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ISO new england

Wind Integration

Lessons Learned

(Murphy's Law Is Alive And Well)

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GENERAL ISSUES

General Wind Location Considerations

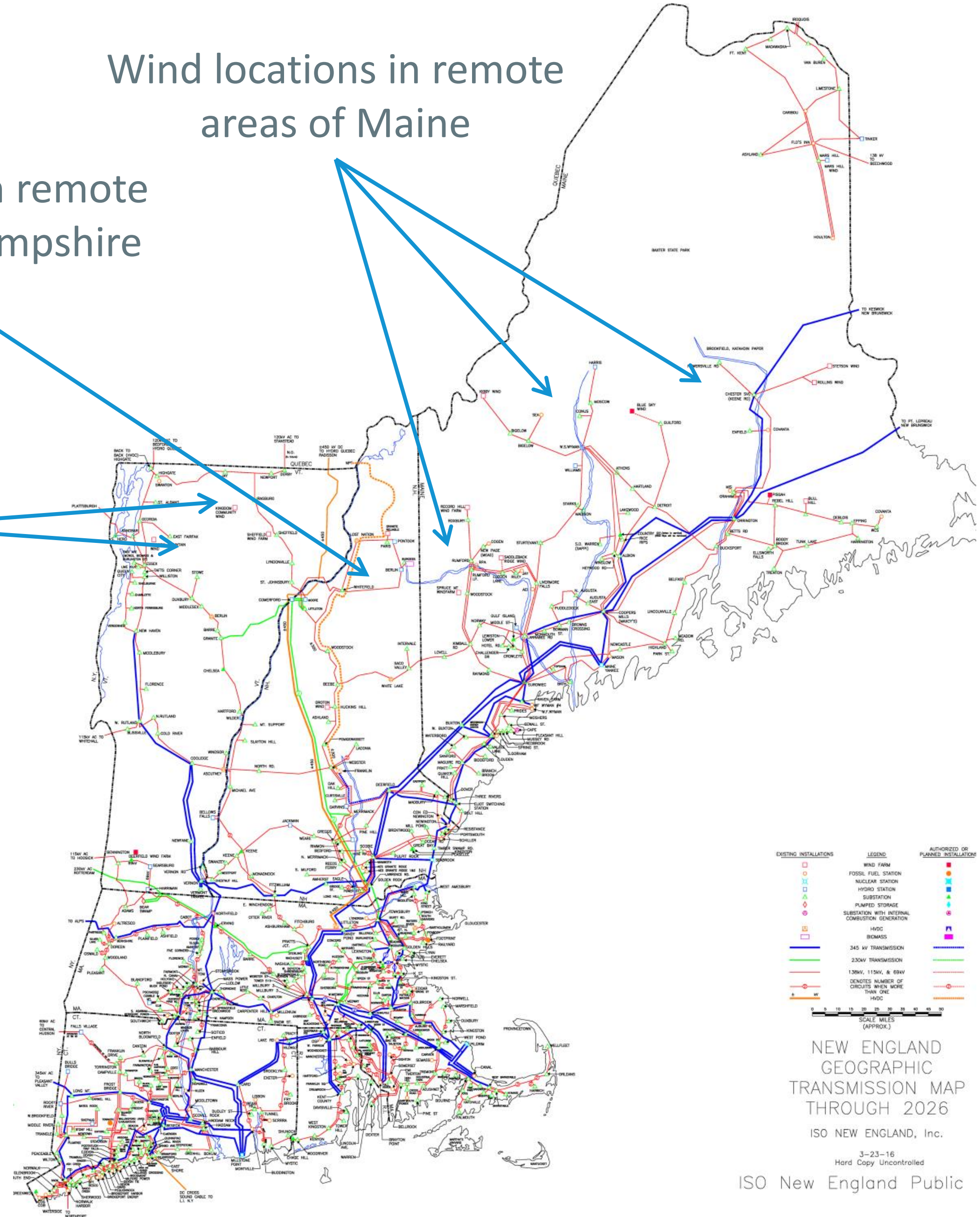
- Most of New England Wind Installations Located on Remote Mountain Ridgelines
- Connect Into Weak Transmission System
  - Away from Bulk Transmission Backbone (345 kV in New England)
  - Serving Sparse Loads
  - Never Designed For High Power Transfers
  - Lack of Reactive Resources in These Areas
  - Lack of multiple transmission paths (single outages cause restriction)
  - Low Short Circuit Strength can cause WTG control stability issues

General Wind Location Considerations

Wind locations in remote areas of Maine

Wind locations in remote areas of New Hampshire

Wind locations in remote areas of Vermont

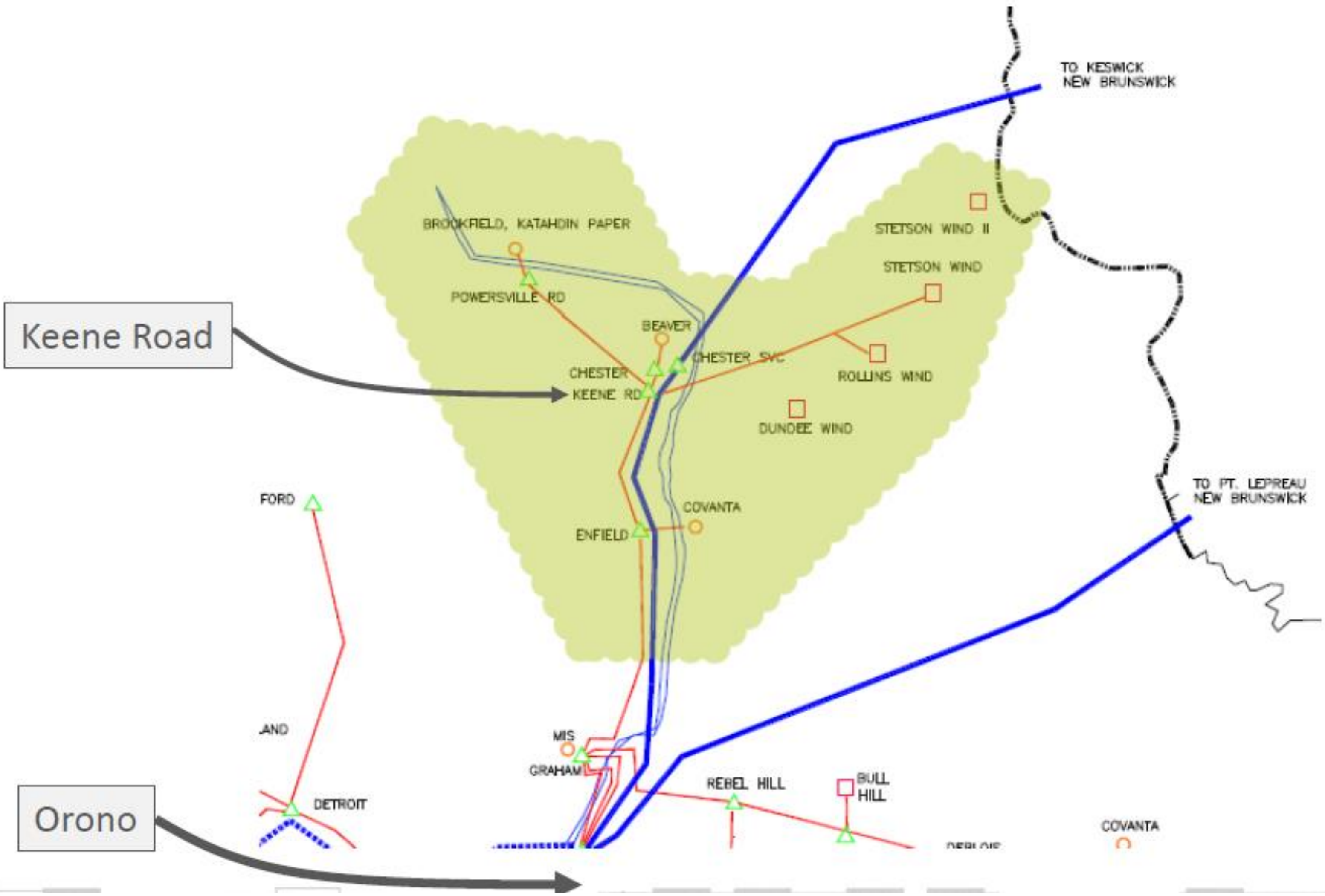


Minimum Interconnection Standard

- This is a tariff requirement imposed by FERC
- Minimum required upgrades, consistent with:
  - No degradation in all-lines-in-service transfer capability
  - All reliability standards must be met
  - ISO can still operate and maintain the system reliably
  - Maximum one-for-one displacement of existing/proposed generation
- Minimum Interconnection Standard
  - Does not ensure incremental transmission capacity to serve load
  - Does ensure no degradation to load-serving capability of the system
  - Consistent with market and Tariff constructs for Network Resources

CASE STUDY ONE

Northern Maine



Keene Road Area

- First proposed wind farm in the area fed by single 115 kV line
  - Low rating, 68 MVA
  - 40 years old at the time, in need of rebuild
  - Serve local paper mill loads in conjunction with mill generation
- Transmission Owner proposed adding 345 kV/115 kV transformation to allow for line rebuild
  - System Impact Study completed in 2008 with proposed 90 MW of wind
    - The area had never been previously assessed for stability issues
  - Transformer tied 115 kV to a +450/-150 Mvar SVC on the 345 kV which in turn is a tie line to neighboring RC (New Brunswick Power)
  - 120 MW existing mill hydro + steam generation with 60 MW mill load
    - Inadequate dynamics models for existing 70+ year old mill generators and loads
- In the same timeframe, other wind farms proposed in area
  - Eventually another 142 MW would be built in the area

Keene Road Area

- Plant studied under minimum interconnection standard
- Post-construction issues identified
  - Totally different characteristics with new 345/115 kV transformer
  - Required operating with one 345 kV breaker normally open
  - Created new contingency not previously studied
    - Loss of a 345 kV line now dead-ends the transformer
  - Stability export limit established based on new contingency
    - Not all generation (wind + mill hydro) in the pocket can fit
  - Certain maintenance conditions cause transient high voltage spike
    - Driven by SVC response to remote/high impedance faults
    - Faults weak enough to prevent SVC from blocking
    - Much too fast phenomena for PSSE, so PSCAD study required
- Requires electrical disconnection of wind turbines to avoid overvoltage damage potential

CASE STUDY TWO

Keene Road Area

- Two additional wind plants located in same general area
- Both plants connected under minimum interconnection standard
- Both connected to 115 kV system with poor SCR (<2)
  - Second plant in-service 16 months after first
- Very similar designs
  - Both plants required synchronous condenser (SC) per Planning to mitigate SCR
  - Same SC and wind turbine generator (WTG) manufacturers

Keene Road Area

- First Plant SC reverse power relay issues
  - Unexpected tripping after remote lightning strike
  - Unknown reverse power protection package on SC
    - Intended for anti-islanding
    - Trip of SC intentionally cross-tripped wind far
  - Detailed event reconstruction
  - Worked with manufacturer on proper settings
  - PSCAD analysis required due to WTG model accuracy required for accurate reverse power shape
- Work with same manufacturers on second plant
  - Plant had not yet been fully commissioned
  - Same protection package
  - Showed more severe reverse power spike

CASE STUDY THREE

Northern New Hampshire

- Plant studied under minimum interconnection standard
- Wind Plant located weak 115 kV looped system
  - Poor reactive support and SCR / low rated 115 kV lines (100 to 150 MVA)
  - Area prone to unacceptable transient and steady state voltage performance
- Planning identified need for additional reactive support
- Severely limited during facility out and nearby generator status
  - Not only generator status but AVR status as well

Northern New Hampshire

- Based on planning criteria lead/lag turbine capability turbines, static caps and, DVAR adequate for full operation
- Planning did not determine exact details on how reactive elements were to be coordinated resulting controls optimized after plant became operational
  - Plant controller manages lead/lag on turbines, static caps, DVAR
  - Restrictive voltage control bandwidth to respect stability limitations
- Reactive capability found to be problematic under facility out conditions
- Plant significantly restricted for many combinations of facility out conditions (multitude of operating guides for operators)
  - Poor voltage damping during transient timeframe
  - Potential for post-fault LVRT actuation due to weak system
  - Potential for post-fault high voltage trip due to weak system
- Required extensive testing in coordination with developer and manufacturer to tweak Plant Controller to cover myriad of additional system configurations
- Majority of all-lines-in-service restrictions eliminated, still some facility out restrictions

CASE STUDY FOUR

Northern Vermont

- Plant connected under minimum interconnection standard
- Located in a weak system, connected radially to networked 46 kV sub-transmission
  - Very poor reactive support and SCR
- General area also contains HVDC tie to Hydro Quebec as well as existing hydro, other wind and fossil resources
- Resulted in new constrained voltage / stability export limited interface
  - Identified during the interconnection process
- Planning identified synchronous condenser requirement in system upgrades to maintain all-facilities-in-service transfer limits

Northern Vermont

- Plant commercial before SC in-service
  - Resulted in significant MW restriction
- Additional limitations identified under facility out conditions
  - Post-contingent low voltage, post-fault LVRT and high voltage trips, as well as sub transmission network thermal overloads all possible
- To ease some restrictions underlying sub-transmission network consider in analysis
- Eventually SC added which mitigated most restrictions
- Weakness of local system results in significant number (> 20) of facility outages which impact the limits

HIGH LEVEL CONSIDERATIONS

General Considerations in New England Region

- Minimum interconnect fall-out
- Wind turbine model issues
  - Don’t work
  - Changing all the time
  - Black box models hard to debug
  - Proprietary models (intellectual property) create issues between software applications
  - Positive sequence models may not be valid below certain SCR threshold
- Short circuit strength issues
- Very diverse reactive strategies employed
- Reactive capability testing revealed issues with installed reactive upgrades
  - Field test of STATCOM overload capability revealed improperly configured overload capability below design
    - Should consider requiring field testing of all components

General Considerations in New England Region

- LVRT Characteristic creates self-oscillation
  - Plant connected in area with low SCR ~1.7:
    - Plant sees low voltage, enters LVRT
    - LVRT characteristic reduced MW
    - Reduced MW allows voltage to recover and exits LVRT characteristic
    - MW ramp back up
    - Voltage declines again, then re-entering LVRT mode
  - Mitigating this required careful reactive power coordination
- PSSE Model behavior can approximate real system however:
    - Approximations can create the appearance of issues that may be fictitious
    - In other cases can mask issues
    - More detail, better documentation improves confidence in models
    - Should always consider PSCAD simulation, requires asked for models upfront

Questions?