Integrated Energy Systems at Scale
Enabling more Renewable Energy

Benjamin Kroposki, PhD, PE, FIEEE
Director – Power Systems Engineering Center
National Renewable Energy Laboratory
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Driving innovation in Energy Systems Integration

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New challenges in a modern grid:

- Increasing levels of power electronics-based VRE: solar and wind
- More use of communications, controls, data, and information (e.g., smart grids)
- Other new technologies: electric vehicles (EVs), distributed storage, flexible loads
- Becoming highly distributed—more complex to control
The US Energy supply is Shifting

Renewable Energy—
not including hydropower—currently produces 10% of the total U.S. electricity generation. Within the next two years, this is expected to grow to 13%.

The Cost of Renewables is Falling

Advanced energy technologies are providing real-world solutions by:
- Becoming increasingly cost-competitive
- Boosting the U.S. energy industry
- Providing jobs for American workers

Source: Lazard’s 2017 Levelized Cost of Energy Analysis, Version 11, 2 November 2017
Current Power Systems Operating with Variable Renewable Energy
We have done the research and demonstrated that achieving 30% VRE is possible with minimal system changes.

What do we need to do to achieve very high levels (more than 50%) of wind and solar integration?
Technical Challenges with Ultra-high Levels of VRE

• Variability and uncertainty of VRE
• Power system stability
• Protection coordination
• Unintentional islanding
• Black-start capability

Variability and Uncertainty

Challenges:

- **Energy shifting** (VRE produces energy when resources are available—variable and uncertain)
- **Forecasting** (renewable resources and load)


Source: A Mills et al., “Dark Shadows: Understanding Variability and Uncertainty of Photovoltaics for Integration with the Electric Power System”
Options for Dealing with Variability and Uncertainty

Solutions:

- Utilize geographic diversity.
- Utilize flexible conventional generation.
- Increase sharing among balancing authority areas.
- Expand the transmission system.
- Curtail excess VRE production.
- Enhance VRE and load forecasting.
- Coordinate flexible loads (active demand response).
- Add electrical storage.
- Interact with other energy carriers.

NREL’s Renewable Electricity Futures Study (2012) estimated the amount of energy storage needed for various penetrations of renewable energy (RE) for the continental US in 2050.

- RE included all types of renewables including hydro.
- The figure on the left shows GW of storage capacity (Y1-axis), % variable generation (Y2-axis) and % total RE energy (x-axis).
- For the 80% RE scenario (that has 45% wind and PV) the estimated storage need was ~120GW of 8hr storage.
- For context, currently there is 22GW of pumped hydro and 1 GW of batteries installed in the US.
- The difference between current levels and 120GW could be made from a variety of new storage technologies, shiftable loads, hydrogen, etc.
Tapping into Demand Response (DR)

Reduced number of Combined Cycle and Gas Turbine Starts due to using demand response

Tapping into Controllable Demand

Energy System Integration (ESI) can increase grid flexibility by increasing connections with other energy domains.

How to control millions of devices?

As we migrate from a centrally controlled, synchronous generator-based grid to a highly distributed, inverter-based system...

We need smart inverters with advanced functionality to maintain grid stability and...

Improved optimization for millions of controllable devices in the grid.

Research Needs

- Control theory
- Advanced control and optimization algorithms
- Imbedded controllers in devices
- Linkage to advanced distribution management systems (ADMS)
- Validation of concepts and deployment.


Source: E. Dall’Anese et al., http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6920041
Autonomous Energy Grids
Blue Rings - Centralized control
Green Dots - Cell controllers
Dashed Red - Cell-to-cell communications
White/Gold - Distributed control
Advancing Technologies through Grid Simulation and Experimentation
Grid Simulation and Data Capabilities

• High Performance Computing (Eagle)
• Large-scale Renewable Integration Studies
• Integrated Transmission, Distribution, Communications, and Markets Grid Co-simulation platform (HELICS)
• Synthetic Grid Datasets
• Renewable Resource Datasets

Grid Experimental Capabilities

• NREL Energy Systems Integration Facility
• Advanced Distribution Management System Testbed
• NREL Flatirons Campus
• Integrated Energy Systems at Scale (IESS) - Integrated multi-site integrated Power Hardware in the Loop Experiments
Unique capabilities:

- Multiple parallel AC and DC experimental busses (MW power level) with grid simulation and loads
- Flexible interconnection points for electricity, thermal, and fuels
- Medium-voltage (15-kV) microgrid area
- Virtual utility operations center and visualization rooms
- Smart grid lab for advanced communications and control
- Interconnectivity to external field sites for data feeds and model validation
- Petascale high-performance computing (HPC) and data management system in showcase energy-efficient data center
- MW-scale power hardware-in-the-loop simulation capability to evaluate grid scenarios with high penetrations of clean energy technologies.
Flatirons Campus

- Total of 11 MW of variable renewable generation currently installed
- Many small wind turbines (less than 100 kW) are installed
- 2.5-MW and 5-MW dynamometers
- 7-MVA controllable grid interface (CGI) for grid integration experiments
- Multi-megawatt energy storage evaluation capability ready for use.
Flatirons
(20 MW+)
(1,000s of devices)

ESIF
(Up to 2 MW)
(100s of devices)
Virtual Emulation Environment
(MW to GW Scale) + (Millions of devices)
NREL Power Systems Engineering Center
www.nrel.gov/grid

NREL: Providing Solutions to Grid Integration Challenges

Thank You!