Costs of Integration for Wind and Solar Energy: Large-scale studies and implications

MIT Wind Integration Workshop

Michael Milligan, Ph.D.

National Renewable Energy Laboratory

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Topics

Large-scale integration studies:
Western Wind and Solar Integration Study
Eastern Wind Integration and Transmission Study

What does it take to integrate variable generation (wind and solar)?

Wind and solar integration cost issues
Large-scale wind integration studies: WWSIS and EWITS

- Managed by NREL – large project teams
- Western Wind and Solar Integration Study, in collaboration with WestConnect
- Eastern Wind Integration and Transmission Study, in collaboration with the Joint Coordinated System Plan and Midwest Independent System Operator
WWSIS www.nrel.gov/wwsis

- Large team, Debbie Lew project manager
- NREL, GE Energy, 3Tier, Northern Arizona University, Exeter, SUNY
- Project partner: WestConnect
- Large stakeholder group
- Technical Review Committee
Overview

Goal
– To understand the costs and operating impacts due to the variability and uncertainty of wind, PV and concentrating solar power (CSP) on the WestConnect grid

Utilities
– Arizona Public Service
– El Paso Electric
– NV Energy
– Public Service of New Mexico
– Salt River Project
– Tri-State G&T
– Tucson Electric Power
– Xcel Energy
– WAPA
Scenario Overview

<table>
<thead>
<tr>
<th>In Footprint</th>
<th>Rest of WECC</th>
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<tr>
<td>Wind</td>
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<td>10%</td>
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<td>20%</td>
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<tr>
<td>30%</td>
<td>20%</td>
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<tr>
<td>Solar</td>
<td>Solar</td>
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<tr>
<td>1%</td>
<td>1%</td>
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<tr>
<td>3%</td>
<td>1%</td>
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<tr>
<td>5%</td>
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Baseline – no new renewables
In-Area – each transmission area meets its target from sources within that area
Mega Project – concentrated projects in best resource areas
Local Priority – Balance of best resource and in-area sites
Plus other scenarios yet to be determined (high solar, high capacity value, high geographic diversity)

Solar is 70% CSP and 30% distributed PV. CSP has 6 hours of thermal storage. Penetrations are by energy.
Study Area Monthly Energy from Wind and Solar for 2004 – 2006 (30% In Area Scenario)

Study Area Total Monthly Wind and Solar Energy for 2004 – 2006


55% of energy from wind and solar

30% is not always 30%
**Geographic Scenarios**

*(high renewables case)*

**In-Area** - each state meets target from sources within that state.

**Mega Project** - concentrated projects in best resource areas.

**Local Priority** - Balance of best resource and In-Area sites.
Wind data

- 3TIER Group ran weather model to recreate weather for 2004, 2005, 2006
- 10 minute wind power output for 960 GW of wind sites in WECC.
- Power profiles were based on Vestas V90 3MW turbine at 100m height.
- Hourly day-ahead power output forecasts.
How does the system operate in the high renewables case?

The operator formerly managed to load but now has to manage the net load.

Net Load = Load - Wind - Solar
How does the system operate in the high renewables case?

Mid-July

Mid-April shows the challenges of operating the grid with 35% wind and solar. This was the worst week of the 3 years studied.
Operations during mid-April

No Wind/Solar

High renewables case
Operating Cost Savings per MWh of Renewable Energy ($/MWh) - WECC - 2006

Perfect forecast cases

State of the art forecast cases
• Built on Joint Coordinated System Plan
• Large project team, Dave Corbus project manager
  • NREL, MISO, EnerNex, AWS True Power, University of Stuttgart, Riso (stochastic model)
  • Representation from RTOs/ISOs, utilities
  • Technical Review Committee
What is Needed to Integrate 20% Wind in the Eastern Interconnection?

• Evaluate the power system operating impacts and transmission associated with increasing wind energy to 20% and 30%
  • Impacts include operating with the variability and uncertainty of wind
• Build upon prior wind integration studies and related technical work;
• Coordinate with current regional power system study work;
• Produce meaningful, broadly supported results
  • Technical Review Committee
EWITS Analysis Provides Detailed Information on

- Wind generation required to produce 20% and 30% of the projected electric energy demand over the U.S. portion of the Eastern Interconnection in 2024
- Transmission concepts for delivering energy economically for each scenario
- Economic sensitivity simulations of the hourly operation of the power system with wind generation, future market structures and transmission overlay
- The contribution made by wind generation to resource adequacy and planning capacity margin
Scenario 1: 20% high capacity factor

Scenario 2: Hybrid w/off-shore

Scenario 3: 20% local, aggressive offshore

Scenario 4: 30% aggressive
Conceptual Transmission Overlays

Scenario 1

Scenario 2

Scenario 3

Scenario 4

Legend:
- 230 kV AC
- 345 kV AC
- 400 kV DC
- 500 kV AC
- 765 kV AC
- 800 kV DC
Transmission - Why are We Always Jumping Through Hoops
Key Task – Wind Integration

• Approach
  • Hourly simulation of operational planning and power system operation using PROMOD
    • Synchronized wind and load
  • Day-ahead unit commitment and scheduling based on load and wind generation forecasts
    • Real-time operations (hourly simulations)
    • Operational structures
Assumed operational structure for the Eastern Interconnection in 2024 (white circles represent balancing authorities)
Increased reserve does not imply increased installed or committed capacity over and above the no-wind case. It implies some generation that would be used for energy in the no-wind case is now used for reserve (or possibly different mix of units in the stack).
Total Annualized Scenario Costs

- Wind Capital Cost
- New Generation Capital Cost
- Transmission Cost
- Integration Cost
- Wind Operational Cost
- Production Cost

Annualized Scenario Cost (2009 USD M$)

Reference: [Cost Details]
Scenario 1: [Cost Details]
Scenario 2: [Cost Details]
Scenario 3: [Cost Details]
Scenario 4: [Cost Details]
EWITS Conclusions

• 20 and 30% wind penetrations are technically feasible with significant expansion of the transmission infrastructure.
  – New transmission will be required for all the future wind scenarios in the Eastern Interconnection
• Without transmission enhancements, substantial curtailment of wind generation will occur
• Interconnection-wide costs for integrating large amounts of wind generation are manageable with large regional operating pools, where benefits of load and wind diversity can be exploited and large numbers of supply resources are efficiently committed and dispatched.
EWITS Conclusions

- Transmission helps reduce the impacts of the variability of the wind and....
  - Reduces wind integration costs
  - Reduces need for building conventional generation
  - Increases reliability of the electrical grid
  - Helps make more efficient use of the available generation resources

- Costs for aggressive expansions of the existing grid are significant, but they make up a relatively small piece of the total annualized costs in any of the scenarios studied

- Wind generation displaces carbon-based fuels, directly reducing carbon dioxide (CO₂) emissions
What is needed for large-scale integration of wind and solar?
Technical
Physical Sources of Flexibility

Alternative generation mix with more flexibility
- Less base-load (or modified for flexibility)
- Aero derivative/fast-response turbines (GE, Siemens)
- Reciprocating engines (Wartsilla)
- Pumped storage

Wind/solar provide regulation
Responsive load
Electric vehicles
Forecasting

Courtesy: WindLogics, Inc. St. Paul, MN
Institutional
Energy scheduling rules and other institutional factors

- Transmission protocols/scheduling in the Western Interconnection
- Fast energy markets
- Ancillary services market (and possible new AS)
- Smarter about reserves
- Smarter about wind forecasts and how to use/visualize them
Smarter Transmission Usage
Non-spin and Supplemental reserves are 10 to 20 times cheaper than regulation and better match wind ramping characteristics

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Larger Balancing Areas (real or virtual)

Operating separate balancing areas causes extra ramping compared to combined operations.
Blue: up-ramp
Green: down-ramp
Yellow: combined ramp

Some areas are ramping up nearly 1000 MW/hr while other areas are ramping down nearly 500 MW/hr.

Ramping that could be eliminated by combining operations

Inter-BA Scheduling and Communication

Better use of existing flexibility

- Tap into maneuverable generation that may be “behind the wall”\(^1\)
- Provide a mechanism (market, contract, other) that benefits system operator and generator/loads
- Fast energy markets help provide needed flexibility\(^2\) and can often supply load following flexibility at no cost\(^3\)

\(^1\)Kirby & Milligan, 2005 Methodology for Examining Control Area Ramping Capabilities with Implications for Wind
http://www.nrel.gov/docs/fy05osti/38153.pdf
http://www.nrel.gov/docs/fy08osti/43251.pdf
\(^3\)Milligan & Kirby 2007, Impact of Balancing Areas Size, Obligation Sharing, and Ramping Capability on Wind Integration .
http://www.nrel.gov/docs/fy07osti/41809.pdf
Do Markets Incent Flexibility?

Short-run
- Ramp products necessary to supplement energy markets?
- Low LMPs and capital cost recovery

Long-run
- Do prices induce long-term development of flexible supply/loads?
Integration Costs
Integration cost of wind and solar

- Can it be measured?
- If so, how is it defined?
- What is proper benchmark unit?
- How are cost and value untangled?
- What about units in one region that economically respond to needs in another region?
- Are there integration costs for other units?
  - Do all AGC units follow the signal?
  - Are there efficiency costs of adding conventional generators?

http://www.nrel.gov/docs/fy09osti/46275.pdf

http://www.nrel.gov/docs/fy10osti/48944.pdf
Not all units can follow AGC

2 coal units show very different ability of following AGC. Unit on the right *increases* the need for regulation on the system by 31 MW.

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Integration cost of wind

• Large nuclear units set the contingency reserve obligation for power pools, resulting in real costs

• When any new generator is added to the generation mix, it potentially impacts all of the units that are above it in the dispatch stack

• Example: new cheap baseload
  – Units formerly run as base load are pushed up the stack: lower capacity factors, higher cycling
  – More cycling $\rightarrow$ higher O&M costs
  – Lower capacity factor $\rightarrow$ less revenue
Integration costs: wind and solar

Solar and wind integration issues are similar
  – Wind is becoming reasonably well understood
  – Solar
    • PV has high potential for short-term variability from cloud variations, but the impact of large PV plants is largely unknown
    • CSP without storage has some thermal inertia and is likely less variable than PV
    • CSP with storage is thought to be much less of an integration challenge but still unknown

Variability and uncertainty
Cycling efficiency
Are not unique to wind or solar
Accommodating Wind and Solar Integration

- Large BA
  - Geographically Dispersed Wind and Solar
  - Wind/Solar Forecasting Effectively Integrated Into System Operations
  - Sub-Hourly Energy Markets
  - Fast Access to Neighboring Markets
  - NonSpinning and 30 Minute Reserves for Wind/Solar Event Response
  - Regional Transmission Planning For Economics and Reliability
  - Robust Electrical Grid
  - More Flexible Transmission Service
  - Flexibility in Generation
  - Responsive Load
  - Overall

Example Utility Structures

<table>
<thead>
<tr>
<th>Weightings Factors</th>
<th>Large RTO with spot markets</th>
<th>Smaller ISO</th>
<th>Interior west &amp; upper Midwest (non-MISO)</th>
<th>Large vertically integrated utility</th>
<th>Smaller Vertically Integrated Local Utility</th>
<th>Unconstrained hydro system</th>
<th>Heavily fish constrained hydro system</th>
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Selected NREL Integration Projects

- Wind → wind and solar
- Scoping EWITS 2, WWSIS 2
- Reserves analysis: UCD, MISO
- WECC’s Efficient Dispatch Toolkit
- Development of variable time-step production simulation model (includes AGC)
- Coal cycling (GE, WECC)
- Wind Turbine Frequency control (EPRI, GE, others)
- Stochastic unit commitment and forecast error characterization
Questions?