Summarizing the Technical Challenges of High Levels of Inverter-based Resources in Power Grids

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Present Grid

Future Grid

New Characteristics

- Less Synchronous Generators
- More Variable, Inverter-based Generation
- More Distributed Generation and Controllable Loads
- Loads – becoming more power electronics based (e.g. LEDs, VSD, inverters, converters)
- Mobility – migrating towards electric vehicles

The future energy system will have more power electronics-based resources (generation, storage, loads, and mobility)

- PV, wind, fuel cells, microturbines, batteries, EVs all use power electronic interfaces to the grid
- Looking at over 50% annual energy from PE generation by 2050 for large grids
- Need to work synergistically with other synchronous generators
The future energy system will have more power electronics-based resources (generation, storage, loads, and mobility).

- PV, wind, fuel cells, microturbines, batteries, EVs all use power electronic interfaces to the grid.

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- Need to work synergistically with other synchronous generators.

Wind and Solar in Synchronous AC Power Systems as a Percent of Instantaneous Power and Annual Energy

2018 Updates

How do we go from 8% to above 50% in the continental US?
Case Study - Ireland

Ireland System
Peak Load = 6.5GW
Annual Wind = 29%
SNSP Limit = 65%

Ireland Island Wide System Non-Synchronous Penetration 2018

Source: http://www.eirgridgroup.com/how-the-grid-works/renewables/
Case Study - Ireland

Ireland System
Peak Load = 6.5GW
Annual Wind = 29%
SNSP limit = 65%

25% of the time, the system is dominated by non-synchronous generation

Source: http://www.eirgridgroup.com/how-the-grid-works/renewables/
So how do we get to very high levels on very big grids?

What does it mean to get above 50% in the US mean?
80% RE had 48% wind and Solar

80% RE Case from NREL Renewable Electricity Futures Study

Exported to other regions

ERCOT system is inverter-dominated 59% of hours
High Renewable Penetrations Require Paradigm Change in Power System Operation

Need advanced controls and technologies to integrate wind and solar while maintaining grid stability and reliability.

Challenges:

- **Transient and dynamic stability** (loss of system inertia could reduce ability to respond to disturbances—need ride-through capabilities in VRE)
- **Frequency regulation** (need primary, secondary, and tertiary response from VRE)
- **Volt/VAR regulation** (need ability to locally change voltage to stay within nominal limits)
Active Power Control from Wind Turbines

Technology addressed:

- Understanding how variable generation (wind and solar) can provide primary and secondary reserves

Impact:

- Inertial control, primary frequency control, and automatic generation control (AGC) from wind and solar are feasible with negligible impacts on loading.


Grid Services from Solar Plants

NREL/FirstSolar/CAISO experiment: 300-MW plant following AGC signal

300-MW PV Plant in California

Control Needs for Deploying High Levels of Distributed Energy Resources

• Demonstrated that large plants can receive and respond to AGC signals on the bulk system, but what about DER?

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
Other Technical Challenges
Protection Coordination

Problem:
Inverters can provide a wide range of fault currents, but typically not more than 1.2x.

Do we need to define an inverter's fault current?

Other Challenges with High Inverter-Based Systems

Challenges:

• **Black-start**—ability to restore system from outage. How will inverters provide reactive power support for motor starts, transformers, and lines?

• **Intentional Islanding** – ability to operate part of the grid using DER (microgrid)

• **Unintentional islanding** (need methods to protect against unintentional islanding)

• **Cybersecurity**?

Source: EPB, Chattanooga Utility Outage Map after Storm

The map shows customers who experienced an outage as part of a storm as red dots. Blue dots are customers that would have been impacted before the distribution automation upgrade, but were not affected during the actual storm.
Definitely need...

- **Normal and Abnormal Voltage and Frequency Control**
  - Inverter-based resources (IBR) need to provide a range of essential grid reliability services to maintain stable grid operations (Does this mean all IBR need to have to operate off peak to provide up/down reg)
  - Inertial and fault-ride through response (Should this just be defined so that all inverters need to provide inertial response or incentivized through a market?)
  - IBR need to act in concert with synchronous generators

- **Protection schemes** that work under high levels of IBR

- Ability to **Blackstart** grids with high levels of IBR

- Accurate **models of IBR controls** for transient and dynamic analysis (moving from equations that describe physics to models that describe inverter controls)

- **Grid codes and standards** are needed that define response characteristics for inverter-based resources to transient and dynamic events. Do we need a standard for how grid forming inverters can infinitely parallel?
Needs to achieve grids with high levels of inverter-based resources

Would be nice if...

• Inverters could **forecast output and flexibility** to provide a specific grid service
• Accommodate **bi-direction control signals** and respond quickly
Providing Solutions to Grid Integration Challenges

Thank You!