Forum for the Implementation of Reliability Standards for Transmission (i2X FIRST) | 12/16/25

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

A DOE initiative supported by the Office of Critical Minerals and Energy Innovation (CMEI)

BERKELEY LAB
ESIG
EPRI

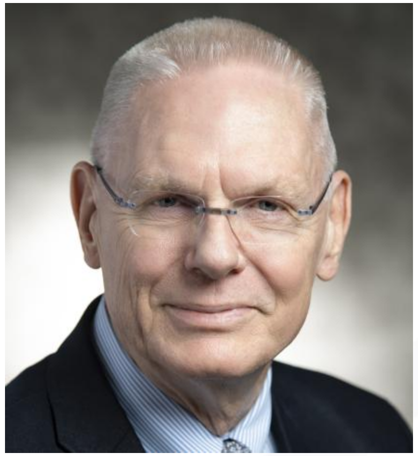
The first half of this meeting call is being recorded and may be posted on ESIG's website. If you do not wish to have your voice recorded, please do not speak during the call. If you do not wish to have your image recorded, please turn off your camera or participate by phone. If you speak during the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

Key Goals and Outcomes from i2X FIRST

- To facilitate understanding and adoption of new and recently updated standards relevant for existing and newly interconnecting inverter-based resources.
- 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



Robert Reedy, Lindahl Reed, contractor to DOE

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: Change Management during IBR Plant Interconnection Process and Commissioning, How to Maintain Conformity

- **Meeting Introduction:** Julia Matevosyan, ESIG
- **IBR Developer Perspective:** Katie Iversen, Joseph Perry, Andrew Lopez, AES
- **OEM Perspective:** Miguel Cova Acosta, Vestas
- **EPC Perspective:** Patrick Hart, Mortenson
- **Q&A and Structured Discussion**, led by Julia Matevosyan, ESIG
  - How can IBR plant developers position themselves best for IBR plant change management to reduce or avoid project development delays?
    - Documentation and model management, contracting
  - What can utilities/ISOs/RTOs do to ensure seamless and reliable interconnection for projects that are undergoing a change?

Meeting summary, recording & presentations are posted here

Key Themes from the Last Meeting

- **Model–Field Alignment Is Mission-Critical:** "As-studied" models must match "as-commissioned/as-left" inverter and PPC settings to ensure compliance, performance, and reliability.
- **Compliance Is a Lifecycle Responsibility:** Grid code conformity spans design, commissioning, and long-term operation. Changes in ownership, equipment selection, or design assumptions introduce risk, especially when documentation is incomplete or knowledge transfer is weak.
- **Early Design Decisions Matter**: Incomplete requirements, generic studies, or premature assumptions drive downstream issues; iterative analysis reduces execution risk.
- **Standardization Improves Confidence:** Consistent parameter naming, data formats, and transparent access to essential settings reduce errors and friction while protecting IP.
- **Commissioning Is Iterative and Collaborative:** Field testing often reveals compliance risks not captured in studies (e.g., communication delays, filtering, metering, hardware limits), requiring close EPC–developer–OEM coordination, controller tuning, and "as-left" verification to ensure sustained compliant performance.

Upcoming i2X FIRST Meetings – Season 2

1. May 27, 2025, 11 a.m. - 1 p.m. ET – **Season 2 Kick-Off**
2. June 24, 2025, 11 a.m.- 1 p.m. ET – **NERC Milestone 3 Standards**
3. July 22, 2025, 11 a.m.- 1 p.m. ET – **IBR Plant Design Evaluation with Applicable Requirements I**
4. August 26, 2025, 11 a.m.- 1 p.m. ET – **IBR Plant Design Evaluation with Applicable Requirements II**
5. September 23, 2025, 11 a.m.- 1 p.m. ET – **IBR Plant Modeling Requirements and Best Practices**
6. October 21, 2025, 11 a.m.- 1 p.m. ET – **Challenges with IEEE2800-2022, Planned Revisions**
7. November 25, 2025, 11 a.m.- 1 p.m. ET – **Change Management during IBR Plant Interconnection Process and Commissioning, How to Maintain Conformity**
8. December 16, 2025, 11 a.m.- 1 p.m. ET – **IBR Plant Commissioning Best Practices I**
9. January 27, 2026, 11 a.m.- 1 p.m. ET – IBR Plant Commissioning Best Practices II
10. February 24, 2026, 11 a.m. - 1 p.m. ET – TBD
11. March 16, 2026 hybrid event during ESIG Spring Workshop: Grid Forming IBR Specifications, Testing Requirements, Lessons Learned

Sign up for all future i2X FIRST Season 2 Meetings here

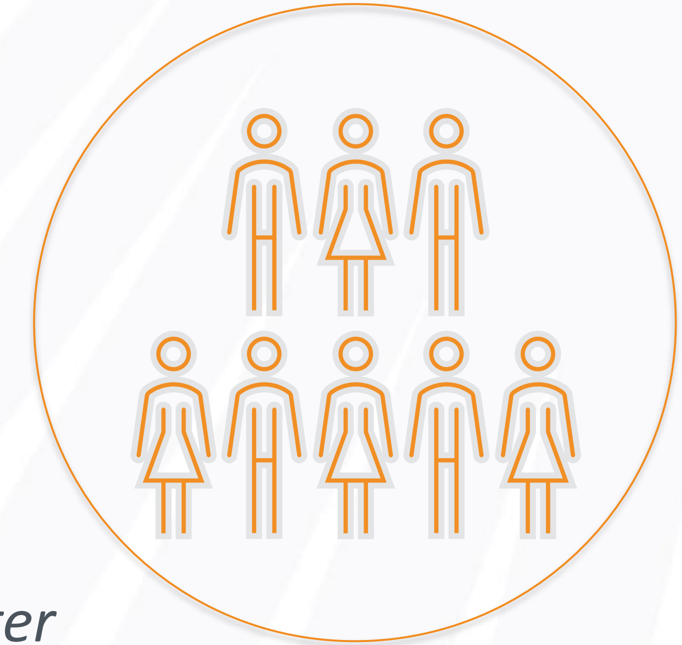
Follow ESIG i2X FIRST website https://www.esig.energy/i2x-first-forum/ for meeting materials & recordings and for future meeting details & agendas

IBR Plant Commissioning Best Practices – Agenda

- **Meeting Introduction:** Julia Matevosyan, ESIG
- **IBR Developer Perspective:** Zachary Hammond, Engie
- **PPC Perspective:** Lars Johnson , Merit Controls
- **ISO Perspective:** Phillip Hiusser, Independent Electricity System Operator (IESO)
- **Q&A and Structured Discussion**, led by Julia Matevosyan, ESIG
  - Commissioning Testing
    - Measurements needed at commissioning
    - What is the best practice process if parameters need to be tuned during commissioning
  - IBR plant model validation based on commissioning testing
    - When should this be done?
    - What happens if the model shows discrepancies?

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*
6. *Please go to slido to ask questions:* ***slido.com*** *and enter event code* ***FIRST8***



Mutual Respect . Collaboration . Openness

Stakeholder Presentations

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Mutual Respect . Collaboration . Openness

Q & A Session

Interactive Group Discussion Topics

Topic #1: Commissioning Testing

- Please go to slido to make comments and add questions of your own: **slido.com** and enter event code **FIRST8**
- For verbal commentary, please use the raise hand feature and we will call on you
- Additional related / associated questions:
  - Measurements needed at commissioning
  - What is the best practice process if parameters need to be tuned during commissioning

Topic #2: IBR plant model validation based on commissioning testing

- Please go to slido to make comments and add questions of your own: **slido.com** and enter event code **FIRST8**
- For verbal commentary, please use the raise hand feature and we will call on you
- IBR plant model validation based on commissioning testing
  - When should this be done?
  - What happens if the model shows discrepancies?

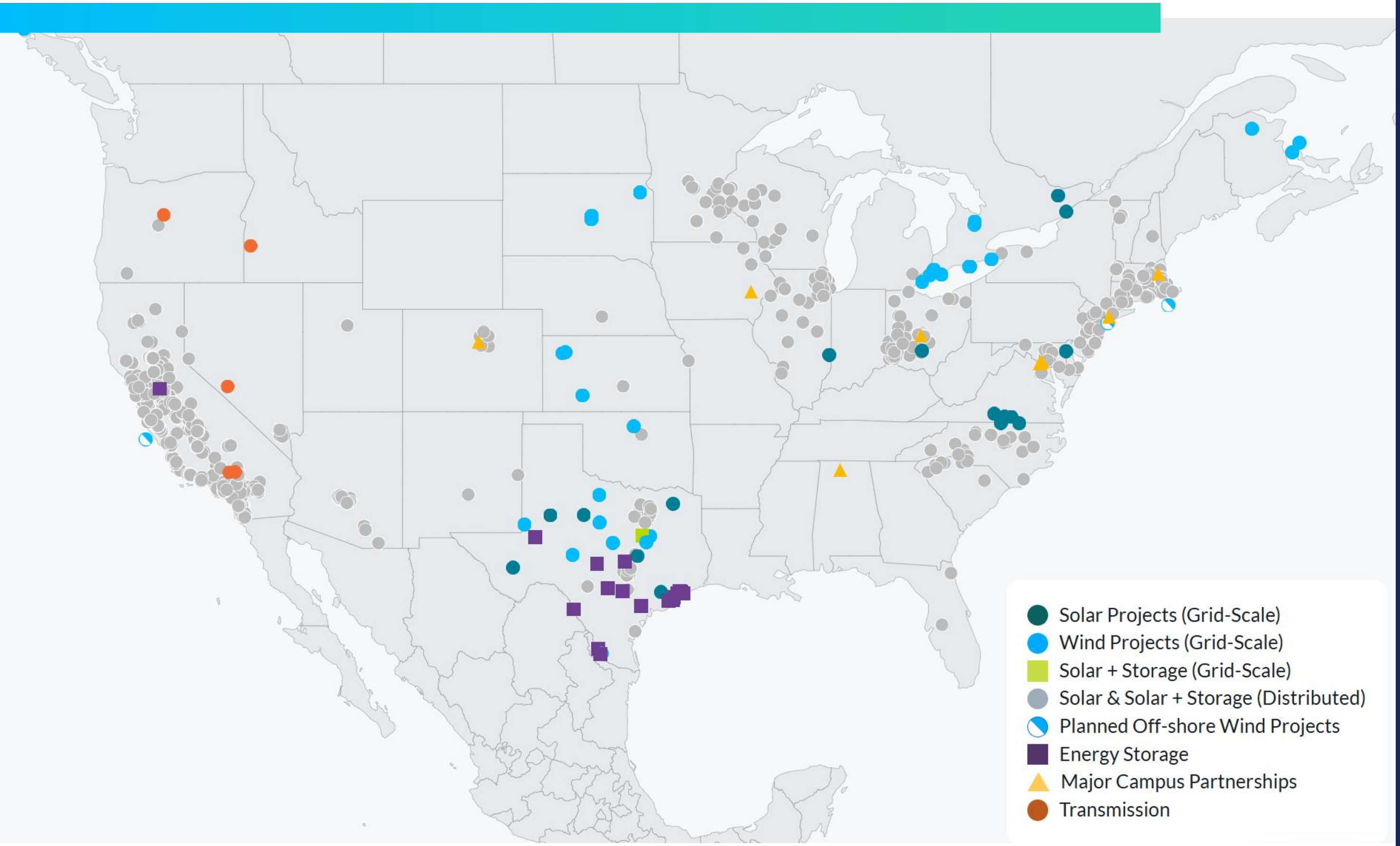
IBR Plant Commissioning Experience and Lessons Learned

Zach Hammond & Rishi Maharaj

December 16, 2025

ENGIE | ESIG ENERGY SYSTEMS INTEGRATION GROUP

ENGIE NORTH AMERICA AT A GLANCE



Data as of 4/07/25

Renewable & Flex Power + Local Energy Infrastructures

Houston
Headquarters

3,400
Employees
(Including Impact)

~9.5 GW
Renewables in Operation
~3.9 GW Onshore Wind
~ 3.2 GW Solar Power
~ 2.1 GW Battery Storage

50+ year
Heritage

1.4 GW
2024 Corporate PPAs Signed

1000+
Communities with active operations, projects or development

2.84 GW
Renewables Under Construction

45,000
Commercial and Industrial retail energy supply customers

Supply & Energy Management

295 TWh
of energy traded / 54 TWh delivered in 2024

~13.5 GW
Asset Management for internal and external assets

Outline

1. Overview of typical mandatory field commissioning tests on IBR plants in North America
2. Experience & recommendations on less typical / “best practice” tests
3. Observations on challenges & shortcomings of existing industry practices
4. Parameter verification vs. simulation models before and after commissioning
5. Lessons learned

Typical IBR plant commissioning tests

- Mandatory testing requirements vary dramatically between regions and AGIRs
  - Some regions have no mandatory requirements at all
  - This does not mean you should not conduct robust commissioning tests
- Level of involvement of the AGIR (ISO/TP/TOP) varies from defining, reviewing and approving tests to no involvement other than receiving the GO/GOP's declaration that testing is complete
- Since NERC registration is triggered by Commercial Operation, NERC Standards do not reach tests that occur as part of plant commissioning. Initial MOD-025/026/027 tests only due ~1 year after COD.
- Commonly mandated tests:
  - Automatic voltage regulator (AVR)
  - Primary frequency response (PFR)
  - Active power control (curtailment)
  - Capacity test (BESS units)
- Test methodology and success criteria vary

Overview of common tests

- AVR testing
  - Can be simple or complex
  - Most common methodology is test with step-changes to the voltage reference (target)
  - Simplest test is basic verification that an AVR exists and is in auto. Basically, “does it move in the right direction?”
  - More comprehensive testing validates capability (ability to deliver specified reactive power capability at the POI under specific conditions) and response time
  - Range of scenarios tested can involve different sizes of Vref step change, simulated voltage change by switching nearby shunt devices or transformer energization
  - Zero-generation functionality (solar night mode, BESS idle mode, zero wind) rarely tested
- PFR testing
  - Typical methodology is to inject or simulate a frequency offset signal in the plant controller and observe response
  - Settings (deadband, droop) and performance criteria usually explicitly defined by BA
  - Overfrequency response only for wind/solar, under/over frequency for BESS

What is the objective of commissioning tests?

Less typical tests

- Try to break it
  - Lots of plant contingencies cannot be tested in simulation or in single-device type testing
  - If you can test it without creating a safety hazard or potential damage to equipment, try it and see what happens
  - Do not rely on the ISO to tell you how to test your own equipment. ISO requirements are complementary to owner testing; they do not replace it.
- Hardware & communications failure tests
  - Plant controller redundancy & fallback modes
  - Response to invalid commands
  - Re-initialization
- Testing large disturbances is impossible, but test the largest disturbance that you can
  - Do not limit to +/-1 or 2% Vref changes just because that is all the ISO requires (but check with the TOP before your test)
  - Shunt switching within the plant or on the transmission system is more realistic than Vref step changes
  - Measurement devices may be external to the PPC and not validated by PPC vendor
- Night mode AVR for solar
- Test PFR with realistic frequency signals not just step changes

Bridging the gap between models and commissioning

- Today many plants will have a PSCAD model developed prior to commissioning. However, challenges exist in fully replicating commissioning tests in simulation:
  - Measurement devices & time delays are not represented accurately in PSCAD
  - Load tap changer (LTC) and shunt switching logic is rarely represented accurately in user-written models
  - Collector system aggregation has drawbacks for simulating terminal voltage at individual IBR units
  - Plant controller PSCAD models may not accurately represent real logic such as reactive power limiters
- Common approach is to start with defaults and tune in the field
  - Time-consuming, and test scenarios are usually limited
  - May not be tuned at all if there are no ISO test requirements
  - Modelling LTC and shunt switching in PSCAD is valuable to define reasonable starting points for field commissioning
  - Simulation can identify if the PPC logic is sufficiently flexible to meet the performance requirements. If PPC features need to be added, it can be done prior to commissioning.
- What is the point of developing an EMT model, if it isn't used to commission the plant?

Examples of PVR Issues

Example #1: Reactive Power (Q) Limits

At one ENGIE site, an engineering consultant developed a plant PSCAD model using the following reactive power limits to ensure correct active power recovery after VRT. This model passed the ISO's model quality assessment.

- *Qmin* = -170MVAr (gross)
- Q*max* = 164.2MVAr (gross)

But the real PPC doesn't use static gross Q limits; Instead, it uses a MW-dependent limiter that is applied to net Q at the POI. Here's an example of how a plant might be configured in the PPC based on a plant rating of 256.21MW:

Pmax (MW)	Qmax (MVAr)	Qmax (pu)	Qmin (MVAr)	Qmin (pu)
0.2	19.23	0.0751	-13.68	-0.0534
26.08	169.86	0.663	-167.82	-0.655
154.42	165.01	0.644	-173.64	-0.678
256.21	109.03	0.4255	-116.31	-0.454

This results in a parameter that if translated directly from PSCAD to field or vice versa, will result in unintended and not-matching behaviour between field and PSCAD.

Examples of PVR Issues

Example #2: Active Power (P) Limits

In PSCAD, the P_{max} parameter measures gross capability at the inverter outputs. For instance, if a site has 50 inverters each rated for 3MW, the P_{max} parameter might be set to ~150MW. But in the PPC, the P_{max} parameter is net active power feedback at the POI, so 34.5kV collection system & transformer losses must be considered to translate between the PPC & PSCAD parameter values:

- $P_{max,\ PSCAD}$ = 150MW
- 34.5kV Collection System Losses = 0.8%
- Transformer Losses = 1.2%
- $P_{max,\ PPC}$ = 147.01MW

Similar to the last example, this results in a disconnect between parameter verification evidence from the PPC and the recommended PSCAD parameter values. Commissioning with "approved" model parameters without understanding the discrepancy will lead to unexpected results.

Lessons learned and recommendations

- ISO testing requirements are the floor, not the ceiling.
- The effort required to fix a problem increases the further you get into a project. Commissioning is the last “simple” time to make changes to a design. Make it count.
- Commissioning faster without detailed testing will result in costly rework.
- Full scale commissioning tests are essential for understanding plant behaviour even when individual equipment has been extensively validated, and even more important when it hasn’t.

ENGIE

engie-na.com

IBR Commissioning Best Practices: PPC, SCADA, and Network Perspective

December 16th, 2025

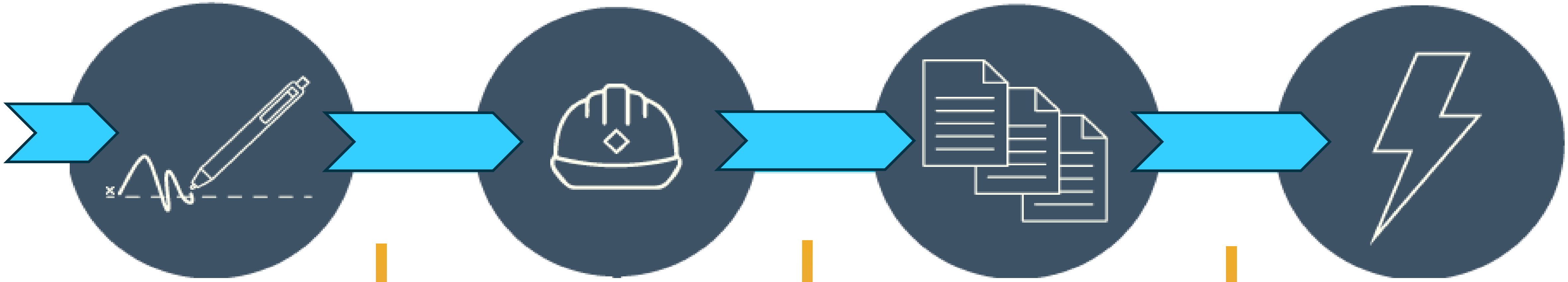
MERIT

Agenda

- About Merit
- Overall Project Flow
- Initial Project Scope
- Design
- Configuration
- Quality Assurance, HIL, FAT
- Site Work
    - Pre-Energization
    - Initial Test Energy
    - SAT and Coordinated Tests
- Handoff
- General Challenges and Lessons

MERIT

Merit: End-to-End Offering



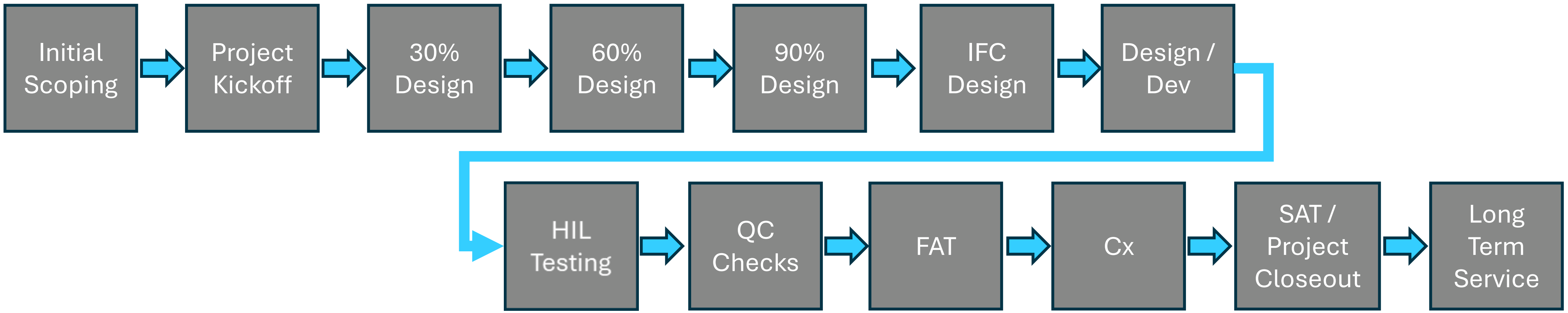
Interconnection
- PSCAD Modeling
- PSSE Modeling

Design / Build
- PPC / EMS
- SCADA
- Network
- DAS / FNE
- Meteorological Stations
- Hardware in the Loop
- Grid Modernization

Commissioning
- Utility / ISO Testing
- CL1, CL2, CL3 (ERCOT)
- MOD 25, 26, 27
- MQT (ERCOT)

Post COD
- Service Agreements
- Extended Warranty
- Performance Reports

Overall Project Flow

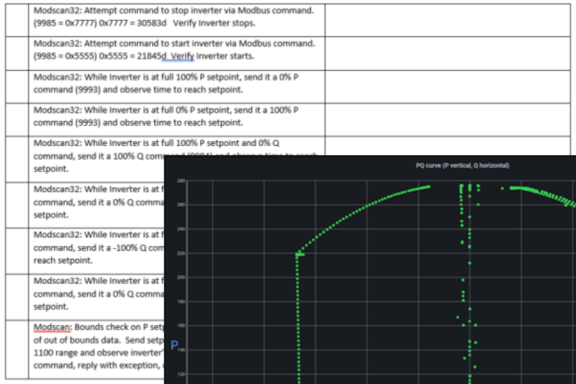


High level project flow

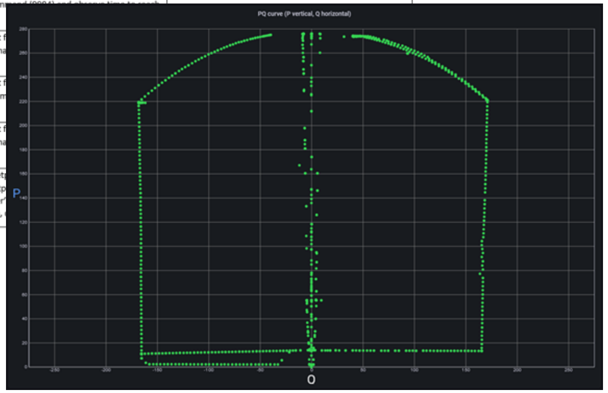
- **Scoping** => Initial project requirements, equipment, region grid codes, features, schedule, etc.
- **Design** => Document solution details for Owner and used as input into build
- **Development** => Using design, build the solution
- **Factory Testing** => Testing the solution at the factory prior to deployment: Engineer testbench, HIL, FAT
- **Site Deploy** / Commission => With equipment onsite, integration begins to field equipment
- **Site Test** => Once all commissioning activities are complete, validate
- **Handoff** => Handing over the solution to the customer, and move into long term service agreement

Integration Meetings and Inverter Equipment Characterization

- Meetings with Inverter Vendor, and other equipment providers to clarify scope, interfaces, data maps, control requirements, etc.
- For new vendors/companies working with for the first time
  - Lab Qualification at Vendors Facility
    - Communications point to point (P2P) tag checkout
    - Setpoint and Control Tests
    - Characterization testing via step tests, and other control tests
  - And HIL or Emulator use of Vendor’s equipment



	Modscan32: Attempt command to stop inverter via Modbus command. (9985 = 0x7777) 0x7777 = 30583d Verify Inverter stops.	
	Modscan32: Attempt command to start inverter via Modbus command. (9985 = 0x5555) 0x5555 = 21845d Verify Inverter starts.	
	Modscan32: While Inverter is at full 100% P setpoint, send it a 0% P command (9993) and observe time to reach setpoint.	
	Modscan32: While Inverter is at full 0% P setpoint, send it a 100% P command (9993) and observe time to reach setpoint.	
	Modscan32: While Inverter is at full 100% P setpoint and 0% Q command, send it a 100% Q com[illegible] setpoint.	
	Modscan32: While Inverter is at f[illegible] command, send it a 0% Q comma[illegible] setpoint.	
	Modscan32: While Inverter is at f[illegible] command, send it a -100% Q com[illegible] reach setpoint.	
	Modscan32: While Inverter is at f[illegible] command, send it a 0% Q comma[illegible] setpoint.	
	Modscan: Bounds check on P setp[illegible] of out of bounds data. Send setp[illegible] 1100 range and observe inverter[illegible] command, reply with exception, [illegible]	

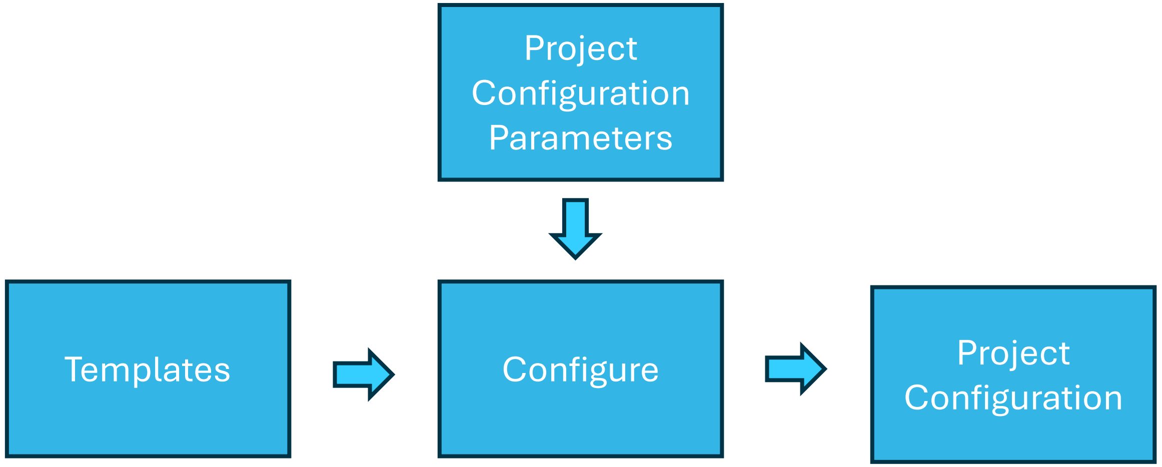


Design: Documentation Submittals, Review, and Improvements

- Document submittals to confirm design, clarify questions, update on customer feedback
  - Design Documents at 30%, 60%, 90%, and IFC
- Coordinate on architecture, integration details between parties, data flow
- Example Documents may include
  - Equipment Diagrams
  - SCADA General Description
  - Control Narrative
  - SCADA Tag List
  - Master IP addressing scheme
  - Test Plans
  - Commissioning Reports

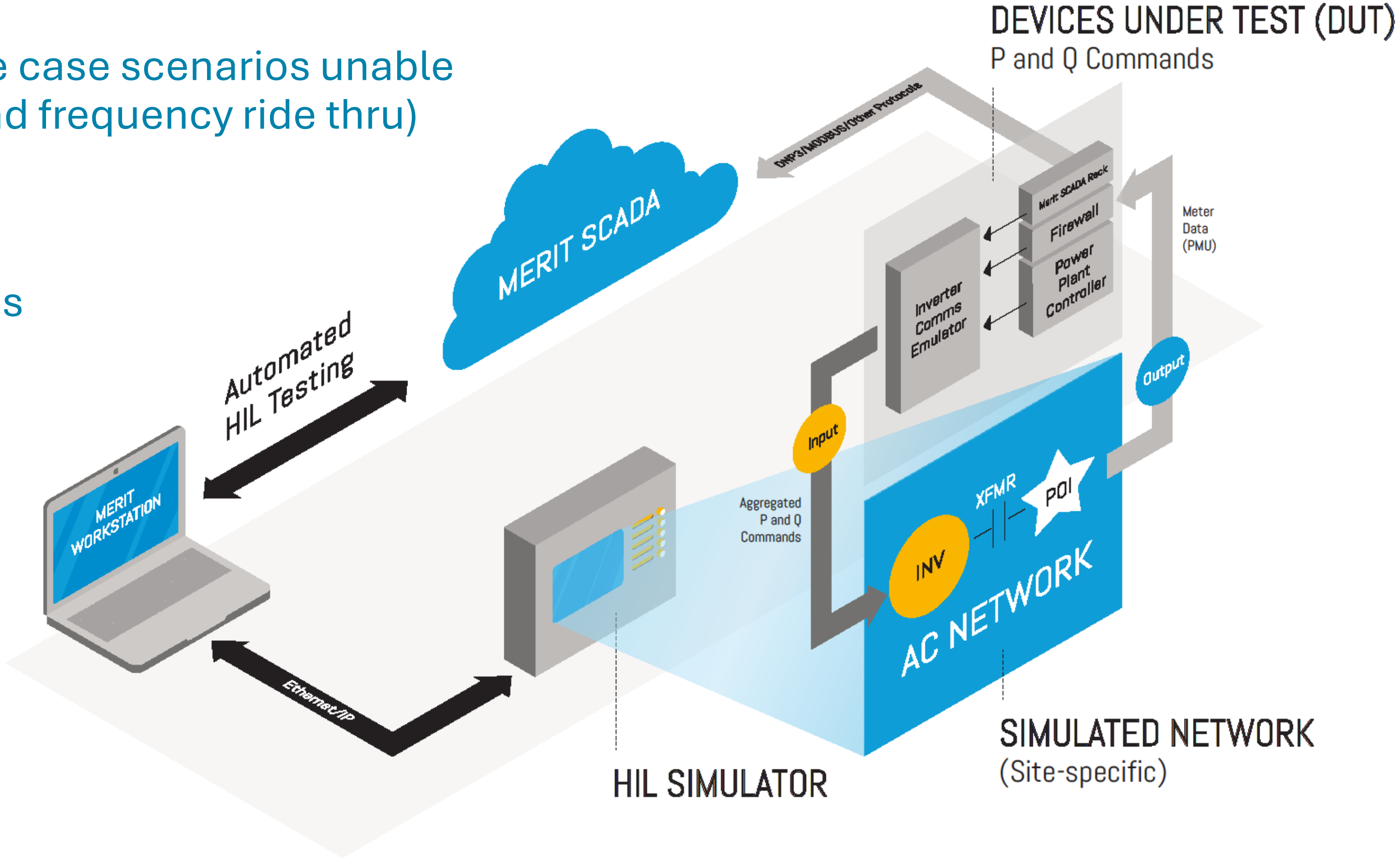
Project Configuration

- Configuration of Project from base templates, product files, script automation
  - SCADA screens, IO maps, tag configuration
  - PPC parameters, communication drivers
  - Network equipment configuration
  - SCADA server and infrastructure configuration



Hardware-in-the-Loop – Quality Assurance

- High Speed simulation using grid interconnection, inverter, and control system models
- Verify settings and IBR reaction to edge case scenarios unable to test in the field (low / high voltage and frequency ride thru)
- Tune system before site deployment
- Performed in-house by Merit associates

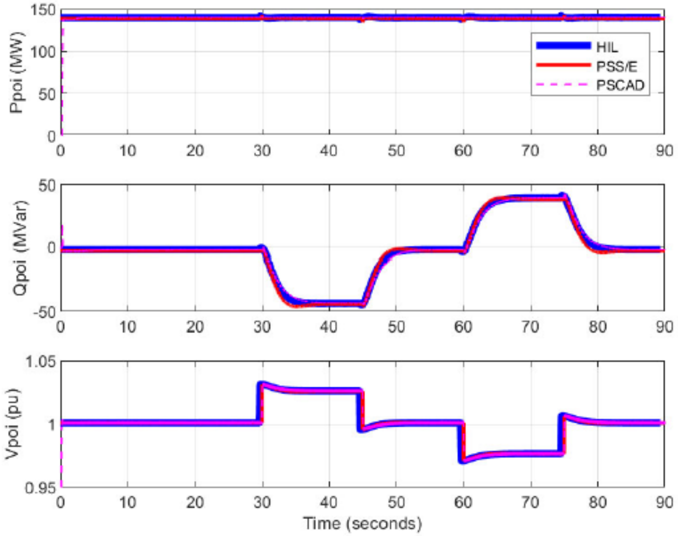


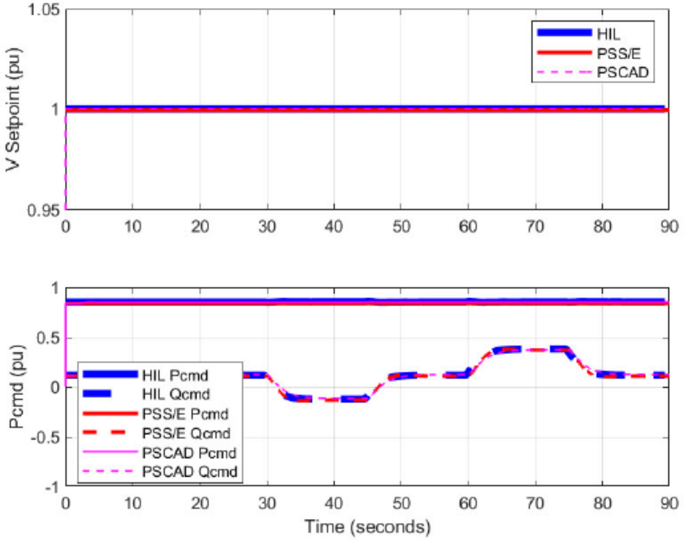
MERIT

Modeling: PPC PSCAD Updates and Validation

- PSCAD model for PV PPC and Master PPC is maintained and kept up to date.
- Comparison using PSSE model using WECC generic REGC_A and REEC_C models
- Tests of PSCAD, PSSE, and PPC in HIL environment showing matching plant response to simulated Frequency, Voltage, and setpoint changes.

Test Description	Result		
	Plots	PPC Recorded CSV Data	Conclusion
4.1. PV – Inverter Control	Tested manually		Pass
4.2. PV – Active Power Control	\Compiled Results\Plots	\Compiled Results\ProcessedData	Pass. Note added on MANUAL to AUTO.
4.3. PV – Frequency Response	\Compiled Results\Plots	\Compiled Results\ProcessedData	Pass
4.4. AVR Reactive Control	\Compiled Results\Plots	\Compiled Results\ProcessedData	Pass
4.5. AVR PF Control	\Compiled Results\Plots	\Compiled Results\ProcessedData	Pass
4.6. AVR Voltage Control	\Compiled Results\Plots	\Compiled Results\ProcessedData	Pass
4.7. AVR Transfer between Control Modes	\Compiled Results\Plots	\Compiled Results\ProcessedData	Pass
4.8. AVR Manual Control Mode	Tested manually		Pass
4.9. AVR Measurements Failure	Tested manually		Pass
4.10. AVR Reactive Power Limit	\Compiled Results\Plots	\Compiled Results\ProcessedData	Pass
4.11. AVR Power Factor Limit	\Compiled Results\Plots	\Compiled Results\ProcessedData	Pass
4.12. AVR Voltage Limit	\Compiled Results\Plots	\Compiled Results\ProcessedData	Pass
4.13. AVR Anti-Windup Test	Tested manually		Pass
4.14. Small Voltage Disturbance Test	\Compiled Results\Plots	\Compiled Results\ProcessedData	Pass
4.15. Low Voltage Ride-Through	\Compiled Results\Plots	\Compiled Results\ProcessedData	Pass
4.16. High Voltage Ride-Through	\Compiled Results\Plots	\Compiled Results\ProcessedData	Pass
4.17. System Strength Test	\Compiled Results\Plots	\Compiled Results\ProcessedData	Pass
4.18. Phase Angle Jump Test	\Compiled Results\Plots	\Compiled Results\ProcessedData	Pass





Factory Acceptance Testing and Validation

- Quality Control Checks and pre-FAT validation
  - SCADA
  - Network (Core Switches and Firewall)
  - PPC equipment
  - Field fiber optic network enclosures (FNE)
  - Plant Emulator (Meters, Inverters, Trackers, MET) to test actual site IP addresses, routing, and firewall rules
  - Security Scan
- FAT testing – Customer witness formality, as all tests have been completed in the QC check phase
- Equipment Shipped to site as fully integrated and tested server racks, and field fiber optic network enclosures (FNE). Just apply power and connect network in the field.

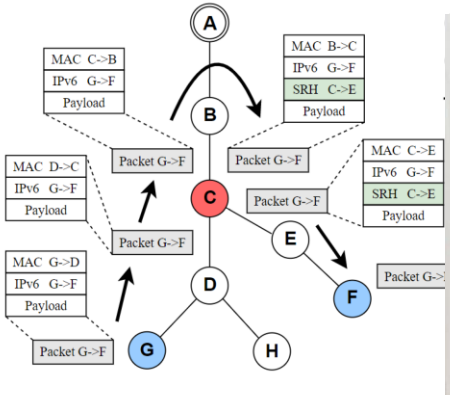
Item	Pass/Fail	Task
2.1.1	Pass	RDP to the Primary SCADA Tag IO Gateway with your Domain Admin account
2.1.2	Pass	Verify correct amount of memory installed
2.1.3	Pass	Verify correct amount of CPU cores
2.1.4	Pass	Verify correct hard drive size
2.1.5	Pass	Verify NTP Sync from GPS Clock
2.1.6	Pass	Verify OS is licensed correctly
2.1.7	Pass	Verify unable to RDP to the Primary SCADA Tag IO Gateway with scada_viewer acc
2.1.8	Pass	Verify unable to RDP to the Primary SCADA Tag IO Gateway with scada_operator ac
2.1.9	Pass	Verify unable to RDP to the Primary SCADA Tag IO Gateway with engineer account
2.2.1	Pass	Log on to the Primary SCADA Tag IO Gateway with sca
2.2.2	Pass	Verify Ignition is licensed
2.2.3	Pass	Verify correct driver modules are installed
2.2.4	Pass	Verify database connections are configured and opera
2.2.5	Pass	Verify device connections are configured
2.2.6	Pass	Verify OPC Connections are configured
2.2.7	Pass	Verify redundancy is enabled
	Pass	Verify redundancy works as expected by forcing a failo
2.2.8	Pass	Verify sufficent memory allocated to the Gateway
2.3.1	Pass	RDP to the Primary SCADA Front End Gateway with yo
2.3.2	Pass	Verify correct amount of memory installed
2.3.3	Pass	Verify correct amount of CPU cores

Site Commissioning Phases

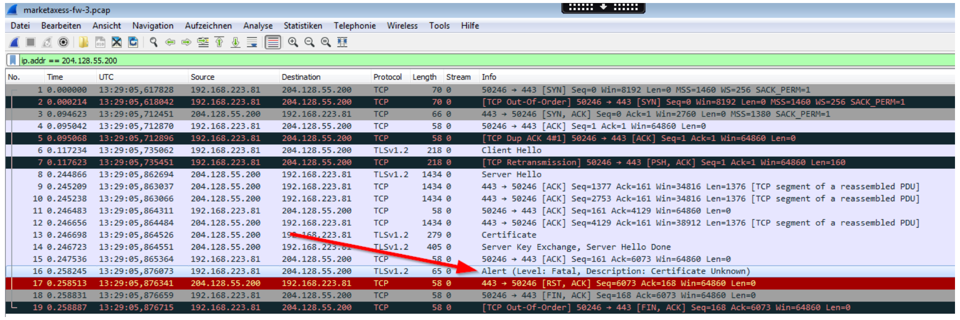
- SCADA Rack Installation
- Field Fiber Network Enclosures Installation
- Pre-Energization – Cold Commissioning
- Backfeed – Hot Commissioning (< 20 MVA connected)
- Site Acceptance Tests (> 20 MVA connected)
- Utility Tests

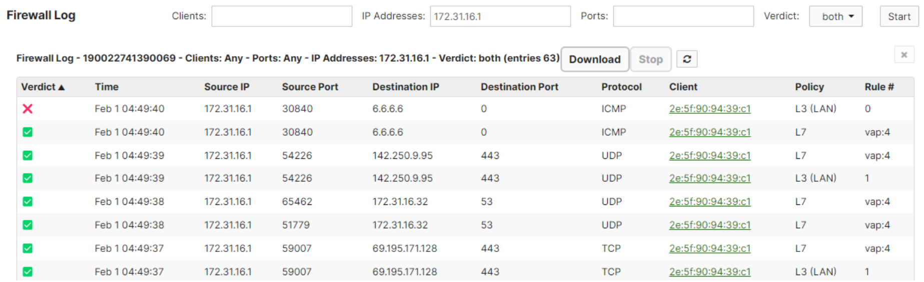
Site Work: Pre-energization (Cold Commissioning)

- SCADA Rack & Fiber Network Enclosure (FNE) Installation
- Network Setup and Validation
  - Internet, Core network, Subnets, VLANs,
  - Field fiber optic loop
  - Firewall configuration and validation
- Telemetry: Tag checkouts, Point to Point (P2P)
- QSE / ISO / data off-taker data integration
- Substation data integration
  - Meter data: quality, scaling, time delay, etc.
  - Breaker validation – before site energization
- FNE validation with generators / temporary power
- Communications troubleshooting
- Network / firewall verification
- Firewall log review, accession control list verification



(a) P2P data flow from G to F




Firewall Log   Clients: IP Addresses: 172.31.16.1   Ports: Verdict: both   Start

Firewall Log - 190022741390069 - Clients: Any - Ports: Any - IP Addresses: 172.31.16.1 - Verdict: both (entries 63)   Download   Stop

Verdict ▲	Time	Source IP	Source Port	Destination IP	Destination Port	Protocol	Client	Policy	Rule #
✗	Feb 1 04:49:40	172.31.16.1	30840	6.6.6.6	0	ICMP	2e:5f:90:94:39:c1	L3 (LAN)	0
✓	Feb 1 04:49:40	172.31.16.1	30840	6.6.6.6	0	ICMP	2e:5f:90:94:39:c1	L7	vap:4
✓	Feb 1 04:49:39	172.31.16.1	54226	142.250.9.95	443	UDP	2e:5f:90:94:39:c1	L7	vap:4
✓	Feb 1 04:49:39	172.31.16.1	54226	142.250.9.95	443	UDP	2e:5f:90:94:39:c1	L3 (LAN)	1
✓	Feb 1 04:49:38	172.31.16.1	65462	172.31.16.32	53	UDP	2e:5f:90:94:39:c1	L7	vap:4
✓	Feb 1 04:49:38	172.31.16.1	51779	172.31.16.32	53	UDP	2e:5f:90:94:39:c1	L7	vap:4
✓	Feb 1 04:49:37	172.31.16.1	59007	69.195.171.128	443	TCP	2e:5f:90:94:39:c1	L7	vap:4
✓	Feb 1 04:49:37	172.31.16.1	59007	69.195.171.128	443	TCP	2e:5f:90:94:39:c1	L3 (LAN)	1

Site Work: Initial Test Energy, < 20 MVA Online (Hot Commissioning)

- Initial sync – typically when only less than 20 MVA is grid connected
- Meter Data verification, communication quality, stability, latency
- Inverters, meteorological stations(MET), BESS Racks, HVAC, etc.
- Data scaling with live data - and non-zero data
- Initial functional tests with test inverters
  - Thorough tag checkout, looking at each point and verifying data
  - Start /stop commands from SCADA/PPC
  - Manual real and reactive power commands. Confirm scaling
  - Initial Auto closed loop control tests for real and reactive power with appropriate limits
- Validation of plant metrics, counters, summation, average values
- HSL High Sustained Limit power plant estimate validation
- P2P Telemetry data validation to 3rd parties and data off takers
- Data logging verification for PRC-028, NOGRR 255, IEEE2800

Site Work: Hot Commissioning (> 20 MVA), Site Acceptance Test (SAT)

- Initial PPC Tests
  - Plant wide manual and auto controls
  - Capacitor Bank Integration
  - Plant wide automatic real and reactive power tests
  - Aggregate output functionality tests
- SAT is performed after all checks are complete and the engineering teams is confident in the system.
  - Includes SCADA, network, and control systems
  - Use to prove the system is in working order
  - Contractual
  - Historical data / screenshots will be required for AE approval
  - Performed before ISO / utility testing.
    - Not replaced by ISO / utility testing. However, can overlapping tests can be noted.

1.2.1. PV Inverter Control

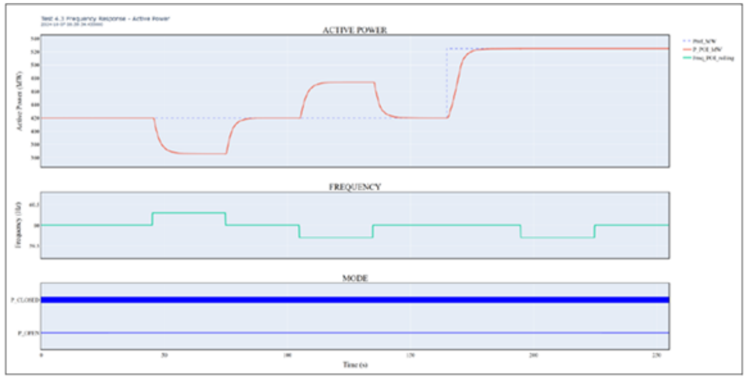
Purpose:
Demonstrates the ability to place an inverter in automatic or manual control, and issue start and stop commands (if applicable). In manual control mode PPC can control the inverter active and reactive power from HMI.

Reference documentation:
PPC design note

Start Date:	Click or tap to enter a date.	Start Time:	Click or tap here to enter text.
End Date:	Click or tap to enter a date.	End Time:	Click or tap here to enter text.

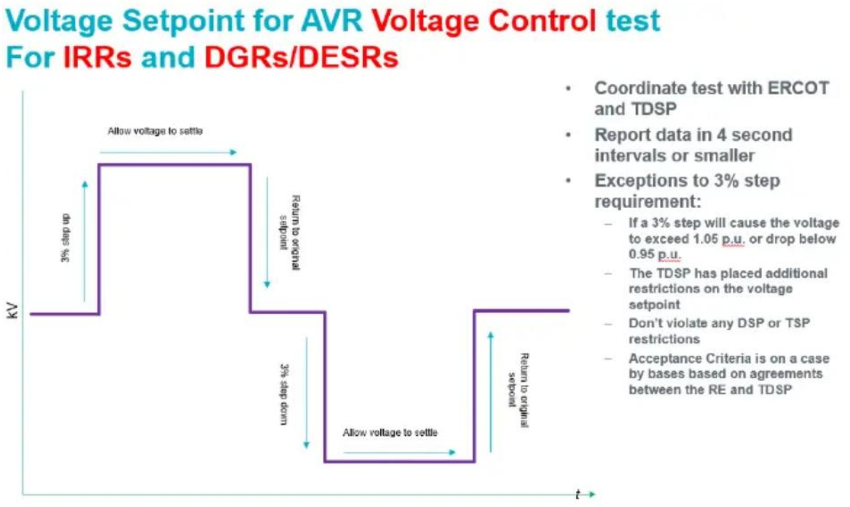
Procedure:
1. Verify the inverter is in automatic mode
2. Through SCADA, command the inverter to manual control mode
3. Verify the inverter transitions to manual control and output is stable
4. Verify SCADA displays the inverter as being in manual control mode
5. Verify the inverter responds to SCADA commands specified in the table below:

Active Power Targets (pu)	Reactive Power Targets (pu)



Site Work: Plant Testing, Larger Power Changes Needing Coordination

- Large real or reactive power changes require coordination with commissioning manager, transmission operator (TO), ISO, etc.
- Typical Plant Capability Tests
  - Plant Real Power full power and zero real power tests
  - Plant Real Power ramp rate tests
  - Primary Frequency Response (PFR) over / under frequency tests using simulated frequency (override meter measurement).
  - 0.95 Power Factor of maximum real power rated capacity (Q ±0.3287 pu). For BESS Plant, 4 Quadrant Tests.
    - Coordinating with utility for hospitable grid voltage conditions
  - Automatic Voltage Regulation (AVR) setpoint change tests
- Possible Region-Specific Tests
  - Voltage Step Tests – either setpoint, simulated measured value, or utility introduces change in network to adjust voltage.
  - Utility, ISO, etc remote telemetry control tests for real and reactive power.



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Retesting

- Retesting may be needed if:
  - Grid Voltage was not in a range that permitted full reactive power testing at the time. Grid or Inverter voltage limits.
  - Equipment outages
    - OLTC was not operating as expected at time of first test
    - Capacitor Bank was not available at time of test
    - Number of inverters running for the test was not met
  - Telemetry data Issue, improper scaling, conversion, incorrect point
  - Clarification on utility requirements criteria and site test plan

Handoff

- Documentation sets. SAT and other test documentation delivery
- MOD test data for modeling validation / updates
- Parameter as left, comparison to original
- Handoff to service team
- Training – Operators, O&M service team, etc.
- Remote Access - handoff to long term remote access suppliers

Challenges and Lessons

- Scheduling challenges, delays, weather, etc.
    - Momentum start, moving, then stop, resources assigned to other projects, then restart of work, going again, and stopping.
    - Schedule delays, keeping up with the latest schedule changes. Scheduling resources and meetings on shifting timelines.
- Squeezed timeline, Immovable COD, but construction or other delays
- Troubleshooting and 3rd party issue identification outside of PPC scope, but is a pre-requisite for PPC work, or discovered by our team.
- Resorucing with multiple project completions at the same time.
- Late requirements. Discovery of gaps late in the game.
- Weak grids. At locations with weak grids, low probability of passing tests on first try. Tuning, work-arounds, utility/ISO meetings, etc lead to retesting.
- Work-around modifications to adapt to site issues, to cross the finish line.
- Preparation, gathering requirements and testing early are key to success.

Thank You

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DECEMBER 16, 2025

Commissioning of IBR Facilities in Ontario: IESO's Experience and Perspective

Phil Hiusser, P.Eng.
Lead Power System Engineer,
Performance Validation & Modelling

ESIG
ENERGY SYSTEMS INTEGRATION GROUP

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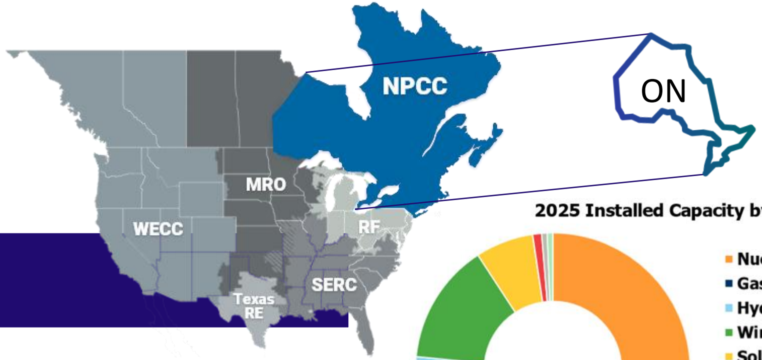
A Little About The IESO…



Ontario is in the NPCC Region.

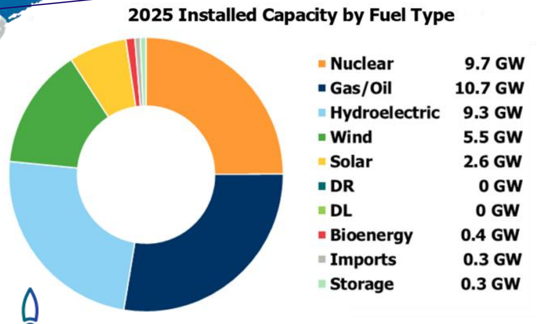
Total installed capacity is about 38.8 GW

5.5 GW of wind, mostly (~90%) grid-connected

2.6 GW of solar, mostly (~80%) distribution-connected

Rapidly increasing battery storage capacity

>1.1 GW of new grid-connected storage capacity added from 2025 to early 2026



2025 Summer Peak Demand:
24,862 MW

2025 Energy Consumption:
151 TWh *(projected)*

2050 Energy Consumption:
262 TWh *(projected)*
~75% growth

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Overview of IESO Commissioning Practices

Connecting to Ontario's Power System

Prepare Application → Obtain Conditional Approval to Connect → Design and Build → Authorize Market and Program Participation → Register Equipment → Commission Equipment & Validate Performance

Final checks and approvals

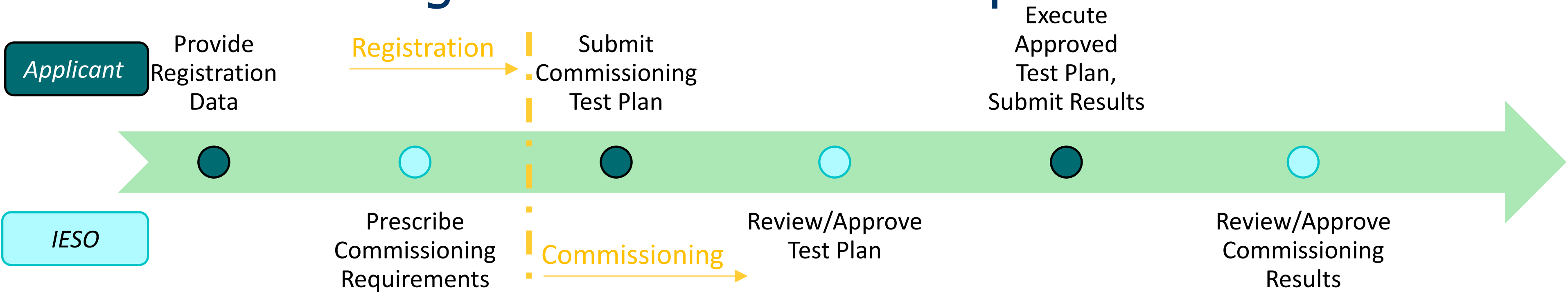
Changes are possible throughout; re-evaluation may be needed

- Proposed equipment ratings and capabilities may be *targets*.
- Models are often *preliminary* or *hypothetical,* using typical or estimated model parameters.
- Many *assumptions* are necessary to assess facility performance against requirements; conclusions are *tentative*;
- Approval to connect is **conditional upon meeting applicable performance requirements.**

- Vendors are selected.
- Detailed design is done, feasibility evaluated, trade-offs made, realistic ratings and capabilities are determined. Some of the preliminary plans may change.
- Equipment is manufactured, and some aspects of the design become irrevocable.
- Preliminary settings are determined, models developed, and for-construction information reaches the IESO; site work often on-going.
- **Changes from original assumptions need to be identified and managed along the way.**

- Equipment is installed.
- Final tuning and testing is done to demonstrate performance and validate models.
- Assessment assumptions confirmed/updated, and operating limits set
- Any significant change may disrupt schedule.
- **Final approval to connect is granted.**

Commissioning – Main Workflow Steps



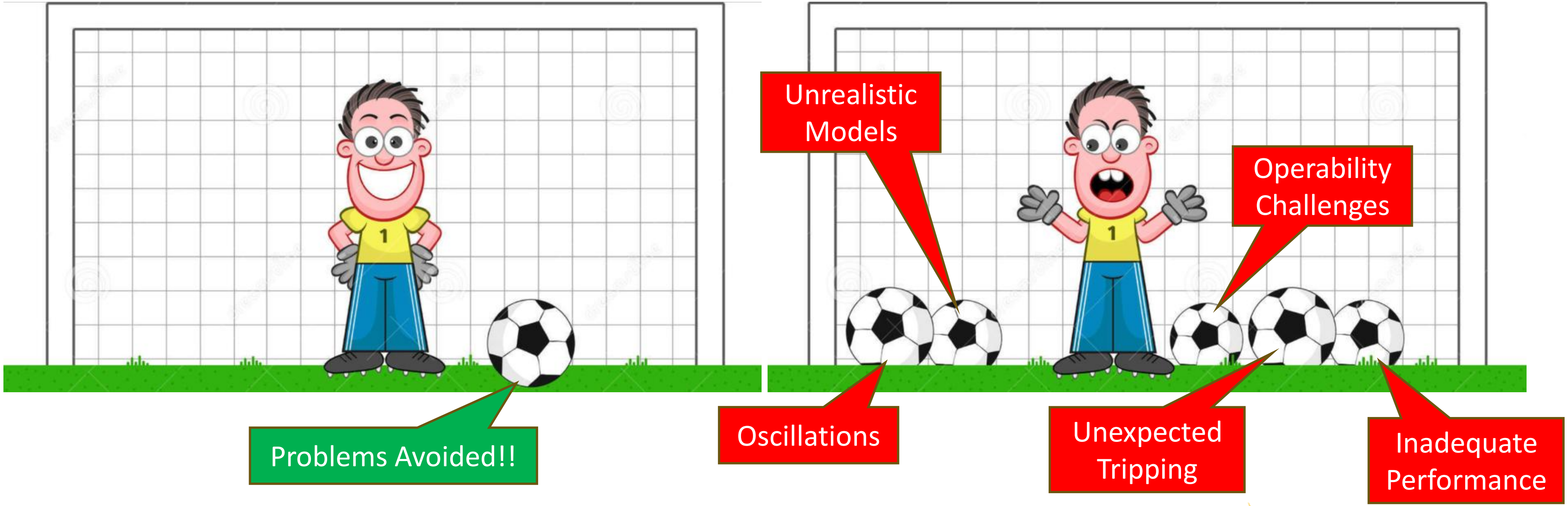
IESO has developed general commissioning guidelines that demonstrate various NERC, NPCC, and IESO Market Rules requirements.

Project-specific requirements may be identified at the interconnection study (SIA) stage; testing or data submissions may be requested during commissioning to confirm these are met.

IBR facilities are complex; testing or data submissions may be required to confirm aspects of the facility's operational behaviour (e.g., switching behaviour; start-up/shut-down; failure modes).

Objectives for Commissioning:

To block potential reliability problems from going into service…



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Objectives for Commissioning:

Two important objectives the IESO has for the Commissioning Phase of the Connection Assessment and Approval Process are:

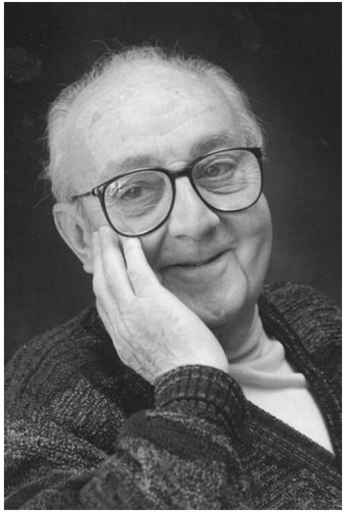
1. To ensure equipment connected to the IESO-controlled grid has the **performance** required to maintain reliability. This generally includes the following aspects:
   a) Meets applicable technical requirements and standards, and
   b) Does not exhibit objectionable behaviour (e.g., oscillations)
2. To show the **models** *and other data* provided to the IESO are suitable and sufficiently accurate to support the IESO's planning and operating decision-making processes.

Wisdom Applicable to Commissioning…

"One accurate measurement is worth a thousand expert opinions."

-Grace Hopper,

Mathematician, Computer Scientist, US Navy Rear Admiral



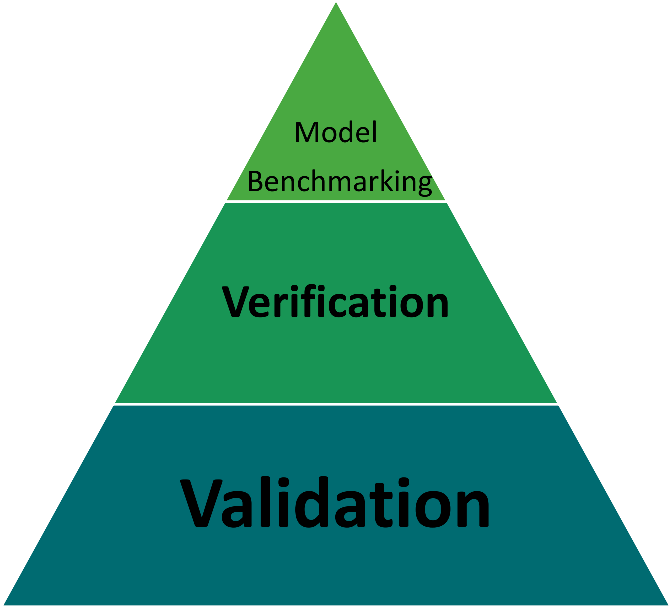
"All models are wrong, but some are useful."

-George E. P. Box,

Professor Emeritus of Statistics, University of Wisconsin-Madison

Methods of Confirming Performance & Models

The IESO uses methods like those described in P2800.2 and MOD-026-2 to confirm models reflect important aspects of equipment configuration and behaviour, including:



Model Benchmarking: comparing PSPD models (generic and UDM) against validated/verified EMT models to build confidence in PSPD models in situations that cannot be readily tested (e.g., at extreme voltages, faults).

Verification: mapping of final 'as-left' configuration and settings to model parameters or expected equipment behaviour, e.g., by reviewing photos, screen shots from HMIs or configuration software, device settings files, reported final settings, etc.

Validation: directly observing measured responses to confirm performance requirements are met; comparing submitted model responses to measurements from staged tests or ambient operation to confirm agreement.

IESO: Typical Performance Validation & Modelling Checks

Steady State and Dynamic Capabilities and Models	Protection System Checks	Other Common Checks

• Real & Reactive Power Capabilities
• Reactive Power/ Voltage Control Performance
• Active Power/ Load Control Performance
• Power Flow models
• Dynamic models
• EMT models
	• Coordination
	• Ride through
	• Loadability
	• Security during recoverable swings
	• NPCC Design Criteria
	• Trip timing
	• Reclosing behaviour
	• RAS performance (timing)
		• Reactive device switching
		• Responses to abnormal conditions, such as:
		  • loss of transmission supply,
		  • loss of service supply,
		  • loss of communications,
		  • etc.
		• Islanding behaviour
		• Start-up/shut-down behaviour (timing)
		• Disturbance Monitoring Equipment (DME) functionality and configuration

Challenges and Suggested Best Practices

Managing Requirements

- Applicable requirements can be complex, arising from many sources, and are often different across regions.

  In Ontario, the following are some common sources of requirements for a typical generation interconnection: NERC; NPCC; IESO Market Rules, Manuals, and forms; System Impact Assessment; Customer Impact Assessment; Protection Transmission System Code; Transmitter Interconnection Requirements, etc.

- ISOs and other authorities should be mindful of process complexity, and try to minimize it to the extent feasible. They can also help steer Developers and Owners to an accurate understanding of the process, and to avoid common pitfalls.
- Developers and Owners can build repeatable processes that capture, track, and manage to completion all requirements in a systematic way.
- Work with vendors and service providers who have experience in the jurisdiction.
- Work with utility customer support services to help navigate complex processes.
- Communicate early and often through the interconnection and commissioning process.
- Meetings can often be more effective than email exchanges to ensure clarity.

Project Scoping and Scheduling

- As in most projects, speed, cost, and scope (quality) are often in tension. Most new interconnections are striving to meet ***ambitious*** schedules.
- Interconnection processes often have necessary, sequential steps – each with definite timelines. Completing site work is rarely the last step required to reach commercial operation.
- If these dependencies are not recognized and accounted for in project schedules, this can result in unrealistic expectations, undue time pressure, mistakes, rework, and missed schedule targets or compromised technical scope.

- ISOs and other interconnection authorities can improve coordination by stating clearly and directly all steps that are involved in bringing a project into service and stating the expected timelines associated with each step. Developers may not be experts in these processes.
- Developers and Owners can improve project success by clearly identifying all project steps, scheduling dependencies, and by setting *realistic* schedules.
- Managing schedule slip throughout execution can avoid last-minute disappointments.

Need for Change, and Change Management

- Ad hoc changes are commonly needed during commissioning, due to unforeseen issues.
- Performance issues may be more likely to arise in ‘challenging’ parts of the grid, or in unusual operating conditions, especially if not thoroughly studied before connection.
- Digital controllers are often flexible and able to be adjusted to mitigate such problems but making such changes can invalidate prior assumptions and cause unanticipated consequences.

- EMT studies are invaluable to investigate the potential for problems such as oscillations in reasonably foreseeable operating conditions (e.g., in weak areas of the grid, in outage configurations, in abnormal plant configurations) and to avoid surprises during commissioning.
- A robust change management strategy should be adopted, including a communication protocol for whom must be notified and how changes will be documented.
- ISOs can have clear guidelines for what kinds of changes will result in the need to repeat studies, and those that will not. Coordinating resources to be available to update studies if – or when – commissioning activities result in changes can minimize related delays.

The Fundamentals – Base Values (etc.)

- Power systems engineering analysis of all kinds relies on base values (MVA, kV, Ohms, Amps).
- In any given project there are MANY, MANY candidate base values, such as those programmed in digital controller(s), protective relay(s), transformers (rated value vs. in-service tap), facility MW/Mvar rating, transmission system base, simulation model's base, etc.
- Mixing and matching quantities on different bases is extremely common.

- Recognize this challenge and treat it with care. Build checks into intake processes.
- Develop a discipline of listing quantities in engineering units as well as in % or p.u., and confirming 'on what base' whenever you see values stated in % or p.u.
- Minimize 'hand' calculations (use scripts, templates, other automation tools) to avoid exposure to making these kinds of mistakes in ad hoc calculations.
- Bonus warning:
  primary vs. secondary ohms, and phase vs. phase-to-phase quantities also cause trouble.

Thank You

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