JULY 15, 2015 | BREWSTER, MA

# New Generator Interconnection: Modeling and Performance

*Reliability Committee/Transmission Committee Summer Meeting*


Al McBride

DIRECTOR, TRANSMISSION STRATEGY & SERVICES

# Purpose of this Presentation

- Discuss modeling and performance issues for new generators, including new inverter-based generators
  - Wind, solar and fuel cell generators typically use inverters

# Agenda

- Problem Statement
- Areas of potential improvements
  - Reactive performance of inverter based generators
  - Defining a complete new Interconnection Request for inverter-based generators
  - Standardized models
  - Material modification
  - Consideration of network upgrades
  - Standard Scope of a Feasibility Study
- Phasor Measurement Units (PMU)

# THE INTERCONNECTION OF NEW GENERATORS

*Problems/challenges currently being experienced with inverter-based generators*

# Problem Summary

- Time taken to complete system impact studies for new inverter-based generators
  - Interconnection Queue backlog
  - Particularly in Maine
- Curtailment and performance issues in system operations for inverter-based generators
- Modeling and performance requirements being introduced by new NERC standards

# Background: Generation Development Behind Transmission Constraints

- All generators in New England compete for transmission use in the Energy Market based on bid price
  - A completed interconnection study, meeting overlapping impact requirements in the Forward Capacity Market, and Large/Small Generator Interconnection Agreement (L/SGIA) do **not** assure that a resource can always produce energy
  - Definite risk of curtailment, even without transmission outages
  - There are areas of the system where new renewable resources compete with thermal resources and existing renewable resources, sometimes the same owner
- Regional transmission constraints
  - Broader areas of the system which may constrain concurrent operation of larger groups of generation
- Local transmission constraints
  - Smaller areas of the system which may constrain concurrent operation of smaller groups of generation
  - May be nested behind other constraints, particularly regional constraints
  - Many wind curtailments due to local constraints

# Nature of the Generator Interconnection

- Any generator located very far from its interconnection to the transmission system is likely subject to voltage and stability performance issues
  - Especially for connections at lower transmission voltages
- Many generators are connecting into electrically weak parts of the New England system
- Wind interconnecting with bare minimum voltage support – no margin
  - Per FERC Order 661, wind plants are required to provide voltage support only if the System Impact Study shows that it is required for reliability
- First-in generators, especially wind, have quickly utilized any limited existing system margins, resulting in more significant system upgrades for subsequent generators, influencing the operation of all area generation

# Implications of Generator Technology

- Synchronous generators can provide voltage and inertial support at their Point of Interconnection (POI)
- Inverter-based generators typically have not provided significant system voltage or stability support, although technologies are improving
- Voltage control/reactive power capability of wind generators, where available, is mostly consumed within the wind farm
  - Little remains for overall system support
- Some wind generator power electronic controls will not function properly in weak areas (described later)
- Frequent performance issues and adjustments to stability models for some wind generator and plant voltage control models throughout study and post-study period

# Consequences for System Operations

- System Impact Study is a discrete testing program to identify the minimum upgrades required to meet the interconnection standards
  - Does not directly capture full range of real-time load, outages and needs of system operators to manage the system and operate under a broad range of conditions
- Interconnections planned with little or no operating margin (pursuant to FERC Order 661) can and will result in significant plant operating restrictions
  - Normal operating conditions remove facilities from service, inherently weakening the system
  - Wind plant interconnection plans can become immediately insufficient, relative to the operating condition
  - Greatly impacted by line-out conditions
  - Actual operating conditions can be much more stressed than in studies
  - Limited margin in study conditions results in greater risk of constraints in normal operation
  - Curtailment very dependent on changing system conditions

# Consequences for System Operations, cont.

- Each plant design is unique; problems mitigated using multiple devices
  - Creates a great challenge to practical system operation
  - Impractical for System Operators to be able to understand all of the unique features of each installation
  - Far too many operating condition permutations
  - This is a growing concern as more facilities are added to the system
- Modeling and information changes can result in:
  - Delays to commercial operation
  - Output limitations
  - Material modification reviews
- These issues with wind farms have resulted in significant complications for system operations
  - For example, the addition of complicated operating interfaces

# Inverter-based Interconnection in Weak Areas Presents Significant and Time-Consuming Study Technical Challenges

- Validation/refinement/replacement of plant models
  - Improper function of initially provided models
  - Electromagnetic transient analysis (PSCAD) required for model validation
  - Restudies caused by mid-study model malfunction
- Detailed voltage analysis inside the wind farm
- Resolution of wind turbine control mode oscillations
- Complexity of plant operational control
- Concurrent steady state voltage, voltage stability, transient stability and inter-area oscillation constraints
- Interaction of local and inter-area transfers
- Limited reactive support by plant of network issues related to plant
- Reactive resource coordination control design
- Electromagnetic transient analysis of power electronic control interactions
- Each incremental plant further stresses the system, increasing study complexity

# Drivers of Individual and Cumulative Study Delays

- Proposals for plants that are overly large for their electrical location
  - Problems getting the basic plant to function
  - Challenges addressing the resultant system issues
- Insufficient initial consideration of wind farm design
- Requests to modify plant characteristics
- Multiple requests to change equipment manufacturer
- Poorly functioning and/or poorly documented models
- Poor consistency of model performance
- Updates to equipment models for proposed projects
- Updates to equipment models for existing projects
- Inclusion of undesirable equipment performance features

# REACTIVE PERFORMANCE REQUIREMENTS

*Inverter-based generators*

# PJM Reactive Performance Requirements[1]

- All new non-synchronous resources should: (1) have the capability to autonomously provide dynamic reactive support within a range of 0.95 leading to 0.95 lagging at inverter terminals; (2) adhere to NERC Reliability Standard PRC-024-1 with respect to voltage and frequency ride-through capabilities, irrespective of resource size
  - Previously, in accordance with FERC Order No. 661, wind resources were not required to provide reactive power unless a system impact study shows that reactive power is needed from that resource to maintain grid reliability

1. Docket No: ER15-1193-000: Conditionally Approved May 05, 2015

# Benefits of Reactive Performance Requirement

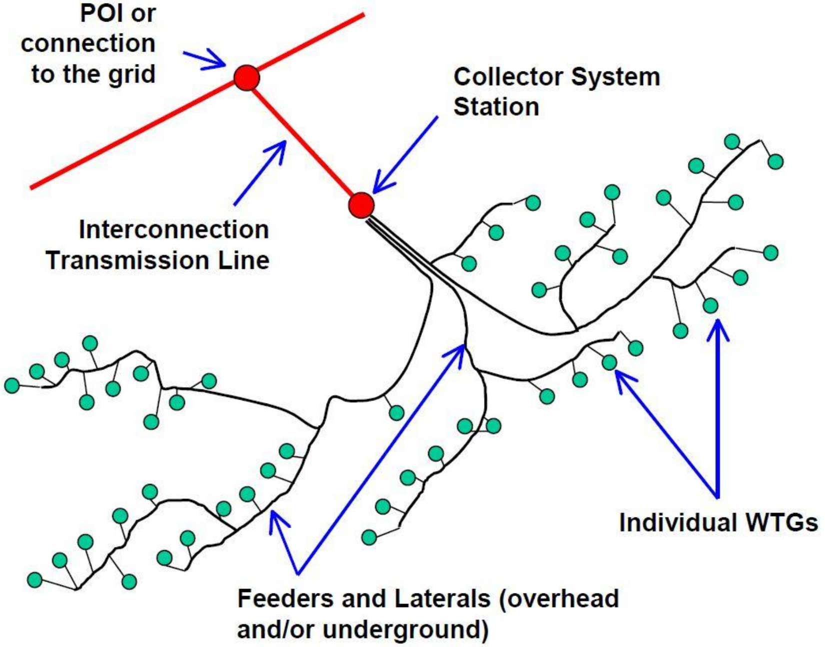
- Reduce the reliance on the design of reactive solutions in the interconnection system impact study
  - Expected to help to reduce time to complete studies
- Capture the benefits of widely available technology improvements
- Can result in fewer operating restrictions
- Anticipate the increasing number of non-synchronous interconnection requests (combined with anticipated resource retirements)
  - Necessitates the availability of reactive power on a presumptive basis to ensure the safety and reliability of the transmission system as a whole

# DEFINING A COMPLETE INTERCONNECTION REQUEST

*Inverter-based generators*

# Detailed Representation of Wind Farms

- System Impact Studies have required full modeling of the wind farm in steady state analysis
  - Single-turbine equivalents are used in stability analysis
- A standard wind farm data set has been drafted and has been used in the collection of data from some existing and new wind farms



# Initial Steps in Wind Farm Electrical Design

- Identify tap settings for the unit step-up transformers and the station step-up transformers
  - Tap settings correspond to the most reasonable voltage conditions on the collector system and the turbine terminals for a range of different voltage conditions at the POI
- The detailed representation provides direction to the tap settings to be used in the equivalent models used in stability analysis
- These analyses can be time-consuming and have been included in the ISO system impact study analysis

# Inverter-Based Interconnections in Weak Portions of the System

- A low short circuit ratio (SCR) is a commonly used indicator of a "weak" system
- In a weak system, the following problems can be associated with inverter-based interconnections:
  - Steady state voltage violations
  - Voltage instability
  - Oscillations
- Power system analysis models provided by manufacturers do not represent actual performance under weak system conditions
  - Reduced confidence in the models
  - Reduced confidence in the ability of turbines to operate reliably in these weak conditions
- Customized generator-specific changes are typically inadequate due to operational system changes and system evolution

# Appropriate Design level of an Interconnection Request for an Inverter-Based Generator

- The detailed project design could be provided by the developer as part of Interconnection Request
  - Developer would provide comprehensive documentation demonstrating conformance with performance requirements
- Interconnection Request submittal could address weak grid performance
  - Certify the lowest acceptable level of short circuit ratio, or provide correction to an acceptable level
  - Provide electromagnetic transient (PSCAD) model
  - Provide documentation of acceptable power system analysis model performance
    - Verify using benchmark comparison with PSCAD

# Benefits of Up-Front Design

- Increased readiness to initiate the system impact analysis of the effect of the project on the network
  - Expected to help to reduce time to complete studies
- Reduced need to consider modifying the project after the interconnection process has begun

# STANDARDIZED MODELS

*Applicable to all generator types*

# NERC Proposal for Standardized Models

- In November 2013, NERC issued a “Proposal for Use of Standardized Component Models in Powerflow and Dynamics Cases”
- NERC Planning Committee (PC) directed the NERC Modeling Working Group (MWG) to develop, validate, and maintain a library of standardized component models and parameters for powerflow and dynamics cases
- The proposal requires that user-defined models should be placed on a swift path to inclusion in the library of standardized models
  - Once a corresponding standardized model is developed and validated, the regions should shift to the standardized model

# Benefits of Using Standardized Models

- Reduces the time required to set-up new study cases
  - Expected to help to reduce time to complete studies
- Eliminates the need for generator owners to update user models when power system analysis software is updated
- Eliminates the use of ISO/Transmission Provider engineering resources in the testing and troubleshooting of user models

# MATERIAL MODIFICATION

*Applicable to all generator types*

# Material Modification Background

- In response to customer requests and to address the backlog in its generator interconnection queue, ISO has reviewed how it administers the process of making a Material Modification determination
- ISO has been implementing procedural rules to add more structure to the process that should expedite the studies of projects in the queue and provide notification to customers on key times to update the technical data for their project

# Material Modification Background, cont.

- Interconnection Customers request changes to their existing or proposed generating facilities for a wide variety of reasons
- These changes can have no impact, can have a large impact on the studies of other proposed projects or can have a significant impact on the reliability of the New England's transmission system
- Proposed changes that may cause a large/significant impact are deemed to be Material Modifications and require submission of a new Interconnection Request and a new queue position
- ISO's Tariff provides a definition of Material Modification in Schedule 22 and provides further information on modifications in Section 4 of the LGIP and Article 5.19 of the LGIA

# Data Refresh at the beginning of the System Impact Study

- ISO-NE will notify the Interconnection Customer 30 days before the study begins and allow the Interconnection Customer 30 days to refresh its data to the degree allowed under the same materiality standards for changes prior to execution of the System Impact Agreement
- Once the System Impact Study Study has started, it will be completed without making any changes except those based on study results that were not anticipated and are agreed to by the System Operator and the Interconnecting Transmission
  - Screening criteria on the following slide

# Screening Criteria for Project Changes

- Changes will be deemed material and require a new Interconnection Request when:
  - A restudy is needed to determine if the change has a significant impact on the reliability of the transmission system, or,
  - A restudy is needed to re-determine the system upgrades and/or the allocation of system upgrade costs, or,
  - A restudy will result in a delay of the study of a later-queued project
- Changes will not be deemed material and will not require a new Interconnection when:
  - There are no performance problems that may be affected by the change to the project that is found in any base cases for the most severe N-1 and N-1-1 contingencies, and,
  - Similar or better performance can be confirmed based on a very limited review

# Benefits of Additional Structure in Material Modification Determinations

- Reduced delay in the conduct of queued studies
  - Expected to help to reduce time to complete studies

# CONSIDERATION OF NETWORK UPGRADES

*Applicable to all generator types*

# Consideration of Network Upgrades

- The selection and design of reactive upgrades can take a significant amount of study effort
  - Sufficient descriptive detail of the proposed reactive upgrades must be available for modeling and analysis
  - Must coordinate with other existing and proposed devices
  - Long time to collect cost estimates
- A request by the developer to consider a different reactive upgrade than the proposed upgrade can cause a significant amount of study re-work
- Static shunt compensation can be inoperable for intermittent resources due to quickly changing output conditions and can be infeasible from an operating standpoint due to frequent switching operations

# Benefits of Focusing on Operable Solutions

- Reduced iterations in the study of upgrade alternatives
  - Expected to help to reduce time to complete studies
- Some scalability of upgrades to build upon in the evaluation of later queue positions
  - Expected to help to reduce time to complete studies

# THE STANDARD SCOPE OF A FEASIBILITY STUDY

*Applicable to all generator types*

# Feasibility Study Scope

- In New England, the Feasibility Study scope has corresponded to a complete steady-state portion of the overall System Impact Study
  - Complete thermal analysis
  - Complete steady state voltage analysis
  - Complete short circuit analysis
- Propose to modify the standard scope of Feasibility Studies to provide screening analysis of the expected areas of concern
  - Benefit is expected to be a high-level study in a shorter amount of time that focuses on the expected problems

# Examples of Reactive Power Screening Tools

- Surge Impedance Loading and VAR Losses
  - Overview of the VAR burden introduced by the interconnection
- "PV" (Power-Voltage) Analysis
  - Voltage feasibility pretest
  - Worst scenario and contingency screening
  - Critical voltage location (bus) searching
  - Understand the voltage profile in the facility and the region
- "QV" (Reactive-Voltage) Analysis
  - Evaluate reactive margin and high/low voltage potential
  - Evaluate the amount and type of reactive compensation needed
- Short Circuit Ratio
  - Evaluate potential issues and recommend focus of study

# PHASOR MEASUREMENT UNITS

*Applicable to all generator types*

# Model Validation: NERC MOD-026 and MOD-027

- MOD-026 will require generators equal to or greater than 100 MVA to verify the generator **excitation control system** or plant volt/var control function model (including the power system stabilizer model and the impedance compensator model) and the model parameters used in dynamic simulations accurately represent the generator excitation control system or plant volt/var control function behavior when assessing Bulk Electric System reliability
- MOD-027 will require generators equal to or greater than 100 MVA to verify the **turbine/governor** and load control or active power/frequency control model and the model parameters, used in dynamic simulations that assess BES reliability, accurately represent generator unit real power response to system frequency variations

# Model Validation: MOD-033

- Requirement

  Each Planning Coordinator shall implement a documented process to validate steady-state and **dynamics** Planning models by comparing performance with actual system behavior

- Compliance measure

  Each Planning Coordinator shall provide evidence that it has a documented validation process according to Requirement R1 as well as evidence that demonstrates the implementation of the required components of the process

# PJM Tariff Language

- 8.5.3. Phasor Measurement Units (PMUs):

  An Interconnection Customer entering the New Services Queue on or after October 1, 2012 with a proposed new Customer Facility that has a Maximum Facility Output **equal to or greater than 100 MW** shall install and maintain, at its expense, phasor measurement units (PMUs). PMUs shall be installed on the Customer Facility **low side of the generator step-up transformer**, unless it is a non-synchronous generation facility, in which case the PMUs shall be installed on the Customer Facility side of the Point of Interconnection. The PMUs must be capable of performing phasor measurements at a minimum of 30 samples per second which are synchronized via a high-accuracy satellite clock. To the extent Interconnection Customer installs similar quality equipment, such as **relays or digital fault recorders**, that can collect data at least at the same rate as PMUs and which data is synchronized via a high-accuracy satellite clock, such equipment would satisfy this requirement. As provided for in the PJM Manuals, an Interconnection Customer shall be required to **install and maintain, at its expense, PMU equipment which includes the communication circuit capable of carrying the PMU data to a local data concentrator, and then transporting the information continuously to the Transmission Provider; as well as store the PMU data locally for thirty days.**

# PJM Tariff Language (Cont')

Interconnection Customer shall provide to Transmission Provider all necessary and requested information through the Transmission Provider synchrophasor system, including the following: (a) **gross MW and MVAR** measured at the Customer Facility side of the generator step-up transformer (or, for a non-synchronous generation facility, to be measured at the Customer Facility side of the Point of Interconnection); (b) **generator terminal voltage**; (c) **generator terminal frequency**; and (d) **generator field voltage and current, where available**. The **Transmission Provider will install and provide for the ongoing support and maintenance of the network communications linking the data concentrator to the Transmission Provider**. Additional details regarding the requirements and guidelines of PMU data and telecommunication of such data are contained in the PJM Manuals.

# Benefits of PMUs

- The traditional off-line staged generator tests are costly and time consuming
- With high-resolution PMU data from generators, model validations may more readily be performed online or using system disturbance data, without taking generation outages
  - Opportunity to detect failures, changed adjustments, drifting, and improper operation of equipment
- Enhanced ability to verify dynamic models using PMU measurements
- Validation and benchmarking system wide models (MOD-033)

# Next Steps

- For all of the items discussed today:
  - Introduce Tariff/Planning Procedure changes at relevant Committees
- Target changes be in effect by the end of 2015

# Questions