GE Energy Management

Technical & Regulatory Standards Development

RENEW / ISONE Interconnection of Renewable Generation

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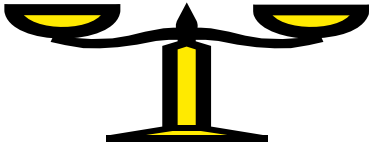
Global Renewable Codes & Standards Development

California ISO Interconnection Requirements for Variable Energy Resources

ISO-NE Technical Requirements for Wind Interconnection & Integration

NERC Standards Drafting and Task Forces

- Integration of Variable Generation Task Force **(IVGTF)**
- Essential Reliability Services Task Force **(ERSTF)**
- Generator Verification Standards Drafting Team **(GVSDT)**



FERC now mandates that all new reliability standards address VER

International

- Ontario IESO Amended Market Rules for Generation Facilities
- Alberta Interconnection Requirements for Wind Generation
- Chinese State Power Grid Technical Code for Wind Interconnection
- Vietnamese Interconnection Requirements for Wind Generation
- Indian CERC Electricity Grid Code for Wind
- German FGW Technical Guidelines for Wind Energy
- Australian Energy Market Operator (AEMO) Guidelines for Wind Energy

NERC GVSDT* standards currently in draft

MOD (Model Validation):

MOD-025: Verification of Generator/Plant Real & Reactive capability

MOD-026: Verification of Dynamic Models and Data for Generator Excitation Control and Plant Volt-Var Control Functions

MOD-027: Verification of Dynamic Models and Data for Turbine/Governor and Load Control or Active Power/Frequency Control Functions

PRC (Protection & Control):

PRC-019: Coordination of Generating Unit/Plant Voltage Regulating Controls with Unit/Plant Capabilities and Protection

PRC-024: Generator Frequency and Voltage Protective Relay Settings

Applicability has been modified to include wind & large solar.
These standards have been adopted in early 2014.

* Generator Verification Standards Drafting Team

FAULT RIDE-THROUGH

NERC PRC-024: Generator Frequency and Voltage Protective Relay Settings

Requirement 1: Frequency Ride-Through

- Each Generator Owner (GO) shall:
  - Set in service frequency protective relaying so that it does not operate to trip the generating unit during frequency excursions within the band described in Attachment 1
  - Conditions and exceptions:
    - Must operate between 59.5 and 60.5 Hz continuous
    - May trip if rate of change >2.5 Hz/sec (Aurora exclusion)

Requirement 2: Voltage Ride-Through

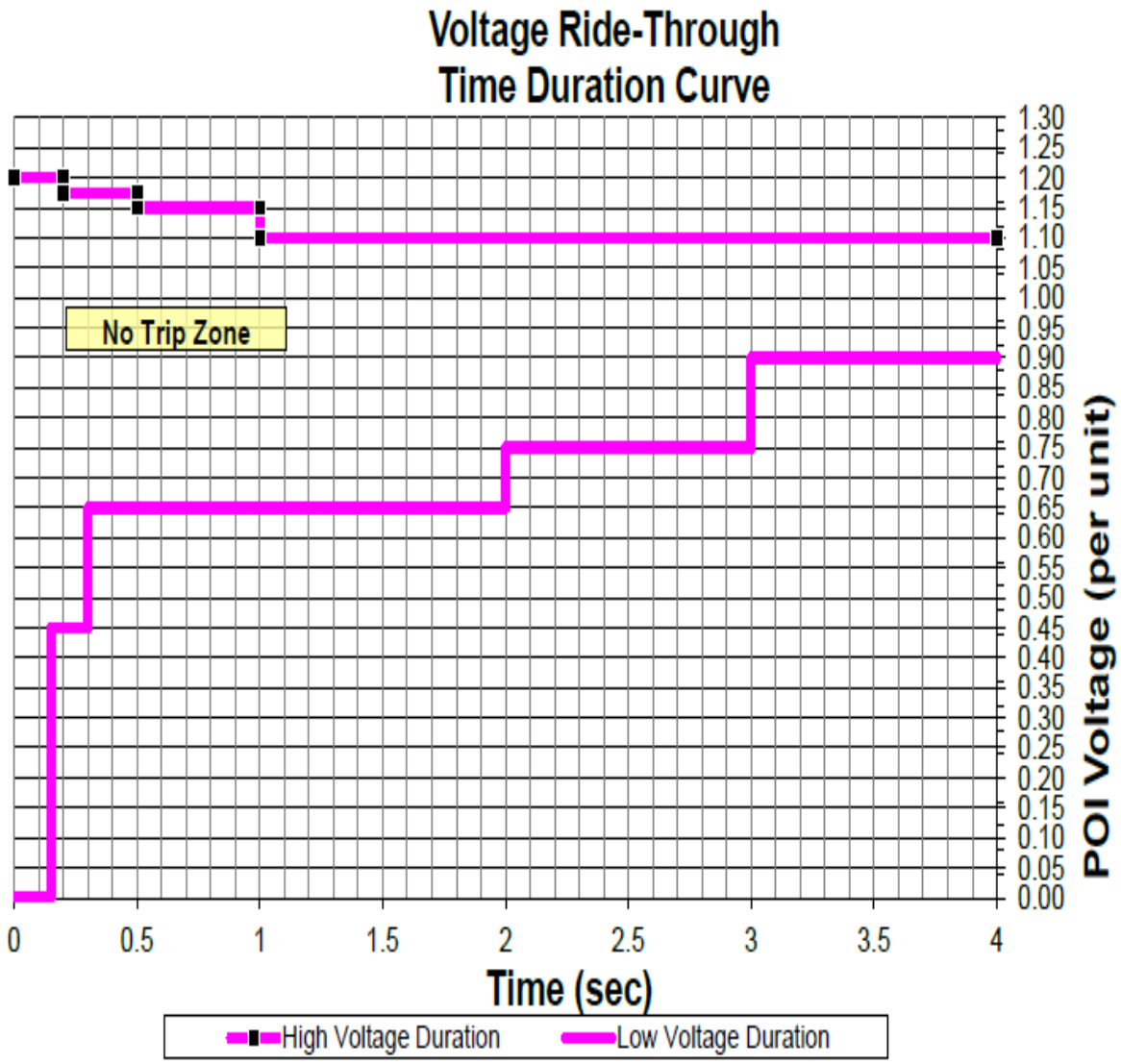
- Each Generator Owner (GO) shall:
  - Set in service voltage protective relaying so that it does not operate to trip the generating unit during voltage excursions within the specified band
  - Conditions and Exceptions:
    - Consider 3-phase Zone 1 faults with normal clearing
    - Site-specific clearing time may be used
    - Generator tripping for SPS, RAS or to clear the fault allowed

NERC PRC-024: Voltage Ride-Through

HVRT DURATION		LVRT DURATION	
Time (Sec)	Voltage (p.u.)	Time (Sec)	Voltage (p.u.)
Instantaneous	1.20	Instantaneous	0.00
0.20	1.175	0.15	0.45
0.5	1.15	0.30	0.65
1.0	1.10	2.0	0.75
		3.0	0.9

Generators / Plant must not trip for credible faults inside the zone unless:

- SPS / RAS requires it
- Generator critical clearing time requires it (synchronous generators)



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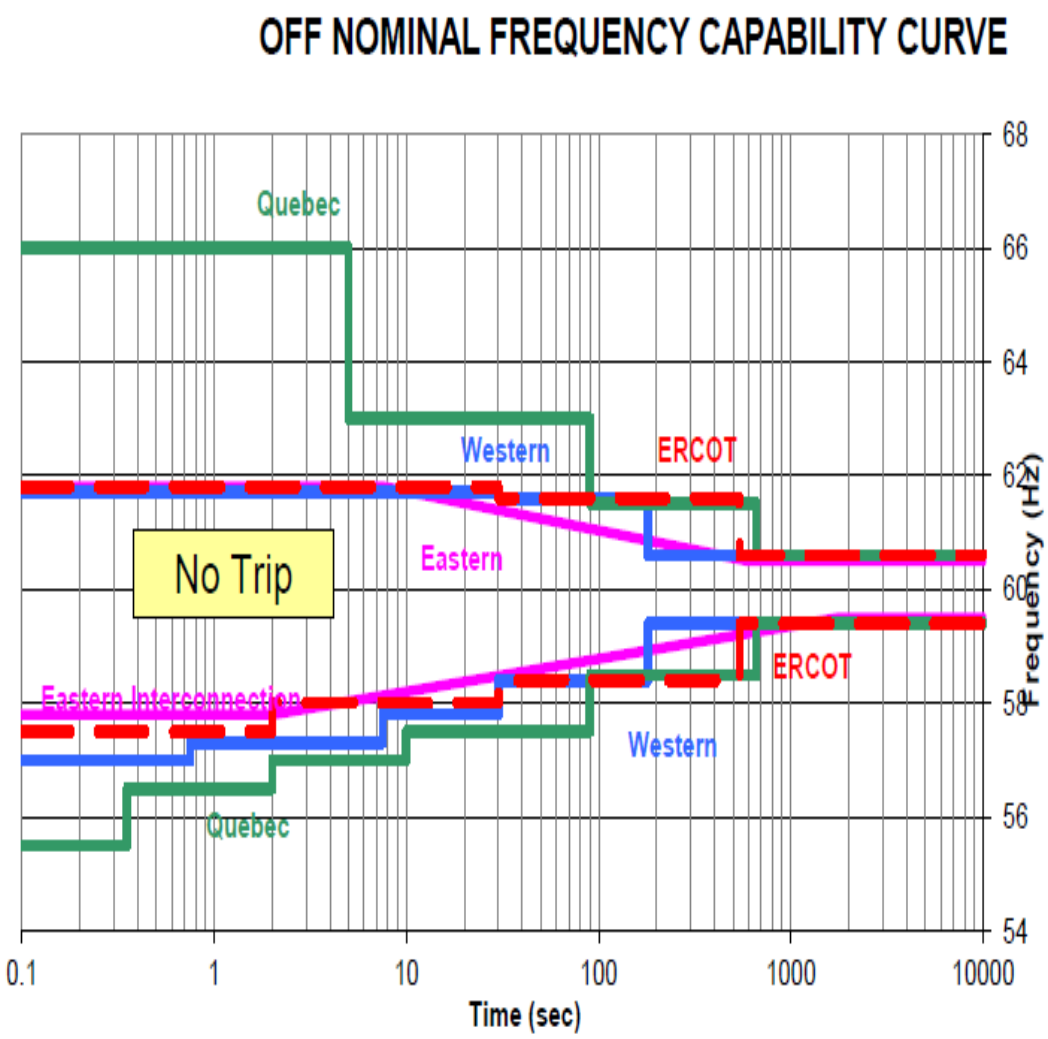
NERC PRC-024: Frequency Ride-Through

QUEBEC			
High Frequency		Low Frequency	
Time (Sec)	Frequency (Hz)	Time (Sec)	Frequency (Hz)
0 - 5	66	0 – 0.35	55.5
5 -90	63	0.35 - 2	56.5
90 - 660	61.5	2 - 10	57
> 660	60.6	10 - 90	57.5
		90 - 660	58.5
		> 660	59.4

WECC			
High Frequency		Low Frequency	
Time (Sec)	Frequency (Hz)	Time (Sec)	Frequency (Hz)
0 – 30	61.7	0 – 0.75	57
30 – 180	61.6	7.5 - 30	57.3
>180	60.6	7.5 - 30	57.8
		30 - 180	58.4
		>180	59.4

ERCOT			
High Frequency		Low Frequency	
Time (Sec)	Frequency (Hz)	Time (Sec)	Frequency (Hz)
0 - 30	61.8	0 – 2	57.5
30 - 540	61.6	2 - 30	58
>540	60.6	30-540	58.4
		>540	59.4

EASTERN INTERCONNECTION			
High Frequency		Low Frequency	
Time (Sec)	Freq. (Hz)	Time (Sec)	Freq. (Hz)
0 – $10^{(90.935-1.45713*f)}$	61.8	0 – $10^{(1.7373*f-100.116)}$	57.8
$10^{(90.935-1.45713*f)}$ - Continuous	60.5	$10^{(1.7373*f-100.116)}$ - Continuous	59.5
Continuous	60.5	Continuous	59.5



PROTECTION COORDINATION

NERC PRC-019: Coordination of Generating Unit/Plant Voltage Regulating Controls with Unit/Plant Capabilities and Protection

Coordination

- Verify limiters are set to operate before protection
- Verify protection is set to operate before conditions exceed equipment capabilities

Elements may include (but are not limited to):

- Field over-excitation limiter and associated protective functions
- Inverter over current limit and associated protective functions
- Volts per Hertz limiter and associated protective functions
- Stator over-voltage protection system settings
- Generator and transformer volts per Hertz capability
- Time versus field current or time versus stator current capability
- Converter over temperature limiter and associated protective functions

PROTECTION COORDINATION

NERC PRC-019: Coordination of Generating Unit/Plant Voltage Regulating Controls with Unit/Plant Capabilities and Protection

Key Points

- It is intended that the coordination verification be performed prior to performing a reactive capability test (MOD-025-2).
- This standard does not require any field testing or other operational verification of limiters or protection. It is an engineering study.
- Five year periodicity requirement.
- Normal five-year re-verification only requires confirmation that the settings and equipment used in the previous study have not changed.

MODEL VALIDATION

NERC MOD-026: Plant Volt / Var Control

NERC MOD-027: Plant Active Power / Frequency Control

Main Requirements

- Each Transmission Planner shall provide existing model and data to the Generator Owner within 30 days of receiving an information request
- Each Generator Owner shall provide to the Transmission Planner a verified and accurate model in accordance with the standard's periodicity table
- Other requirements that cover special circumstances

Staged test or ambient monitoring is allowed

The GO **"owns"** the model and is responsible for its validity

- Responsible for selecting proper structure and determining parameters
- Responsible for determining if match is "good enough"
- Peer Review process is included to facilitate technical discussions between the Generator Owner (GO) and the Transmission Planner (TP)

MODEL VALIDATION

NERC MOD-026: Plant Volt / Var Control

NERC MOD-027: Plant Active Power / Frequency Control

To mitigate the reliability gap associated with Variable Energy Resource (wind/solar) modeling:

- Applicability section expanded
  - Based on review of in-service renewable plant plant data that includes approximately **80%** of the plant MVA capacity in each Interconnection
  - The MVA threshold for plants was decreased from
    - 200 MVA to 100 MVA for the Eastern and Quebec Interconnections
    - 150 to 75 MVA for the WECC Interconnection
    - 100 to 75 MVA for the ERCOT Interconnection
      - Note: reducing the MVA threshold for plants in ERCOT any further would have exceeded the NERC Compliance Registry criteria.
  - The language makes clear that units less than **20 MVA** should be verified in aggregate when possible
- Targeted 2 to 11 year phase-in period and 10 year periodicity

Back-up

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Existing NERC Standards Relevant for Renewables

VOLTAGE REGULATION

NERC VAR-001: Voltage and Reactive Control

NERC VAR-002 : Generator Operation for Maintaining Network Voltage Schedules

Main Requirements

- Each Transmission Operator shall acquire sufficient reactive resources and specify a voltage or reactive power schedule at the POI
- Each Generation Operator shall operate each generator in automatic regulation mode and follow the voltage or reactive power schedule provided by the Transmission Operator or as otherwise directed by the Transmission Operator

DISTURBANCE CONTROL / FREQUENCY REGULATION

NERC BAL-002: Disturbance Control Performance
NERC BAL-003: Frequency Response and Bias

Main Requirements

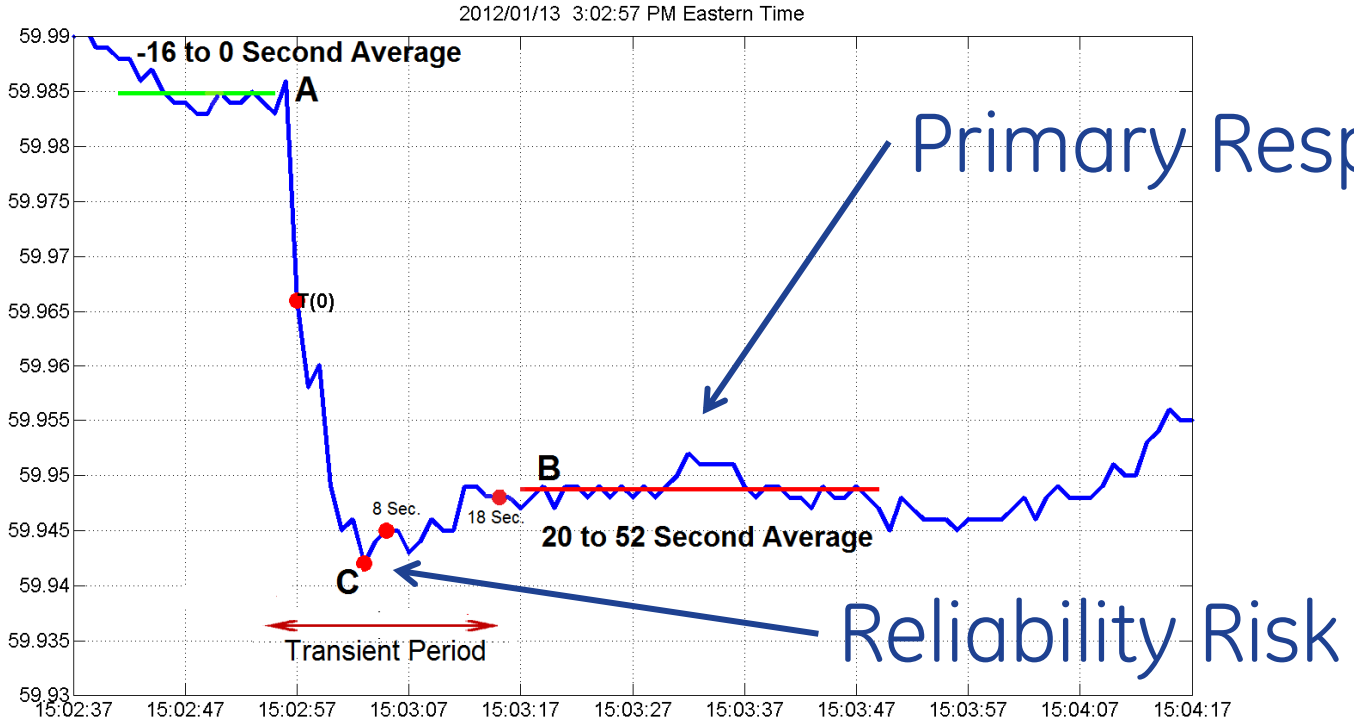
- Each Balancing Authority shall have access to and/or operate Contingency Reserve to respond to Disturbances. Contingency Reserve may be supplied from generation, controllable load resources, or coordinated adjustments to Interchange Schedules.
- **Frequency Response Obligation (FRO):** The Balancing Authority's share of the Frequency Response required for reliable operation across the entire interconnected system. This will be calculated as MW/0.1Hz. [Included in BAL-003.1x draft, now in balloting process]

DISTURBANCE CONTROL / FREQUENCY REGULATION

NERC BAL-002: Disturbance Control Performance

NERC BAL-003: Frequency Response and Bias

Frequency Response Measurement and Calculation



$$FRO_{BA} = FRO_{Int} \times \frac{Peak\ Gen_{BA} + Peak\ Load_{BA}}{Peak\ Gen_{Int} + Peak\ Load_{Int}}$$

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Facility Connection and Modeling

NERC FAC-001: Facility Connection Requirements
NERC FAC-002 : Coordination of Plans for New Generation/Transmission/End User
NERC MOD-010: Steady-State Data for System Models & Simulation
NERC MOD-012: Dynamics Data for System Models & Simulation

Main Requirements

- Transmission Owners shall document, maintain and publish facility connection requirements that address generation, transmission and end-users.
- Generator Owners, Transmission Owners, Distribution & Load-Serving entities must coordinate and cooperate in system assessment that:
- Evaluates reliability impact of new facilities/connections and ensures compliance with NERC Reliability Standards
- Evidence and documentation of steady-state, short circuit and dynamics analysis was performed per TPL-001, and that study assumptions and system performance alternatives are stated in the report.
- Transmission Owners/Planners, Generator Owners, and Resource Planners shall provide steady-state and dynamic model data and structures that reflects the plant design.

THANK YOU

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Solar Codes and Standards

Solar Standards Issues

IEEE 1547 requires a distributed generator to:

- Never regulate the feeder voltage
- Trip immediately for a grid disturbance
- Avoid islanding, by some means

Furthermore, UL 1741 requires

- A built-in anti-islanding detection
- Inherently excludes a direct transfer trip approach
  - DTT more suitable for a large utility scale plant

However

- IEEE standards are voluntary
- Utility within purview to wave requirements (sometimes)

Solar Standards Issues

Update: IEEE 1547a now *allows* a distributed generator to:

- Regulate the feeder voltage if capable
- Ride through grid disturbances if capable

This is a PERMISSIVE requirement for voltage regulation and ride-through. It is not mandated that DG must do these things.

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Solar Codes and Standards

- Utility-scale PV is different from rooftops
  - Greater impact on the grid
  - Needs to be a good “grid citizen”
- PV plants can:
  - Mitigate their own voltage impact
  - Support the grid during disturbances
- Current standards (IEEE-1547, UL-1741) can be impediments to implementation of best solutions
  - Inflexible prohibition of DG providing voltage regulation
- Will new standards (like IEEE 1547.8) correct these gaps?

Summary

- Grid code harmonization is in the interest of all the stakeholders, including GE
- There are legitimate grounds for some special or non-standard requirements, but these should be objectively evaluated
- GE continues to invest and develop wind and solar generation equipment that provides the highest level of economy and reliability for grid operation
- Codes and standards for transmission-connected PV solar are still under development and need further revision
- GE is committed to participation in development of harmonized grid codes

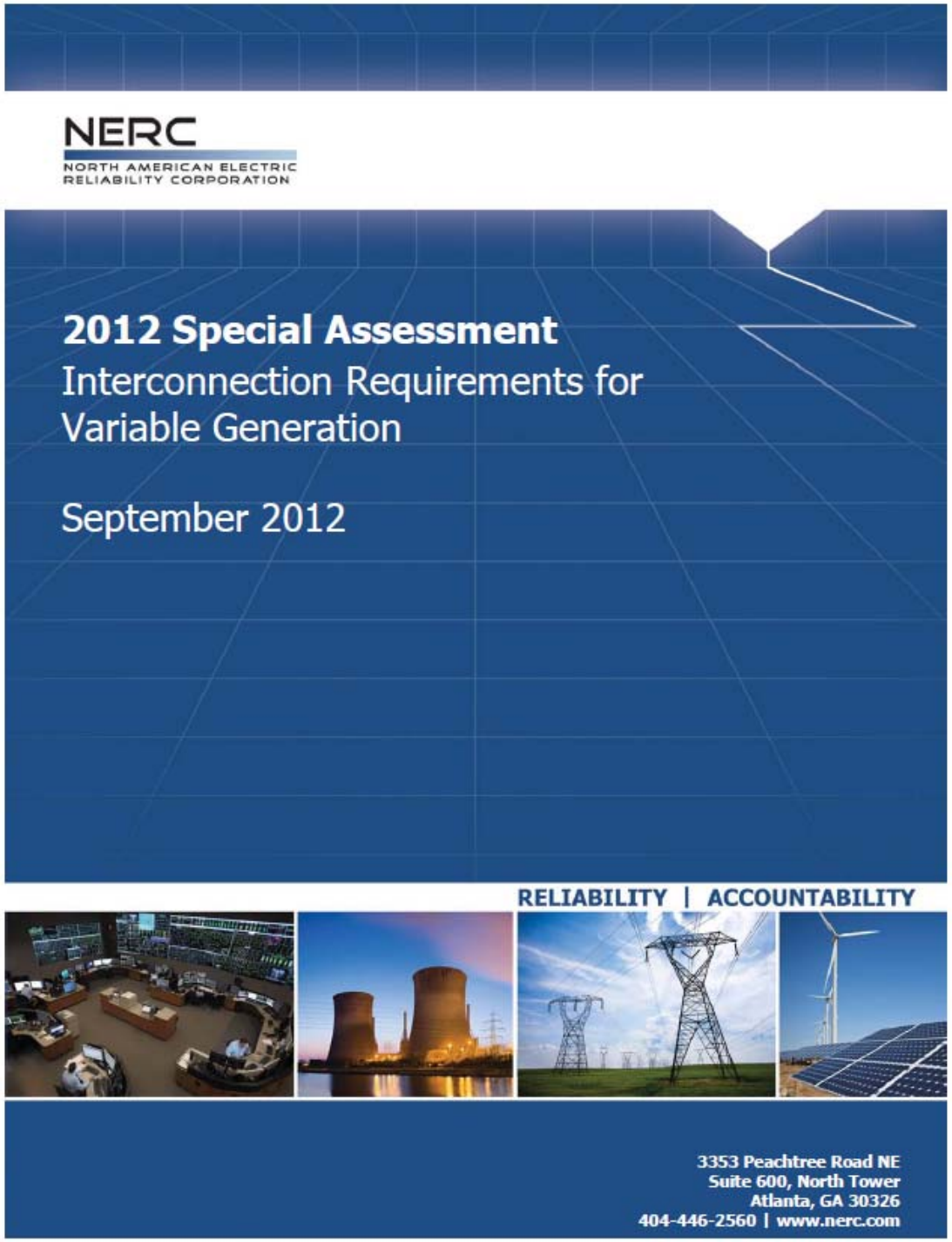
Reference Material:
NERC Integration of Variable Generation Task Force (IVGTF)

Project History

- Draft report was written by a team of industry experts and NERC members
- Sub-groups worked on individual chapters
- Drafting team and industry comments incorporated
- Final version completed September 2012

GOAL FOR TODAY:

- Summarize a few relevant recommendations from each chapter of the report



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Appendices

Introduction

- The report focuses on utility-scale generation resources, connected to the transmission system
- Other IVGTF groups are looking at distributed resources
  - Task Force 1-8: Potential Reliability Impacts of Distributed Resources
    - ✓ Visibility/controllability of distributed energy resources and impacts on load forecast
    - ✓ Ramping/variability of certain distributed energy resources and impacts on base load/cycling generation
    - ✓ Reactive power control
    - ✓ LVRT and LFRT and coordination with the IEEE Standard 1547
    - ✓ Under-Frequency-Load-Shedding (UFLS) and Under-Voltage-Load-Shedding (UVLS)
  - Task Force 1-7: Reconciling Existing LVRT and IEEE Requirements
    - ✓ Primary focus is IEEE Std. 1547 and FERC Order 661-A

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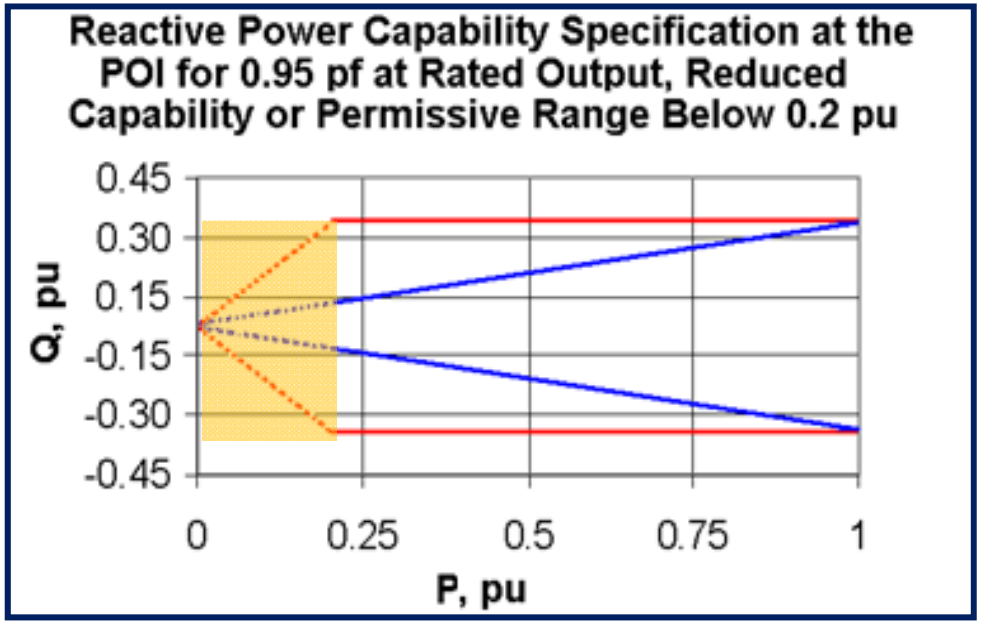
Chapter 2: Reactive Power and Voltage Control

- Standards Development
  - Existing standards developed with synchronous machines in mind, and therefore do not fully define performance requirements for reactive power
  - NERC should promote greater uniformity and clarity for interconnection standards
  - NERC should consider a standards project to establish minimum reactive power requirements and clear definitions of acceptable control performance

Chapter 2: Reactive Power and Voltage Control

Specific Recommendations

- ❑Applicability
  - ✓ Requirements should be established for all generator technologies.
  - ✓ "Technology-neutral" is a reasonable goal, but unique characteristics of some technologies may justify different criteria or appropriate variances
- ❑Specification of Reactive Range
  - ✓ Baseline capability of ±0.95 power factor at full load and nominal voltage
  - ✓ Smaller "permissive" reactive power range at low power (below 20%)



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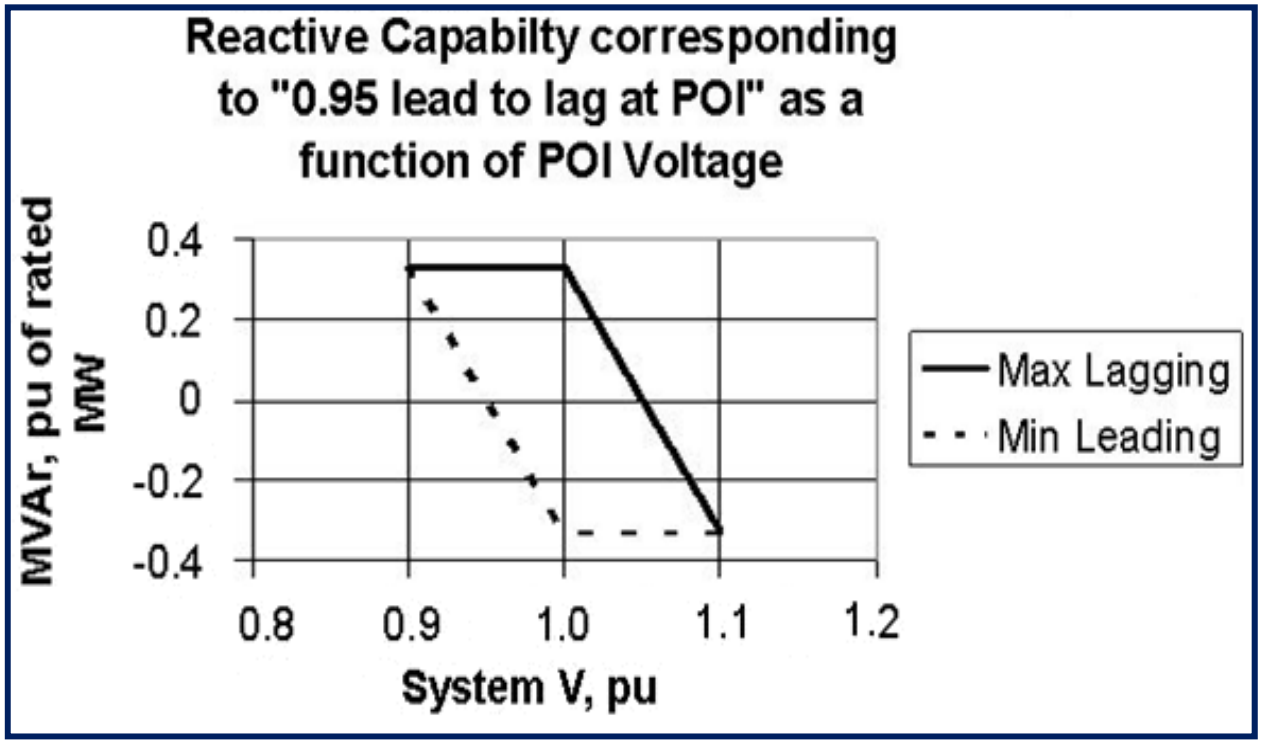
Chapter 2: Reactive Power and Voltage Control

Specific Recommendations

- ❑ Specification of Dynamic Reactive Capability
  - ✓ Define a portion of the reactive range to be dynamic (eg., 50%)
  - ✓ Define control performance (eg., time response)



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Chapter 2: Reactive Power and Voltage Control

Specific Recommendations

- Definition of Control Performance
  - ✓ Define specific response time constants for voltage control, power factor control, and reactive power control (eg., 10 seconds)
  - ✓ Similar response criteria to synchronous generators
- Technical Alternatives to Meet Reactive Power Capability
  - ✓ Capability measured at POI
  - ✓ Could use combination of generator/converter reactive output and plant-level reactive support equipment (eg., capacitors, reactors, STATCOM)
- Commissioning Tests
  - ✓ Objective is to verify full capability at full load
  - ✓ Test plans should allow for situations where full load may not be possible

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Chapter 3: Performance During and After Disturbances

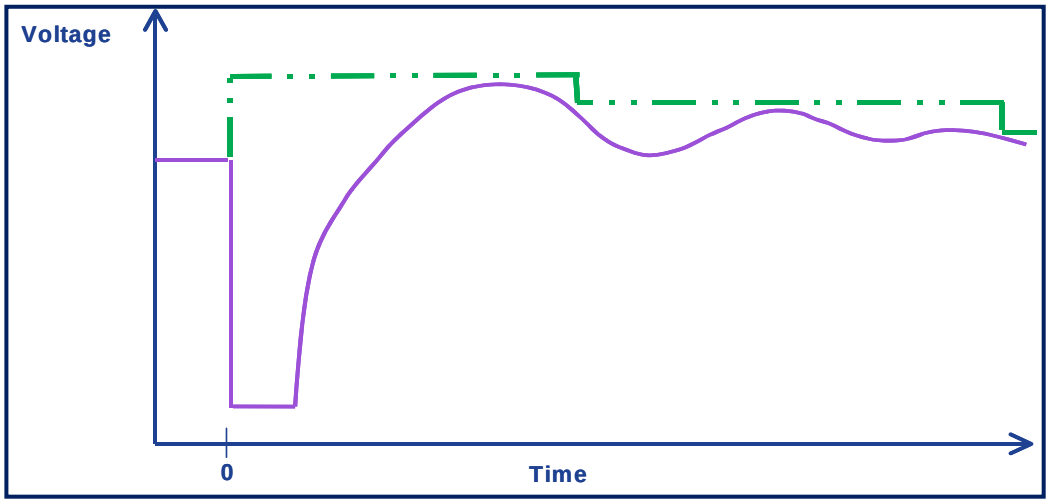
Specific Recommendations

- ❑ Frequency Ride-Through
  - ✓ A single NERC-wide requirement for frequency ride-through is not recommended
    - 2.5 Hz/sec is reasonable for most operating areas
    - Some regions may require 4.0 Hz/sec
- ❑ Voltage Ride-Through
  - ✓ Voltage ride-through plots should be provided, specifying both high and low voltage requirements
  - ✓ Zero-voltage ride-through (ZVRT) should be coordinated with 3-phase fault clearing times (eg., up to 9 cycles, but may be less depending on CT)
  - ✓ High-voltage ride-through (HVRT) requirement should be defined as a severity-duration criterion

HVRT Requirement: Traditional vs. Severity-Duration

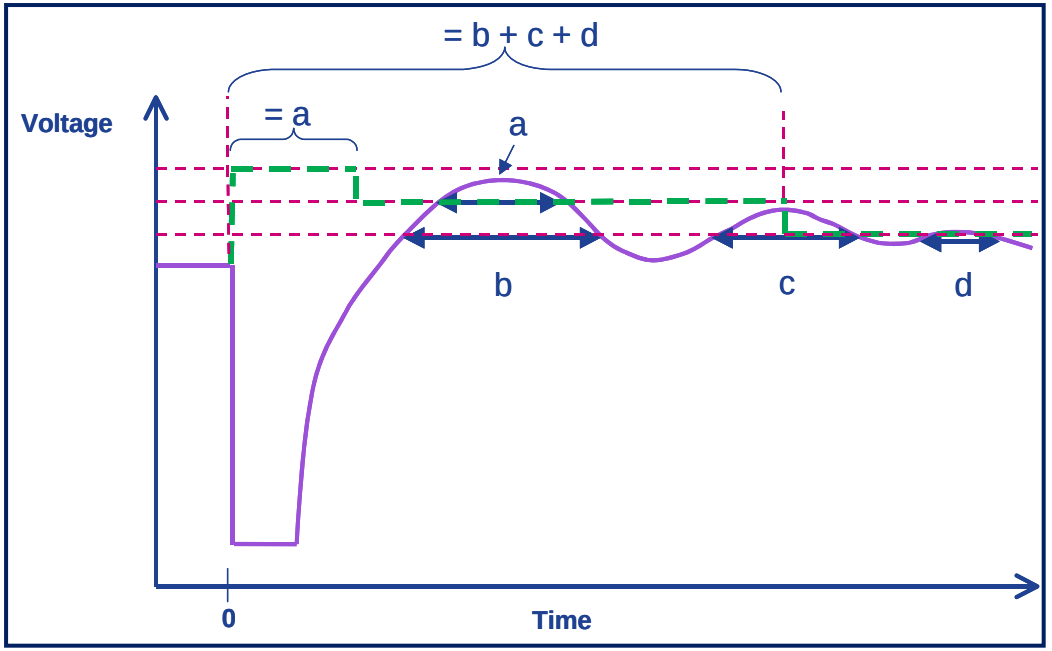
Traditional HVRT Req'mt

- Timer starts at beginning of fault



Recommended HVRT Req'mt

- Timer starts when voltage exceeds high-voltage threshold
- Objective is to align criteria with equipment duties/capabilities



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Chapter 3: Performance During and After Disturbances

Specific Recommendations

- ❑ Power Recovery
  - ✓ Standard recovery profiles can be counterproductive; the best profile is system-dependent
  - ✓ Detailed power recovery criteria is not necessary. If studies show grid performance criteria are not met, TO can work with plant owner on a mitigation plan.
- ❑ Standards for Manufactured Equipment
  - ✓ PV inverters designed to comply with IEEE 1547 do not provide disturbance ride-through performance necessary to meet NERC's grid reliability objectives
  - ✓ Utility-scale plants may have hundreds of small 1547-compliant inverters
  - ✓ NERC should develop new standards for utility-scale PV plants to drive the industry towards adoption of new inverter specifications, testing requirements, and certifications

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Chapter 4: Active Power Control Capabilities

Specific Recommendations

- Require curtailment capability, but avoid requirement for excessively fast response
- Require capability to limit rate of increase of power output
- Encourage or mandate reduction of active power in response to high grid frequency (over-frequency governor function)
- Consider requiring capability to provide increased active power in response to grid low frequency (under-frequency governor function)
- Consider requiring inertial response in the near future

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Chapter 5: Harmonics and Subsynchronous Interaction

Although harmonics and SSR/SSI pose reliability risks in some locations, such situations are rare.

Problems can be avoided by prudent engineering practices.

Specific Recommendations

- ❑Request design study reports that assess harmonic performance of all wind and solar plants
- ❑Request design study reports that assess risk, and if necessary mitigation, for wind and solar plants located near series compensated lines

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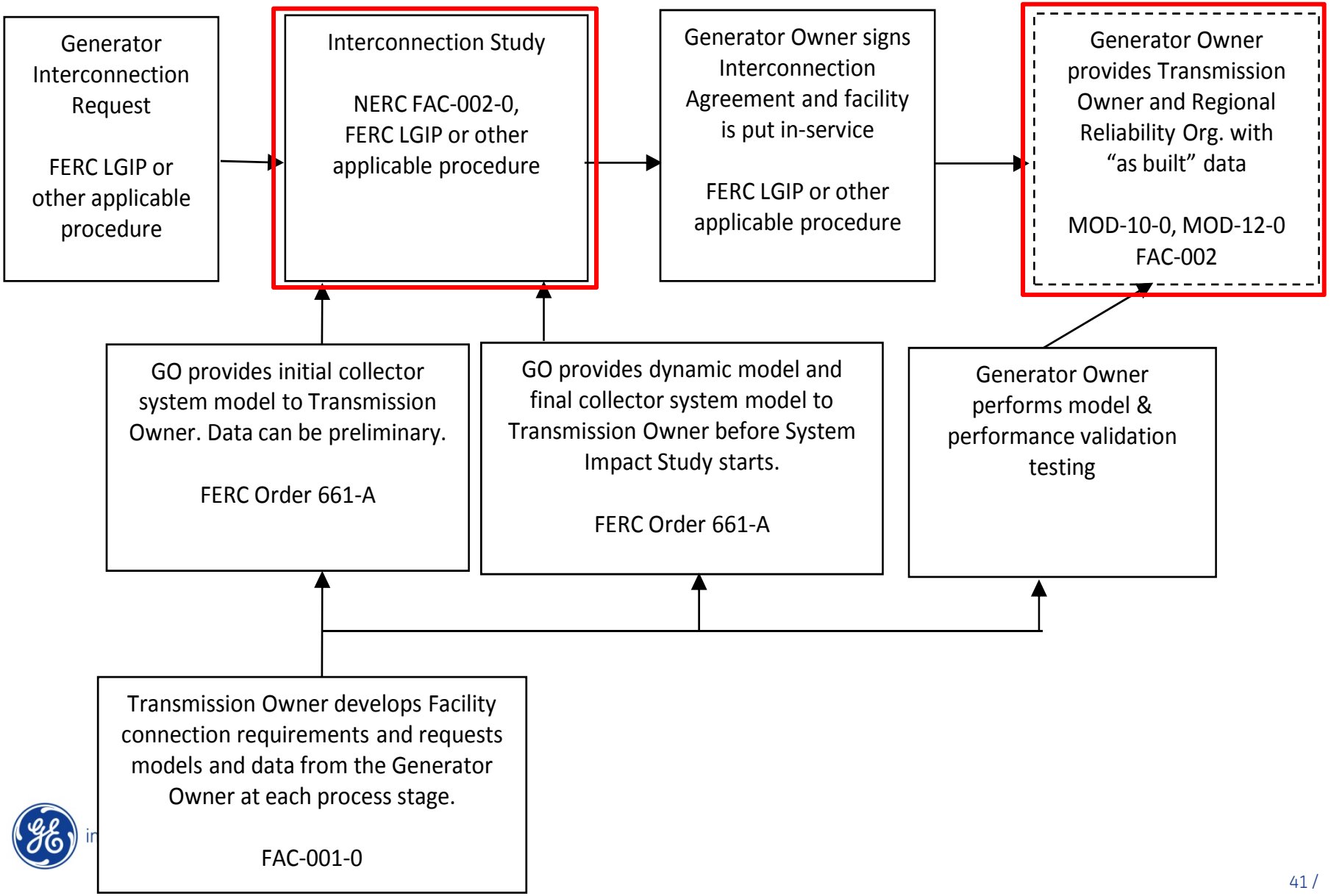
Chapter 6: Models for Facility Interconnection Studies



Chapter 6: Models for Facility Interconnection Studies

Specific Recommendations

- Preliminary model data may be used for the initial feasibility study of a variable generator interconnection project.
- The best model available should be used for the final System Impact Study or Facilities Study. These models can be user-written and require non-disclosure agreements.
- The detailed dynamic model must be accurate over the frequency range of 0.1 to 5 Hz. Time constants in the model should not be less than 5 ms.
- The detailed dynamics model must have been validated against a physical or type test.
- Verification of detailed model performance should be confirmed during commissioning to the extent possible. The following tests shall be performed:
  - ✓ Primary/secondary voltage control
  - ✓ Low voltage and high voltage ride through
  - ✓ Power factor/reactive power capability
  - ✓ Power ramping and power curtailment

Chapter 6: Models for Facility Interconnection Studies

Specific Recommendations

- ❑Verification of the non-propriety model accuracy may be performed by simulation tests compared with the detailed model performance.
- ❑At the end of the commissioning tests, the Generator Owner shall provide a verified detailed model and a non-proprietary model, ideally in IEEE, IEC or other approved format, for ongoing regional studies

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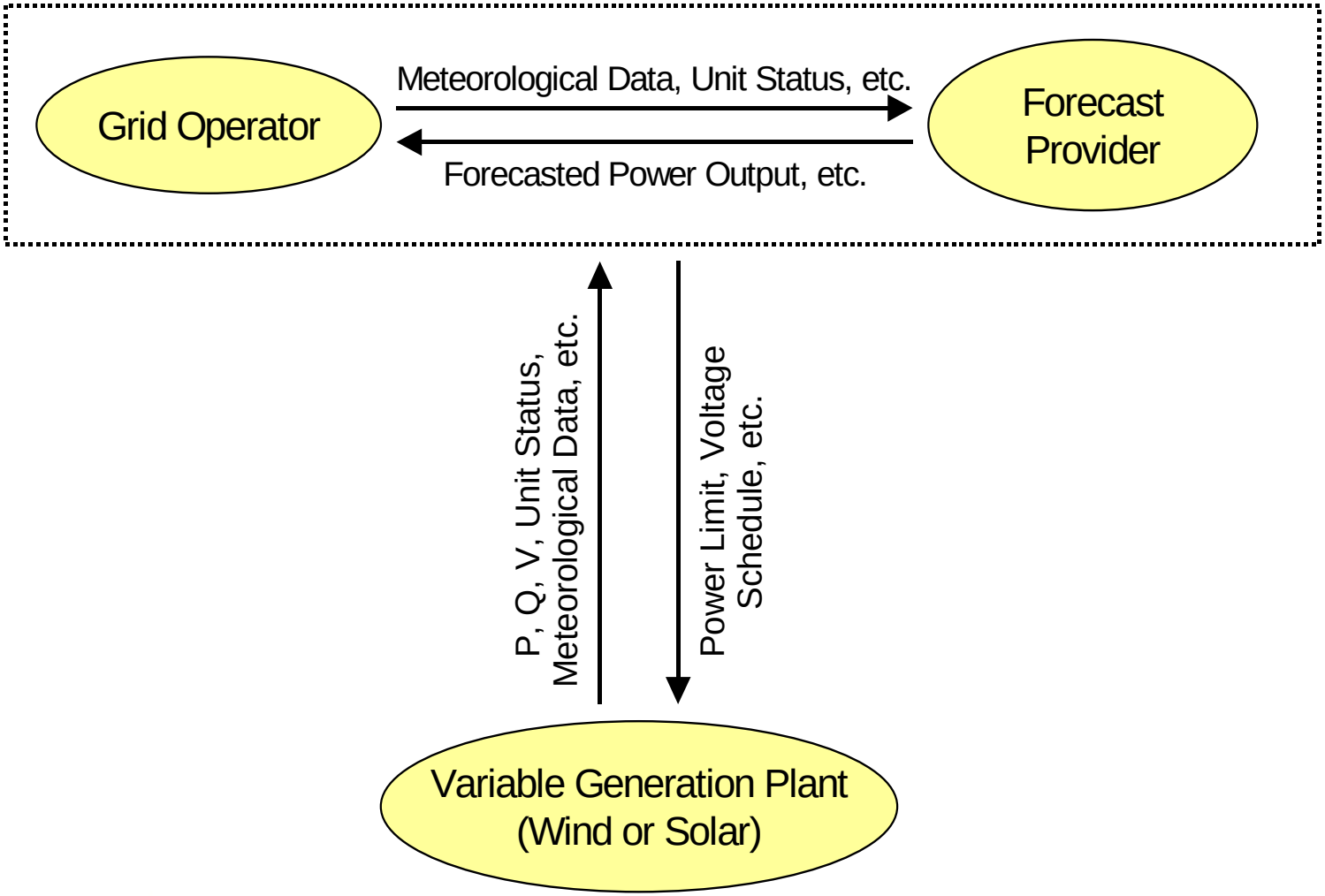
Chapter 7: Communications between Variable Generators and Grid Operators



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Chapter 7: Communications between Variable Generators and Grid Operators

Specific Recommendations

- ❑Variable generation plants should send a minimum set of monitoring data to the grid operation via the grid's SCADA network
- ❑Variable generation plants should receive and execute command signals (power limit, voltage schedule, ramp rate limit, etc.) sent from the grid operator via the SCADA network
- ❑Variable generation plants should have trained on-call plant operators that can receive calls from the grid operator 24/7 and immediately execute verbal commands. The plant operators would not need to be located at the plant provided they have secure remote control capability for the plant.

Chapter 7: Communications between Variable Generators and Grid Operators

Monitoring Signals from Wind Plant to Grid Operator

(Similar signals would be required for Solar Plants)

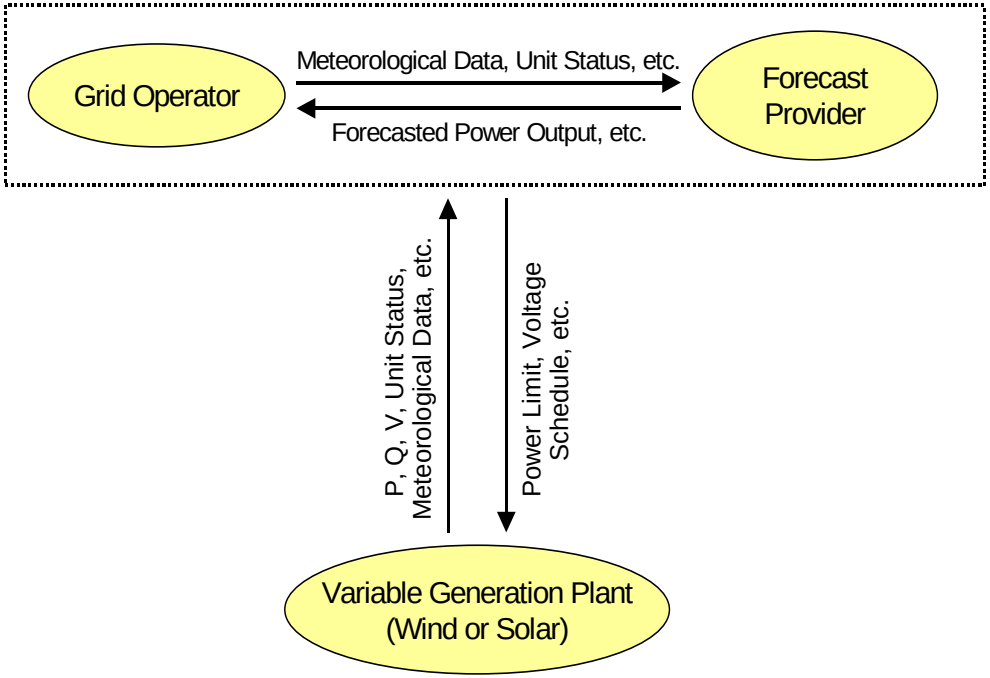
- Active power (MW)
- Reactive power (MVAr)
- Voltage at POI
- Number of turbines available (or total MW rating of available turbines)
- Number of turbines running
- Number of turbines not running due to low wind speed
- Number of turbines not running due to high speed cutout
- Maximum and minimum reactive power capability of plant
- Total available wind power (equal to production unless curtailed)
- Average plant wind speed
- Plant main breaker (binary status)
- Plant in voltage regulation mode (binary status)
- Plant in curtailment (binary status)
- Plant up ramp rate limiter on (binary status)
- Plant down ramp rate limiter on (binary status)
- Plant frequency control function on (binary status)
- Plant auto-restart blocked (on/off)

Chapter 7: Communications between Variable Generators and Grid Operators

Control Signals from Grid Operator to Wind Plant

(Again, similar concept for solar plants)

- Plant breaker trip command
- Voltage order (kV, setpoint for wind plant voltage regulator)
- Maximum power output limit (MW, for curtailment)
- Engage up ramp rate limiter (on/off)
- Engage down ramp rate limiter (on/off)
- Engage frequency control function (on/off)
- Block auto-restart (on/off)



Chapter 7: Communications between Variable Generators and Grid Operators

Data Required by Forecast Providers

(Again, similar concepts for solar plants)

Operating Conditions

- Wind plant status and future availability factor
- Number or percentage of turbines on-line
- Plant curtailment status
- Average plant power or total energy produced for the specified time intervals
- Average plant wind speed as measured by nacelle-mounted anemometers
- Average plant wind direction as measured by nacelle-mounted wind vanes or by turbine yaw orientation

Meteorological Data

- Average (scalar) wind speed
- Peak wind speed (several-second duration) over measurement interval
- Average wind direction
- Air temperature
- Air pressure
- Relative humidity or other atmospheric moisture parameter