Integrating Variable Renewable Energy into the Grid

Key Issues and Emerging Solutions
Agenda and Learning Objectives

- **Part 1: Key Issues**
  - Understand the primary challenges to integrating variable renewable energy (RE) to the grid
- **Part 2: Flexible Power Systems**
  - Identify sources of power system flexibility
- **Part 3: Myths and Frequently Asked Questions**
  - Understand system impacts of high RE on reliability, need for storage, and cost
- **Part 4: Greening the Grid Toolkit**
  - Identify resources and technical assistance available through the Greening the Grid initiative
- **Part 5: Questions and Panel Discussion**
Part 1

KEY GRID INTEGRATION ISSUES
Why is grid integration an important topic?

Introduction

Trends:
- Increasing energy demand
- Urbanization
- Climate change mitigation targets
- Need for grid modernization

Every power system has characteristics that promote and inhibit integration of variable RE.

**Grid integration** is the practice of developing efficient ways to deliver high penetration levels of variable RE to the grid.

Source: “Renewable Energy Futures” 2012
Integrating wind and solar energy resources requires an evolution in power system planning.

RE is variable, uncertain, and geographically dispersed.

- Balancing requires more flexibility.
- Existing thermal assets used less frequently, affecting cost recovery.
- More reserves needed.
- More transmission, better planning needed.
- Voltage control, inertia response come at added cost.
Part 2

FLEXIBLE POWER SYSTEMS
“Flexibility” can help address the grid integration challenges

**Flexibility:** The ability of a power system to respond to change in demand and supply

- Increases in variable generation on a system increase the variability of the ‘net load’
  - ‘Net load’ is the demand that must be supplied by conventional generation unless RE is deployed to provide flexibility
- High flexibility implies the system can respond quickly to changes in net load.
Frequently used options to increase flexibility

Low capital cost options, but may require significant changes to the institutional context.

Option costs are system-dependent and evolving over time.
Frequently used options to increase flexibility

- Numerous options for increasing flexibility are available in any power system.
- Flexibility reflects not just physical systems, but also institutional frameworks.
- The cost of flexibility options varies, but institutional changes may be among the least expensive.

Low capital cost options, but may require significant changes to the institutional context.
Faster dispatch to reduce expensive reserves

Dispatch decisions closer to real-time (e.g., intraday scheduling adjustments; short gate closure) reduce uncertainty.
Broader balancing areas and geographic diversity can reduce variability and need for reserves.

Source: NREL/FS-6A20-63037
Increase balancing area coordination

System Operations

Consolidated Operation

Coordinated Scheduling
Economic transactions

Unit Commitment

Reserve Sharing
(Non-economic transactions)

Economic Dispatch
(sub-hourly to hourly)

Flexibility Reserves

Regulating Reserves

Contingency Reserves

Timescale of Coordination

Days

Hours

Minutes

Seconds

Aid in Variable RE Integration

• Greater energy transactions
• Increased transmission utilization
• Higher implementation costs
• Greater economic efficiency
Increase thermal plant cycling

0% wind and solar

33% annual wind and solar energy penetration

Source: WWSIS Phase 2 (2013)
Flexible generation from wind

- Wind can provide synthetic inertial control and primary and secondary frequency response
- Wind can follow economic dispatch signals, and can be incorporated into economic dispatch or market operations
- This example shows how Public Service Company of Colorado improved its Area Control Error using controllable wind energy during a period of very high wind and low demand

Figure: Impact of wind power controls regulation, dispatch, and area control error

Public Service Company of Colorado
Flexible demand

Demand response (DR)
• Examples: direct load control, real-time pricing
• Cost effective for extreme events and for reserves

Policy and Regulatory Options
• Allow DR to compete on a par with supply-side alternatives in utility resource planning and acquisition
• Introduce ratemaking practices—such as time-varying electricity pricing—that encourage cost-effective demand response, even in communities without significant deployment of smart meters.
• Consider potential value of enabling DR when evaluating advanced metering

Studies have found that it is cheaper to pay load to turn off (demand response) for the 89 problem hours (1%) than to increase spinning reserves for 8760 hours/year.
Part 3

MYTHS AND FREQUENTLY ASKED QUESTIONS
Can grids support high levels (>5-10% annually) of variable RE?

<table>
<thead>
<tr>
<th>Country</th>
<th>% Electricity from Wind</th>
<th>Balancing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>39% in 2014</td>
<td>Interconnection, flexible generation (including CHP), and good markets</td>
</tr>
<tr>
<td>Portugal</td>
<td>25% in 2013</td>
<td>Interconnection to Spain, gas, hydro, and good market</td>
</tr>
<tr>
<td>Spain</td>
<td>21% in 2013</td>
<td>Gas, hydro, and good market</td>
</tr>
<tr>
<td>Ireland</td>
<td>18% in 2013</td>
<td>Gas and good market</td>
</tr>
</tbody>
</table>

Many grids are operating with 20%–30% variable renewables.

Their experiences demonstrate that actions taken to integrate wind and solar are unique to each system, but do follow broad principles.
Do individual renewable energy plants require backup by conventional plants?

- **Reserves** are already a part of every system.

- **Individual** plants do not require backup
  - Reserves are optimized at system level.

- Wind and solar could increase need for operating reserves.
  - But this reserve can usually be provided from other generation that has turned down to accommodate wind/solar
  - This reserve is not a constant amount (depends on what wind/solar are doing)
  - Many techniques are available to reduce needed reserves.

- Wind can also provide reserves; in both directions when curtailed, but it may not be economic to obtain up-reserve from wind or solar.
Does variable renewable energy generation require storage?

- Storage is always useful, but may not be economic.
- Detailed simulations of power system operation find no need for electric storage up to 30% wind penetration (WWSIS, CAISO, PJM, EWITS).
- 50% wind/solar penetration study in Minnesota found no need for storage (MRITS, 2014).
- At higher penetration levels, storage could be of value.
  - Recent E3 integration study for 40% penetration in California: storage is one of many options.

Source: Adrian Pingstone (Wikimedia Commons)
How expensive is integrating variable renewable energy generation to the grid?

All generation (and load) has an integration cost:

- Any generator can increase cycling for remaining generation
  - E.g., Baseload nuclear can increase coal cycling, as shown in lower figure

- Conventional plants can impose variability and uncertainty costs
  - Contingency reserves sized for largest plant, often thermal
  - Operating reserves needed for plants that cannot follow dispatch signals precisely

- Conventional plants can create conditions that increase need for system flexibility
  - Must-run hydropower, must-run IPP contracts, thermal plants that
Key Takeaways

• Wind and solar generation increase variability and uncertainty
• Actual operating experiences from around the world have shown up to 39% annual penetrations are possible
• Often most the cost effective changes to the power system are institutional (changes to system operations and market designs)
• Specific back-up generation is not required, but additional reserves may be necessary
• Specific detailed analyses will help identify the most cost effective measures to integrate RE in each power system
Part 4

GREENING THE GRID TOOLKIT
What is Greening the Grid?

Greening the Grid provides technical assistance to energy system planners, regulators, and grid operators to overcome challenges associated with integrating variable renewable energy to the grid.
What We Do

Offer a **toolkit** of information and guidance materials to inform the development and implementation of grid integration roadmaps

Facilitate direct **technical assistance** tailored to the unique power system characteristics and priorities of each partner country

Greening the Grid is a component of the U.S. Government’s Enhancing Capacity for Low Emission Development Strategies (EC-LEDS) program
The Greening the Grid Toolkit

Understand Grid Integration Basics
Review concise fact sheets covering a variety of key issues. Read more

Greening the Grid

What is Grid Integration?
The Challenge: Large-Scale, Grid Connected Clean Energy
Power grids are complex networks that balance electricity supply and demand around the clock, every day of the year. Renewable energy, such as solar and wind, can significantly reduce greenhouse gas emissions from electricity generation. Read more

What We Do
Technical Assistance and Collaboration
Greening the Grid offers a toolkit of information, guidance materials, and technical assistance to support countries in significantly scaling up the amount of variable renewable energy connected to the electricity grid. Read more

Ask an Expert
Request Information and assistance
Greening the Grid connects power system stakeholders to experts from our grid integration expert network to provide no-cost, remote consultation and advice. Submit a Request

greeningthegrid.org
Greening the Grid Factsheets

Topics Now Available:

- Integrating Variable RE into the Grid: Key Issues
- Scaling Up Renewable Energy Generation
- Balancing Area Coordination
- Using Wind and Solar to Reliably Meet Electricity Demand
- Sources of Operational Flexibility
- Methods for Procuring Power System Flexibility
- Wind and Solar on the Power Grid: Myths and Misperceptions
- Grid Integration Studies: Data Requirements

Coming Soon:

- The Evolution of Power System Planning
- Grid Expansion and Upgrades
- Demand Response and Storage
- Integrating Distributed Solar
- Evaluating Costs of Grid Integration
Integration Topics

- Ancillary Services
- Balancing Area Coordination
- Demand Response and Storage
- Flexible Generation
- Forecasting
- Grid Integration Studies
- System Operations Improvements

Coming Soon
- Resource Adequacy
- Distributed Generation
- Target-Setting

Resources in the Toolkit:
- Background information
  - Tools
  - Methodologies
  - Videos
- Technical reports
- Case studies
- Model policies and regulations
- Example grid integration studies
Greening the Grid Technical Assistance Opportunities

**Ask an Expert Service**
- No cost, remote expert consultation on grid integration questions
- High-level guidance; review of drafts of strategies; examples from other systems
- Supported by experts from the National Renewable Energy Laboratory and the Clean Energy Solutions Center expert network

**Demonstration Projects**
- In-depth USAID-funded direct assistance to partner countries to identify and implement actions to increase variable RE penetration
- Examples:
  - Support for grid integration studies and roadmaps
  - Integrating forecasting into system operation controls
  - Addressing technical and regulatory challenges of distributed solar PV

*We welcome requests!*
Coming Soon

• Additional factsheets and integration topics

• Webinar series
  – Next topic: Best Practices in Grid Integration Studies (September 2015)

• Integration demonstration projects with partner countries

• More case studies and examples from developing countries
  – Please let us know of resources that you would like to see highlighted!
Part 5

QUESTIONS AND PANEL DISCUSSION
Contacts and Additional Information

Webinar Panel

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APPENDIX
**Key Terms**

**Load** - An end-use device or customer that receives power from the electric system; electrical demand

**Net Load** – Load minus the solar and wind output; the demand that must be supplied by conventional generation if all RE is used

**Operating Reserve** – Extra online capacity to help manage variability in net demand and unforeseen events so that system balance can be maintained

**Scheduling/Unit Commitment** – Starting and scheduling generators so that they are available when needed

**Dispatch (economic dispatch)** – A method by which system operators choose among available generators to deliver energy at least operating cost

**Flexibility** - The ability of a power system to respond to change in demand and supply

**Curtailment** - A reduction in the output of a generator from what it could otherwise produce given available resources (e.g., wind or sunlight)
Flexibility reflects not just physical system, but institutional framework

- Flexibility can come from two sources
  - Physical power system: generators, transmission, storage, interconnection
  - Institutional system: making dispatch decisions closer to real time, better use of forecasting, better collaboration with neighbors

- Power system operation must carefully consider both

Smarter grids require smarter frameworks and markets
Impacts of faster dispatch, shorter gate closure, and larger balancing areas

Average Total Regulation for 6 Dispatch/Lead Schedules by Aggregation (Dispatch interval - Forecast lead time)

<table>
<thead>
<tr>
<th>Dispatch Interval – Gate closure (min)</th>
<th>Footprint Large</th>
<th>Regional Medium</th>
<th>BAU Small</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-10</td>
<td>Faster</td>
<td>Faster</td>
<td>Faster</td>
</tr>
<tr>
<td>30-10</td>
<td>Faster</td>
<td>Faster</td>
<td>Faster</td>
</tr>
<tr>
<td>30-30</td>
<td>Faster</td>
<td>Faster</td>
<td>Faster</td>
</tr>
<tr>
<td>60-10</td>
<td>Faster</td>
<td>Faster</td>
<td>Faster</td>
</tr>
<tr>
<td>30-40</td>
<td>Faster</td>
<td>Faster</td>
<td>Faster</td>
</tr>
<tr>
<td>60-40</td>
<td>Faster</td>
<td>Faster</td>
<td>Faster</td>
</tr>
</tbody>
</table>

Milligan, Kirby, King, Beuning (2011), The Impact of Alternative Dispatch Intervals on Operating Reserve Requirements for Variable Generation. Presented at 10th International Workshop on Large-Scale Integration of Wind (and Solar) Power into Power Systems, Aarhus, Denmark. October
Incorporate forecasting in unit commitment and dispatch

- Reduces uncertainty
- Improves scheduling of other resources to reduce reserves, fuel consumption, and operating, maintenance costs
- More accurate closer to operating hour
- Forecasting of extreme events may be more important than mean error reduction
- Access to renewable energy plant data is critical

At 24% (annual) wind penetration levels, improving forecasting by 10%–20% can provide significant savings in annual operating costs in the U.S. West.

Strategic curtailment

Costs to achieve flexibility

Benefits of reduced or no curtailment

Economically optimal amount of flexibility could include certain level of curtailment.
Revise energy market designs

• Ramp products
  • May better value flexibility

• Larger, faster, more frequent markets

• Negative pricing
  – Economically efficient way to reduce output during excess generation
  – Allows curtailment to proceed through scheduling software rather than manual intervention

• Forecast integration and allowing variable RE to participate as dispatchable generators
  – Improves market efficiencies and opportunities for wind/solar

Source: Milligan et al. (2012) NREL/CP-5500-56212
Flexible generation

- New or retrofitted conventional power plants can improve system flexibility by incorporating capabilities to:
  - Rapidly ramp-up and ramp-down output to follow net load
  - Quickly shut-down and start-up
  - Operate efficiently at a lower minimum level during high renewable energy output periods
Flexible generation from wind

- Wind can provide synthetic inertial control and primary and secondary frequency response
- Capability to curtail to a set-point command during periods of system stress
- Several regions in the U.S. and elsewhere are beginning to mandate that wind generators provide primary and secondary frequency response.

Figure: Impact of wind power controls on frequency nadir

Wind with inertia and primary frequency control (PFC) response significantly improves frequency nadir at 50% penetration levels

http://www.nrel.gov/docs/fy14osti/60574.pdf
Increased supply of flexibility: Storage

**ENERGY STORAGE can support:** Load Leveling/ Arbitrage; Provide Firm Capacity and Operating reserves; Ramping/Load Following; T&D Replacement and Deferral; and Black-Start. Storage must compete with other sources of flexibility

Two applications of energy storage:

- *Operating reserves* – respond within seconds to minutes and provide regulating and contingency reserves.
- *Energy management* – continuous discharge over a period of hours to provide operating reserves as well as firm and system capacity.

**Factors limiting energy storage:** Cost

Source: DOE/GO-102011-3201
Flexible transmission networks

Transmission networks can access flexibility by:

- Improving the capacity and geographic extent of existing networks
- Interconnecting with neighboring networks
- Employing smart network technologies and advanced management practices to minimize bottlenecks and optimize transmission usage
Does variable renewable energy require new gas capacity to provide flexibility?

• If wind and solar are added to an already reliable system, there is no need for new gas or new reserves; existing generation will back down, providing up-reserves.

• Wind and solar can increase the need for system flexibility
  • (Due to more cycling, faster ramps, lower turn-downs).

• Wind/solar can often provide flexibility if incentives exist

• But, flexibility is not new—conventional systems are also designed for flexibility.

Low VRE penetrations:
Most systems sufficiently flexible

Medium VRE penetrations:
Likely least-cost source of flexibility is to change how the system is operated
  e.g., faster schedules, forecast integration, deeper cycling of coal, demand response
  
  Wind turbines may provide frequency support

High VRE penetrations:
 Might need new physical sources of flexibility
  e.g., new natural gas turbines, additional services from wind/solar
What impact does variable renewable energy have on emissions (due to thermal cycling)?

Increase in plant emissions from cycling to accommodate wind and solar are more than offset by overall reduction in CO$_2$, NO$_x$, and SO$_2$.

**Scenario: 33% wind and solar energy penetration as percentage of annual load**

<table>
<thead>
<tr>
<th>Emission Reduction Due to Renewables</th>
<th>Cycling Impact</th>
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<tbody>
<tr>
<td>CO$_2$</td>
<td>Negligible Impact</td>
</tr>
<tr>
<td>260–300 billion lbs</td>
<td></td>
</tr>
<tr>
<td>29%–34%</td>
<td></td>
</tr>
<tr>
<td>NO$_x$</td>
<td>3–4 million lbs</td>
</tr>
<tr>
<td>170–230 million lbs</td>
<td></td>
</tr>
<tr>
<td>16%–22%</td>
<td></td>
</tr>
<tr>
<td>SO$_2$</td>
<td>3–4 million lbs</td>
</tr>
<tr>
<td>80–140 million lbs</td>
<td></td>
</tr>
<tr>
<td>14%–24%</td>
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</table>

Results from Western Wind and Solar Integration Study (WWSIS), Phase II (2013)
http://www.nrel.gov/electricity/transmission/western_wind.html
What impact does variable renewable energy have on grid stability?

**Frequency stability** (supply-demand balance) is only a potential issue at extremely high penetration levels

- **Solution:** Wind turbines will need to provide active power controls (synthetic inertia, governor response)
- **Example:** ERCOT mandates governor response on wind turbines

**Voltage stability:** potential issue in small and/or weak systems, such as those with long, radial lines

Field test data that shows a single turbine tracking a step change in the de-rating command followed by primary frequency control response to an under-frequency event

http://www.nrel.gov/docs/fy14osti/60574.pdf