Renewable Energy Integration
In Power Systems

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Goals for the audience

• Address common myths related to solar energy, and be able to debunk these misperceptions

• Identify key tools that decision makers around the world use to improve solar energy integration
Supply electric power to customers

- Reliably
- Economically

Consumption and production must be balanced continuously and instantaneously

Maintaining system frequency is one of the fundamental drivers of power system reliability
Solar and Wind Energy is Variable and Uncertain

**Variability** – solar generator output varies with the intensity of the energy source (sun);
- Timescales: minute (regulation), hour (ramping), diurnal, seasonal, annual.

**Uncertainty** – Wind and solar generation are similar to “load”;
- Partially dispatchable – output is predicted by a forecast,
- Actual power output is different than forecast output.
"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 'net load'
  - 'Net load' is energy demand after accounting for solar and wind generation
Keeping the System in Balance at all Timescales Requires a Portfolio of Generators

Generators may offer different services (in addition to energy) into the market, which are appropriate for balancing demand at many different timescales.
It isn’t just about technology

• The power system is made up of two critical systems
  o Physical power system – generators, transmission...
  o Institutional system, including markets, reliability rules, general operating practice
• Integration must carefully consider both
Sources of Flexibility (Reduction in Need for Flexibility)

Institutional:
- Speed of Scheduling and Dispatch
- Balancing area (BA) cooperation
- Forecasting
- Demand response
- Curtailment
- Reserves

Physical:
- Non-renewable generation fleet
- Renewables with active power control
- New loads (PHEV)
- Storage
- Transmission
Other Integration Options

RELATIVE ECONOMICS OF INTEGRATION OPTIONS

- Involuntary Load Shedding
- Chemical Storage
- Transmission Expansion
- Fuel Storage/Flexible Scheduling
- Pumped Hydro Storage
- Thermal Storage
- Residential Demand Response
- Coal Ramping
- Transmission Reinforcement
- Advanced Network Management
- Expanded Balancing Footprint/Joint System Operation
- Upward Reserve and Dispatch
- CT and CCGT Gas Ramping
- Hydro Ramping
- Option costs are system-dependent and evolving over time

Type of Intervention

- Load
- Flexible Generation
- Transmission
- Storage

NATIONAL RENEWABLE ENERGY LABORATORY
Things We Have Heard:

- Wind and solar cannot make a significant contribution to the energy mix because...
  - ...the diffuse and remote nature of the resource
  - ...it requires large amounts of “backup” which will be very costly and generate lots of emissions
  - ...our “fragile” grid can take up to 10-20% renewables but beyond that something “breaks”
  - ...it needs massive deployment of energy storage because the wind doesn’t always blow and the sun doesn’t always shine
This Looks Scary...

Output from a PV plant
This Looks Scary...

Sample Net Load – March 31, 2012

The duck curve shows steep ramping needs and overgeneration risk

(ramp need ~13,000 MW in three hours)

(from the California Independent System Operator)
Many Power Systems Have Achieved High Penetrations of VRE

<table>
<thead>
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<th>System Size (GW)</th>
<th>% Variable Renewable Energy (of annual energy)</th>
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- **Alaskan Village**: 80%
- **Denmark**: 42%
- **Philippines**: 23%
- **CA 50%**: 14%
- **Germany**: 13%
- **Oahu, HI**: 0.001
- **Maui, HI**: 0.01
- **Kauai, HI**: 0.01
- **Uruguay**: 0.1
- **Ireland**: 1
- **Cont. USA**: 10
- **CA**: 100
- **Cont. USA**: 1000

* Part of a larger, synchronous AC power system

New sources of flexibility needed
Mostly operational changes
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 may 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
  - 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.
Does variable renewable energy require energy storage?

• Storage is useful, and becoming more cost-effective even at lower penetration levels on islands
  o Actual power system operation experience on Oahu has shown minimal need for electric storage even with 37% wind and solar penetration (2010 Oahu Wind Integration Study)
  o 50% wind/solar penetration study in Minnesota found no need for storage (MRITS, 2014)
• At higher penetration levels, storage could be of value
  o Recent E3 integration study for 40% penetration in California: storage is one of many options

Source: Adrian Pingstone (Wikimedia Commons)
How often does the wind stop blowing everywhere at the same time?

Source: ERCOT, WindLogics
How expensive is integrating variable renewable energy generation to the grid?

All generation (and load) has an integration cost:

• Any new generator can increase cycling for remaining generation

• Traditional plants can impose variability and uncertainty costs
  o Contingency reserves sized for largest plant, often thermal
  o Operating reserves needed for plants that cannot follow dispatch signals

• Conventional plants can create conditions that increase need for system flexibility
  o Must-run hydropower and IPP contracts; thermal plants that cannot be turned down
Key Takeaways

• Flexibility is a prized quality of power systems with increasing levels of wind and solar generation

• The “flexibility supply curve” is different in every power system, but often most the cost effective changes to the power system are institutional (changes to system operations and market designs)

• Actual operating experiences from around the world have shown very high annual penetrations are possible

• Specific back-up generation is not required, but additional reserves may be necessary