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

Forum for the Implementation of Reliability Standards for Transmission (i2X FIRST) | 10/24/24

An initiative spearheaded by the Solar Energy Technologies Office and the Wind Energy Technologies Office

BERKELEY LAB

ESIG

EPRI

The first half of this meeting call is being recorded and may be posted on DOE's website or used internally. If you do not wish to have your voice recorded, please do not speak during the call. If you do not wish to have your image recorded, please turn off your camera or participate by phone. If you speak during the call or use a video connection, you are presumed consent to recording and use of your voice or image.

Polling Question 1

What industry sector are you representing?

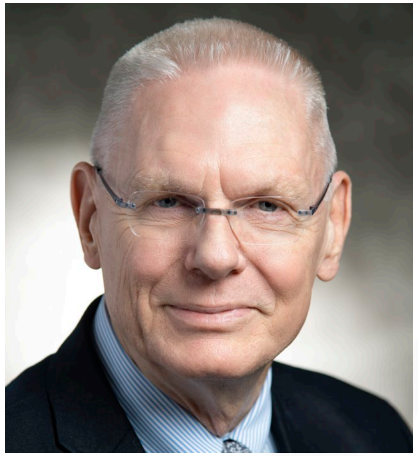
[Go to **slido.com** and enter event code **FIRST6**, then go to **Polls** tab]

Key Goals and Outcomes from i2X FIRST

- To facilitate understanding and adoption of new and recently updated standards relevant for existing and newly interconnecting wind, solar and battery storage plants
- The Forum will convene the industry stakeholders to enable practical and more harmonized implementation of these interconnection standards.
- The presentation portion of the meeting will be recorded and posted, and presentation slides will be shared.
- Additionally, the leadership team will produce **a summary of each meeting** capturing:
  - Recommended best practices
  - Challenges
  - Gaps that require future work

Leadership Team

Cynthia Bothwell, Boston Government Services, contractor to DOE's Wind Energy Technologies Office



Robert Reedy, Lindahl Reed, contractor to DOE's Solar Energy Technologies Office

Will Gorman, Lawrence Berkley National Laboratory

Jens Boemer, Electric Power Research Institute

Julia Matevosyan, Energy Systems Integration Group

Ryan Quint, Elevate Energy Consulting

Summary of the last meeting – Measurement Data for Performance Monitoring and Model Validation

- I2x FIRST Intro – Will Gorman, LBNL
- NERC Technical Conference Update – Kyle Thomas, Elevate Energy Consulting
- Need for Disturbance Monitoring – Alex Shattuck, NERC
- IEEE 2800-2022 Clause 11 *Measurement data for performance monitoring and validation* and NERC PRC-028 *Reporting Requirements for Inverter-Based Resources* – Manish Patel, EPRI
- Q&A and Structured Discussion – led by Ryan Quint, Elevate Energy Consulting
  - Measurement and Monitoring Requirements
  - Differences between PRC-028 and IEEE 2800-2022, Clause 11

Meeting summary, recording & presentations are posted here (click on Past Events at the bottom of the page)

Key Themes from the Last Meeting

- Strong industry engagement, at the NERC IBR Ride-Through Technical Conference led to effective discussions and changes to the regulatory requirements to align with industry needs.
- The updated version of NERC PRC-029 following the conference included aligning the frequency ride-through-curves with IEEE 2800-2022 and allowing for exemptions based on technically justified hardware limitations.
- NERC, transmission providers, and asset owners have leveraged high-speed data at the plant-level and inverter-level, to improve the reliability of IBRs. Availability of higher resolution data provides deeper insights for better forensic analysis and mitigation of IBR performance issues.
- There are significant differences between the requirements set forth in IEEE 2800-2022 and NERC PRC-028. This is mostly due to applicability of NERC PRC-028 to new and existing IBRs, and likely inability of the latter to meet more stringent IBR monitoring requirements, particularly for unit-level monitoring.
- Existing assets will be required to meet the new NERC PRC-028, where applicable, and reasonable implementation times (and extensions) were included by the drafting team.
- New assets should seek to meet IEEE 2800-2022 requirements (particularly where those requirements are mandatory). This approach will also help new assets comply with the technical requirements of NERC PRC-028 since IEEE 2800-2022 monitoring requirements are notably more stringent.

Upcoming i2X FIRST Meetings

1. May 28th, 2024, 11 a.m.- 1 p.m. ET: Introduction of Evolving Standards Landscape
2. June 25th, 2024, 11 a.m.- 1 p.m. ET: IEEE2800 Ride Through Requirements
3. July 30th, 2024, 11 a.m.- 1 p.m. ET: IEEE2800 Ride Through Requirements, OEM Readiness
4. August 20th, 2024, 11 a.m.- 1 p.m. ET: IEEE2800 Ride Through Requirements, OEM Readiness, cont.
5. September 24th, 2024, 11 a.m.- 1 p.m. ET: Measurement Data for Performance Monitoring and Model Validation
6. October 24th, 2024 hybrid, full day, during ESIG Fall Workshop, Providence, RI: Conformity Assessment
7. November 26th, 2024, 11 a.m.- 1 p.m. ET: IEEE 2800 Active-Power—Frequency Response Requirements
8. December 17th, 2024, 11 a.m.- 1 p.m. ET:
9. January 28th 2025, 11 a.m.- 1 p.m. ET:
10. February 25th 2025
11. March 20th, 2025 hybrid full day event during ESIG Spring Workshop, Austin, Texas

Sign up for all future i2X FIRST Meetings here: https://www.zoomgov.com/meeting/register/vJItceuorTsiErIC-HInpPbWuTUtrYQAuoM#/registration

Follow DOE i2X FIRST website: https://www.energy.gov/eere/i2x/i2x-forum-implementation-reliability-standards-transmission-first for meeting materials & recordings and for future meeting details & agendas

i2X FIRST Workshop, Conformity Assessment – Agenda

8:00 a.m. – 9:45 a.m.
Session 1: Opening Remarks and Background Information
Session Chair: Ryan Quint, Elevate Energy Consulting

Introduction to DOE i2x FIRST and the Workshop
Julia Matevosyan, ESIG

Need for IBR Plant Conformity Assessment
Ryan Quint, Elevate Energy Consulting

IEEE 2800.2 Progress Update
Andy Hoke, NREL

Importance of IBR Modeling and Design Evaluation
Alex Shattuck, NERC

i2X FIRST Workshop, Conformity Assessment – Agenda

10:15 a.m. – 12:00 p.m.
Session 2: IBR Plant Modelling and IEEE P2800.2 Design Evaluation
Session Chair: Andy Hoke, NREL

Review of Design Evaluation Requirements and Recommended Best Practices in IEEE 2800-2022 and IEEE P2800.2
Alex Shattuck, NERC

OEM Perspective: IBR Plant Design Evaluation through Testing and Modeling
Miguel Cova Acosta, Vestas

Present-Day Design Evaluations Analysis and Challenges
Billy Yancey, EPE

i2X FIRST Workshop, Conformity Assessment – Agenda

1:15 p.m. – 3:00 p.m.
Session 3: IEEE 2800.2 Design Evaluation, Model Validation and Benchmarking Deep Dive
Session Chair: Julia Matevosyan, ESIG

IEEE P2800.2: The Trouble with Model Validation!
Andrew Isaacs, Electranix

OEM Perspective: IBR Unit Model Validation
Miguel Cova Acosta, Vestas

IEEE P2800.2 Design Evaluation Tests – A Deep Dive
Andrew Isaacs, Electranix

i2X FIRST Workshop, Conformity Assessment – Agenda

Session 4: “As-Built” Evaluation and Commissioning Testing
Session Chair: Billy Yancey, EPE

Review of “As-Built” Evaluation and Commissioning Testing Requirements and Recommended Best Practices in IEEE 2800-2022 and IEEE P2800.2
Chris Milan, CrestCura

Examples and Challenges of “As-Built” Evaluation and Commissioning Testing
Chris Milan, CrestCura

Virtual Meetings Code of Conduct

1. *Assume good faith and respect differences*
2. *Listen actively and respectfully*
3. *Use "Yes and" to build on others' ideas*
4. *Please self-edit and encourage others to speak up*
5. *Seek to learn from others*

Mutual Respect . Collaboration . Openness

Stakeholder Presentations

Importance of IBR Modeling and Design Evaluation

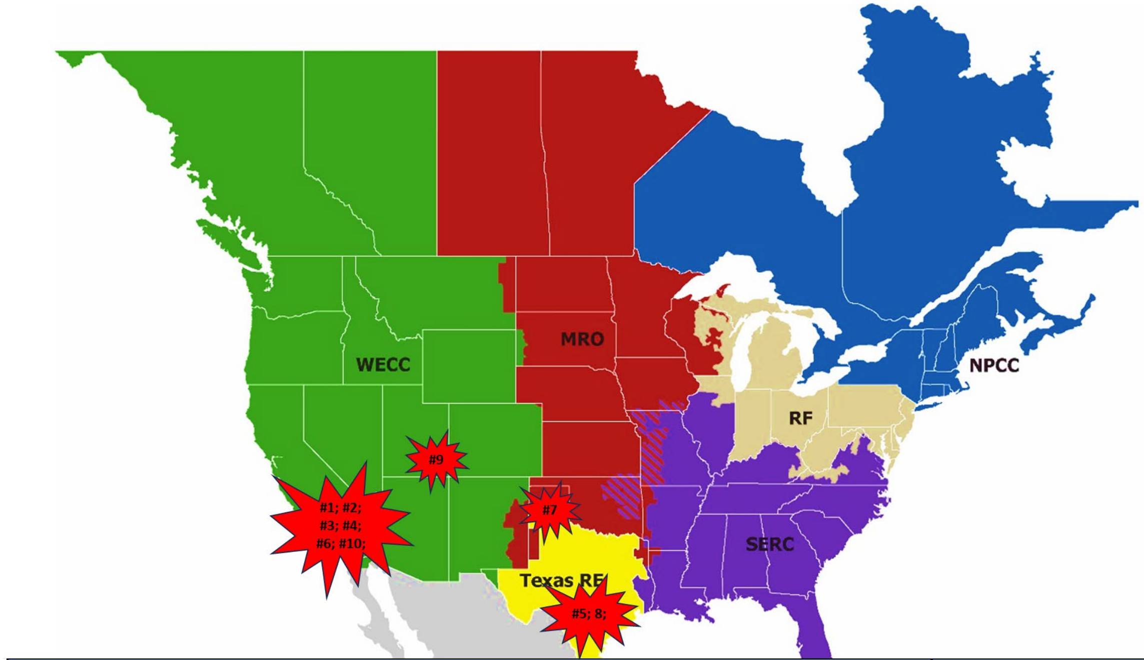
Aung Thant, Senior Engineer
i2X FIRST Hybrid Workshop: Interconnection Standards
October 24, 2024

NERC IBR Strategy

Risk Analysis	Interconnection Process Improvements	Best Practices and Education	Regulatory Enhancements
Event Analysis	Improvements to GIAs and GIP	Reliability Guidelines	NERC Standards Projects
Disturbance Reports	Enhanced Interconnection Requirements	Webinars and Workshops	BES Definition Review
Alerts	Modeling and Study Improvements	Outreach and Engagement	Inverter-Specific Requirements and Standards
Lessons Learned	IEEE 2800-2022	Emerging Reliability Risk Issues	Risk-Based Compliance

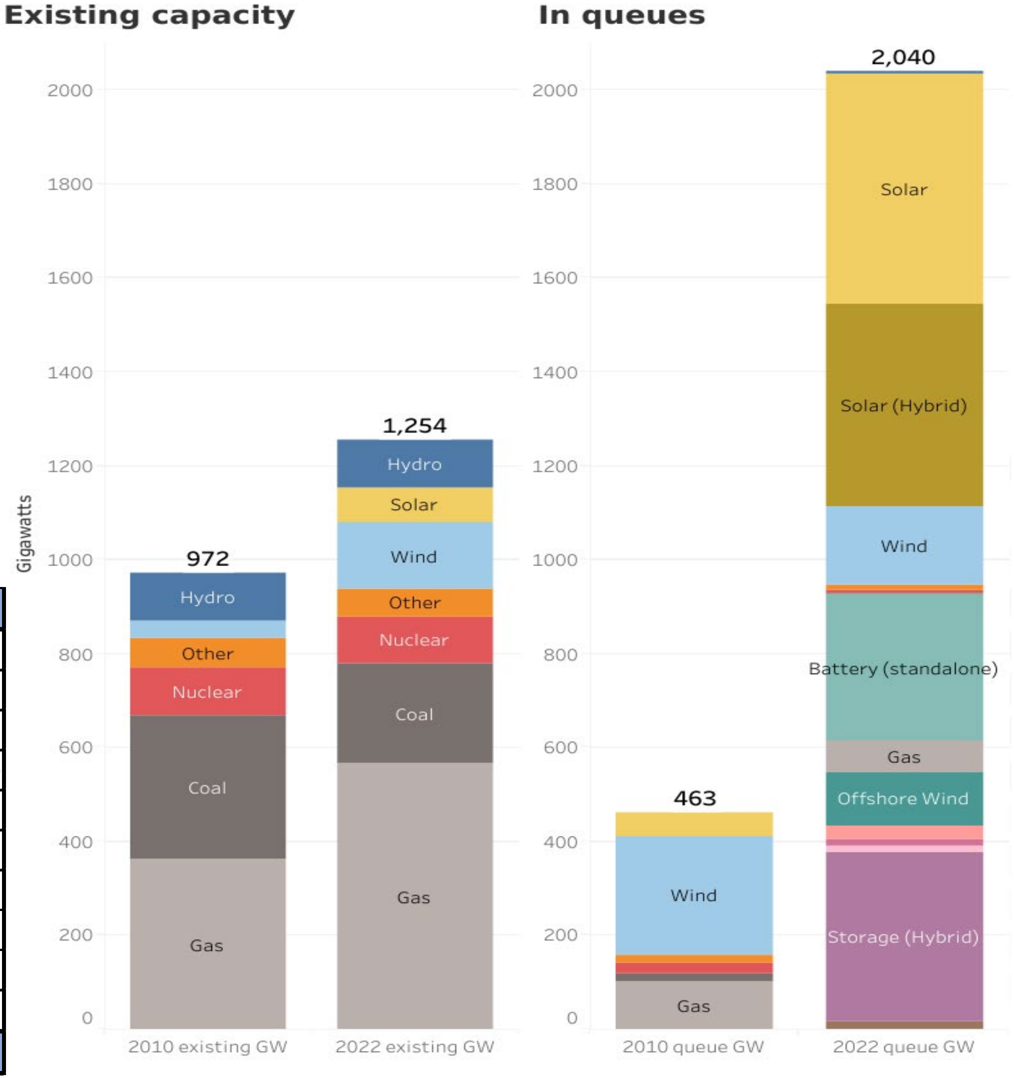
NERC IBR Strategy

Motivation



Disturbance		IBR Reduced (MW)	Year
#1	Blue Cut Fire	1,753	2016
#2	Canyon 2 Fire	1,619	2017
#3	Angeles Forest & Palmdale Roost	1,588	2018
#4	San Fernando	1,205	2020
#5	Odessa, 2021	1,112	2021
#6	Victorville; Tumbleweed; Windhub; Lytle Creek Fire	2,464	2021
#7	Panhandle Wind	1,222	2022
#8	Odessa, 2022	1,711	2022
#9	Southwest Utah	921	2022
#10	California Battery Energo Storage	906	2023
Total Reduced Output (MW)		14,501	

Source: LBL.GOV
Generation, Storage, and Hybrid Capacity in Interconnection Queues



490GW

430GW

312GW

357GW

Major Event Observations Provide a Snapshot

- 15,000 MW of unexpected reduction in IBR resources since 2016
  - Approximately 10,000 MW of unexpected reduction since 2020
  - Analysis revealed systemic model inaccuracies
    - No models of affected facilities accurately represented the performance during the event
    - System models did not "predict" major events
- Poor model representation is a symptom of poor design evaluation
- Obtaining IBR plant data is often difficult and time consuming
  - The lack of readily available IBR facility data, even fundamental information, is also a symptom of poor design evaluation practices

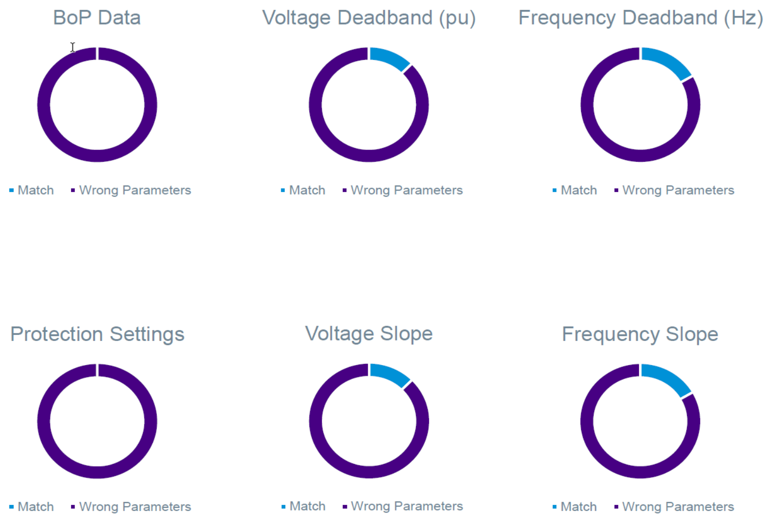
Do the models recreate the cause of reduction?

Table 3.4: Review of Solar PV Facilities

Facility ID	Reduction [MW]	Cause of Reduction	Positive Sequence Model Capable?	EMT Model Capable?
Plant B	133	Inverter phase jump (passive anti-islanding) tripping.	Unknown*	Unknown
Plant C	56	Inverter phase jump (passive anti-islanding) tripping.	Unknown	Unknown
Plant E	159	Inverter ac overvoltage tripping.	Unknown*	Unknown
Plant U	136	Inverter ac overvoltage tripping; feeder underfrequency tripping.	Unknown	Unknown
Plant F	46	Unknown.	Unknown	Unknown
Plant I	196	Inverter phase jump (passive anti-islanding) tripping.	Unknown	Unknown
Plant J	106	Inverter dc voltage imbalance tripping.	Unknown	Unknown
Plants K + L	130	Momentary cessation/inverter power supply failure.	Unknown	Unknown
Plant M	146	Inverter dc voltage imbalance tripping; incorrect inverter ride through configuration.	Unknown	Unknown
Plant N	35	Unknown.	Unknown	Unknown
Plant O	15	Unknown.	Unknown	Unknown
Plant P	10	Inverter ac overcurrent tripping.	Unknown*	Unknown
Plant Q	12	Inverter ac overcurrent tripping.	Unknown	Unknown
Plant R	261	Inverter ac overcurrent tripping.	Unknown*	Unknown
Plant S	94	Inverter dc voltage imbalance tripping.	Unknown*	Unknown
Plant T	176	Inverter ac overcurrent tripping; feeder underfrequency tripping.	Unknown*	Unknown

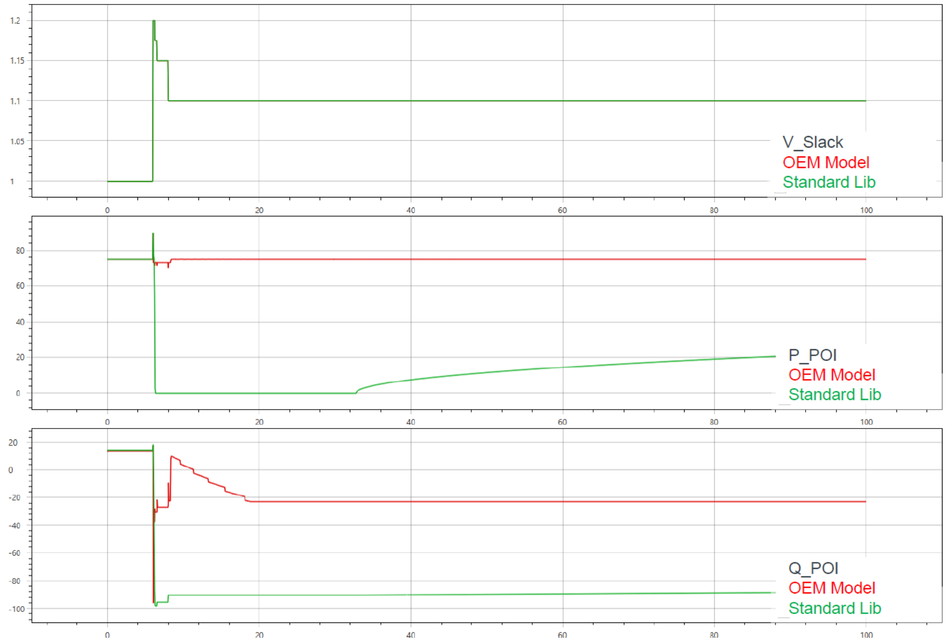
Industry Observations Align

- 15,000 MW of unexpected reduction in IBR resources since 2016
  - Approximately 10,000 MW of unexpected reduction since 2020
  - Analysis of the models of affected facilities revealed systemic model inaccuracies
- Real world case study from a Major Manufacturer also showed systemic model inaccuracies



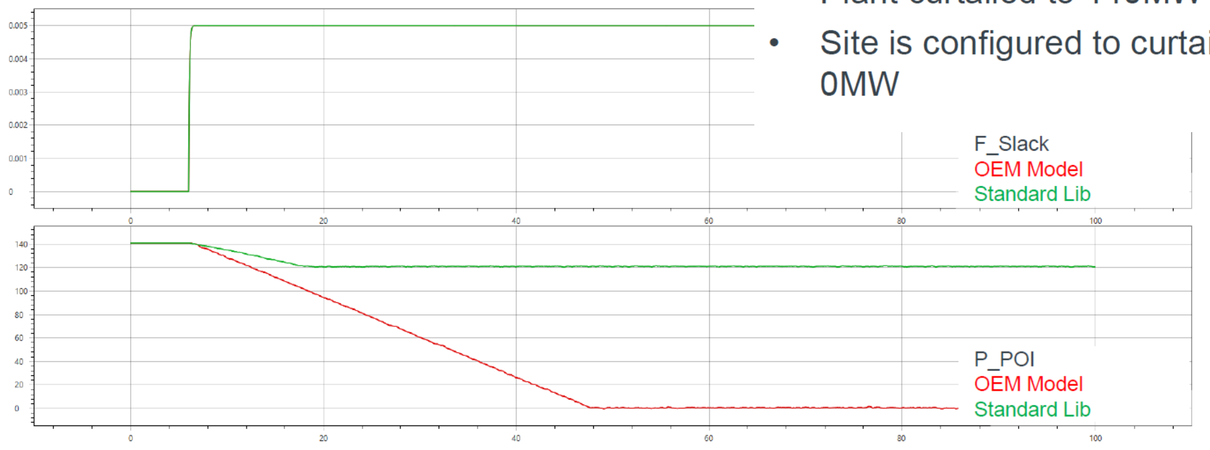
Notes:

- HVRT
- Plant curtailed
- P Response unstable and numerical not working in PSSE
- Q response not matching site response and recovery state



Notes:

- Frequency step-up 0.005pu
- Plant curtailed to 140MW
- Site is configured to curtail to 0MW

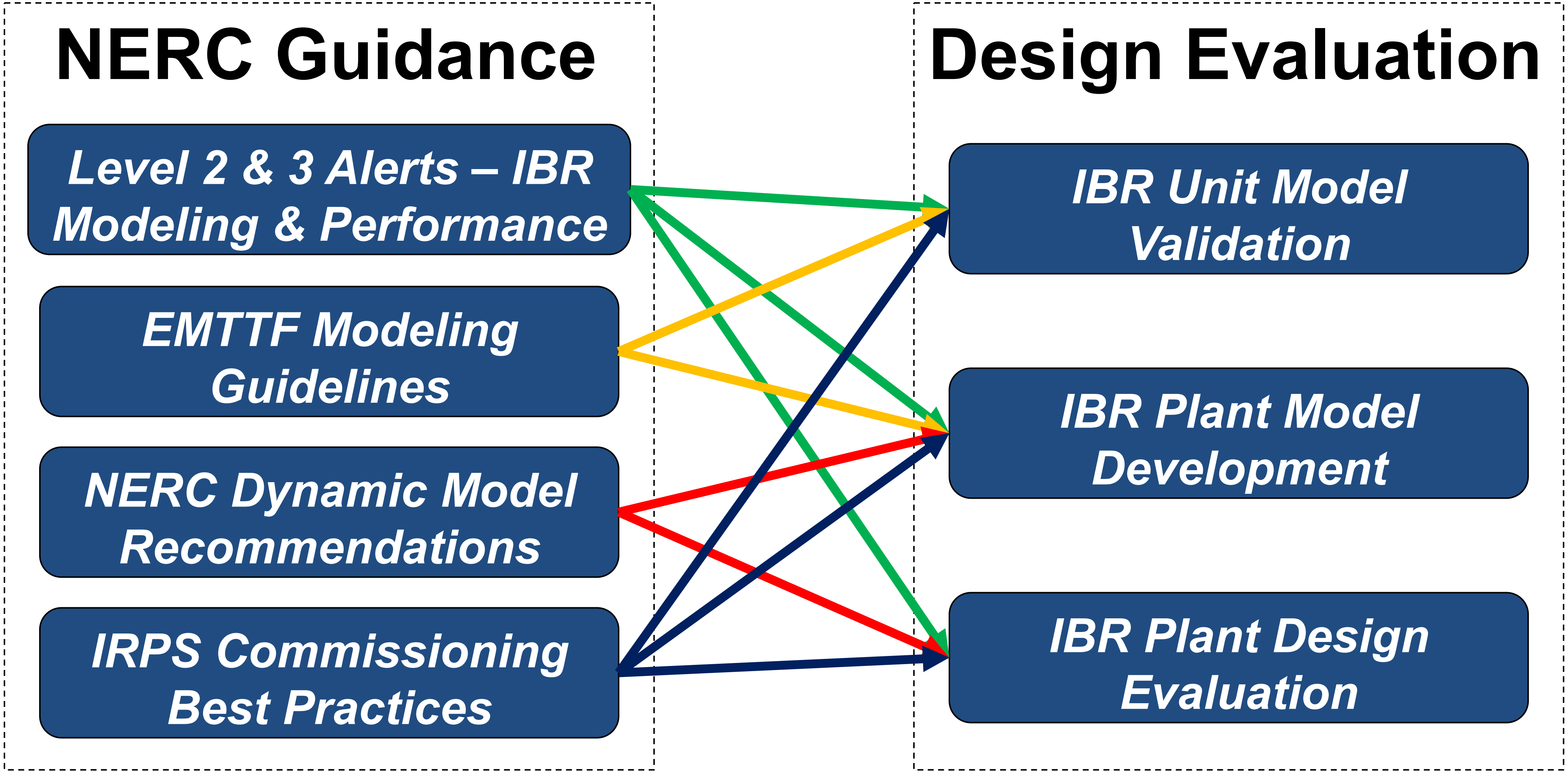


Source: Thomas Grau – Director, Vestas – February 2024 IRPS Meeting

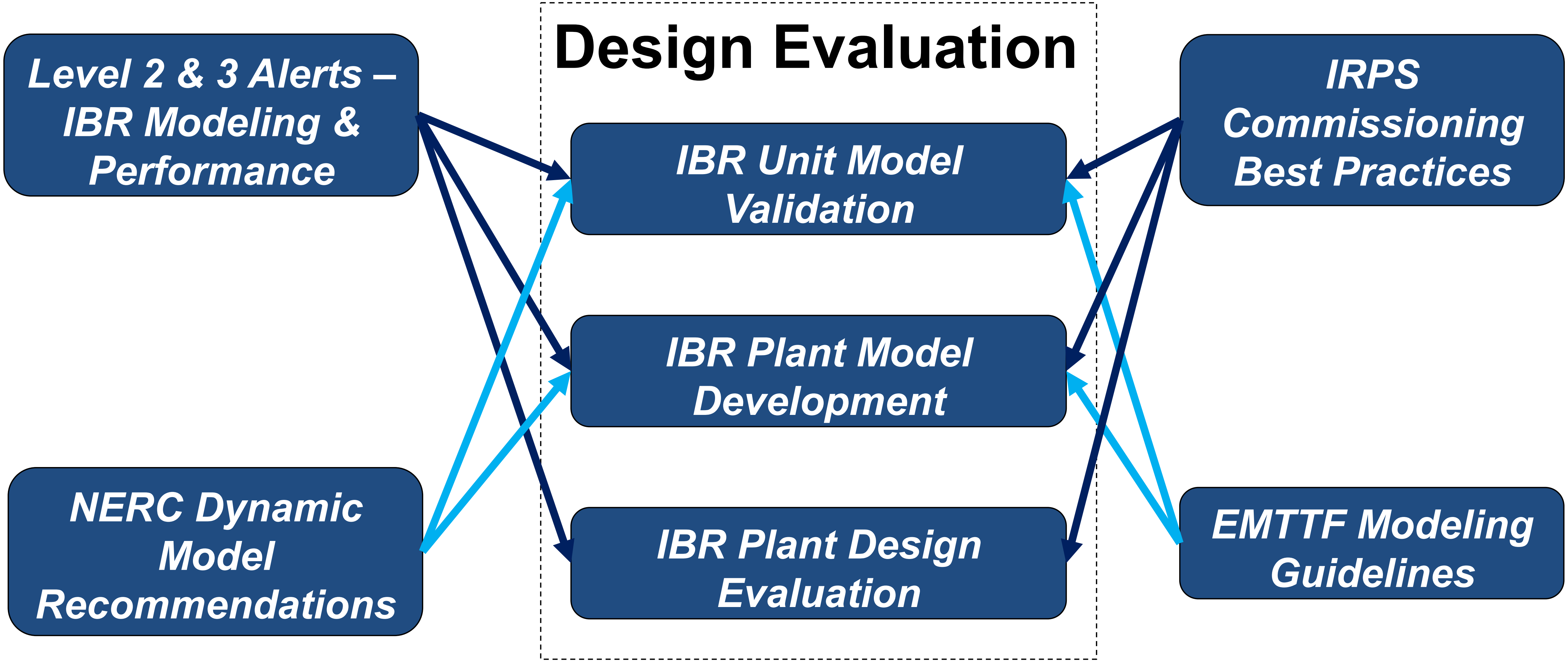
NERC Alert Results Align

- Both IBR-related alerts required data submission deadline extensions due to a lack of submittals
  - Submittals were lower than 10% for both alerts at the original deadline **(submittals for the modeling alert are still at a historic low with the updated deadline on November 1, 2024)**
  - Requested data aligns with data utilized or determined through design evaluation
    - Protection settings
    - Control modes
    - Plant performance
    - Plant capabilities
- If sufficient design evaluation was performed, the requested data should be readily available

NERC Guidance Aligns With Design Evaluation Pillars



NERC Guidance Supports SG3 Design Evaluation Pillars



Key Next Steps

- Report on Level 2 NERC Alert on IBR Modeling
  - Data submission deadline is November 1, 2024 after a ~2-month extension
  - Presents dynamic modeling recommendations
  - Data requests for NERC to analyze and present the extent of condition of modeling
- Level 3 NERC Alert on IBR Performance and Modeling
  - Target publish date is end of 2024
  - Will present recommendations on IBR performance and modeling
  - Will contain Essential Actions intended to help mitigate known deficiencies
- Part II of the EMTTF EMT Modeling Reliability Guideline
- NERC next steps align with the need for detailed design evaluation and the improvement of best practices

Questions and Answers

Feel free to reach out to us if interested in participating in the NERC IRPS or EMTTF!

alex.shattuck@nerc.net

Review of Design Evaluation Requirements and Recommended Best Practices in IEEE 2800-2022 and IEEE P2800.2

Alex Shattuck, Andrew Isaacs
IEEE P2800.2 Subgroup 3 (Design Evaluation) Co-Leaders
Jens Boemer, IEEE P2800.2 WG Vice-Chair

i2X FIRST Hybrid Workshop: Interconnection Standards Workshop with the Focus on Conformity Assessment
ESIG 2024 Fall Technical Workshop
Thursday, October 24, 2024
Providence, RI

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Use of an IEEE standard is wholly voluntary

Overview of conformity assessment steps in IEEE P2800.2, *Recommended Practice for Test and Verification Procedures for IBRs Interconnecting with Bulk Power Systems*

Type Tests

Lab or field tests of individual IBR unit for model validation

IBR Unit Model Validation

Based on type test data

IBR Plant Model Development

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

IBR Plant Design Evaluation

Simulations to assess plant conformity to IEEE 2800

Design Evaluation

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

Plant construction complete

This is a general diagram of the process. Details are under development in IEEE P2800.2. Some variations permitted.

More information at https://sagroups.ieee.org/2800-2/ and expression of interest to participate here.

Source: Andy Hoke (NREL), Jens Boemer (EPRI)

Recap: Industry Terms for Safety, Quality, and Efficiency

Compatibility

- Design equipment to support conformity or compliance of a complex system (e.g., IBR plant)
  - ➢ **Equipment level**

Conformity[1]

- Adherence to certain voluntary industry standards or procedures (e.g., IEEE 2800.2)
  - ➢ **Plant level**

Compliance

- Meeting mandatory legal and regulatory obligations (e.g., NERC Reliability Standards)

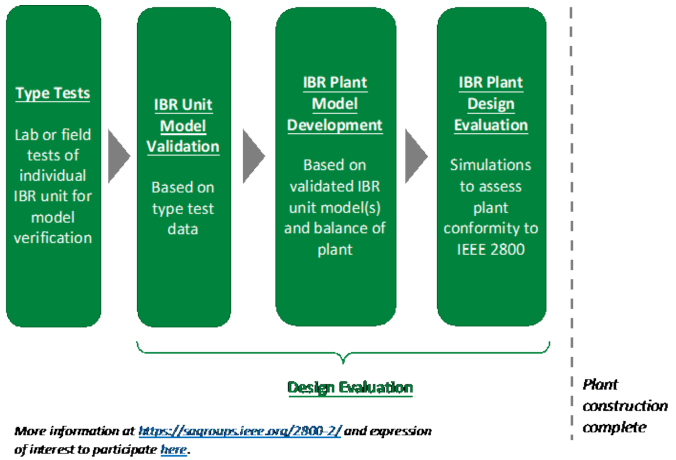
[1] The term "conformance" is depreciated and should not be used any longer.

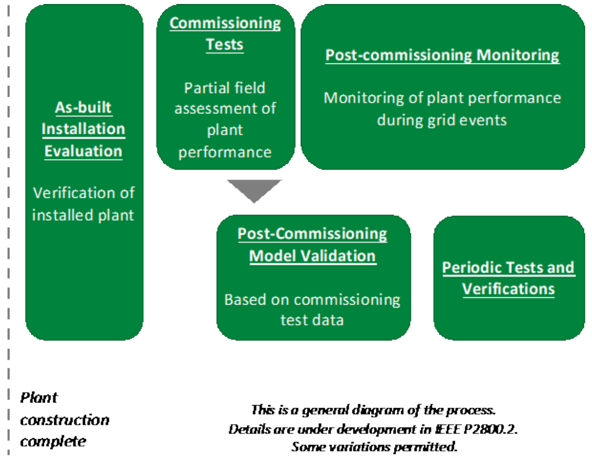
References:

- https://www.inboundlogistics.com/articles/conformance-vs-compliance
- https://www.linkedin.com/pulse/conformity-vs-conformance-compliance-carlos-cisneros-cqa/
- https://www.standardsuniversity.org/e-magazine/september-2017/introduction-conformity-assessment-compliance/
- https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8082574

Source: EPRI, 2024

Overview IEEE P2800.2 D2.0

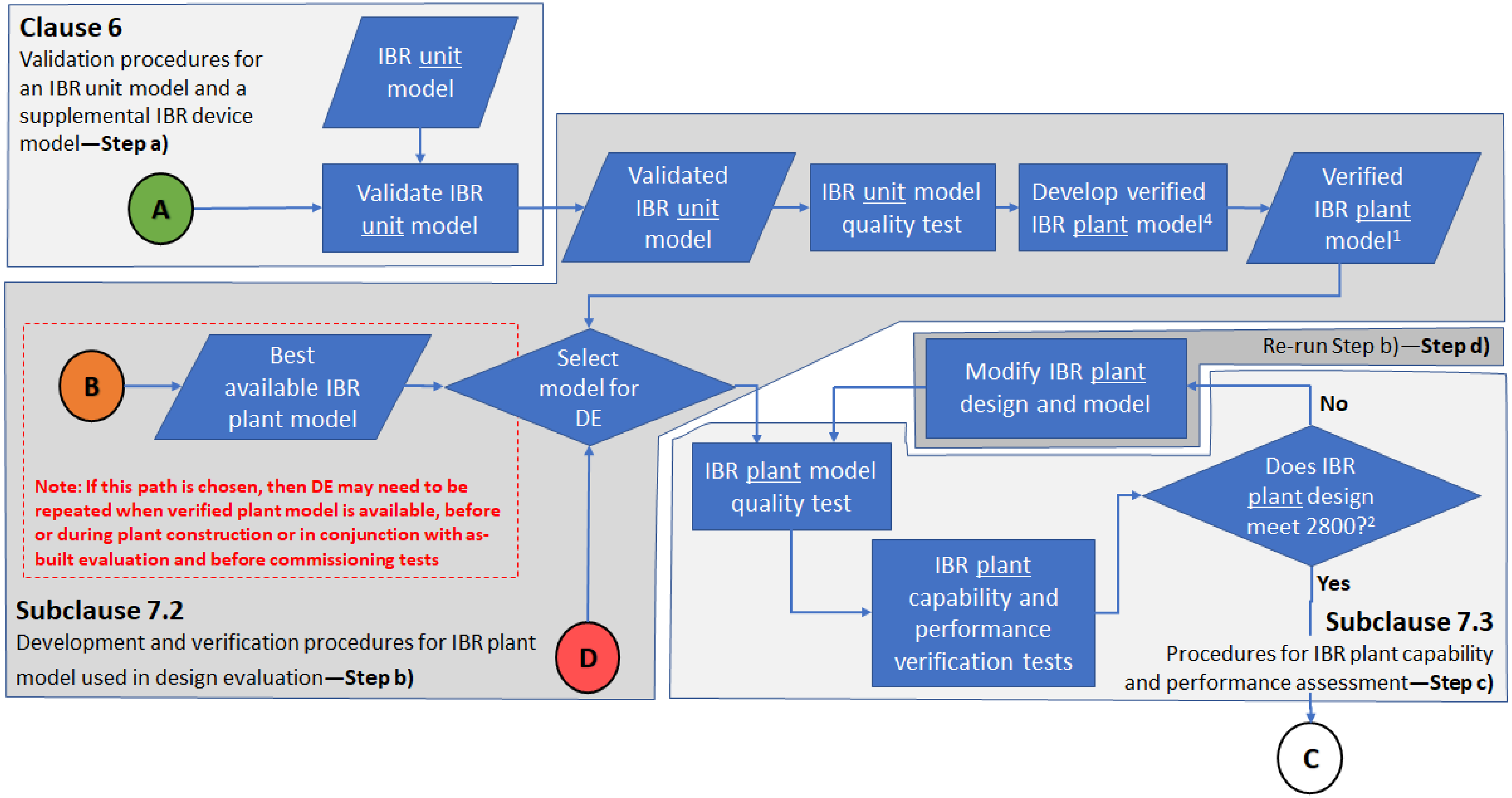




Source: EPRI, 2024

➢ **IBR Design Evaluation Should Use a Verified Plant Model with Validated Equipment Models**

Overview Clause 6 and Clause 7



➢ IBR Design Evaluation Should Use a Verified Plant Model with Validated Equipment Models

7.1.3 Scope and procedure types

Requirement	RPA where requirement applies	Design evaluation	Procedure type	IBR Plant Representation Detail and Data [a]
Clause 4 General interconnection technical specifications and performance requirements				
4.2 Reference points of applicability (RPA)	POM (default)	R	IBR plant design documentation	Disaggregated single line diagram
4.4 Measurement accuracy	POC and POM	R	OEM documentation	IBR unit(s) and supplemental IBR device(s)
4.5 Operational measurement and communication capability	POM	R	OEM documentation	IBR unit(s) and supplemental IBR device(s)
4.6 Control capability requirements	POM	R	OEM Documentation	IBR unit(s) and supplemental IBR device(s)
4.6.1 Execution of mode or parameter changes	POM	R	OEM Documentation	IBR unit(s) and supplemental IBR device(s)
4.6.2 Ramping for control parameter change	POM	R	OEM Documentation	IBR unit(s) and supplemental IBR device(s)
4.7 Prioritization of IBR responses	POM	R	IBR plant design documentation	IBR unit(s) and supplemental IBR device(s)
4.8 Isolation device	POM	R	IBR plant design documentation	Disaggregated single line diagram
4.9 Inadvertent energization of the TS	POM and POC	R	Protocol Documentation between GO and TO	[TBD]
4.10 Enter service	POM	R	Protocol Documentation between GO and TO	IBR unit(s) and supplemental IBR device(s)
4.11 Interconnection integrity	POM	R	OEM documentation	IBR unit(s) and supplemental IBR device(s)
4.12 Integration with TS grounding	POM	R	IBR plant design documentation	Aggregated single line diagram

[1] Refer to footnote 38 for examples of OEM documentation and to footnote 39 for examples of *IBR plant* design documentation.
[2] In this version of the document, representing the *IBR plant* with a non-aggregated model may be limited to steady-state power flow and short-circuit, and [fundamental-frequency stability dynamic modeling] domains. The development and use of a non-aggregated *IBR plant* model in electromagnetic transient (EMT) modeling domain may be computational burdensome and time-consuming with limited benefits—a good compromise may be to use a partially aggregated EMT model in special cases and where justified. For more information about differentiating between applicability of simulation domains and inverter mathematical models in these domains refer to [B23].

7.1.3 Scope and procedure types

Requirement	RPA where requirement applies	Design evaluation	Procedure type	IBR Plant Representation Detail and Data [a]
Clause 5 Reactive power—voltage control requirements within the continuous operation region				
5.1 Reactive power capability	POM	R	*IBR plant* design documentation, OEM documentation and steady-state power flow or [positive-sequence] modeling	Aggregated model or Disaggregated model subject to [7.2.4.1]
5.2 Voltage and reactive power control modes	POM	R for capability	OEM documentation	IBR unit(s) and supplemental IBR device(s)
		R for performance of 5.2.2	Positive-sequence modeling or EMT modeling	Aggregated model
Clause 6 Active-power—frequency response requirements				
6.1 Primary frequency response (PFR)	POC and POM	R	Positive-sequence and EMT modeling	Aggregated model
6.2 Fast frequency response (FFR)[1]	POC and POM	R	Positive-sequence and EMT modeling	Aggregated model

[1] Refer to footnote 38 for examples of OEM documentation and to footnote 39 for examples of *IBR plant* design documentation.
[2] In this version of the document, representing the *IBR plant* with a non-aggregated model may be limited to steady-state power flow and short-circuit, and [fundamental-frequency stability dynamic modeling] domains. The development and use of a non-aggregated *IBR plant* model in electromagnetic transient (EMT) modeling domain may be computational burdensome and time-consuming with limited benefits—a good compromise may be to use a partially aggregated EMT model in special cases and where justified. For more information about differentiating between applicability of simulation domains and inverter mathematical models in these domains refer to [B23].

7.1.3 Scope and procedure types

Requirement	RPA where requirement applies	Design evaluation	Procedure type	IBR Plant Representation Detail and Data [a]
Clause 7 Response to TS abnormal conditions				
7.2.2 Voltage disturbance ride-through requirements	POC	R	OEM documentation on capability	*IBR unit(s)* and *supplemental IBR device(s)*
			EMT Modeling	
	POM	R	Positive-sequence and EMT modeling	Aggregated model
7.2.3 Transient overvoltage ride-through requirements	POM	R	*IBR plant* design documentation and OEM documentation	As appropriate
7.3.2 Frequency disturbance ride-through requirements	POM	R	Positive-sequence and EMT modeling	[Aggregated model]
7.4 Return to service after IBR plant trip	POM	Refer to line entries for 4.10		
Clause 8 Power quality				
8.1.2 Rapid voltage changes (RVC)	POM	R	[TBD]	[TBD]
8.1.3 Flicker	POM	NR	[TBD]	[TBD]
8.2.1 Harmonic current distortion	POM	R	[TBD]	[TBD]
8.2.2 Harmonic voltage distortion	POM	D	[EMT modeling or Frequency Domain]	[TBD]
8.3.1 Limitation of cumulative instantaneous overvoltage	POM	R	[TBD]	[TBD]
8.3.2 Limitation of overvoltage over one fundamental frequency period	POM	R	[TBD]	[TBD]

[1] Refer to footnote 38 for examples of OEM documentation and to footnote 39 for examples of *IBR plant* design documentation.
[2] In this version of the document, representing the *IBR plant* with a non-aggregated model may be limited to steady-state power flow and short-circuit, and [fundamental-frequency stability dynamic modeling] domains. The development and use of a non-aggregated *IBR plant* model in electromagnetic transient (EMT) modeling domain may be computational burdensome and time-consuming with limited benefits—a good compromise may be to use a partially aggregated EMT model in special cases and where justified. For more information about differentiating between applicability of simulation domains and inverter mathematical models in these domains refer to [B23].

7.1.3 Scope and procedure types

Requirement	RPA where requirement applies	Design evaluation	Procedure type	IBR Plant Representation Detail and Data [a]
Clause 9 Protection				
9.1 Frequency protection	POC and POM	R	Applicable *IBR plant* design documentation on […], Applicable OEM documentation on […], and validated *IBR unit* and *supplemental IBR device* models	*IBR unit(s)* and *supplemental IBR device(s)*, *collector system*, *main IBR transformer*, any other *IBR plant* equipment
9.2 Rate of change of frequency (ROCOF) protection	POC and POM	R		
9.3 Voltage protection	POC and POM	R		
9.4 AC overcurrent protection	POC and POM	R		
9.5 Unintentional islanding protection	POC and POM	D		*IBR unit(s)* and *supplemental IBR device(s)*
9.6 Interconnection system protection	POM	R		*main IBR transformer*, *intertie line*
Clause 10 Modeling Data				
10 Modeling data	POC and POM	R	OEM documentation	*IBR unit(s)* and *supplemental IBR device(s)*, *collector system*, *main IBR transformer*, any other *IBR plant* equipment

[1] Refer to footnote 38 for examples of OEM documentation and to footnote 39 for examples of *IBR plant* design documentation.
[2] In this version of the document, representing the *IBR plant* with a non-aggregated model may be limited to steady-state power flow and short-circuit, and [fundamental-frequency stability dynamic modeling] domains. The development and use of a non-aggregated *IBR plant* model in electromagnetic transient (EMT) modeling domain may be computational burdensome and time-consuming with limited benefits—a good compromise may be to use a partially aggregated EMT model in special cases and where justified. For more information about differentiating between applicability of simulation domains and inverter mathematical models in these domains refer to [B23].

7.2.4 Procedures to develop a verified IBR plant model

Simulation Domain / Model Detail	Non-aggregated model	Aggregated model		Notes[a]
		Partially aggregated model	Fully aggregated model	
steady-state power flow model	Yes[a]	n/a	Yes	In cases where aggregation provides limited benefit (for example battery systems with no substantial collector grid, or for very small plants), aggregated models may be used.
steady-state short-circuit model	Yes	n/a	Yes	
Fundamental-frequency phasor-domain (PDT) model (user-defined model and/or generic model)	[Maybe[a]]	Maybe[a] (maximize non-aggregation based on model limitations)	Yes	A non-aggregated stability model may inform proper coordination between IBR Unit protection, voltage protection, and voltage ride-through capability specified at the point of measure.. In cases where aggregation provides limited benefit (for example battery systems with no substantial collector grid, or for very small plants), aggregated models may be used.
electromagnetic transient (EMT) models	No[a]	Maybe[a]	Yes	Computing a non-aggregated EMT model may be overly burdensome and not add sufficient value in most cases.

[a] Refer to subclause 7.2.4.1 for guidance on potential benefits and costs of aggregated and disaggregated IBR plant models.

[1] Refer to footnote 38 for examples of OEM documentation and to footnote 39 for examples of *IBR plant* design documentation.

[2] In this version of the document, representing the *IBR plant* with a non-aggregated model may be limited to steady-state power flow and short-circuit, and [fundamental-frequency stability dynamic modeling] domains. The development and use of a non-aggregated *IBR plant* model in electromagnetic transient (EMT) modeling domain may be computational burdensome and time-consuming with limited benefits—a good compromise may be to use a partially aggregated EMT model in special cases and where justified. For more information about differentiating between applicability of simulation domains and inverter mathematical models in these domains refer to [B23].

Where is EMT modeling used in IEEE P2800.2?

Design Evaluation
(These clauses are a work in progress)

Type Tests

Lab or field tests of individual IBR unit for model validation

IBR Unit Model Validation

Based on type test data

- Unit-level EMT model should be validated against type tests
- Lists variables to be included in validation (P, Pref, Q, Qref, V1, V2, I1, I2, f)
- Defines hybrid quantitative/qualitative validation process
- Quantitative pass/fail criteria under discussion

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, Pref step, PFR, FFR, phase jump, SCR change
- Contents under debate

As-built Installation Evaluation

Verification of installed plant

Commissioning Tests

Partial field assessment of plant performance

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**

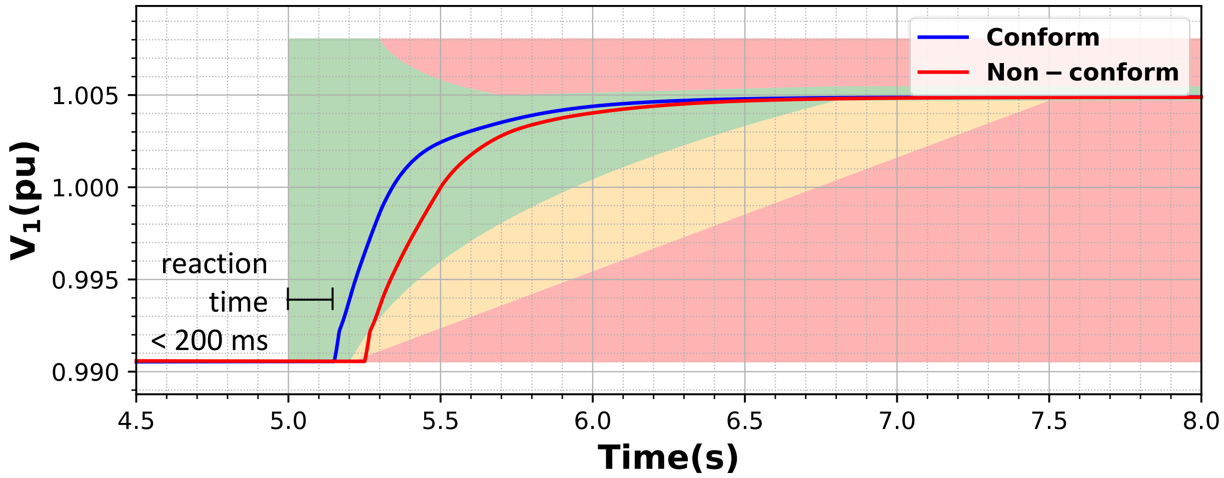
Post-commissioning Monitoring

Monitoring of plant performance during grid events

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

Periodic Tests and Verifications

Simulation-based IEEE 2800 Conformity Assessment—Voltage Control



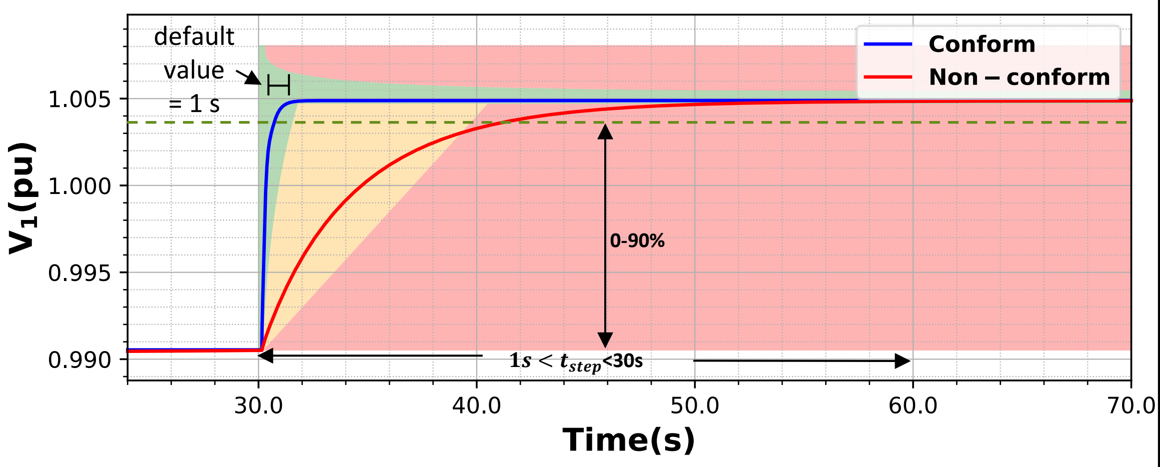
- IEEE 2800 requires the **reaction time to be less than 200 ms**, with a **maximum response time between 1 s and 30 s**, and a **damping ratio of 0.3 or higher** for the response to a voltage reference step (Table 5 —Performance target range).
- “Stable and damped response shall take precedence over response time” (Clause 5.2.2 Voltage control).
- **Factors contributing to slow reaction time:**
  - Cycle time of the PPC;
  - Communication latency of PPC command to the IBR unit; and
  - IBR unit's control delay.

IEEE 2800 – 5.2.2 Voltage control

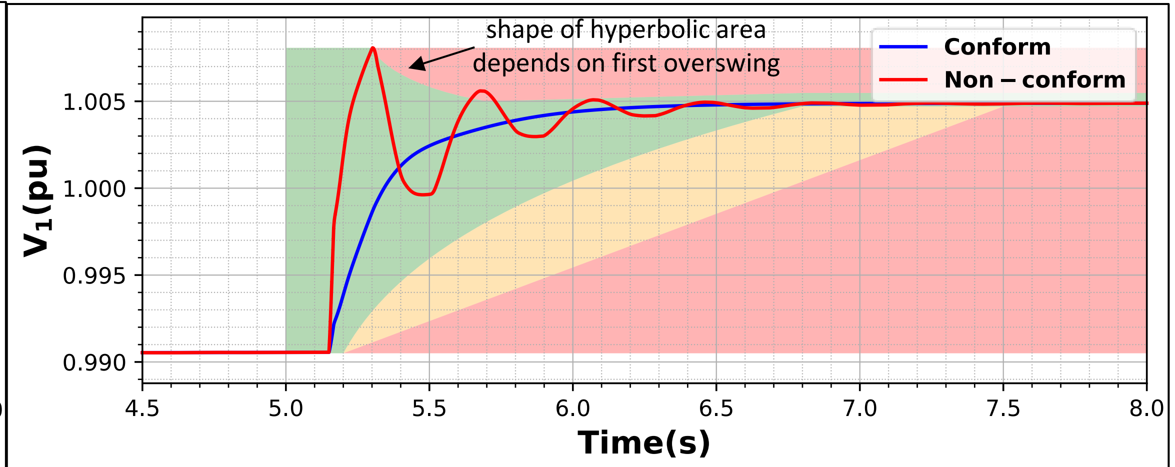
- When in this mode, the IBR plant shall operate in closed-loop automatic voltage control mode to **regulate the steady-state voltage** at the RPA to the reference value, as adjusted by the droop function, **to within 1% of the RPA voltage set point** unless to do so requires reactive power exceeding the reactive power capability of the IBR plant.
  - The dynamic reactive power response of the IBR plant to a step change in the RPA voltage within the continuous operation region and within **IBR plant’s reactive power capability shall be as specified in Table 5**.
  - The response shall be stable and any oscillations shall be positively damped with a **damping ratio of 0.3 or higher**. **Stable and damped response shall take precedence over response time**.

Source: EPRI, 2024

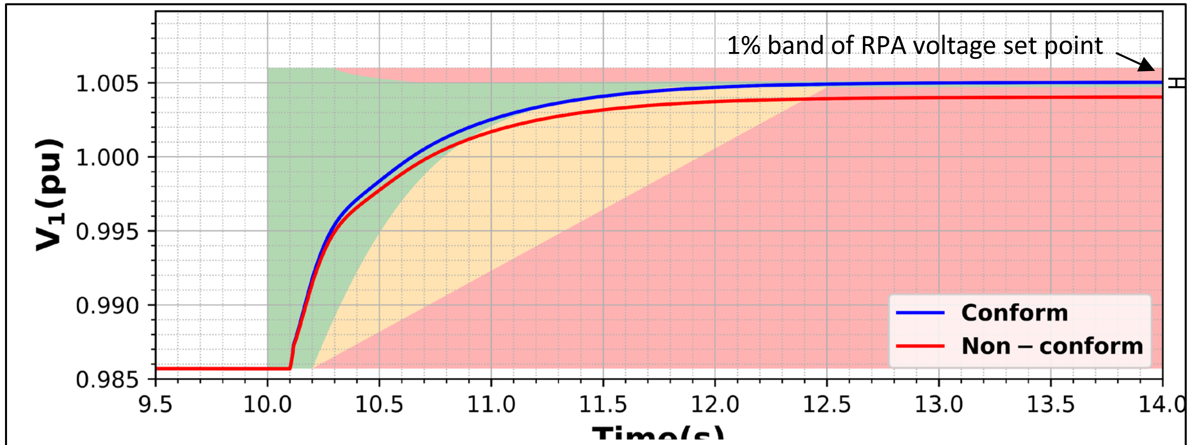
Simulation-based IEEE 2800 Conformity Assessment—Voltage Control



maximum response time between 1 s and 30 s



damping ratio of 0.3 or higher



regulate the steady-state voltage at the RPA to the reference value, as adjusted by the droop function, **to within 1% of the RPA voltage set point**

Source: EPRI, 2024

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IEEE 2800-2022
Available from IEEE at https://standards.ieee.org/project/2800.html
and via IEEExplore: https://ieeexplore.ieee.org/document/9762253/

Thank You

6. Validation procedures for *IBR unit* models and *supplemental IBR device* models

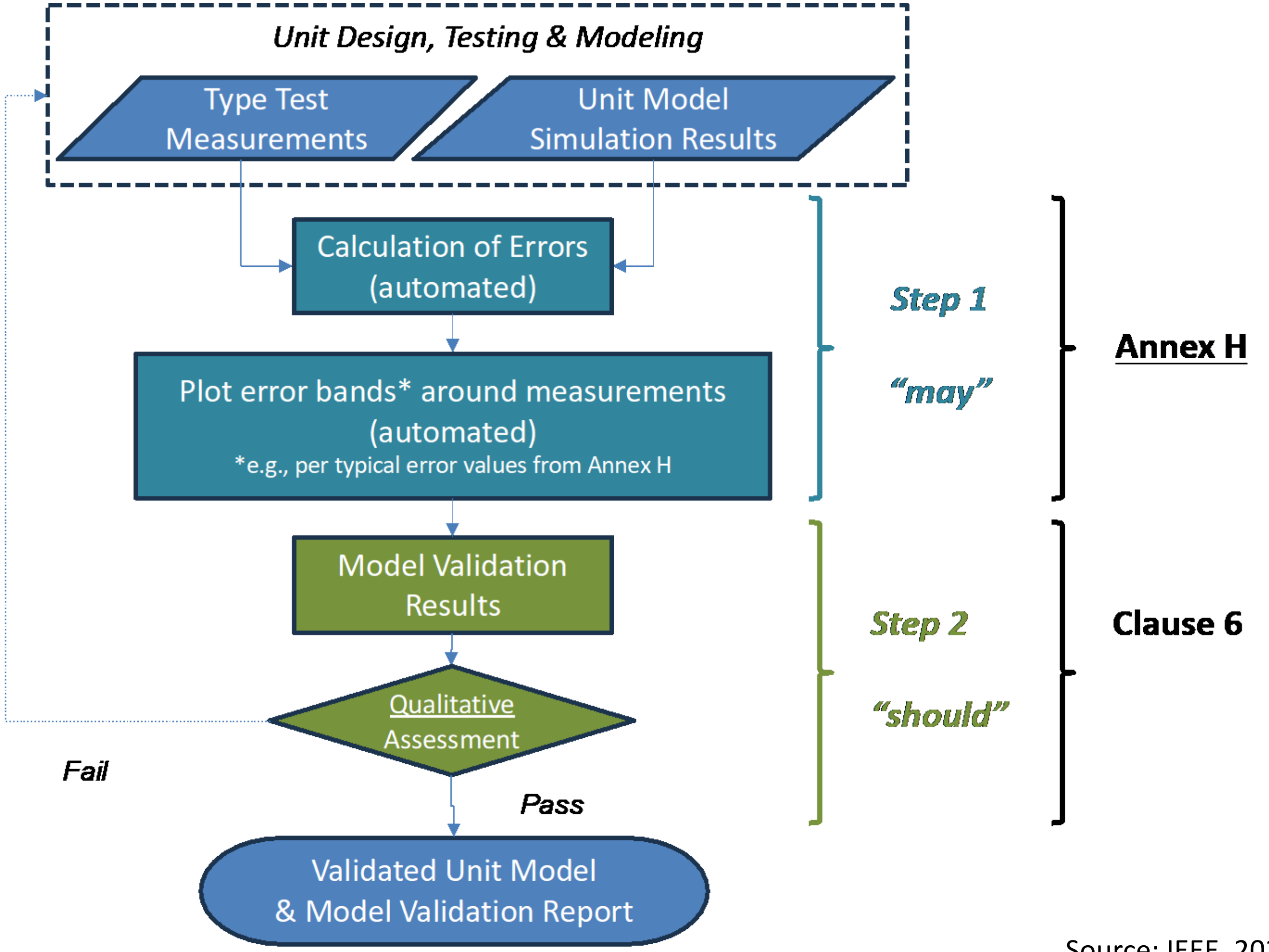
6.3 Procedures

The recommended model validation procedure is based on engineering review where the differences between the measurements from the type test and the simulated response of the model are assessed, referred to as *qualitative* model validation. The informative Annex [H] provides a framework for a *quantitative* model validation procedure and criteria that may be used as a screening tool or first step in a model validation process and should be followed by a thorough engineering review, i.e., qualitative model validation.

6.3.2 Engineer review procedure

[…]

Where quantitative model validation procedures per Annex [H] are used, applicable error bands may be plotted around the measured response to aid engineer review of the validity of the simulation model.



Source: IEEE, 2024

i2X FIRST Hybrid Workshop
The Trouble with Model Validation!

October 24, 2024

Andrew Isaacs

ELECTRANIX
SPECIALISTS IN POWER SYSTEM STUDIES

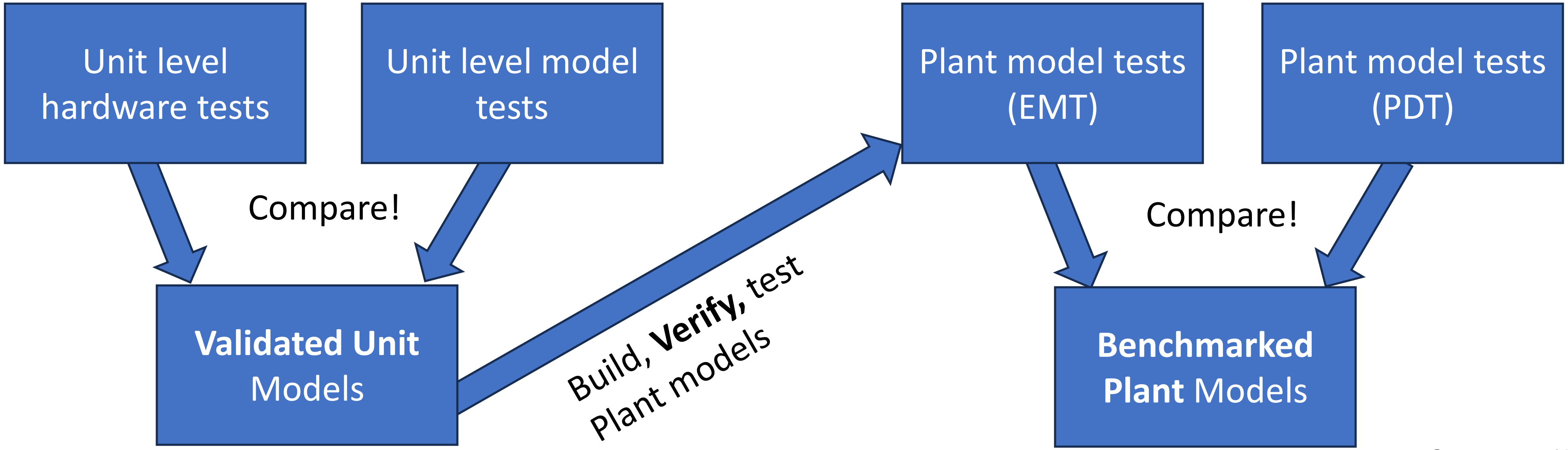
Disclaimer!!

- I am helping with the standard drafting and trying to build a consensus based standard
- I also have experiences and opinions!!
- **Where the following slides are good, then I am representing the SG3 leadership team. Where the following slides are wrong or bad, I am representing myself!! ☺**

Acknowledgement: Much hard work and discussion from members of sub-group 3. In particular, manufacturer teams helped us a lot!

Definitions:

- **model validation:** The process of comparing measurements with simulation results for the assessment of whether a model response sufficiently mimics the measured response.
- **model benchmarking:** the process of comparing simulation results from two models for the assessment whether a response from one model sufficiently mimics the response from the other model for the same disturbance and external power system conditions
- **model verification:** The process of checking documents and files or equipment and respective settings (e.g., controls & protection), and comparing them to model parameters or model structure.



Source: IEEE ©2024

Why do we care?

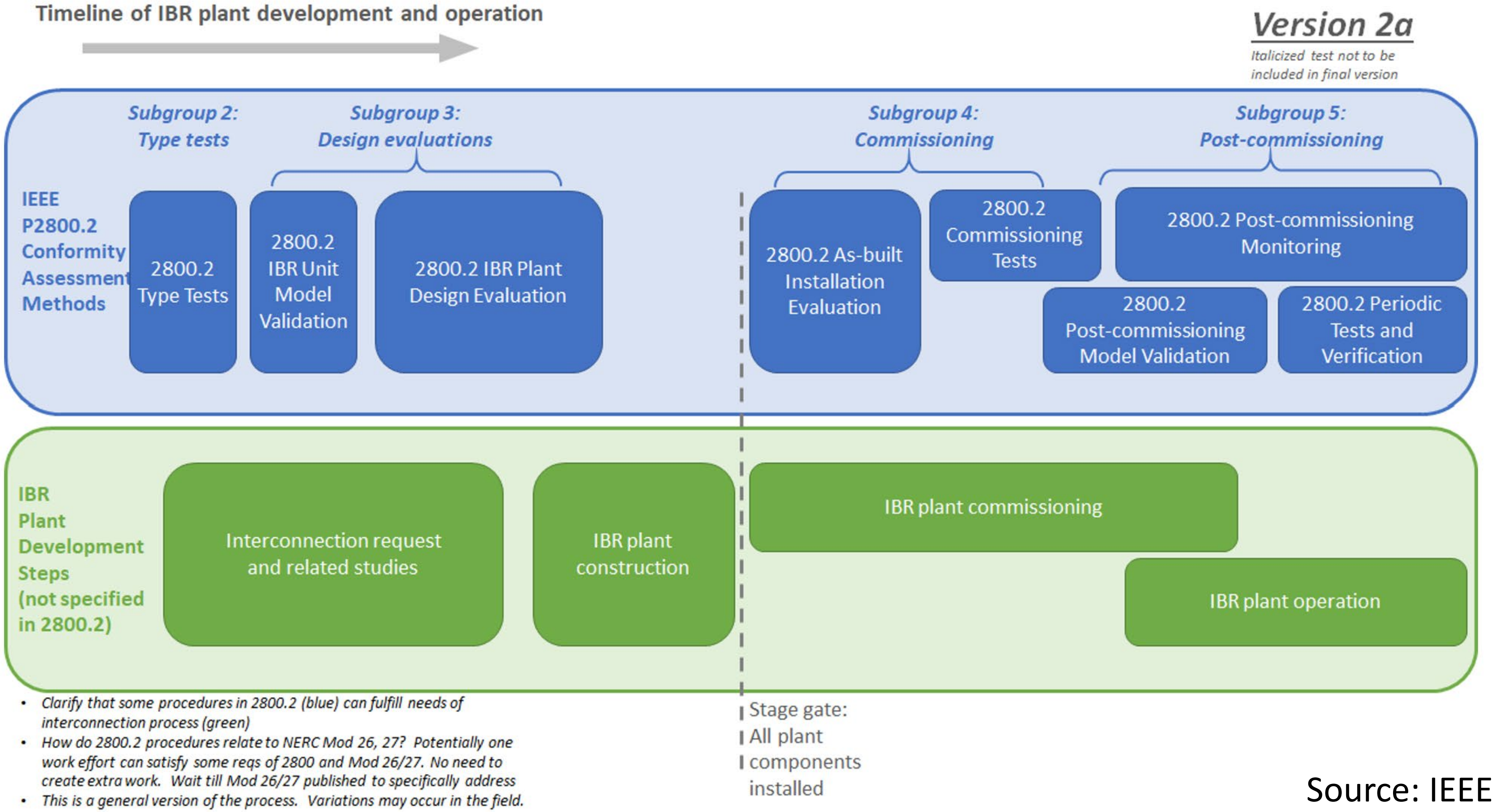
- Reliability!
  - Studies accurately predict system performance
    - (verified) Plant models accurately represent what is constructed and how it is configured
      - (validated) Unit equipment models accurately represent the controls and protection functions…

IEEE 2800-2022 requires validation!!

Per IEEE 2800 Clause 12 (Test and verification requirements), *the original equipment manufacturer (OEM) shall perform IBR unit level testing and testing of the supplemental IBR device equipment*. The details of these equipment-level type tests to be performed are listed in clause 5.

Source: IEEE ©2024

Where does validation sit in the process?



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What validation test sets are being proposed?

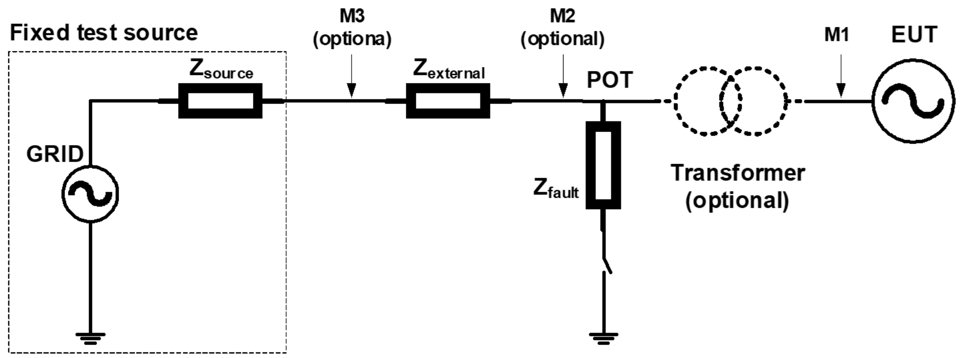


Figure 16—Test circuit for method 1

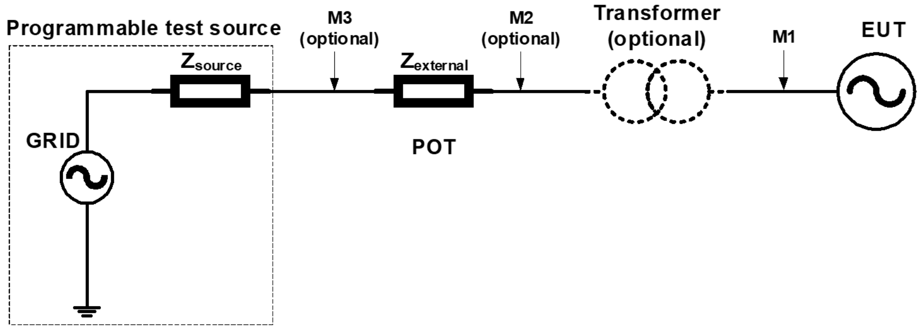


Figure 17—Test circuit for method 2

- Method 3: Control Hardware In the Loop (CHIL)
  - Connect control hardware to real-time EMT simulator test benches

Source: IEEE ©2024

What will be validated?
(models compared against type tests)

1. Voltage and reactive power control modes – Clause 5.7.4
2. Primary Frequency response – Clause 5.9.4
3. Fast Frequency response – Clause 5.9.4
4. Voltage disturbance ride through – Clause 5.11.4 to 5.11.8
5. Frequency disturbance ride through – Clause 5.13
6. Limitation of overvoltage over one fundamental frequency period – Clause 5.14.4
7. PPC Testing – Clause 5.17
8. Frequency Scanning
9. Protections – Clause 5.15
    a. Frequency protection
    b. ROCOF protection
    c. Voltage protection
    d. AC overcurrent protection
    e. Unintentional islanding protection

Source: IEEE ©2024

Unit Validation challenge!

Note that hardware and model may both “ride-through” in Validation testing, but accuracy and correctness is needed in each aspect to ensure confidence in ride-through behaviour in plant and system contexts.

What gets in the way of close comparisons?

- Insufficient care in modeling practice.
  - Developing good EMT modeling practice takes time and a strong investment in modeling by OEMs.
  - “real code” techniques and appropriate processes are needed

- Uncertainties in test system conditions (for example)
  - Nonlinearities (eg. Transformers)
  - Point-on-wave impacts
  - Measurement error
  - Simulation artifacts

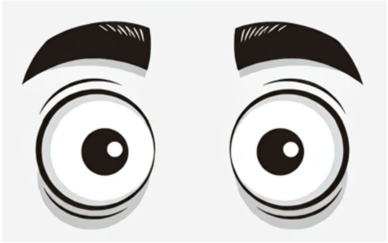
Quantitative and Qualitative

- Huge point of discussion in 2800.2… possibly the most contentious part of the entire standard. A few discussions were *lengthy.*
  - Where should the quantitative bands be drawn?
  - “Should we even use quantitative metrics at all?”

Which is best? ☺

Quantitative

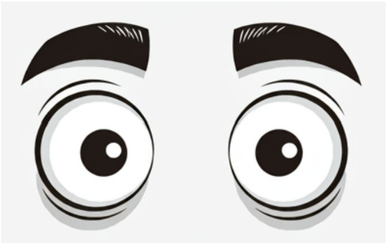
Qualitative



Quantitative: Pros and Cons

- Pros:
  - Can standardize model quality to a degree. Repeatable, transparent outcomes are desirable.
  - Can automate the evaluation
  - Can theoretically be performed with little experience
- Cons:
  - **False "pass":** If bands are too wide, serious errors in modeling can be sent through as validated models.
  - **False "fail":** If bands are too narrow, legitimate differences may be flagged as errors and delay and headache is introduced.
  - Can theoretically be performed with little experience

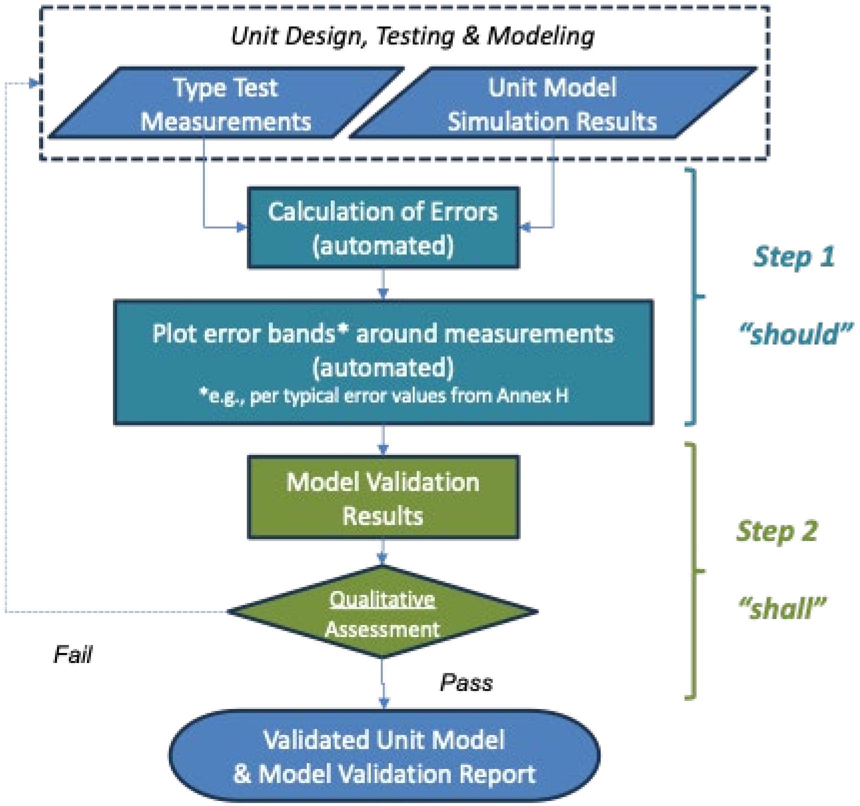
Qualitative: Pros and Cons



- Pros:
  - Experienced engineers can sufficiently evaluate whether the model is suited for purpose, and ask questions appropriately
  - When done well, effectively identifies important errors in models
- Cons:
  - There may not be enough “experienced engineers” to do this correctly at scale.
  - You can’t get help from automation tools. Large amounts of data can make any engineer’s eyes glaze over, regardless of experience.
  - Without standardization, opinions will differ on what is “acceptable”

Recommended approach:

- **Note: Whether to recommend *Quantitative* analysis or just provide guidance is not well agreed in the current draft.**
- OEM (could be other parties) writes a “validation report” that includes:
  - Use quantitative comparison as guidance to identify regions that lie outside appropriate error bands (example bands provided in informative annex)
  - Engineering review and discussion of comparisons which lie outside error bands
  - Qualitative comparison using expert engineers
- Recipient or users of unit level models should review the validation report and accept, reject, or ask questions as appropriate.
- If you have an opinion, submit comment on the draft!



Source: IEEE ©2024

Example quantitative bands in current draft:

Source: IEEE ©2024

[Table X] – Permissible maximum errors when EUT is type tested by P-HIL testing method

Case description	Time window	Positive- and negative-sequence values							
		Active power		Reactive power		Active current		Reactive current	
		Transient	Quasi steady state	Transient	Quasi steady state	Transient	Quasi steady state	Transient	Quasi steady state
Case dependent information such as pre-fault voltage, test equipment settings such as short circuit impedance if used, etc.	Pre-fault	n/a	0.05	n/a	0.05	n/a	0.05	n/a	0.05
	Fault	0.2	0.15	0.2	0.15	0.2	0.15	0.2	0.15
	Post-fault	0.2	0.15	0.2	0.15	0.2	0.15	0.2	0.15

[Table Y] – Permissible maximum error when EUT is type tested in field

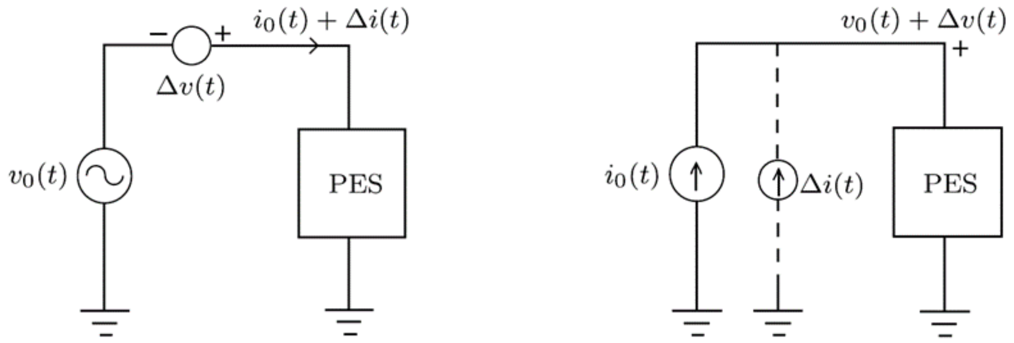
Case description	Time window	Positive- and negative-sequence values							
		Active power		Reactive power		Active current		Reactive current	
		Transient	Quasi steady state	Transient	Quasi steady state	Transient	Quasi steady state	Transient	Quasi steady state
Case dependent information such as pre-fault voltage, estimated grid Impedance, grid operating condition, etc.	Pre-fault	n/a	0.05	n/a	0.05	n/a	0.05	n/a	0.05
	Fault	0.2	0.15	0.2	0.15	0.2	0.15	0.2	0.15
	Post-fault	0.2	0.15	0.2	0.15	0.2	0.15	0.2	0.15

[Table Z] – Permissible maximum error when EUT is type tested by C-HIL testing method

Case description	Time window	Positive- and negative-sequence values							
		Active power		Reactive power		Active current		Reactive current	
		Transient	Quasi steady state	Transient	Quasi steady state	Transient	Quasi steady state	Transient	Quasi steady state
Case dependent information such as pre-fault voltage, test equipment settings such as short circuit impedance if used, etc.	Pre-fault	n/a	0.05	n/a	0.05	n/a	0.05	n/a	0.05
	Fault	0.1	0.05	0.1	0.05	0.1	0.05	0.1	0.05
	Post-fault	0.1	0.05	0.1	0.05	0.1	0.05	0.1	0.05

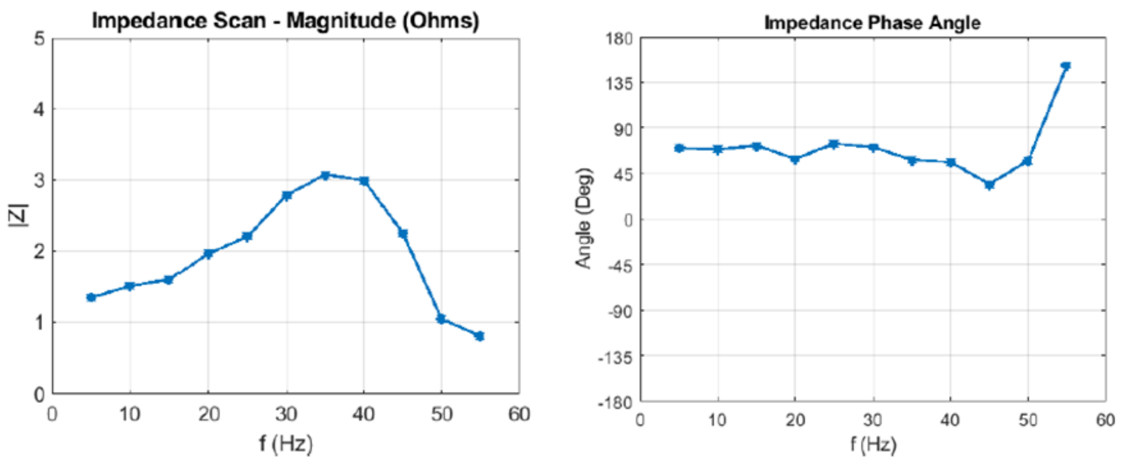
Frequency Scans!!

- Variation of converter impedance characteristics with frequency is widely used in real studies, and happens to provide a good representation of the small signal control characteristics!
- We can use this for model validation!

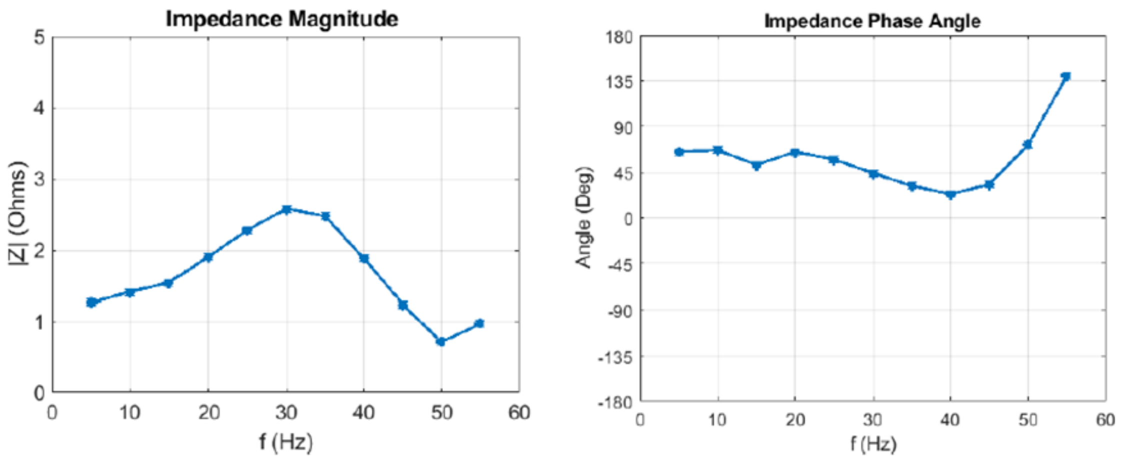


Source: IEEE ©2024

PSCAD Results



HiL-RTS Results



Questions?

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i2X FIRST Hybrid Workshop

IEEE P2800.2 Design Evaluation Tests – A Deep Dive

October 23, 2024

Andrew Isaacs

ELECTRANIX

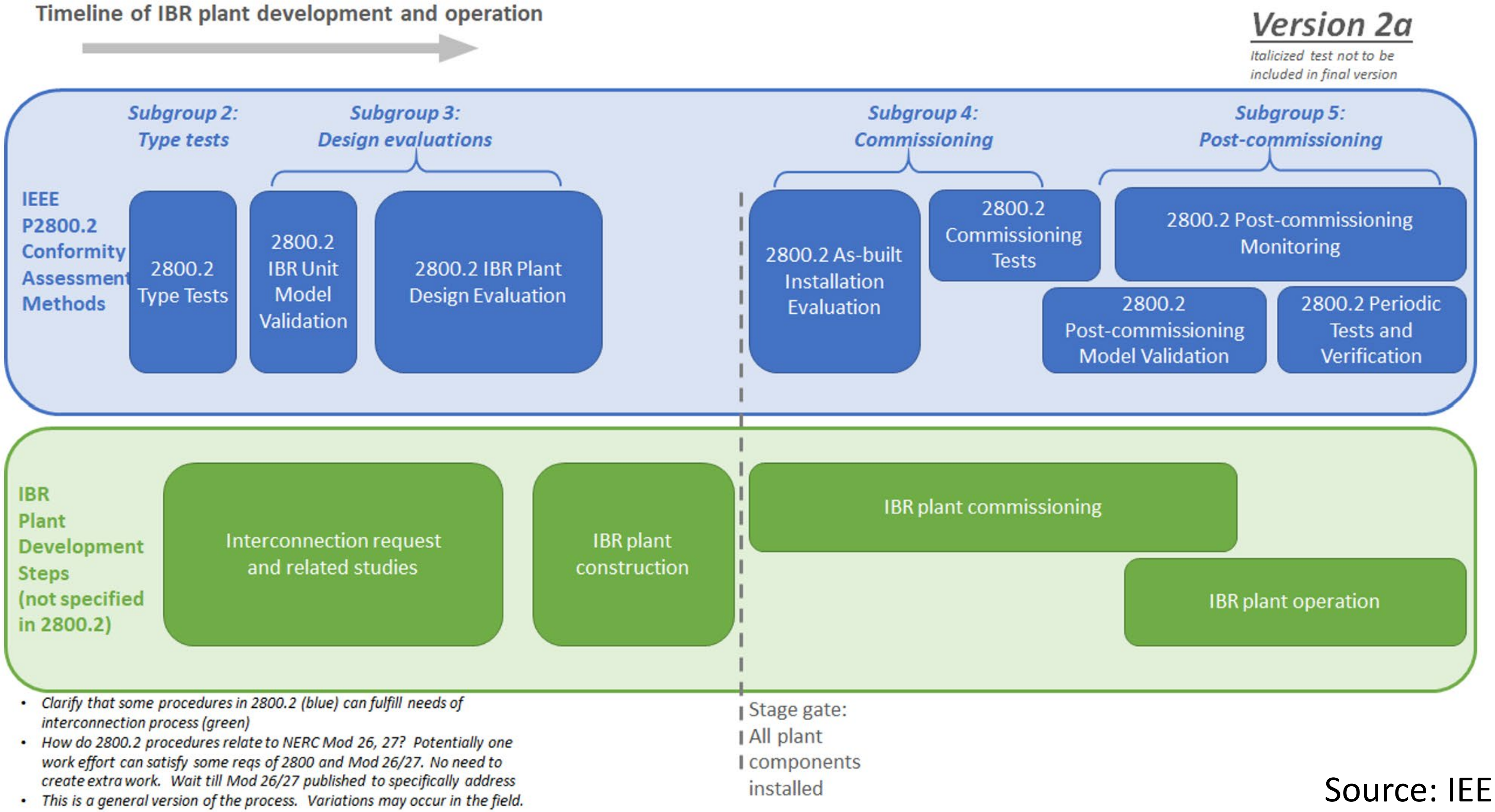
SPECIALISTS IN POWER SYSTEM STUDIES

Disclaimer!!

- I am helping with the standard drafting and trying to build a consensus based standard
- I also have experiences and opinions!!
- **Where the following slides are good, then I am representing the SG3 leadership team. Where the following slides are wrong or bad, I am representing myself!! ☺**

Acknowledgement: Much hard work and discussion from members of sub-group 3.

Where does Design Evaluation sit in the process?



Source: IEEE ©2024

What goes into design evaluation?

- Review of validation report
- Model quality checks
- Documentation check (verification)
- **Performance tests**

What kind of test systems can we use?

Interconnection specific
Detailed system model

Pros:
- Can capture more interconnection specific risks and issues

Cons:
- Requires data that may be confidential
- Difficult or impossible to control POM conditions to assess capability

Controllable source equivalent

Pros:
- Easy to control POM conditions
- Requires no data other than the plant under study

Cons:
- Simplified representation of the grid can miss factors which could cause performance issues

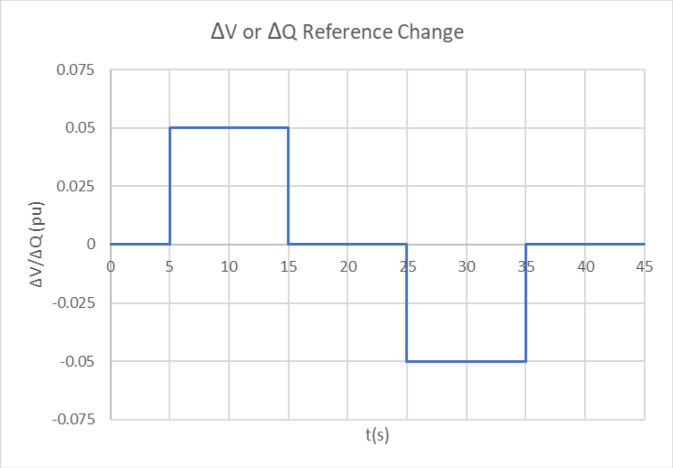
Focus on controllable source equivalent

Controllable source equivalent
(Closed Loop)

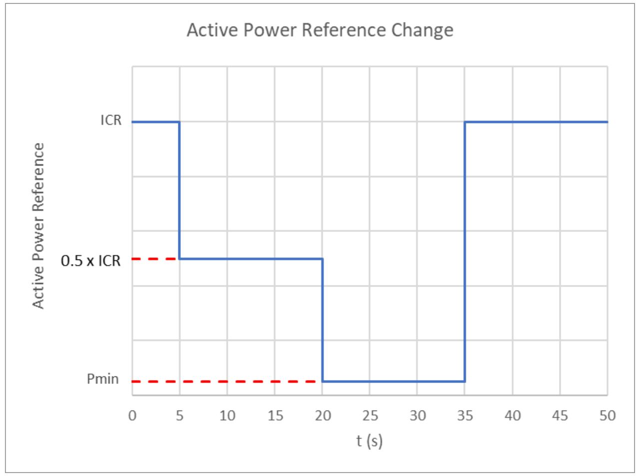
Controllable source equivalent
(Open Loop)

Selected Tests

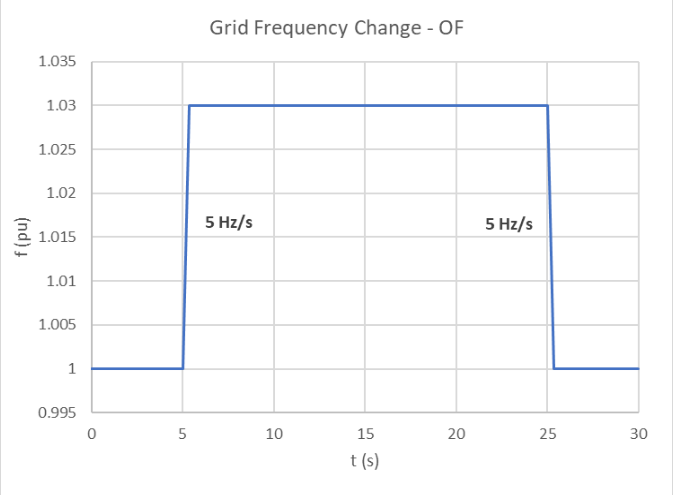
Voltage Step Response



Power Reference Change



Frequency Response



Grid Angle Step

High Voltage Ride-Through

Low Voltage Ride-Through

Source: IEEE ©2024

A tricky basic test!

Table A.5: High-voltage ride-through tests [EMT and PDT]

Test #	Test Description				Success Criteria
	Duration [s]	**Three-phase voltage at RPA[54]**	**Active Power**	**Initial Approx. Reactive Power**	
4-1	1	1.19 pu	ICR	0	1. Plant does not trip or enter current blocking mode. 2. Current response will meet the performance specifications in 7.2.2.3.5, including requirements on response time, settling time, and settling band 3. If active power is reduced, recovery of active power to 100 percent of pre-fault apparent current between 1 and 10 seconds.
4-2	*1*	1.19 pu	ICR	0.3287 x ICR injecting[55]	
4-3	*1*	1.19 pu	ICR	0.3287 x ICR absorbing	

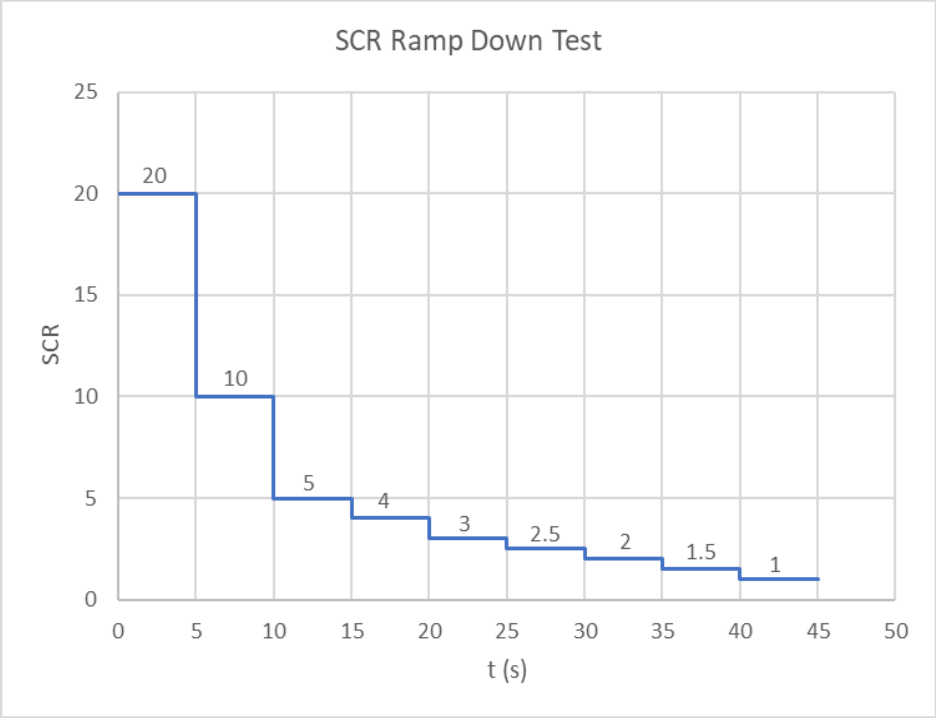
- HVRT with high Q injection…
- Can cause very high terminal voltages

Source: IEEE ©2024

Informational tests (At Plant RPA)

- This test is not “pass/fail”
- Provides information on weak grid fault ride-through for a specific configuration
- This test may not survive to the final draft?

Mixing System Strength Reduction with Fault Disturbances



Source: IEEE ©2024

Tests which are *not* in the draft standard:

- Transient Over-Voltage
  - Subject of significant discussion!
  - Difficulties:
    - TOV standard applies at the POM
    - Correctly modelling transient behaviour of the collector system back to each inverter terminal in the plant is challenging.
    - There are many different possible profiles of TOV that fit in the base standard requirements
  - **You can definitively show "pass/fail" after an event happens. Therefore it will be up to GO/OEM to design a plant with sufficient margin to ride through system TOVs.**

Tests which are *not* in the draft standard:

- Base standard requires a wide range of possible “consecutive events”.
  - Difficulties:
    - Many different tests would be required to sufficiently assess capability
    - Models need to include special physical protections (often missing). Risk of “false pass”

Unit Level Test for Validation purposes (Not done in plant level tests)

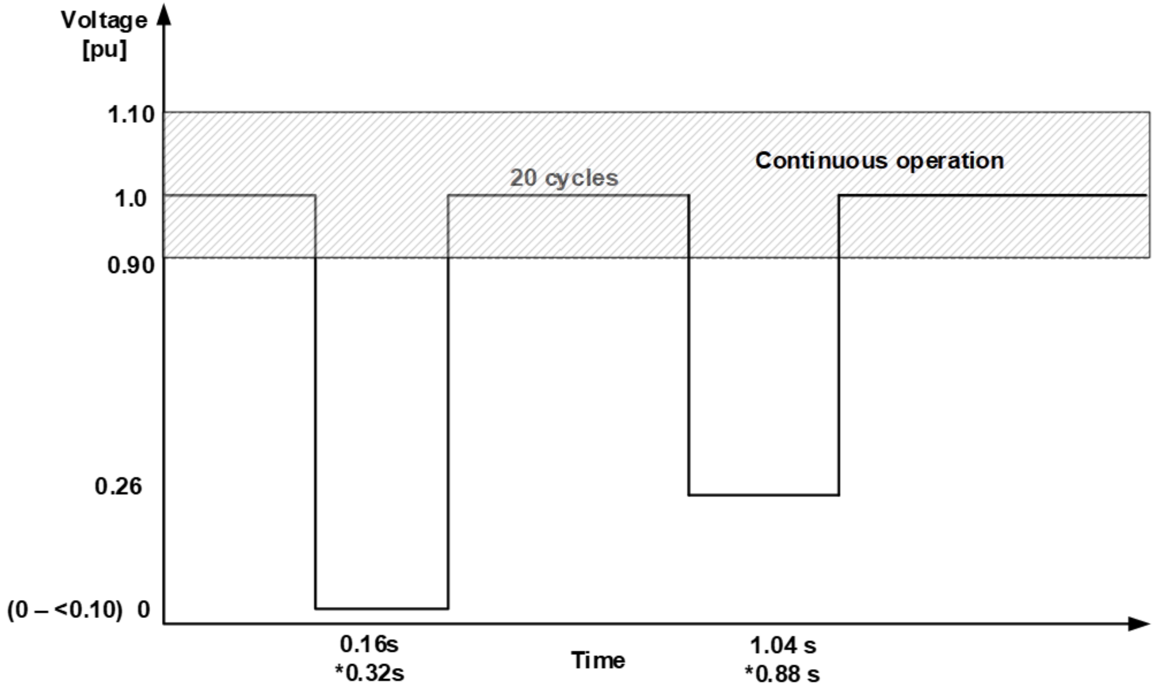


Figure 24—Consecutive voltage ride-through test

Source: IEEE ©2024

Many other important topics:

- Power quality
- PDT tests and benchmarking
- How to review documentation provided?
- How to check quality of model submissions?
- **How to use models in interconnection studies? (not in the standard!)**

… no time right now… good luck… ;)

Questions?

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IEEE P2800.2 Overview for i2X FIRST Conformity Assessment Workshop

ESIG Fall Workshop

ANDY HOKE, P2800.2 WG CHAIR
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October 24, 2024

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

Acknowledgements and disclaimers

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- Draft standard disclaimer:
  - 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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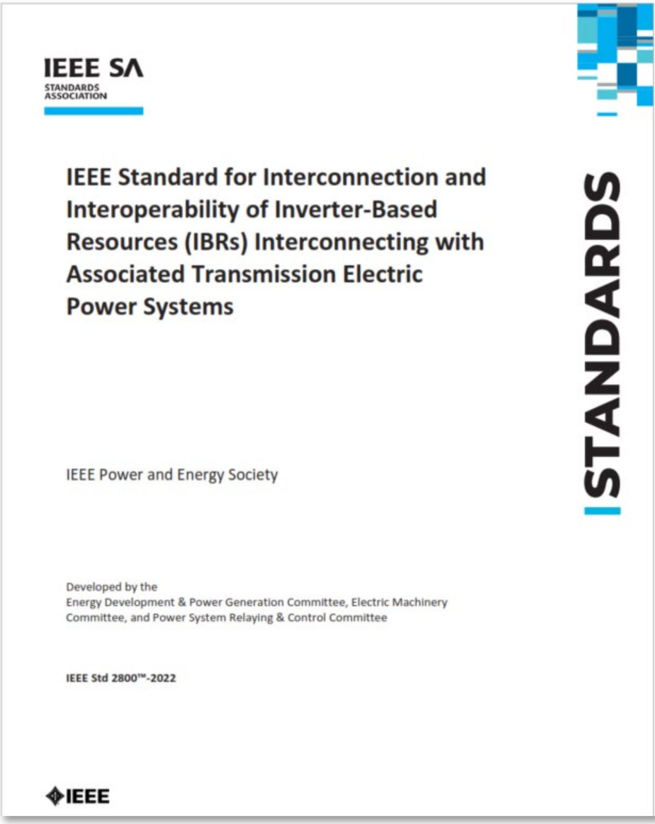
Status of IEEE 2800-2022

- 94% ballot approval. **Published April 22, 2022**.
- Harmonizes interconnection requirements for large solar, wind, and storage plants (and other inverter-based resources)
- A consensus-based standard developed by over ~175 Working Group participants from utilities, system operators, transmission planners, & OEMs over 2+ years
- IEEE standards are **voluntary until adopted by an appropriate entity**. Such entities are encouraged to consider adoption of 2800 to the extent feasible even before IEEE P2800.2 is complete. Many entities have begun adoption process.


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

IEEE

STANDARDS

Available at https://standards.ieee.org/ieee/2800/10453/

IEEE PES Power & Energy Society®

IEEE

IEEE 2800-2022 Technical Minimum Capability Requirements

TS owner can require additional capability

Raising the minimum bar

Capability Required in 2800

General Requirements

“shall have”

- Measurement accuracy
- Controls Prioritization
- Control responses
- Applicability to Diverse IBR Plants

Frequency Response

- Fast Frequency Response for under-frequency conditions
  “may” for over-frequency conditions
- Primary Frequency Response

Reactive Power – Voltage Control

- Q for voltage control at zero active power
  AC-connected offshore wind: “should have”
- Automatic Voltage Regulation Functions
- Reactive Power

Power Quality

TS owner “should” specify

- Harmonic Voltage Limitations
- Prevent Transient Overvoltage
- Harmonic Current Limitations
- Phase Unbalance
- Rapid Voltage Change
- Flicker Limitations

Ride-Through Capability and Performance, Protection

- Unbalanced Current Injection
- Balanced Current Injection
- Voltage Ride-through
  including TrOV + Consecutive
- Frequency & Phase-jump Ride-through
- Coordination of Protection

Modeling & Validation, Measurement Data, and Performance Monitoring

- Process and criteria for model validation
- High Fidelity Performance Monitoring
- Validated Models

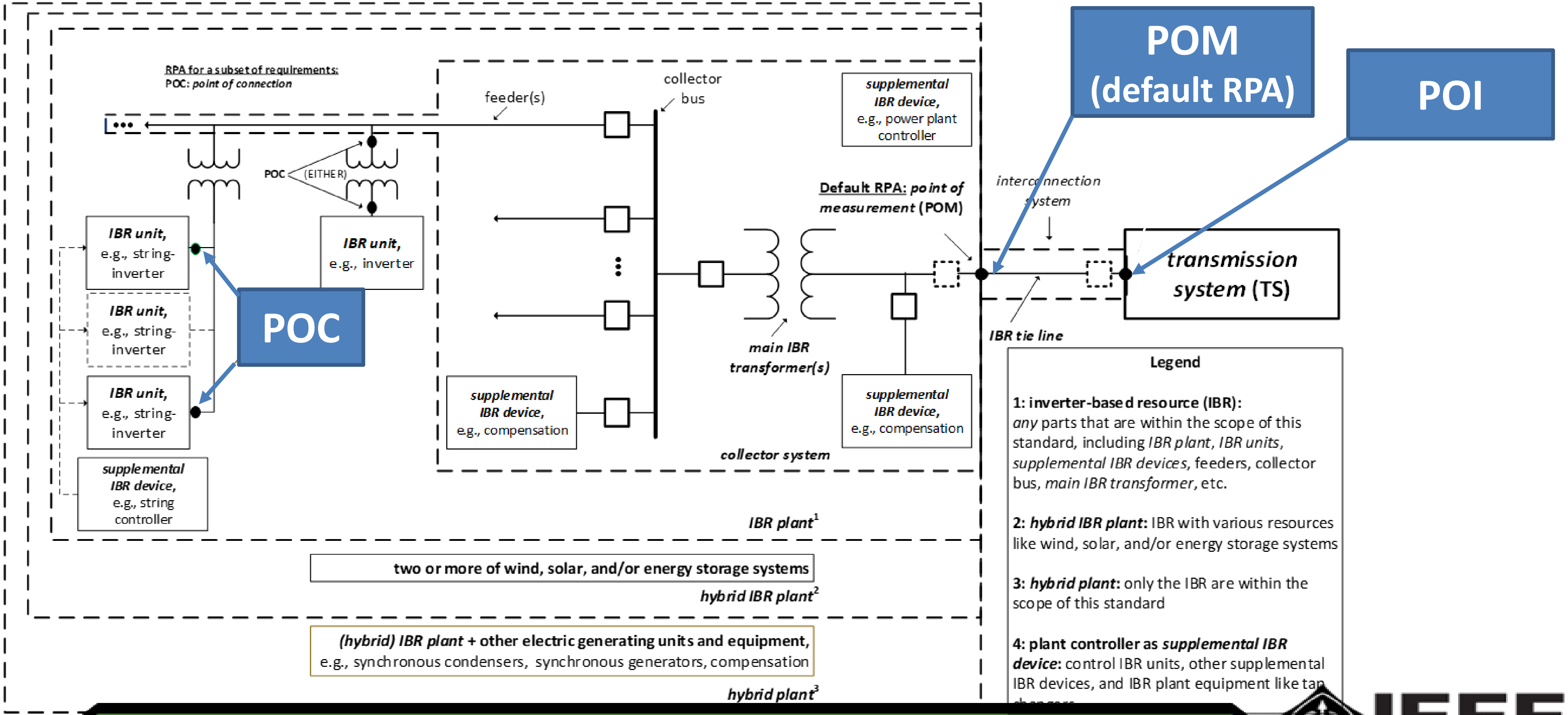
Tests and verification requirements

- Post-commissioning Monitoring
- Plant-level Evaluation & Modeling
- Commissioning Tests
- Type tests

Slide courtesy of Jens Boemer, EPRI

Where 2800 requirements apply?

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



Status of IEEE 2800-2022 adoption

General Reference

- Florida Power and Light (FPL)
- HECO
- NRCAN (as condition of certain programs)

Detailed Reference & Customization

- AESO
- BPA
- Duke Energy[4]
- ISO New England[1,8]
- Southwest Power Pool (SPP)[7]

Hybrid Reference, Customization & Specification

- ERCOT[2,9]
- MISO Phase 1[5], Phase 2
- Long Island Power Authority
- New York ISO[3] & NYSRC RR#151
- PJM
- Salt River Project (SRP)[2]
- Southern Company[1]

Full Specification & Customization

- Ameren IL[6]
- NERC

- **Other utilities/ISOs considering IEEE 2800-2022 adoption:** Great River Energy, Manitoba Hydro, TVA

Legend:
Green—Adoption completed
Orange—Adoption in progress

Slide modified from Jens Boemer, EPRI

[1]: Presented on November 15, 2022 webcast: link
[2]: Presented on February 15, 2023 webcast: link
[3]: Presented on March 15, 2023 webcast: link
[4]: Presented on April 12, 2023 webcast: link
[5]: Presented on May 17, 2023 webcast: link
[6]: Presented on June 14, 2023 webcast: link
[7]: Presented on September 20, 2023 webcast: link
[8]: Presented on November 15, 2023 webcast: link
[9]: Verbal update on Jan 17, 2024 webcast: link

Overview of conformity assessment steps in IEEE P2800.2

Type Tests

Lab or field tests of individual IBR unit for model validation

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

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

Plant construction complete

This is a general diagram of the process.
Details are under development in IEEE P2800.2.
Some variations permitted.

Equipment certification?

- Almost all requirements in IEEE 2800 apply to the IBR plant (not the inverter/WTG)
- The type tests in IEEE P2800.2 do not generally have pass/fail criteria.
  - Instead, they generate data (e.g. test waveforms) to validate the unit-level model.
- Certification of inverters/WTGs to 2800 is not applicable because compliance is at the plant level
  - Required unit-level capabilities depend strongly on balance of plant
- Therefore **an “IEEE 2800 *certified* inverter/WTG” probably will not exist**
  - Instead, inverters/WTGs could perhaps be considered “2800 compatible” if 2800 requirements have been taken into consideration so that they can be used to build a 2800-compliant plant.
- This is different from the IEEE 1547/1547.1/UL 1741 paradigm on the distribution system, where pass/fail type tests and NRTL certification play a large role in conformity assessment

- What is the required WTG/inverter capability for 2800 compliance?

- There are many ways to comply
- For example, an inverter could have limited reactive power capability, but still comply with 2800 if the plant designer includes appropriate supplemental equipment
- Even with ride-through capability, the required inverter-level capability is not defined by 2800 because the voltage that each inverter sees is not the same as the voltage the plant sees (and the 2800 requirement is at the plant level)
- Therefore, **OEMs and plant designers will need to work together to decide how to achieve plant-level compliance**
- This flexibility is intentional. 2800 does not want to tell anyone how to design a plant. It just specifies minimum performance capabilities for the plant. It is up to the plant designer to decide how to achieve them.

• Adoption of IEEE 2800:

- Adoption of IEEE 2800 is not contingent upon publication/adoption of IEEE P2800.2
  - ***In the absence of IEEE P2800.2*, IBR owners, TS owners/operators, OEMs, etc. could develop their own conformity assessment procedures or use existing procedures**
- For systems experiencing IBR ride-through events/problems, some requirements may be higher priority than others (ride through of low voltage, TOV, ROCOF, phase jump)
- Needs consideration of enforcement date, grandfathering etc.
- Possible adoption methods:
  - Full adoption by simple reference
  - Full or partial adoption, clause-by-clause reference, additional requirements
- Many utilities/ISOs are already moving towards adoption

Some definitions

- **model validation:** The process of comparing measurements with simulation results for the assessment of whether a model response sufficiently matches the measured response.
  - NOTE 1—measurements are obtained from type tests for IBR units or supplemental IBR devices, or from field measurements for IBR plants or IBR units.
  - NOTE 2—simulation results are obtained from an IBR unit or supplemental IBR device model or from an IBR plant model. All models should be appropriately configured for the application.
- **model benchmarking:** the process of comparing simulation results from two models for the assessment whether a response from one model sufficiently matches the response from the other model for the same disturbance and external power system conditions.
  - NOTE 1—For the purposes of model benchmarking, a model may be an IBR unit model, a supplemental IBR device model, or an IBR plant model. The two models may be implemented in the same domain (e.g. EMT, phasor, etc.) or in different domains. All models should be appropriately configured for the application.
  - NOTE 2— Comparing results from a model to results from a hardware-in-the-loop (HIL) test is a form of model validation, not model benchmarking.

Some definitions

- **model verification:** The process of checking documents and files or equipment and respective settings (e.g., controls & protection), and comparing them to model parameters or model structure.

IEEE P2800.2 Subgroup Scopes

SG 1

Overall document and general requirements

SG 2 Type tests

SG 3 Design Evals.

SG 4 Commissioning and As-built

SG 5 Post-commissioning model validation, monitoring, etc.

Frequency Scanning Task Force

Power Quality Task Force

Excerpt of 2800 Table 20: Verification Methods Matrix

Requirement	RPA at which requirement applies	*IBR unit*-level tests (at the POC)		*IBR plant*-level verifications (at the RPA)					
		Type tests[152]	Design evaluation (including modeling for most require-ments)	As-built installation evaluation	Commissioning tests	Post-commissioning model validation	Post-commission-ing monitoring	Periodic tests	Periodic verification
		Responsible Entity							
		IBR unit or supplemental IBR device manufacturer	*IBR developer / TS owner / TS operator*	*IBR developer / TS owner / TS operator*	*IBR developer / TS owner / TS operator*	*IBR developer / IBR operator / TS owner / TS operator*	*IBR operator / TS owner / TS operator*	*IBR operator / TS owner / TS operator*	*IBR operator / TS owner / TS operator*
4.12 Integration with TS grounding	POM	NR	R	R	NR	NR	NR	D	NR
Clause 5 Reactive Power—Voltage Control Requirements within the Continuous Operation Region									
5.1 Reactive power capability	POM	R	R	R	R	R	D	D	D
5.2 Voltage and reactive power control modes	POM	D	R	R	R	R	D	D	D
Clause 6 Active-Power – Frequency Response Requirements									
6.1 Primary Frequency Response (PFR)	POC & POM	NR[153]	R	R	R	R	D	D	D
6.2 Fast Frequency Response (FFR)	POC & POM	R[154]	R	R	R	R	D	D	D
Clause 7 Response to TS abnormal conditions									
7.2.2 Voltage disturbance ride-through requirements	POC[155] & POM[156]	R	R	R	NR	R	R	D	D
Clause 8 Power quality									
8.2.2 Rapid voltage changes (RVC)	POM	NR	R	R	R	D	R	D	D
8.2.3 Flicker	POM	NR	NR	NR	R	D	R	N/A	D
8.3.1 Harmonic current distortion	POM	R[157]	R	R	R	D	R	N/A	D
~~8.3.2 Harmonic voltage distortion~~	POM	D	D	D	D	D	D	D	D
8.4.1 Limitation of cumulative instantaneous over-voltage	POM	R	R	R	NR	NR	R	NR	NR
8.4.2 Limitation of over-voltage over one fundamental frequency period	POM	D	R	R	NR	NR	R	NR	NR

IEEE P2800.2 Structure and Leaders

Subgroup	Vice Chair	Subgroup Chair(s)
2: Type tests	Steve Wurmlinger Stephen.Wurmlinger@sma-america.com	Pramod Ghimire, Michael Ropp
3: Design evaluations	Jens Boemer j.c.boemer@ieee.org	Andrew Isaacs, Alex Shattuck
4: Commissioning and as-built evaluation	Divya Chandrashekhara DKUCH@orsted.com	Chris Milan, Dave Narang
5: Post-commissioning model validation and monitoring, and periodic tests and verifications	Julia Matevosyan julia@esig.energy	Jason MacDowell, Brad Marszalkowski

Lead subgroup and coordinate with other subgroups

Facilitate subgroup calls

Draft specific verification procedures with subgroup input

Most of the detailed work occurs in the subgroups and task force via periodic calls

Chair	Andy Hoke Andy.Hoke@nrel.gov
Secretary	Manish Patel Manish.P@ieee.org
Vice Chair	Bob Cummings
Vice Chair	Mahesh Morjaria

Compile drafts; Lead Subgroup 1 (overall document and general requirements)

Lead overall WG

Power Quality Task Force	
Co-Lead	Eugen Starschich
Co-Lead	David Mueller

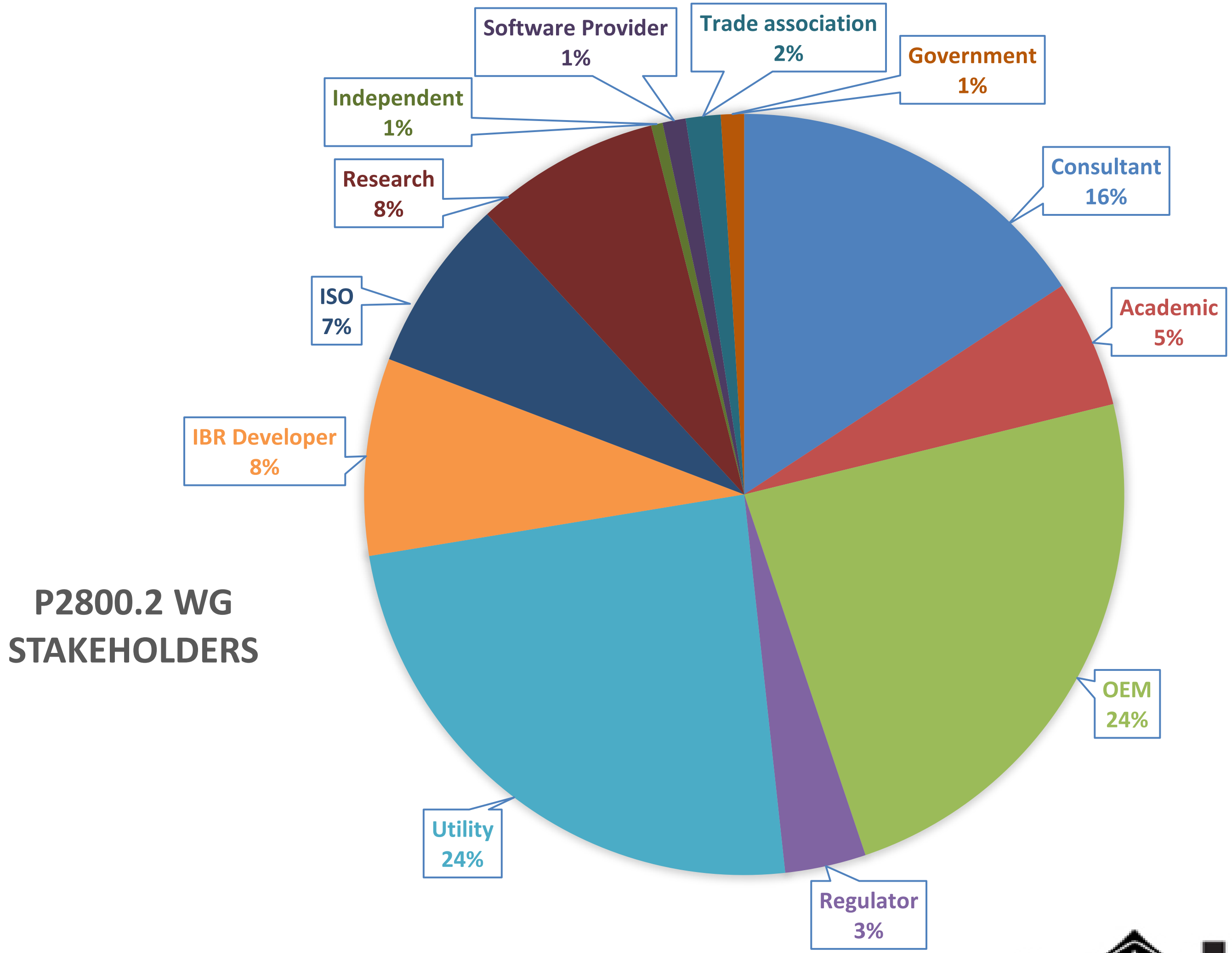
Provide input to subgroups on PQ requirements verification

Frequency Scanning Task Force	
Co-Lead	Wes Baker
Co-Lead	Shahil Shah

Develop frequency scanning content

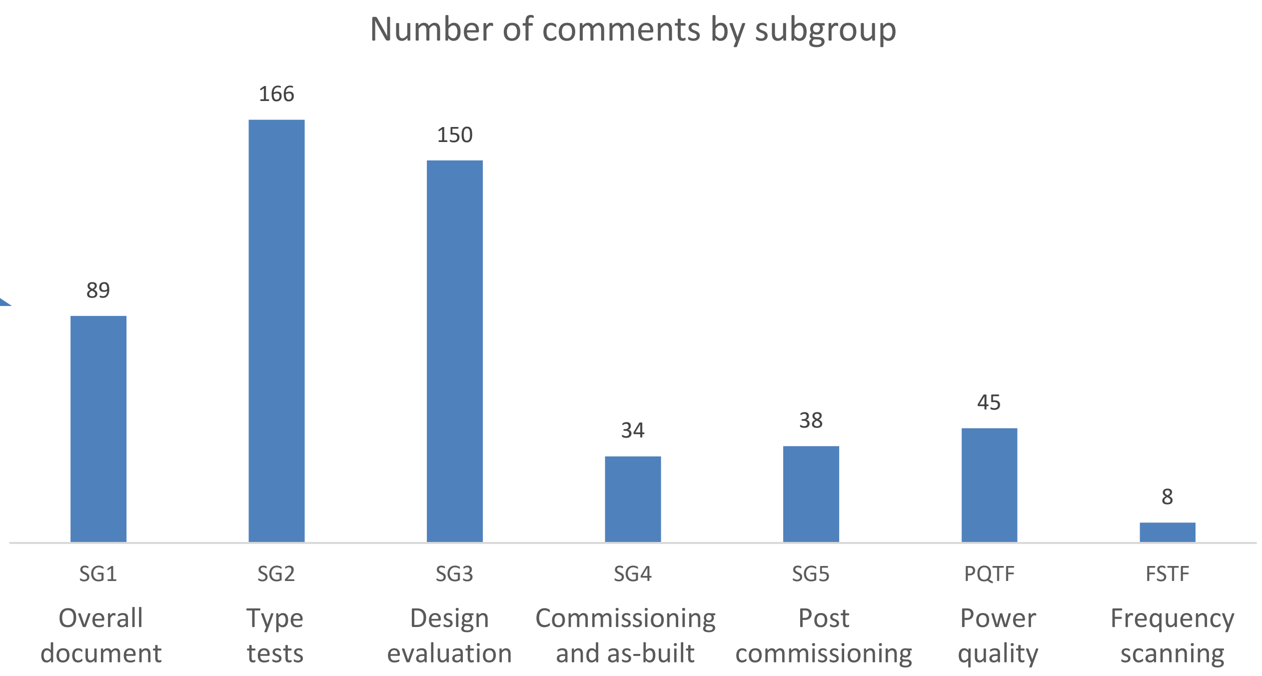
P2800.2 Working Group Membership

- 160 Voting members
- 45 Non-voting members
- All major stakeholder groups represented



P2800.2 status

- >95% of content is complete
- 7th Working Group meeting held April 30-May 2, 2024
- 530 formal comments received on May 22
  - First round of comments on nearly complete draft
- Draft 2.0 produced yesterday
  - Call for WG comments open
- 8th WG meeting next week – Oct 30-Nov 1
- Over next ~3 months, subgroups and task force will address comments
- Expect to ask WG for approval to start IEEE-SA ballot in ~February



P2800.2 Timeline

Jan 2022 — WG Kickoff

2022-2024 — Subgroups & WG draft content

Oct 2022 — Draft 2.0 posted

Oct 30 – Nov 1, 2024 — WG meeting

Nov – Dec 2024 — Subgroups address WG comments

Q1 2025 — Post D3.0 and vote

Q1 2025 — Start IEEE-SA ballot

Q2-Q4 2025 — Address ballot comments

Q1 2026 — Publication?

Future dates are tentative

Potential Adoption Timeline

	Jan 2019-Dec 2020	Q2-Q4 2021	Q2 2022	Q2-Q4 2022	2023	Current Phase 2024	2025	2026 and Beyond
2800	WG Drafting in Parallel Subgroups	Balloting and Recirculation	Publication					
P2800.2 Conformance verification			Kick-off and Directional Alignment	WG Drafting in Parallel Subgroups	WG Drafting in Parallel Subgroups	Complete WG Draft;	Balloting and Recirculation	Publication
Related activities	IEEE 1547.1 is published	NERC IRPWG Guidelines		FERC GI NOPR IEEE 1547 Revision Kickoff	Potential 2800 Adoption, FERC 901 and 2023, NERC Stds	Potential 2800 Adoption	Potential 2800 Adoption	Potential P2800.2 Adoption

To get involved in IEEE P2800.2:

- To join Working Group:
  - If you have attended two WG meetings and want to be a WG voting member, email Manish Patel: Manish.P@ieee.org; CC Andy.Hoke@nrel.gov
  - If not, attend two meetings and request membership
- Join listserv for any subgroup or task force of interest
- WG member iMeet site: https://ieee-sa.imeetcentral.com/p2800-2/home
  - Contains draft documents, subgroup documents, references, etc.
- Public website: https://sagroups.ieee.org/2800-2/

Present-Day Design Evaluation Analysis and Challenges

i2X FIRST Hybrid Workshop: Interconnection Standards Workshop with Focus on Conformity Assessment

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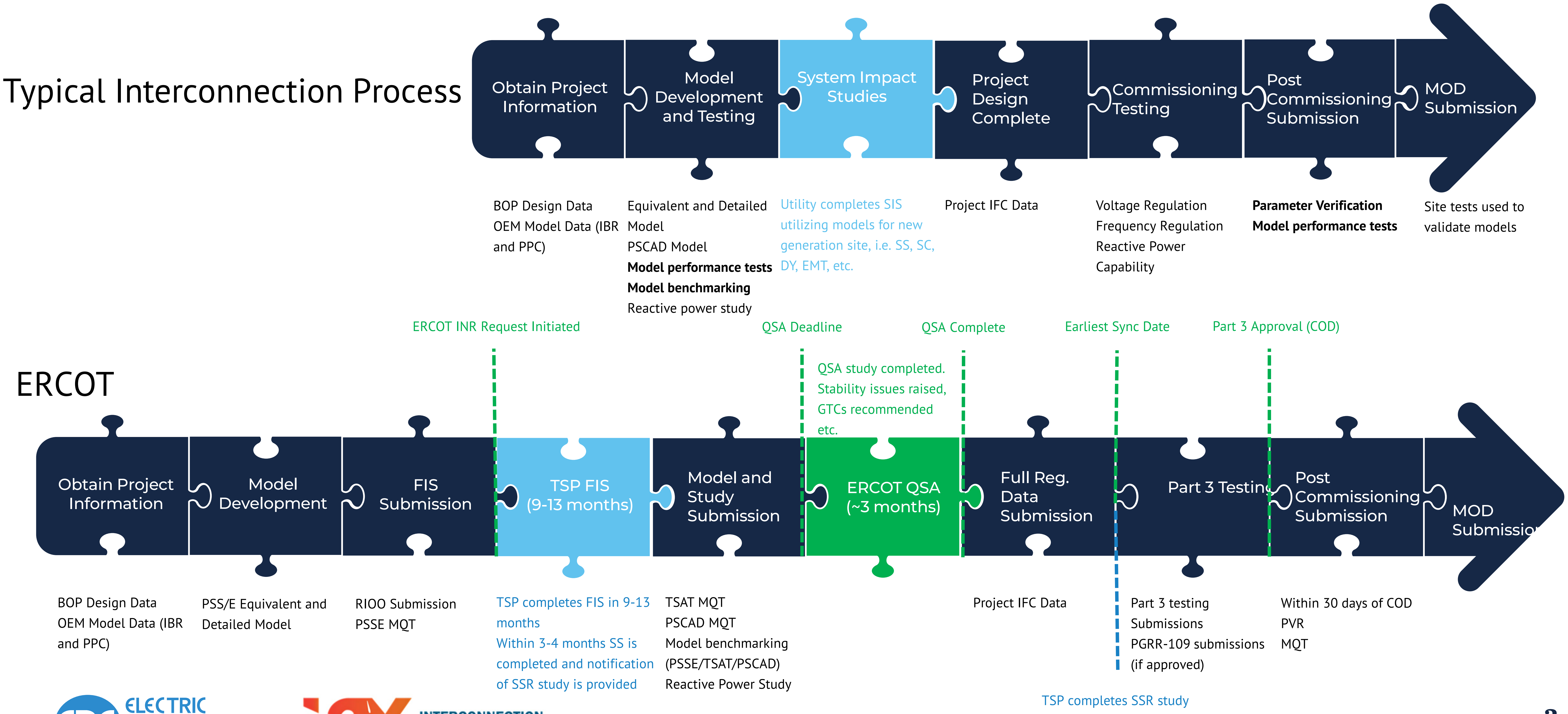
DELIVERING ENERGY INTELLIGENCE

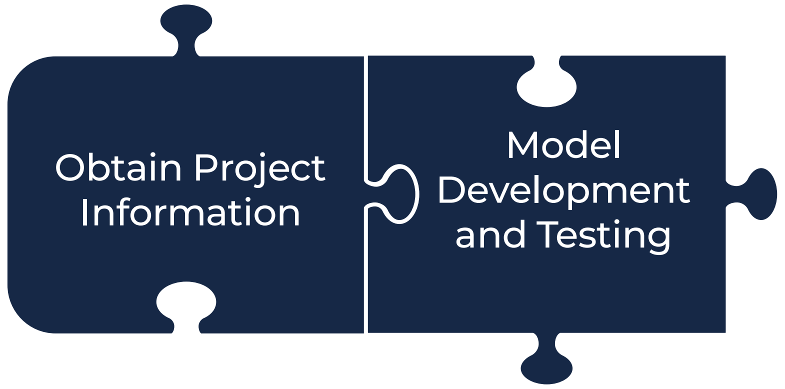
Key Objectives

- **The Interconnection Process focused on “Design Phase”**
  - Explore the interconnection process
  - Identify gaps in the process
- **Importance of Project Modeling**
  - Types of models
  - Design tests
  - Where are the gaps
- **Meeting regulatory and ISO/utility requirements**
  - Aligning development with regulatory requirements
- **Collaborative opportunities with ISO/utility and OEMs**
  - Understand how and where collaboration is necessary to reach the common goal

Project Timeline: Interconnection to Operation

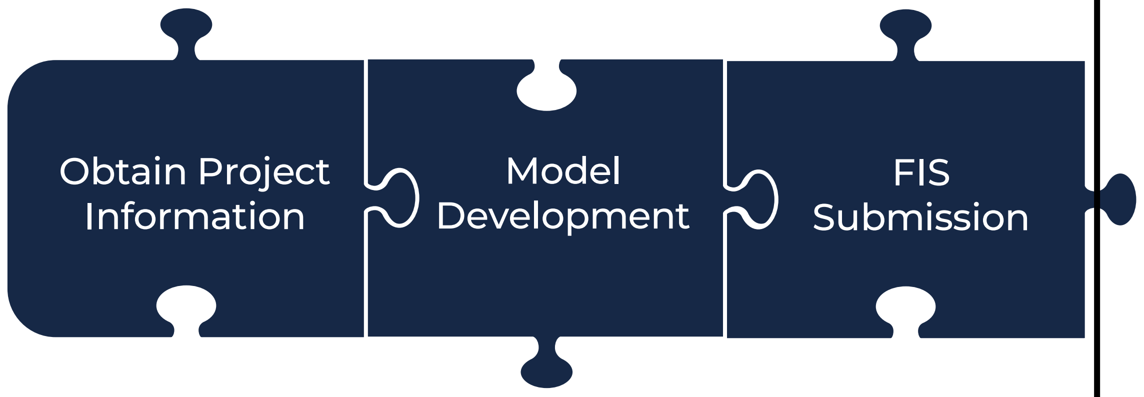


Interconnection Phase (Preliminary Design?)



BOP Design Data
OEM Model Data (IBR and PPC)

Equivalent and Detailed Model
PSCAD Model
Model performance tests
Model benchmarking
Reactive power study



BOP Design Data
OEM Model Data (IBR and PPC)

PSS/E Equivalent and Detailed Model

OEM Challenges

- **Dynamic/Transient Model (PSSE/TSAT/PSCAD) and MQT**
  - UDM vs GM
  - Default and hidden control parameters
  - Transient initialization (P and Q)
  - Minimal to no documentation related to Model Quality Test (MQT)
  - VRT response concerns
  - Default protection settings
  - IBR OEMs provide PPC model even though it is not available or typically installed
  - No clarity on integrating external PPC
  - Use of Generic PPC
  - Hybrid PPCs

Developer Challenges

- **Steady State Model (PSSE)**
  - MPT sizing and OLTC control
  - Need for additional reactive devices
  - Quantity of IBRs and OEM selection

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Design Phase

System Impact Studies — Utility completes SIS utilizing models for new generation site, i.e. SS, SC, DY, EMT, etc.

Project Design Complete — Project IFC Data

TSP FIS (9-13 months) — TSP completes FIS in 9-13 months
Within 3-4 months SS is completed and notification of SSR study is provided

Model and Study Submission — TSAT MQT
PSCAD MQT
Model benchmarking (PSSE/TSAT/PSCAD)
Reactive Power Study

ERCOT QSA (~3 months) — QSA study completed. Stability issues raised, GTCs recommended etc.

Full Reg. Data Submission — Project IFC Data

OEM Challenges

- **MQT and Benchmarking**
  - IBR OEMs do not have TSAT UDM
  - PPC OEMs do not have PSSE/TSAT UDM
  - PSCAD model is not aligned with PSSE/TSAT model
  - Performance concerns meeting requirements
- **QSA Study**
  - Accurate models
  - Many study scenarios
  - More detailed assessment (PSCAD) may be necessary

Utility/ISO Challenges

- **SIS/FIS Study**
  - Model doesn't pass VRT
  - Time to resolve model issue for VRT
  - Solutions to resolve any system events follow typical means of system upgrades/curtailments
- **QSA**
  - Accurate models
  - Many study scenarios
  - More detailed assessment (PSCAD) may be necessary

Developer Challenges

- **SIS/FIS Study**
  - Visibility to any stability issues
- **MQT and Benchmarking**
  - Design changes from reactive power study
  - MQT results reviewed by ERCOT
- **QSA**
  - Visibility to any stability issues or GTCs that result from the study
  - Results could drive changes to models

Project Modeling

- Different regions, ISOs and utilities have different modeling requirements.
- Most have started the process for incorporating IEEE 2800 requirements into their local protocols
- Models required in different platforms at very early stages of development/design, i.e. PSSE, PSLF, PSCAD, TSAT, etc.
- Generic Models or User Defined Models (Now both!)

ercot

Dynamics Working Group
Procedure Manual

Revision 20

ROS Approved: October 5, 2023

pjm

PJM Dynamic Model Development Guidelines for Interconnection Analysis

Prepared by:
Interconnection Analysis & Interconnection Planning Analysis Departments
PJM Interconnection

Revision 0
September 18, 2023

For Public Use

Appendix B Attachment 3

HAWAIIAN ELECTRIC GENERATION FACILITY TECHNICAL MODEL REQUIREMENTS AND REVIEW PROCESS

March 22, 2023

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

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Types of Design Evaluation

SMIB

- ERCOT Model Quality Test
- IEEE 2800
- IEEE P2800.2
- Insulation Coordination
- TOV/TRV
- Switching Studies
- Ferroresonance

Network

- Stability criteria set by ISO/Utility
- Utility only gets to evaluate
- Ferroresonance
- Subsynchronous Resonance
- IEEE P2800.2?

Needs

- Where in the process do we want to identify a system issue, i.e. GI, Planning, Ops.?
- Further define and refine when to use RMS vs EMT simulators
- Increased collaboration between developers and utilities for system stability solutions, i.e. black box network connectivity
- HIL model validation
- Automation

Case Study: IBR Grid Integration

250 MW solar PV project in West Texas subject to Odessa Event

Original interconnection request was submitted with a generic model. Site met the current performance criteria during commissioning in 2021.

Project was commissioned with voltage ride through characteristics similar to that of the generic model.

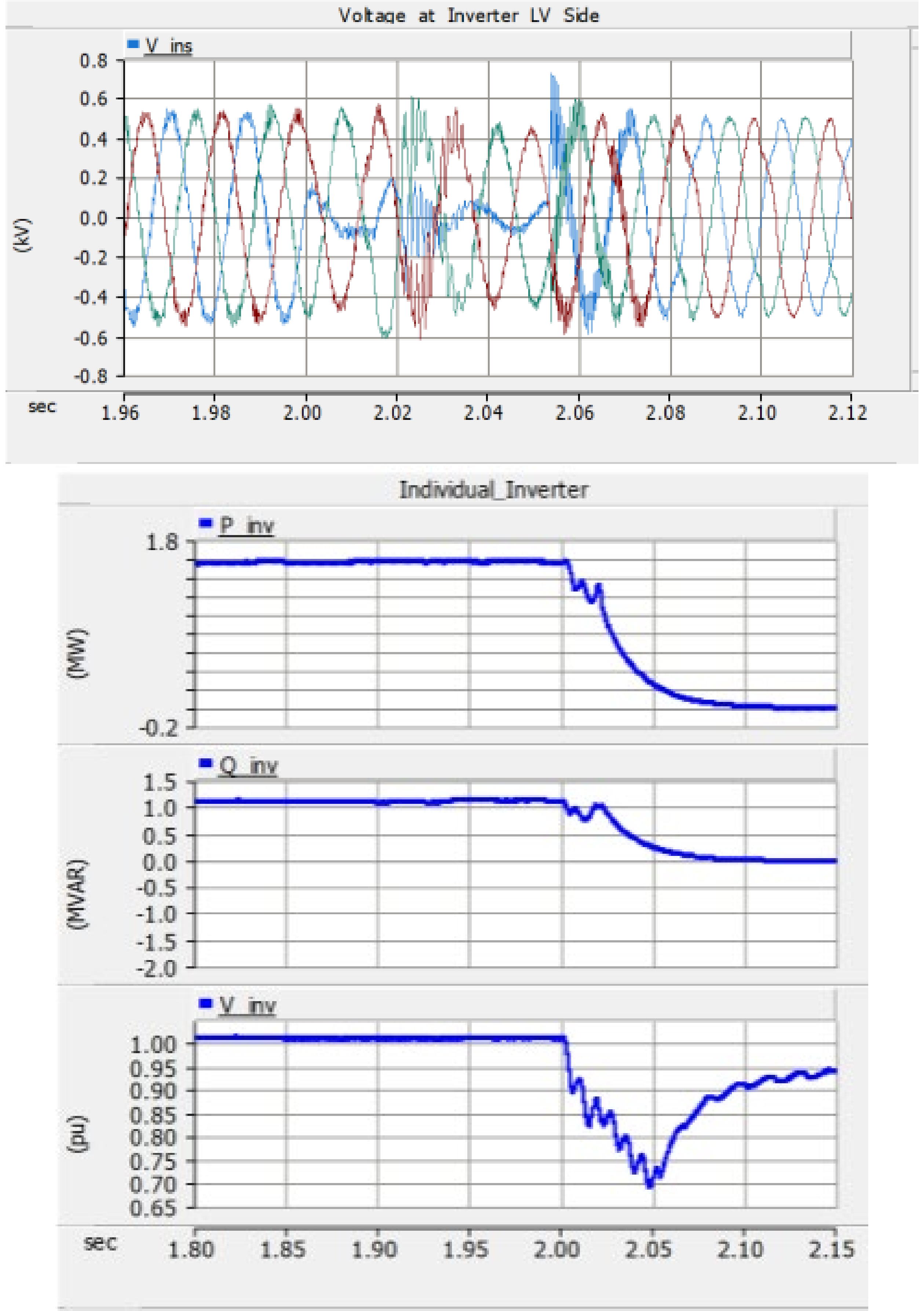
A SLG fault occurred nearby and was cleared in 3 cycles, yet the project reduced output and tripped partially offline.

Event was recreated in PSCAD with a partial equivalent model

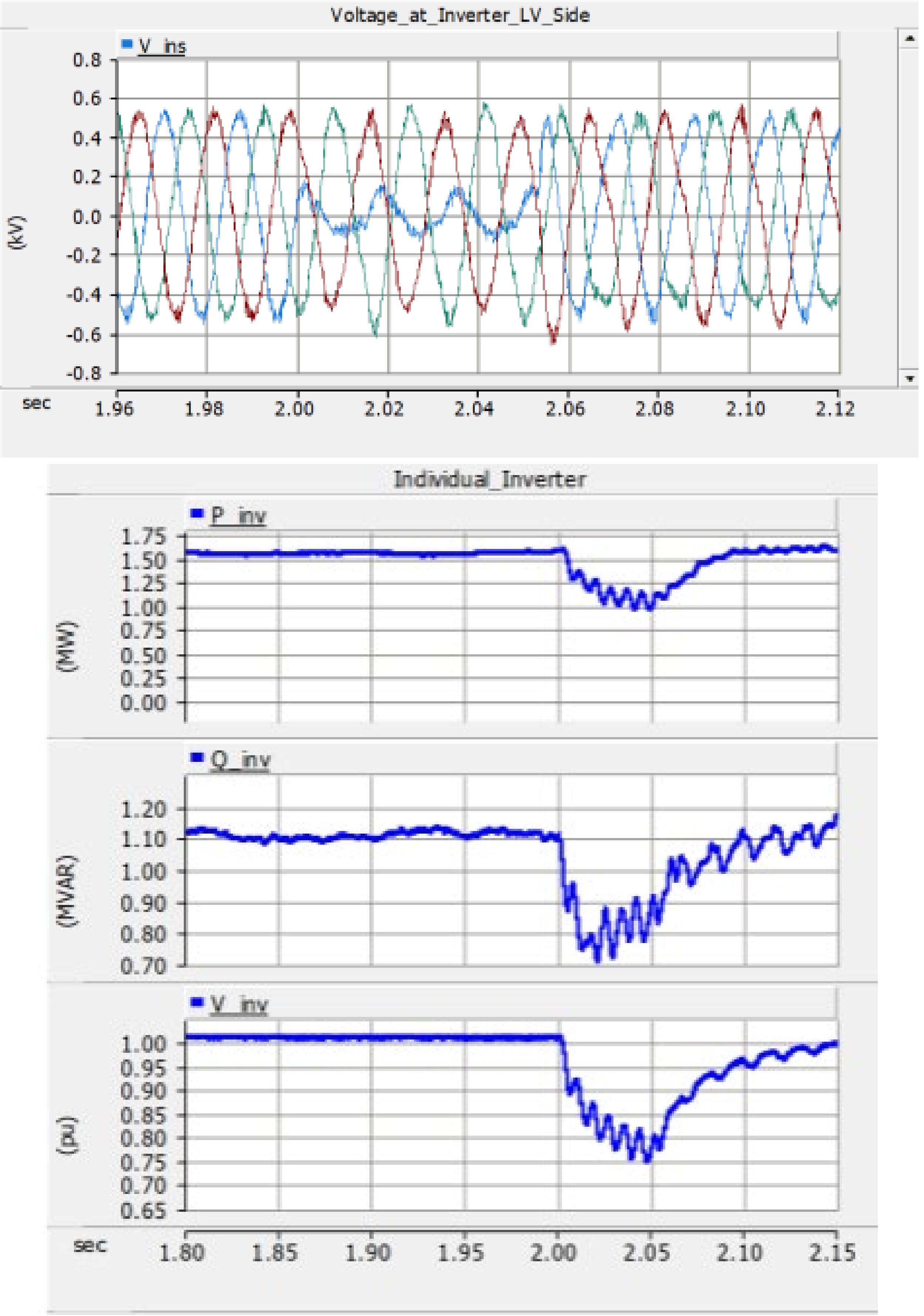
Found that original reactive current injection value was too high and needed to be reduced. Updated generic model with user defined model with parameters from PSCAD and site. Once reduced the project rode through the fault, however it now does not meet the interconnection performance criteria

Modeling Challenges

Before Solution



After Solution



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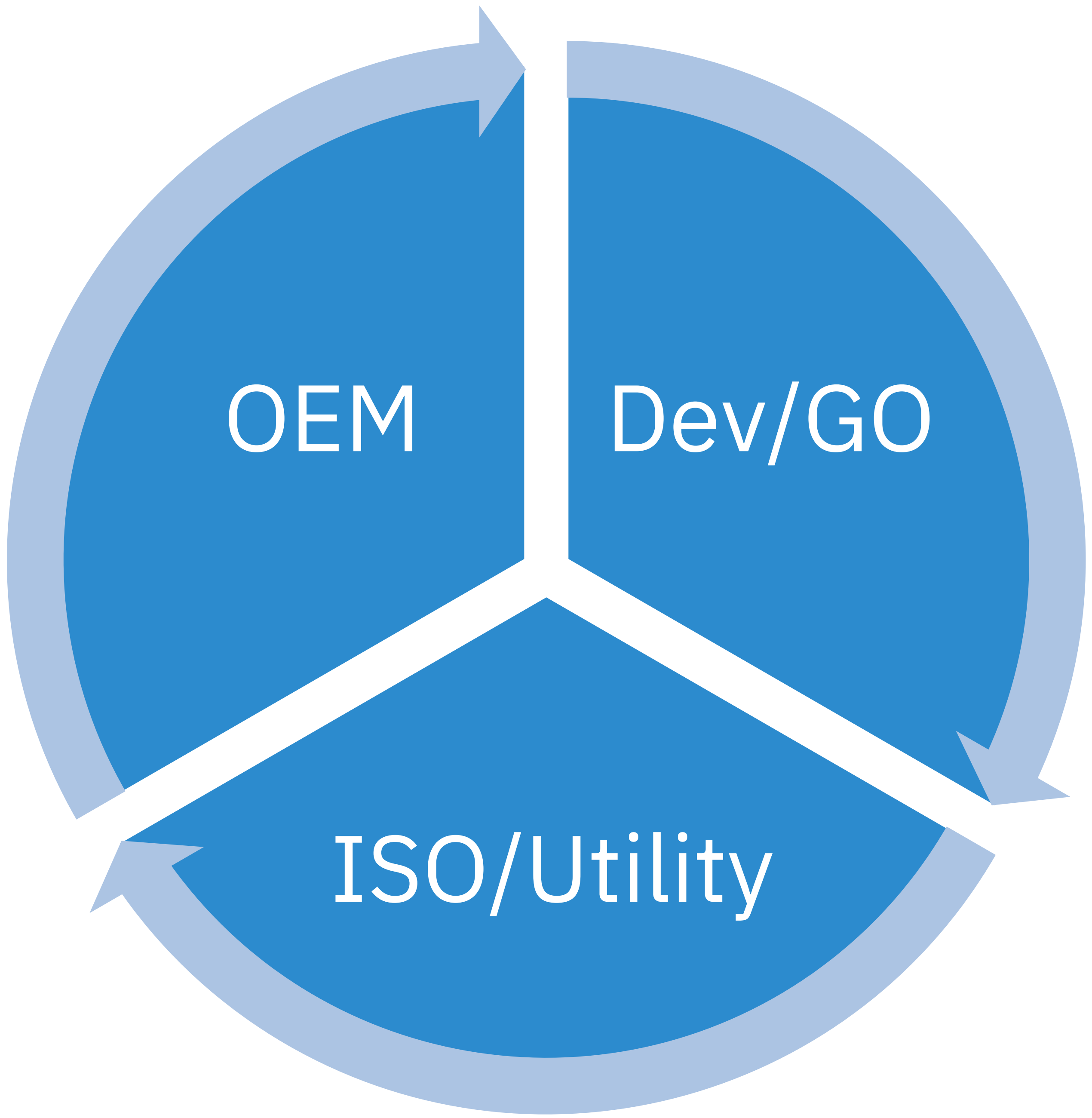
Collaborative Planning Needed

- Developer/GO goal is to get the project connected with minimal financial impact, i.e. operational curtailment, system upgrades, etc.

- Open and flexible to working with ISOs/Utilities to resolve any issues that result from system impact studies.

- What can be done to share data/results between each other to allow for evaluation of alternative solutions to solve the problem?



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U.S. DEPARTMENT OF ENERGY

Key Takeaways

- **Summary of challenges and opportunities**
  - Visibility from ISO/utility on study issues and ability to provide alternative solutions
  - Model control clarity surrounding tunable parameters
- **Collaborative strategies to drive future success**
  - Workforce Development
    - Universities: Short courses, summer programs, internships, etc.
    - Existing Industry: Workshops, OJT exercises, new technology forums, etc.
  - Increase presence at developer/utility focused conferences: Distributech, RE+, IEEE T&D, etc.
  - Increased communication between all parties: ISO, utility, developer, OEM, etc.
  - Whitepapers, guidelines, recommended practices, lessons learned, etc.

Questions?

CrestCura

DOE i2X FIRST Hybrid Workshop

"As-Built" Evaluation and Commissioning Testing and Recommended Best Practices in IEEE 2800-2022 and IEEE P2800.2

Talking Points

1. Introduction
2. As-built Installation Evaluations
3. Commissioning Tests

As-built Installation Evaluations – IEEE 2800-2022

- Clause 12.2.4
- The IBR plant as-built installation evaluation (on-site) is an evaluation at the time of commissioning to verify that IBR units, the collector system, supplemental IBR device(s), and protective functions forming an IBR plant as delivered and installed meets or exceeds the design as defined in the IBR plant design evaluation
- Table 20 Verifications methods matrix
- Supports Annex G – Modeling Data

As-built Installation Evaluations – Clause 8

- The IBR plant as-built installation evaluation (on-site) is an evaluation at the time of commissioning to verify that IBR units, the collector system, supplemental IBR device(s), and protective functions forming an IBR plant as delivered and installed meets or exceeds the design as defined in the IBR plant design evaluation

- The IBR plant model used for design evaluation studies should be verified to be consistent with the IBR unit and supplementary control firmware versions (including settings and control coordination, if applicable). Annex G of the IEEE Std 2800-2022 provides a summary for the model and plant data that need to be verified.

- The key here is that if significant changes are made to the controls, protection, or design that might potentially change IBR plant performance then a design reevaluation and possibly conformity assessment with IEEE Std 2800 may be necessary.

- The need for design re-evaluation and conformity assessment, and what aspects of capability and performance requirements require re-evaluation should be determined through consultation among all parties (i.e. IBR owner/IBR operator and TS owner/TS operator). Any changes made on-site (including control tuning) that affect the IBR plant performance should be reflected in updated IBR plant models as necessary.

As-built Installation Evaluations - Summary

- Summary of As-built installation evaluation: Clause 8 of the IEEE P2800.2 std
  - Purpose: Plant and unit models/data provided during design evaluation studies match the physical equipment (hardware, software and settings) constructed and installed on-site.
  - Approach: Recommended to verify firmware version and the models/data sheet provided for studies
  - Check for changes to plant hardware/firmware/software/settings:
    - Changes that may result in the plant capabilities and performance to be altered may trigger restudy (plant design evaluation).
    - This could impact a single clause or multiple clauses of the IEEE 2800std and those impacted requirements or capabilities may need to be re-studied

Commissioning Tests – IEEE 2800-2022

- The IBR commissioning tests are verifications conducted in the field on one or more IBR unit(s), supplemental IBR devices, and/or an IBR plant to verify that the IBR plant as designed, delivered, and installed meets the interconnection and interoperability requirements of this standard.

- All commissioning tests shall be performed based on written test procedures. These test procedures shall follow good engineering practice and shall be subject to approval by the TS operator, as appropriate for the requirement specified in Table 20. Commissioning tests may include, as applicable, operability and functional performance tests.

Commissioning Tests – Background

CrestCura

- IBR commissioning tests as specified for IEEE Std 2800 are tests conducted on-site on one or more IBR unit(s), supplemental IBR devices, and/or an IBR plant to verify through field testing that the installed IBR plant meets the requirements of that standard.
- Most tests performed on-site are used to provide data to validate the IBR plant models (within the limited operating conditions of the plant and transmission grid). The tests are limited to practically feasible small disturbance tests.
- On-site commissioning test procedures are not intended to guarantee IBR plant conformity with the IEEE 2800std

CrestCura

Commissioning Tests – Background

- Most tests are verification and documentation.
- Tests and verifications are intended to be performed after the IBR plant construction is complete and the plant is fully operational.

Commissioning Tests – Informal Categories

- Verification and Documentation – No testing only verification and documentation.
- Non-Specified Tests – Testing recommended without any specific details in 2800.2 standard.
  - Specifics may be called out in 2800-2022 and/or referenced to another standard.
- Specified Tests – Testing with specific details. May or may not have a pass/fail criteria.

Commissioning Tests – Verification & Documentation

- Verification and Documentation – No testing only verification and documentation.

  - 9.1 Measurement Accuracy
  - 9.2 Isolation Device
  - 9.3 Enter Service
  - 9.13 Harmonic Voltage Distortion
  - 9.14 Protection
  - 9.15 Measurement Data for Performance Monitoring and Validation

Commissioning Tests – Verification & Documentation

- 9.1 Measurement Accuracy
  - The subclause 4.4 in IEEE Std 2800-2022 specifies accuracy requirements for steady-state and transient measurements taken as specified throughout the IBR plant.
  - The accuracy of measurement equipment cannot be tested on-site during commissioning.
  - Confirm that the measurement accuracy of as-built equipment installed on-site meets the accuracy requirements based on manufacturer documentation.

Commissioning Tests – Verification & Documentation

- 9.2 Isolation Device

    - The subclause 4.8 in IEEE Std 2800-2022 specifies that when required by the TS operating practices, a readily accessible, visible break isolation device is installed between the TS and the IBR plant, meeting the requirements of the TS owner.

    - The IEEE Std 2800 does not specify any testable requirements. Verify that installed isolation device meets the requirements of the TS owner.

Commissioning Tests – Verification & Documentation

- 9.3 Enter Service

  - This requirement applies at the POM. Confirm and document that all control, relay, & protection settings meet the requirements of Table 3 of clause 4.10.2 of the IEEE Std 2800-2022.

  - If any these settings change, it is required to re-document that the changed settings still meet the requirements of Table 3, clause 4.10.2 of IEEE Std 2800-2022.

Commissioning Tests – Verification & Documentation

- 9.13 Harmonic Voltage Distortion
  - If possible, measurements of the background harmonic voltage conditions would be trended before the plant collection system (cable resonances) are energized. This data would be especially useful if the commissioning reveals issues.
  - IEEE 2800-2022 does not specify harmonic voltage disturbance limits.

Commissioning Tests – Verification & Documentation

- 9.14 Protection

  - The frequency, ROCOF, voltage, AC overcurrent, AC overvoltage, unintentional islanding, and interconnection system protection are all relevant to this evaluation.

  - All these protection requirements apply at the POC and the POM.

  - Verify that the on-site IBR plant (feeder or substation) level and where applicable the IBR unit protection settings do not conflict with the IBR plant ride-through capability and are consistent with the design evaluation that was performed (as described in clause 7).

Commissioning Tests – Verification & Documentation

- 9.15 Measurement Data for Performance Monitoring and Validation
  - Verify that the measurement equipment is located at the correct location.
  - Verify that the measurement device and recorded data meet the Table 19 of the IEEE Std 2800-2022.
  - Monitoring measurement equipment (e.g., digital fault recorders and other similar digital measurement equipment) should be installed and configured in the plant during commissioning.

Commissioning Tests – Non-Specified Tests

- Non-Specified Tests – Testing recommended without any specific details in 2800.2 standard.
  - Specifics may be called out in 2800-2022 and/or referenced to another standard.
    - 9.9 Voltage Disturbances within Continuous Operating Region
    - 9.10 Rapid Voltage Changes (RVC)
    - 9.11 Flicker

Commissioning Tests – Non-Specified Tests

- Non-Specified Tests – Testing recommended without any specific details in 2800.2 standard.
  - Specifics may be called out in 2800-2022 and/or referenced to another standard.
    - 9.9 Voltage Disturbances within Continuous Operating Region
    - 9.10 Rapid Voltage Changes (RVC)
    - 9.11 Flicker

Commissioning Tests – Non-Specified Tests

- 9.9 Voltage Disturbances within Continuous Operating Region
  - Testing for ensuring IBR plants can meet reactive power capability
  - 2800-2022 references
    - 4.7 Prioritization of IBR Responses
    - 5.1 Reactive Power Capability
    - 7.2.2.2 Voltage disturbances within continuous operations range

Commissioning Tests – Non-Specified Tests

- 9.9 Voltage Disturbances within Continuous Operating Region
  - 2800-2022 7.2.2.2 Voltage disturbances within continuous operations range
    - Voltage disturbances of any duration, for which the applicable voltage within the continuous operation region, shall not cause the IBR plant to trip from the TS. The IBR plant shall remain in operation during any such disturbance and shall continue to deliver pre-disturbance level of active power or available active power, whichever is less. Changes of active power are permitted in response to control commands in accordance with 4.6 or in response to other control settings. Temporary deviations of active power output are permitted as agreed upon between the IBR owner and the TS operator.
    - If the IBR plant cannot deliver both active and reactive power due to its current limit (or apparent power limit), when the applicable voltage is below 95%, then preference shall be given to active or reactive power according to requirements specified by the TS operator
    - Exceptions provided.

Commissioning Tests – Non-Specified Tests

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- 9.10 Rapid Voltage Changes (RVC)
  - Testing would not confirm worst case conditions, considering the variety of switching point on wave and remanence flux conditions possible for main power transformer energization.
  - 2800-2022 references
    - 8.1.2 Rapid Voltage Changes
    - The IBR plant shall not cause RVC at the RPA to exceed 2.5% of nominal voltage. The method for defining compliance with this RVC requirement shall be as specified in IEC 61000-4-30:2015/AMD1:2021 or later. Any exception to the limits is subject to approval by the TS owner with consideration of other sources of RVC within the TS.
    - These RVC limits shall apply to sudden changes due to frequent energization of transformers, frequent switching of capacitors, or from abrupt output variations caused by IBR plant misoperation. These RVC limits shall not apply to infrequent events such as switching, unplanned tripping, or transformer energization related to commissioning, fault restoration, or maintenance.

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Commissioning Tests – Non-Specified Tests

- 9.11 Flicker

  - Properly controlled plants should not cause objectionable flicker, but flicker measurements during commissioning are recommended.

  - IEEE 2800-2022 Reference
    - 8.1.3 Flicker

    - The IBR plant contribution (emission values) to the flicker, applied at the RPA, shall not exceed the greater of the limits listed in Table 16 and the individual emission limits determined as per the procedure described in IEC TR 61000-3-7 Section 9.117 Any exception to the limits may be allowed if accepted by the TS owner with consideration of other sources of flicker within the TS.

Table 16 —*IBR plant* flicker emission limits at the RPA[a]

E_{Pst}	E_{Plt}
0.35	0.25

[a] 95th percentile value of the measurements should not exceed the emission limit based on a one-week measurement period.

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Commissioning Tests – Specified Tests

- Specified Tests – Testing with specific details. May or may not have a pass/fail criteria.

  - 9.4 Reactive Power Capability
  - 9.5 Voltage and Reactive Power Control Modes
  - 9.6 Primary Frequency Analysis
  - 9.7 Fast Frequency Response
  - 9.8 Return to Service After IBR Plant Trip
  - 9.12 Harmonic Current Disturbance

Commissioning Tests – Specified Tests

- 9.4 Reactive Power Capability - Background

  - The subclause 5.1 in IEEE Std 2800-2022 specifies the minimum reactive power capability requirements for IBRs.
    - An IBR plant shall have the capability to inject and absorb a minimum reactive power defined by $|Q_{min}| \geq 0.3287 \times ICR$ at the RPA when injecting active power into the TS
    - An IBR plant shall have the capability to inject and absorb minimum reactive power defined by $|Q_{min}| \geq 0.3287 \times ICAR$ at the RPA when absorbing active power from the TS. The ICAR of an IBR plant may be less than ICR.
      - The minimum reactive power coefficient of 0.3287 corresponds to a reactive power at active power 1.0 p.u. and a power factor of 0.95, i.e., (1.0*tan(acos(0.95)).
    - IBR units shall have the capability to provide reactive power support when the primary energy source is available and not available, and during the transition between these two resource availability states.
    - IBR units shall have the capability to remain in service while not exporting or importing active power.
    - There is a number of specific technology and configuration caveats.

Commissioning Tests – Specified Tests

- 9.4 Reactive Power Capability - Background

  - The reactive power capability tests will only be achievable to the extent that TS and IBR plant operating conditions allow.
  - The results of such tests should not be taken as the final determining factor as to the actual reactive capability of the plant.
  - Evaluate if it is possible to coordinate with the TS owner/TS operator to adjust other nearby reactive resources to counter (lead and/or lag) the reactive power being injected or absorbed by the IBR plant.
  - The tests described should be performed and the reactive power should be held at the pre-defined steady state value for a duration agreed upon between the TS operator and the IBR plant operator (for example 5 to 10 minutes)

Commissioning Tests – Specified Tests

- 9.4 Reactive Power Capability - Procedure
  - Injecting Reactive Power
    - While carefully monitoring the voltages at the RPA and along the collector system, slowly increase injection of the reactive power from the IBR plant at the RPA towards the plant maximum reactive power capability
    - If at any point in time voltages on either the collector system or at the RPA approach undesirably high levels (i.e., close to planning and/or equipment limits) then immediately stop the test.
    - Record the level of reactive output achieved at the RPA, as well as the voltage and active power levels, and the reason for stopping (limiting factor) the test. Additionally, record the key collector system voltages within the IBR plant.

Commissioning Tests – Specified Tests

- 9.4 Reactive Power Capability - Procedure
  - Absorbing Reactive Power
    - While carefully monitoring the voltages at the RPA and along the collector system, slowly increase absorption of the reactive power into the IBR plant at the RPA towards the plant maximum reactive power capability.
    - If at any point in time voltages on either the collector system or at the RPA approach undesirably low levels (i.e., close to planning and/or equipment limits) then immediately stop the test.
    - Record the level of reactive output achieved at the RPA, as well as the voltage and active power levels, and the reason for stopping (limiting factor) the test. Additionally, record the key collector system voltages within the IBR plant.

Commissioning Tests – Specified Tests

- 9.4 Reactive Power Capability - Procedure

  - Prioritization of Reactive Power
    - If the IBR plant includes capacitor banks for reactive power control, then during commissioning, tests should be done for the compensation level (MVar, including the combination of multiple capacitor bank steps) that may result in high risk of resonance conditions (identified in the design evaluation study) and for the most common capacitor banks switching statuses.
    - The IEEE Std 2800-2022 requires the IBR unit(s)/plant to not trip during any such capacitor bank switching events regardless of the time between switching.
    - If any IBR unit(s) or the IBR plant trips, then POM and medium voltage (MV) bus (where the capacitor banks are located) voltage waveforms should be recorded for each capacitor bank step. Tripping of the IBR plant or any IBR unit indicates non-conformity with IEEE Std 2800.
    - The results of this test are not intended to be used for validating the IBR plant model.

Commissioning Tests – Specified Tests

- 9.4 Reactive Power Capability - Procedure

  - Test Procedure Recommendations
    - The reactive power capability tests may be repeated, when possible, at different IBR plant operating condition to capture different primary energy source conditions (e.g., low wind/solar and high wind/solar as well as various states of charge for BESS) and grid condition (e.g., N-1 contingency, different system loading condition, short circuit strength) to provide higher confidence in validating the IBR plant models.
    - For validating the IBR plant model, it is recommended that the IBR plant on-site test be performed at different active power outputs.

Commissioning Tests – Specified Tests

- 9.4 Reactive Power Capability – Data Analysis
  - Test Results Data Analysis
    - The results obtained from these commissioning tests should be used to validate the IBR plant simulation study results, by comparing the recorded measurement data o comparable conditions in the simulations.
    - To compare the simulation results with the measurements taken during the commissioning tests, it is also important to record TS, IBR plant, and critical IBR unit operating conditions, including the IBR unit terminal voltage.
    - While it may not be feasible to verify the full reactive capability of the IBR plant, it should be verified that the plant is capable of injecting and absorbing reactive power while producing active power and, in the case of IBRs that do not consist of Type 3 wind turbines, while not producing active power.

Commissioning Tests – Specified Tests

- 9.5 Voltage and Reactive Power Control Modes - Background
  - The subclause 5.2 in IEEE Std 2800-2022 specifies the voltage and reactive power control mode requirements for IBRs
    - The IBR plant shall provide voltage regulation capability by changes of reactive power output whenever the RPA voltage is in the continuous operation region for voltage.
    - When in voltage control mode, the IBR plant shall operate in closed-loop automatic voltage control mode to regulate the steady-state voltage at the RPA to the reference value, as adjusted by the droop function, to within 1% of the RPA voltage set point.
    - The voltage control system shall be capable of reactive power droop to provide a stable and coordinated response. The droop setting shall be settable and coordinated by the TS operator and IBR operator.

Commissioning Tests – Specified Tests

- 9.5 Voltage and Reactive Power Control Modes - Background

Table 5—Performance target range

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

Commissioning Tests – Specified Tests

- 9.5 Voltage and Reactive Power Control Modes - Background

  - For all the test procedures stated care should be taken not to push the plant to unsafe operating points.
  - Only one of the two tests specified needs to be performed.
  - In most cases the voltage step test specified is the easiest and most effective
  - The goal is to test the IBR plant response to a voltage change (ie. the change in reactive power in response to a change in voltage at the RPA).
  - Tests may be repeated, when possible, at different IBR plant and TS operating condition.

Commissioning Tests – Specified Tests

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- 9.5 Voltage and Reactive Power Control Modes – Test Procedure

  - Voltage Step Test
    - This test is performed by injecting a small (typically 1% to 3% of nominal voltage) step change into the voltage reference set-point (up or down) of the PPC.
    - Step voltage change is maintained for a minute or two. Then the step is removed.
    - The RPA voltage, PPC voltage reference, active power, and reactive power output of the IBR plant should be recorded for a minute or so before the step change, for the entire duration of the test, and for a minute or so after the step is removed to ensure all the dynamics are captured.

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Commissioning Tests – Specified Tests

- 9.5 Voltage and Reactive Power Control Modes – Test Procedure
  - Shunt Reactive Device Switching
    - In cases where a large enough switched shunt capacitor or reactor bank is available at or in the electrical vicinity of the point of interconnection then in coordination with the TS owner/TS operator a test can be performed where the shunt device is switched
    - Shunt device is to be kept in that state for a few minutes, and then switched back.
    - The shunt device should be large enough so that switching of it in or out causes a 1% or so change in voltage at the RPA.
    - The RPA voltage, active power, and reactive power output of the IBR plant should be recorded for a minute or so before the step change, for the entire duration of the test, and for a minute or so after the step is removed to ensure all the dynamics are captured.

Commissioning Tests – Specified Tests

- 9.5 Voltage and Reactive Power Control Modes – Test Procedure
  - Shunt Reactive Device Switching
    - In cases where a large enough switched shunt capacitor or reactor bank is available at or in the electrical vicinity of the point of interconnection then in coordination with the TS owner/TS operator a test can be performed where the shunt device is switched
    - Shunt device is to be kept in that state for a few minutes, and then switched back.
    - The shunt device should be large enough so that switching of it in or out causes a 1% or so change in voltage at the RPA.
    - The RPA voltage, active power, and reactive power output of the IBR plant should be recorded for a minute or so before the step change, for the entire duration of the test, and for a minute or so after the step is removed to ensure all the dynamics are captured.

Commissioning Tests – Specified Tests

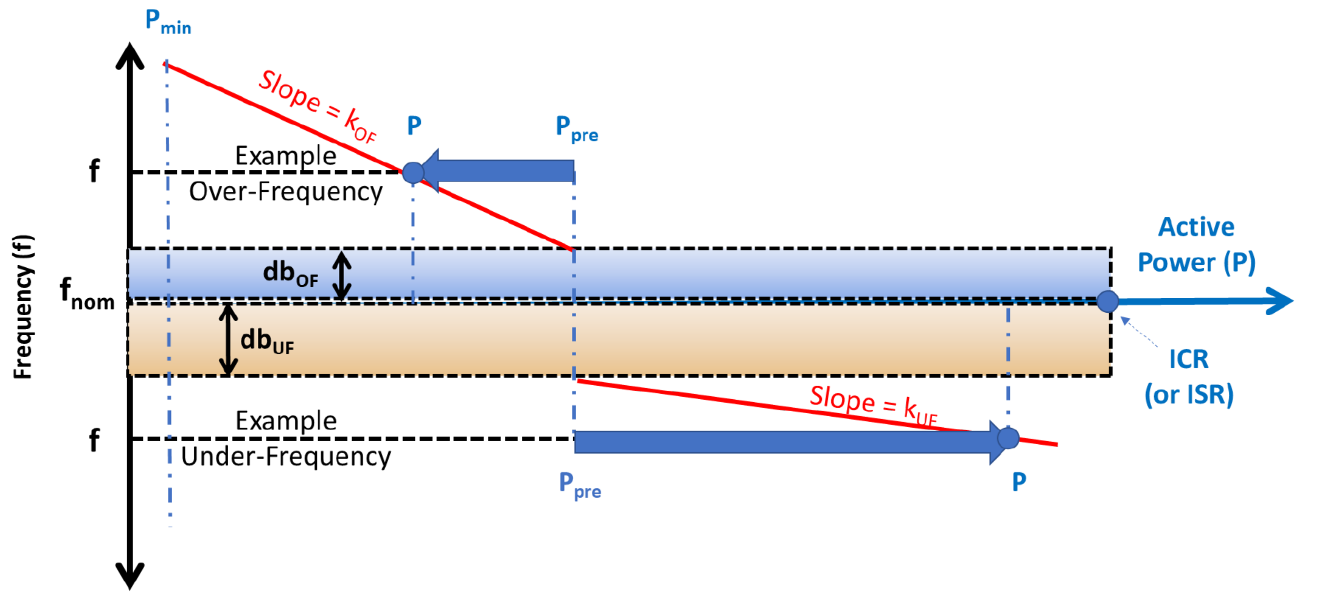
- 9.5 Voltage and Reactive Power Control Modes – Data Analysis
  - The recordings obtained from these commissioning tests should be used to assess conformity with reactive power and control mode requirements specified in clause 5.2 of IEEE Std 2800-2022.
  - The commissioning test results are also used to validate the IBR plant model.
    - . In order to compare the simulation results with the measurements taken during commission tests, it is also important to record TS and IBR plant operating conditions.

Commissioning Tests – Specified Tests

- 9.6 Primary Frequency Analysis - Background
    - The subclause 6.1 in IEEE Std 2800-2022 specifies the primary frequency response requirements for IBRs.
        - The primary frequency response function and overall response capability of an IBR plant shall meet the specified performance requirements at the RPA as shown in Figure 9 and Table 6.

Commissioning Tests – Specified Tests

- 9.6 Primary Frequency Analysis - Background



NOTE 1—Figure 9 shows examples of a frequency-droop characteristic which has different slopes for OF and UF conditions, illustrating *IBR plant* response to a similar frequency disturbance, in magnitude, produces a more aggressive response to UF condition compared to OF condition.

NOTE 2—There may be multiple droop characteristics for under-frequency and over-frequency conditions. While the specification may not change, different parameters may be specified by the *TS operator* for different frequency ranges.

Figure 9—Primary frequency response characteristic

Commissioning Tests – Specified Tests

- 9.6 Primary Frequency Analysis - Background

Table 6—Formula for frequency-droop (frequency-power) operation for low-frequency conditions and high-frequency conditions for *IBR plant*

Low frequency	$p = \min\{p_{avl}, p_{pre} + p_{PFR}\} = \min\left\{p_{avl}, p_{pre} + \max\left(0, \frac{f_{nom} - f - db_{UF}}{f_{nom} \times k_{UF}}\right)\right\}$ e.g., ICR = 100 MW, k_{UF} = 0.03 Hz/MW (0.05 p.u. droop), db_{UF} = 0.036 Hz p_{pre} = 50 MW = 0.50 p.u., p_{avl} = 51 MW = 0.51 p.u., f_{nom} = 60 Hz; f = 59.9 Hz, then $p = \min\{0.51, 0.50 + (60 - 59.9 - 0.036)/60/0.05\} = \min\{0.51, 0.5213\} = 0.51 \text{ p.u.} = 51 \text{ MW}$
High frequency	$p = \max\{p_{min}, p_{pre} + p_{PFR}\} = \max\left\{p_{min}, p_{pre} + \min\left(0, \frac{f_{nom} - f + db_{OF}}{f_{nom} \times k_{OF}}\right)\right\}$ e.g., ICR = 100 MW, k_{OF} = 0.024 Hz/MW (0.04 p.u. droop), db_{OF} = 0.036 Hz, p_{min} = 10 MW = 0.10 p.u. f = 60.1 Hz, p_{pre} = 50 MW = 0.50 p.u., then $p = \max\{0.10, 0.50 + (60 - 60.1 + 0.036)/60/0.04\} = \max\{0.10, 0.4598\} = 0.4598 \text{ p.u.} = 45.98 \text{ MW}$

Commissioning Tests – Specified Tests

- 9.6 Primary Frequency Analysis - Background

  - Before performing the PFR test it is important to coordinate and confirm that the TS owner/operator can safely operate the system when the IBR plant causes a temporary active power imbalance in the system.
  - The "fictitious" frequency step imposed on the measured frequency signal going into the PPC is large enough to be greater than the intentional deadband in the controls.
  - The IBR plant's output at the time of testing is such that the imposed step changes in frequency (or frequency reference) will not push the IBR plant to any of its limits (i.e. ICR, ISR, or the minimum active power).

Commissioning Tests – Specified Tests

- 9.6 Primary Frequency Analysis - Procedure

  - While performing this test the IBR plant controls and any supervisory controls (if used by the IBR plant) must be enabled, as is done for normal IBR plant operation.
  - This test should be performed by artificially injecting a signal (recommended to be a small step such as 0.2% to 0.5% or 125 mHz to 300 mHz for a 60 Hz system) on top of the frequency measurement signal going into the PFR controls.
  - The injected signal is maintained until the plant active power output has reached within the settling band and then is removed.
  - The data (frequency and IBR plant active power output) should be recorded prior to the start of the test, for the entire duration of the test, and until the plant active power output has reached the settling band after the signal is removed to ensure all dynamics are captured.

Commissioning Tests – Specified Tests

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- 9.6 Primary Frequency Analysis - Procedure
  - The PFR test should be performed for the following two operating conditions:
    - Test 1 – Frequency step test under normal IBR plant operating condition:
      - Since many plants typically always operate at the maximum power tracking point and thus have no headroom, the frequency signal injected will first be an increase in frequency (to make the IBR plant go down in power) and then the step is removed (to make the IBR plant go back up in power).
    - Test 2 – Frequency step test while IBR plant is curtailed for wind and solar (for BESS the output is below the inverter MVA rating):
      - In this test the IBR plant is intentionally curtailed, i.e., the active power output is deliberately reduced to below the available active power, and then the artificial step in frequency is first imposed to reduce the frequency signal (to make the IBR plant go up in power) and then the signal is removed (to make the IBR plant go back down in power).

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Commissioning Tests – Specified Tests

- 9.6 Primary Frequency Analysis - Procedure

  - NOTE—an alternative to the tests described is to impose the step change in the frequency reference of the PFR controls, rather than adding it to the measured frequency signal.
    - Keep in consideration that changing the frequency reference has the opposite effect to changing frequency (i.e., a step up in frequency reference will cause an increase in active power output, while a step down in frequency reference will cause a decrease in active power output).
  - The tests may be repeated, when possible, at different IBR plant and TS operating condition.
  - For IBR plants that are intended to be capable of absorbing active power (ie Battery Storage), the test should be conducted both while absorbing active power and while injecting active power.

Commissioning Tests – Specified Tests

- 9.6 Primary Frequency Analysis – Data Analysis
  - The recordings (frequency, active power output, etc.) obtained from these commissioning tests should be used to assess conformity with primary frequency response requirements specified in clause 6.1 of IEEE Std 2800-2022.
  - The commissioning test results are also used to validate the IBR plant model.
  - To compare the simulation results with the site measurement it is also important to record TS and IBR plant operating conditions.

Commissioning Tests – Specified Tests

- 9.7 Fast Frequency Response – Background

  - The subclause 6.2 in IEEE Std 2800-2022 specifies the fast frequency response requirements for IBRs.
    - The IBR plant shall have fast frequency response (FFR) capability for under-frequency conditions, with exceptions specified by the TS operator in coordination with the load balancing entity.
    - The IBR plant may also have FFR capability for over-frequency conditions as specified by the TS operator and the load balancing entity, and mutually agreed to by the IBR owner.
  - If the fast frequency controls are implemented at the IBR unit level, then the test may be performed individually or simultaneously on at least a significant sampling of IBR units
  - For PV and storage-based IBR plants, the measurement equipment, site conditions and test procedure for FFR is the same as for PFR for underfrequency conditions. This is because FFR control structures for PV and storage-based IBR plants are likely the same as the PFR control structures.

Commissioning Tests – Specified Tests

- 9.7 Fast Frequency Response – Wind Turbines
  - WTG-based IBR plants, on the other hand, most likely have an FFR controls with a different control structure.
  - For testing the FFR capability and performance of WTG-based IBR plants, the IBR plant should not be curtailed as FFR is required to be provided when the WTGs are operating at or above 25% of rated power.
  - While performing this test, best results are obtained if the wind speed before, during and after the test is fairly constant.
  - Changes in site wind speed conditions could cause significant discrepancy between the measured and simulated IBR plant FFR response.

Commissioning Tests – Specified Tests

- 9.7 Fast Frequency Response – Wind Turbines Procedure

  - A “fictitious” or a over riden frequency step signal should be introduced in the measured frequency signal at the input to the FFR controls at the POM and should be a step down in frequency
  - The step down in frequency should be large enough to emulate a sudden and large dip in system frequency. (ie 500 mHZ to 1 Hz)
  - The active power response of the IBR wind plant should be measured and recorded at the POM.
    - Note that this measurement and recording should begin before the frequency change and continue till the wind plant completely recovers back to its pre-disturbance operating point. The injected frequency should also be recorded. It is assumed that during this entire duration, the wind plant site condition does not vary significantly.
  - The tests stated may be repeated, when possible, at different IBR plant and grid operating conditions.

Commissioning Tests – Specified Tests

- 9.7 Fast Frequency Response – Data Analysis
  - The recordings (frequency, active power output, etc.) obtained from these commissioning tests should be used to assess conformity with the fast frequency response requirements specified in clause 6.2.1 of IEEE Std 2800-2022.
  - The commissioning test results are also used to validate the IBR plant model.

Commissioning Tests – Specified Tests

- 9.8 Return to Service After IBR Plant Trip

  - This requirement applies at the POM if applicable per agreement with the TS operator if the plant is offline due to the plant breaker being open or a plant shutdown. It needs to be ensured that a plant unintended startup does not occur.
  - Procedure:
    - Place the plant in a shutdown (or simulated trip) state.
    - One at a time, inject an out of bound signal (voltage or frequency signal, typically at PPC) from IEEE 2800-2002 4.10 Table 3 and attempt to start up the plant.
    - Ensure the plant does not startup (does not inject active power).
    - Return Table 3 conditions to allowable start up ranges. Attempt to start up the plant and ensure the plant starts up.

Commissioning Tests – Specified Tests

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- 9.8 Return to Service After IBR Plant Trip

Table 3—Enter service criteria for IBR plants

Enter service criteria		**Default settings**[c]	***Ranges of available settings***
Permit service	When enabled	Disabled	Enabled/disabled
Applicable voltage within range	Minimum value	Specified by *TS operator*	0.90 p.u. to 0.95 p.u.[a]
	Maximum value	Specified by *TS operator*	1.05 p.u. to 1.10 p.u.[b]
Applicable frequency within range	Minimum value	Specified by *TS operator*	0.98 p.u. to 0.99 p.u. (58.8 Hz to 59.4 Hz @ 60 Hz) (49.0 Hz to 49.5 Hz @ 50 Hz)
	Maximum value	Specified by *TS operator*	1.002 p.u. to 1.02 p.u. (60.12 Hz to 61.2 Hz @ 60 Hz) (50.1 Hz to 51 Hz @ 50 Hz)

[a] For an *IBR plant* connected to a weak grid, the minimum voltage value to *enter service* may be mutually agreed upon between the *IBR operator* and the *TS operator*.

[b] Voltages above 1.05 p.u. may be outside the current interrupting capability of fault-interrupting devices rated for maximum system voltage in accordance with ANSI C84.1.

[c] *Enter service* criteria should consider any limitations of various equipment inside the *IBR plant*.

Commissioning Tests – Specified Tests

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- 9.12 Harmonic Current Disturbance - Background
  - This section provides recommendations for testing relate to IEEE Std 2800 harmonic current limits.
  - Power quality meters that meet the requirements of IEC 61000-4-30 (Class A) should be used for this capture. Specifically, the instrumentation should use 200 msec windows, three-second average values, and trend min/max/average for one-minute intervals (for certain tests) or 10-minute intervals for longer periods of recording. Waveshape captures should also be captured for the range of output conditions.
  - It is important that the instrumentation record harmonic current (amperes) and not harmonic current percentage
  - Instrumentation frequency response must be appropriate to at least the 50th harmonic (3 kHz). Unless frequency compensation circuitry is installed with the capacitive coupled voltage transformers, the wound potential connections are preferred.

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Commissioning Tests – Specified Tests

- 9.12 Harmonic Current Disturbance - Background
  - It is recommended that monitoring be performed at both the HV point of measurement (POM) and also at the main plant MV collection bus.
  - Projects with multiple main power transformer (MPT) connections to the HV could be evaluated as individual units or summed together.

Commissioning Tests – Specified Tests

- 9.12 Harmonic Current Disturbance - Procedure

  - The monitoring should capture the plant at full generation output, at zero output, and at a range in between.
    - Generally, only a couple of daily cycles of wind or solar conditions are enough, but some projects monitor for one or two weeks to ensure these conditions.
  - If the project includes capacitor banks for reactive power control, then tests should be done of each possible compensation level (MVar, including the combination of multiple capacitor bank steps) to evaluate resonance conditions.
    - It is recommended that each step be monitored for at least 5 minutes, and that the monitoring capture be set to 1 minute min/max/average values. Waveforms should also be recorded for each capacitor bank step.

Commissioning Tests – Specified Tests

- 9.12 Harmonic Current Disturbance – Data Analysis
  - The data should be evaluated against the recommended current limits of IEEE Std 2800.
  - The data analysis should include timed trends showing harmonics against generation (real and reactive power levels).
  - The data analysis should include statistical evaluations (as recommended in IEEE Std 519-2022) of the CP95% (cumulative probability 95%) for the voltage and current values.
  - The data should be evaluated for consideration of harmonics that are being absorbed from the grid (usually 5th, 7th, 11th harmonics).
  - The data should be evaluated considering the achievable resolution and accuracy of the monitoring equipment.

Commissioning Tests – Specified Tests

- 9.12 Harmonic Current Disturbance – Report

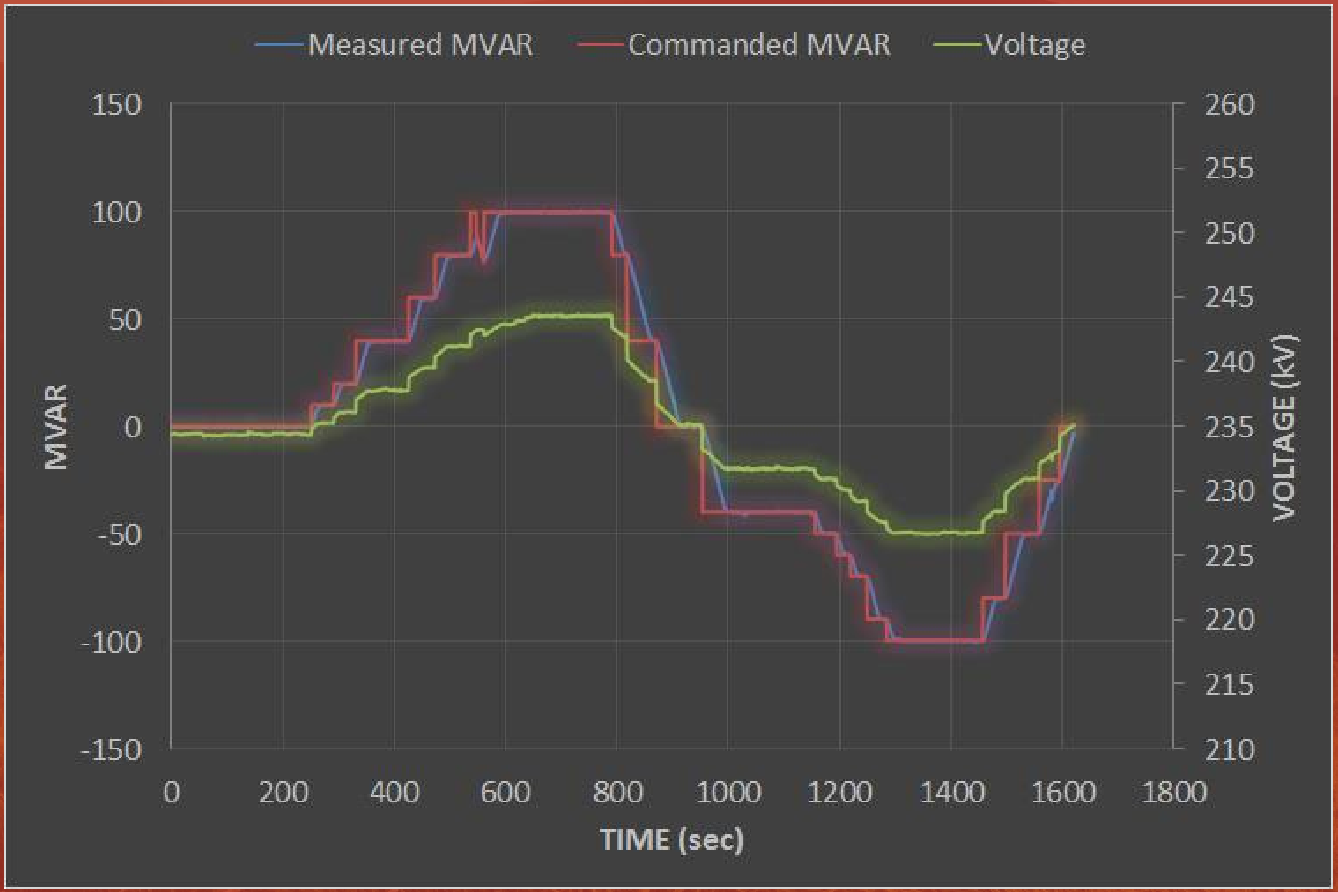
  - The report should include the overall plant characteristics, and the monitoring equipment used. It should also include trends of the voltage, current, and active and reactive power levels. Trends of the harmonic voltages and currents should also be included.
  - The report should include the statistical analysis as described above. It should include voltage and current waveforms from various operating conditions, along with the harmonic frequency spectrum of these waveforms.
  - The report should detail the capacitor bank testing results.
  - The report should include a summary of whether all of the recommended limits are being complied with, showing the measured values against the limits. It should include recommendation if all limits are not being complied with.

Commissioning Tests – Specified Tests

- 9.12 Harmonic Current Disturbance – Report
  - If the current limits are found to be exceeded, analyze if the harmonic currents contribute to an increase in the harmonic voltages. Also, if disconnecting the plant results in higher harmonic voltages, then this also would show that the plant harmonic currents to do not cause increased harmonic voltages.
  - If a harmonics study (design evaluation) was done, the report should compare results with the harmonic study. The harmonic study should be "trued up" to match the results from the field. Some variation from the study might be due to the changing grid harmonic impedance conditions.

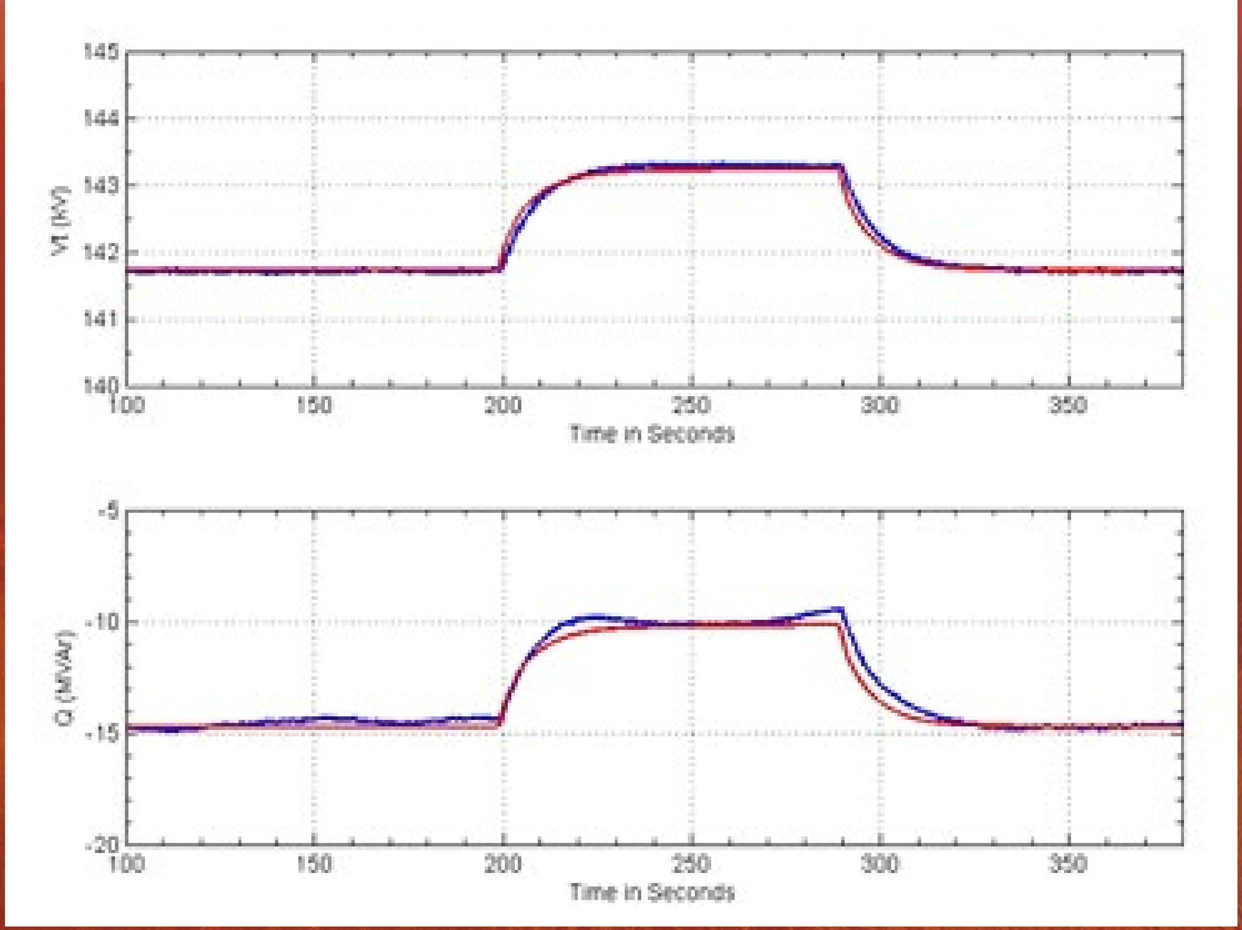
Commissioning Tests – Examples

Reactive Power Test (Zero MW Output)



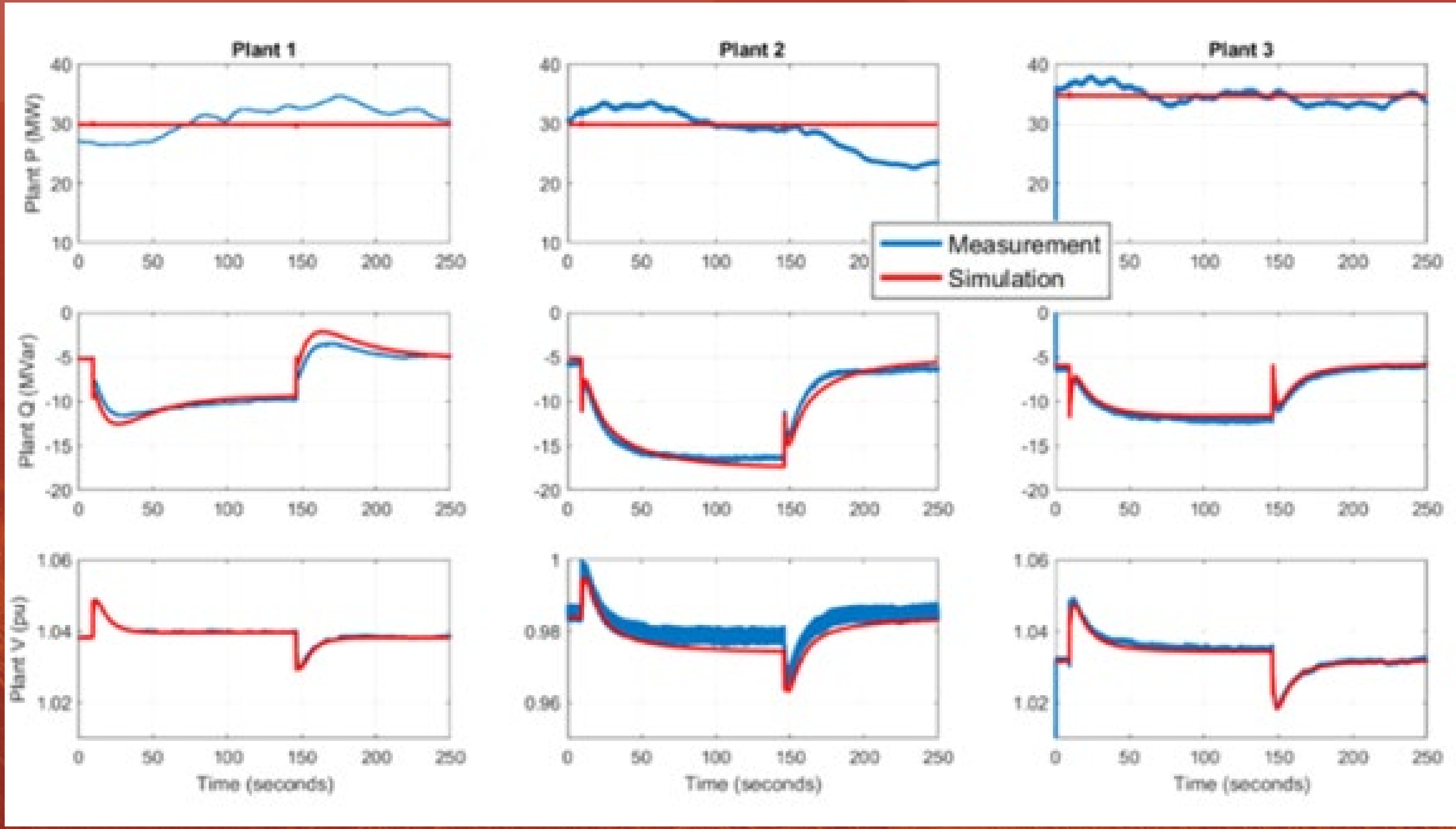
Commissioning Tests – Examples

Voltage Reference Step Test



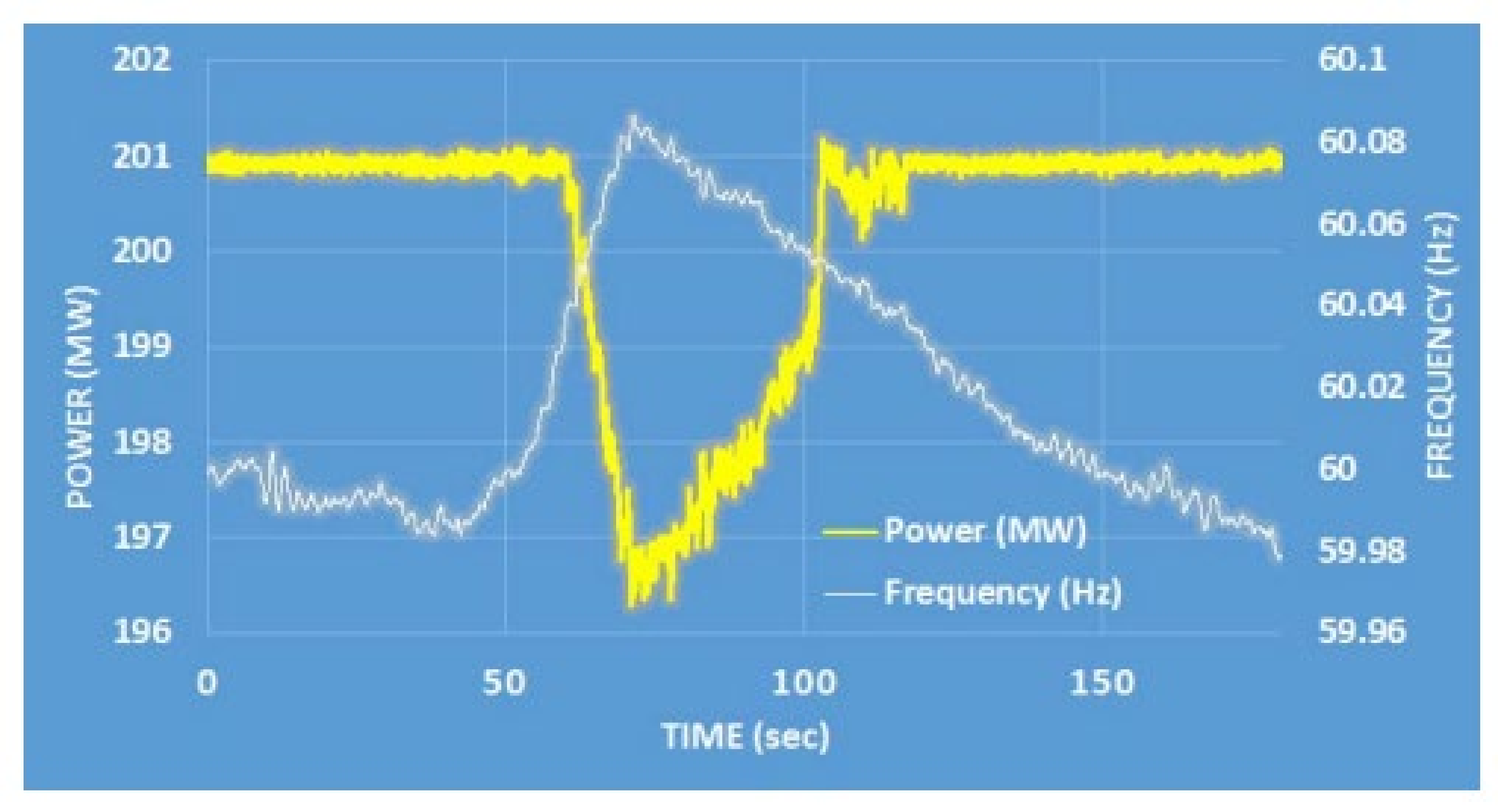
Commissioning Tests – Examples

Voltage Reference Step Test using capacitor switching (WTG)



Commissioning Tests – Examples

Solar Frequency Response Test



OEM Perspective: IBR Plant Design Evaluation through Testing and Modeling

i2X FIRST Hybrid Workshop: Interconnection Standards Workshop with the Focus on Conformity Assessment

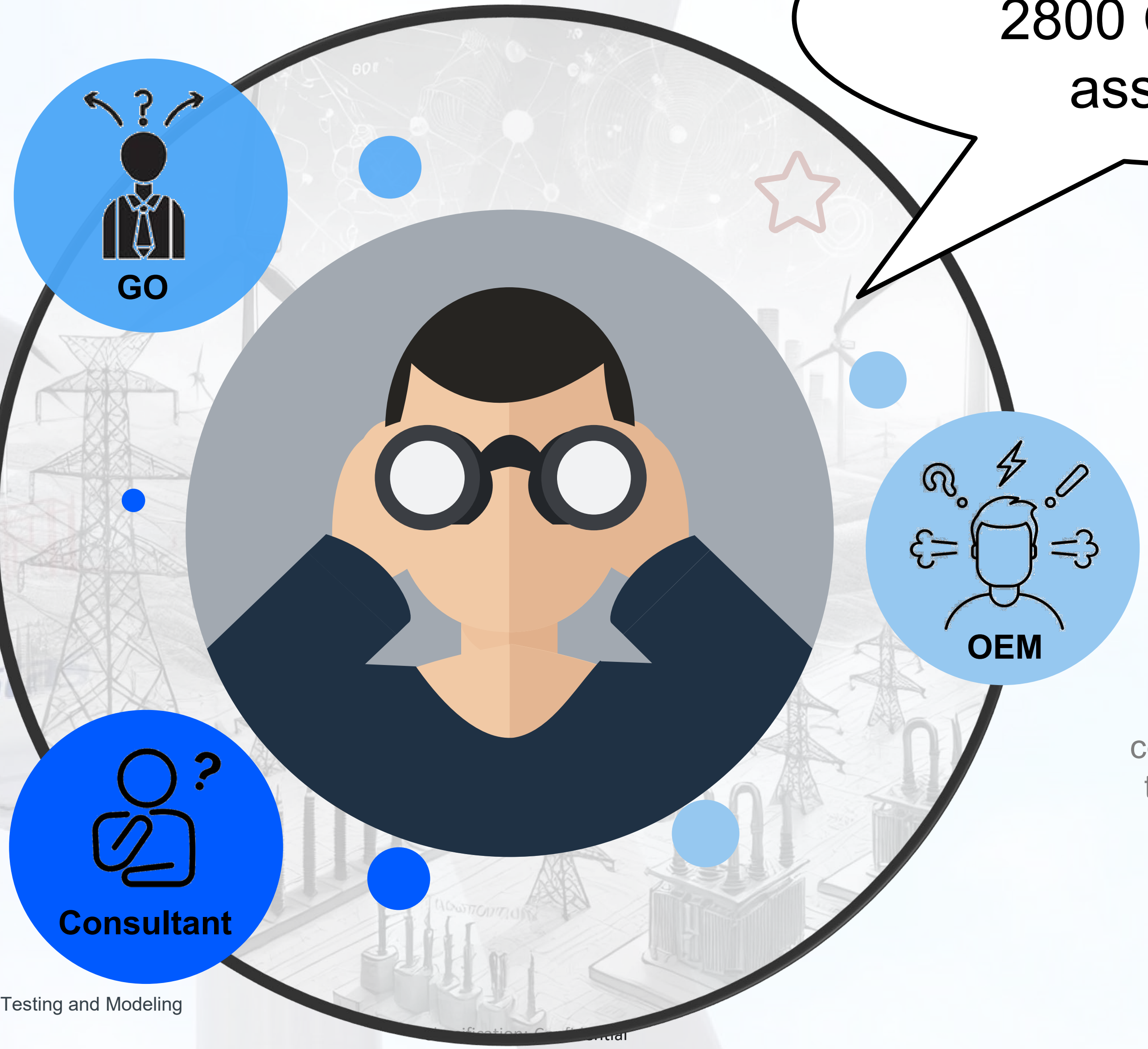
Miguel A. Cova Acosta

Plant Compliance Responsibility

GO – OEM - Consultant

Looking for IEEE 2800 Compliance assessment

GO aims to assess the compliance of both existing and new projects with IEEE 2800 standards and local implementation requirements



Consultants state they lack a complete overview of the generating units' capabilities and compliance criteria

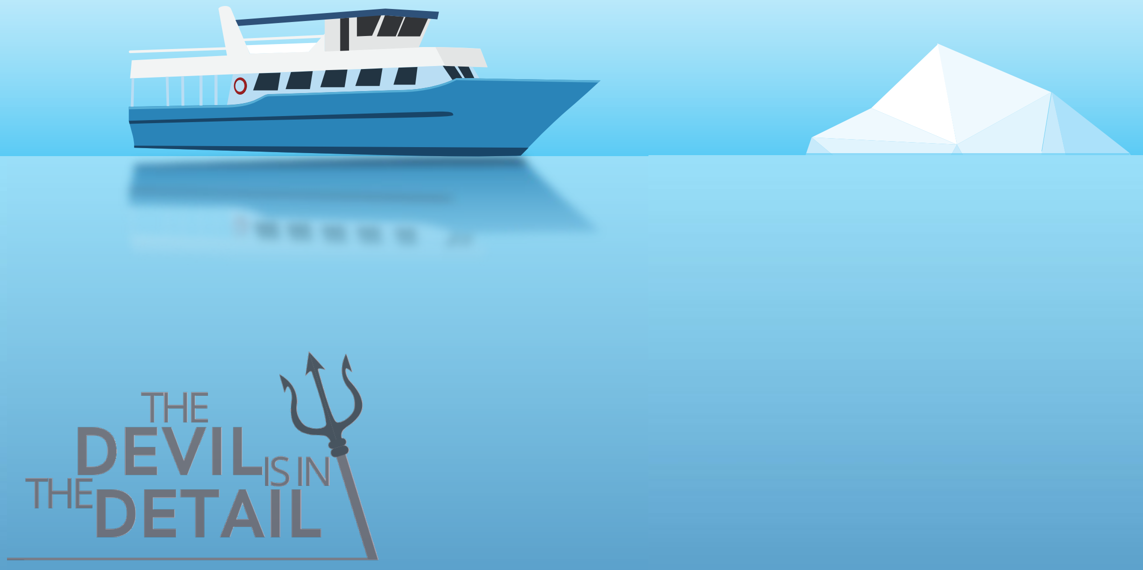
The OEM states that compliance is determined at the point of interconnection and is specific to each project and not WTG level.

Vestas

IEEE 2800-2022 – Full Picture

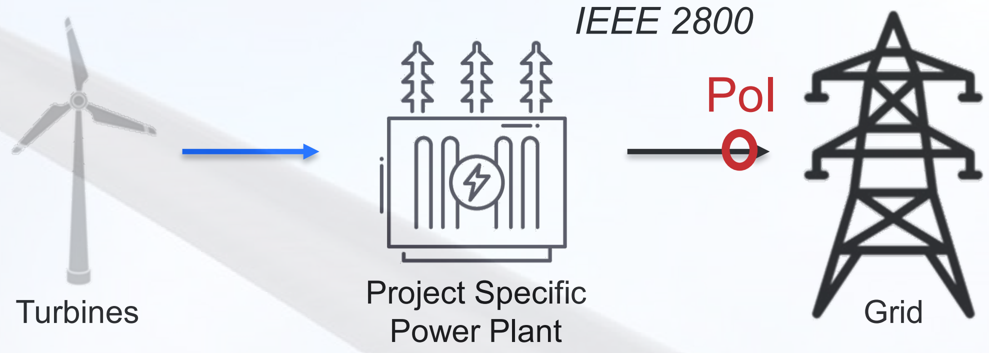
Known

- Reactive power / voltage control requirements within the continuous operation region (Clause 5)
- Active power / frequency response requirements (Clause 6)
- Response to TS abnormal conditions (Clause 7)
- Power quality (Clause 8)
- Protection (Clause 9)
- Modelling (Clause 10)



IEEE 2800-2022 Compliance

3 Way Catch-22 Paradox

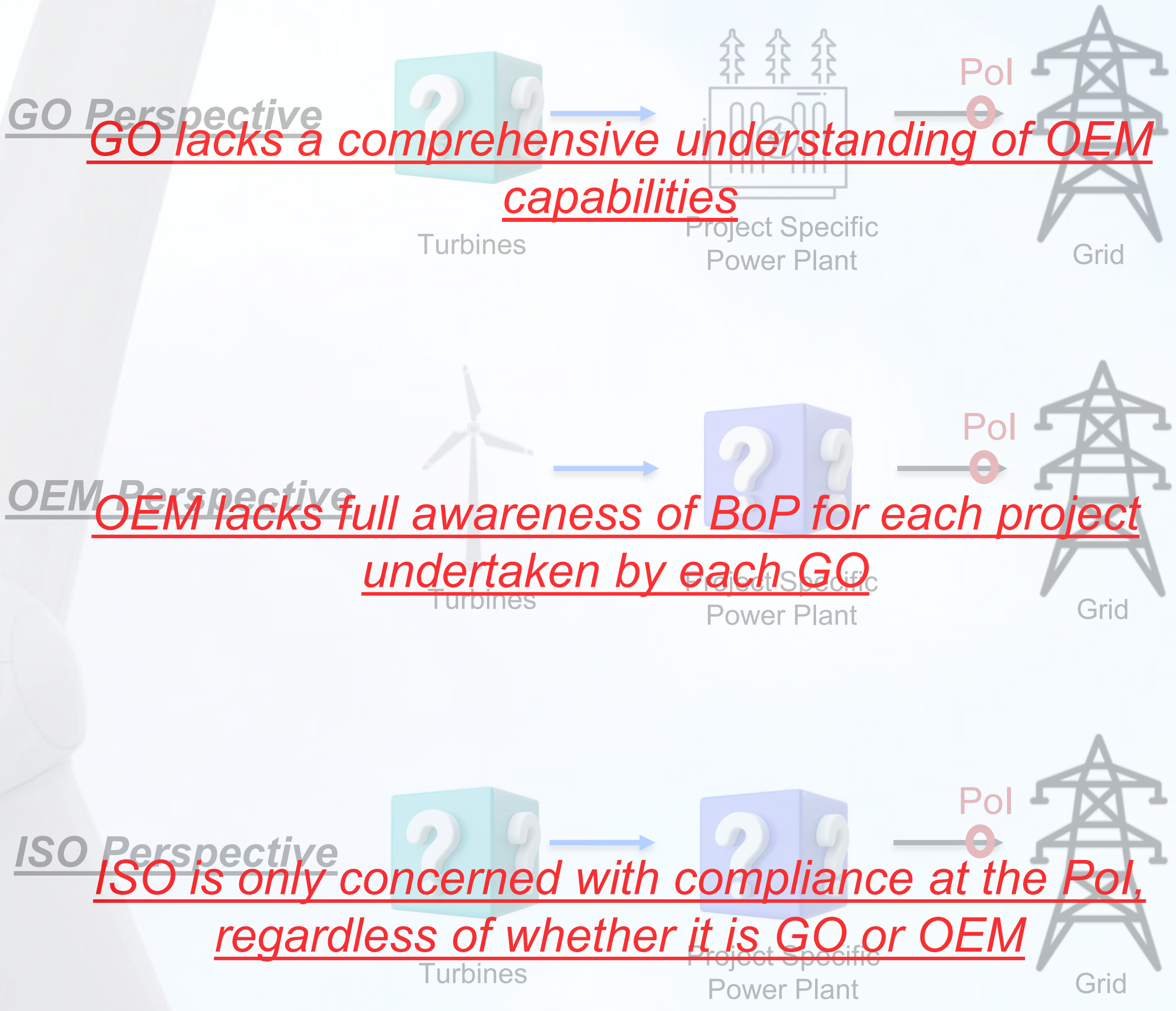


Evaluation Criteria

- Operational Points
- Loading Factor
- Project specific control tuning

Project Specific Conditions that will affect the compliance outcome:

- Grid Stiffness
- Single Line Diagram/Reactive Compensation devices
- PPC Configuration (Control strategy)
- Nearby IBR plants
- Others



GO lacks a comprehensive understanding of OEM capabilities

OEM lacks full awareness of BoP for each project undertaken by each GO

ISO is only concerned with compliance at the PoI, regardless of whether it is GO or OEM

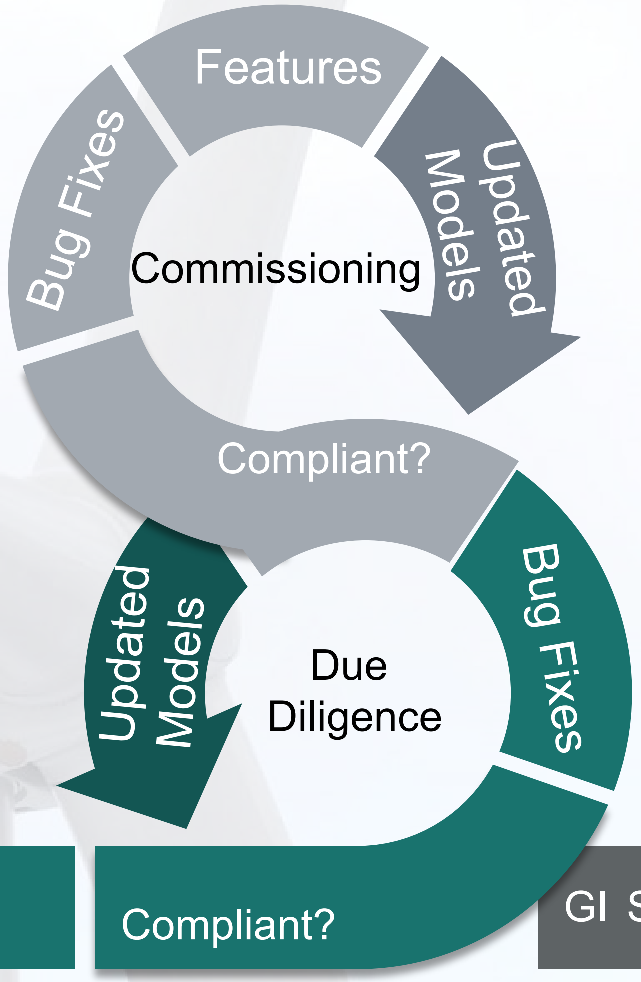
24 October 2024

Plant Model Lifecycle

- *Active and Reactive Current Profile*
- *LVRT Recovery timings*
- *Control Bandwidths*
- *PLL PI Control Constants*
- *Reactive Controller Constants*
- *Negative Sequence Support*
- *Grid Harmonic Damping*
- *Post Fault Support*

Plant Lifecycle

- Plant is recurrently reconfigured to mitigate potential grid connection issues
- Models are updated based on bug fixes or new features for real product
- Constant monitoring of performance and usability for Grid Code Compliance



New Project
Beginning of model cycle release for a new potential sales project

Operational Project
Ending of lifecycle when project is energized and delivering full power to grid

Preliminary Models | GI Studies | Mature Models | Compliant? | GI Studies | Plant Connection

Simulation Buckets required for IEEE Compliance Assessment

4 Main Groups

0. EMT Model Validation

1. Model consistency and Robustness

- Verify RMS vs EMT BoP models
- Assess model accuracy limitations

2. Grid Compliance Demonstration

- Project specific grid compliance and stability demonstration

3. Commissioning

- Verifies compliance with grid stability, frequency control, and other technical requirements.

Vestas Power Plant - Software and Grid Interconnection Tools

4 Pillars of Automation

Access to Models – Library Repository
Immediate access to simulation models available for SW release – No Need extra development.

Contingency Analysis Automation
Reduce to minimum the repetitive work to simulate contingencies for grid interconnection studies. Reduce the human mistakes and repetitive work

Project plant layout model Automation
Reduce the time spent by Engineers in building plant layout in simulation tools manually. Reduce the human mistakes and repetitive work

Grid Code Project Compliance
Automate report generation and grid compliance check. Automate Grid interconnection requirements for model submission

0804.2019

Step by Step IEEE 2800.2 Compliance Verification

How to be prepared?

Step 1: Source Code Integration

Ensure that OEM source code is integrated into both PSSE and PSCAD models for seamless operation across Power System simulation tools

Step 2: Unified Parametrization

Implement identical and swappable parameter settings between RMS and EMT tools, ensuring consistency in model performance across both systems.

Step 3: BoP Model Consistency

Ensure that BoP modelization is identical between RMS and PSCAD, particularly to maintain the same short circuit current contributions in both platforms.

Step 4: Automated Case Simulations

Automate the process of running contingency simulation scenarios, enhancing efficiency and accuracy during system studies.

Step 5: Model Agreement Evaluation

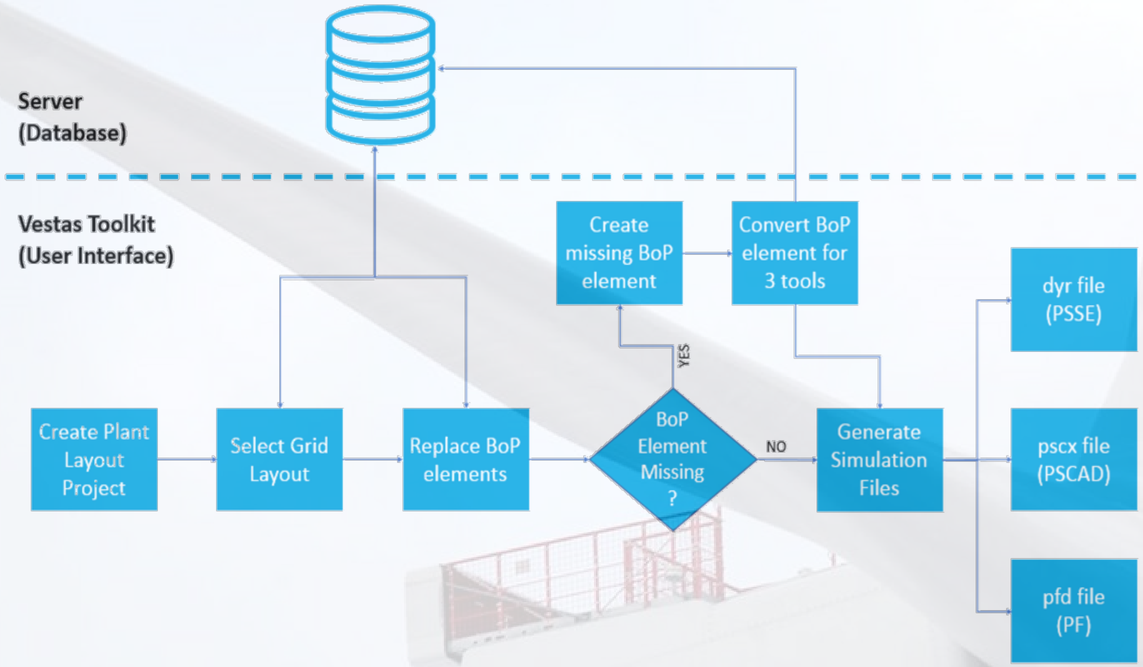
Develop automated processes to evaluate the agreement between RMS and EMT models, ensuring that the output and performance are aligned.

Step 6: Grid Code Compliance

Automate the evaluation of model compliance with grid code requirements, integrating these checks into the simulation process.

Automation – Vestas Approach

Consistent Plant Modelling & Agile Automation



Toolkit - Agility

- Model released in required plant layout
- No plant layout need to be maintained and/or developed
- Centralize database with plant layout & BoP Components
- No model integration is needed in project specific plant layout

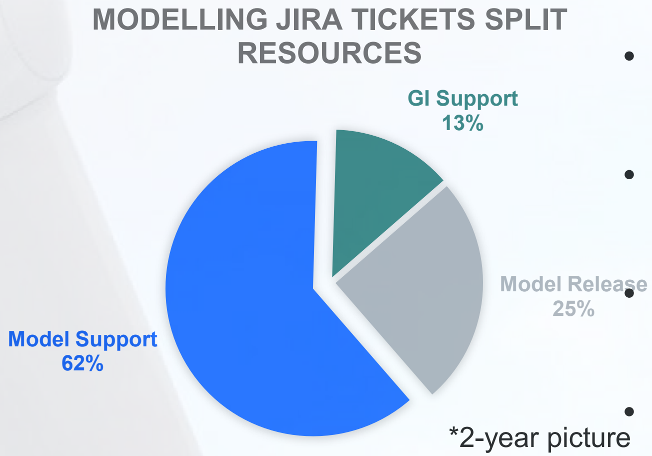
Consistency across tools

- Plant Modelling is carried out in a unified manner
- Full alignment in plant modelling between PSCAD vs other tools (like PSSE)

Smooth benchmark across simulation tools

2-3 FTE saved by doing smart plant release

Reduce LD risk exposure due to delay during grid interconnection process



*2-year picture

- Fail to benchmark different software tools
- Around 2 FTE debugging plant model misconfiguration
- Delay on Grid Interconnection Process
- 15-30 h saved on building plant models per project

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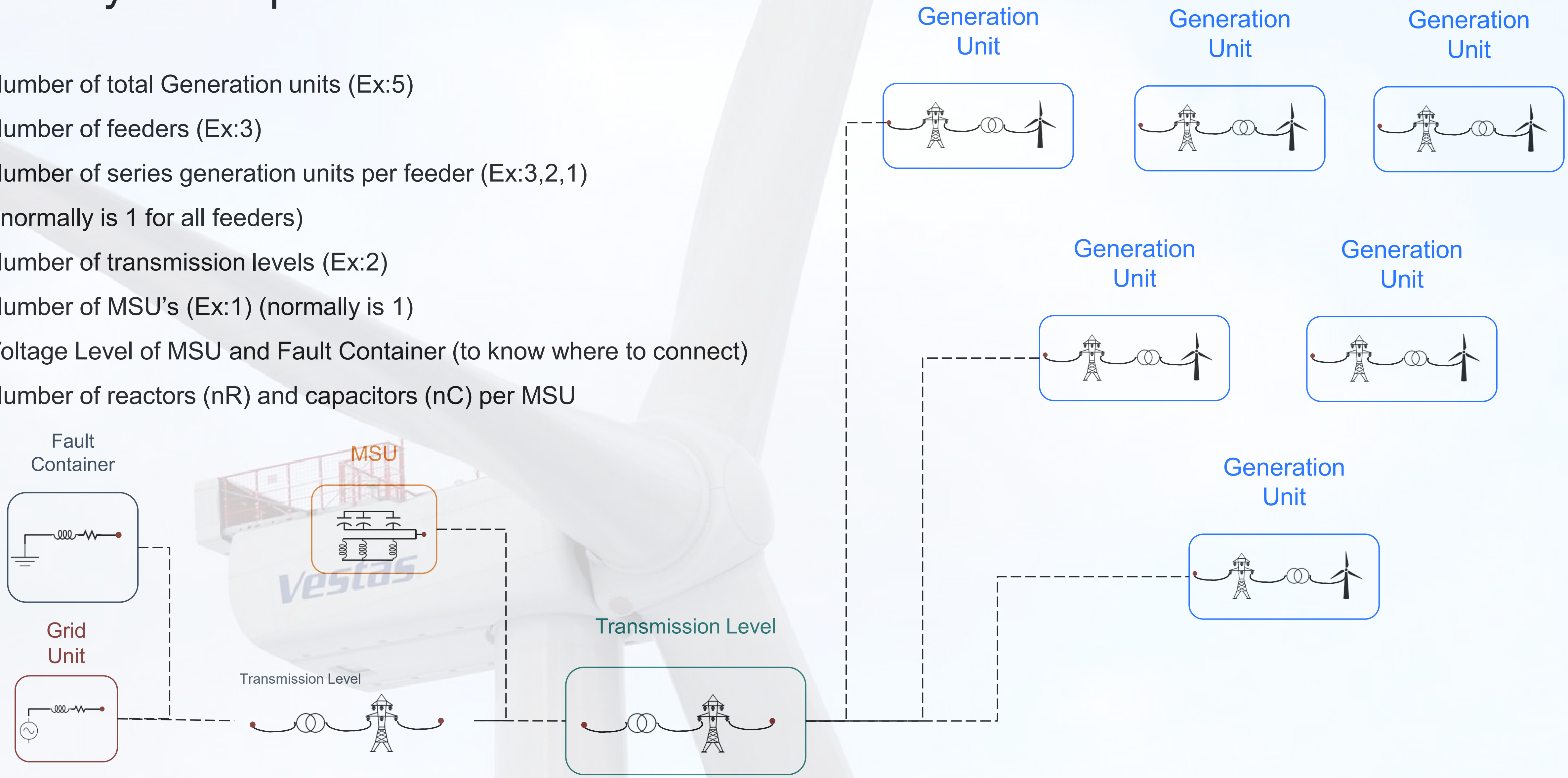
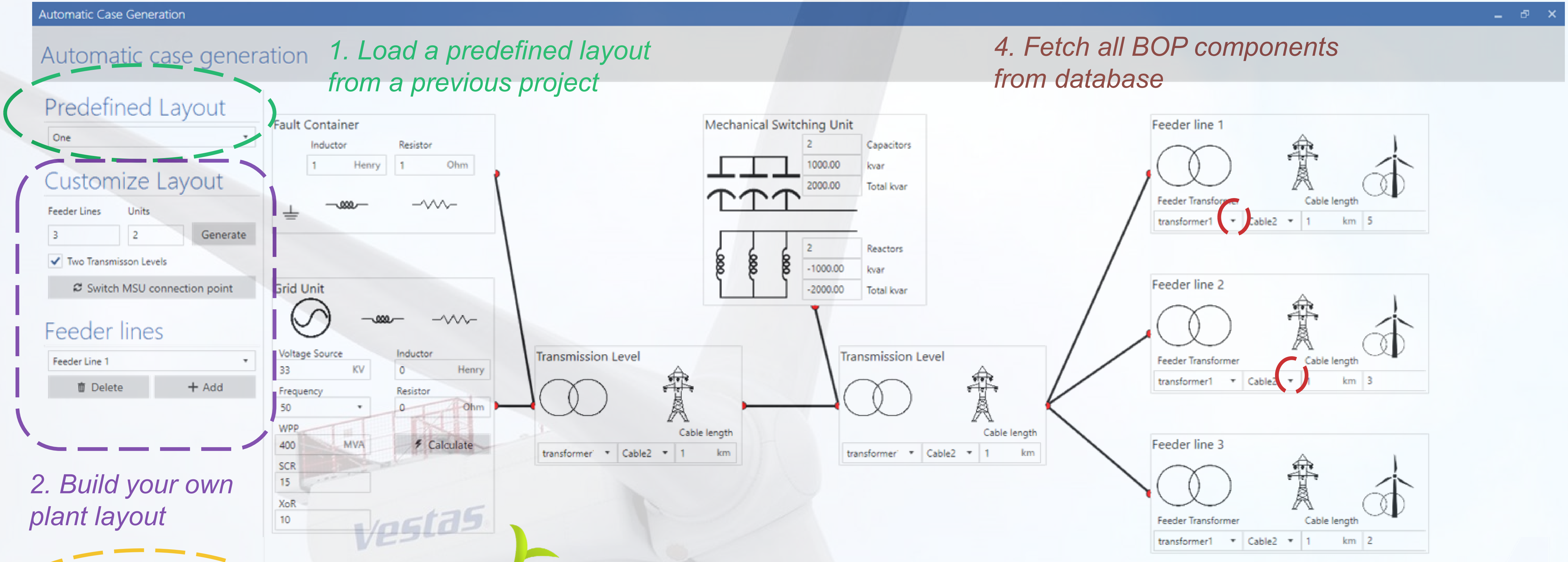
Plant Layout - Inputs

- Number of total Generation units (Ex:5)
- Number of feeders (Ex:3)
- Number of series generation units per feeder (Ex:3,2,1)
- (normally is 1 for all feeders)
- Number of transmission levels (Ex:2)
- Number of MSU's (Ex:1) (normally is 1)
- Voltage Level of MSU and Fault Container (to know where to connect)
- Number of reactors (nR) and capacitors (nC) per MSU



Automatic Case Generation

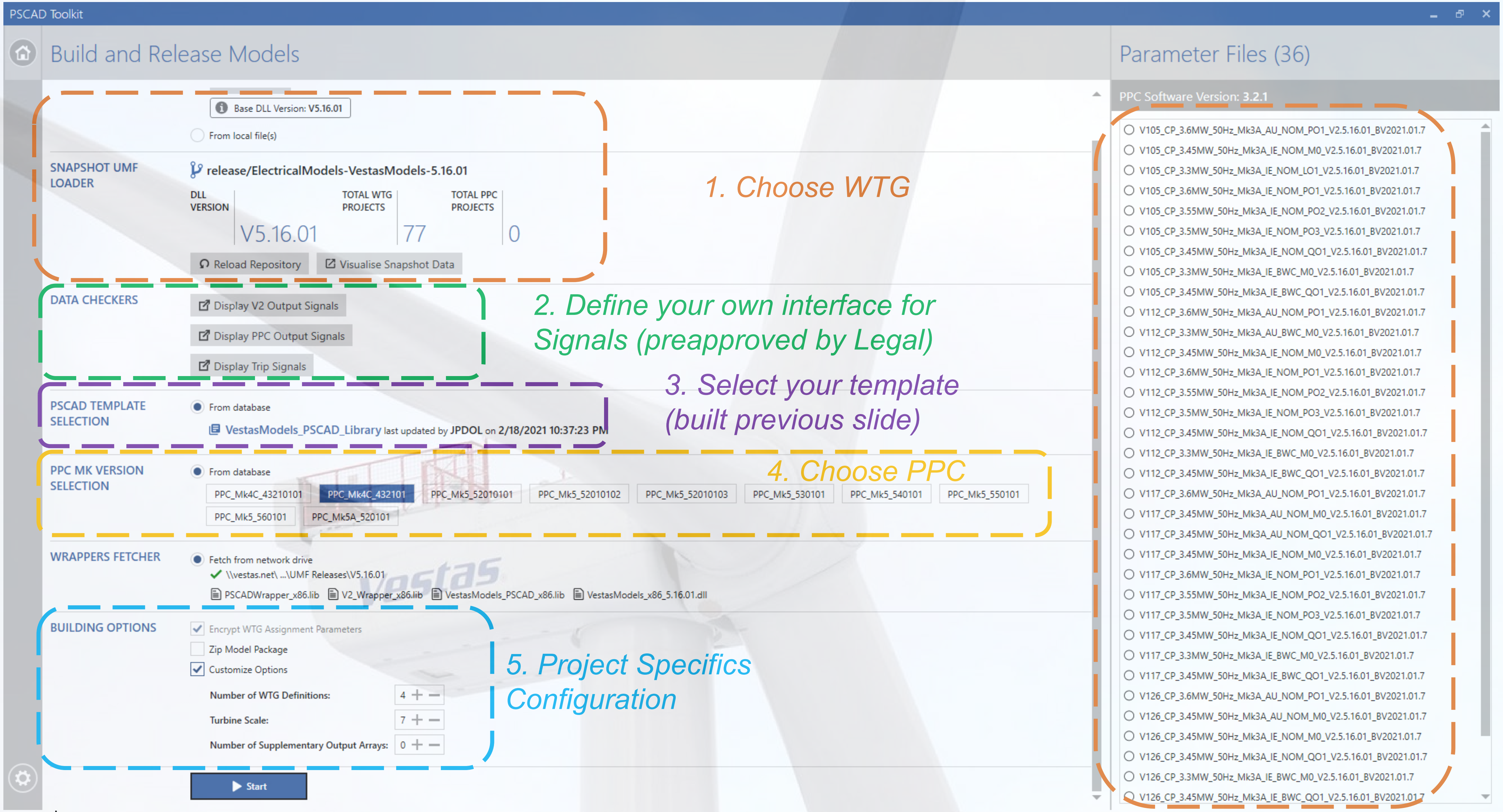


3. Load a user defined layout

UNIQUE
seed to generate all simulation tools

Power Factory PSCAD PSSE

Automatic Case Generation



1. Choose WTG

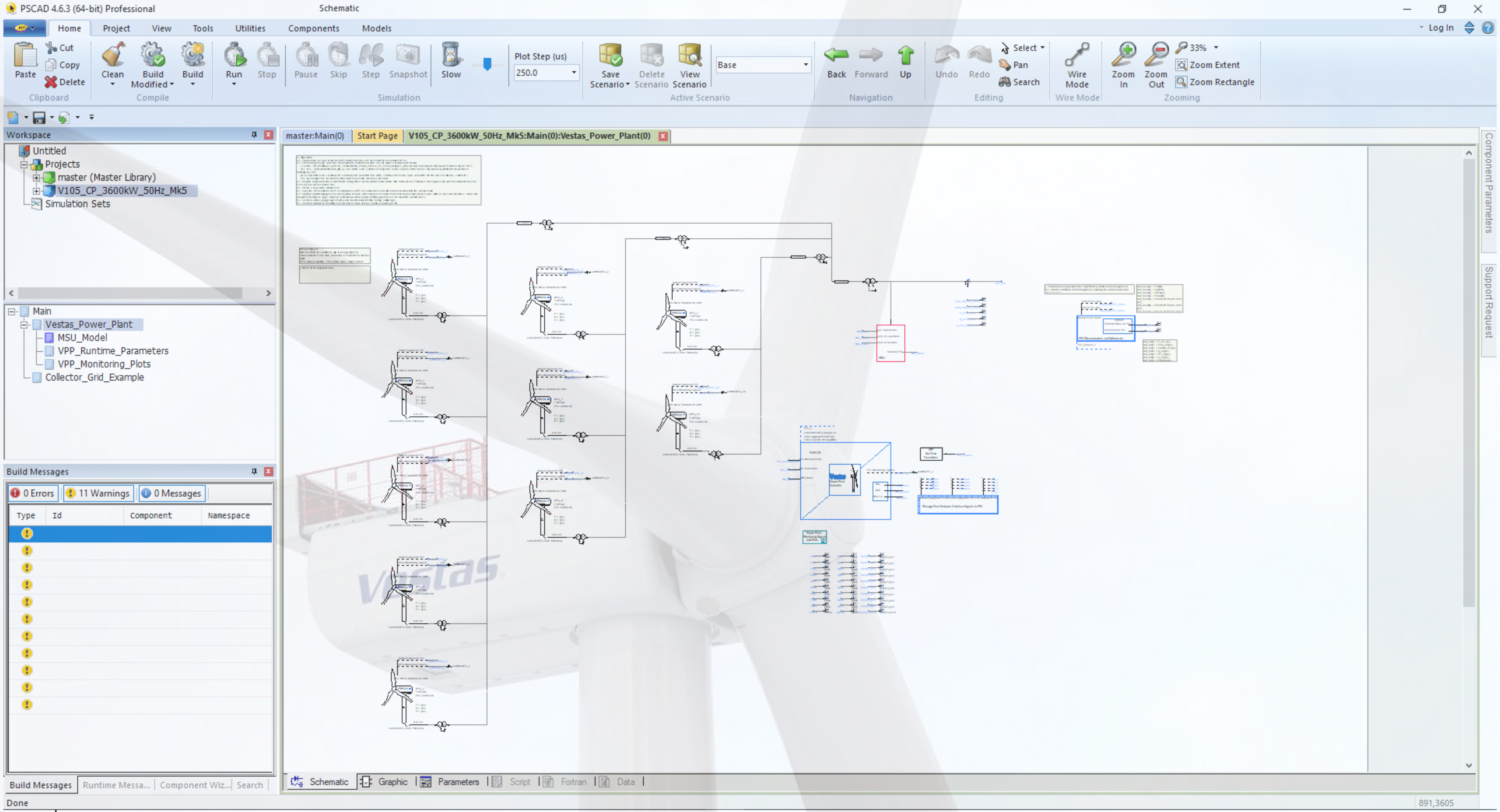
2. Define your own interface for Signals (preapproved by Legal)

3. Select your template (built previous slide)

4. Choose PPC

5. Project Specifics Configuration

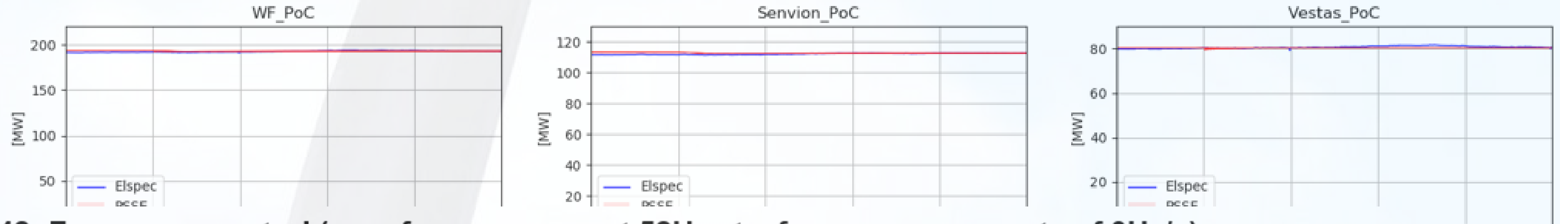
Automatic Case Generation



Validation Example

Automation is the key

S5.2.5.13 – Voltage reference – Step #14



5.3.6 Case 35: FRT-23 (Fault Impeda

5.3.13 Case 42: Frequency control (over frequency event 52Hz at a frequency ramp rate of 3Hz/s)

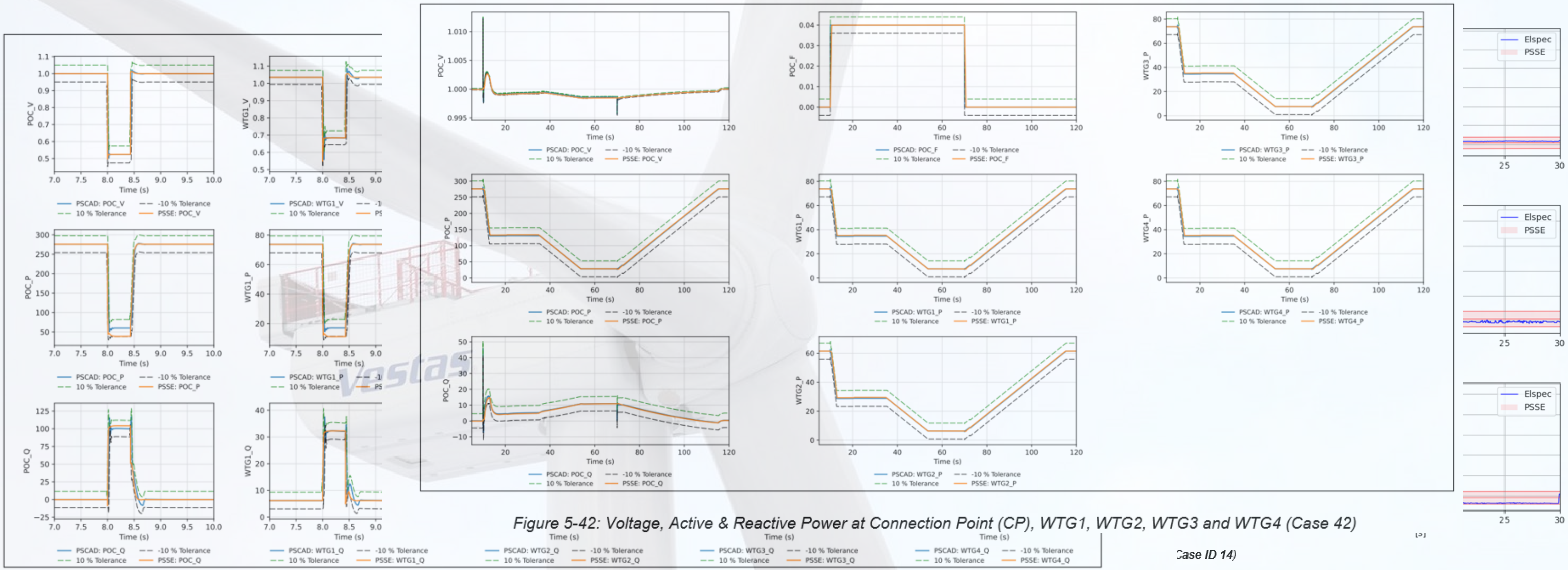


Figure 5-42: Voltage, Active & Reactive Power at Connection Point (CP), WTG1, WTG2, WTG3 and WTG4 (Case 42)

Case ID 14)

Figure 5-35: Voltage, Active & Reactive Power at Connection Point (CP), WTG1, WTG2, WTG3 and WTG4 (Case 35)

Thank You

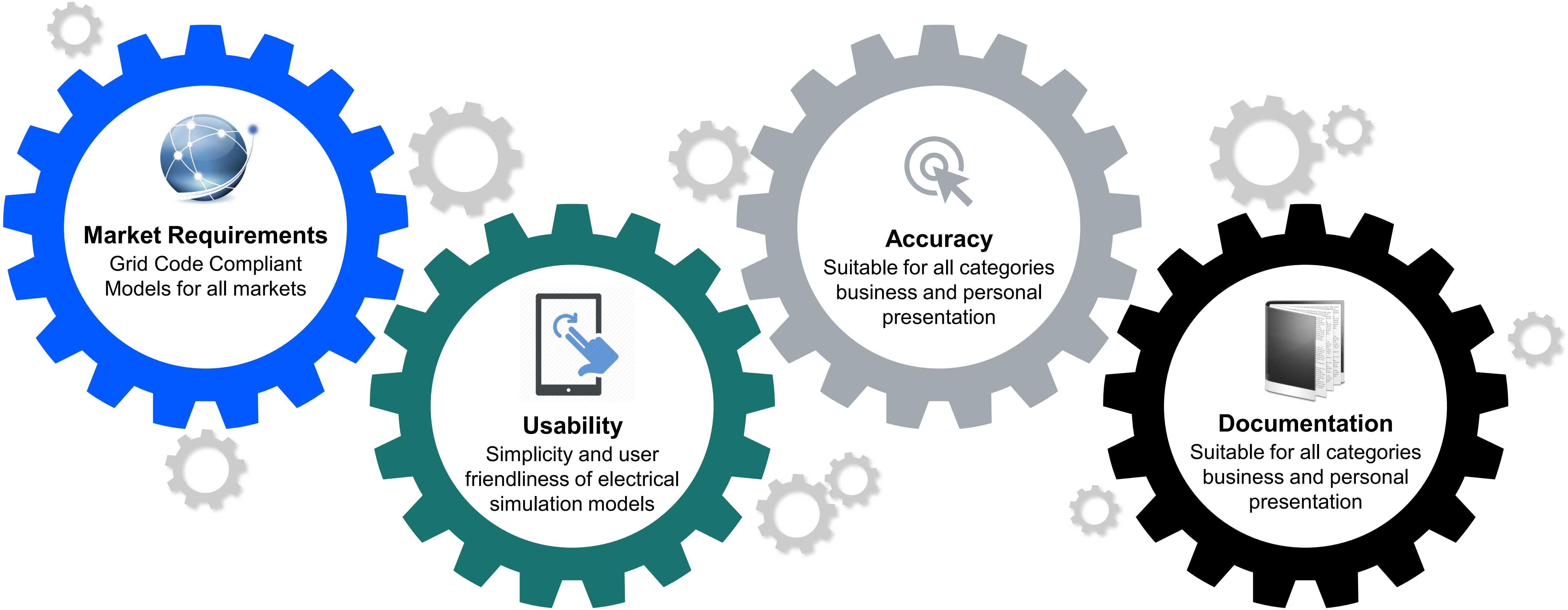
OEM Perspective: IBR Unit Model Validation

i2X FIRST Hybrid Workshop: Interconnection Standards Workshop with the Focus on Conformity Assessment

Miguel A. Cova Acosta

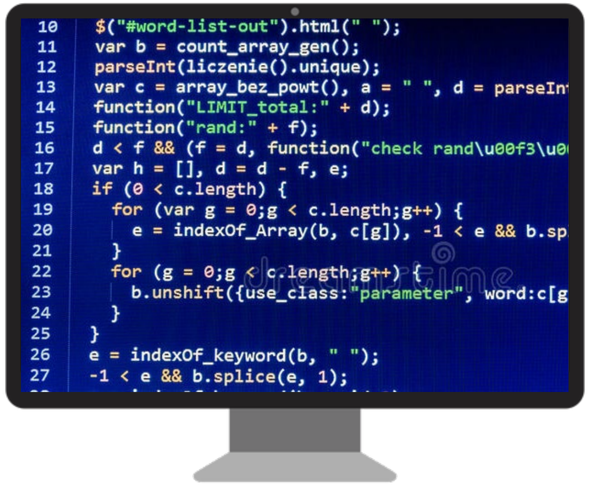
Vestas Model Development

Model Products Gears

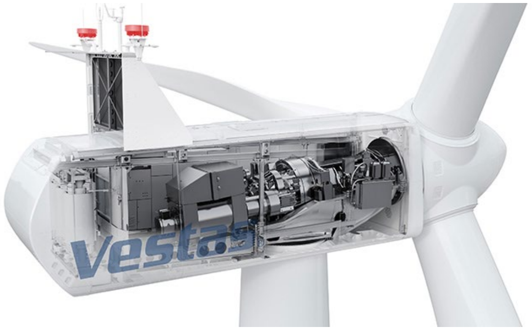


Digital Twin: Electrical Simulation Models vs. Product

UMF: One Library, Many Simulation Tools



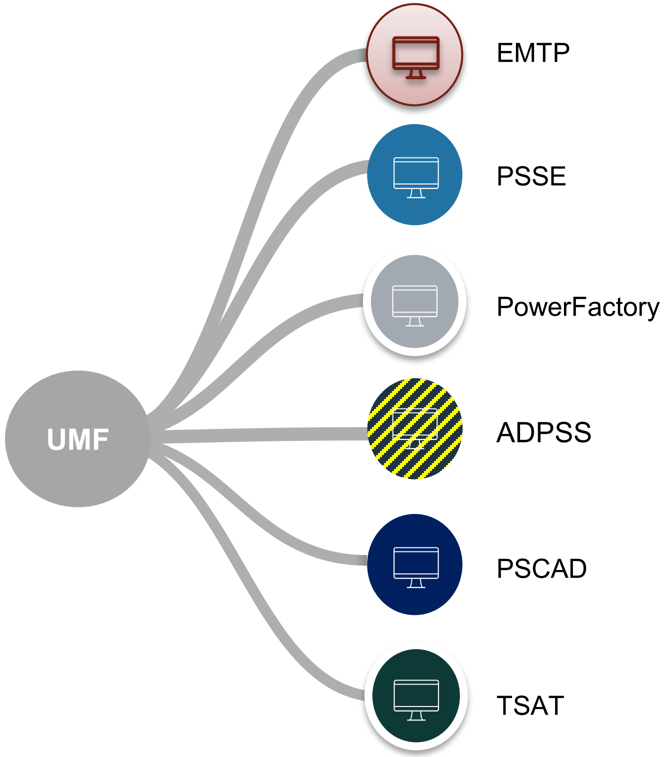
Product Software
Source Code



Wind Turbine
Generator

Power Plant Controller

Encrypted
*.dll File



Unified Model Framework (UMF)

(Used Across Commercially Available
Power System Simulation Tools)

Source code represents the main control code for wind turbines and/or Power Plant Controller. *Source code* is the actual control code that is installed in the real hardware and operates the real product.

Model Validation and Product Design

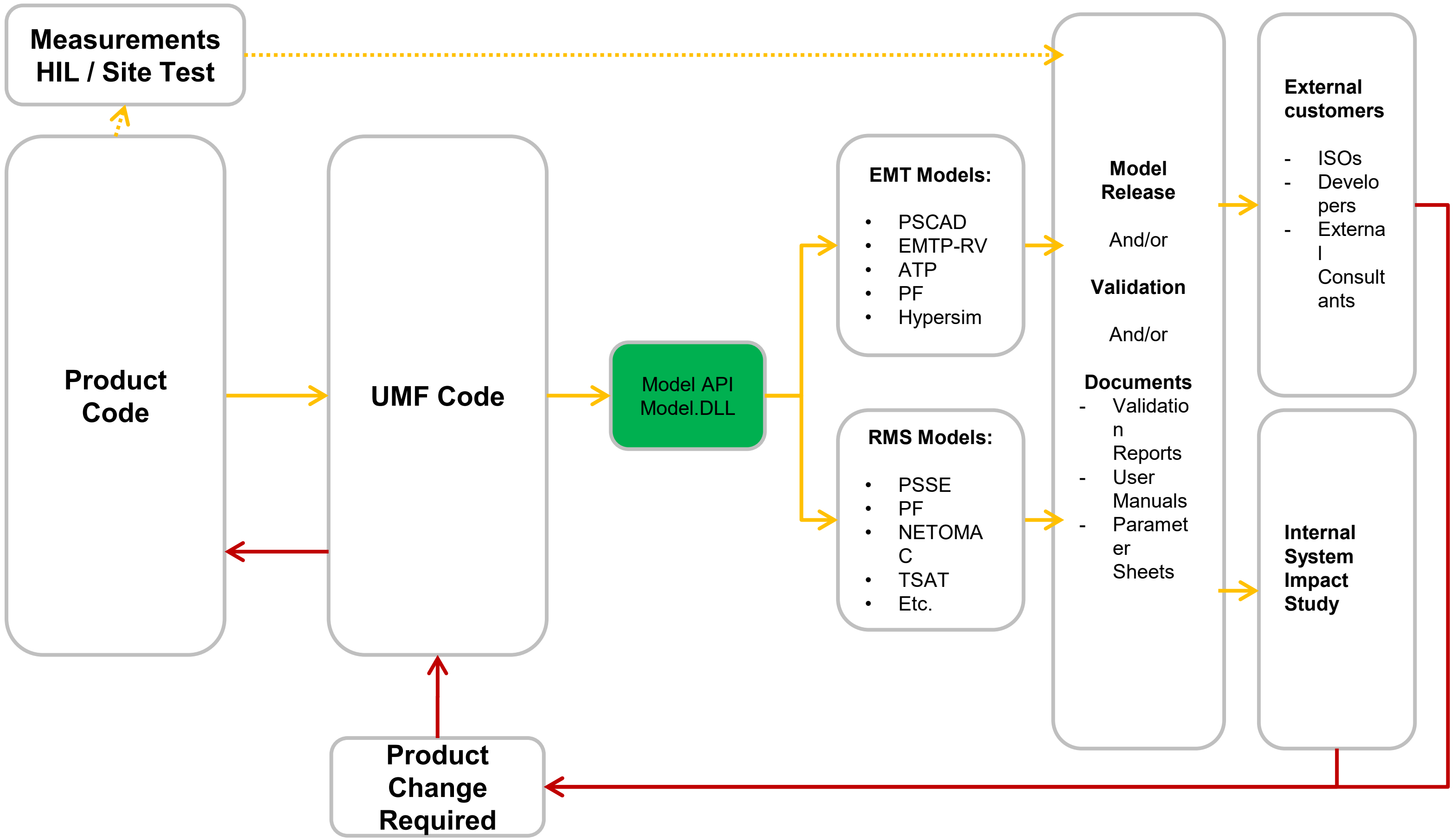
Product To Model – Model To Product

Use cases

- Time-critical software updates
- Product performance modifications to support grid stability
- Change orders requested by ISO/Developer

Timeline

- Product to Model Code – 1-2 hours
- Model to Product Code – 1-2 hours
- Product Integration and HIL test varies on the update
- Model Release and parameter Extraction 0.5h
- Documentation Auto Generated
- Validation is automated



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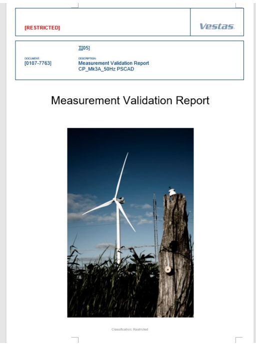
Model Validation

What are we looking at?

It's extremely important to define a Tolerance Criteria

International Electrotechnical Commission

FGW

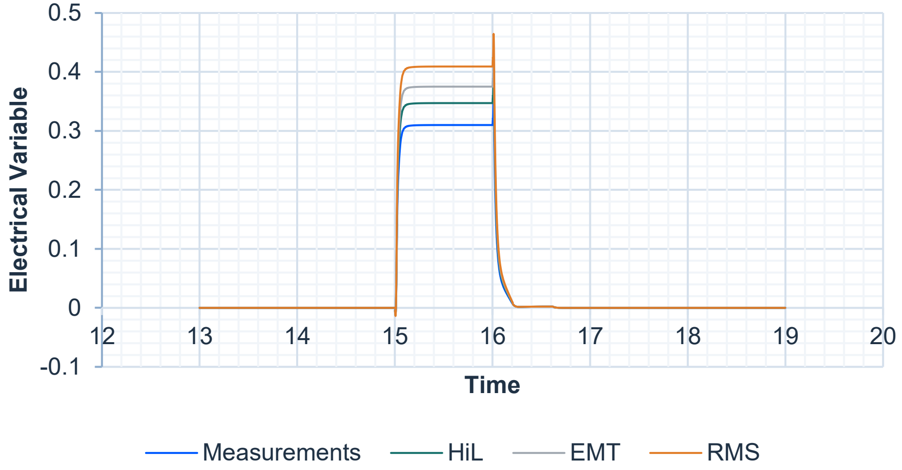


	Pre Fault						Fault						Post Fault					
	MA		ME		MAE		MA		ME		MAE		MA		ME		MAE	
	Tol [pu]	Dev [pu]	Tol [pu]	Dev [pu]	Tol [pu]	Dev [pu]	Tol [pu]	Dev [pu]	Tol [pu]	Dev [pu]	Tol [pu]	Dev [pu]	Tol [pu]	Dev [pu]	Tol [pu]	Dev [pu]	Tol [pu]	Dev [pu]
Case 1																		
P_pos	0.150	0.009	±0.100	-0.002	0.120	0.003	0.500	0.007	±0.130	0.000	0.300	0.002	0.500	0.014	±0.150	0.002	0.170	0.003
Q_pos	0.150	0.003	±0.100	0.001	0.120	0.001	0.550	0.047	±0.280	0.004	0.380	0.004	0.790	0.015	±0.150	0.006	0.220	0.006
Ip_pos	0.150	0.033	±0.100	-0.001	0.120	0.002	0.700	0.030	±0.300	0.002	0.630	0.003	0.530	0.015	±0.150	0.003	0.170	0.004
Iq_pos	0.150	0.003	±0.100	0.001	0.120	0.001	0.510	0.062	±0.290	0.006	0.350	0.006	0.760	0.015	±0.170	0.006	0.220	0.006
Case 2																		
P_pos	0.150	0.013	±0.100	-0.003	0.120	0.003	0.500	0.018	±0.130	0.002	0.300	0.003	0.500	0.012	±0.150	0.001	0.170	0.003
Q_pos	0.150	0.006	±0.100	0.001	0.120	0.001	0.550	0.076	±0.280	0.000	0.380	0.003	0.790	0.042	±0.150	0.016	0.220	0.016
Ip_pos	0.150	0.044	±0.100	-0.002	0.120	0.003	0.700	0.033	±0.300	0.002	0.630	0.005	0.530	0.012	±0.150	0.001	0.170	0.004
Iq_pos	0.150	0.007	±0.100	0.001	0.120	0.001	0.510	0.191	±0.290	-0.001	0.350	0.004	0.760	0.043	±0.170	0.017	0.220	0.017
Case 3																		

We must avoid moving targets. Reference is the key!

Example

- Measurements vs HiL on Site ≈ +/-5% - **Validated ?**
- HiL vs EMT ≈ +/- 8% **Validated ?**
- EMT vs RMS ≈ +/- 10% **Validated ?**
- Measurement vs RMS ≈ ???



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Model Validation Variances

Power System Model Validation Types

Model vs Real Contingencies
Model validation based on real contingencies occurring in operating wind farms

Model vs HiL
Model validation against Hardware in the Loop setup

Model vs Model
Model validation based on the power system tool nature (RMS/EMT)

Model Validation Types
Depending the purpose, different validation options are available for UDM

Model vs SiL
Model Validation against Software in the Loop setup

Model vs Park Performance
Model validation used for plant commissioning

Model vs Field Test
Model validation based on measurement campaigns during product design

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HIL

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Model validation based on measurement campaigns during product design

Expected Simulations in Real Time

Typical Simulation Studies evaluated by TSO

Reactive Power Capability:

- Capability curves covering 90%-110% operating voltage range,
- Capability curves for temperature derating curves.

Voltage Disturbances:

- Response to contingency events and capability for reactive support as well as response to UVRT and OVRT events
- Settings of protection systems.
- Voltage and reactive power control capabilities
- Voltage protection system
- Capability curve (for OVRT and UVRT) showing the range of voltages for which the WTG can ride through
- Shunt and series voltage compensation transient response

Frequency Disturbances:

- Study how frequency is derived by PLL.
- Application of df/dt and applicable trip settings to assess the operating conditions.

Fault rid trough events:

- Reactive and current injection profile during balanced faults
- Reactive and current injection profile during unbalanced faults
- PLL angle tracking during FRT transition
- Consecutive FRT events to evaluate multiple FRT protections

Global Projects & TSO/ISO

Real Time Projects – SiL/HiL Models

Projects under Execution

- 4 Projects in Heibei Region in China – 500 MW
- 1 Project in Shetland Islands in the Northern Atlantic – 450MW
- 1 Project in Tasmania - TBD
- 1 Research Project in EU – InterOpera R&D Project Consortium
- Multiple global internal EPC Vestas projects – Several GW

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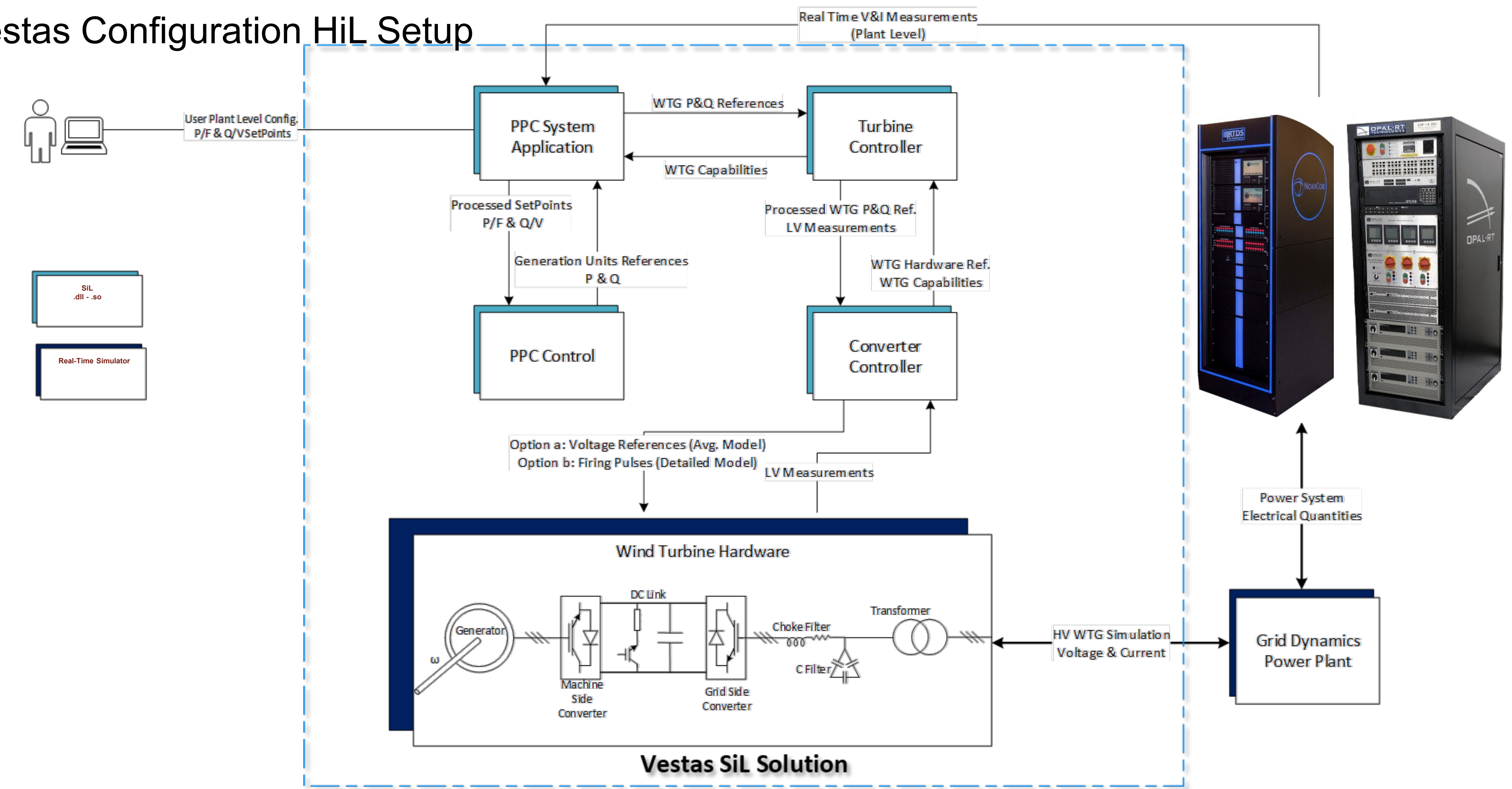
Model vs HiL Validation

Vestas Configuration HiL Setup



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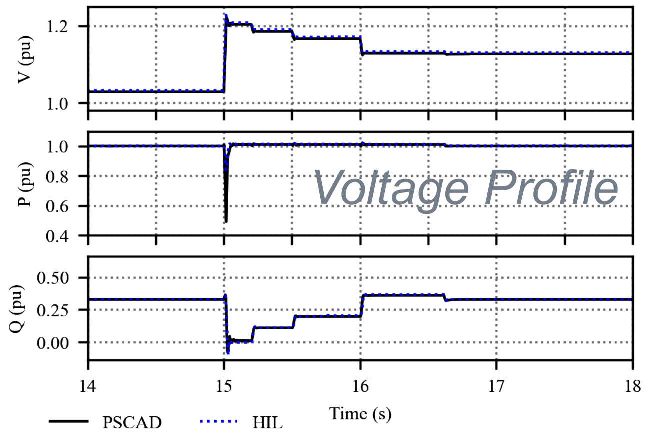
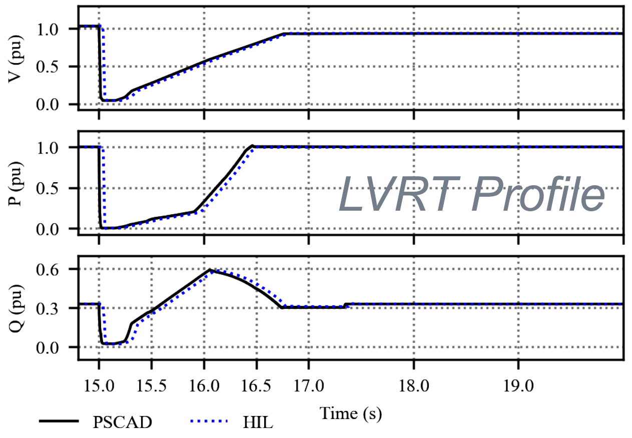
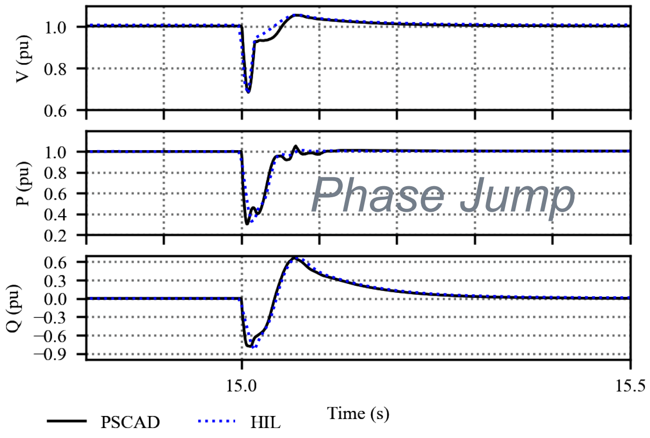
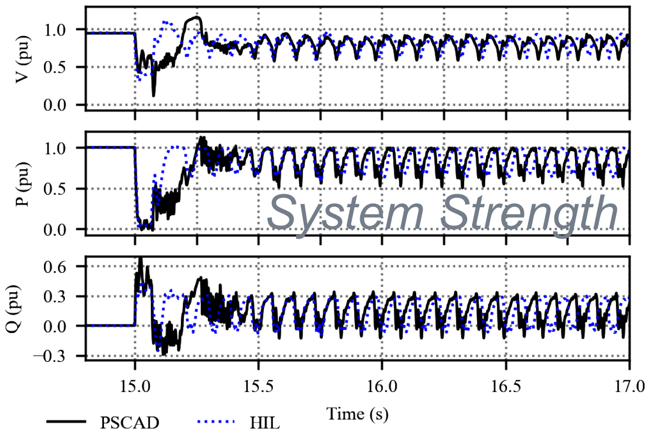
Classification: Confidential

Unit Model Validation Results



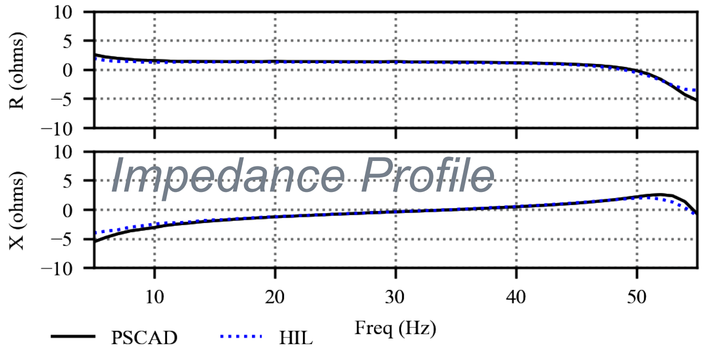






Observations:

- Perfect agreement between HiL measurements and PSCAD simulation results
- Specific turbine control is not optimized for weak grid conditions and that the performance for the real product
- Great correlation between HiL impedance profile sweep and PSCAD simulation results.



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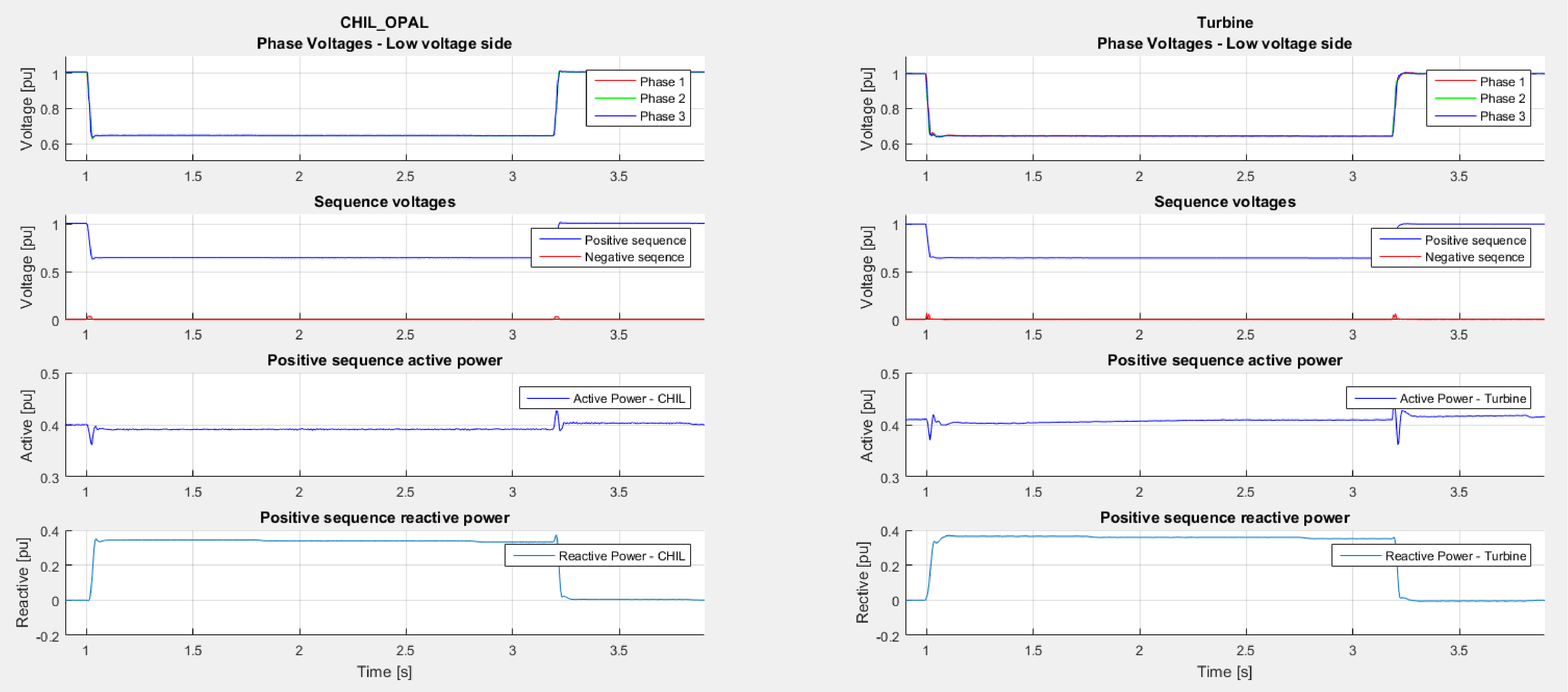
RT CHIL output vs real turbine during FRT

UVRT 60% positive sequence, **3 phase**



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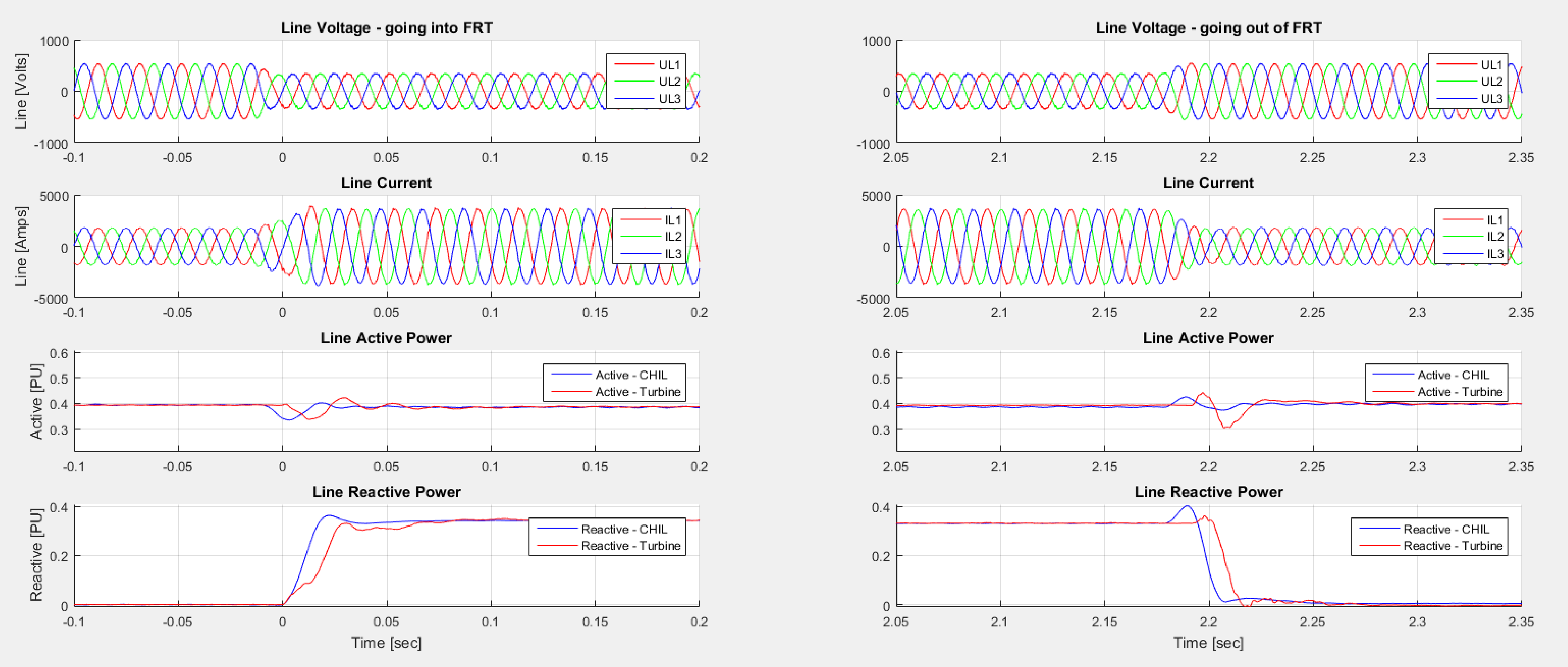
RT CHIL output vs real turbine during FRT

UVRT 60% positive sequence, **3 phase** – zoomed transitions



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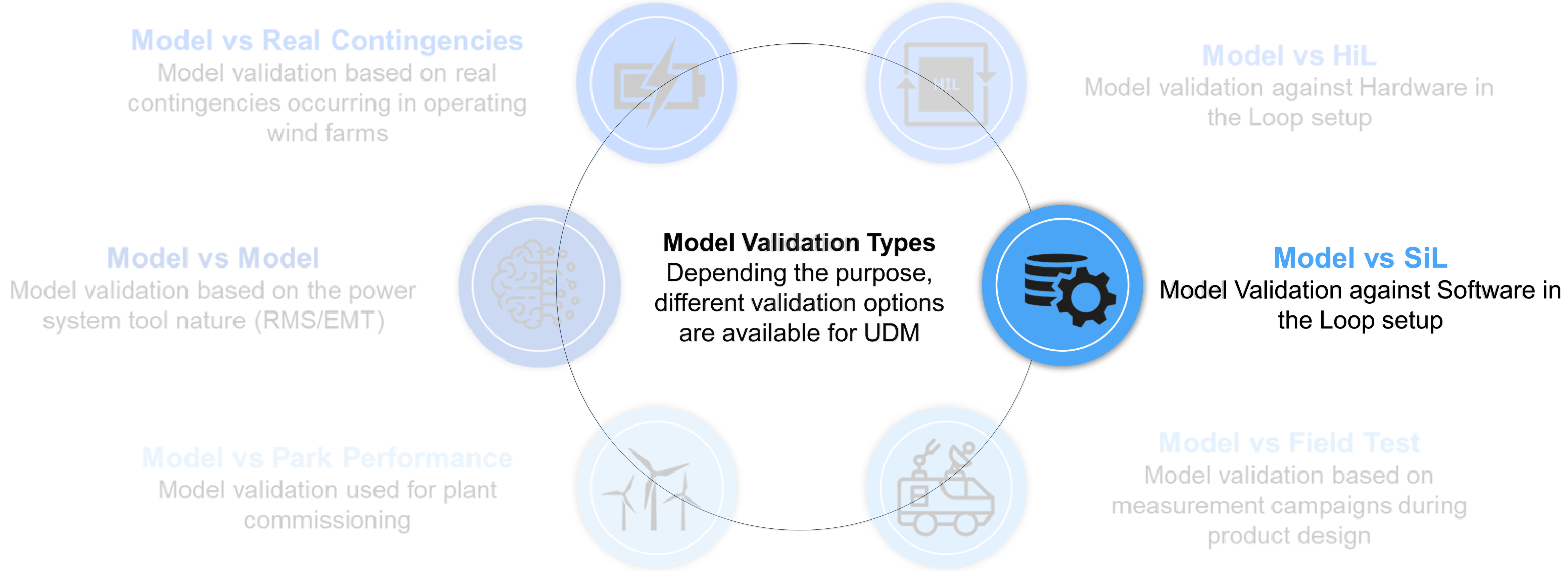
Model Validation Variances

Power System Model Validation Types



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Model vs HiL Validation

WTG simulation integration: External plant model dependent

Configuration of Controller – any variant selection is possible – but needs project settings
WTG variant, grid code and site tuning build into converter SW

Wind power plant

RT Simulator (WTG)

Converter Controller

Country / Grid code selection

Titl

RT Simulator (Plant)

Project and plant specific grid configuration.

Needed to configure Controller SW accordingly.

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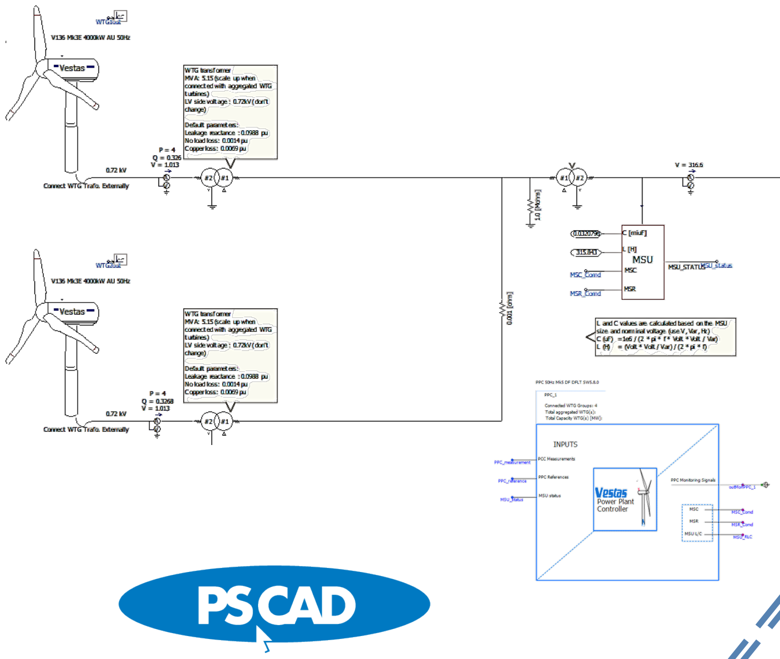
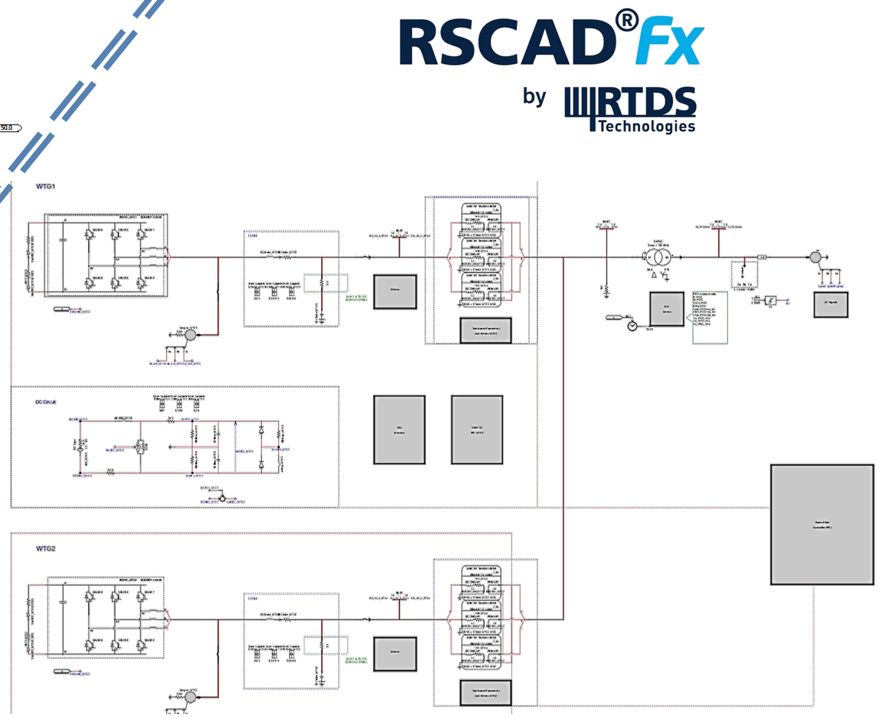
Model vs SiL/HiL Validation

Setup PSCAD compared to RSCAD



VS



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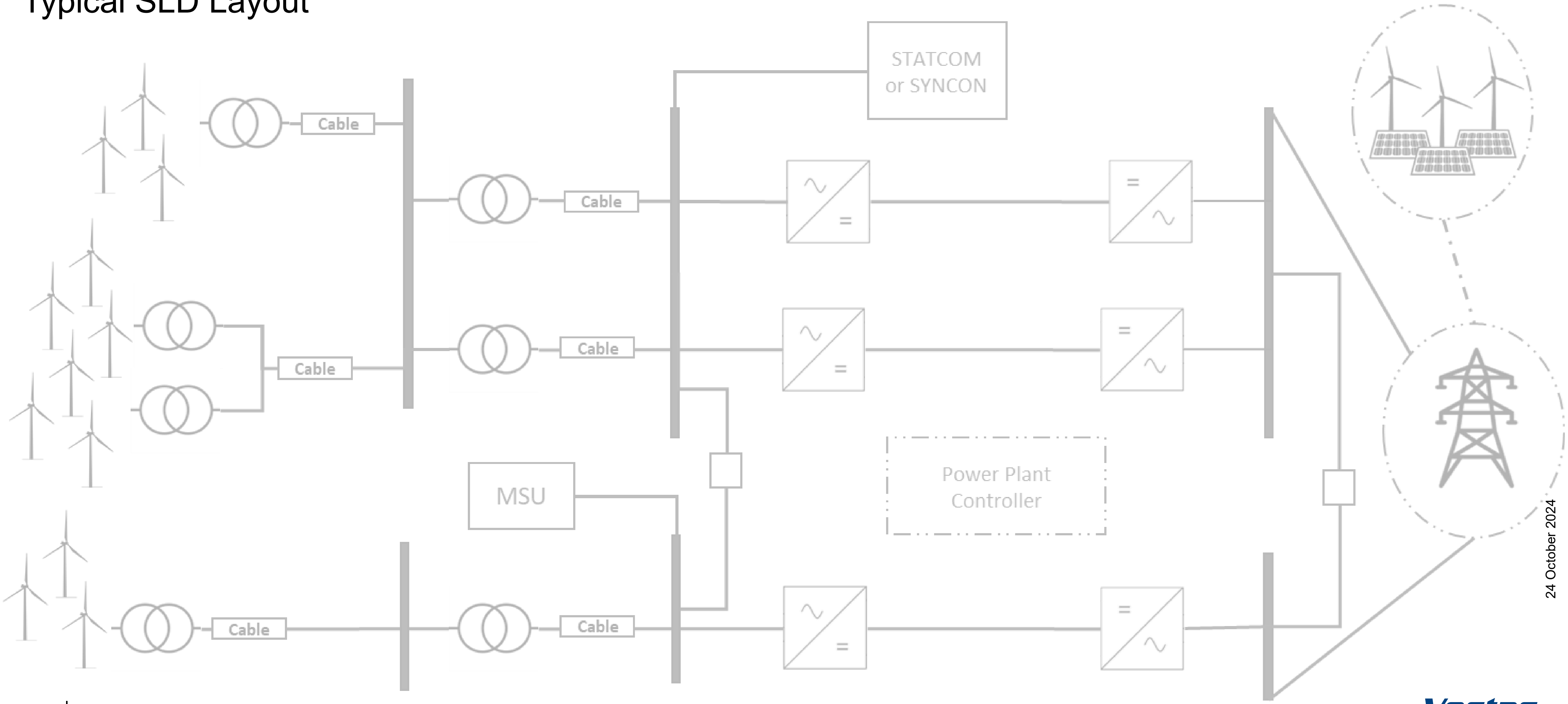
WPP Project - Example

Typical SLD Layout



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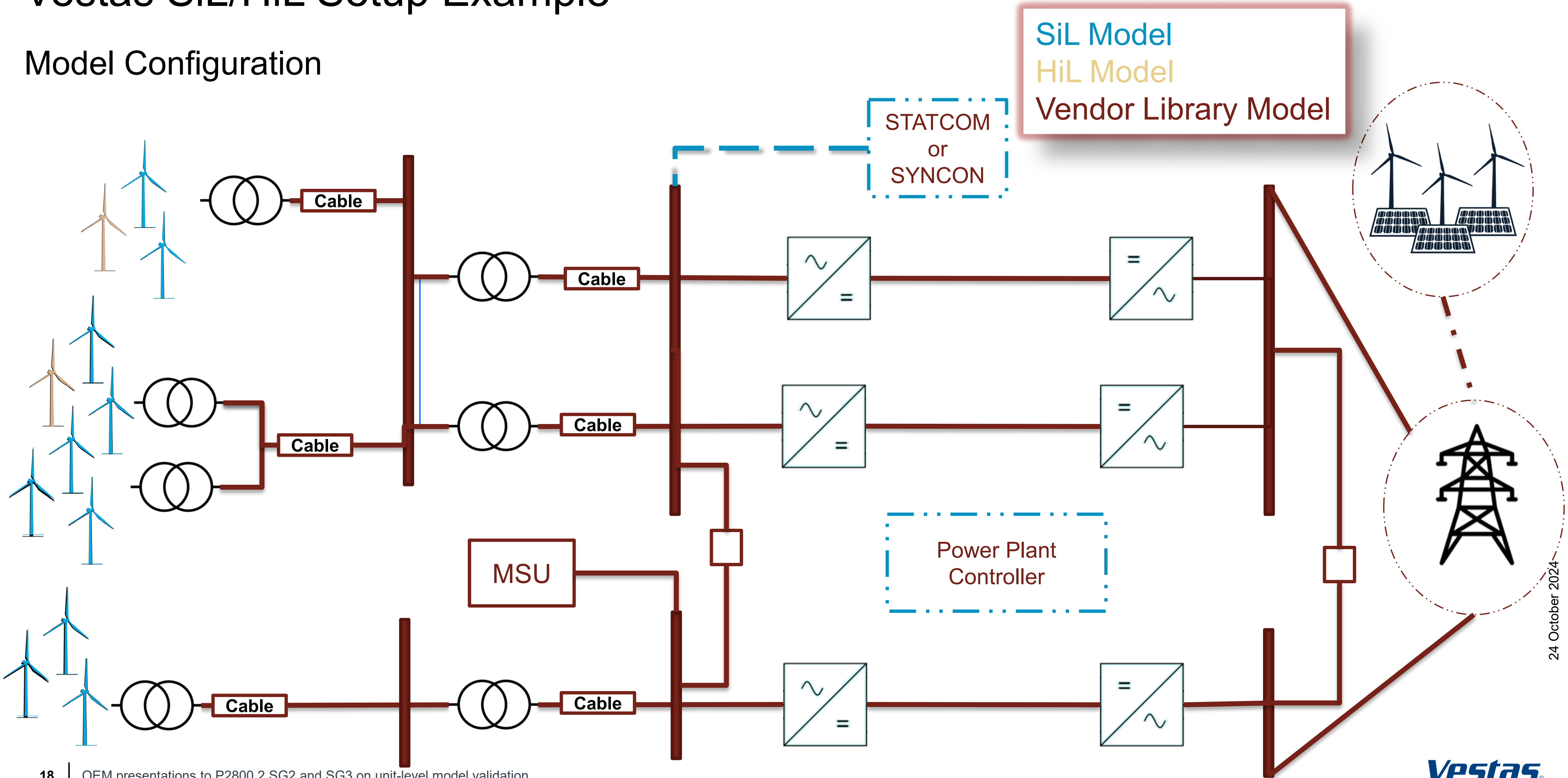
Vestas SiL/HiL Setup Example

Model Configuration



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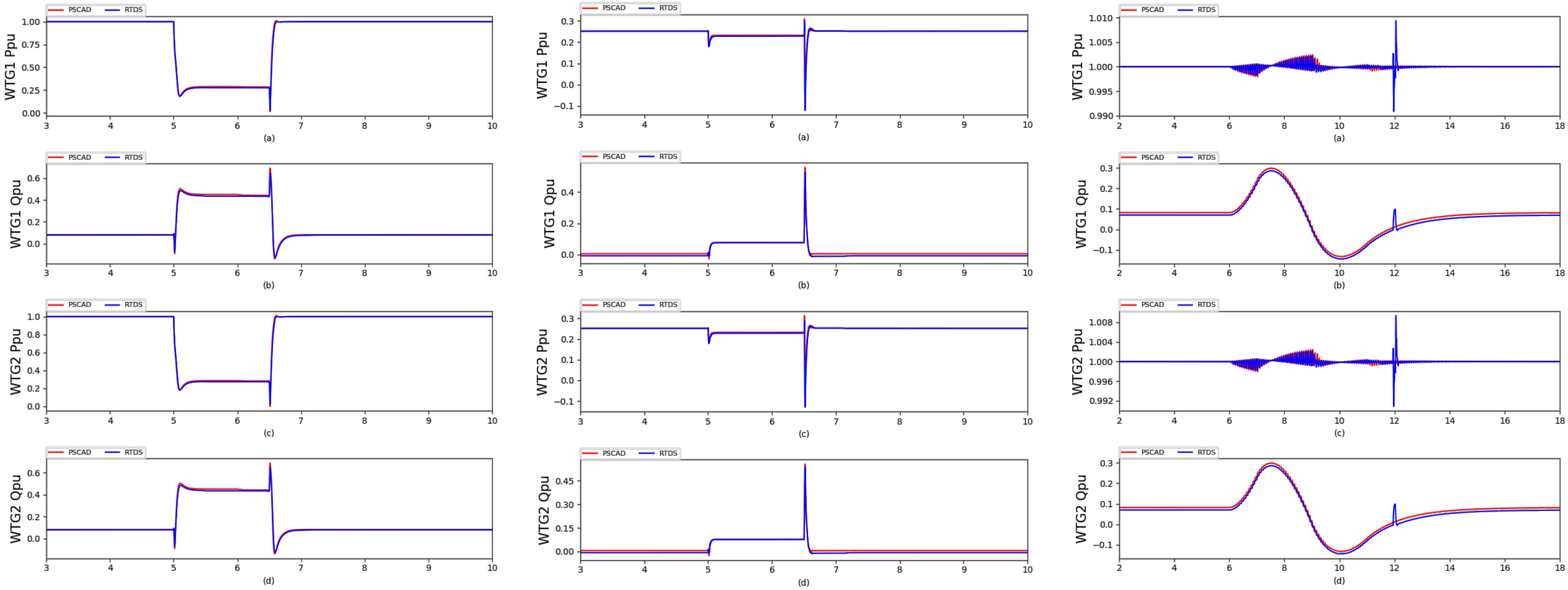
Validation EMT vs SiL RT – RESULTS LV WTG



Case 1: 25% Voltage dip – Full Load

Case 2: 20% Voltage dip – Partial Load

Case 3: Q Ramp up/down

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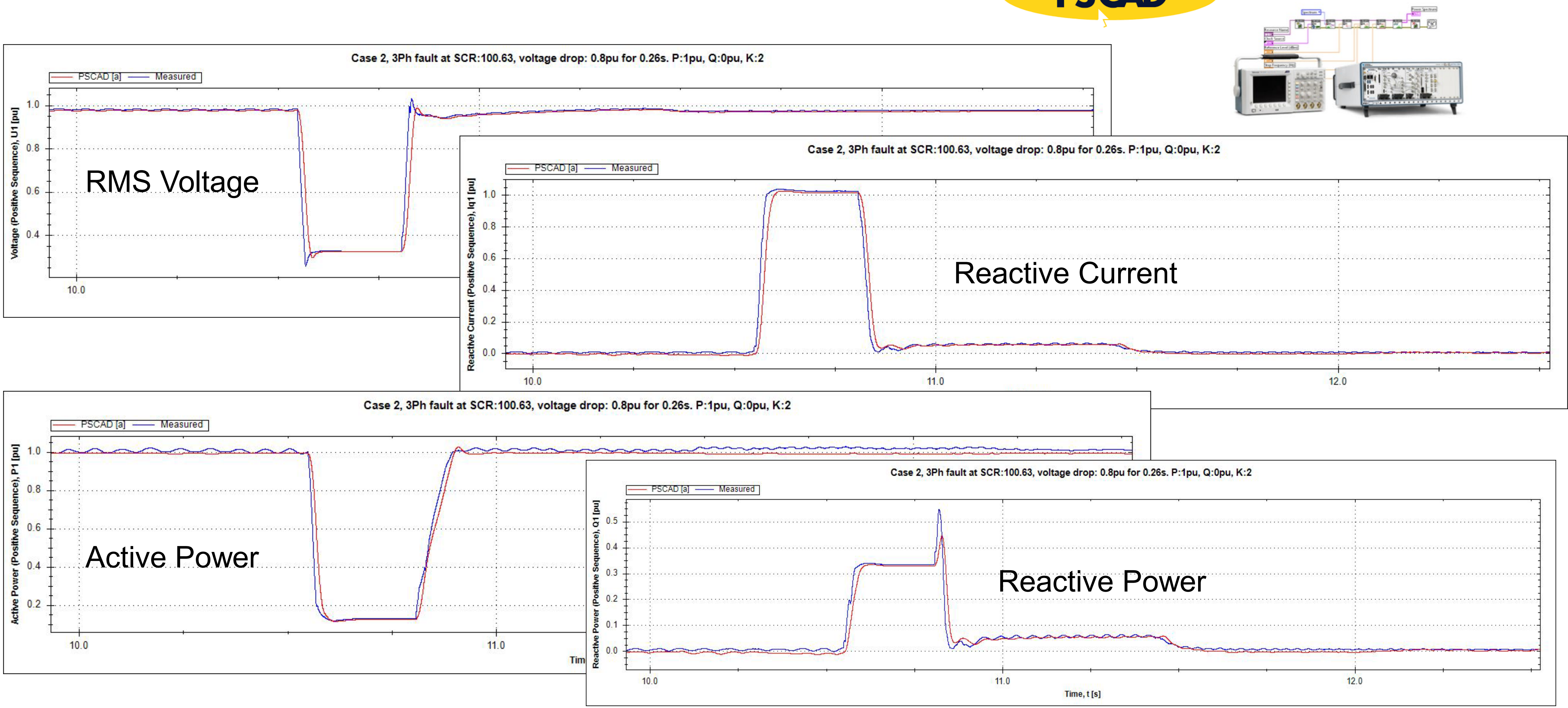
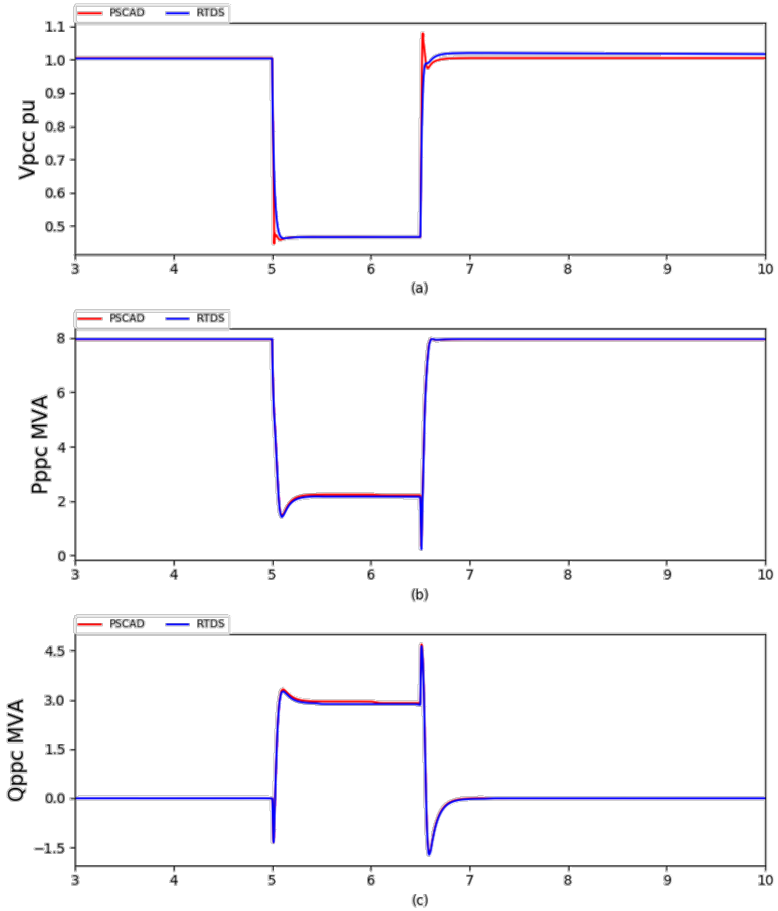
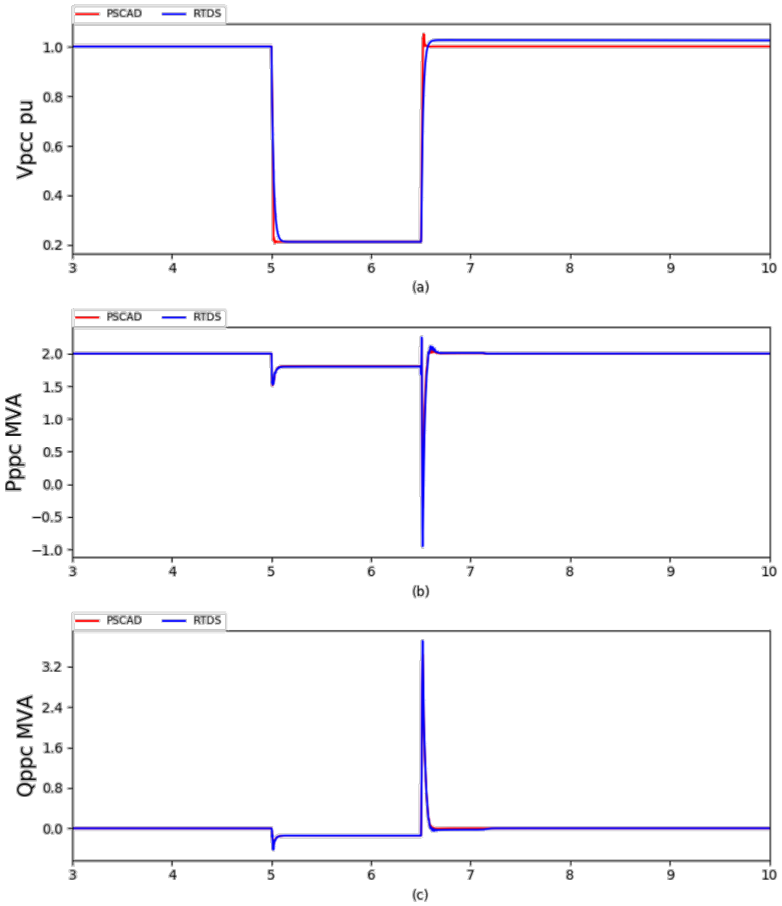
Validation EMT models (PSCAD) vs Emulator



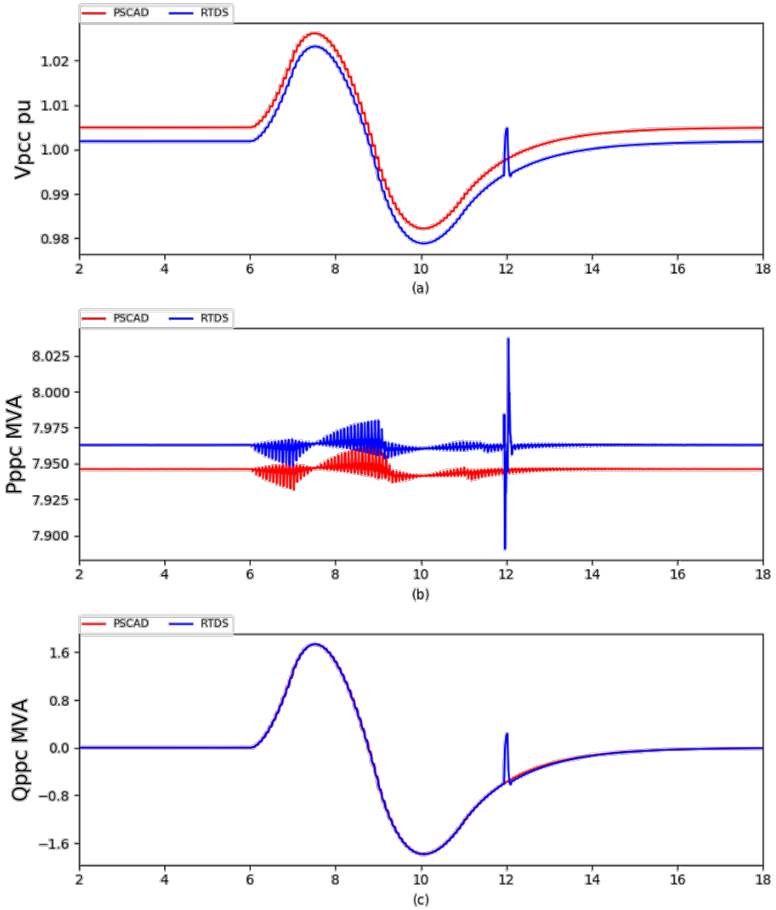
Validation EMT vs SiL RT – RESULTS LV PCC



Case 1: 25% Voltage dip – Full Load



Case 2: 20% Voltage dip – Partial Load



Case 3: Q Ramp up/down

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Model validation based on measurement campaigns during product design

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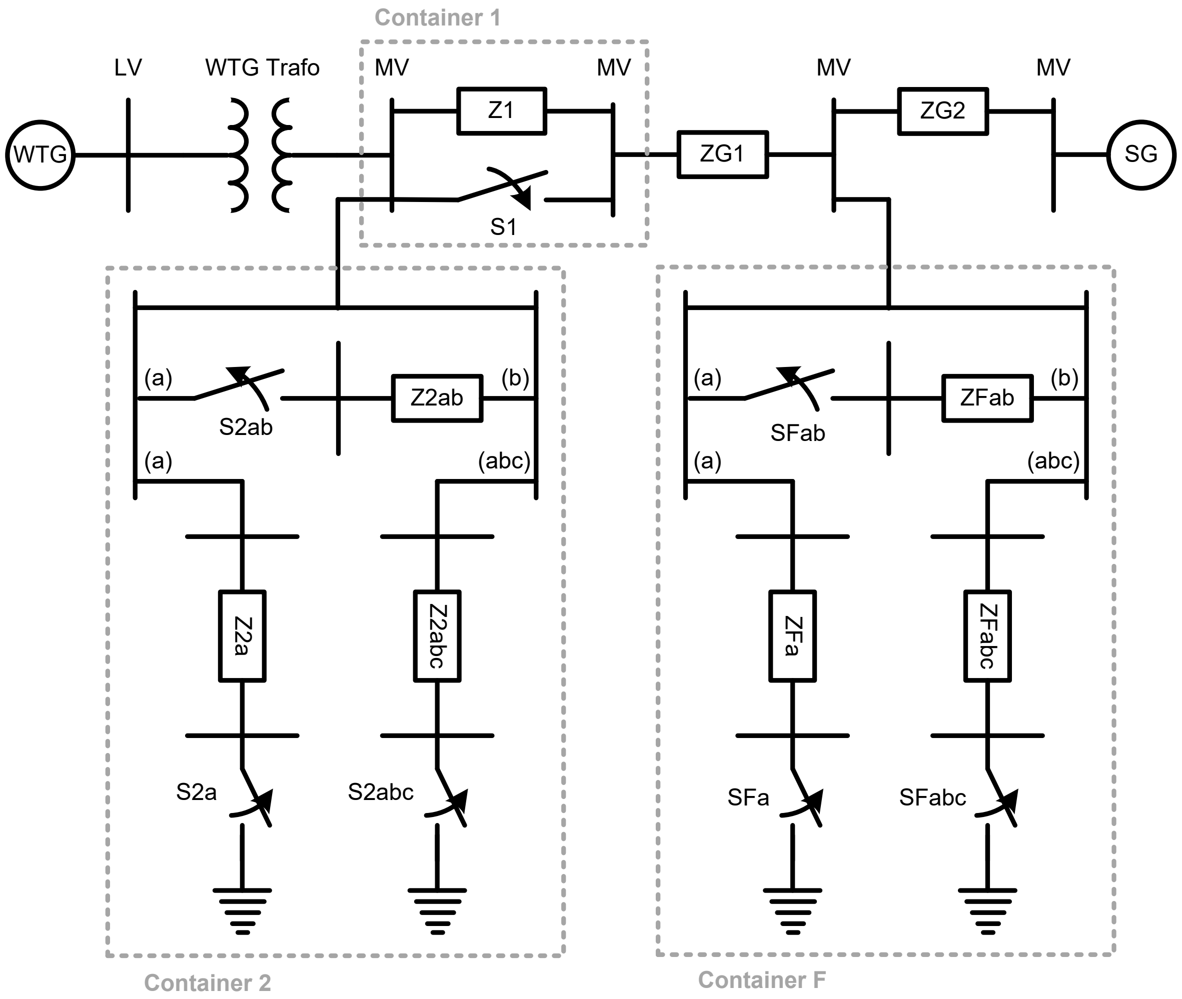
Model vs Field Test

Test Setup

- A common grid is used to run tests
- Different portions of the grid are indicated by the containers and (a), (b) and (abc) indicate that connections.
- For test cases that involve a fault ride-through, the fault is created by toggling the appropriate switches in Container F during the simulation.
- The setups in Container 1 and Container 2 are used exclusively for the Reference Performance Test Cases.



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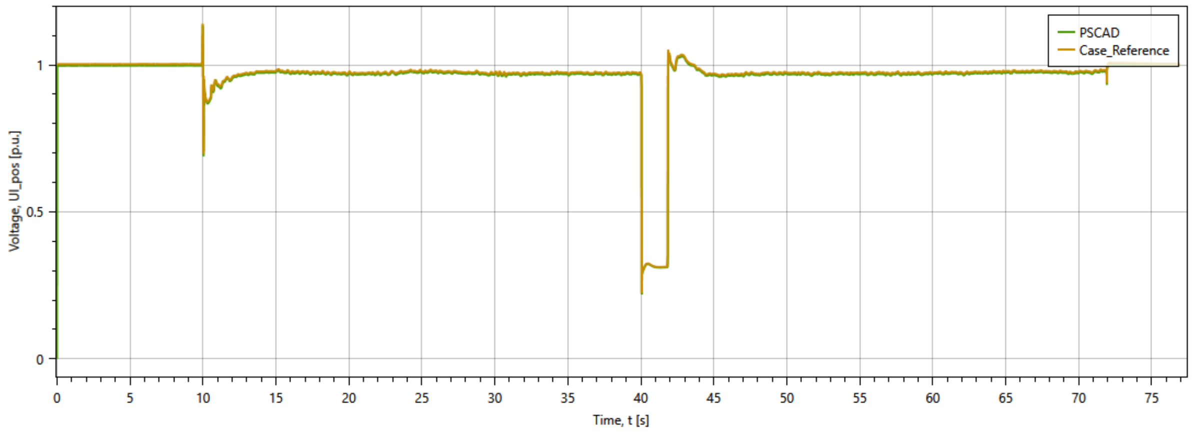
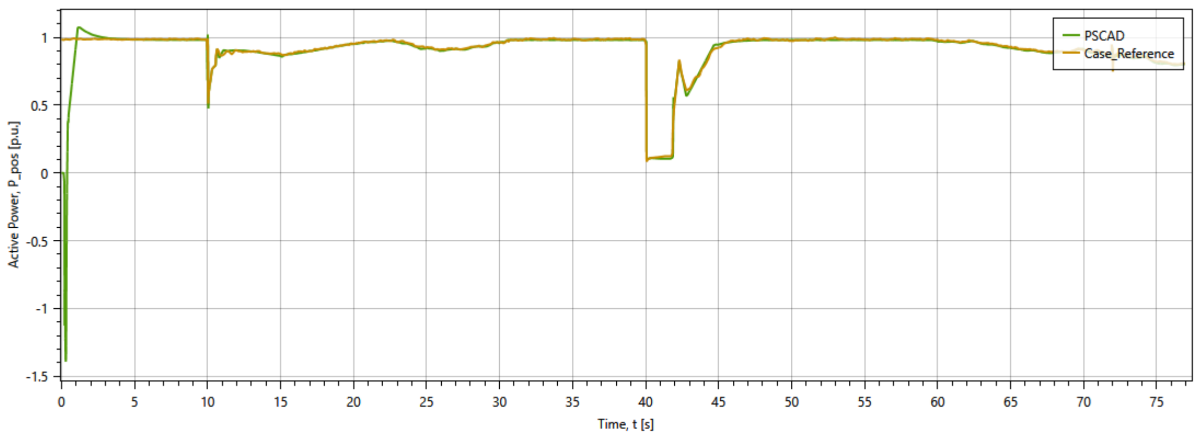
Model vs Field Test

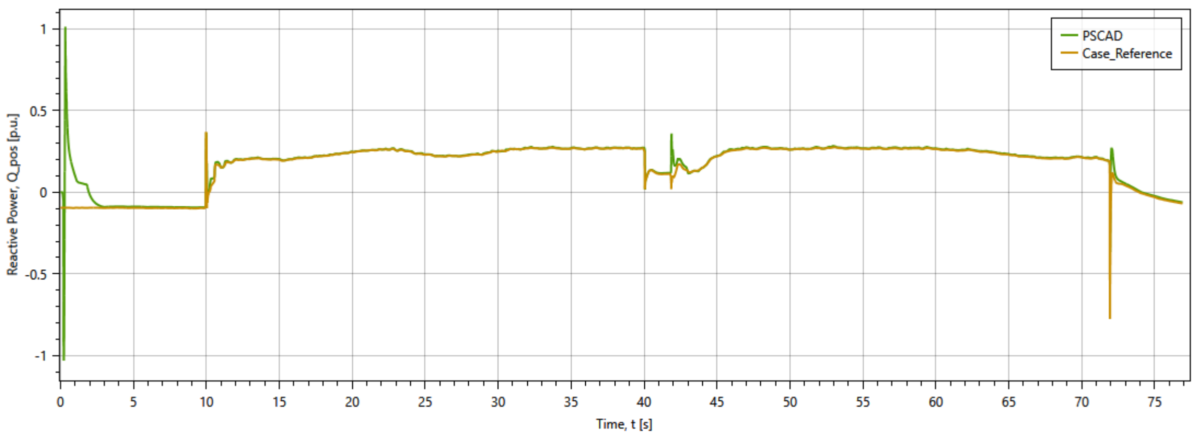
Impedance Switch

In these test cases the simulation model is validated against real FRT reference performance test case results.

The simulation is run using an ideal voltage source, and as such cannot be used to validate the negative-sequence voltages for 3-phase faults.







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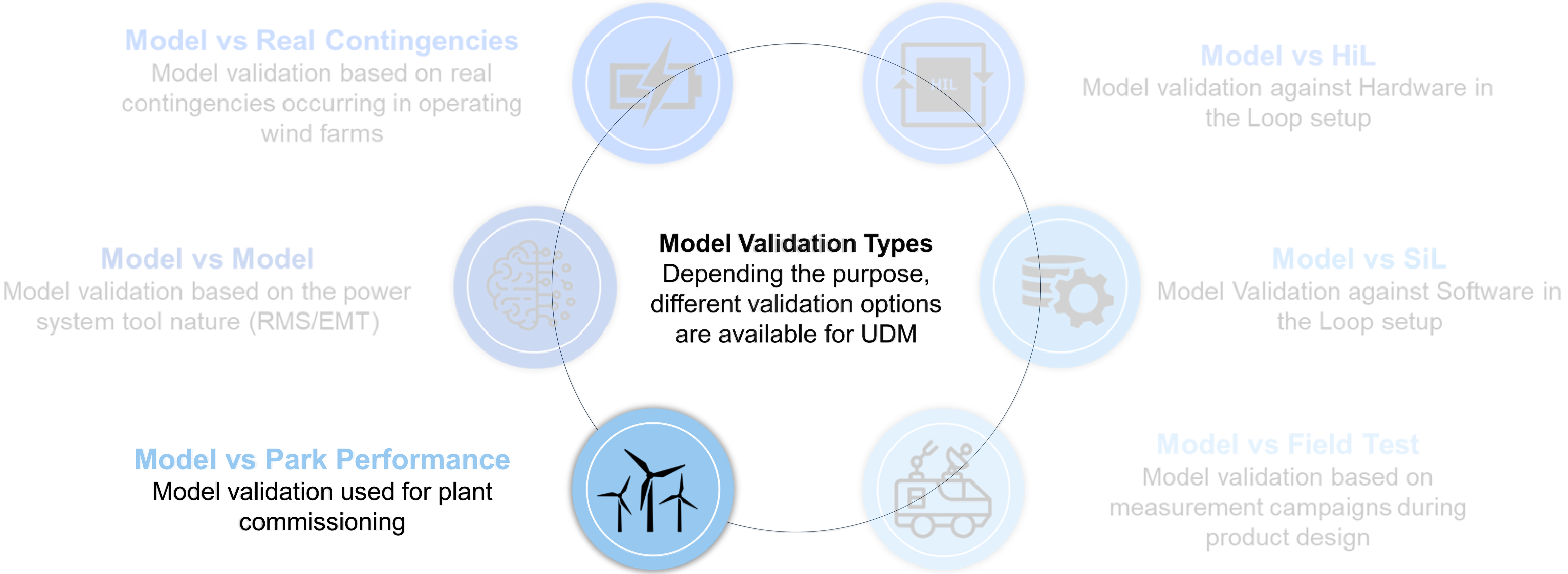
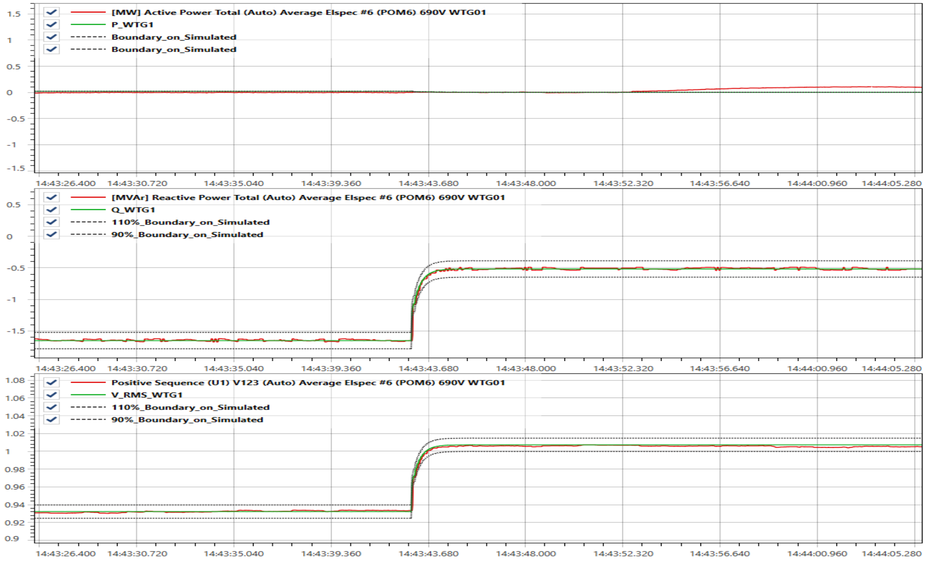
Model Validation Variances

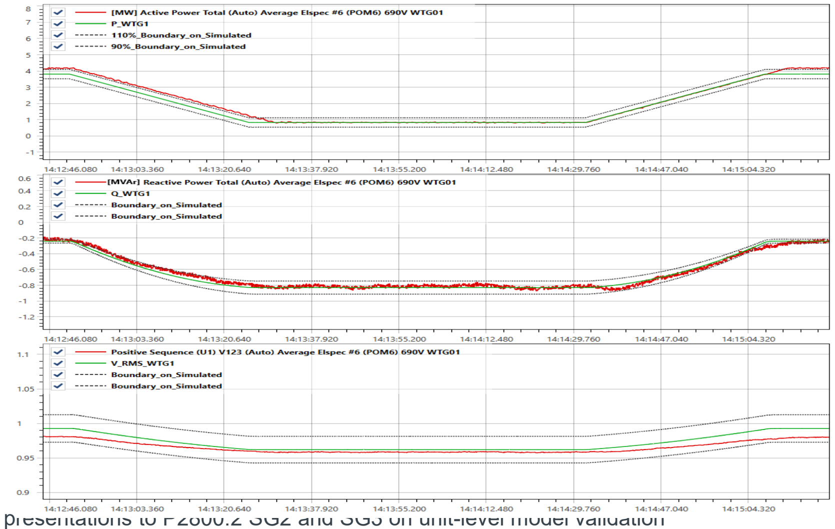
Power System Model Validation Types

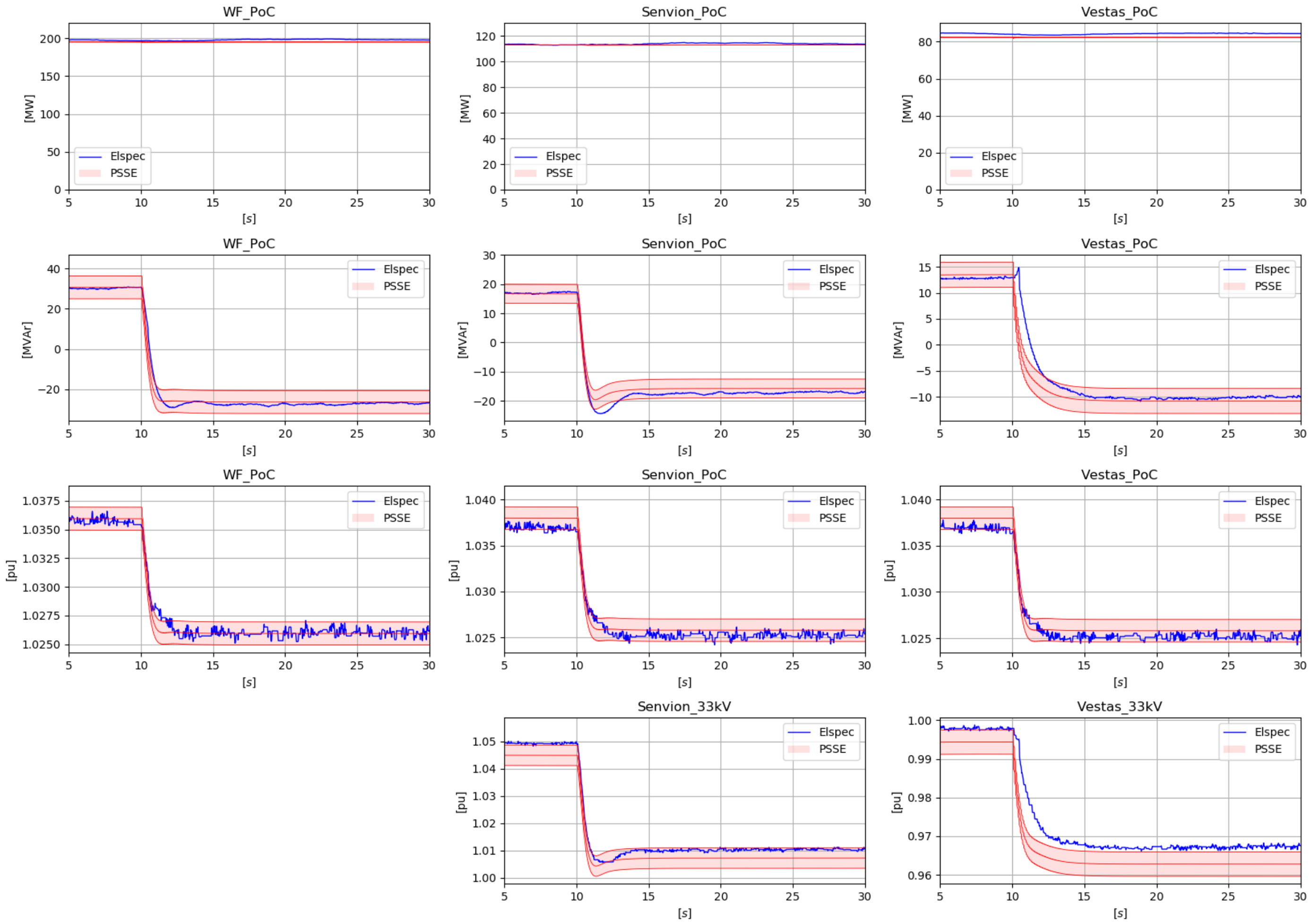


Model vs Park Performance

Wind Farm Commissioning







Model Validation Variances

Power System Model Validation Types

Model vs Real Contingencies
Model validation based on real contingencies occurring in operating wind farms

Model vs HiL
Model validation against Hardware in the Loop setup

Model vs Model
Model validation based on the power system tool nature (RMS/EMT)

Model Validation Types
Depending the purpose, different validation options are available for UDM

Model vs SiL
Model Validation against Software in the Loop setup

Model vs Park Performance
Model validation used for plant commissioning

Model vs Field Test
Model validation based on measurement campaigns during product design

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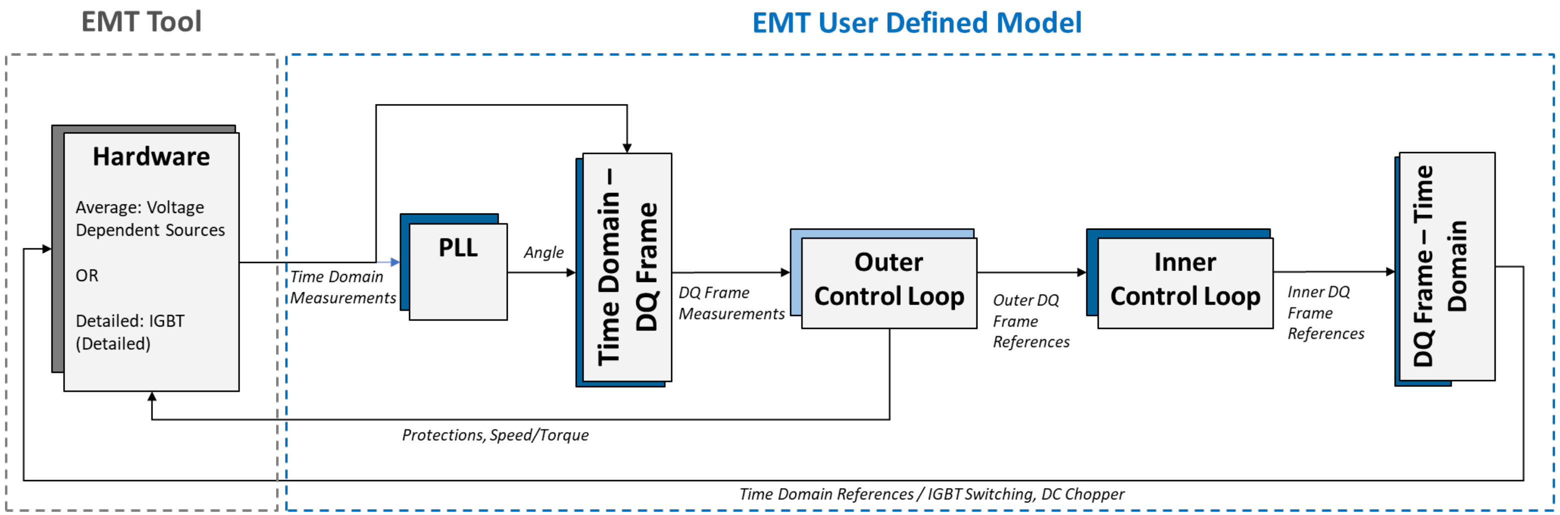
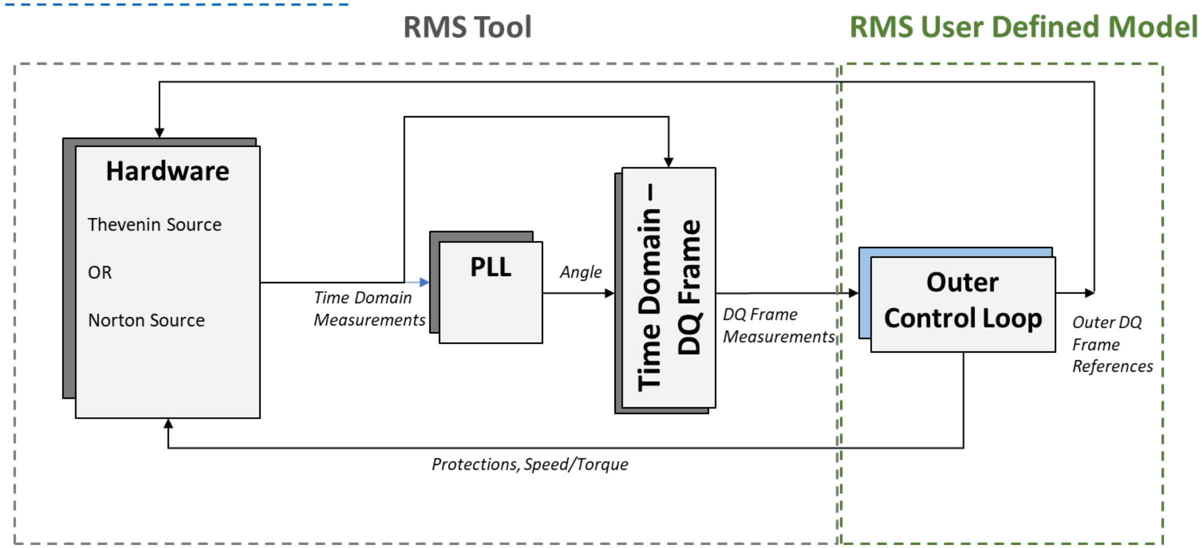
Model vs Model Validation

EMT Model compared against RMS models



- Time Domain
- Low Time Step
- Full Code Integration

- Phasor Domain
- High Time Step
- Partial Code Integration



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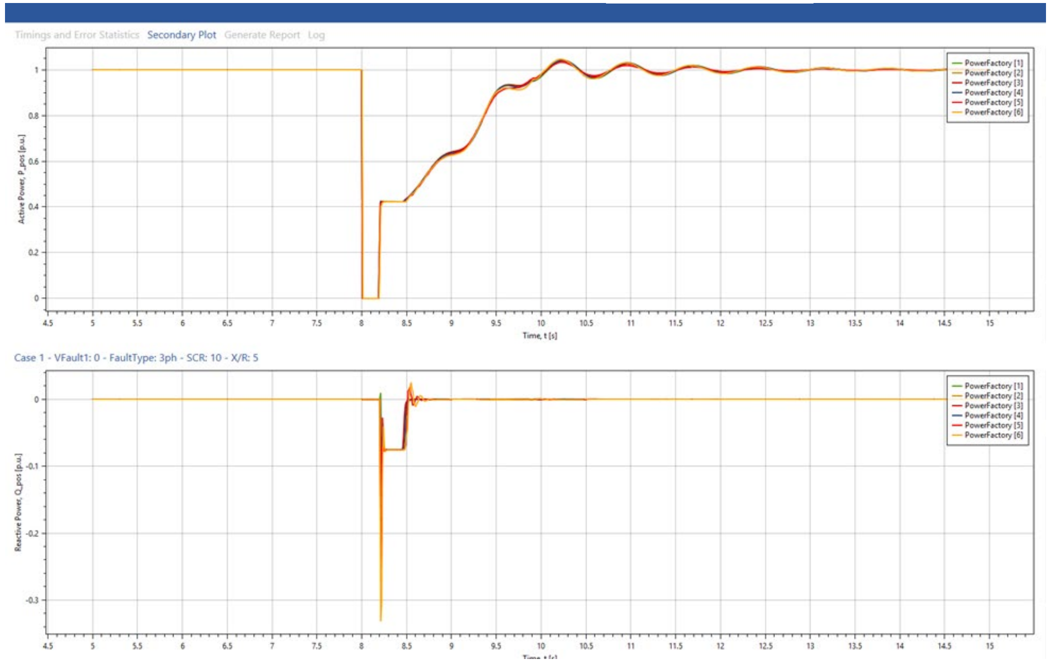
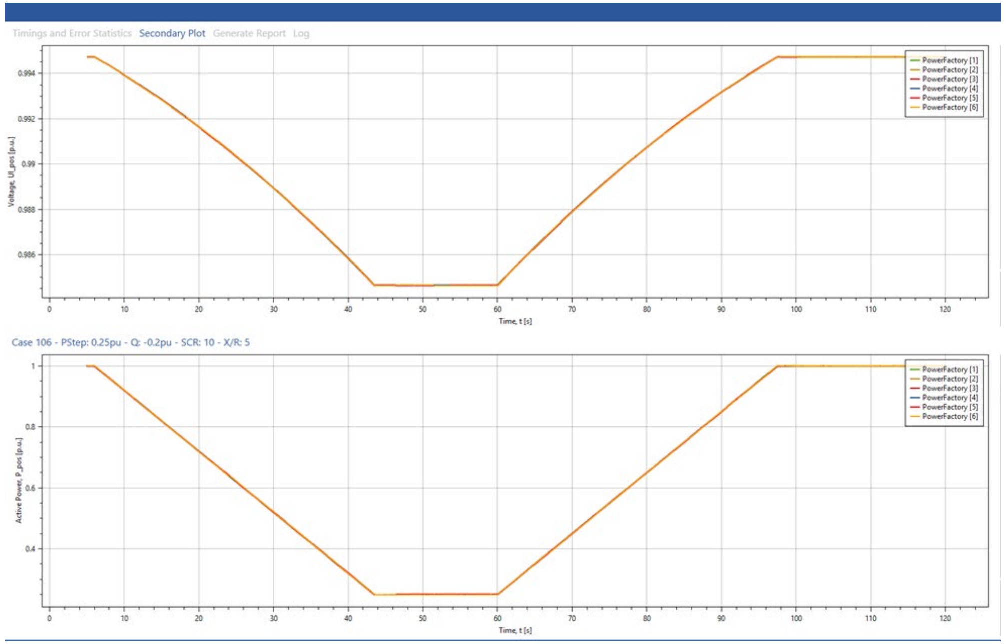
Electrical Simulation Model verification at different time steps

RMS models show a consistent performance regardless time step chosen from user. Commonly timesteps used are ½ and ¼ cycles of fundamental frequency



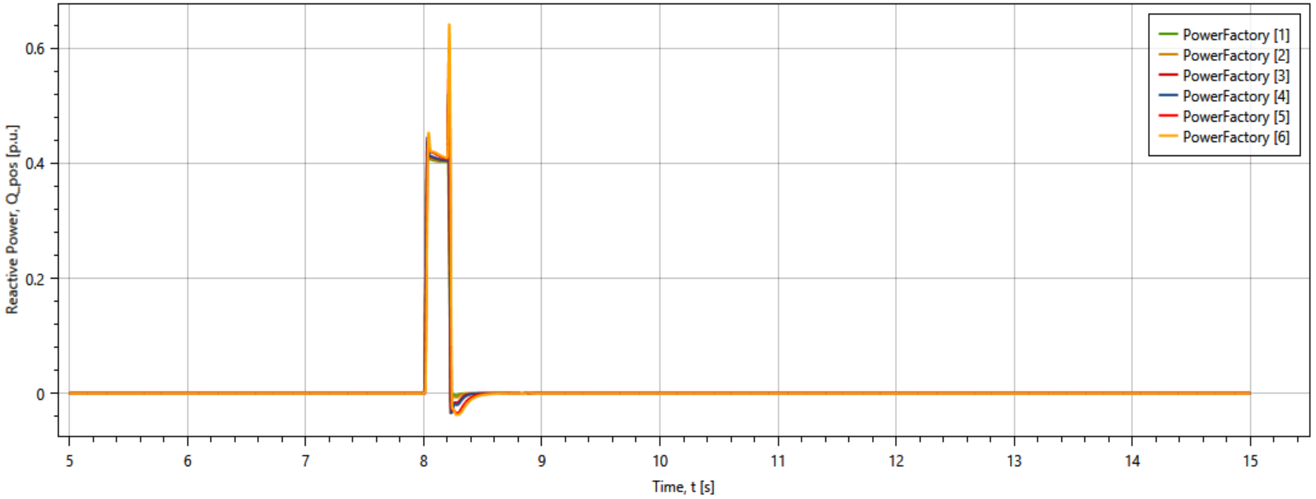


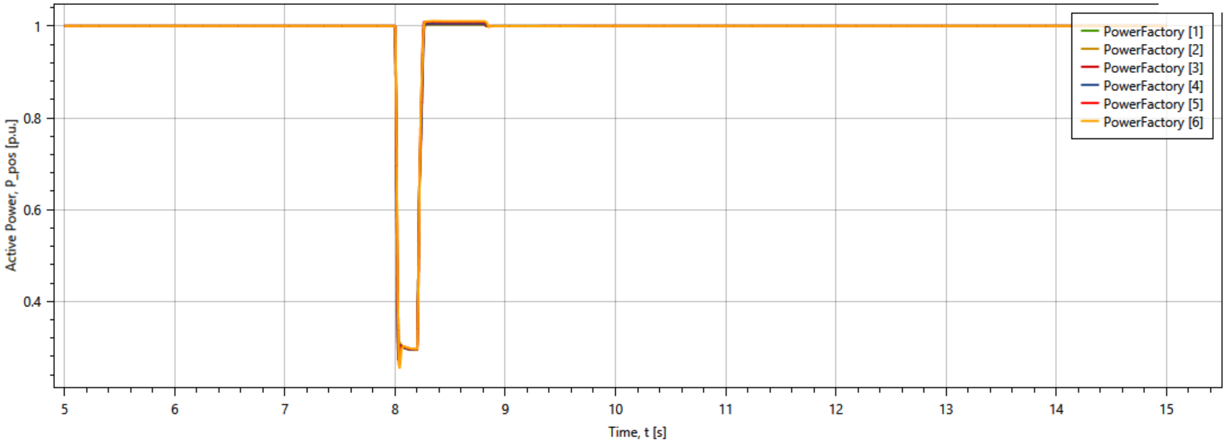
Different Time Step Performance

1 - 4.16 - 5 - 8.33 - 10 ms

Electrical Simulation Model verification at different time steps

RMS models show a consistent performance regardless time step chosen from user. Commonly timesteps used are ½ and ¼ cycles of fundamental frequency





Different Time Step Performance

1 - 4.16 - 5 - 8.33 - 10 ms

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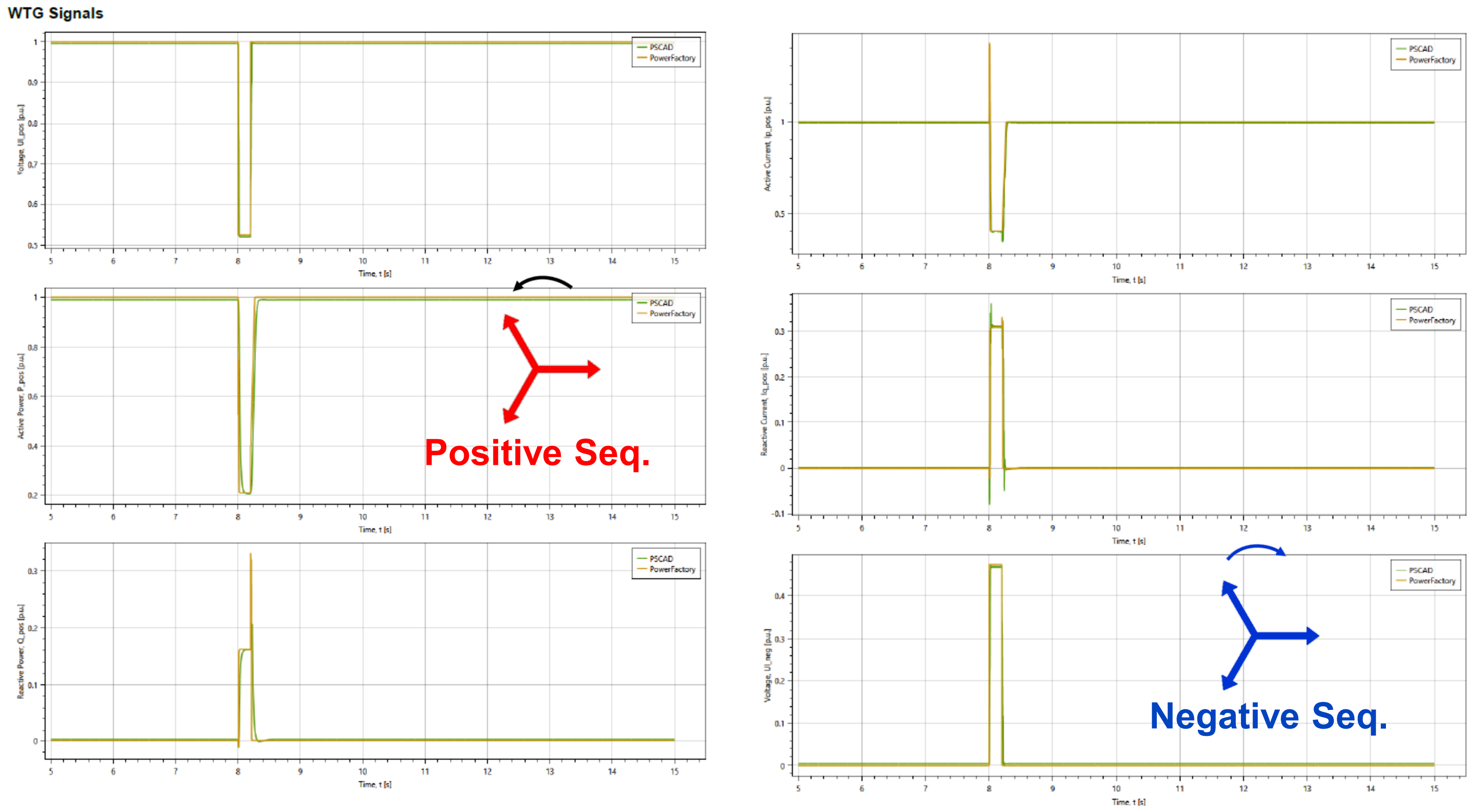
Electrical Simulation Model Verification @ turbine level

What about Unbalance Faults?

Models shows a consistent performance between RMS and EMT models for unbalance faults !

Vs.



Validation models EMT vs RMS models @ POC

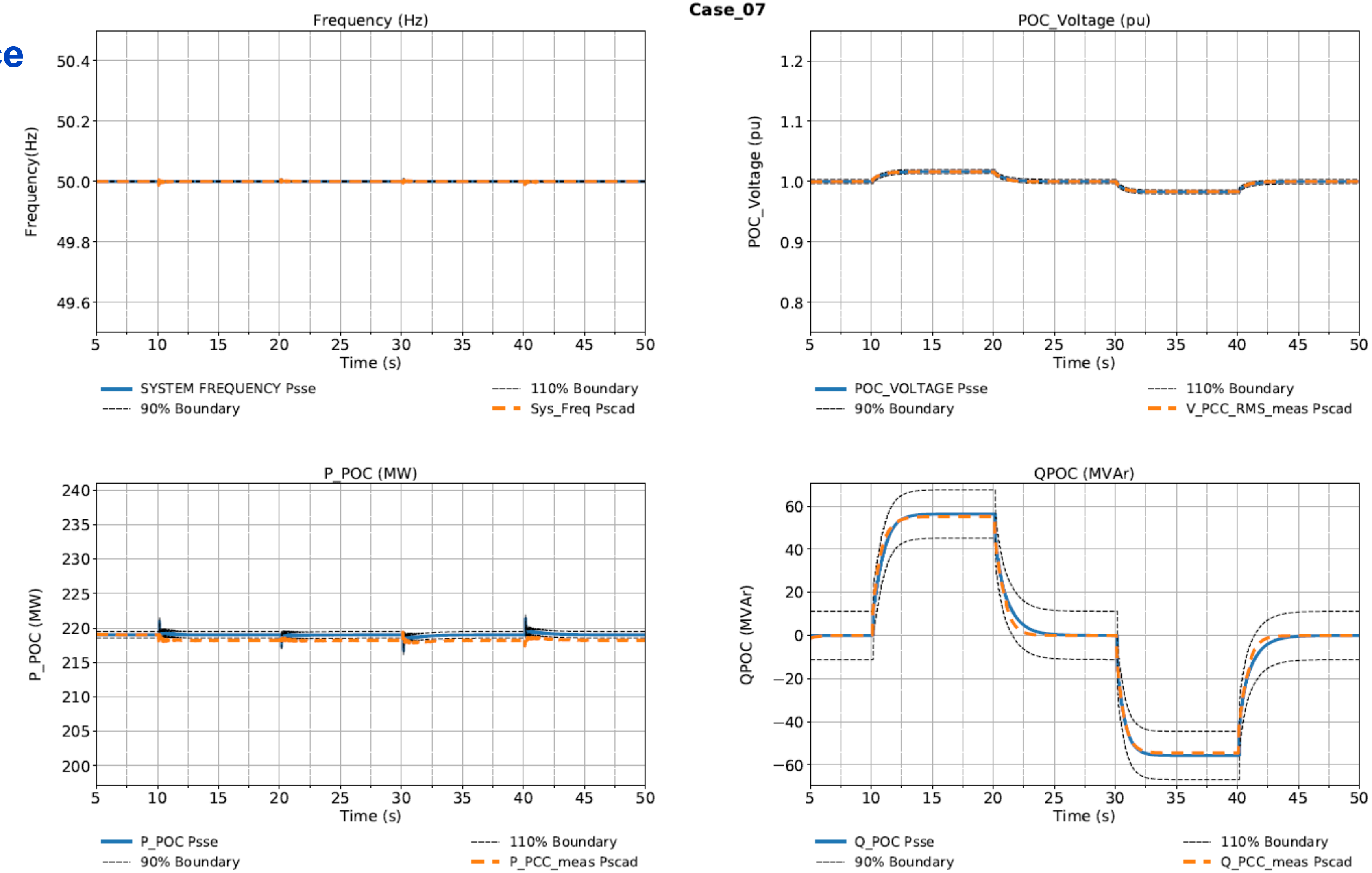
Case: Voltage setpoint reference step change to +5% and -5%

Benchmark of models between RMS and EMT is successful. Remarkable match across simulation tools at plant level.

PSS®E

Vs.

PSCAD



Validation models EMT vs RMS models @ POC

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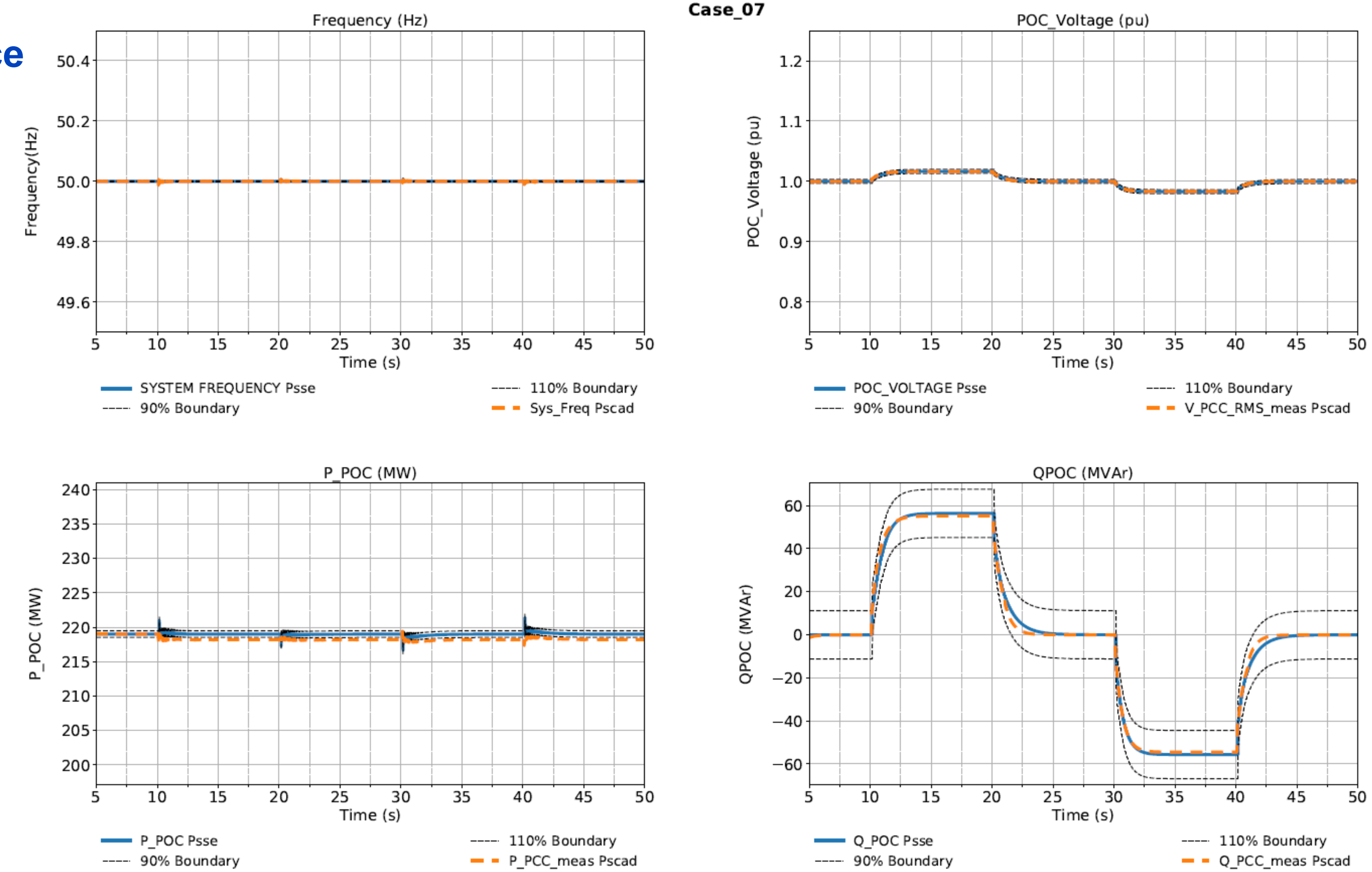
Vs.

PSCAD



Validation models EMT vs RMS models @ POC

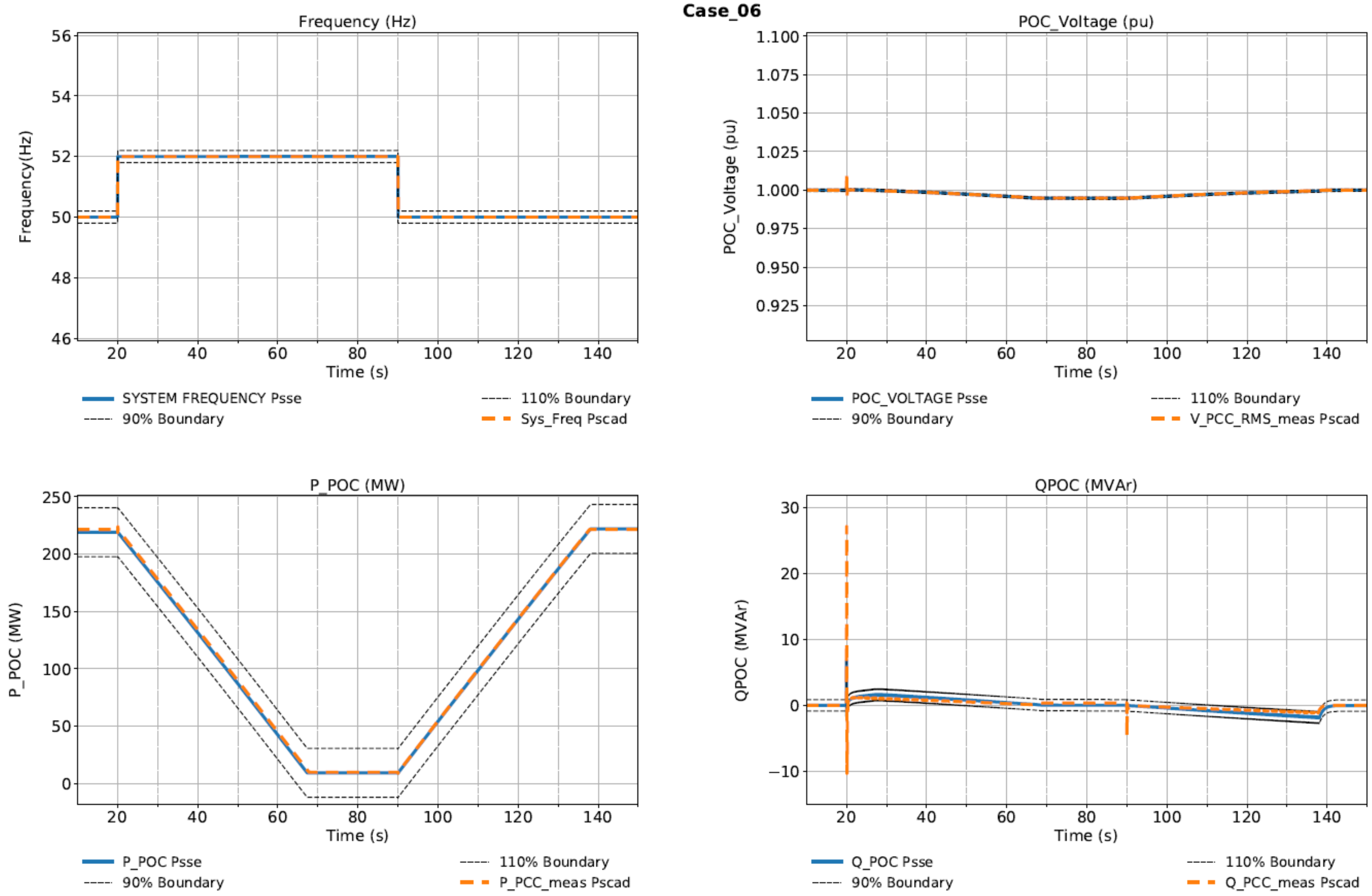
Frequency control test (52Hz)

Benchmark of models between RMS and EMT is successful. Remarkable match across simulation tools at plant level.

PSS®E

Vs.

PSCAD



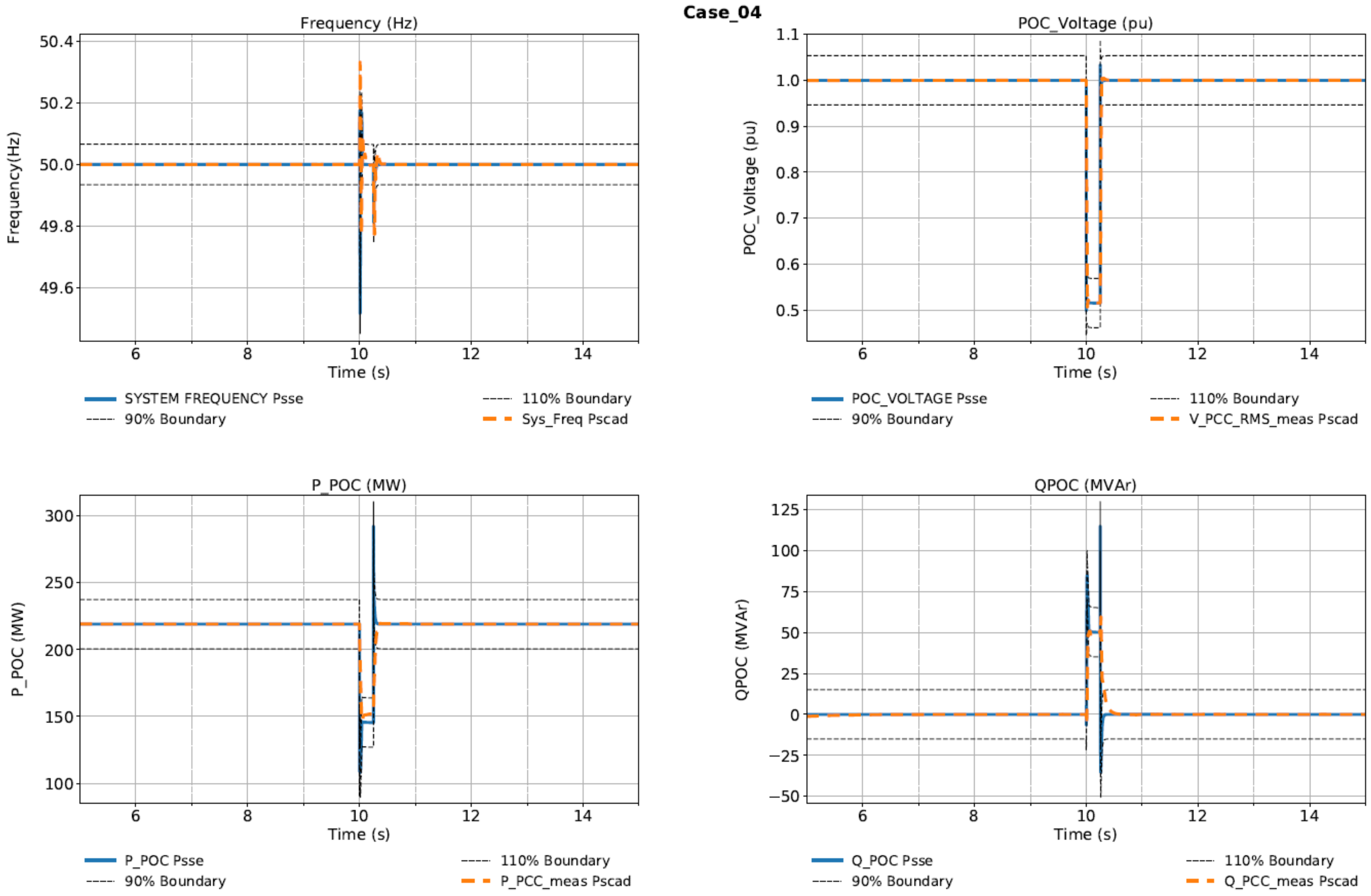
Vestas

Validation models EMT vs RMS models @ POC

FRT with 0.5 dip at PCC

Benchmark of models between RMS and EMT is successful. Remarkable match across simulation tools at plant level.

Vs.

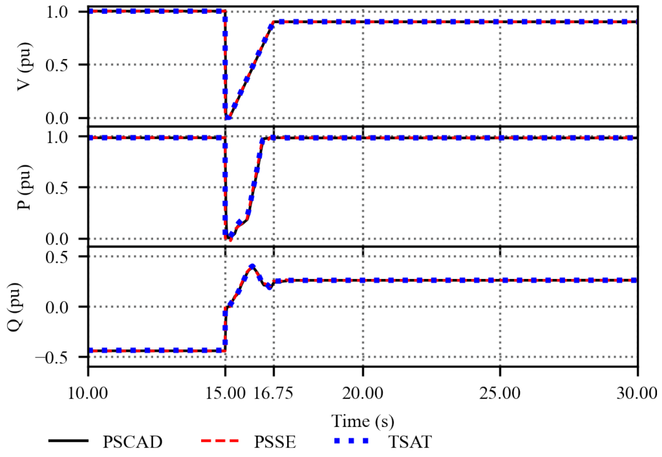


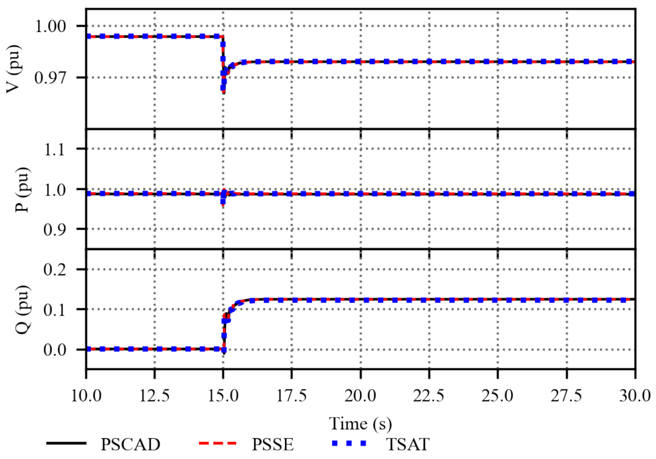
Benchmark of RMS vs EMT Simulation Models

ERCOT Model Quality Test Benchmark

Small Voltage Disturbance Test

In this test, a step increase of 3% of voltage at the POI is applied and, in a separate simulation, a decrease of 3%. The acceptable behavior in this case is to have the plant decreasing its reactive power output following a step increase of voltage, and increase it following a step decrease.



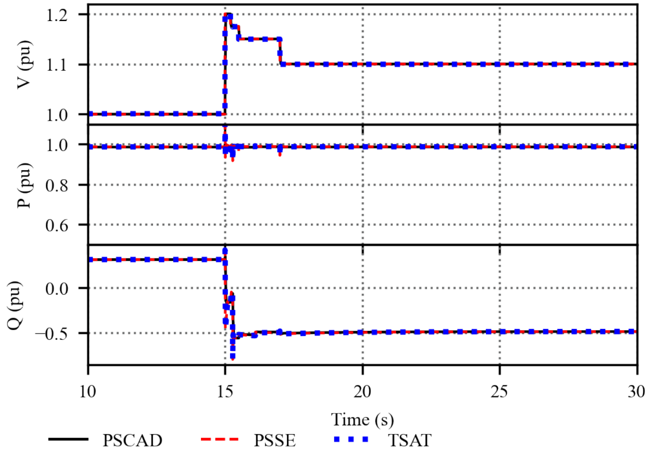


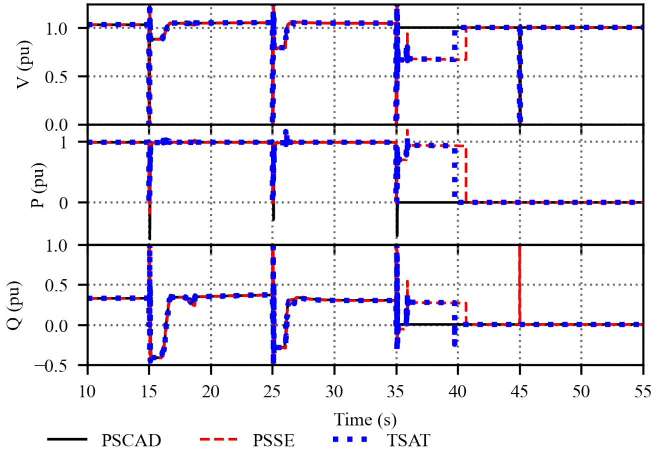
Low Voltage Disturbance Test (LVRT)

The LVRT test uses a specific voltage profile starting at 1 pu and settling at 0.9 pu. After the POI voltage drops to zero, it is gradually increased to the final value of 0.9 pu. This test consists of two simulations with the WPP initially operating at full capacitive and full inductive reactive power output.

High Voltage Disturbance Test (HVRT)

This test uses a specific voltage profile starting with 1.0 pu, having a transient with 1.2 pu maximum value, and settling at 1.1 pu.



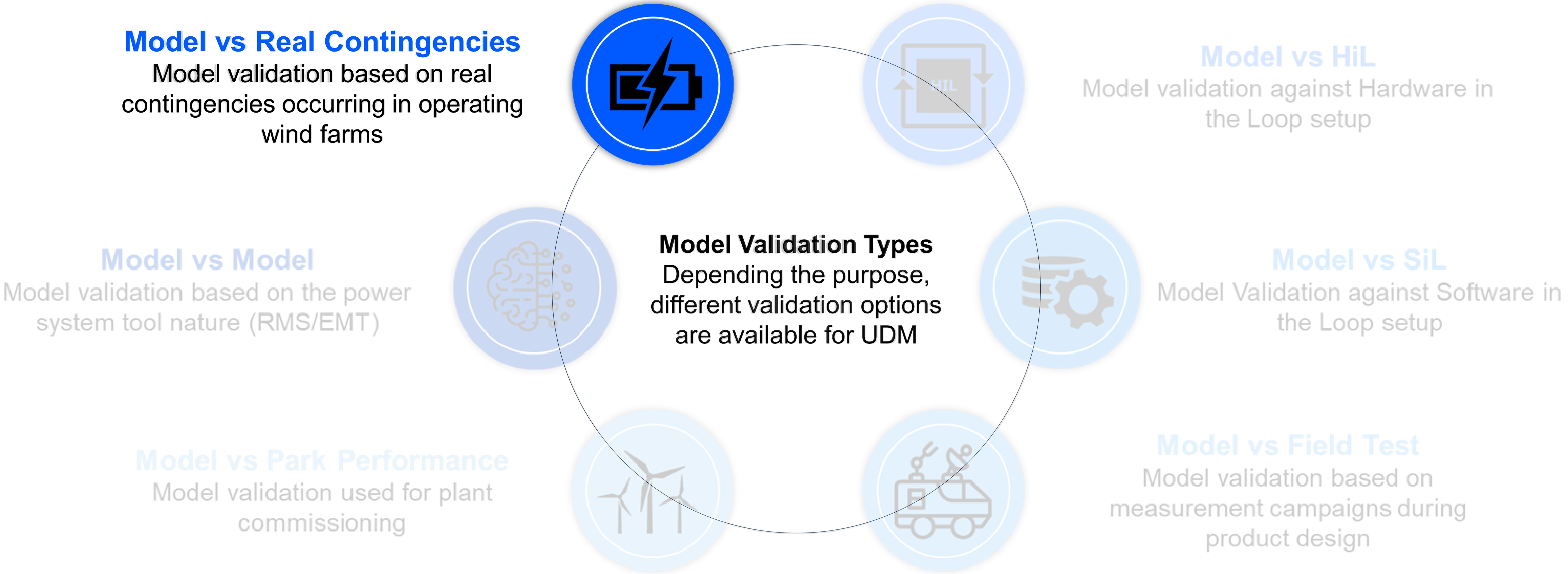


System Strength Test

For this test, the model performance is tested under different short circuit ratios (SCR). The motivation is that the SCR of the grid in which the WPP is connected can vary due to contingencies, device switching, etc. and the model must perform well for a SCR range. The model is required to be stable down to SCR=3.

Model Validation Variances

Power System Model Validation Types



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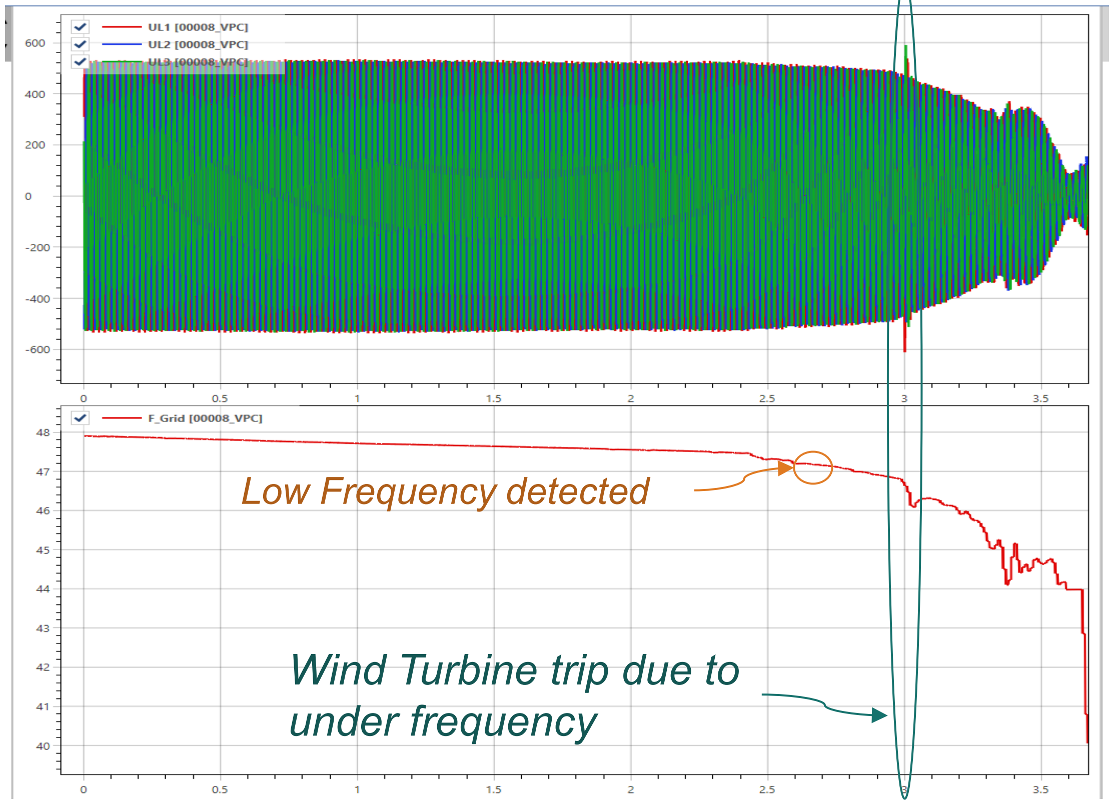
Validation EMT models vs Data Tracks from a real fault

Blackout in Argentina – Vestas Turbine Model Validation

Argentina and parts of Uruguay were hit by a power outage that **left 50 million people in the dark**.

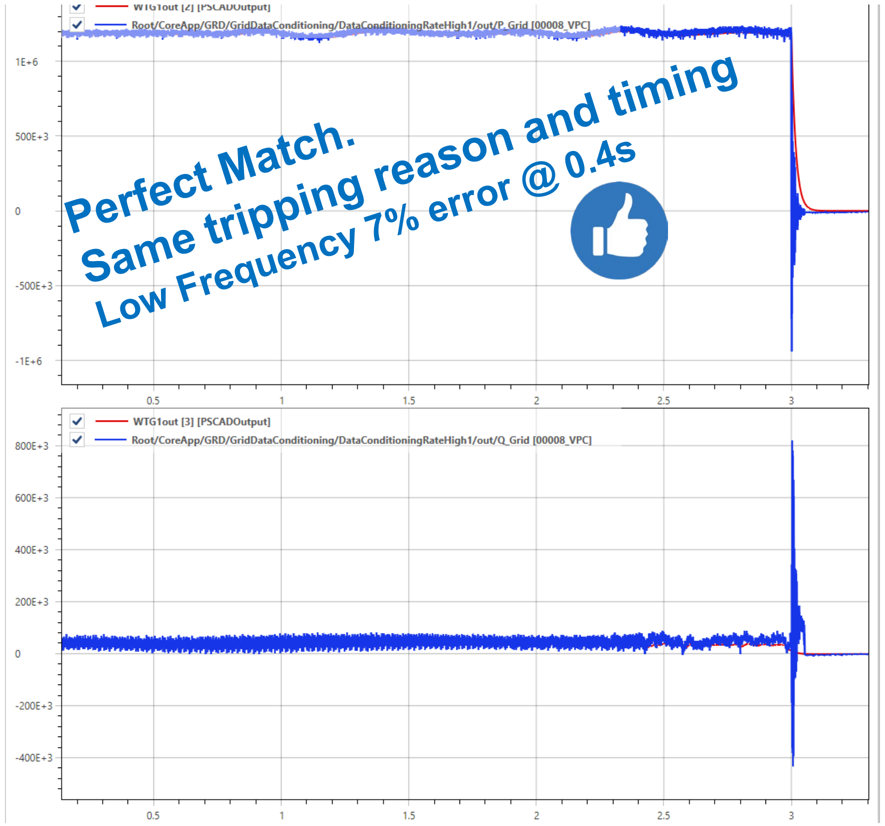
How did Vestas turbines performed during the blackout?



Will models reproduce same real contingency?

Model Validation

PSCAD Model vs Measurement from "*Corti*" wind farm (Argentina)



Models are validated against real measurement campaigns. However, campaigns are carried out in a control environment. Validate Models against real contingencies event increase quality insurance and confidence in models

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Conclusions/Recommendations

The model development process should always follow a source code integration concept.

Source Code Integrated Model & Product must preserve a mirror parametrization and performance.

Guaranteed model maintenance and accuracy of the model during the product lifetime.

*"**All models are wrong**; the practical question is **how wrong do they have to be to not be useful**."*

George E. P. Box

How accurate a model must be to perform grid interconnection studies considering the future challenges in a power system with high penetration of inverter-based generation sources?

Source code integrated models!

24 October 2024

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Wind. It means the world to us.™

Thank You

Concluding Remarks

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

"If you spend too much time thinking about a thing, you'll never get it done."

BRUCE LEE

Key Messages

- Ensure clear and appropriate requirements for IBR technology – start early
- Leverage industry standards – harmonization
- Engage multiple departments; avoid siloes
- All parties and perspectives need a voice
- Lack of clarity leads to confusion
- Effective requirements can streamline the interconnection process
- Avoid retroactive application unless technically justified
- Be reasonable with applying and enforcing new requirements
- Accommodate an evolving landscape – forward and backward looking

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Adopt IEEE 2800-2022

General F…
Cite IEEE 2…

"Point to s…
existing req…

- ✓Minimal eff…
- × **Limited syst… details***
- × Lacks clarity… specificity
- × **Leaves gaps… implementa… understand…**

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

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Hybrid Integration
Organic Integration

"Point to specific clauses and add clarifying language in existing requirements"

- ✓Targeted enhancements
- ✓Allows phased approach
- ✓Allows adaptation and additional requirements
- ✓**System-specific and clear**
- ✓Enables conformity language additions

Detailed Spec
Recreate Specs of IEEE 2800

"Recreate requirements language entirely"

- ✓Targeted enhancements
- ✓Allows phased approach
- ✓Allows adaptation and tailored solution for specific rules framework
- ✓Enables conformity language
- × **Significant work and duplication for AGIR**
- × Copyright concerns

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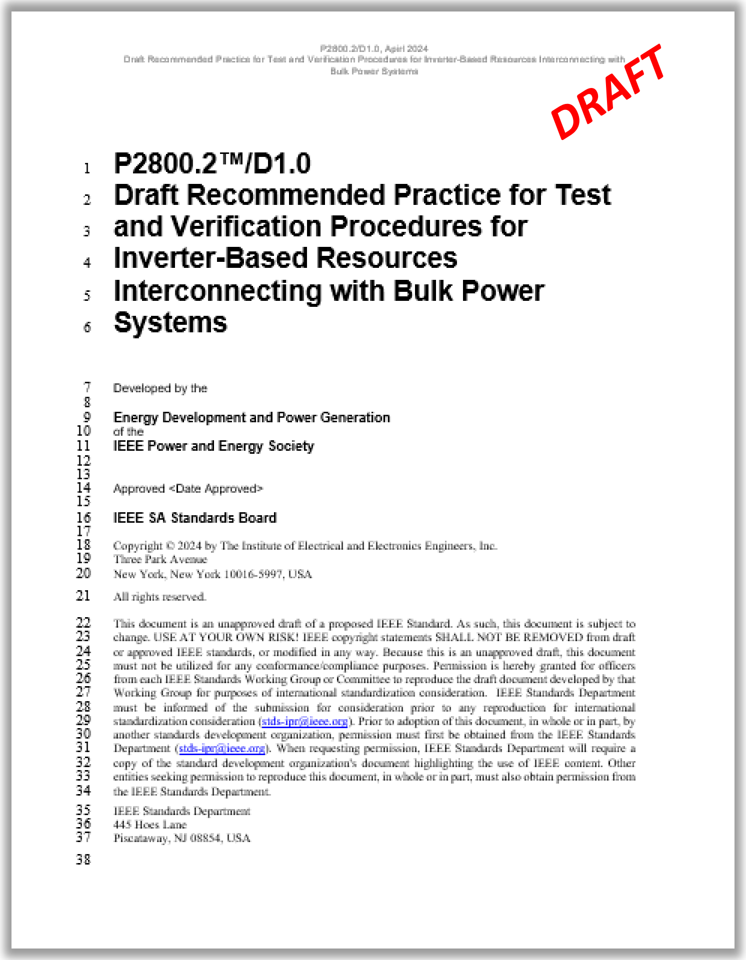
Alignment of Concepts



P2800.2/D1.0, April 2024
Draft Recommended Practice for Test and Verification Procedures for Inverter-Based Resources Interconnecting with Bulk Power Systems

DRAFT

P2800.2™/D1.0
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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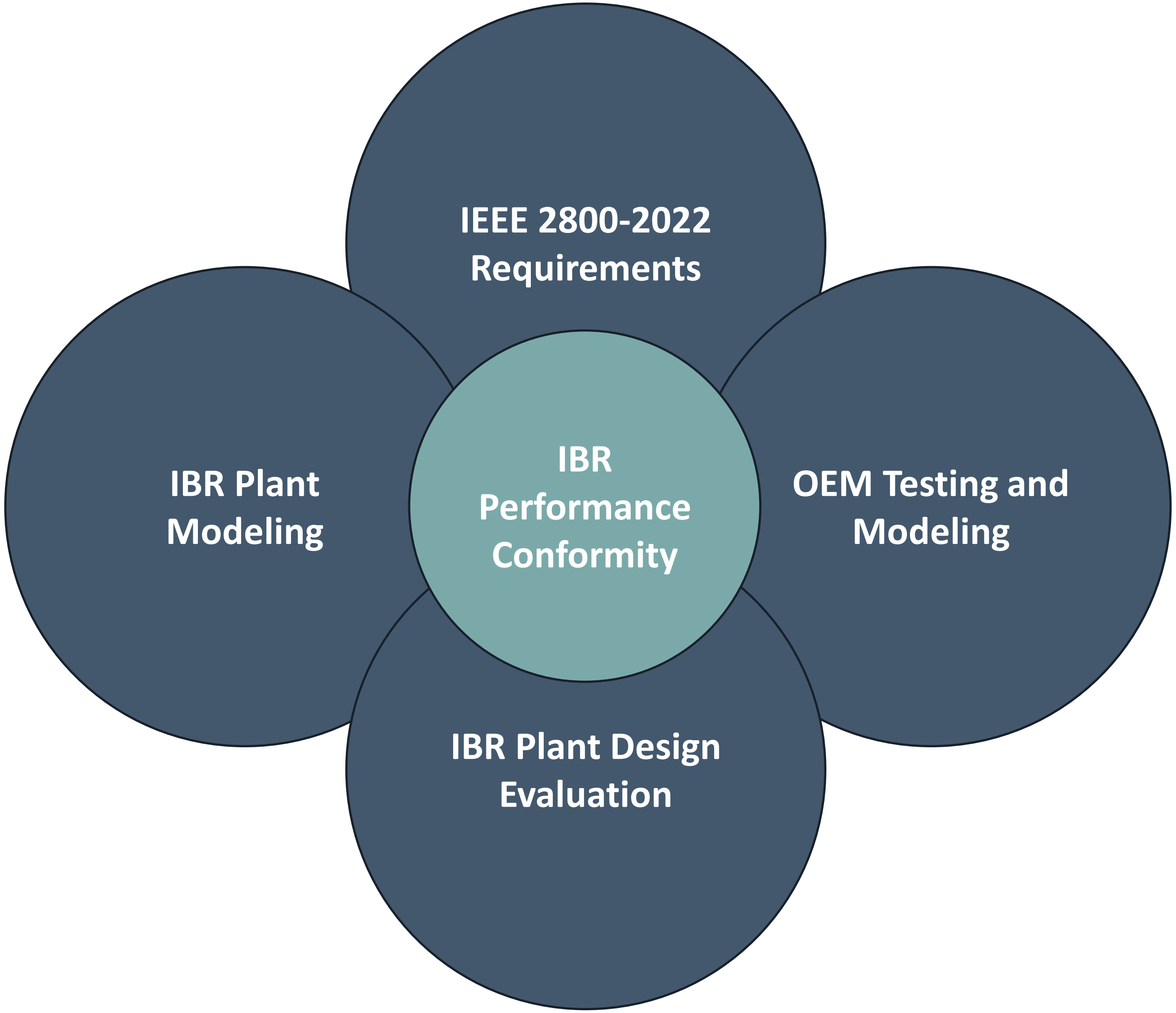

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IEEE P2800.2 Takeaways

- Adopt IEEE 2800-2022 in a harmonized manner
- Thoughtful implementation is critical – next major hurdle
- IEEE P2800.2 serves as a useful guide – needs integration
- Some entities already have some flavor of “IBR plant testing” – starting point
- Design evaluations involve multiple parties and collaboration is key
- Design evaluation (tests) and IBR modeling can go hand in hand
- Balance comprehensiveness with speed – costs on both sides
- As-built evaluations ensure that what was studied gets installed
- Improve IBR commissioning and testing procedures

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Ryan Quint
Founder and CEO
ryan.quint@elevate.energy

Introduction: The Need for IBR Plant Conformity Assessments

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

DOE i2X FIRST Hybrid Workshop

October 24, 2024

US DOE i2X FIRST

i2X Forum for the Implementation of Reliability Standards for Transmission (FIRST)

Interconnection Innovation e-Xchange

Interconnection Innovation e-Xchange » i2X Forum for the Implementation of Reliability Standards for Transmission (FIRST)

To ensure the reliable and secure operation of clean energy resources connected to the electric grid, interconnection standards need to address inverter-based generator capabilities, expected performance, cybersecurity requirements, and other relevant issues. Some of these standards, such as Institute of Electrical and Electronics Engineers (IEEE)-2800, have been developed, but still need to be widely adopted and implemented. Other standards, as well as procedures for assessing and verifying plant conformity with them, have yet to be developed.

https://www.energy.gov/eere/i2x/i2x-forum-implementation-reliability-standards-transmission-first

Technical Topics:

- IEEE 2800 Requirements and Clauses
- Equipment Manufacturer Readiness
- Transmission Provider Perspectives
- Ongoing Regulatory Activities
- Generation Owner/Operator Perspectives
- Changing System Conditions and Dynamics
- Emerging Technologies

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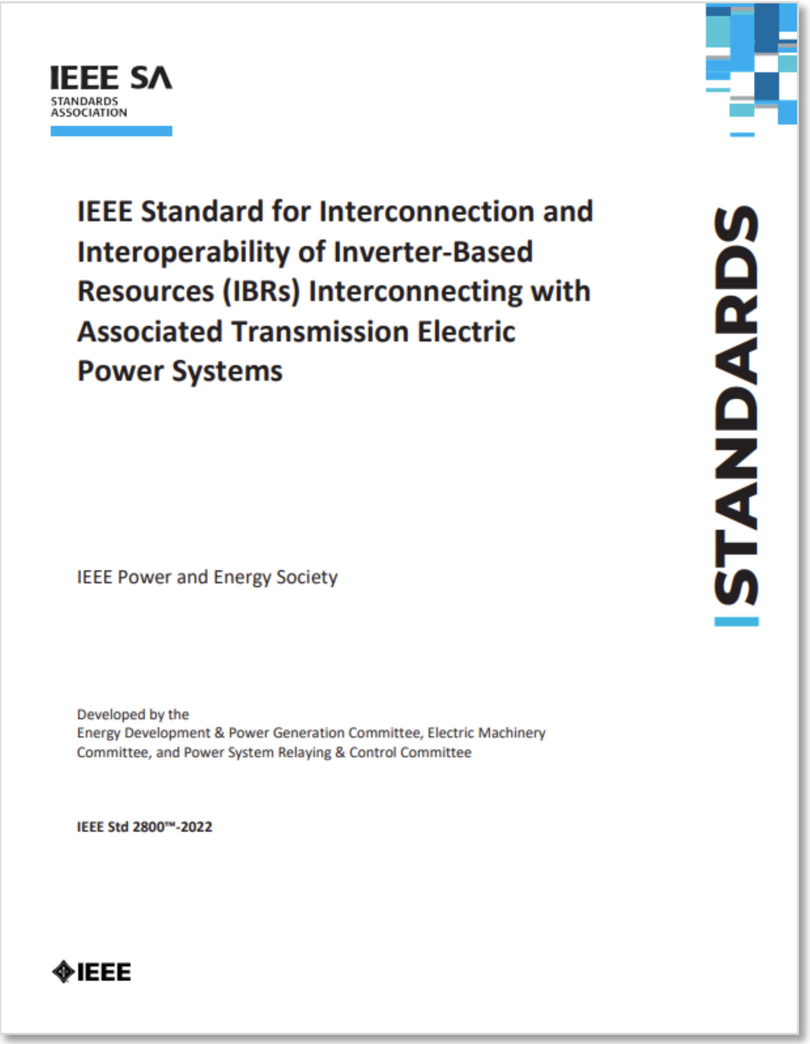
IBR Standardization

Provides ***uniform technical minimum requirements*** for the ***interconnection, capability, and performance*** of ***inverter-based resources*** interconnecting with ***transmission and sub-transmission systems***.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Developed by the
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IEEE Std 2800™-2022

IEEE

STANDARDS

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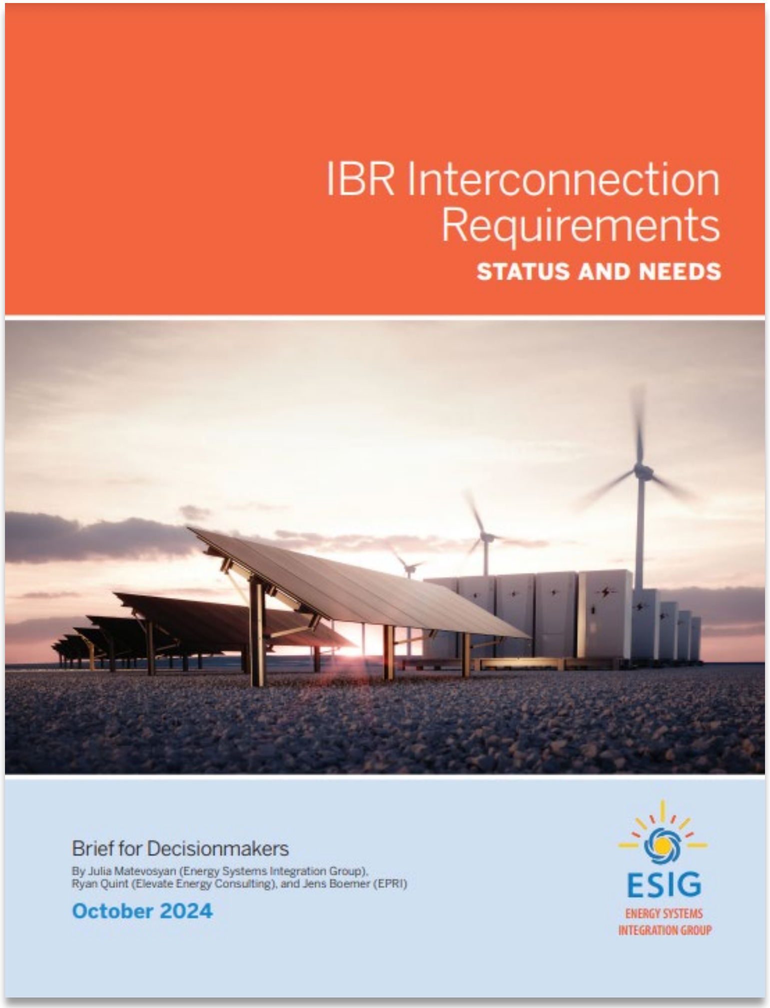
ESIG Brief for Decisionmakers

Call to Action

ISO/RTOs, transmission providers, and their customers will benefit from adopting large parts of voluntary industry standards such as IEEE 2800-2022 as an effective solution to mitigate reliability risks during this energy transition. The rapid pace of the energy transition calls for proactive steps to mitigate risks. The adoption of voluntary technical standards plays a major role in this process and can help inform policies, regulatory rulemaking, and other business decisions, as well as help streamline and expedite the interconnection process for new IBRs.



Source: ESIG

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IEEE 2800 Adoption Strategies

General Reference *Cite IEEE 2800 in Full*	Detailed Reference *Cite IEEE 2800 Clauses*	Hybrid Integration *Organic Integration*	Detailed Spec *Recreate Specs of IEEE 2800*
"Point to standard in existing requirements"	"Point to specific clauses in existing requirements"	"Point to specific clauses and add clarifying language in existing requirements"	"Recreate requirements language entirely"
✓Minimal effort to adopt × **Limited system-specific details*** × Lacks clarity and specificity × **Leaves gaps in implementation and understanding**	✓Targeted enhancements ✓Allows phased approach × **Limited system-specific details***	✓Targeted enhancements ✓Allows phased approach ✓Allows adaptation and additional requirements ✓**System-specific and clear** ✓Enables conformity language additions	✓Targeted enhancements ✓Allows phased approach ✓Allows adaptation and tailored solution for specific rules framework ✓Enables conformity language × **Significant work and duplication for AGIR** × Copyright concerns

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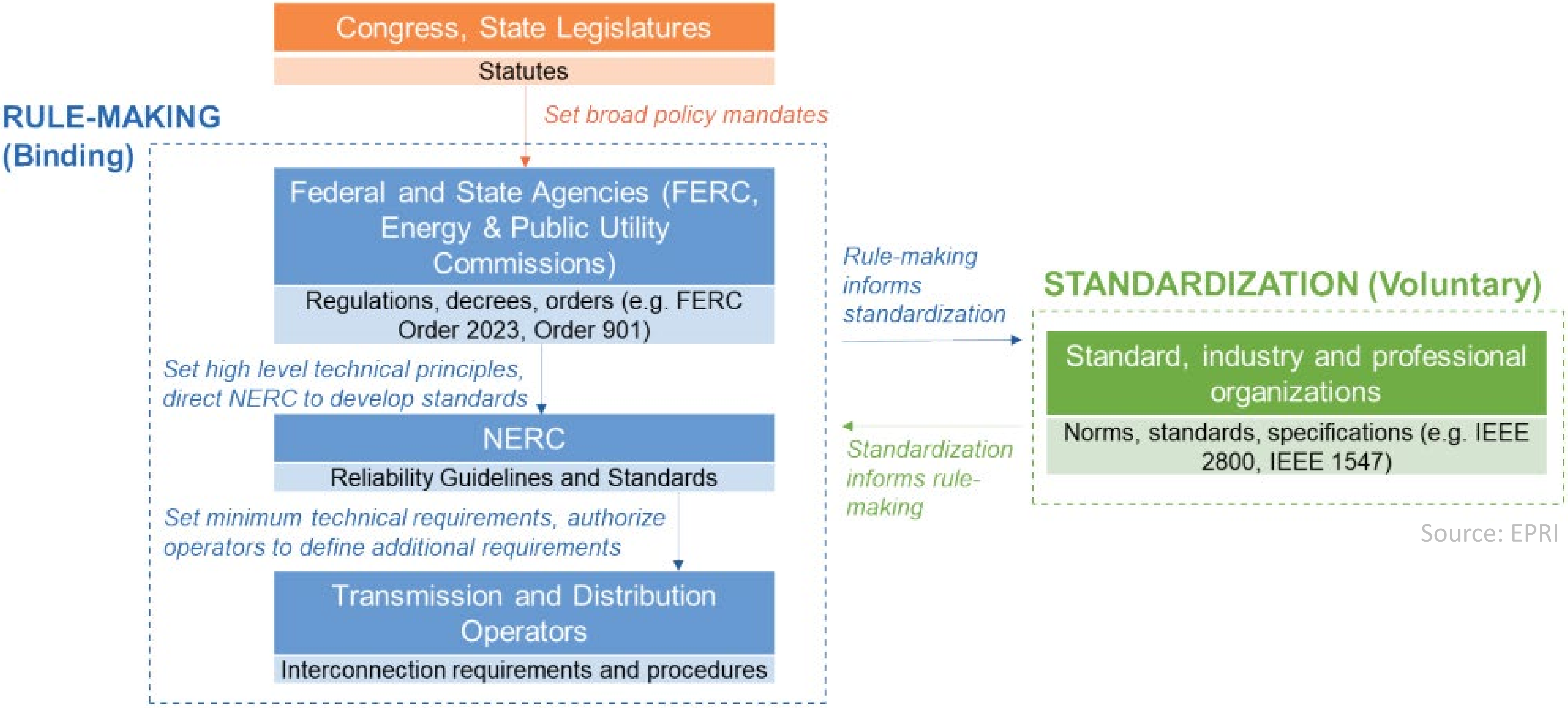
* Industry practice has tended to not provide the necessary AGIR-specific details (i.e., functional settings) needed for complete adoption of IEEE 2800-2022.

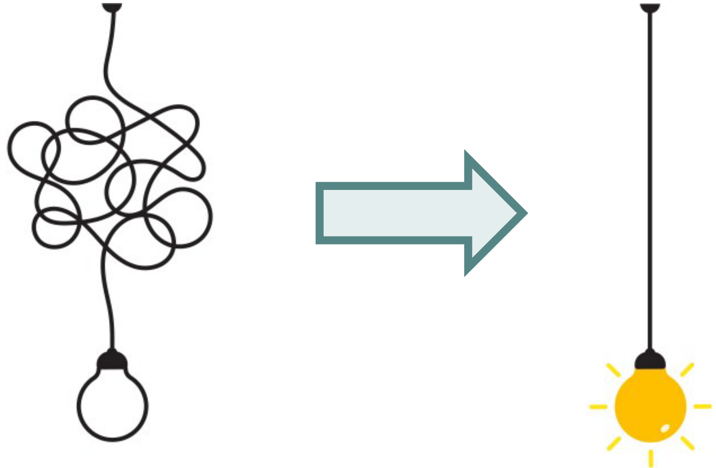
Policy, Regulation, and Standards in the US



Source: EPRI

Key Drivers – Why Are We Here?

- Reduce costs for all stakeholders and ratepayers
- Streamline and accelerate generation interconnection process
- Eliminate unnecessary rework
- Harmonize (fair and consistent) requirements across regions
- Ensure reliable and resilient operation of the bulk power system



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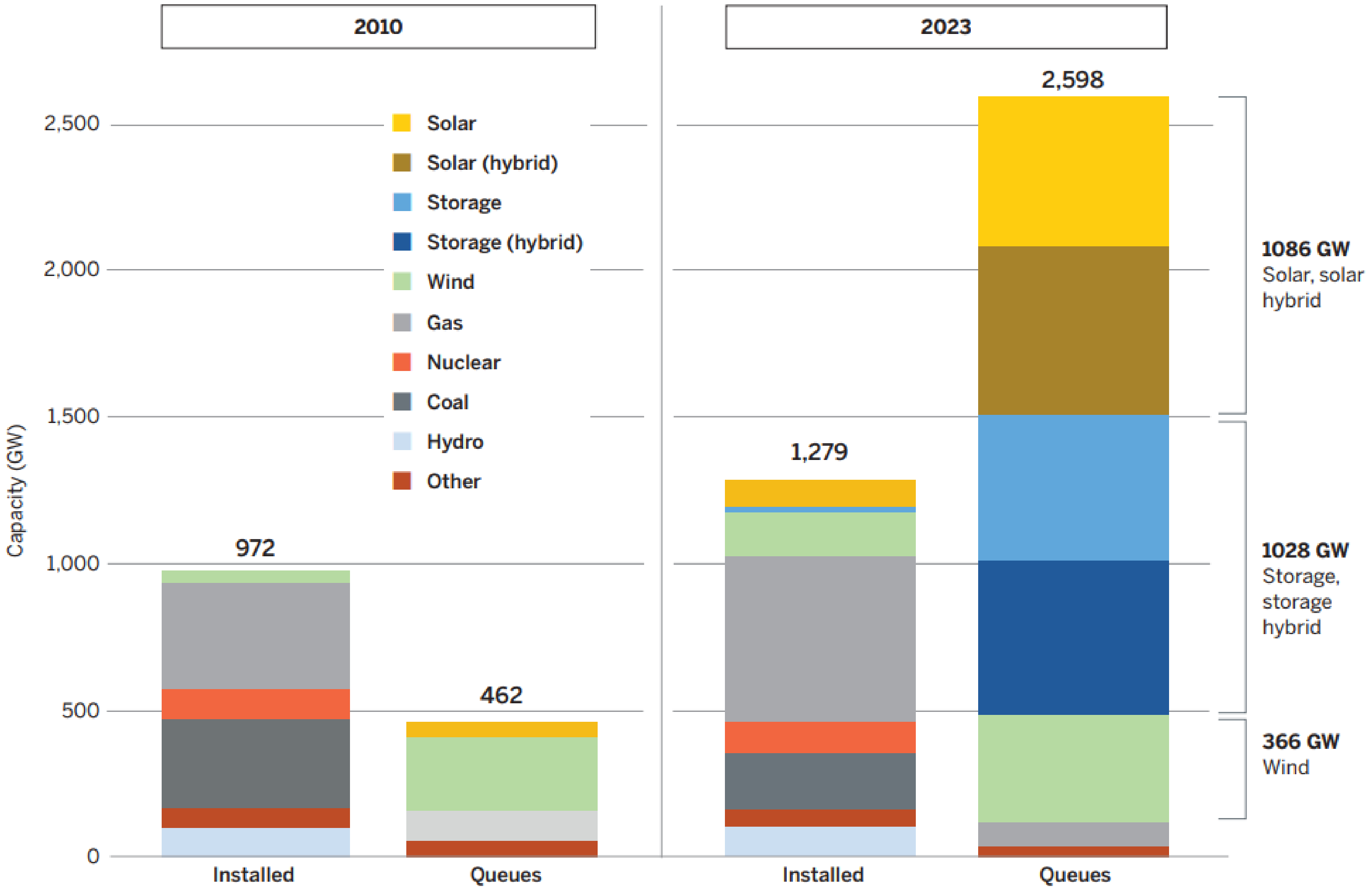
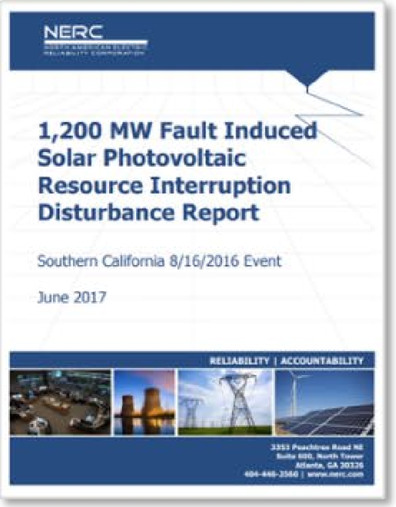
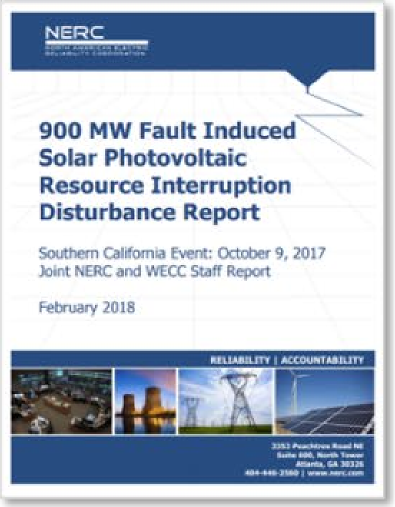
Interconnection Queue:
Large and Inverter-Based

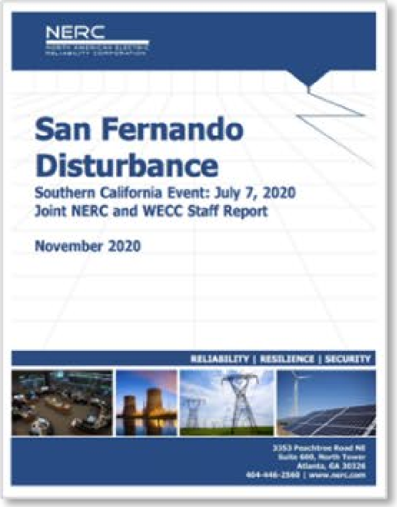


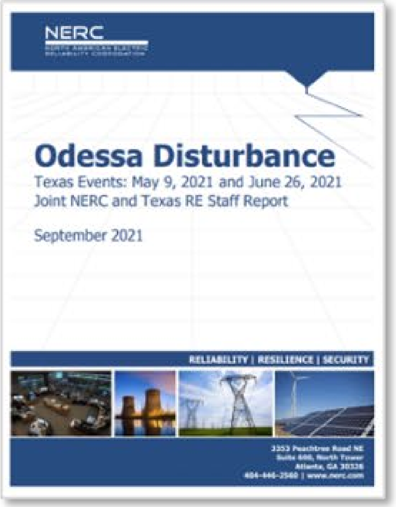
Source: LBNL

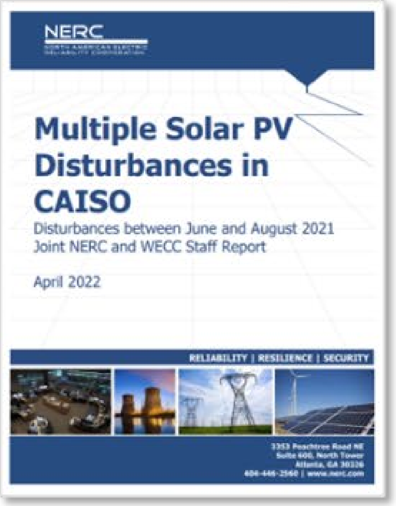
Early Indicators of the Need for Improvement

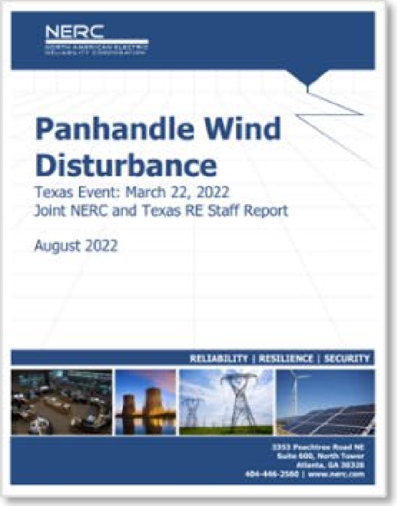


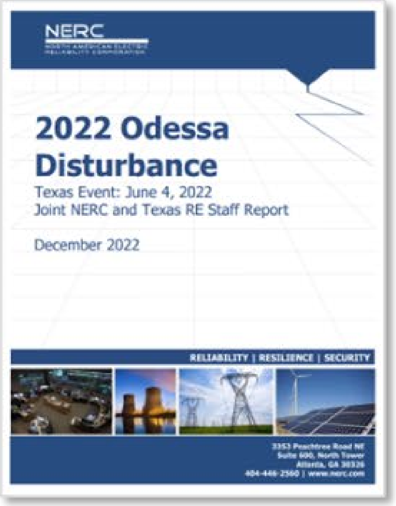


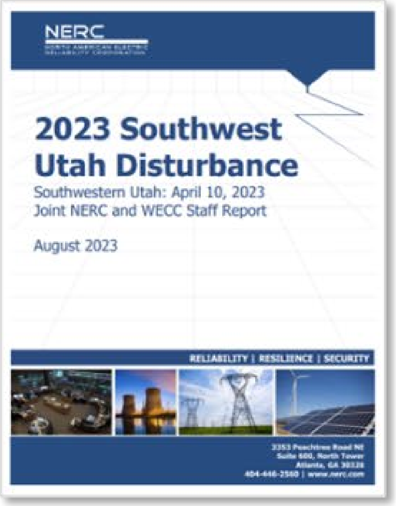


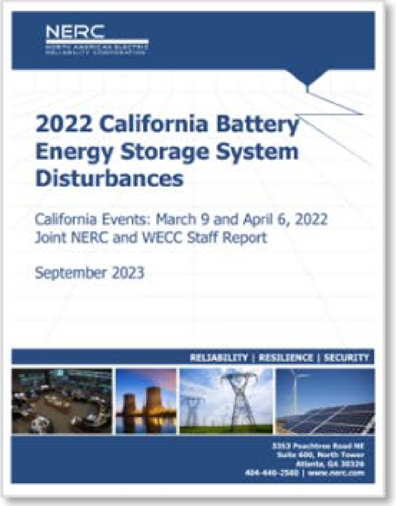












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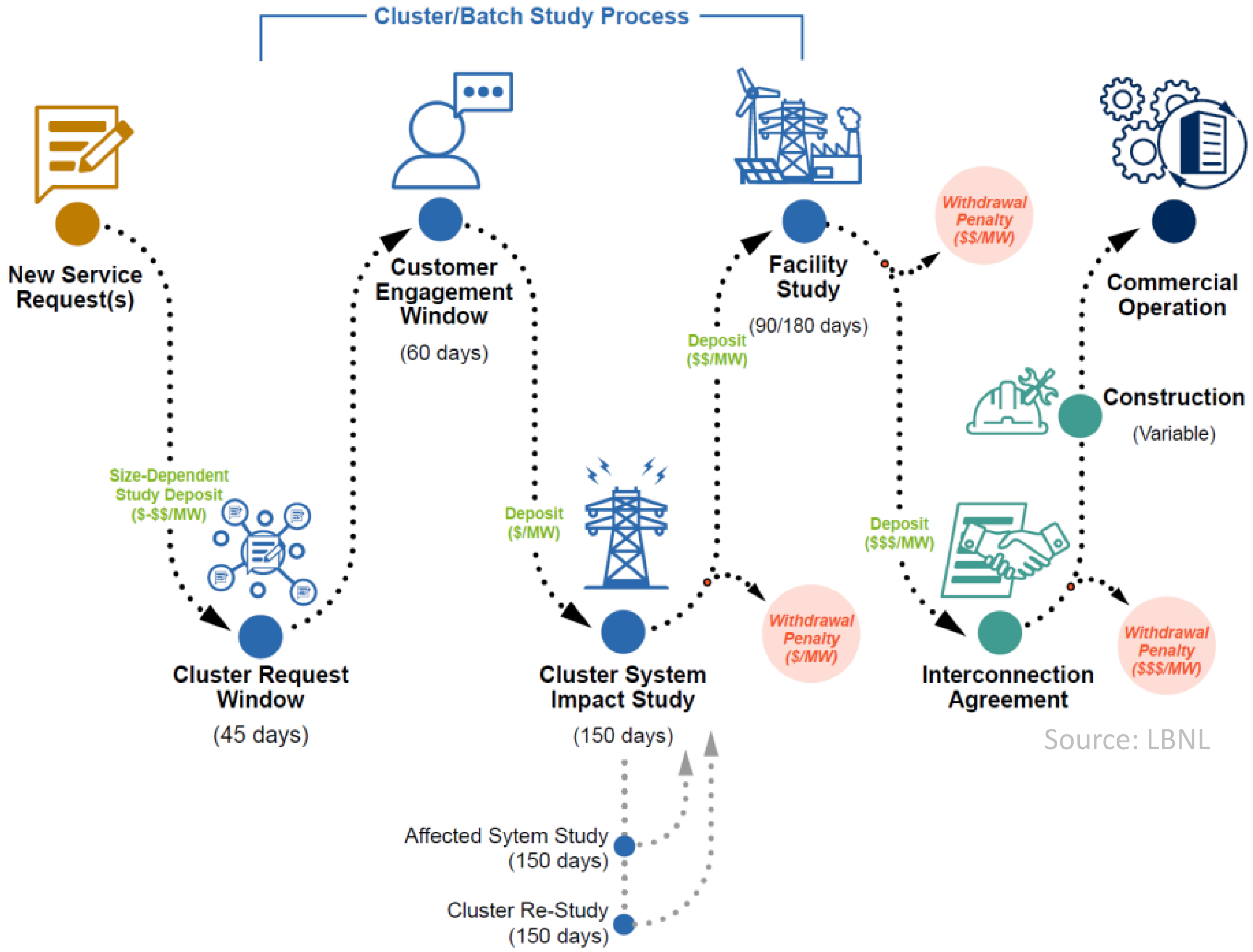
Eye on the Interconnection Process



Source: LBNL

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Key Stakeholders

Transmission System Owners

Independent System Operators

Transmission System Operators

Renewables Developers

Independent Power Producers

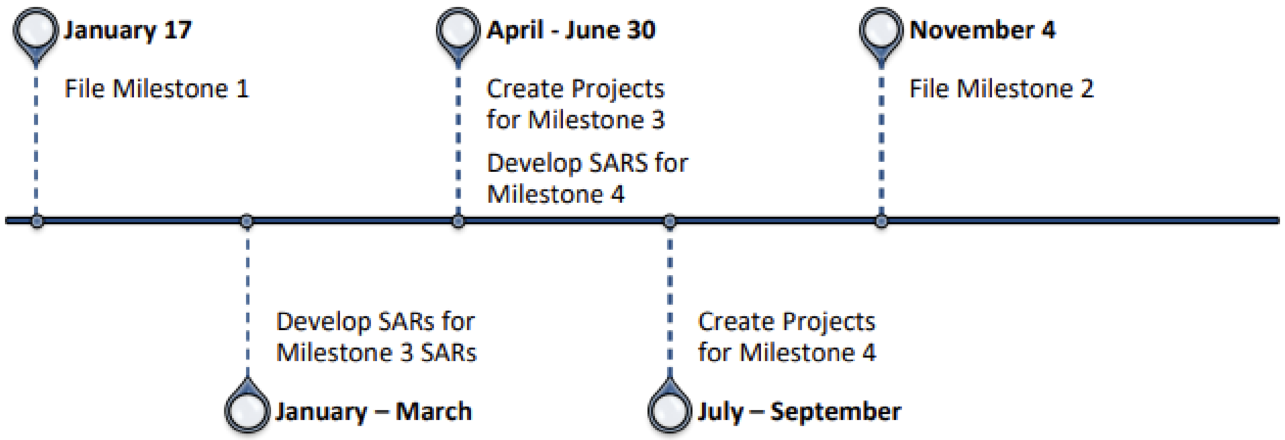
Original Equipment Manufacturers

EPC Contractors & Consultants

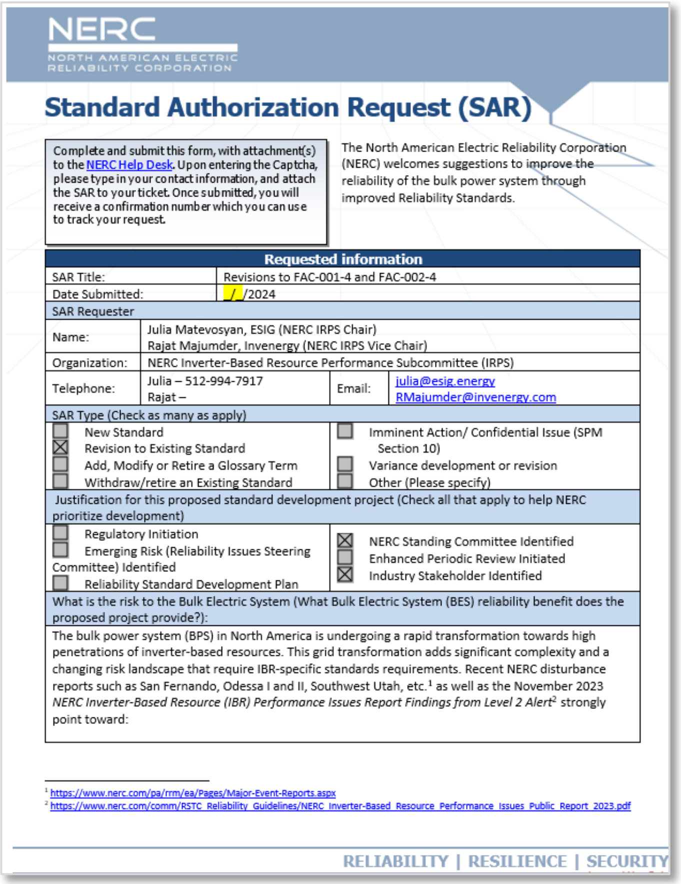
Systems Integrators

NERC 901 Work Plan and IRPS SAR

- **Milestone 1:** Submission of Order No. 901 Work Plan (January 2024)
- **Milestone 2:** Filing of Standards to Address Performance Requirements and Post-Event Performance Validation for Registered IBRs (November 4, 2024)
- **Milestone 3:** Filing of Standards to Address Data Sharing and Model Validation for all IBRs (November 4, 2025)
- **Milestone 4:** Filing of Standards to Address Planning and Operational Studies Requirements for all IBRs (November 4, 2026)



Source: NERC



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:	Revisions to FAC-001-4 and FAC-002-4		
Date Submitted:	_/_/2024		
SAR Requester			
Name:	Julia Matevosyan, ESIG (NERC IRPS Chair) Rajat Majumder, Invenergy (NERC IRPS Vice Chair)		
Organization:	NERC Inverter-Based Resource Performance Subcommittee (IRPS)		
Telephone:	Julia – 512-994-7917 Rajat –	Email:	julia@esig.energy RMajumder@invenergy.com
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	
What is the risk to the Bulk Electric System (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. This grid transformation adds significant complexity and a changing risk landscape that require IBR-specific standards requirements. Recent NERC disturbance reports such as San Fernando, Odessa I and II, Southwest Utah, etc.[1] as well as the November 2023 *NERC Inverter-Based Resource (IBR) Performance Issues Report Findings from Level 2 Alert*[2] strongly point toward:			

[1] https://www.nerc.com/pa/rrm/ea/Pages/Major-Event-Reports.aspx
[2] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/NERC_Inverter-Based_Resource_Performance_Issues_Public_Report_2023.pdf

RELIABILITY | RESILIENCE | SECURITY

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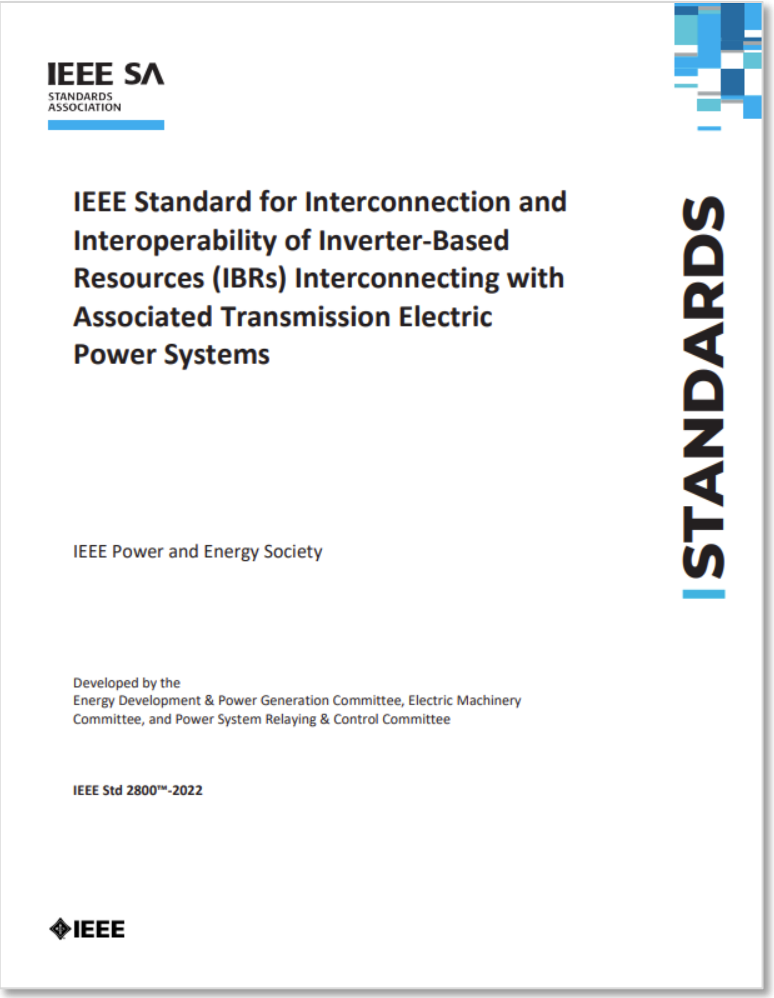
IEEE 2800-2022 and IEEE P2800.2



IEEE SA
STANDARDS ASSOCIATION

STANDARDS

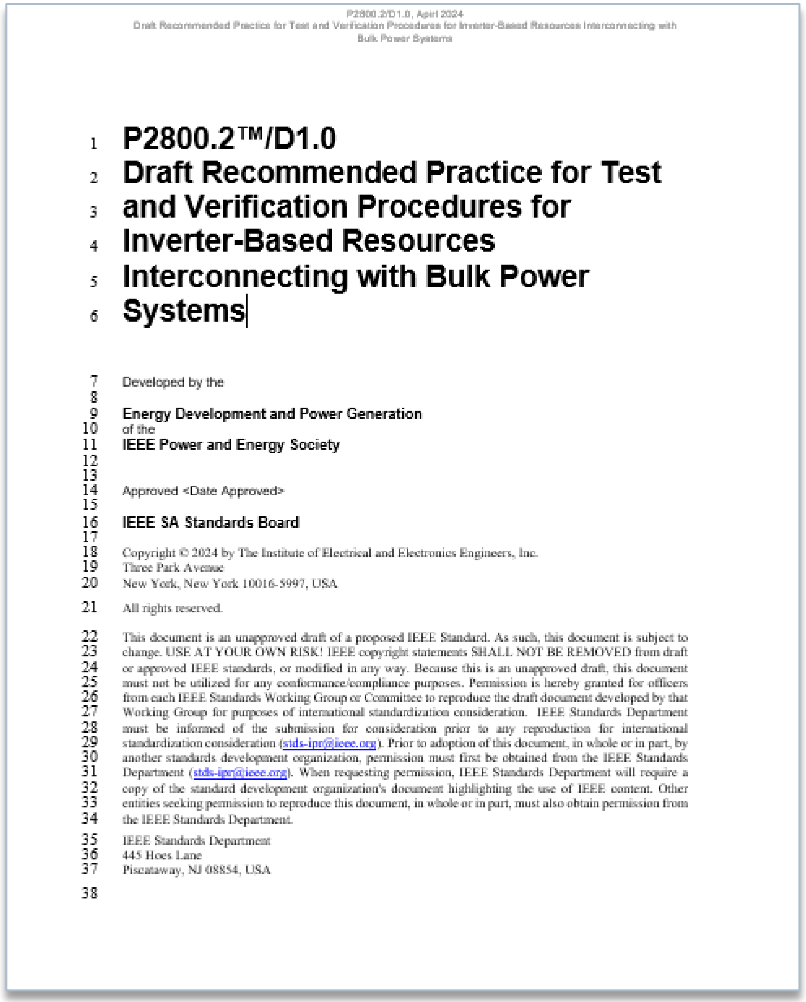
IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems

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

IEEE



P2800.2/D1.0, April 2024
Draft Recommended Practice for Test and Verification Procedures for Inverter-Based Resources Interconnecting with Bulk Power Systems

P2800.2™/D1.0
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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THE WHAT

THE HOW

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Collaboration; not Contention

- IBR plant conformity assessment is an iterative process
  - IBR plant design evolves throughout the process
  - Key milestones where decisions solidify
  - Evolving technology and changes by OEMs throughout
- Improving process for conducting IBR plant conformity assessments can benefit ***both*** interconnection customer and transmission provider

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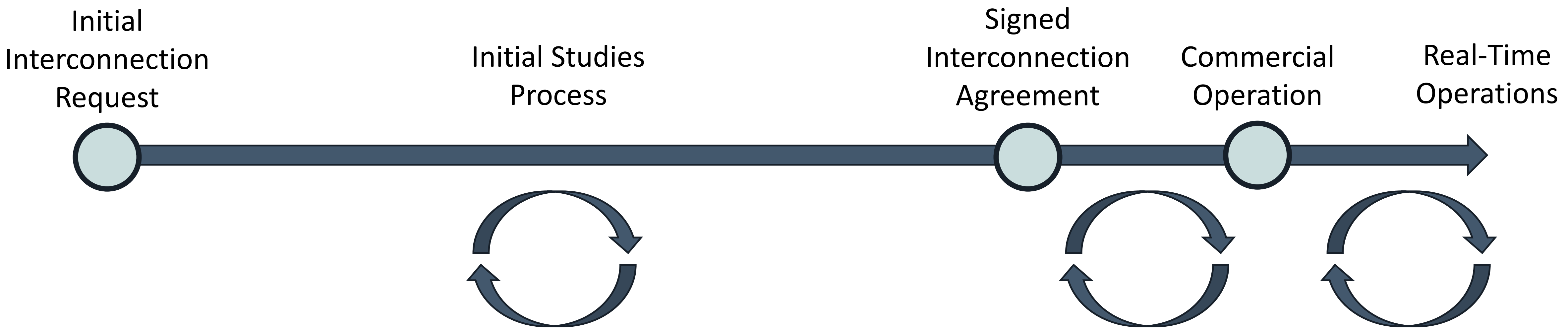
Interconnection Process



<u>Interconnection Process</u>

- Initial interconnection request involves lots of default data about IBR plant design
- IBR plant design evolves throughout process (allowed by FERC process)
- Ongoing IBR plant model developments to match changes
- Increasingly technical reliability studies (needing actual/planned IBR designs)
- Transmission provider technological change management procedures

<u>Signed Interconnection Agreement and Commissioning Procedures</u>

- Signed interconnection agreement is major milestone in development
- Serves as baseline for what is to be built and commissioned
- Commissioning process may further refine some protection and controls
- Sufficient checks and balances needed to ensure what gets commissioned matches what was (finally) studied
- More change management needed

<u>Real-Time Operations</u>

- Changes occur during real-time operations, whether knowingly or unexpectedly
- Changes in real-time operations may require reverification that the capability and performance requirements are still met
- Models need to be updated to match reality

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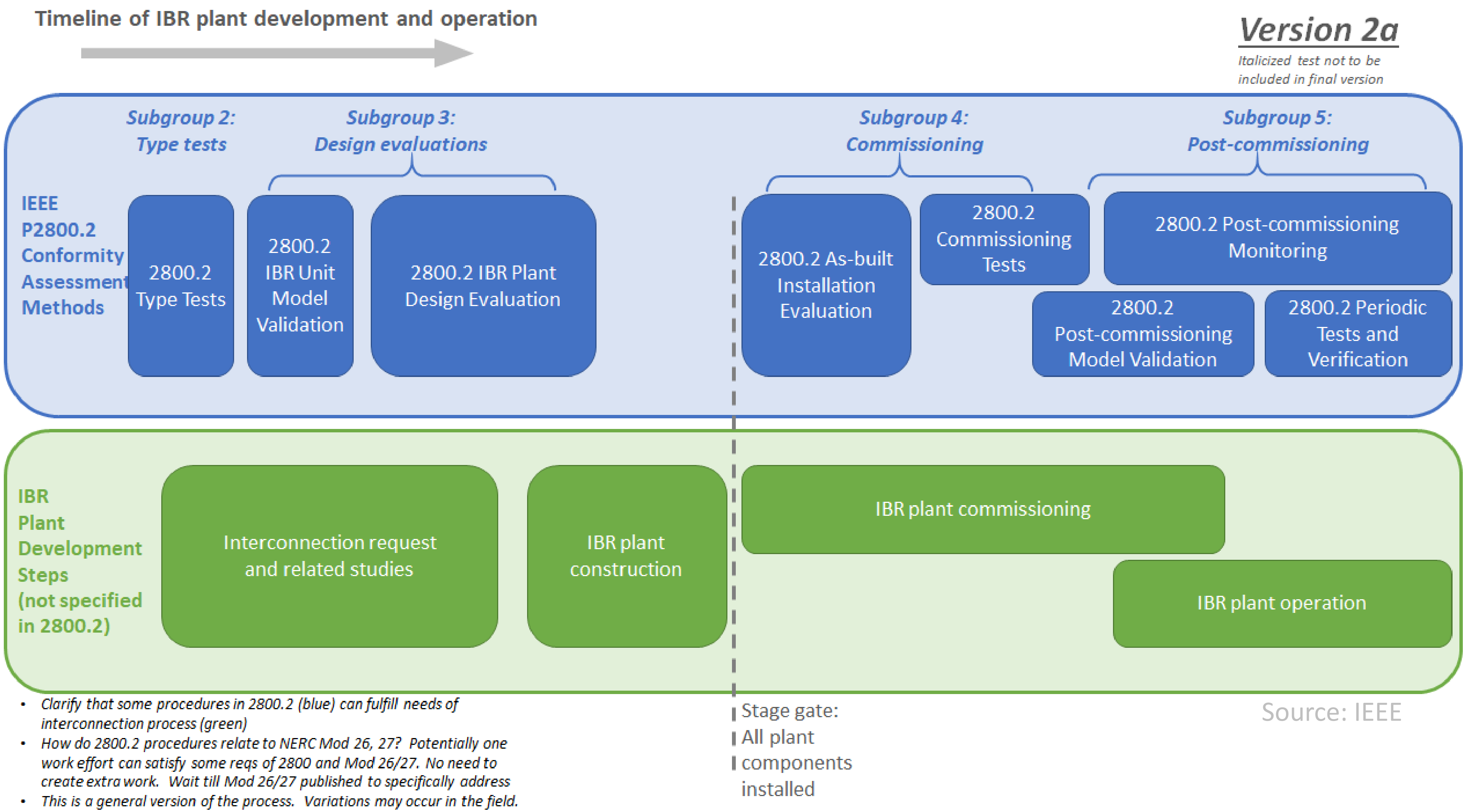
Integration of IEEE P2800.2 Subgroups



- *Clarify that some procedures in 2800.2 (blue) can fulfill needs of interconnection process (green)*
- *How do 2800.2 procedures relate to NERC Mod 26, 27? Potentially one work effort can satisfy some reqs of 2800 and Mod 26/27. No need to create extra work. Wait till Mod 26/27 published to specifically address*
- *This is a general version of the process. Variations may occur in the field.*

Source: IEEE

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Key Goals

- Increase the baseline minimum capability and performance requirements of IBR plants
- Speed up the interconnection process and foster collaboration between necessary parties
- Avoid significant (re)work for either transmission provider or interconnection customer
- Accommodating change management throughout the process
- Fully leverage modern IBR technology and avoid past “risks” identified
- Ensure IBR plants are designed and commissioned to provide grid-supportive capabilities, performance, and services
- Ensuring grid reliability and resilience with sufficient checks and balances throughout process
- Allow and enable emerging technology innovation

- Needs:
    - Comprehensive understanding and adoption of IEEE 2800-2022
    - Insights on how to effectively implement IEEE P2800.2 recommendations
    - Automation and tools to expedite the analysis of all this technical assessment

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Kickoff Panel and Rest of Workshop

8:00 a.m. – 9:45 a.m.

Session 1: Opening Remarks and Background Information

Session Chair: Ryan Quint, Elevate Energy Consulting

Introduction to DOE i2x FIRST and the Workshop
Julia Matevosyan, ESIG

Need for IBR Plant Conformity Assessment
Ryan Quint, Elevate Energy Consulting

IEEE 2800.2 Progress Update
Andy Hoke, NREL

Importance of IBR Modeling and Design Evaluation
Alex Shattuck, NERC

Other Panels Today:

- IBR Plant Design Evaluations and Tests
- IBR Modeling and Model Validation
- IBR As-Built Evaluations and Commissioning Testing

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