Grid Services from Variable RE

Clayton Barrows, Ph.D.
National Renewable Energy Laboratory

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Evolving characteristics of wind and solar

Characteristic	Old	New
Dispatchability	Uncontrollable, "must take"	Dispatchable through participation in economic dispatch
Forecast/uncertainty	Unpredictable	Increasingly forecastable
Variability	Highly variable over multiple timescales	Very short-term variability largely mitigated via spatial diversity
Reserve requirements	Requires dramatic increase in operating reserves from thermal units	Relatively small increase in regulation required. Can self-provide multiple reserves across multiple timescales with selective/economic curtailment
Grid support	Provides no grid support/decreases grid stability	Can provide multiple grid support services

Source: Milligan et al 2015

Two primary areas where RE will be essential

- **Dispatch:** Support for balancing under normal conditions ("non-events")
  - Minutes-to-hours load following, meeting daily demand peaks

- **Contingency response:** Grid support following an outage or other grid disturbance ("events")

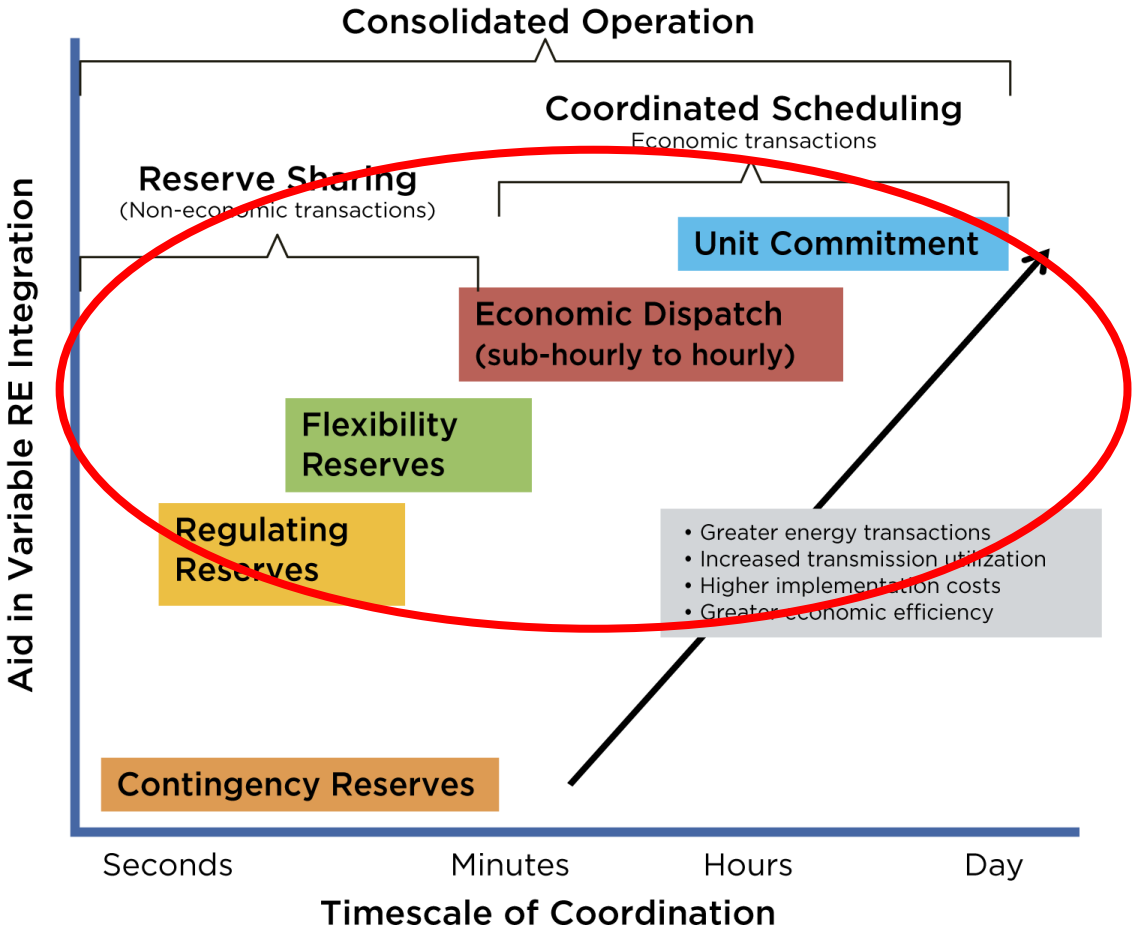
Variable RE can increase the responsiveness and flexibility of the power system to help address both needs…

But only if the policy and market frameworks support their participation.

Dispatch: System balancing under normal conditions

Where RE can support the grid:

- Automatic generation control (AGC) for regulation
- Inclusion in economic dispatch and scheduling



Source: Denholm and Cochran 2015

Dispatch: System balancing under normal conditions

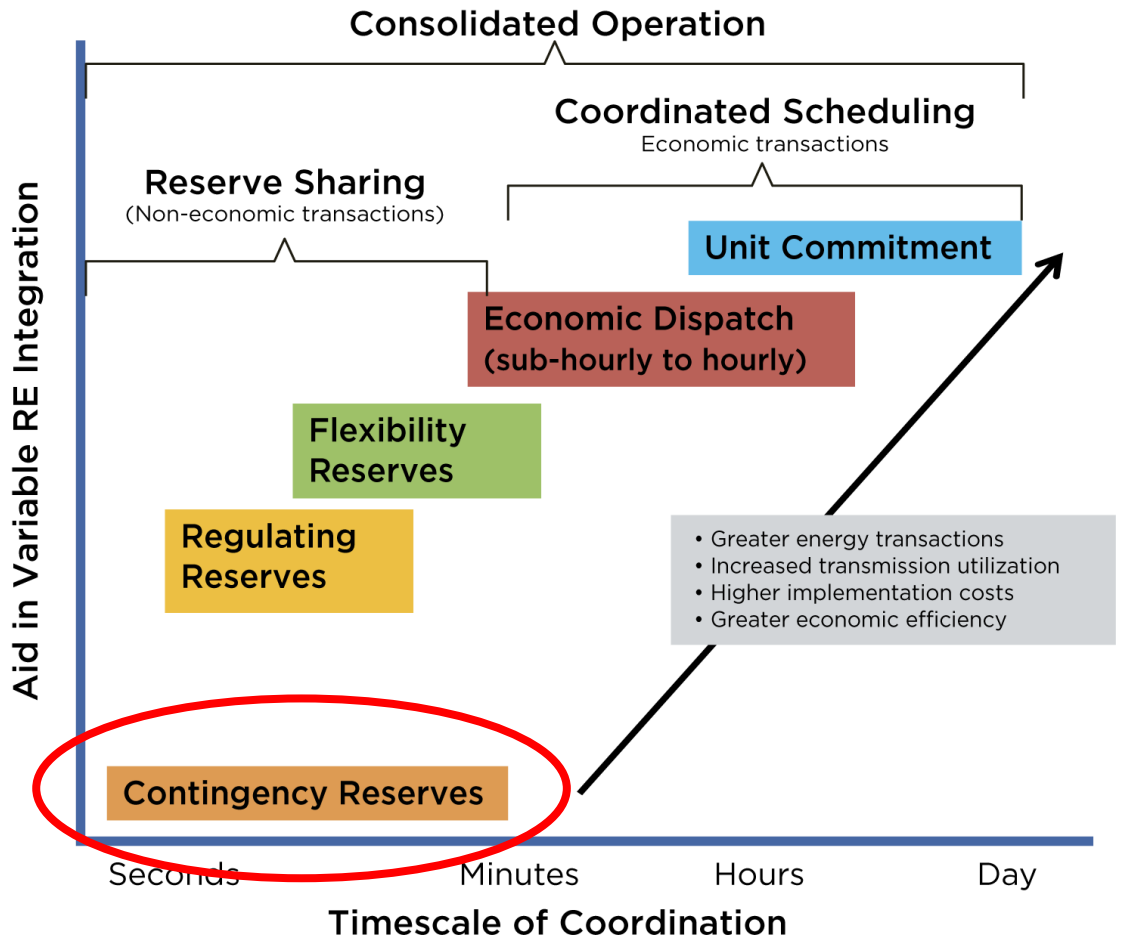
Examples where RE provides grid support:

- Xcel Energy in Colorado (vertically-integrated utility) requires wind turbines to have AGC
  - Xcel uses this to curtail wind to manage ramps and periods of overgeneration
- Alberta moved to negative pricing in response to overgeneration in neighboring BA
- Midcontinent ISO requires wind to be dispatched

Contingency response: System balancing following an outage

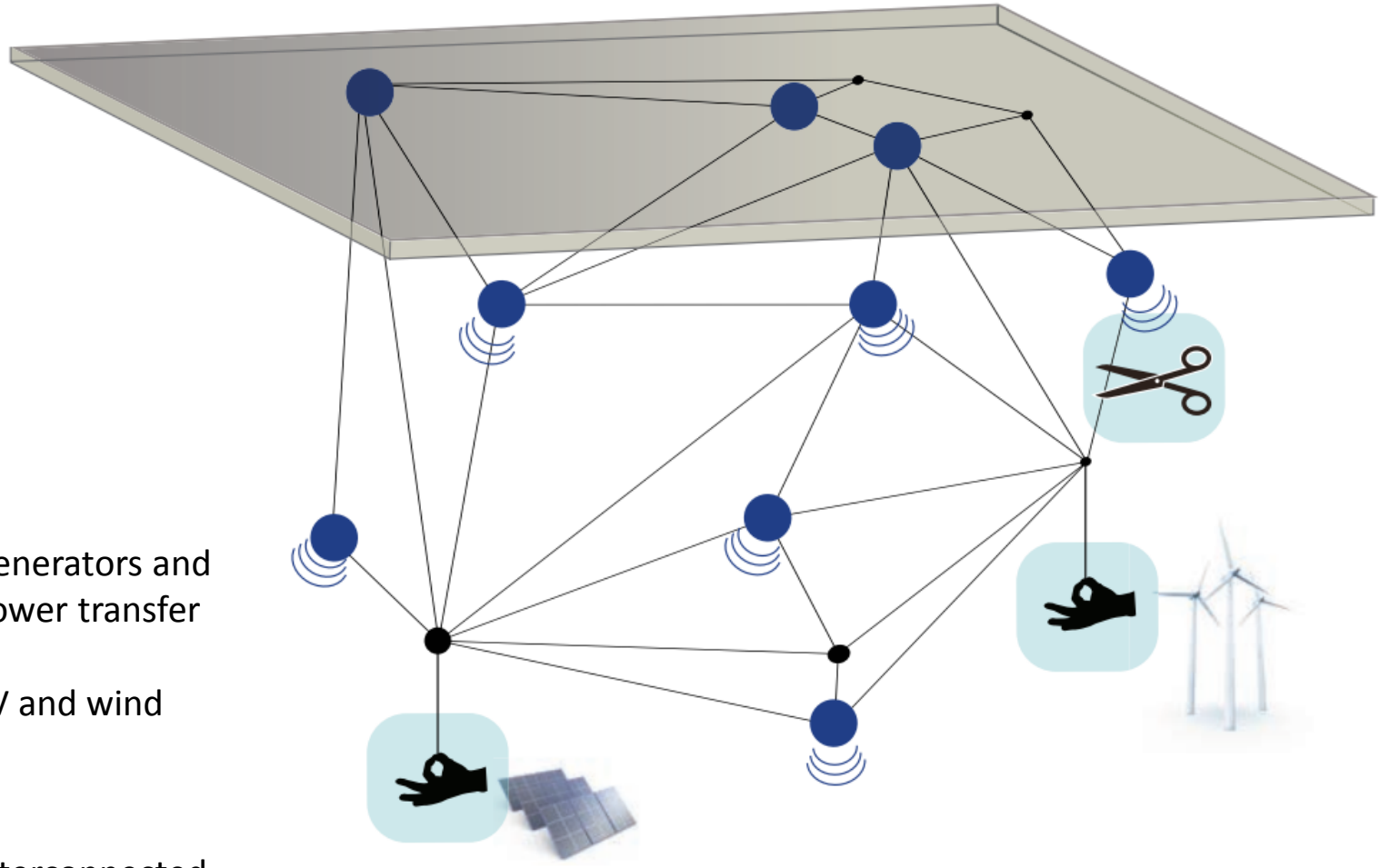
Where RE can support the grid:

- Simulated inertial response, governor response
- Voltage support



Source: Denholm and Cochran 2015

What happens to the grid in a disturbance?



Generators and power transfer

PV and wind

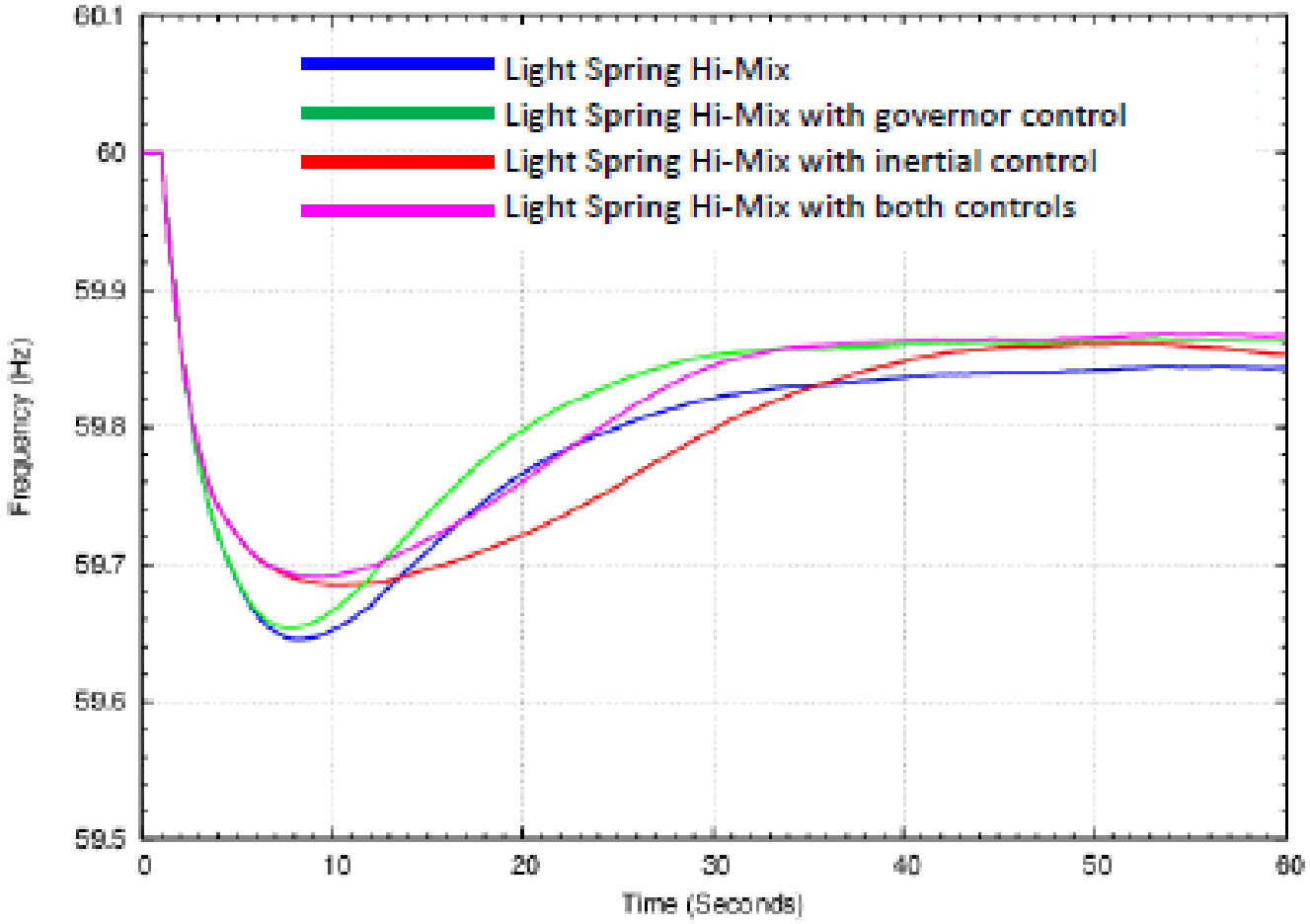
Interconnected grid

Disturbance

Source:
http://www.nrel.gov/docs/fy16osti/65302.pdf

WWSIS-3 evaluated whether high RE system can recover from a disturbance, and how RE can help

- Sample result from the Western Wind and Solar Integration Study (WWSIS-3), Phase 3



Source: http://www.nrel.gov/electricity/transmission/western_wind.html

Contingency response: System balancing following an outage

Examples where RE provides grid support:

- ERCOT required all capable wind turbines to be retrofitted with governor response
- Voltage support (for normal and contingencies) has become standard practice
- FERC in comment phase of proposal that new interconnection standards require VRE to provide primary frequency response
- California Public Utility Commission updating interconnection requirements for distributed PV to include smart inverters that provide local voltage support, meet ramp rate requirements after an outage, and ride through frequency and voltage events

Critical institutional elements that enable RE to provide RE grid support

1. Plants have the physical capability to do so, requiring regulations

   e.g., interconnection and market rules that require AGC

2. System operators have access to these capabilities, through, for example,
   - Market rules that require RE to be dispatched
   - Negative prices that enable automatic, cost-effective management of overgeneration conditions
   - Power purchase agreements that allow curtailment
   - Effective RE forecasting that allows system operators to anticipate variability and resource availability

Summary chart: flexibility from RE can occur at many timescales

Timescale of Flexibility	Type of Flexibility	How variable renewable energy provides this
Sub-second	Autonomously generated: Synthetic inertia	Fast frequency response with a power electronic converter
Seconds	Autonomously generated: Synthetic governor response	Slower frequency response through electronic governor
Minutes	Remotely operated: Automatic generation control	Market or system operator inclusion in ancillary services
Minutes to hour	Economic dispatch	Market or system operator inclusion in dispatch
Day	Scheduling (unit commitment)	Market or system operator inclusion in day-ahead scheduling

Source: Jacobs, et al. 2016

QUESTIONS

For more information: http://greeningthegrid.org