**Big, Fast, and Flexible: Grid Operations for Efficient Variable Renewable Integration**

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Learning objectives

• Recognize how the speed of power system operations and the size of the balancing area footprint affect power system flexibility and enable variable renewable energy (VRE) integration

• Distinguish various approaches to increasing power system flexibility under market and non-market institutional contexts

• Identify policy and other actions to improve grid operations for efficient variable renewable energy integration
Outline

• Power system operation and VRE integration—what are the basics?

• Flexible power systems: the principles of big and fast

• Alternative approaches to coordination among balancing regions

• Examples of pathways to achieve “big and fast” under different institutional contexts
Where are we?

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Power System Objectives

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
What is a balancing authority?

Responsible for controlling electricity transmission flows and maintaining system **voltage and frequency** within certain limits

- **Ancillary services** are used to support reliable system operations in the case of a disturbance, such as an unplanned generator outage or line disruption

- **Reserves** are an important ancillary service that consist of unloaded generation and demand response that can be quickly dispatched

Source: Western Electricity Coordinating Council
Time horizons of power system operation

- **Unit commitment/scheduling**: the amount of time before power system operators need to start generators so that they are available when needed to meet demand (e.g., day-ahead, hour-ahead).

- **Gate closure**: the point at which the most recent actual data (operational, market) is no longer collected, and setpoint calculation/communication process begins (e.g., 1+ days ahead, hour-ahead, minutes-ahead).

- **Dispatch**: the frequency with which the power system operator chooses among available generators to deliver energy (e.g., hourly, 15-min, 5-min).

*Example system with 5-minute dispatch:*

00:00 Monday

- **Gate closure \( t_1 \)**
  - System state (e.g., current output, bids, wind and solar forecasts) captured and fed into dispatch model

- **Dispatch \( t_1 \)**
  - Generation units are instructed to deliver energy

Calculation, communication, and movement to setpoints
Time horizons of power system operation

- **Unit commitment/scheduling**: the amount of time before power system operators need to start generators so that they are available when needed to meet demand (e.g., day-ahead, hour-ahead).
- **Gate closure**: the point at which the most recent actual data (operational, market) is no longer collected, and setpoint calculation/communication process begins (e.g., 1+ days ahead, hour-ahead, minutes-ahead).
- **Dispatch**: the frequency with which the power system operator chooses among available generators to deliver energy (e.g., hourly, 15-min, 5-min).

Example system with 5-minute dispatch:

- **Day-ahead commitment**: Decide which units will be available in the next 24 hour period.
- **Gate closure $t_1$**: System state (e.g., current output, bids, wind and solar forecasts) captured and fed into dispatch model.
- **Gate closure $t_2$**: Calculation, communication, and movement to setpoints.
- **Dispatch $t_1$**: Generation units are instructed to deliver energy.
- **Dispatch $t_2$**: Calculation, communication, and movement to setpoints.
- **Gate Closure $t_5$**
- **Dispatch $t_3$**

Diagram showing the time horizons with labels for each phase.
Why is grid integration important?

- Wind and solar are variable – the wind and sunlight change.
- Wind and solar energy are uncertain – we can forecast them reasonably well for time periods ranging from minutes, hours, a few days.
- **Grid integration** is the practice of developing efficient ways to deliver high penetration levels of variable RE to the grid.
- The variable and uncertain nature of wind/solar require additional power system flexibility…
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 the demand that must be supplied by conventional generation
- High flexibility implies the system can respond quickly to changes in net load.
Frequently used options to increase flexibility

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.
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• **Flexible power systems: the principles of big and fast**

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Geographic diversity can reduce variability and need for reserves.

Aggregation and geographic diversity reduces the variability of wind energy.

Source: NREL wind plant data
Approximately 8 hours
How does a larger balancing area support RE integration?

- Example: Balancing area A is ramping up 600 MW, at the same time that Balancing Area B is ramping down 400 MW.
- Combining these balancing areas can eliminate 400 MW of ramping up and down.
- Balancing area A and B can each ramp 1000MW/hour. Combined, they can ramp at 2000MW/hour. Ramping capability increases more than ramping needs.

How does faster scheduling support RE integration?

- Making scheduling and dispatch decisions closer to real-time reduces uncertainty and the need for expensive ancillary services
  - Increase flexibility and reduce system costs
- Better alignment with the timescale of variable RE resources, enabling better utilization of wind and solar forecasts
  - Reduce wind and solar curtailment
Big and fast in combination: Impacts of faster dispatch, shorter gate closure, and larger balancing areas

- Large, agile systems can more cost-effectively integrate high quantities of variable wind and solar
- Faster interchange has a similar impact as faster dispatch

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
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Uncoordinated balancing areas (typical operations)

- Each balancing area authority balances supply and demand within its own geographic boundary, with limited imports and exports
Balancing area coordination: Reserve sharing

- Sharing reserves between balancing areas means each balancing area can maintain less reserve capacity, lowering costs.
Balancing area coordination: coordinated dispatch

Example: Energy Imbalance Market
Balancing area coordination: consolidated operations

• Consolidated operations involves merging of two or more balancing authorities into a single entity

Fully captures the benefits of geographic diversity in demand, wind, solar, and provides more accurate dispatch
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Pathways to achieving “big and fast”

NON-MARKET MECHANISMS
Flexibility mechanisms

**Big**
- Expand balancing footprints and consider geographic diversity
- Coordinate dispatch with neighboring balancing areas
- Coordinate unit commitment with neighboring balancing areas
- Merge business practices with neighbors: consolidated operations

**Fast**
- Economic dispatch at 5-minute time steps
- Sub-hourly (e.g., 15-minute) interchange schedules
- Revise contracts to value flexibility, such as fast changes to purchased generator output

Non-market Mechanisms

These mechanisms do not require a market
Pathways to achieve "big" and "fast"

Levels of Operational Coordination

1. Reserve-sharing
2. Coordinated dispatch
3. Coordinated commitment
   - Revise interchange from 1 hour to 15 minutes
   - Ancillary service: joint provision
       - 15 minutes to 5 minutes
       - Zonal to nodal
           - Spin, non-spin, ramp, frequency response

Operational Evolution/Speed

Non-market Mechanisms
Case study: India

India has moved towards big and fast system operations

- Synchronized national grid in 2013
- Modified the dispatch time block from one hour to 15-minutes in 2012
  - More gradual ramping and smoother morning and evening peaks
- Future: improved coordination among state balancing areas?

Source: NREL
Pathways to achieving “big and fast”

MARKET MECHANISMS
Big and Fast: Mechanisms for Flexibility

**Big**
- Increase balancing area footprint
- Increase market participation from generation currently self-scheduled
- Coordinate with neighbors
  - Reserve sharing
  - Energy imbalance market (EIM)
  - Consolidated market operations

**Fast**
- Faster dispatch
- Faster interchange
- Shorter gate closure
- Rolling unit commitment
Why start with an Energy Imbalance Market?

An Energy Imbalance Market (EIM) pools electricity generation within a region to balance the variability of electricity demand and renewable energy resources.

- EIM is coordinated dispatch
- EIM does not address any type of coordinated unit commitment
- Relatively “easy” step towards more coordination
- Does not require any ancillary services, day-ahead, or other market
Case Study: Southwest Power Pool

Experience from the U.S.
Southwest Power Pool (SPP)

Source: www.basinelectric.com

- Reserve sharing
- Energy Imbalance Service (EIS)
- Consolidated market operations
Case study: Southwest Power Pool

Levels of Market Coordination (Big)

1. Reserve-sharing

Speed
Case study: Southwest Power Pool

1. Reserve-sharing
2. Energy Imbalance Service
15 minutes to 5 minutes

Levels of Market Coordination (Big)

Speed
Case study: Southwest Power Pool

Levels of Market Coordination (Big)

1. Reserve-sharing
2. Energy Imbalance Service
3. Full “day-2” market with regulating reserves

15 minutes to 5 minutes

Speed
Case study: Southwest Power Pool

Levels of Market Coordination (Big)

1. Reserve-sharing
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15 minutes to 5 minutes

Revise interchange from 1 hour to 15 minutes

Speed
Pathways to achieving “big and fast”

NON-MARKET TO MARKET TRANSITIONS AND HYBRID SYSTEMS
Case Study: Energy Imbalance Market in the Western U.S.

- Modeled after SPP EIS
- EIM could potentially cover all of Western Interconnection
- Initial reluctance, but market is underway
- Market is gradually expanding
Example: Mountain West Transmission Group considering formation of an RTO

Levels of Operational Coordination

1. Reserve-sharing

Operational Evolution/Speed

Non-Market to Market and Hybrid
Example: Mountain West Transmission Group considering formation of an RTO

Levels of Operational Coordination

1. Reserve-sharing
   - 2. Coordinated dispatch
   - 3. Coordinated commitment

Revise interchange from 1 hour to 15 minutes

15 minutes to 5 minutes

Zonal to nodal

Ancillary service: joint provision

Spin, non-spin, ramp, frequency response

Operational Evolution/Speed

Non-Market to Market and Hybrid
Takeaways

Moving to a large balancing footprint with faster gate closure and dispatch is the key to efficient integration of variable wind and solar energy.

This principle applies to market and non-market areas. A market is not necessary to have larger balancing footprints and to dispatch more frequently.

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
Contacts and Additional Information

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Greening the Grid

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References and further reading


