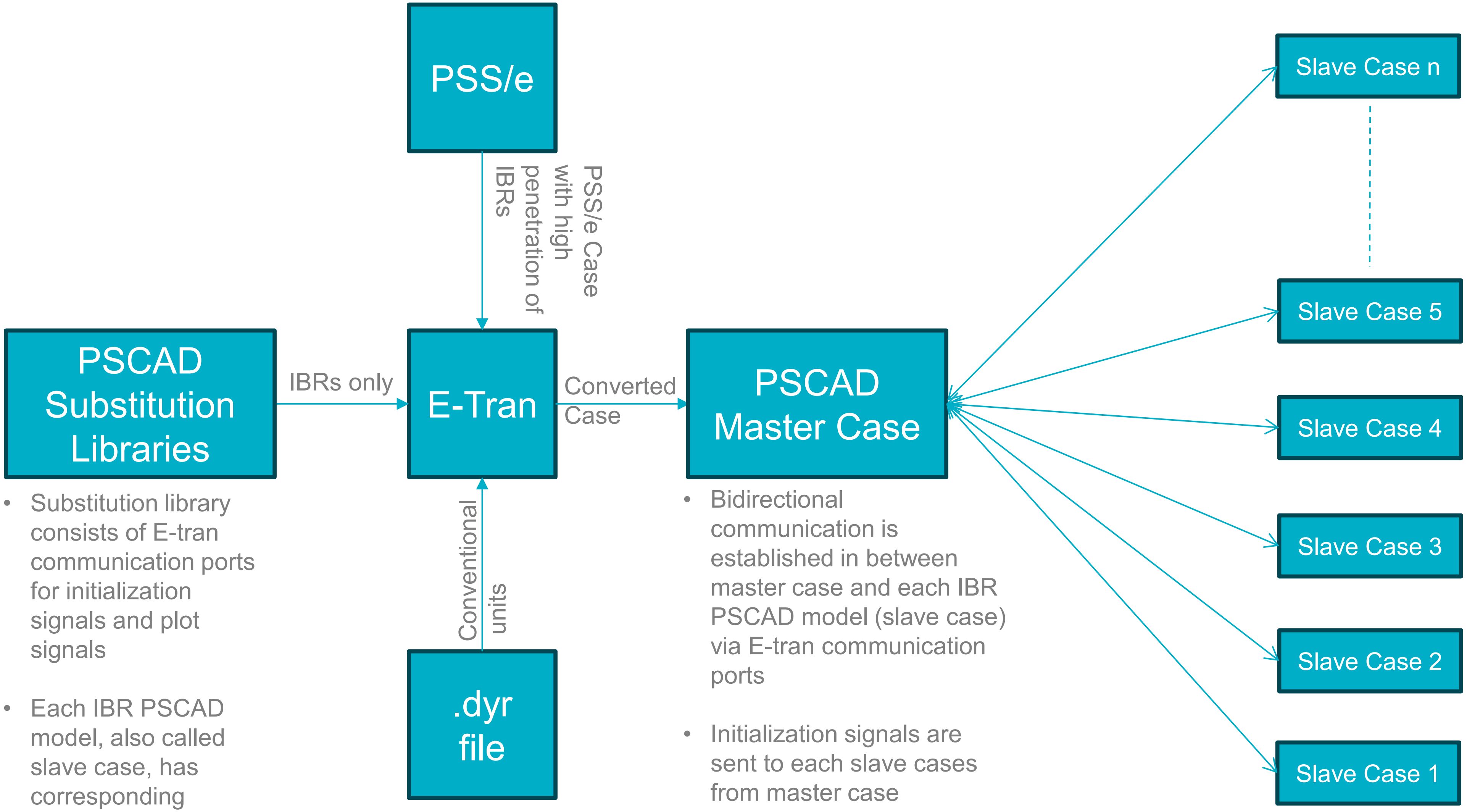
<Public>

Study Case Development – South Texas Export GTC

- Study Case: ERCOT PSS/e power flow case representing a system with high penetration of IBRs and low load conditions
- Study Case Year: 2026
- Study Area: South Texas Weather Zone
- Software
  - PSS/e power flow case
  - PSCAD V5.0.1
  - E-Tran V5.0
  - County mapping tool (internal tool)

<Public>

Study Case Development



- Substitution library consists of E-tran communication ports for initialization signals and plot signals
- Each IBR PSCAD model, also called slave case, has corresponding communication ports

- Bidirectional communication is established in between master case and each IBR PSCAD model (slave case) via E-tran communication ports
- Initialization signals are sent to each slave cases from master case
- Plot signals are returned from slave cases to master case

- Each slave case is initialized based on the signals received from master case, and returns plot signals through E-trans communication ports

<Public>

Configuration and Computational Speed

- **Computer Configuration**
  - CPU: Intel Xeon R Gold 6248R CPU @ 3.00 GHz
  - RAM: 128 GB
  - Number of Cores: 48
  - Number of Logical Processors: 96
  - Speed: 2934 MT/s
- **Computational Speed**
  - 36 PSCAD IBR models in South Texas PSCAD study case
  - Took 2 hrs for simulation time of 20 s

<Public>

Preliminary Results and Limitations

- Both PSS/e and PSCAD simulations show similar GTC limit (GTL) under prior outage condition
- Testing critical contingencies is still in progress
- Current E-Tran V5.0 are limited up to 36 substitution libraries, i.e., 36 generation projects can be added in PSCAD case. However, future release of E-Tran V6.0 will remove this limitation
- ERCOT started to collect PSCAD models since 2015. Therefore, very few older units may not have PSCAD models available. However, ERCOT is in the process of obtaining those PSCAD models
- Certain IBR owners could have challenges if the original OEM is not longer in business

<Public>

Acknowledgement

- Jonathan Rose
- Mehdi Rezvani
- Scott Zuloaga
- Sun Wook Kang

<Public>

Questions/Comments?

moinul.islam@ercot.com

<Public>

IDAHO POWER

Electromagnetic Transient at Idaho Power Company

WECC EMT Strategic Workshop

Dr. Andrés Valdepeña Delgado

November 2025

<Public>

Where We Serve

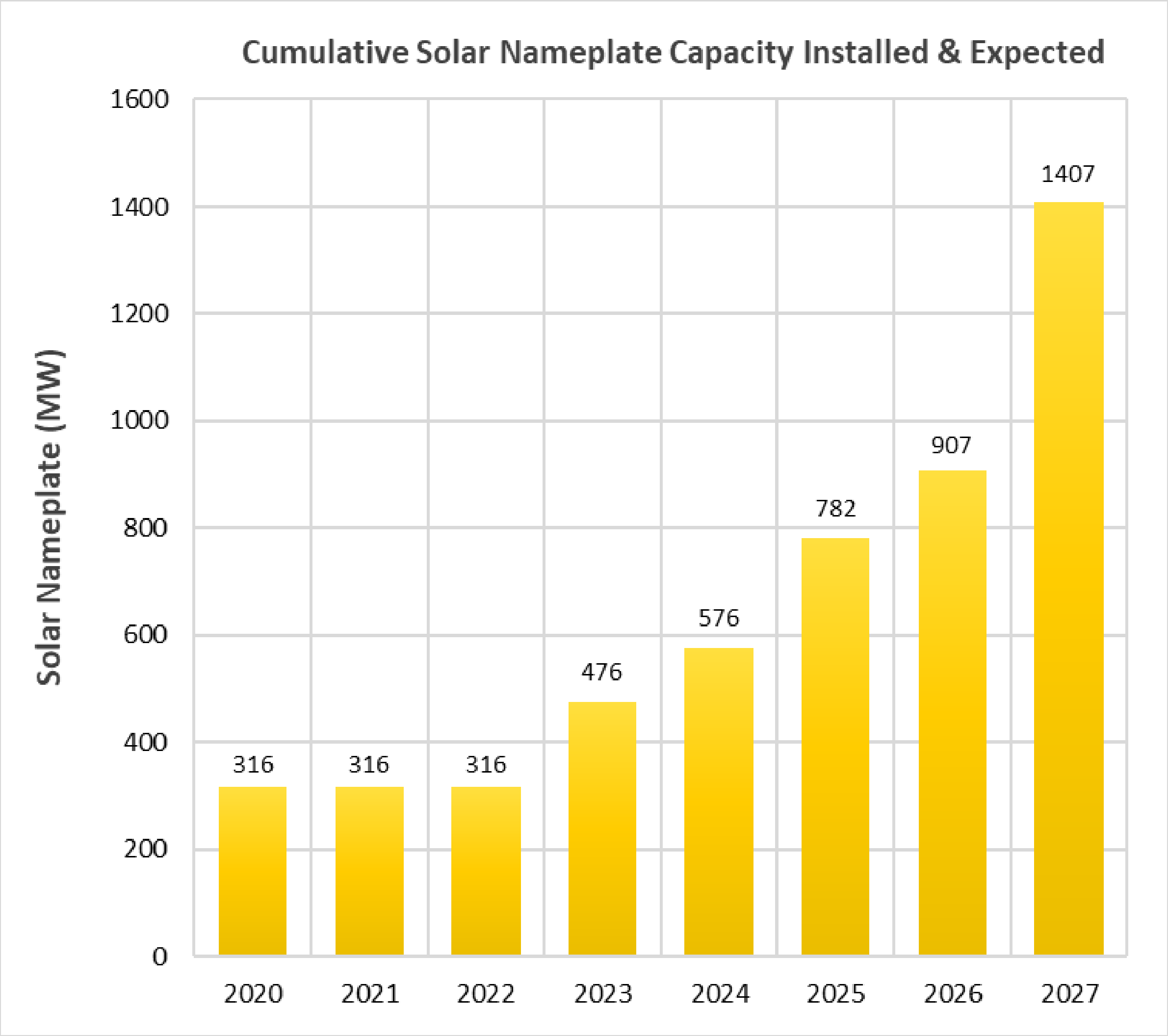
24,000 sq. mile service area

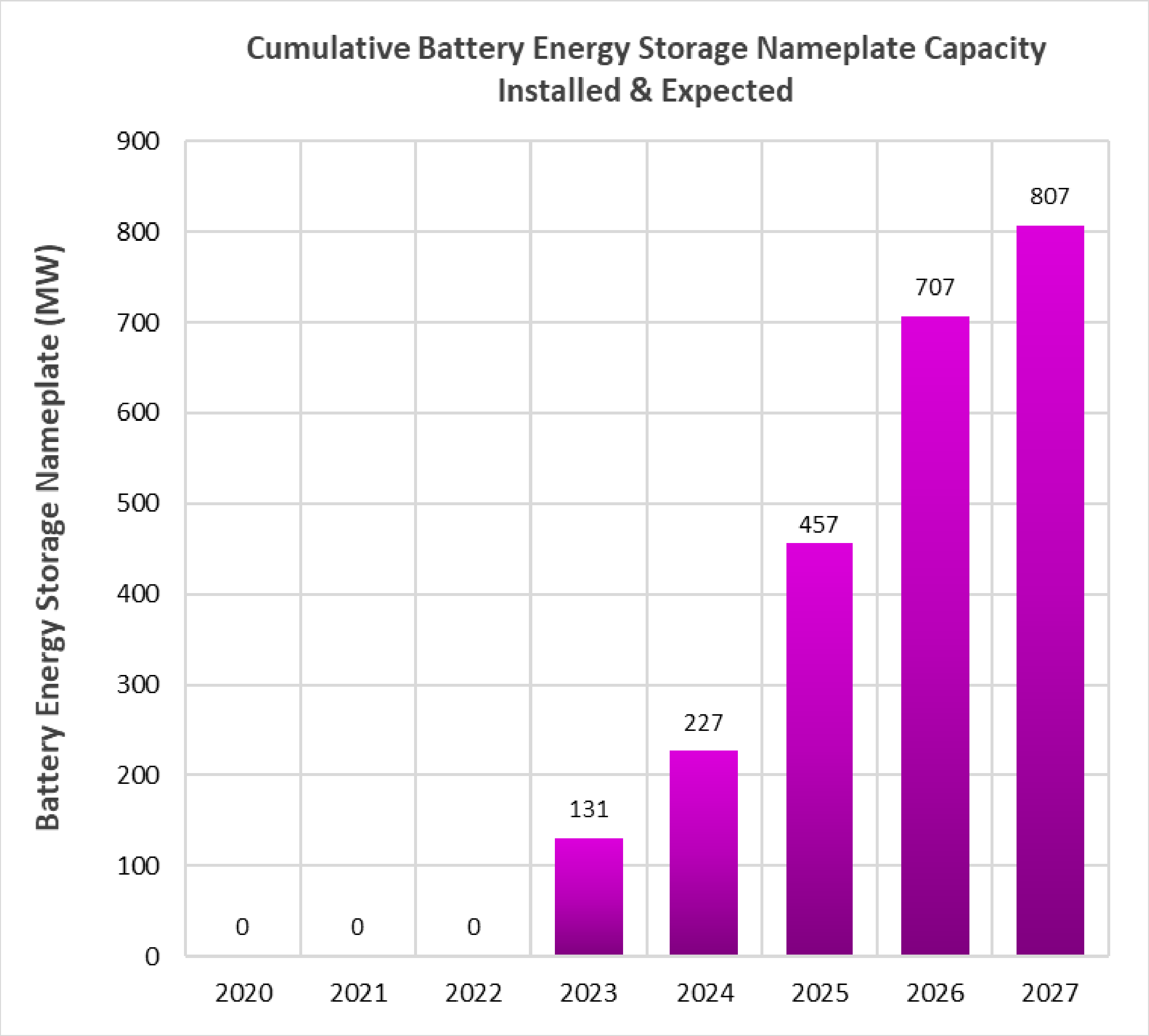
<Public>

IDAHO POWER

Inverter-Based Resources

On Idaho Power's System





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EMT at Idaho Power: Timeline

IDAHO POWER

2022

IBR Studies

GI Queue

NERC

PSCAD

EMTP

etap

2022

Evaluated EMT Vendor

2023 PSCAD

Acquired PSCAD License

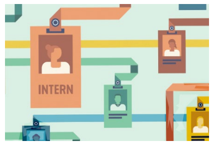
Training

2023 - Ongoing

Stand-Alone Studies

2024

EMT Intern



2025

230-kV System Study

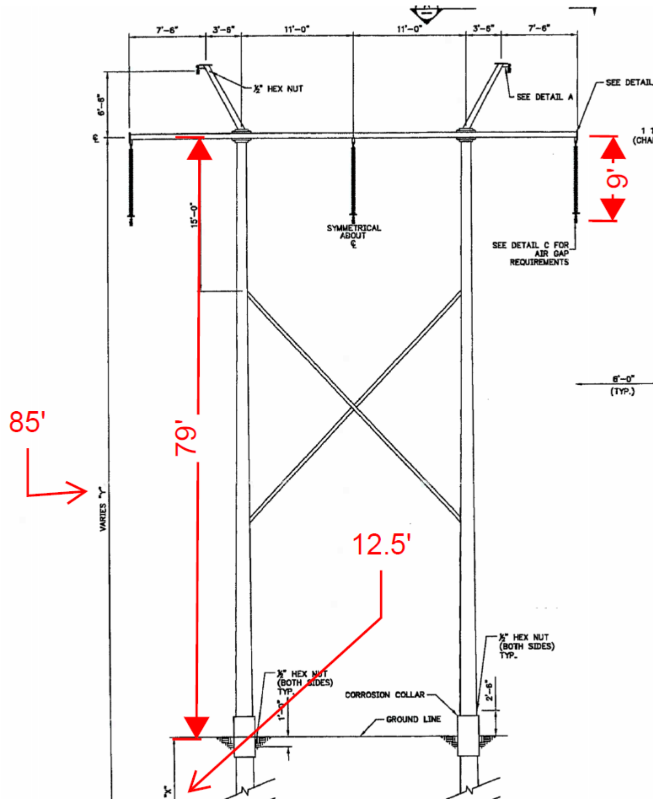
What's Next?

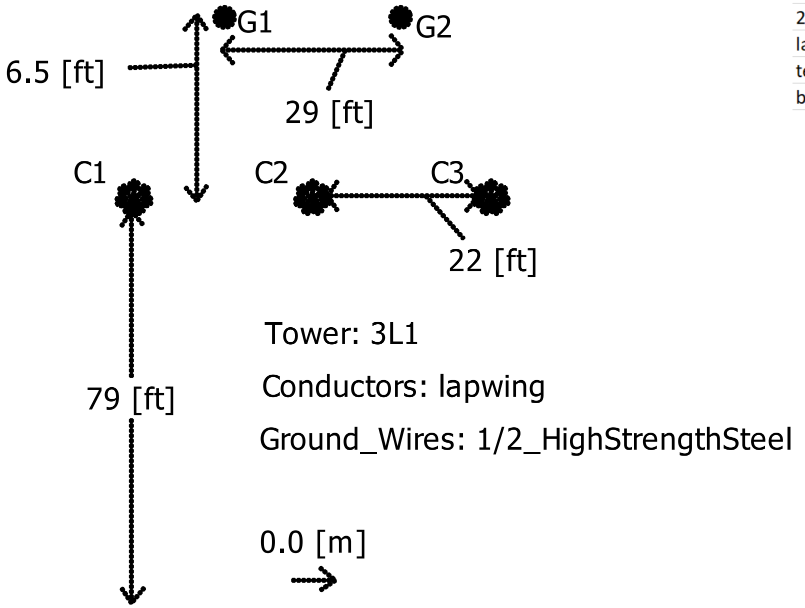
- Complete 230-kV System Study
- Prepare for NERC Compliance (MOD-26-2)
- Build Up Internal Team Expertise
- Integrate Model Checks & Validations in GI Queue

<Public>

EMT at Idaho Power: PSCAD

IDAHO POWER





Tower Structure: TSH-230

Conductor: 1590 ACSR Lapwing

PSCAD (Conductor Data/Conductor Properties)

Name	Conductor Size AWG or Kcmil	Outer radius	Total Number of Strands
250 MCM Cu (12)	250	7.61492 [mm]	12
lapwing	1590	19.10080 [mm]	45
tern	795	13.50010 [mm]	45
bittern	1272	17.08150 [mm]	45

Excel Tool to Convert Conductor Datasheet to PSCAD Format for Easy & Reliable Data Entry

ArcMap

Tower Representation in:

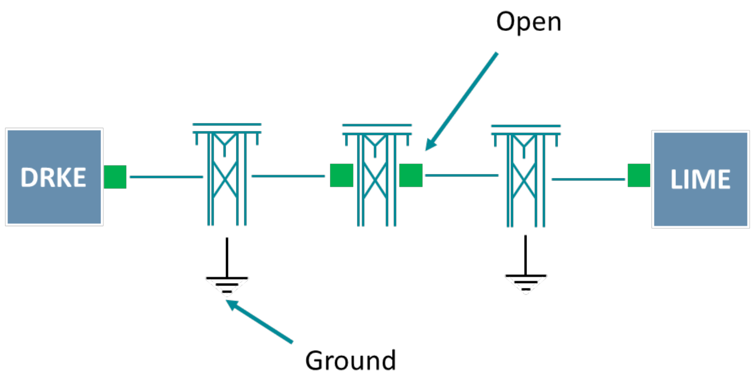
PSCAD

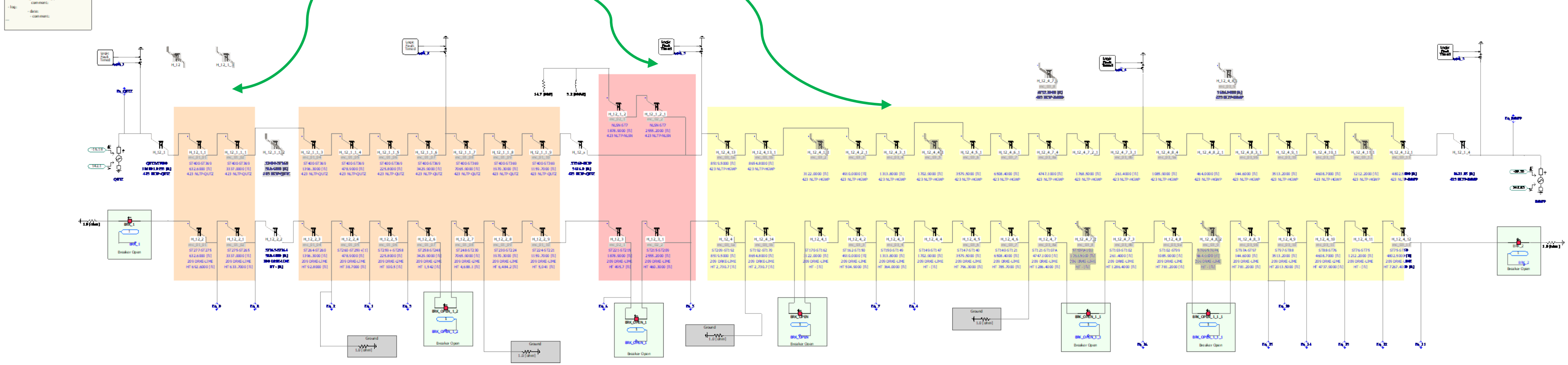
PSCAD

<Public>

<Public>

EMT at Idaho Power: Simulations





Simulation Setup in PSCAD for Mutual Coupling

<Public>

EMT at Idaho Power

Stability in an Energy-Mix

- 4 Solar PV Power Plants (IBRs)

  ~825 MW

- 7 Synchronous Generators

  ~1250 MW

- 2 Data Centers

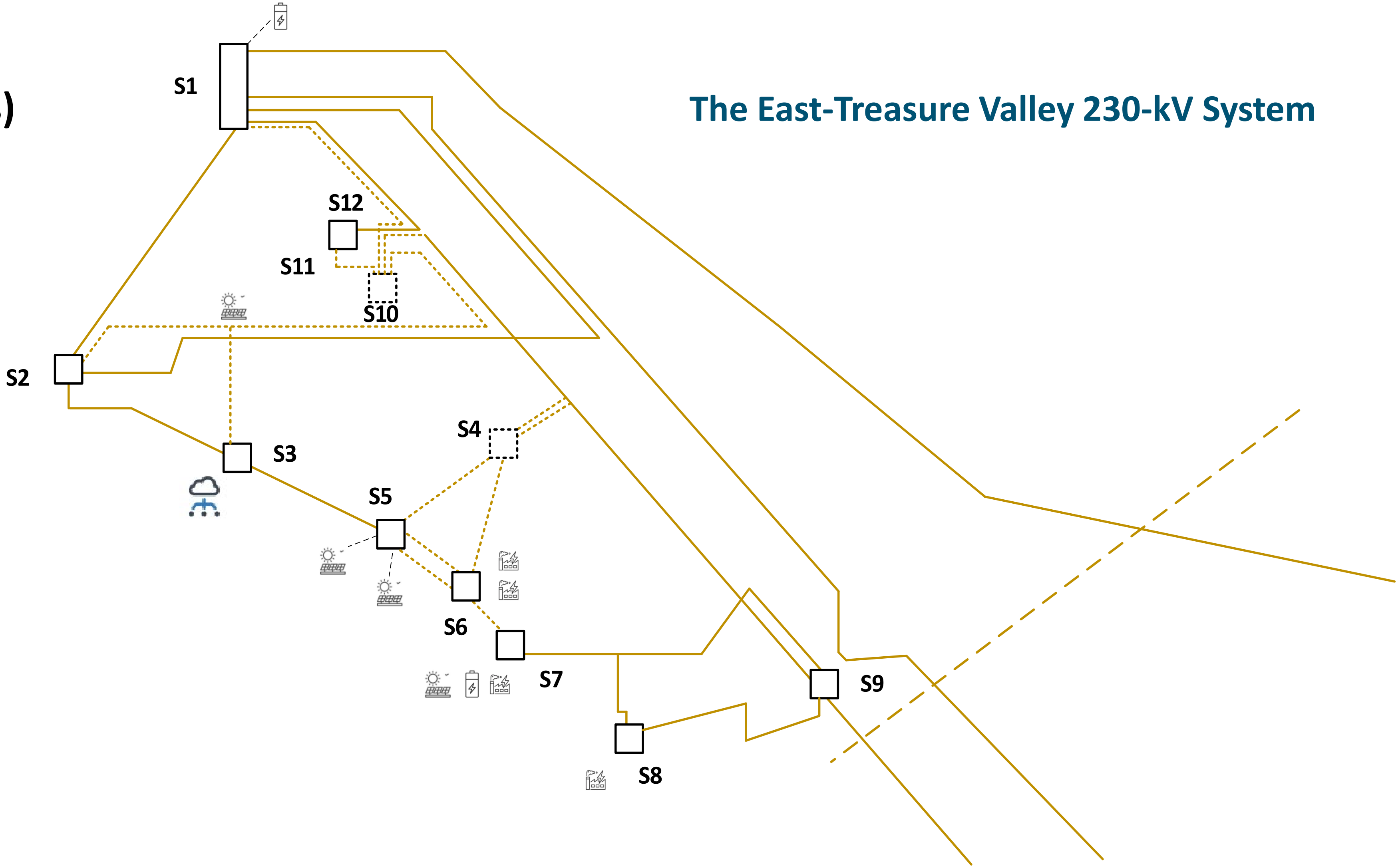
  ~400 MW

- 1 Semiconductor Fab

  ~1000 MW

- 12 Stations

The East-Treasure Valley 230-kV System



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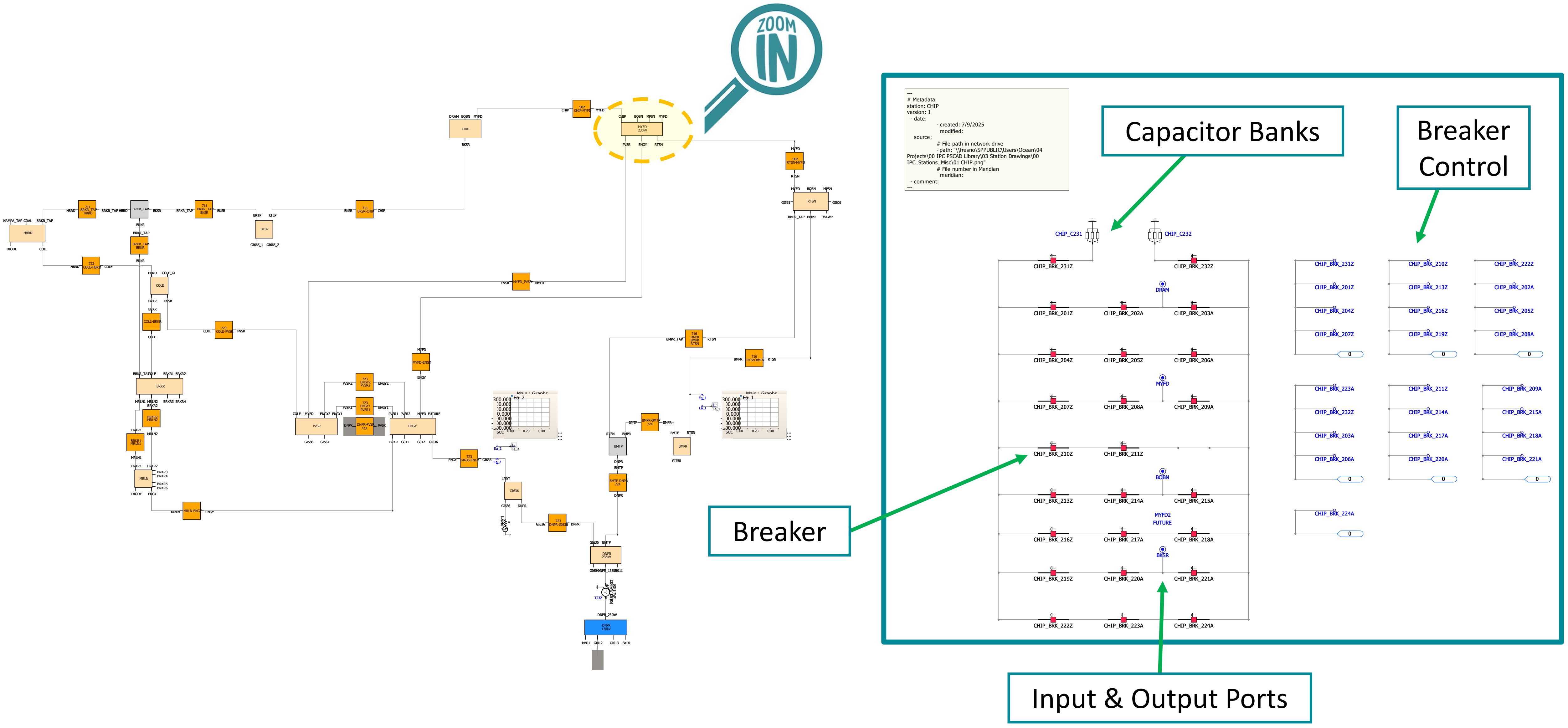
EMT at Idaho Power



01 Models for Projects Under Construction do not Represent Final Projects (Generation Interconnection Queue)

02 Need to Build Tools to Create Models Faster (GIS, Power Flow)

03 Most of the Data Already Exists within the Company

04 Compilers! Compilers! Compilers!

<Public>

IDAHO POWER

EMT at Idaho Power: Summary

Evolving System

- The Grid is Evolving Quickly with the Increase of IBRs, and our Studies to Adjust to Reflect the Changing System

Electromagnetic Transient Studies

- Idaho Power is Committed to Increasing Their Activity in the EMT Field
- The Company’s Internship Program has Proven to Successfully Help Build Out our EMT Models

<Public>

Biography

Dr. Andrés Valdepeña Delgado
Idaho Power System Consulting Engineer

PhD Electrical & Computer Engineering
12+ Years of Experience
PE in Power in the State of Idaho

Andrés Valdepeña Delgado joined Idaho Power in 2014. He currently works as a System Consulting Engineer in the planning department, assisting with resource, system and distribution planning. Andrés holds a bachelor's degree in electrical engineering from the Durango Institute of Technology, and both a master's degree and doctorate in electrical and computer engineering from Boise State University.

Andrés is an adjunct professor at Boise State University where he teaches power-related courses. In his spare time, Andrés enjoy traveling, tending to his garden, swimming and playing board games.

<Public>

ATC EMT Study Experience with IBRs, Data Centers, etc.

PRESENTED BY:

Michael B. Marz

Principal Engineer

American Transmission Company

WECC EMT Strategic Workshop November 20, 2025

<Public>

ATC

Energizing Your Future

- 5 million consumers in WI, MI, IL & MN.
- More than 10,000 miles of lines 69 to 345 kV.
- Over 500 employees.
- HVDC, SVC, STATCOM
- AI Data Centers coming!

<Public>

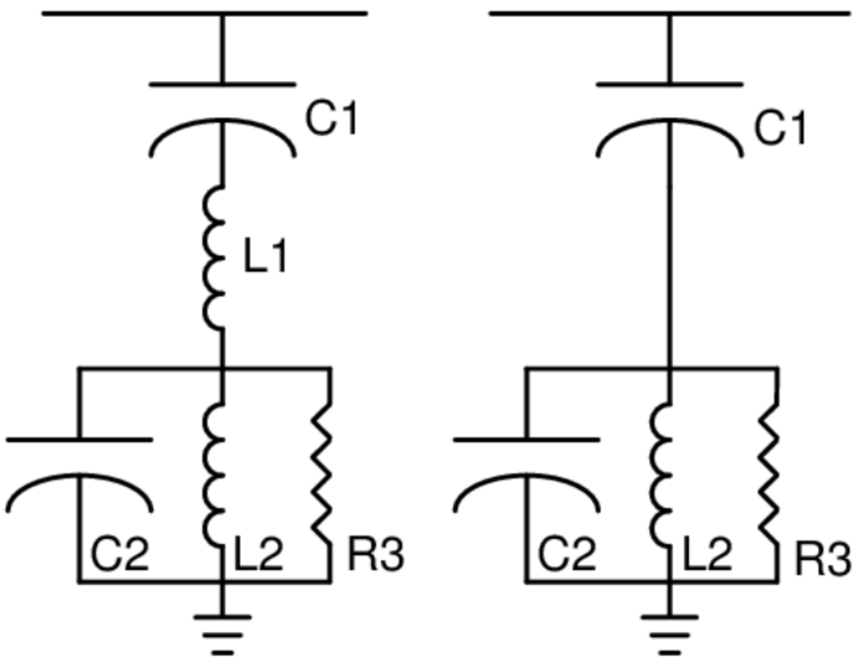
ATC EMT Studies

- Before Mackinac HVDC
  - Rare - always consultants
  - Inrush, switching, rating, etc.
- Mackinac VSC Back-to-Back HVDC
  - Needed to model control details
  - Islanding, fault response, etc.
- IBR Generation: Low SCR or near other IBRs (software fixes possible)
- AI Data Centers: Flicker, Oscillations

<Public>

Some Unusual EMT Studies

- Mackinac Very High Frequencies
  - Local relay failed during commisioning
  - HVDC did not have a high pass filter
  - Removing filter inductor solved issue
- AI Data Center Harmonic Study
  - Model background harmonics
  - Tested Digsilent model with PSCAD
  - Some Digsilent model issues resolved
- AI data center impact on nearby generator shaft tortionals
- Grid following vs. grid forming batteries (ESIG)



<Public>

Building EMT (PSCAD) Expertise

- Going slower than I would like!
  - Prior to Mackinac (2014) all studies contracted
  - Generator Interconnection studies
    - ATC tests generator/model acceptability
    - Still contract out most detailed studies
  - Large Variable AI Data Center Loads
    - Criteria Development
    - Issue Mitigation: STATCOM, etc.

<Public>

The Future of EMT at ATC

- Do all studies internal?
  - Necessary as demand for consultants increases?
  - Still use consultants for complex models?
- Building internal expertise
  - Hiring engineers with PSCAD experience
  - Dedicating engineers to PSCAD
- Improving EMT Study Tools?
  - Electranix increasing automation capabilities.
  - Improved interface? How much is possible?

<Public>

Q&A

<Public>

<Public>

NOV. 20, 2025

From Vision to Reality: Ontario’s Path to EMT Adoption

IESO's EMT Adoption Roadmap

Mohamed ElNozahy, Ph.D., P.Eng., PMP, Sr.M.I.E.E.E
Engineering Manager, EMT Studies

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Ontario's Grid is Evolving

Ontario's grid is undergoing a major transformation due to refurbishments, Pickering NS retirement, net-zero emission targets, etc.

Ontario has successfully replaced coal with nuclear, gas, wind and solar - more changes are coming that will continue to increase the number of IBRs on the system as supply needs to grow to meet demand

While IBRs (could) have faster response and provide clean source of energy, IBRs are lacking some of the beneficial attributes provided by conventional generators such as inertia contribution, short circuit contribution, etc.

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Practical Experience

In 2019

3.5-Hz oscillations were observed in real power and reactive power measurement for two 230-kV type-4 WPPs in **Ontario** after a planned 230-kV bus 3 outage.

- The outage caused a significant reduction in system strength.
- A nearby solar PV also reported un-damped reactive power oscillations.
- **Existing simulation tools didn't reveal** any performance **issues** for the project pre-commissioning.

An **EMT study** was performed to **identify solutions** to allow the connection (i.e. modify the controller settings and reduce the maximum SIA assessed level of active power output, under outage conditions).

In 2015

Poorly damped 20-Hz oscillations were observed RMS voltage of a 44-kV distribution feeder in **Ontario** after the energization of a 30-Mvar shunt capacitor at the substation

These examples highlighted the **need** to perform **EMT studies** prior to connection to ensure system reliability

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When to Start? … **NOW (That was back in 2023)**

"TPs and PCs [*] *should understand upfront that performing EMT simulations requires new skillsets, new tools, new hardware and software capabilities, and more time that traditional planning studies. This may require increasing study engineer resources with specialized expertise related to EMT modeling and studies."*

NERC Reliability Guideline: Electromagnetic Transient Modeling for BPS Connected IBRs

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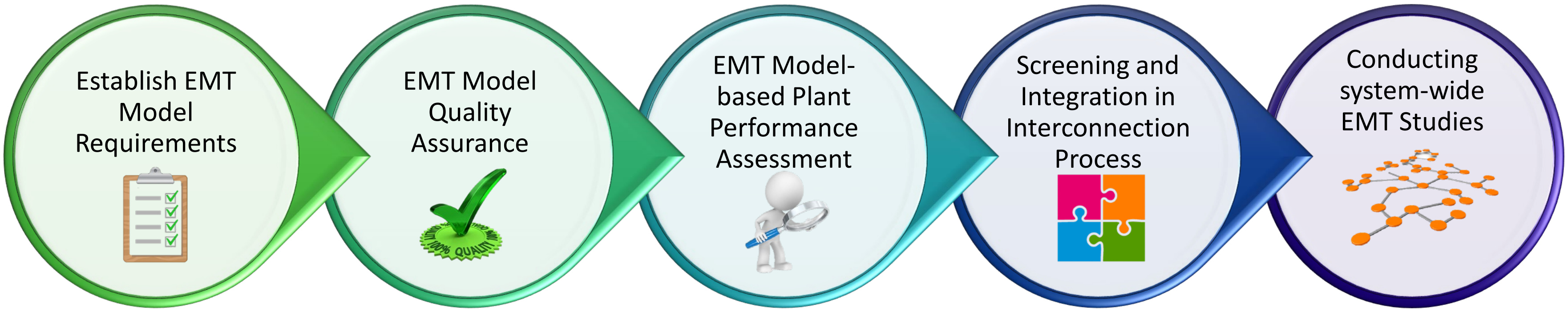
IESO EMT Roadmap*



* Adopted from the NERC EMT Modeling Adoption Roadmap

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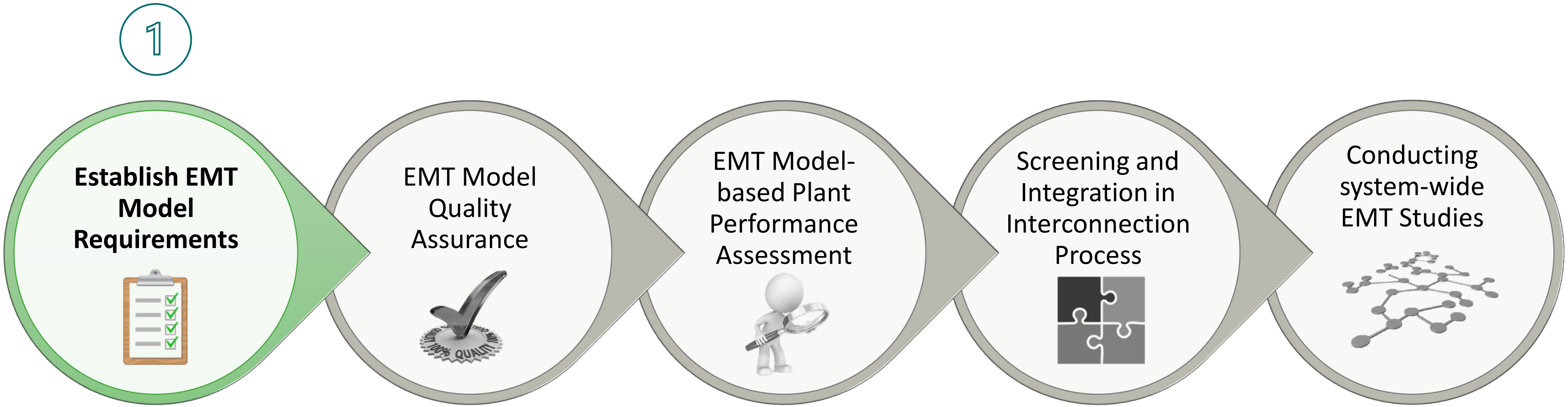
IESO EMT Roadmap*



- Published Q1 2023
- Industry best practices
- Developed checklist

* Adopted from the NERC EMT Modeling Adoption Roadmap

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Establish EMT Model Requirements

IESO Requirements for Electromagnetic Transient Models for BES-Connected Inverter-Based Resources

Purpose

This document has been prepared to establish the IESO requirements that the market participants (MPs) must meet for the validation of Electromagnetic Transient (EMT) Models for BES-Connected Inverter-Based Resources. It should be noted that the IESO is the only registered entity with NERC for Ontario, and therefore, the IESO is ultimately responsible for meeting NERC requirements.

Scope

This document outlines the validation criteria and guidelines established by the Independent Electricity System Operator (IESO) for Electromagnetic Transient (EMT) models applied to Bulk Electric System (BES)-Connected Inverter-Based Resources. It defines the necessary parameters, data requirements, and simulation protocols to ensure accurate representation of Inverter-Based Resource behavior within the power system.

Types of Required Models

The MP should provide the IESO with the following models (Fig. 1):

A) Based on Aggregation:
   i) Aggregated Models (Plant-Level Models): In these models, the entirety of the plant is represented as a single-machine single-collector equivalent model. These models are used by the IESO while conducting large-scale system impact studies to simulate the behavior of the plant at the point-of-connection.
   ii) Detailed Models (Inverter-Level / Collector-Level Models): In these models, the entirety of the plant is represented in full detail, down to the individual inverter level. In cases where the number of inverters becomes too large, making simulation impractical, and when the inverters are within close geographical proximity (i.e., BESS plants), the MP may, with IESO's approval, submit collector-level semi-aggregated models. Detailed models are used for conducting detailed ride-through verifications as well as assessing differential-mode circulating oscillations.

B) Based on Inverter modeling:
   i) Discrete-Switch Models: In these models, each individual power electronic switch is modeled separately and solved by the main circuit solution algorithm. Discrete-switch models are used when conducting harmonic/control interaction studies.

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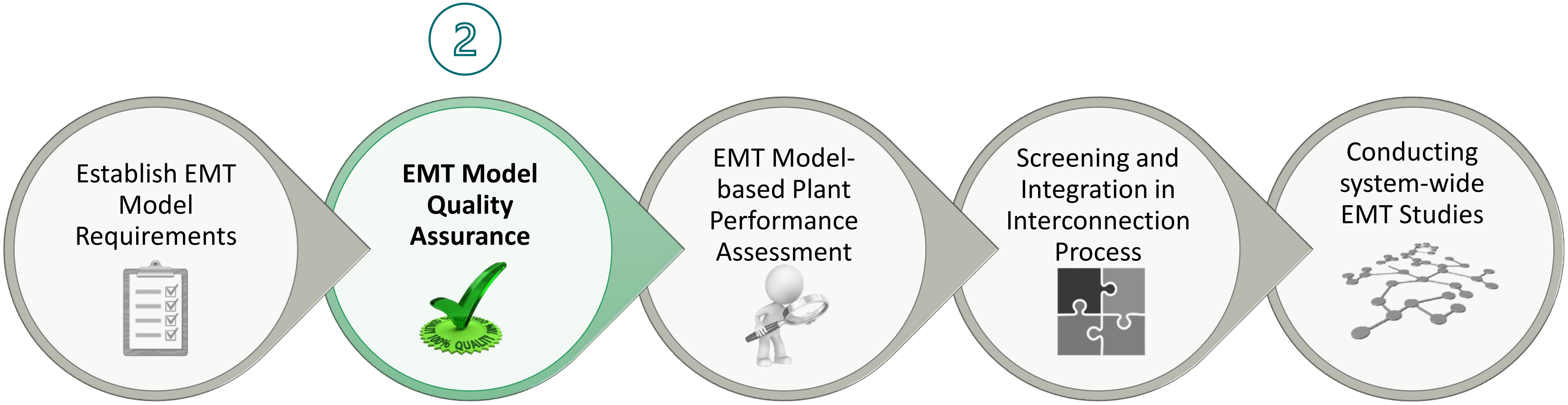
IESO EMT Roadmap*



- 3 GW of Storage projects validated
- Verify model quality: Usability, Efficiency and Accuracy
- High quality EMT models as pre-requisite

* Adopted from the NERC EMT Modeling Adoption Roadmap

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EMT Model Quality Assurance

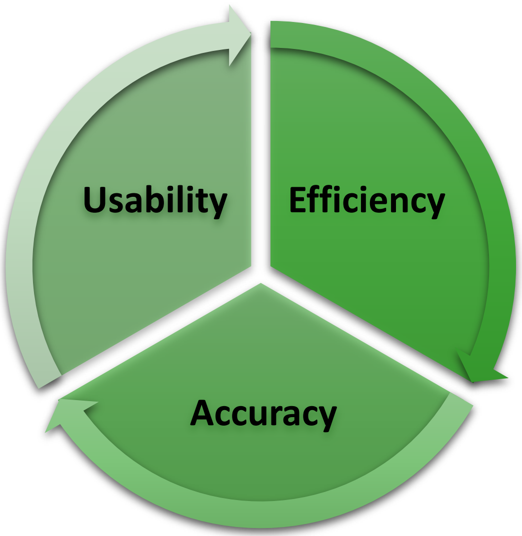
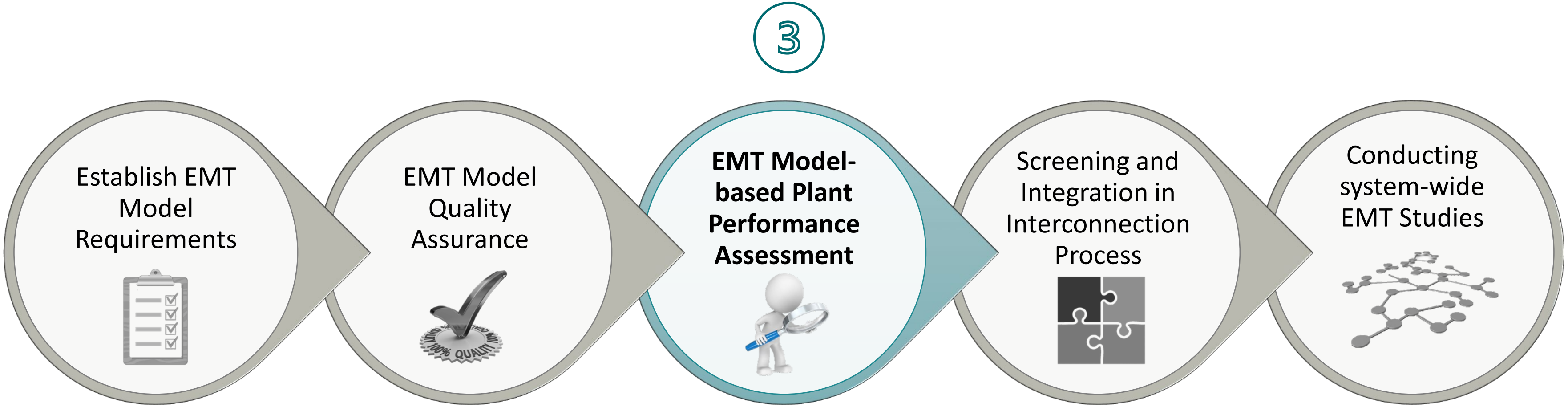


Table 1: EMT Model Minimum Requirements

Status	Requirement
Usability	
	Pertinent control functions and associated parameters are accessible to the user (for example, adjustable protection thresholds or real power recovery ramp rates). Diagnostic flags (e.g. flags to show control mode changes or which protection has been activated) shall be accessible to aid in analysis. Moreover, the following electrical quantities must be recorded and accessible to the users:
	⋮
Efficiency	
	Model uses a time step greater than or equal to 10 **μs** and does not require a specific time step. Most of the time, requiring a smaller time step means that the control implementation has not used the interpolation features of PSCAD. Lack of interpolation support introduces inaccuracies into the model
	⋮
Accuracy	
	For aggregated models, plant collector system and inverter GSU equivalencing techniques are documented and ratings are visible to the end-user.
	Aggregation and scaling techniques used to develop the aggregate inverter model and their limitations are clear to the end-user and documented.

<Public>

IESO EMT Roadmap*



- Automated tool (684 Tests)
- Assess Ride-Through performance
- IESO's MRs and P2800
- Highlighted several issues with facilities

* Adopted from the NERC EMT Modeling Adoption Roadmap

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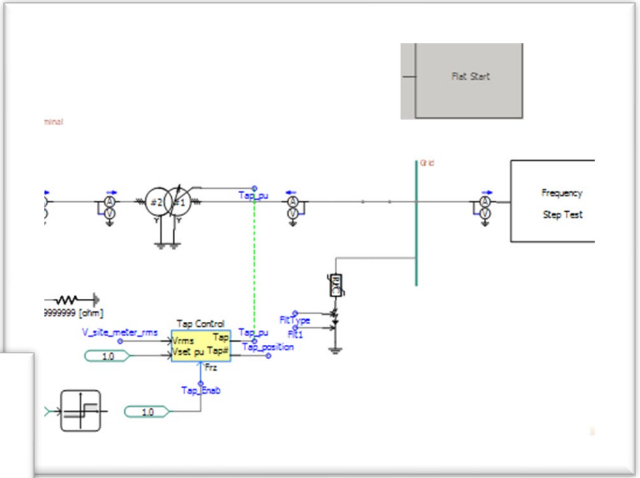
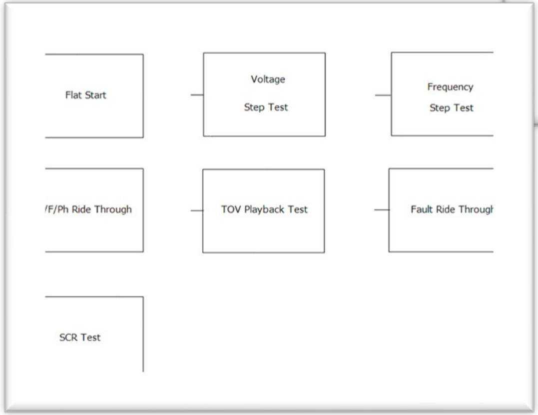
EMT Model-based Plant Performance Assessment

IESO Library

- Repository of IESO validated system blocks
- Supports rapid test setup and consistent benchmarking
- Continuously updated with new validations and refinements





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EMT Model-based Plant Performance Assessment

Ride Through

	SCR	P (pu)	Vref
1	2.5	1	0.9
2	2.5	1	1
3	2.5	1	1.1
4	2.5	0.1	0.9
5	2.5	0.1	1
6	2.5	0.1	1.1
7	2.5	-0.1	0.9
8	2.5	-0.1	1
9	2.5	-0.1	1.1
10	2.5	-1	0.9
11	2.5	-1	1
12	2.5	-1	1.1
13	10	1	0.9
14	10	1	1
15	10	1	1.1
16	10	0.1	0.9
17	10	0.1	1
18	10	0.1	1.1
19	10	-0.1	0.9
20	10	-0.1	1
21	10	-0.1	1.1
22	10	-1	0.9
23	10	-1	1
24	10	-1	1.1
25	9999	1	0.9
26	9999	1	1
27	9999	1	1.1
28	9999	0.1	0.9
29	9999	0.1	1
30	9999	0.1	1.1
31	9999	-0.1	0.9
32	9999	-0.1	1
33	9999	-0.1	1.1
34	9999	-1	0.9
35	9999	-1	1
36	9999	-1	1.1

Fault Ride Through

1		SCR	P (pu)	Vtest (Q)	Tf	Fault Ty
2	1	2.5	1	0.9	3 Cycle	3P-Vs
3	2	2.5	1	0.9	3 Cycle	3P-G
4	3	2.5	1	0.9	3 Cycle	1P-G
5	4	2.5	1	0.9	3 Cycle	2P-G
6	5	2.5	1	0.9	3 Cycle	SP
7	6	2.5	1	0.9	8 Cycle	3P-Vs
8	7	2.5	1	0.9	8 Cycle	3P-G
9	8	2.5	1	0.9	8 Cycle	1P-G
10	9	2.5	1	0.9	8 Cycle	2P-G
11	10	2.5	1	0.9	8 Cycle	SP
12	11	2.5	1	1	3 Cycle	3P-Vs
13	12	2.5	1	1	3 Cycle	3P-G
14	13	2.5	1	1	3 Cycle	1P-G
15	14	2.5	1	1	3 Cycle	2P-G
16	15	2.5	1	1	3 Cycle	SP
17	16	2.5	1	1	8 Cycle	3P-Vs
18	17	2.5	1	1	8 Cycle	3P-G
19	18	2.5	1	1	8 Cycle	1P-G
20	19	2.5	1	1	8 Cycle	2P-G
21	20	2.5	1	1	8 Cycle	SP
22	21	2.5	1	1.1	3 Cycle	3P-Vs
23	22	2.5	1	1.1	3 Cycle	3P-G
24	23	2.5	1	1.1	3 Cycle	1P-G
25	24	2.5	1	1.1	3 Cycle	2P-G
26	25	2.5	1	1.1	3 Cycle	SP
27	26	2.5	1	1.1	8 Cycle	3P-Vs
28	27	2.5	1	1.1	8 Cycle	3P-G
29	28	2.5	1	1.1	8 Cycle	1P-G
30	29	2.5	1	1.1	8 Cycle	2P-G
31	30	2.5	1	1.1	8 Cycle	SP
32	31	2.5	0.1	0.9	3 Cycle	3P-Vs
33	32	2.5	0.1	0.9	3 Cycle	3P-G
34	33	2.5	0.1	0.9	3 Cycle	1P-G
35	34	2.5	0.1	0.9	3 Cycle	2P-G
36	35	2.5	0.1	0.9	3 Cycle	SP
37	36	2.5	0.1	0.9	8 Cycle	3P-Vs
38	37	2.5	0.1	0.9	8 Cycle	3P-G
39	38	2.5	0.1	0.9	8 Cycle	1P-G
40	39	2.5	0.1	0.9	8 Cycle	2P-G
41	40	2.5	0.1	0.9	8 Cycle	SP
42	41	2.5	0.1	1	3 Cycle	3P-Vs
43	42	2.5	0.1	1	3 Cycle	3P-G
44	43	2.5	0.1	1	3 Cycle	1P-G
45	44	2.5	0.1	1	3 Cycle	2P-G
46	45	2.5	0.1	1	3 Cycle	SP
47	46	2.5	0.1	1	8 Cycle	3P-Vs
48	47	2.5	0.1	1	8 Cycle	3P-G
49	48	2.5	0.1	1	8 Cycle	1P-G
50	49	2.5	0.1	1	8 Cycle	2P-G
51	50	2.5	0.1	1	8 Cycle	SP
52	51	2.5	0.1	1.1	3 Cycle	3P-Vs

Diverse Test Scenarios:

- Test Scenarios: Different SCRs, voltage setpoints, LVRT/HVRT, frequency ride-through, fault ride through
- 684+ automated test cases executed across multiple projects
- Captures full operating envelope of inverter + PPC behavior
- Ensures models reflect field-ready reliability

<Public>

EMT Model-based Plant Performance Assessment

Use of automation:

- End-to-end workflow scripted in MATLAB & Python
- Automatically runs large sets of scenarios (SCR, voltage setpoints, LVRT/HVRT, frequency ride-through, fault ride through)
- Generates standardized plots, data extraction and pass/fail flags
- Enables fast repeatability of 684+ tests across multiple projects

```
        0,  # "AUP"
        0,  # "ADOWN"
        0,  # "P2800_Phase"
        0   # "P2800_ROCOF"
]
'''
Projectname    = "TrailroadRT"
Runtime_Mat    = [25, 25, 25, 25, 25, 25, 50, 24, 24, 55, 25] # Optimized for in
Initial_period = 10 # Initialization period to be added to the beginning of the
Pmax, Vnom     = 150, 230


# Study combinations: Setting up different combinations for the study parameters
SCR_XR      = [[7, 3], [12, 12], [50, 50]]
'''SCR_XR     = [[6, 6], [10, 10], [999,99]]'''
Ptest       = [1, 0.05, -0.05, -1]
Vtest       = [0.95, 1 , 1.05]
'''
SCR_XR      = [[6,6], [10, 14], [999, 99]]
Ptest       = [100]
Vtest       = [0.9391]
'''
IESO_Library_id         = 1249316742
Vinput_Text_id          = 1146935351
Finput_Text_id          = 1568476624
Phinput_Text_id         = 319466367
voltage_graph           = 1755266375
power_graph             = 48327613
current_graph           = 737439503
Freq_graph              = 1520971219
Disconnect_graph        = 1961712008
VRT_graph               = 746165577
Inverter_V              = 482461981
```


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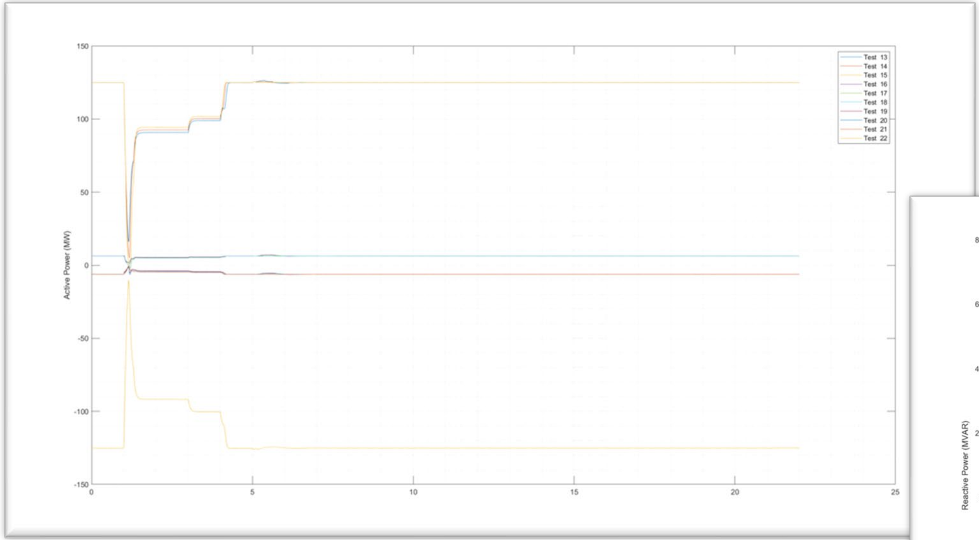
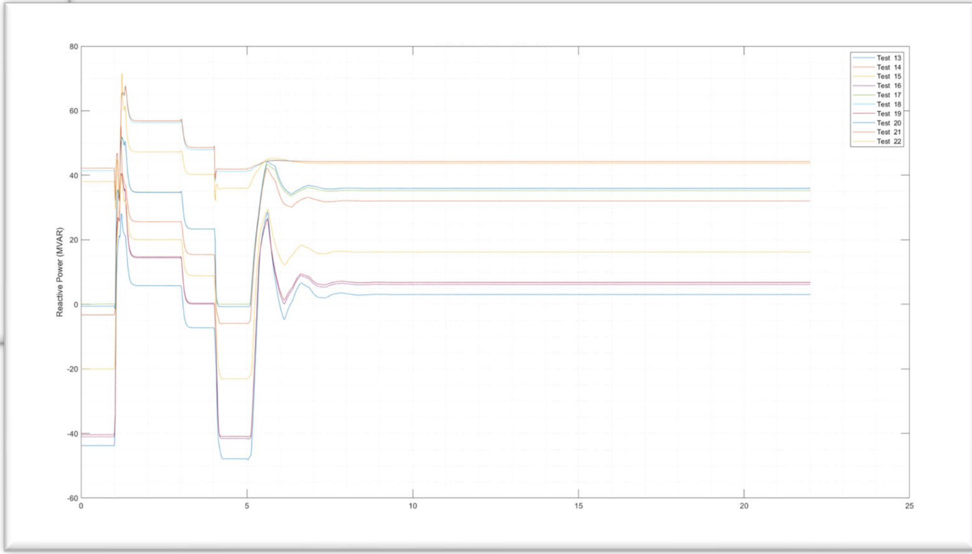

Active Power (MW)
Test 13
Test 14
Test 15
Test 16
Test 17
Test 18
Test 19
Test 20
Test 21
Test 22


Reactive Power (MVAR)
Test 13
Test 14
Test 15
Test 16
Test 17
Test 18
Test 19
Test 20
Test 21
Test 22

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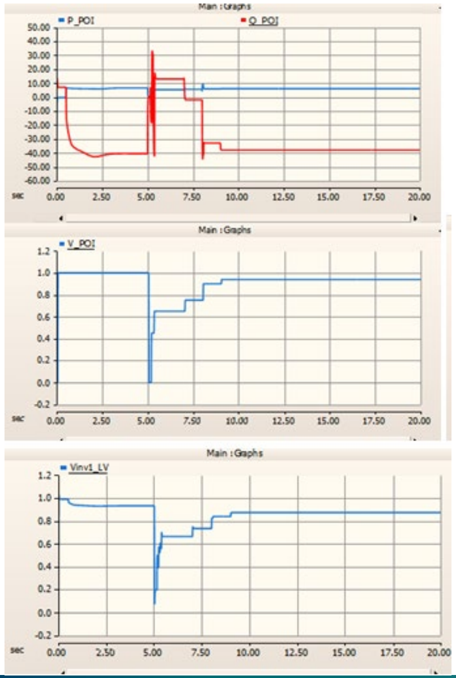
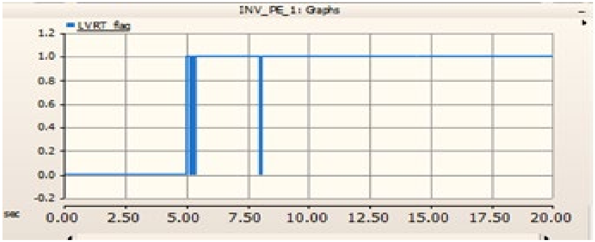
EMT Model-based Plant Performance Assessment

Issues with ride- through performance (Mode Cycling)





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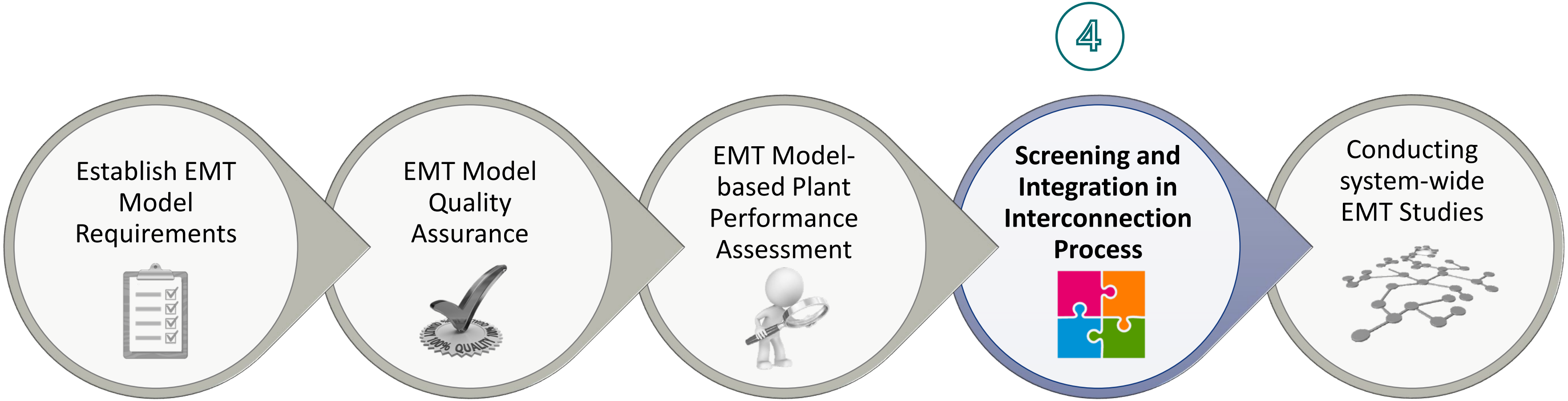
IESO EMT Roadmap*



- SSCI: AFL Tool
- SSR: Topology Scan

* Adopted from the NERC EMT Modeling Adoption Roadmap

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Screening and Integration in Interconnection Process

Available Fault Level (AFL) Screening Tool

Determine short circuit strength of the network at POI

Help to assess the potential impacts of new IBR interconnections into the ICG.

Help identify feasible connection points for new IBRs in the Ontario Power System to maximize the installed capacity.

Sub-Synchronous Resonance (SSR) Topology Screening tool

Uses **Ford-Fulkerson's max-flow min-cut theorem**

Finds number of contingencies (n) that will make an IBR injection-point radial with a series-compensated circuit

Checks if these situations could cause SSR problems. Highly susceptible injection points ($n \leq 3$) are excluded

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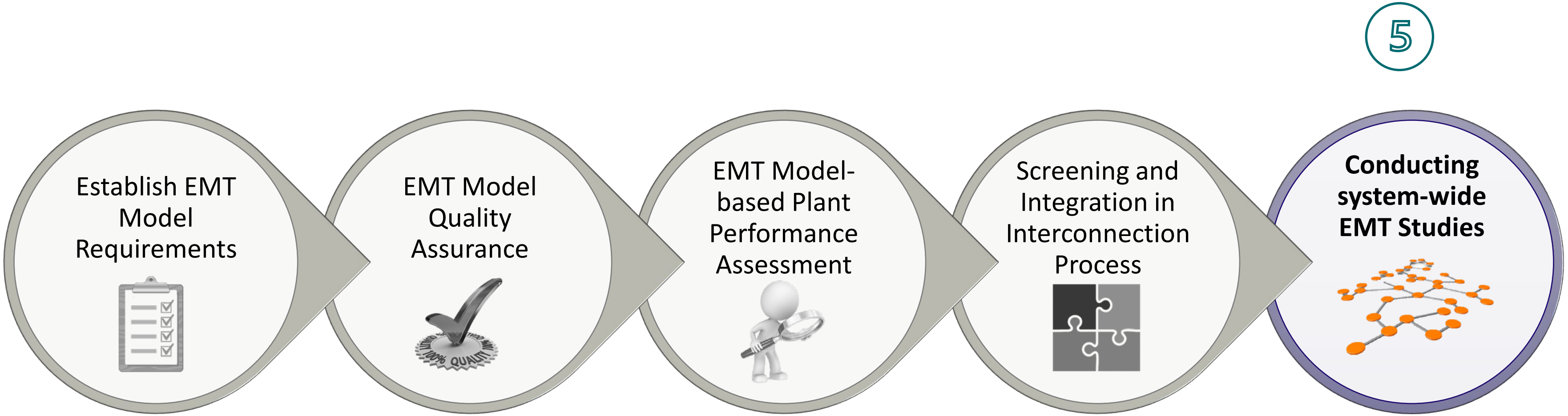
IESO EMT Roadmap*



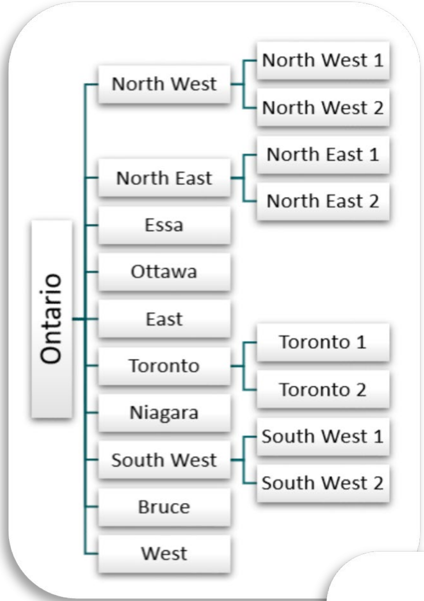
- Developed Large-scale EMT base case (Collaborated with MHI)
- Conduct large-scale EMT studies

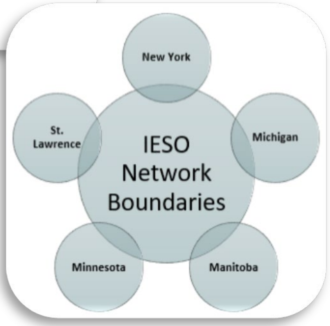
* Adopted from the NERC EMT Modeling Adoption Roadmap

<Public>

IESO Large Scale EMT Model

- The Ontario network is divided into 10 zones, expanded into 15 cases to improve simulation run time + 5 boundaries for parallel execution across multiple CPU cores
- Each IBR plant is simulated on a separate core to optimize processing efficiency
- Regularly updated (twice a year) to reflect system changes
- Study areas selected based on analysis needs and system topology to improve performance.





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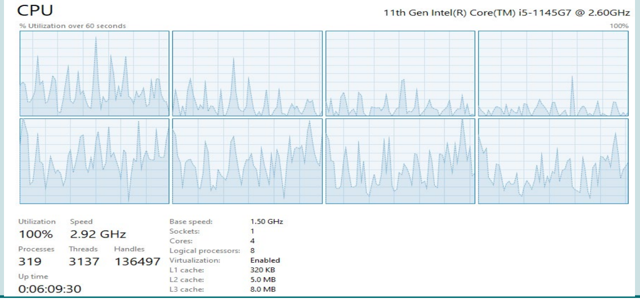
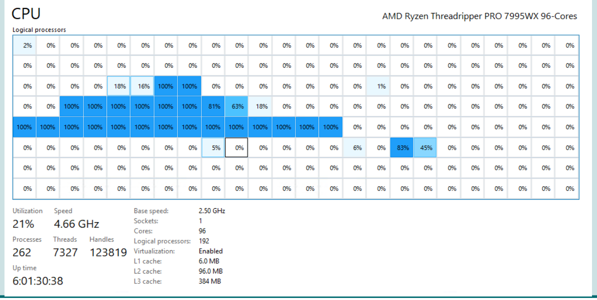
Managing Complexity and Performance in IESO Large Scale EMT Model

Full System without IBRs (2 Sec)		
	Laptop	**Workstation**
Run time	Elapsed time 1:11:51	Elapsed time: 00:24:59
CPU Processor during building		

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IESO Large Scale EMT Study Procedure

- Reduce and extract subsystems for targeted analysis (area of interest)
- Reinitialize the model for multiple test cases and operating points
- Flexibility to create external network equivalents for boundary systems
- Validation of power flow and dynamic performance against PSS®E results

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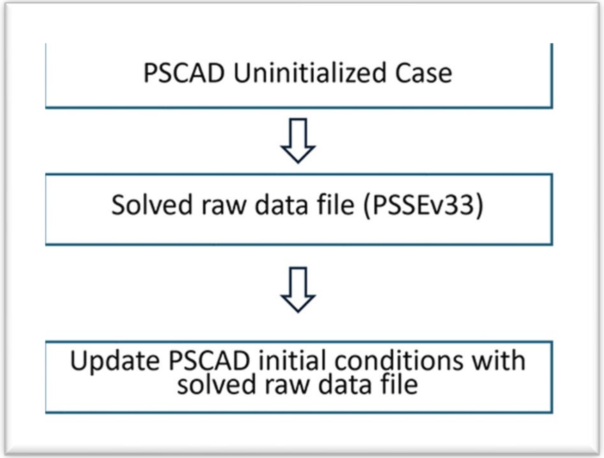
Step 1. Network Parameter Reinitialization

Redispatch script reads the network state from the PSS®E RAW file.

The script adjusts PSCAD cases and network components to reflect the required operating state.

Dynamic components such as generators, STATCOMs, and wind farms defined within page modules are reinitialized accordingly.



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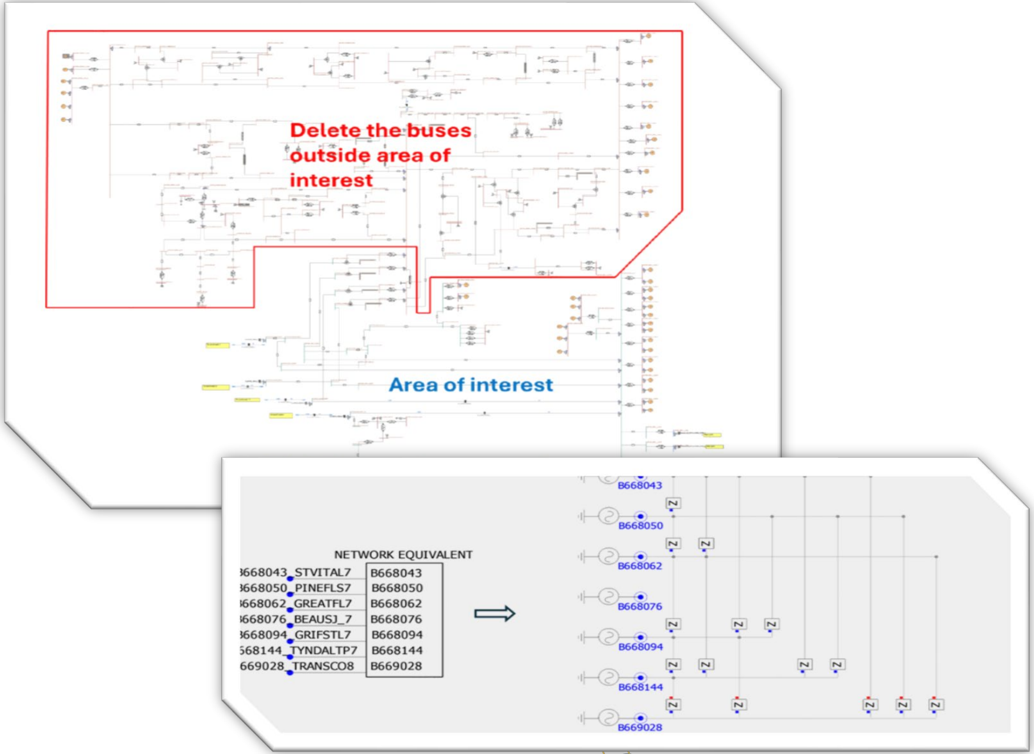
Step 2. Network Equivalent (NETEQ) Updating Script

NETEQ simplifies the modeling of external networks (area outside scope of interest) by using a reduced representation.

Instead of modeling all components in detail, equivalent impedance is used to represent the external network behavior.

Reduces simulation complexity while maintaining accurate study.



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Step 3. Case Validation

Three tools are available to validate the accuracy of initialization and NETEQ modeling:

1. P and Q injection: Inject P and Q at selected buses to align PSCAD power flow with PSS®E

2. Power flow validation: Run the PSCAD case and compare PSCAD bus voltages and angles against PSS®E steady-state results

3. Dynamic validation: Apply a fault at a specific bus (e.g., the study bus), then, compare the results against PSSE dynamic response

typ	bus_name	namespace	id	p	q
pq	B157072_ABIT_JQ26_10	Niagara_V03_reduced	1214602594	.000	-.010
pq	B157062_BECK__2_BP76	Niagara_V03_reduced	1727603377	.026	-.026
pq	B158165_CROSSLN_JQ26	Niagara_V03_reduced	1372744321	.393	-.044
pq	B157063_BECK__2_PA27	Niagara_V03_reduced	508100920	.025	-.071
pq	B157275_ALLANBURG_R1	Niagara_V03_reduced	1457223405	-.010	-.125
pq	B157083_ABIT_J_Q26M	Niagara_V03_reduced	1936248064	-.029	.143
pq	B157082_ABIT_J_Q35M	Niagara_V03_reduced	1283758029	-.019	-.168
pq	B157276_ALLANBURG_R2	Niagara_V03_reduced	2095037125	.056	-.184
pq	B157070_NIA_WEST_J25	Niagara_V03_reduced	1750894439	-.517	.217
pq	B157069_NIA_WEST_J23	Niagara_V03_reduced	644506902	-.507	.236
pq	B157051_BECK__2_H302	Niagara_V03_reduced	1029070588	.012	-.259
pq	B157078_ALLANB_WJQ26	Niagara_V03_reduced	90307707	-.146	.328
pq	B157200_ALLANBRG_DH1	Niagara_V03_reduced	287936368	.680	-.372
pq	B157064_RSFPTHRLD230	Niagara_V03_reduced	288423126	.708	-.479
pq	B157061_BECK_PS_Q21P	Niagara_V03_reduced	844958519	-.312	-.524
pq	B157054_ALLANBRG_Q26	Niagara_V03_reduced	1032303291	-.283	-.544
pq	B157050_BECK__2_H301	Niagara_V03_reduced	461315109	.012	-.977
pq	B157055_ALLANBRG_Q28	Niagara_V03_reduced	774572074	-.125	-1.036
pq	B157278_ALLANBURG_R4	Niagara_V03_reduced	1550095278	-.371	-1.036
pq	B157277_ALLANBURG_R3	Niagara_V03_reduced	1902871242	-.353	-1.090

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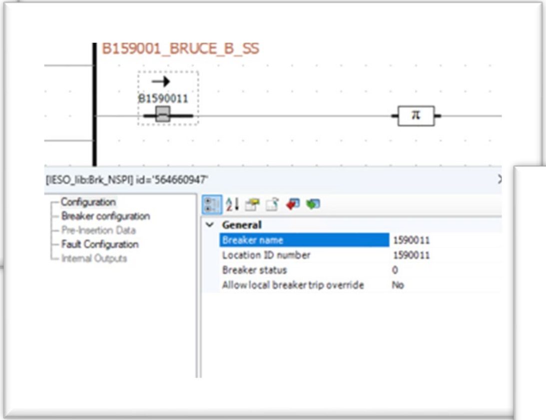
Step 4. Running contingencies in the Large Scale Model

Update the Contingency List → Add Contingency Blocks to PSCAD Model → Run the Python Script

Contingency description	enable [0], disable [0]	time _inc	unit	action	idents	
Bruce three phase fault	1	15	sec	ABCG	1590011	159000
Three phase to ground fault in bus 159000 and 159001		4	cycles	Open	1590011	159000
		2	cycles	Open	1590031	159007
Wawa 230 three phase	1	15	sec	ABCG	1520611	
Three phase to ground		6	cycles	Open	1520611	152063




```
Files Path
-----------------------------------------------------------------------------
:ipt_dir = os.path.dirname(os.path.abspath(__file__))
ames_path = os.path.join(script_dir, 'frames.xlsx')
itingencies_path = os.path.join(script_dir, 'IESO_Contingencies.xlsx')
:kspace_dir = Path(os.path.split(script_dir)[0])
:kspace_path = os.path.join(workspace_dir, 'IESO full case workspace.psw
: folder = workspace_dir
```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Contingency Results using the IESO network model

Contingency No. 1

Bruce three phase fault

Three phase to ground fault in bus 159000 and 159001

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IESO's EMT Transformation: People and Results

Organizational Journey

- Started with 1 engineer in 2023
- Built a full EMT team (4+ staff)
- Partnered with MHI, vendors, ISOs
- Embedded EMT as core capability

Outcomes and Impact

- Avoided potential grid issues
- Verified 3+ GW of resources
- Improved visibility into grid behavior
- Positioned IESO as industry leader

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Questions

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Thank You

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Day 2 Group Discussion and Roadmap for Future: Prioritization, Lessons Learned, and Harmonization

Vic Howell
Director, Reliability Assessments and Modeling

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Group Discussion Talking Points

- **Where EMT Studies Add the Most Reliability Value**
  Which grid conditions, areas, controls, scenarios, or other factors give the highest return on investment for EMT studies in the Western Interconnection or nationally? Which scenarios should be elevated first (weak grid areas, large clustered IBR additions, proximity to series capacitors, data centers, etc.)?

- **EMT Screening Approaches and Opportunities for Harmonization**
  Are there opportunities for harmonizing EMT screening methods and tools across the West for the benefit of many TPs and PCs? How and what could this look like?

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Group Discussion Talking Points

- **Best Practices for Building Internal EMT Expertise**
  What are some of the "best practices" regarding building internal EMT experience and capacity? How to attract talent, train, upskill, resource appropriately, etc.

- **Lessons Learned from Early EMT Implementation**
  Capture what utilities, developers, and vendors have learned so far—successes, bottlenecks, unexpected challenges.

- **Developer Pain Points and How Utilities Can Reduce Friction**
  Discuss how unclear requirements, inconsistent data requests, or divergent expectations slow project schedules—and what the community can streamline.

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Group Discussion Talking Points

- **Preparing for Future Technologies (GFM, Hybrids, HVDC, Co-Located)**
  What should industry be doing or how should we be thinking about evolving IBR technologies and how EMT plays a role here?

- **Model Version Control and Sharing**
  How are utilities/ISOs and developers tracking changes to facilities and updating models appropriately? What requirements or processes have been effective or ineffective in this area?

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Group Discussion Talking Points

- **Top Three Collective Priorities for the Coming Year**
  What are the top three priorities collectively walking out of this strategic workshop on how industry can:
  - Improve skills and capabilities related to EMT
  - Harmonize IBR modeling requirements and checks/tests
  - Leverage IEEE 2800-2022 and align with changes to regulatory requirements
  - Foster community and alignment on this topic moving forward

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Day 1 Group Discussion: Prioritization, Lessons Learned, and Harmonization

Vic Howell

Director, Reliability Assessments and Modeling

Electric Reliability & Security for the West

November 19, 2025

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Group Discussion Talking Points

- **Aligning EMT Requirements Across Utilities**
  How can Western Interconnection TPs and PCs harmonize their EMT (and positive sequence) modeling requirements, submittal formats and processes, and model quality checks/tests to reduce confusion and improve model consistency?

- **Integration with IEEE 2800 and P2800.2**
  How can IBR modeling requirements being developed per NERC FAC-002 and MOD-026 align best with IEEE 2800-2022 and IEEE P2800.2? How should utilities be thinking about aligning in these areas? When is the right time?

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Group Discussion Talking Points

- **Model Quality and Tests: Defining Minimum Acceptable Requirements**
  Based on panelist presentations and discussion, what are the minimum set of model quality and performance tests that should be adopted? Why? What challenges do we face in accomplishing uniformity and harmonization here?

- **Cross-Industry Unified IBR Modeling Requirements in the West**
  Is there opportunity to develop a unified and harmonized set of IBR modeling requirements across the West? Who is the best organizational body to accomplish such this? Recurring meetings, templates, WECC working group, etc.? What works best?

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Group Discussion Talking Points

- **Developer Pain Points and How to Reduce Friction**
  What were the key IBR developer pain points we heard and how can processes be streamlined to support improvements in this area?

- **Model Verification and Validation: What's Achievable Today**
  With the new MOD-026-2, how and when should model verification/validation be done for newly connecting IBRs? Why? How are TPs and PCs thinking about the identification of legacy IBRs for requiring EMT models be provided and verified/validated?