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

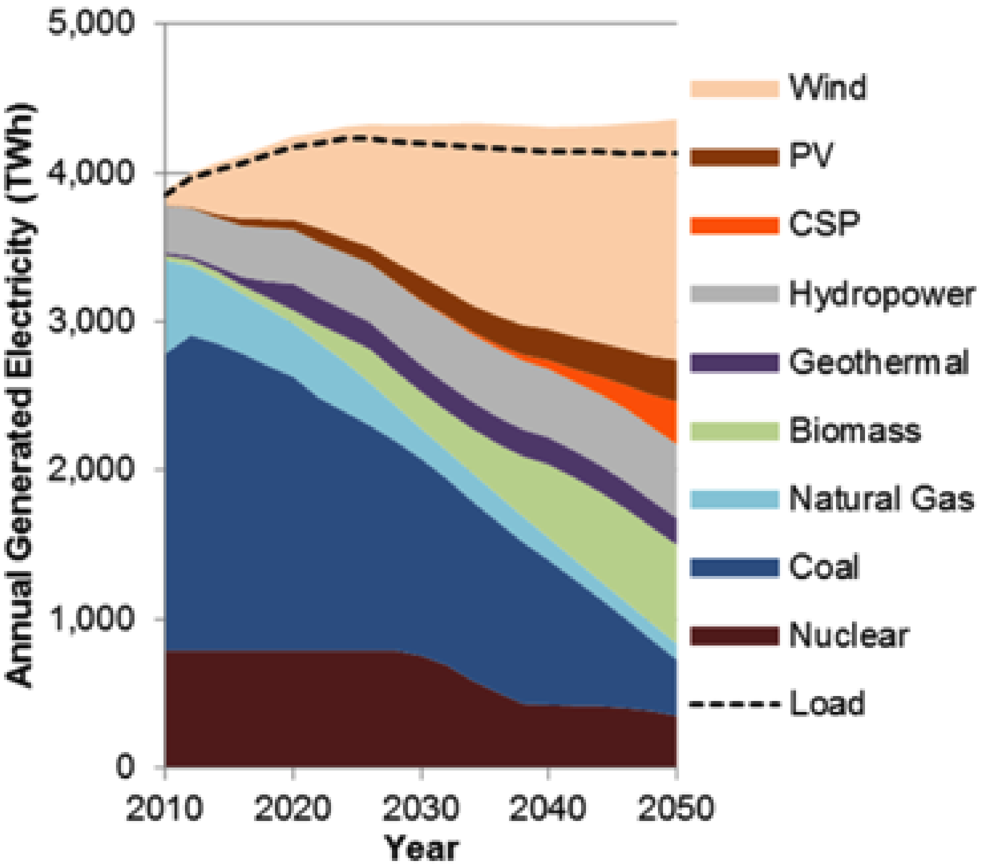
Urbanization

Climate change mitigation targets

Need for grid modernization

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

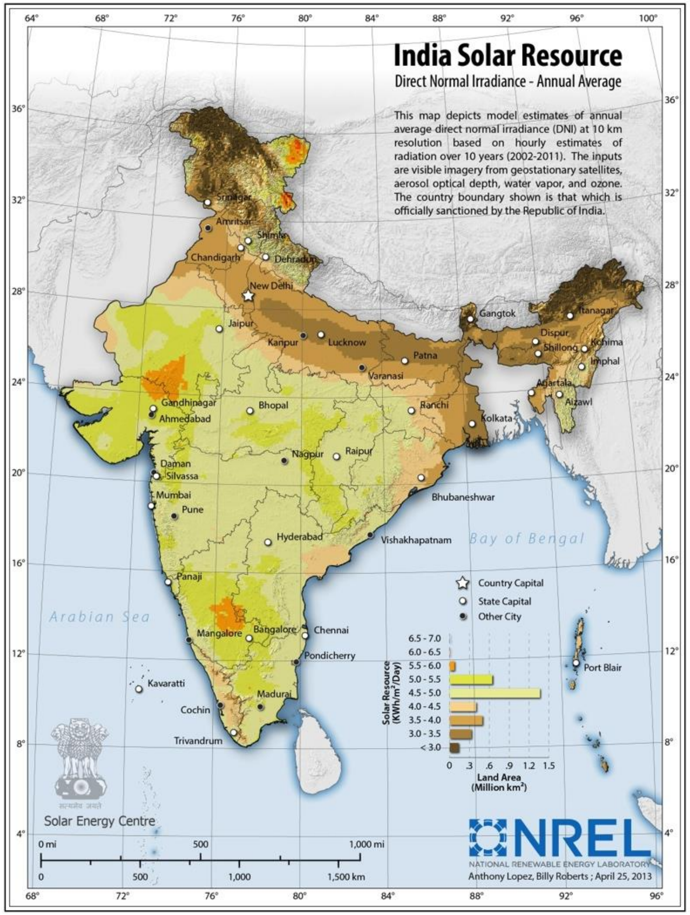
Grid integration is the practice of developing efficient ways to deliver high penetration levels of variable RE to the grid



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



…raising new considerations for grid planning and operations

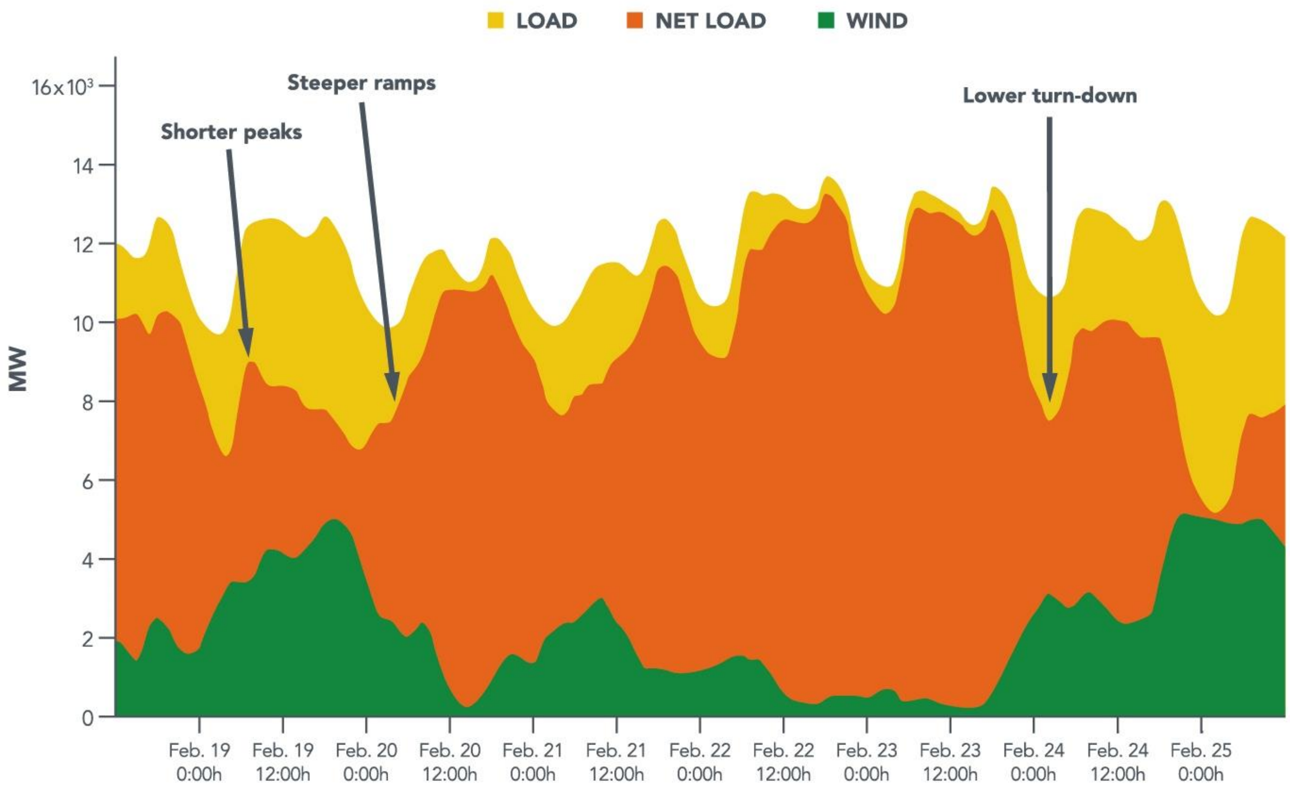
1. Balancing requires more flexibility
2. Existing thermal assets used less frequently, affecting cost recovery
3. More reserves
4. More transmission, better planning needed
5. Voltage control, inertia response come at added cost

Part 2

FLEXIBLE POWER SYSTEMS

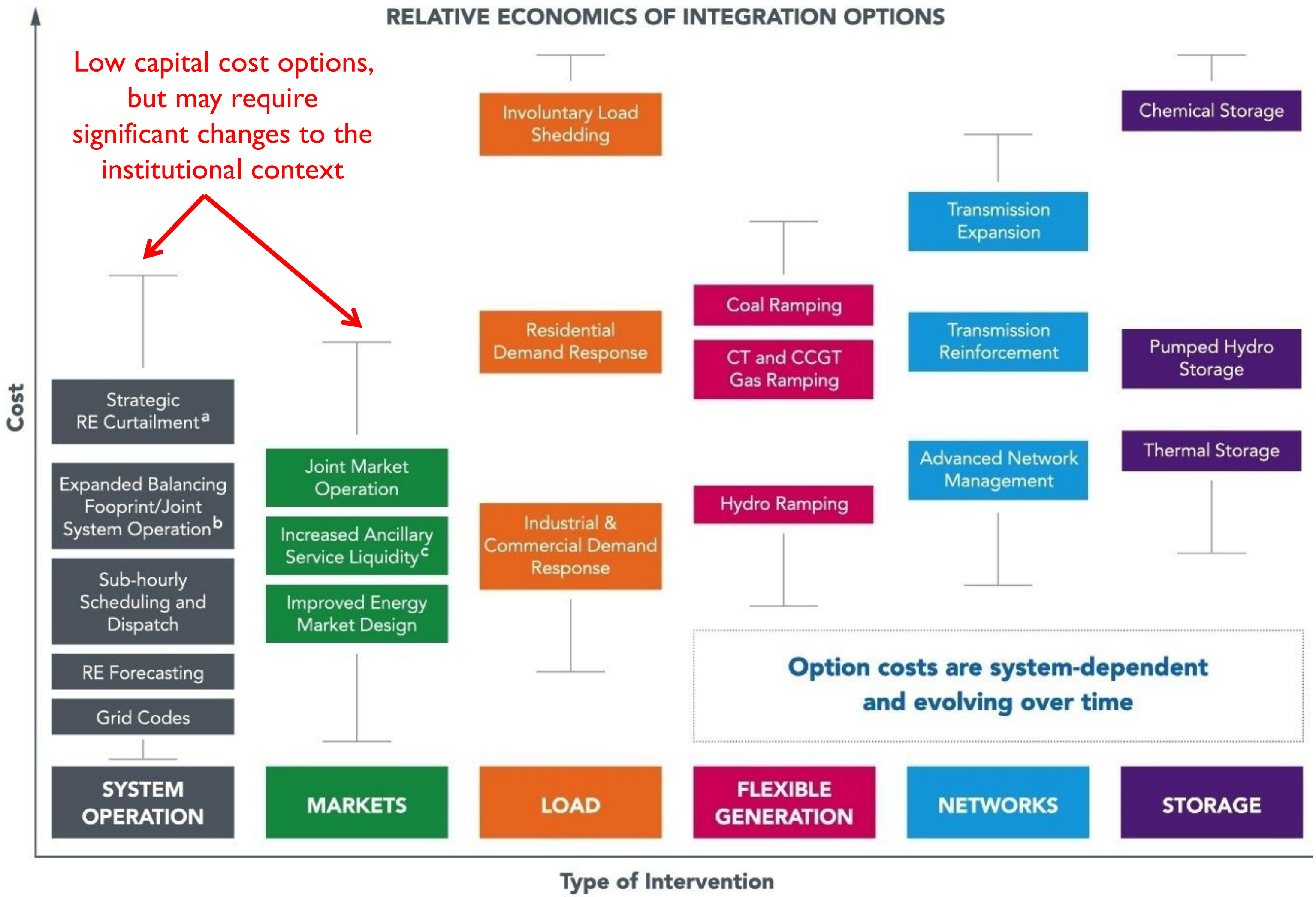
"Flexibility" can help address the grid integration challenges

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

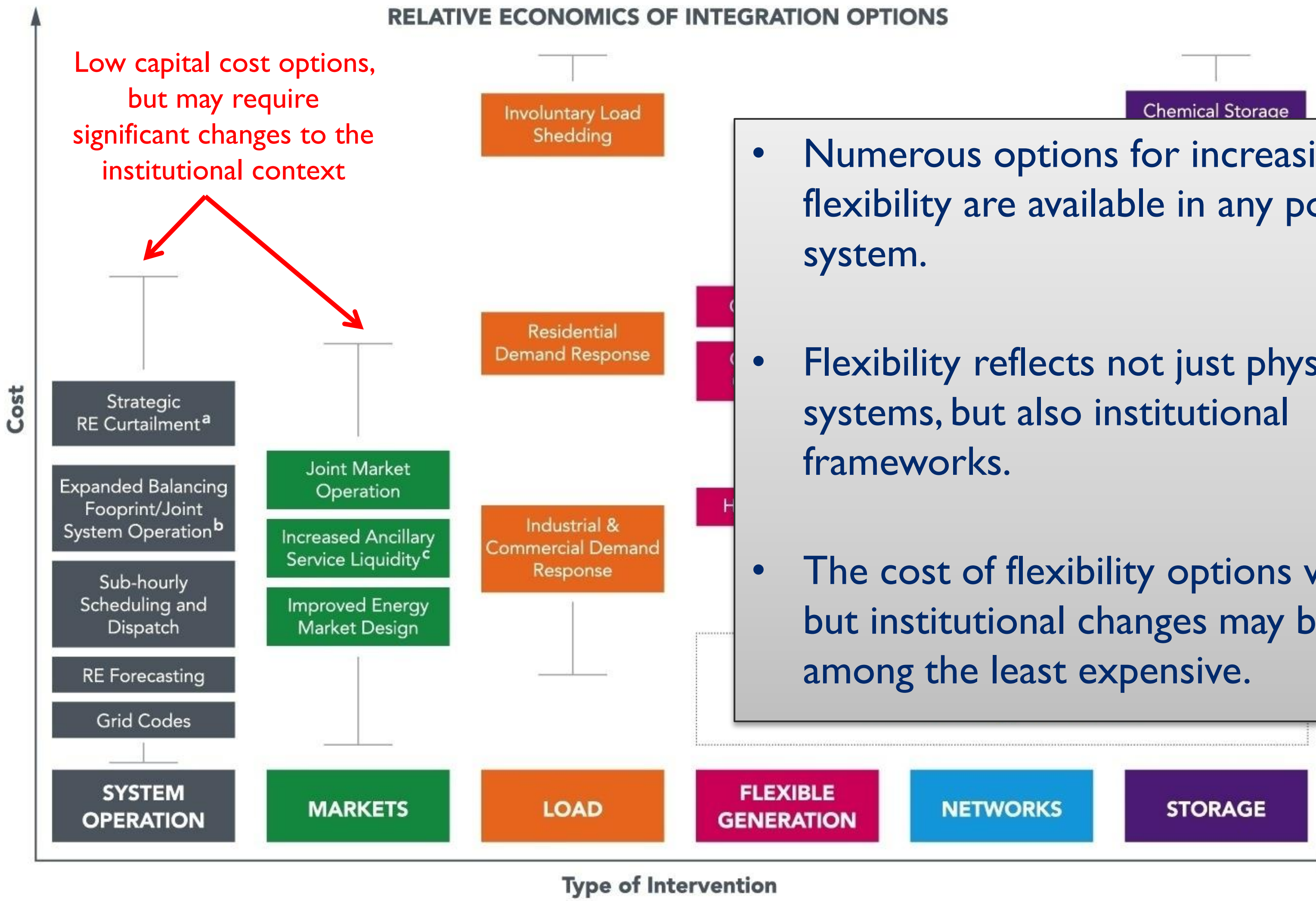


- Increases in variable generation on a system increase the variability of the 'net load'
  - 'Net load' is the demand that must be supplied by conventional generation unless RE is deployed to provide flexibility
- High flexibility implies the system can respond quickly to changes in net load.

Frequently used options to increase flexibility



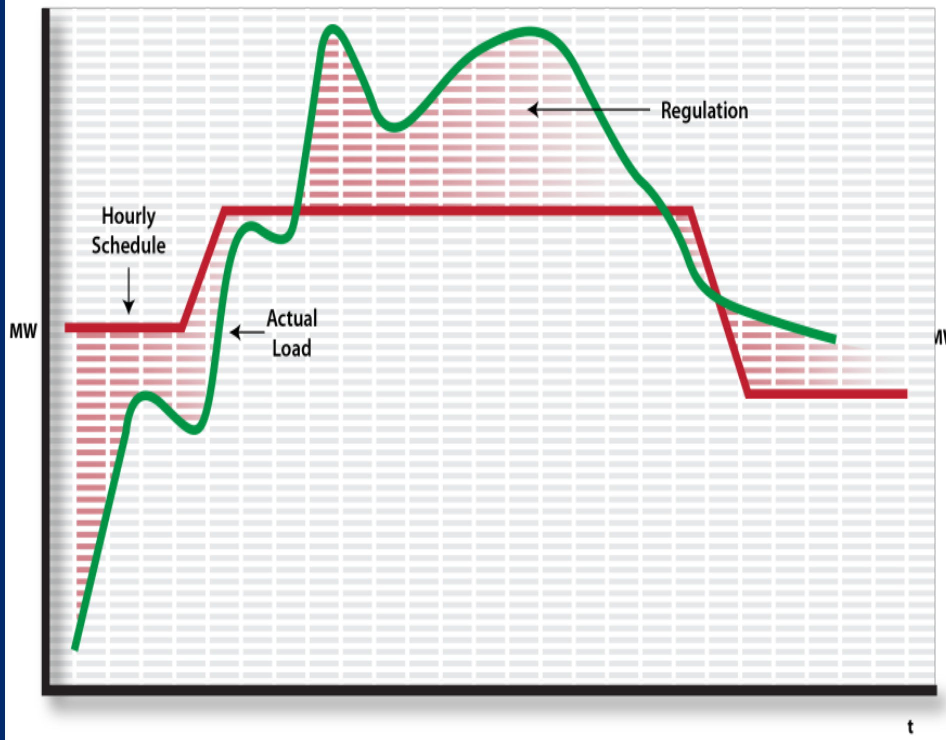
Frequently used options to increase flexibility



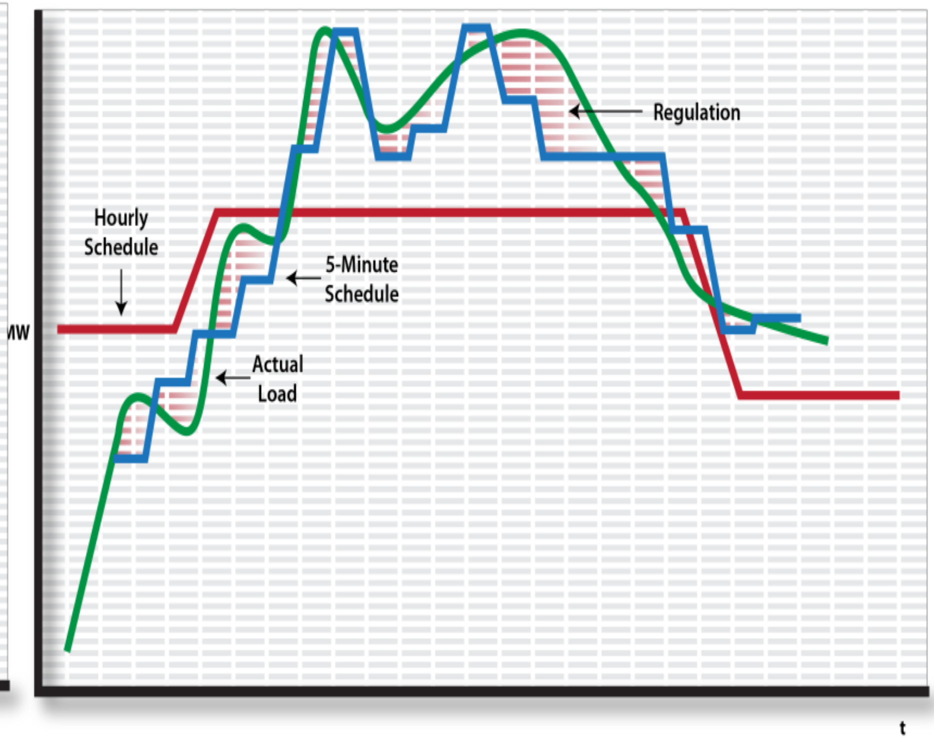
- Numerous options for increasing flexibility are available in any power system.
- Flexibility reflects not just physical systems, but also institutional frameworks.
- The cost of flexibility options varies, but institutional changes may be among the least expensive.

Faster dispatch to reduce expensive reserves

Hourly dispatch and interchanges



Sub-hourly dispatch



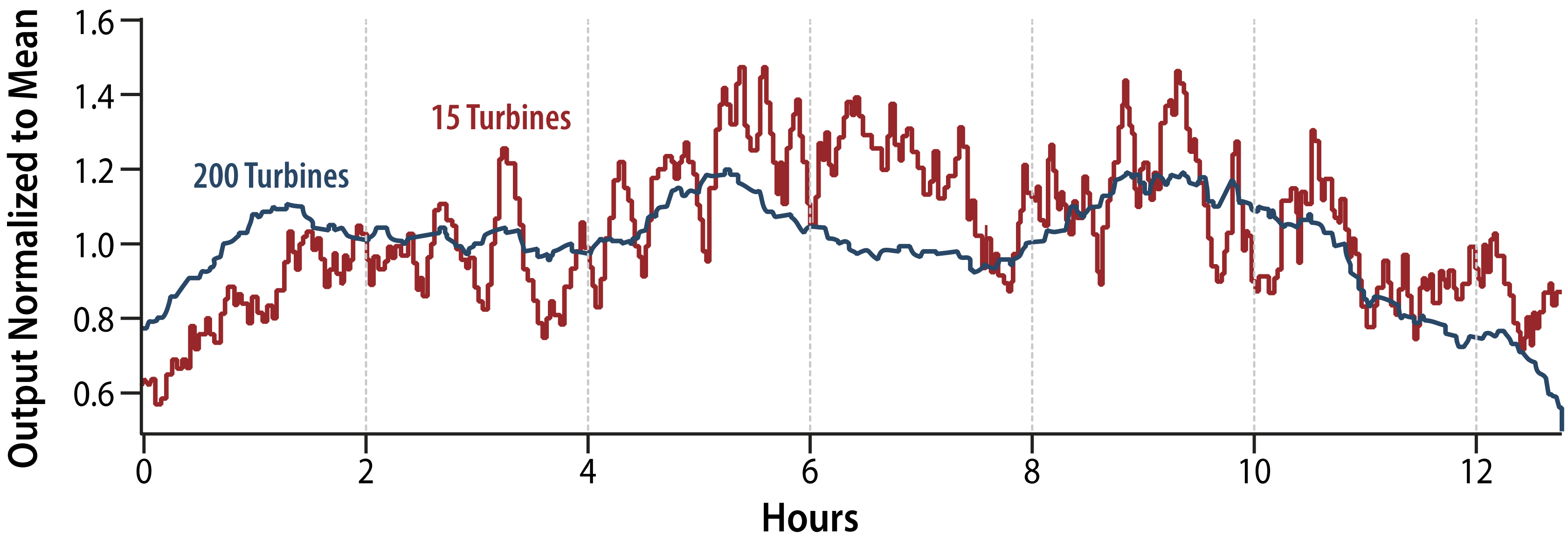
Source: NREL

Dispatch decisions closer to real-time (e.g., intraday scheduling adjustments; short gate closure) reduce uncertainty.

Expand balancing footprint

System Operations

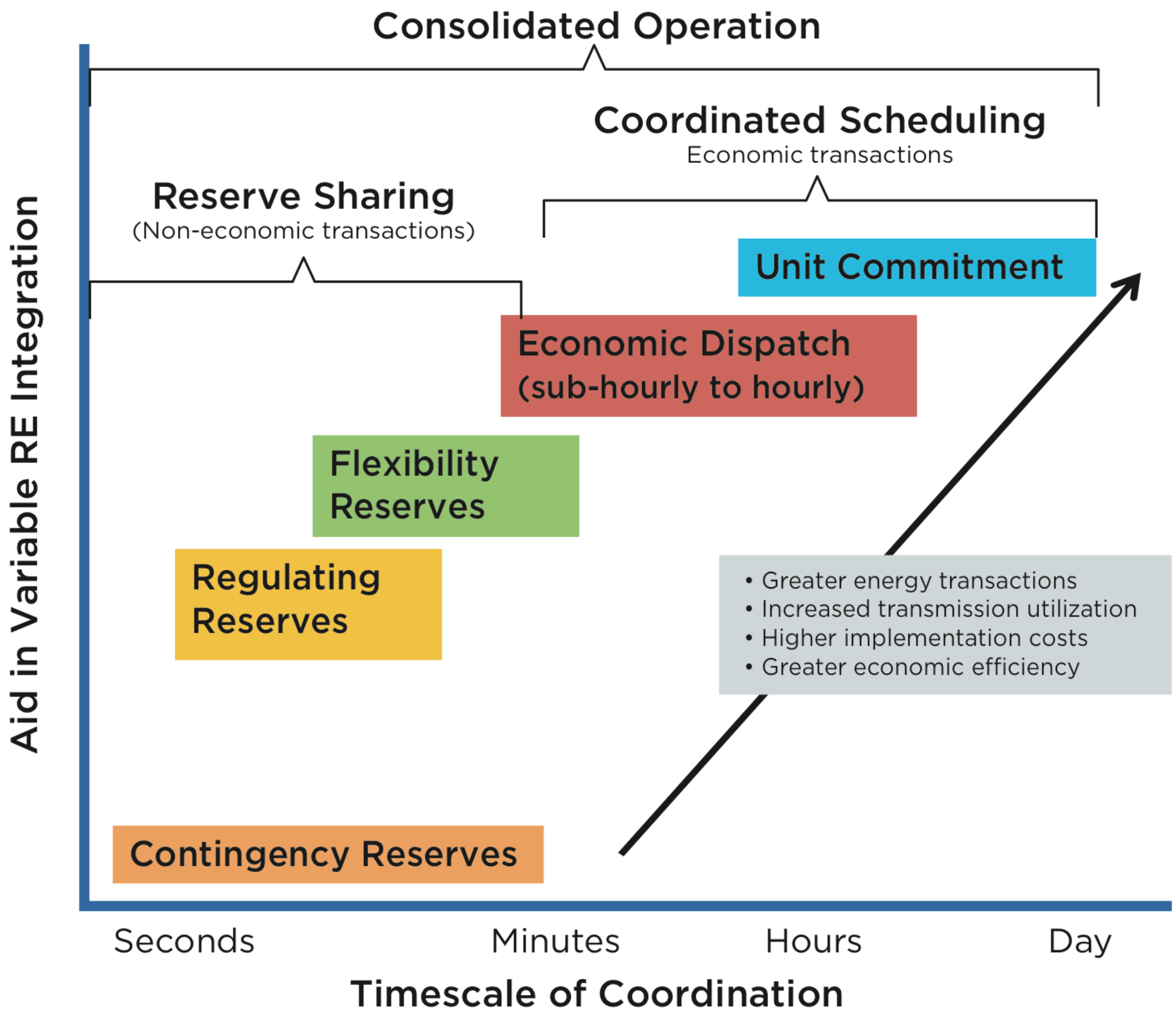
Broader balancing areas and geographic diversity can reduce variability and need for reserves.



Source: NREL/FS-6A20-63037

Increase balancing area coordination

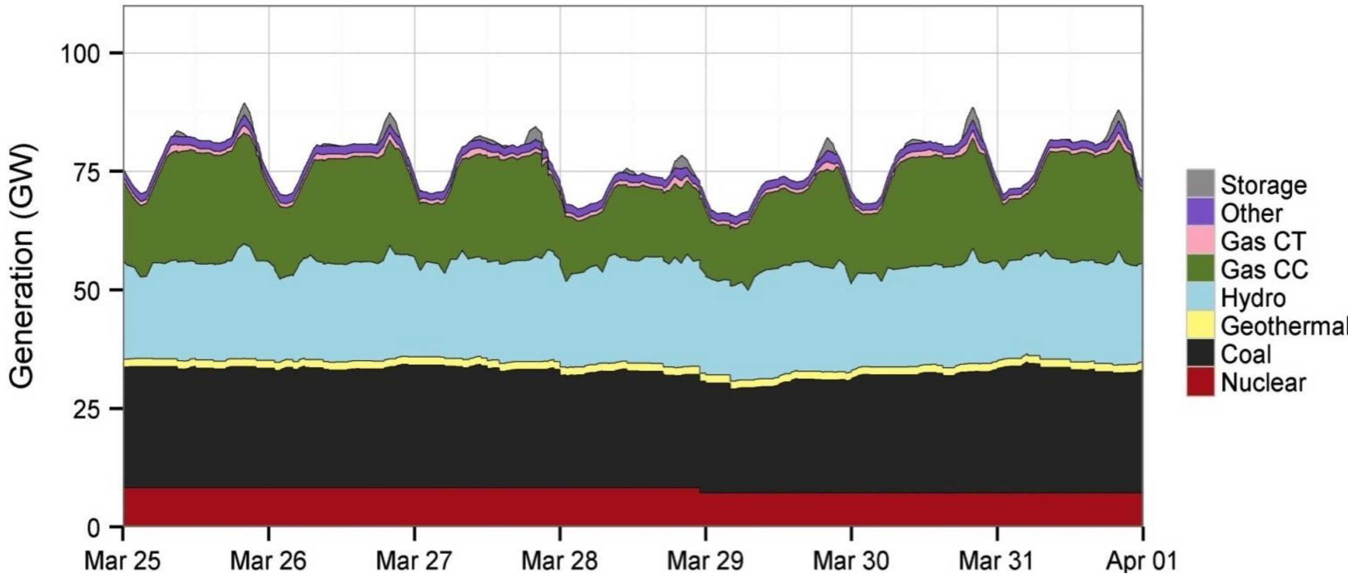
System Operations



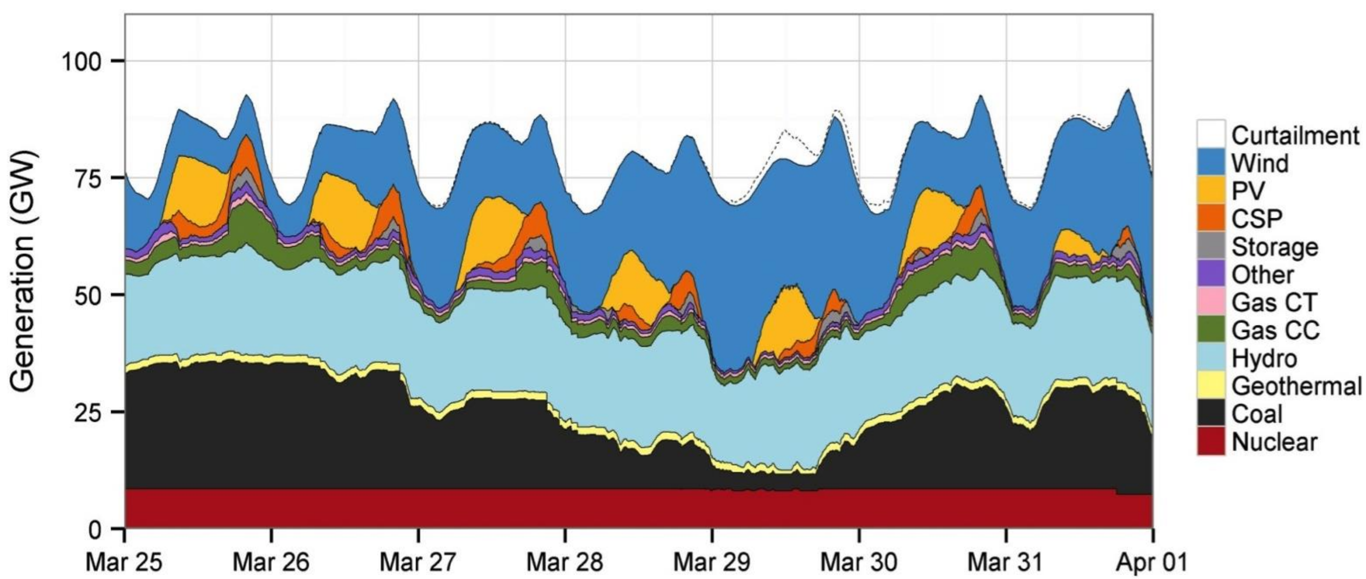
Increase thermal plant cycling

Flexible Generation

0% wind and solar



33% annual wind and solar energy penetration



Generation dispatch for challenging spring week in the U.S. portion of WECC

Source: WWSIS Phase 2 (2013)

Flexible generation from wind

Flexible Generation

- 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

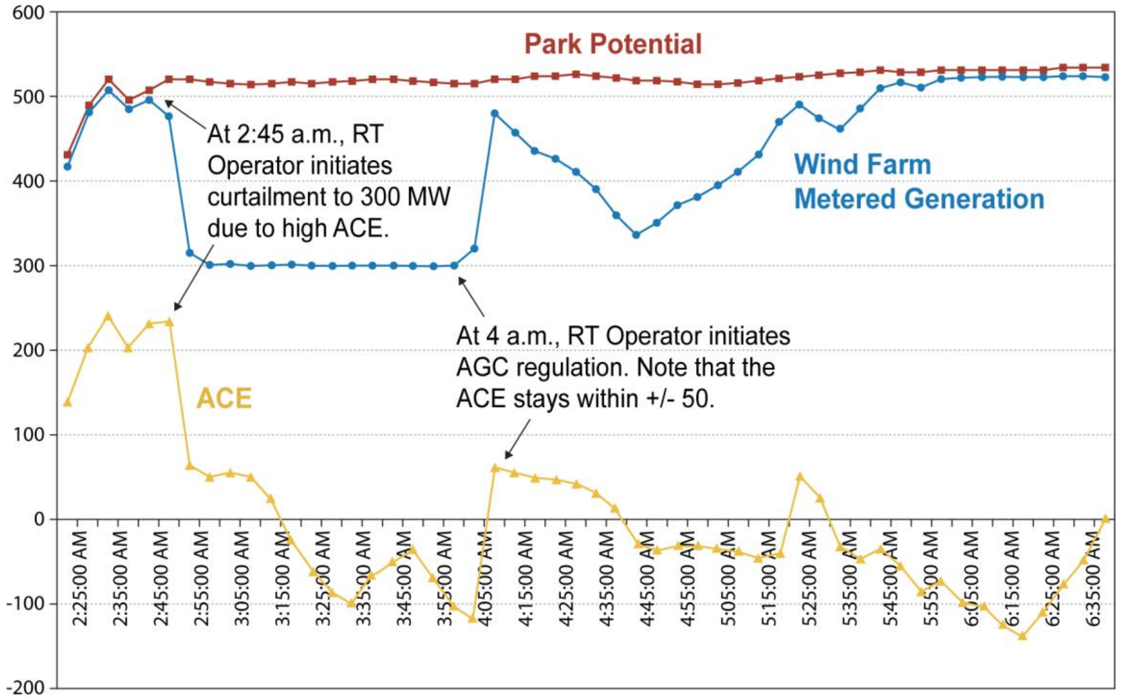


Figure: Impact of wind power controls regulation, dispatch, and area control error

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

Photo credit: Susan Bilo

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?

Country	% Electricity from Wind	Balancing
Denmark	**39% in 2014**	Interconnection, flexible generation (including CHP), and good markets
Portugal	**25% in 2013**	Interconnection to Spain, gas, hydro, and good market
Spain	**21% in 2013**	Gas, hydro, and good market
Ireland	**18% in 2013**	Gas and good market

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 do obtain up-reserve from wind or solar.

Photo from iStock 72283000

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)

Source: Adrian Pingstone (Wikimedia Commons)

- At higher penetration levels, storage could be of value.
  - Recent E3 integration study for 40% penetration in California: storage is one of many options.

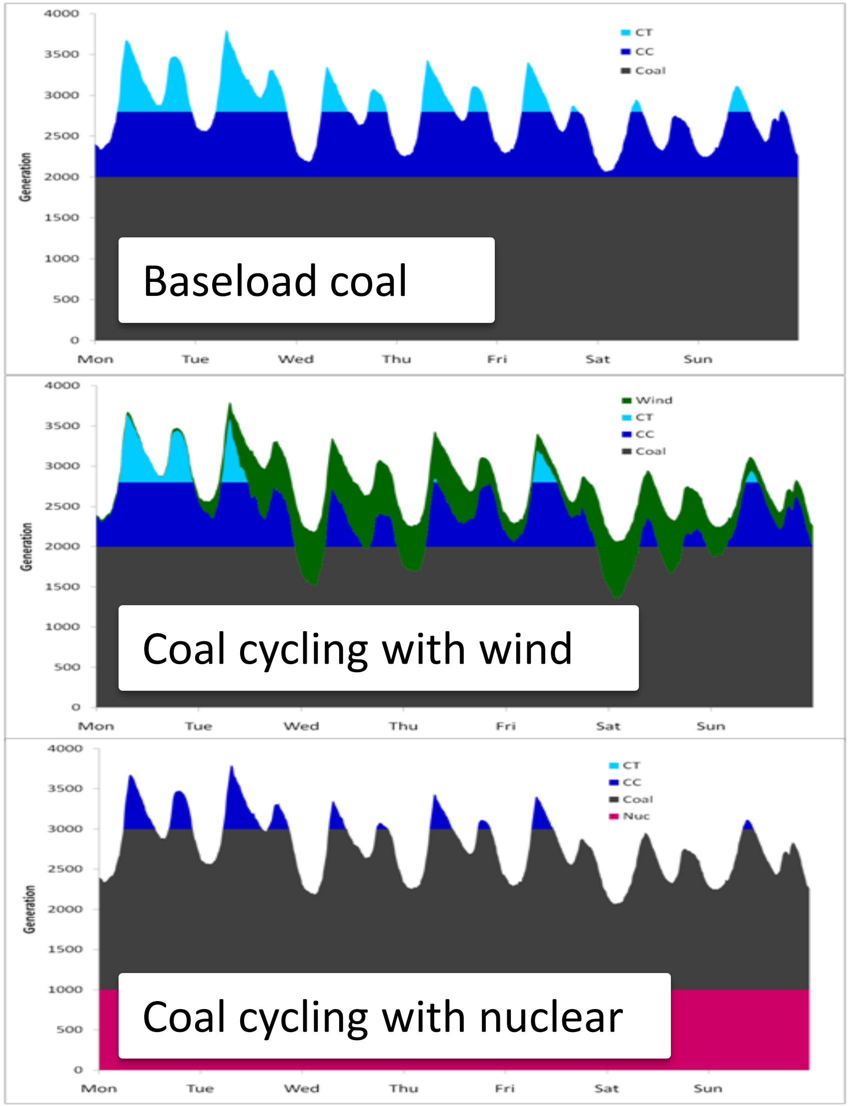
How expensive is integrating variable renewable energy generation to the grid?

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



http://www.nrel.gov/docs/fy11osti/51860.pdf

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

NREL/PIX 10926

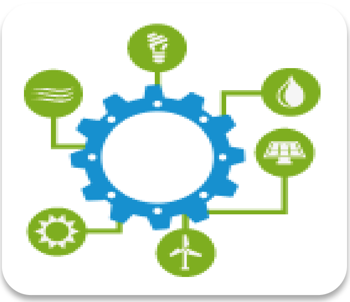
Part 4

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

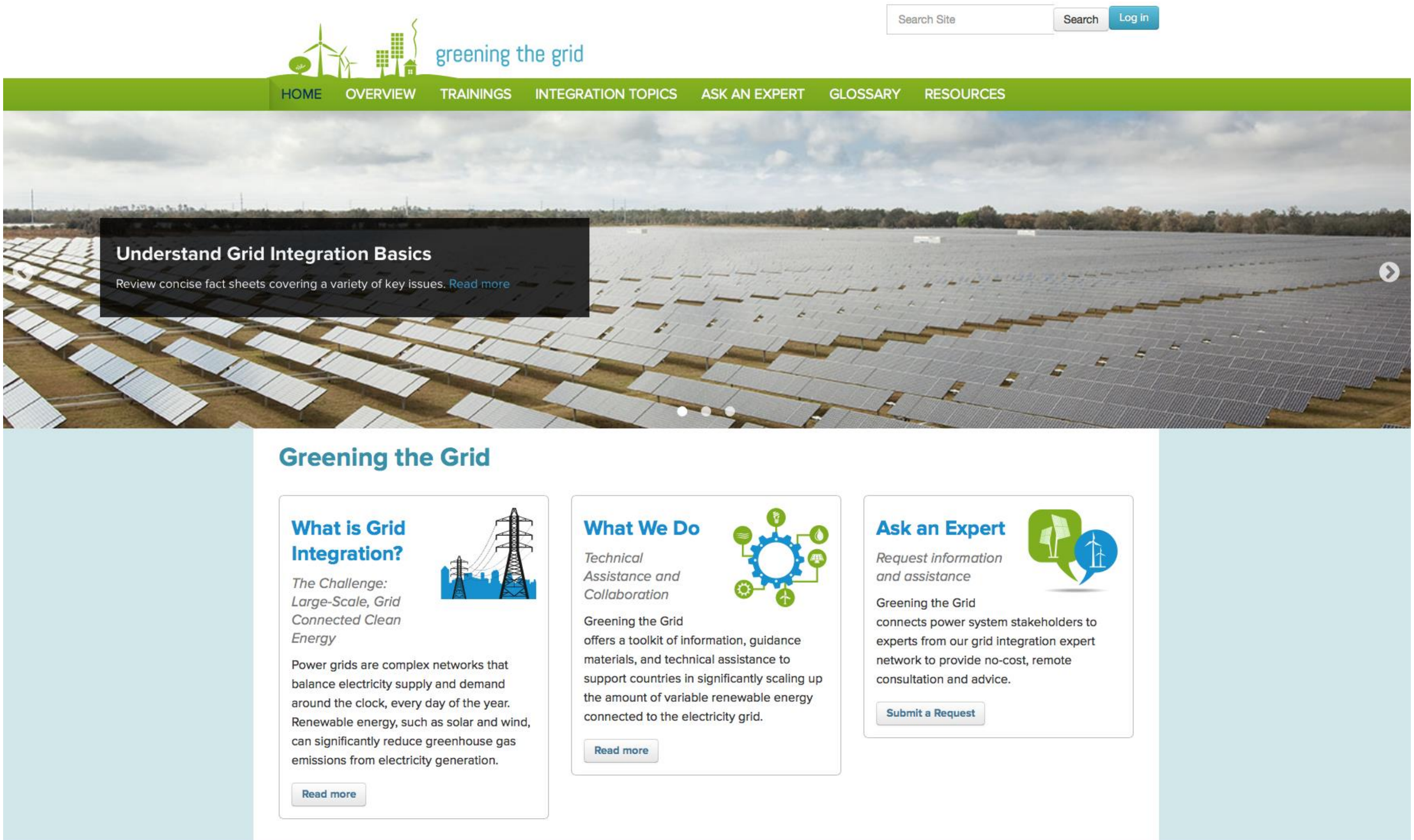


Offer a ***toolkit*** of information and guidance materials to inform the development and implementation of grid integration roadmaps

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



greeningthegrid.org

Greening the Grid Factsheets

<u>Topics Now Available:</u>

- *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*

<u>Coming Soon:</u>

- *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

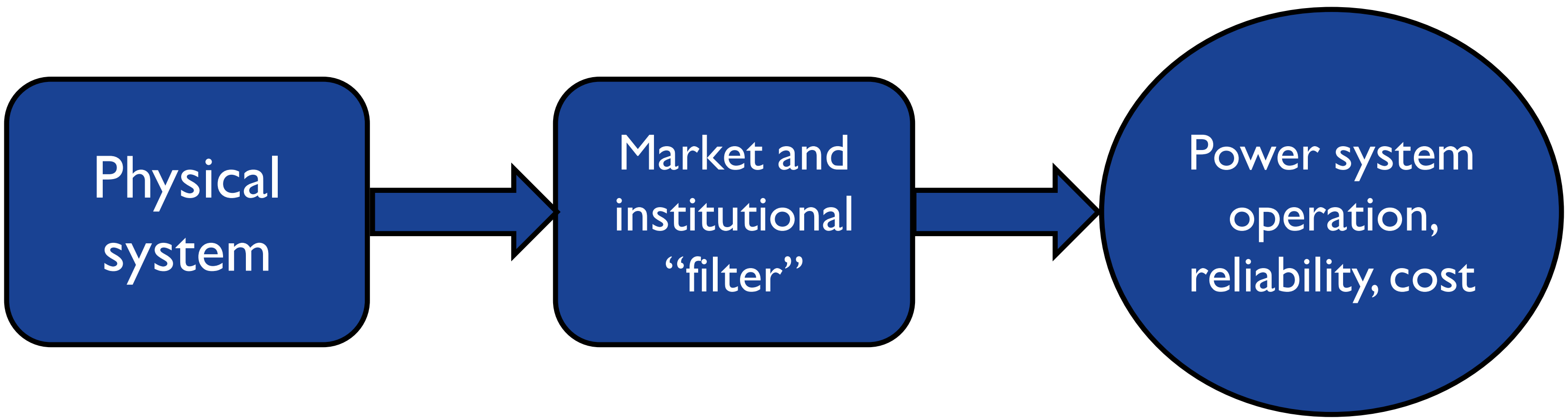
Dispatch (economic dispatch) – A method by which system operators choose among available generators to deliver energy at least operating cost

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)

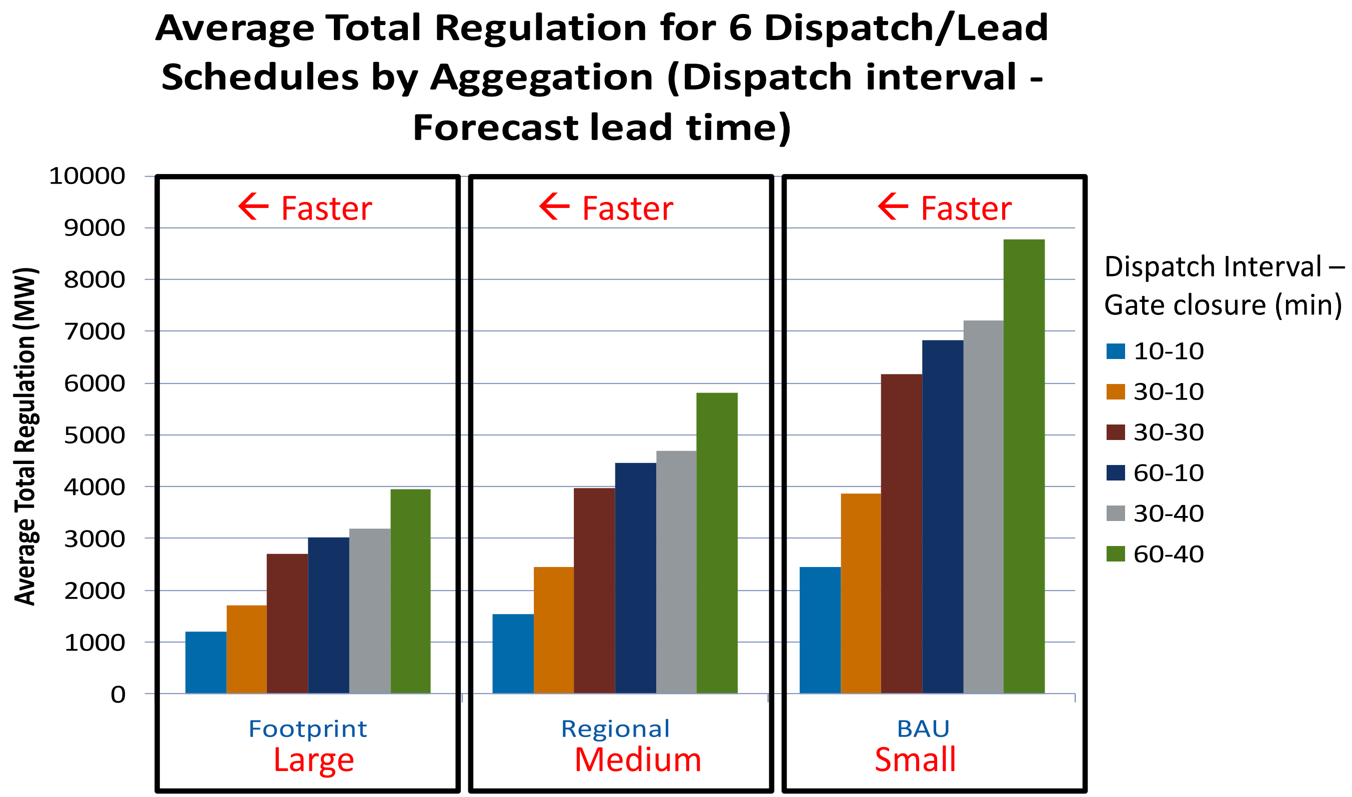
Flexibility reflects not just physical system, but institutional framework

- 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

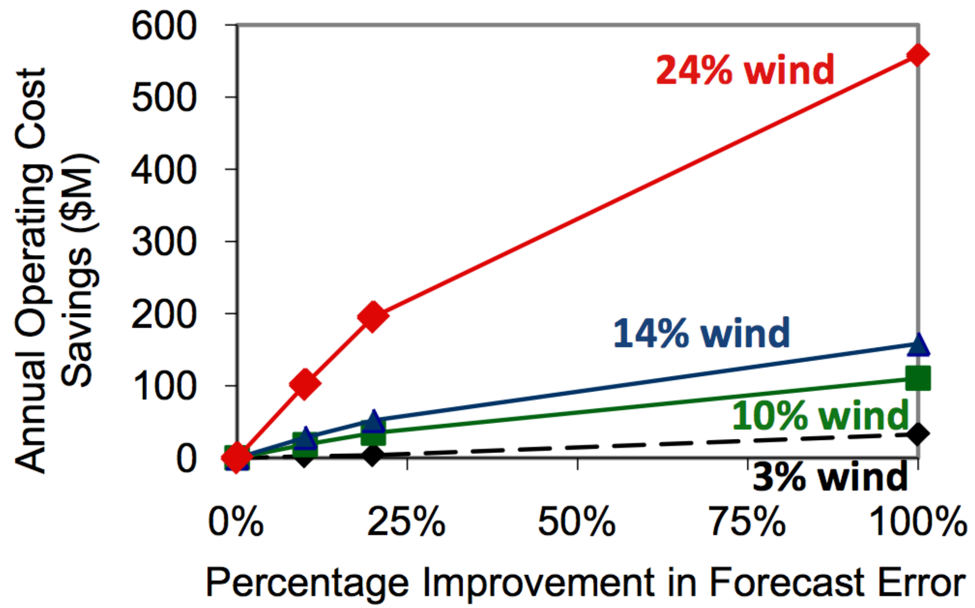


Milligan, Kirby, King, Beuning (2011), The Impact of Alternative Dispatch Intervals on Operating Reserve Requirements for Variable Generation. Presented at 10th International Workshop on Large-Scale Integration of Wind (and Solar) Power into Power Systems, Aarhus, Denmark. October

Incorporate forecasting in unit commitment and dispatch

System Operations

- 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.

http://www.nrel.gov/docs/fy11osti/50814.pdf

Strategic curtailment

System Operations

Costs to achieve flexibility

Benefits of reduced or no curtailment

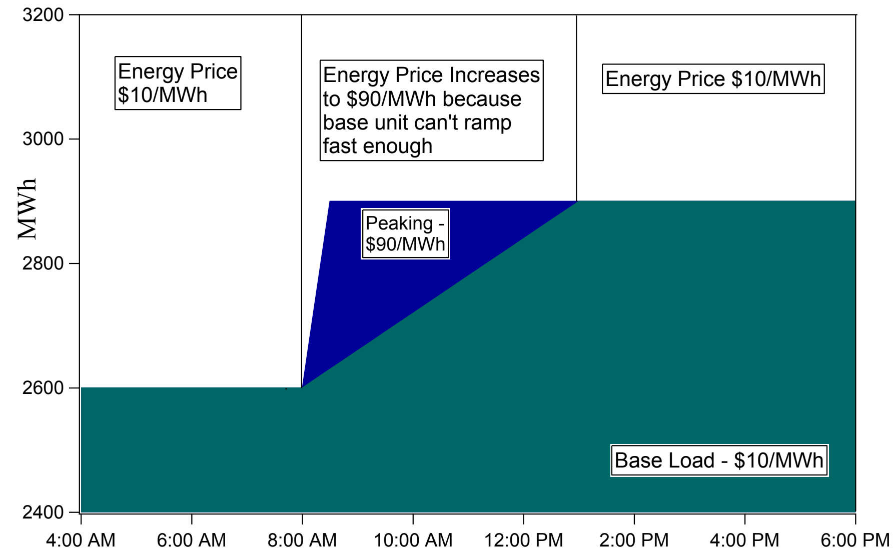
Economically optimal amount of flexibility could include certain level of curtailment.

Image: Commons.wikimedia.org

Revise energy market designs

Markets

- Ramp products
  - May better value flexibility



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

- 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

Flexible generation

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

NREL PIX 06392

Flexible generation from wind

Flexible Generation

- 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.

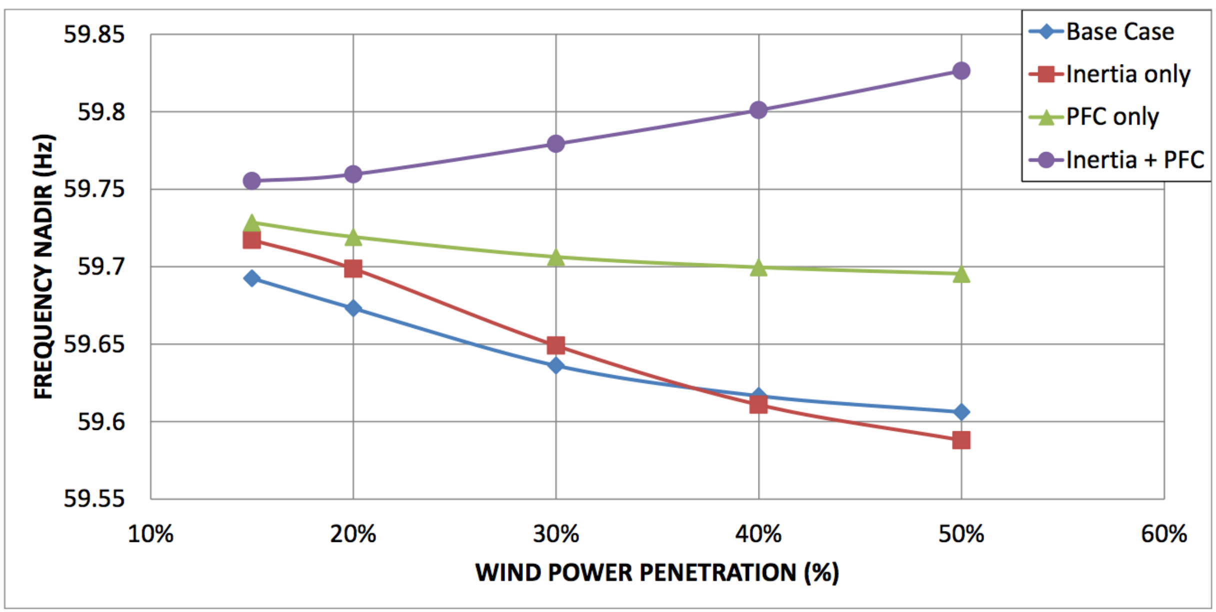


Figure: Impact of wind power controls on frequency nadir

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

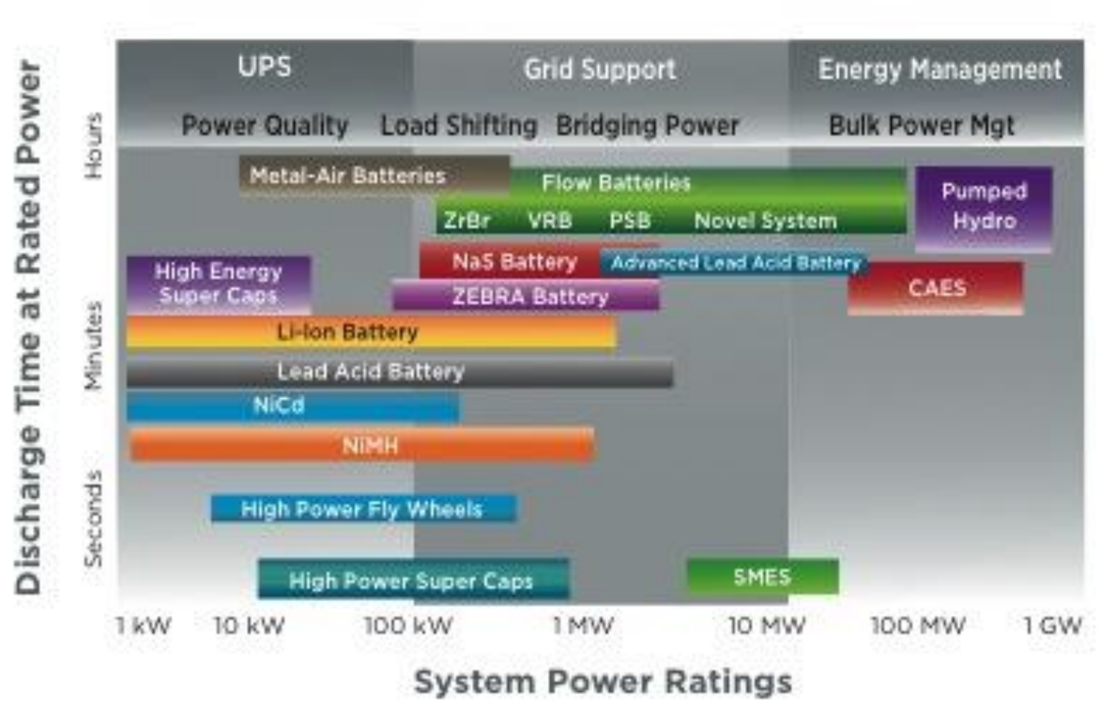
Increased supply of flexibility: Storage

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

Networks

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

	Emission Reduction Due to Renewables	Cycling Impact
CO_2	260–300 billion lbs; 29%–34% (decrease)	Negligible Impact
NO_X	170–230 million lbs; 16%–22% (decrease)	3–4 million lbs (decrease)
SO_2	80–140 million lbs; 14%–24% (decrease)	3–4 million lbs (increase)

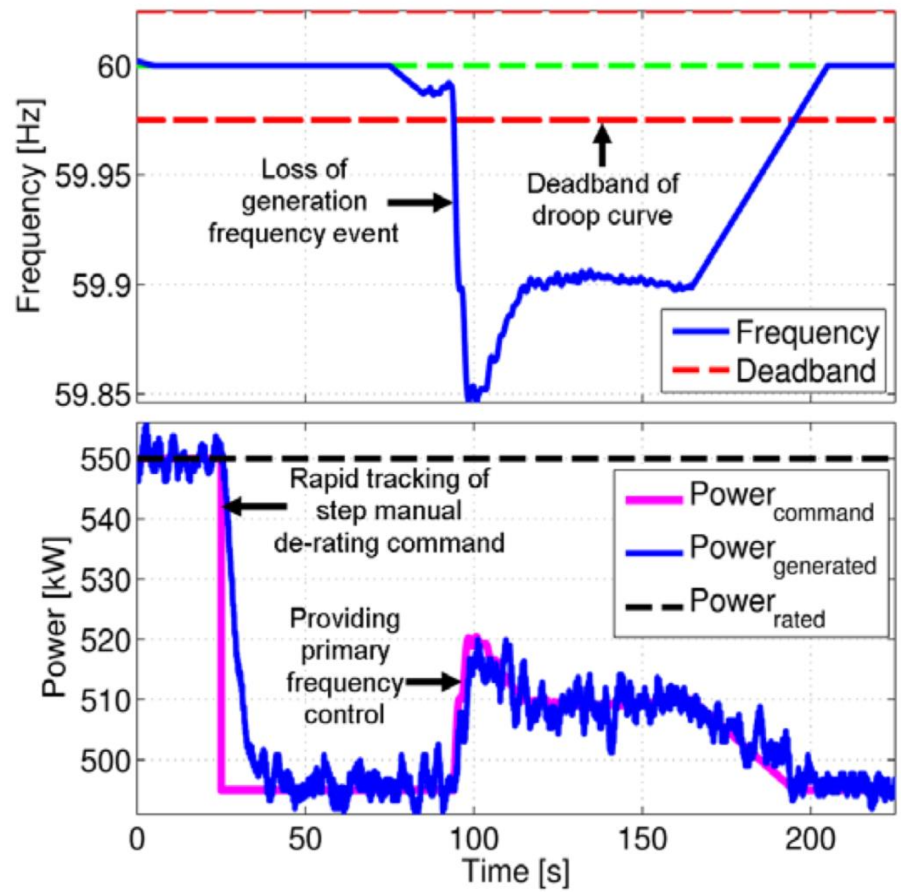
Results from Western Wind and Solar Integration Study (WWSIS), Phase II (2013)
http://www.nrel.gov/electricity/transmission/western_wind.html

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