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

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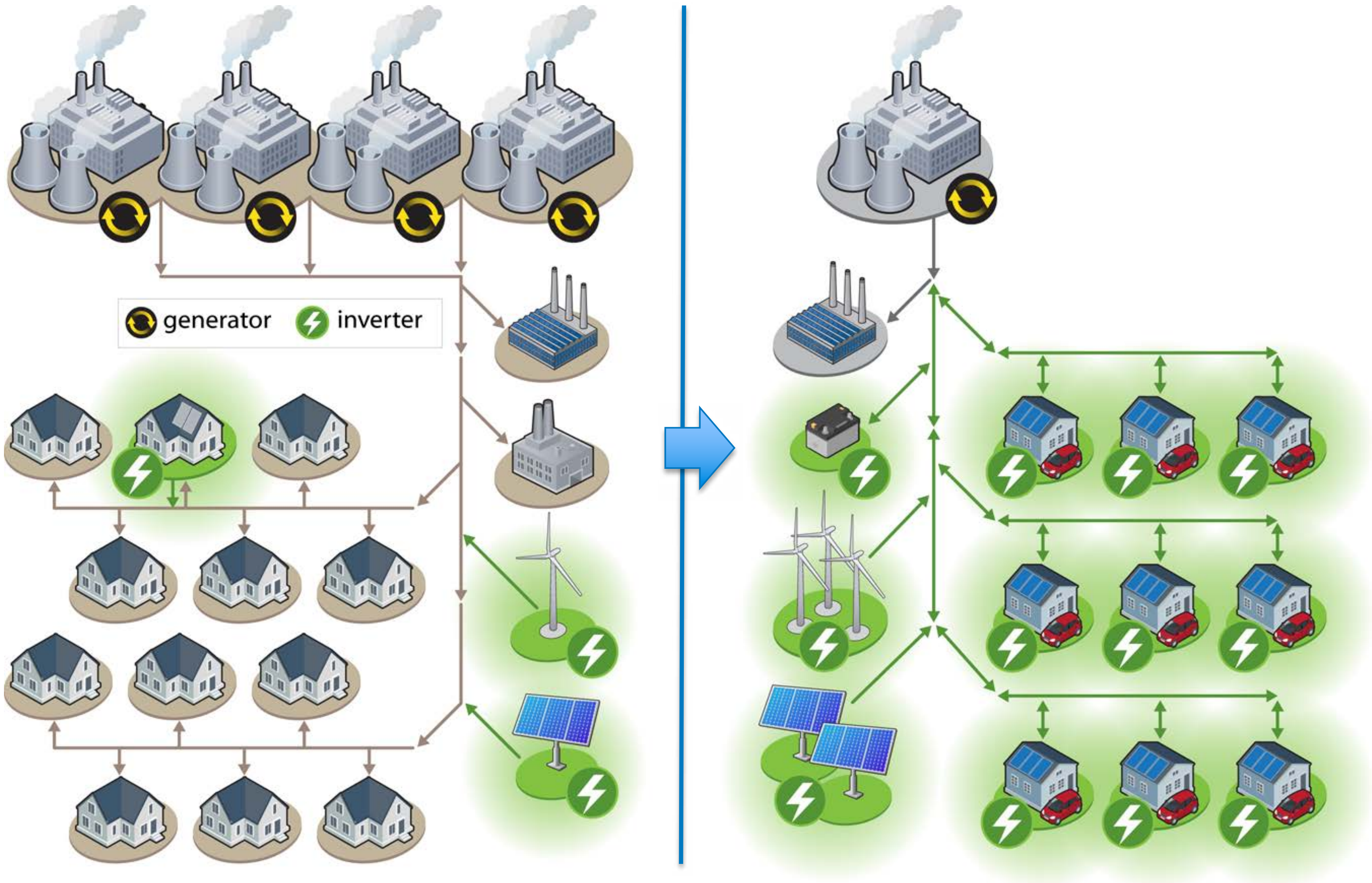
Disclaimer

Present Grid Future Grid



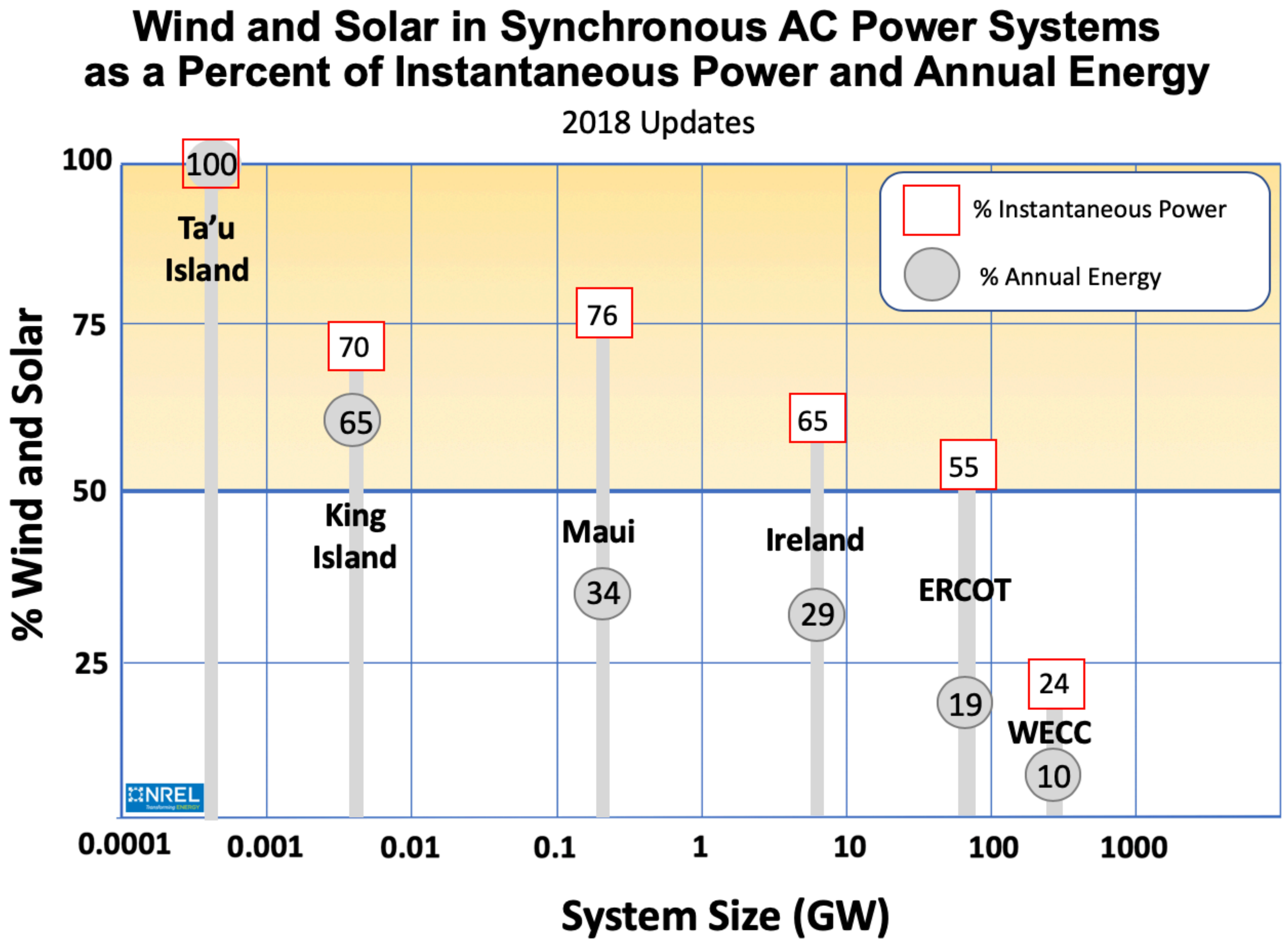
New Characteristics

- 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

Source: "Achieving a 100% Renewable Grid – Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy," http://ieeexplore.ieee.org/document/7866938/

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



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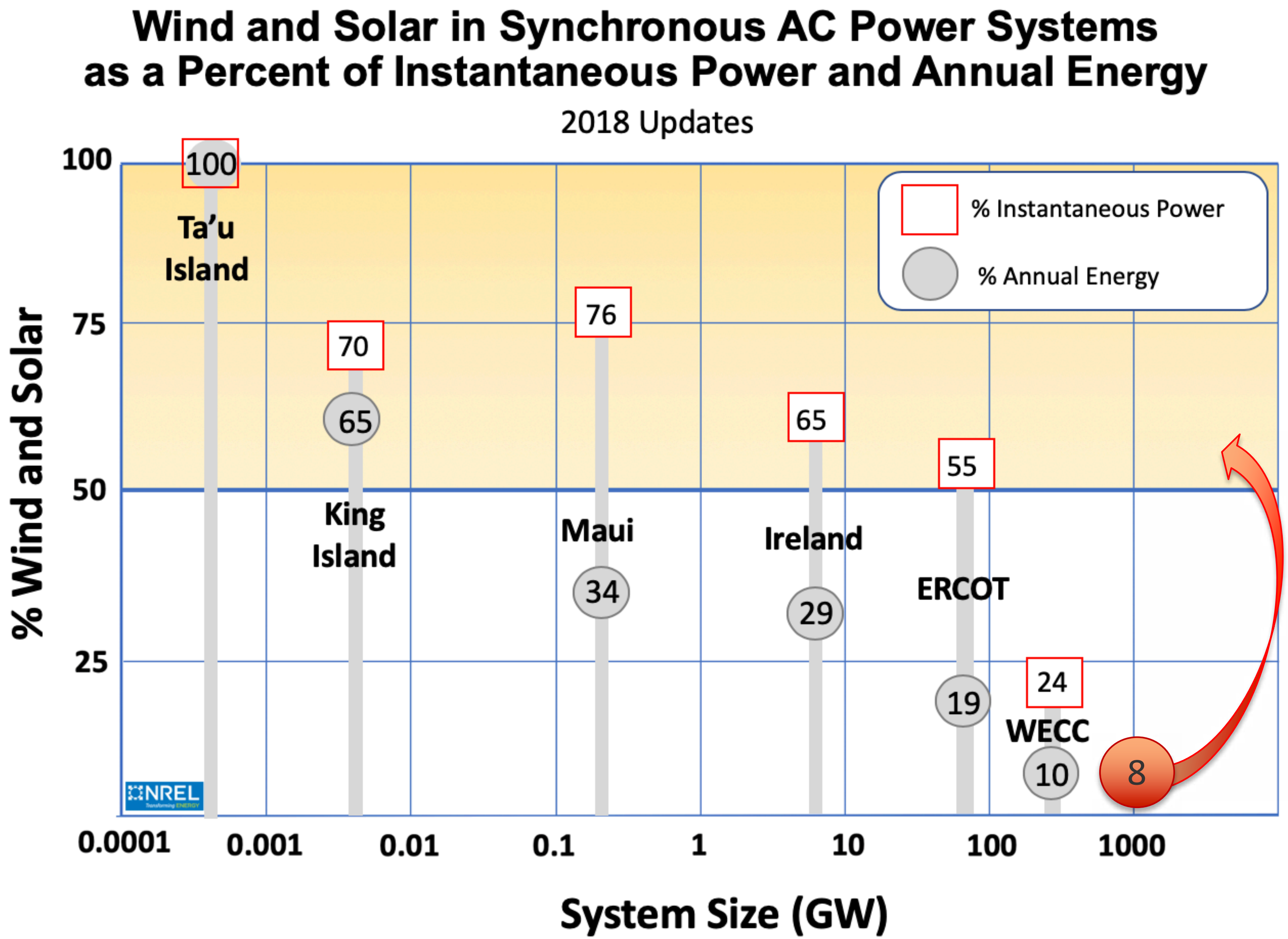
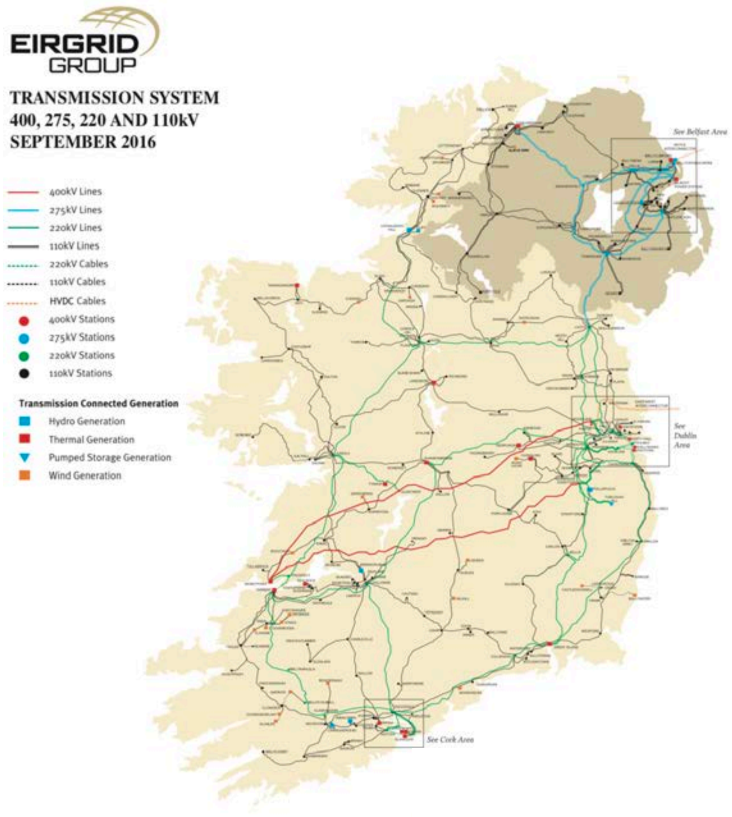


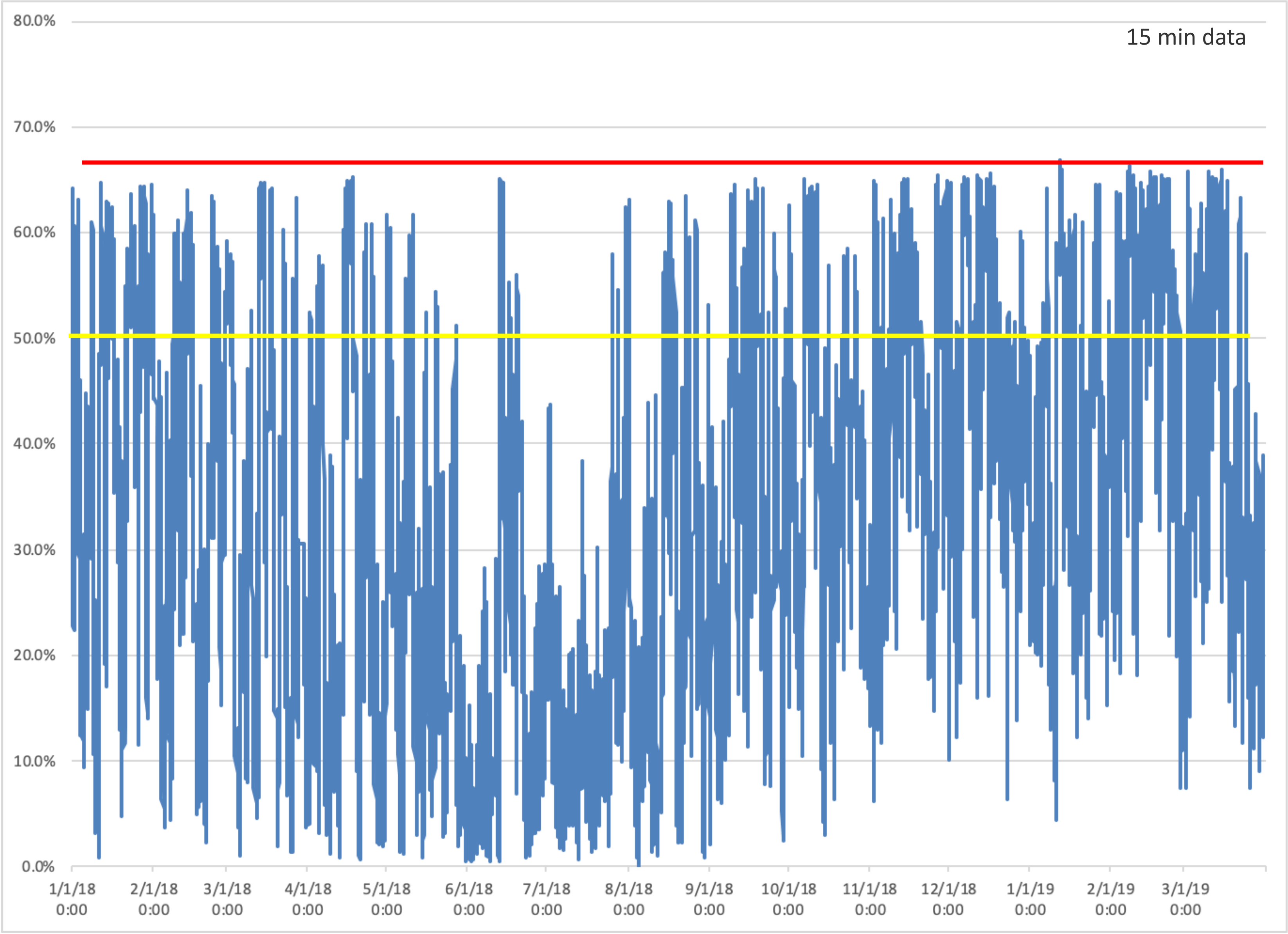
How do we go from 8% to above 50% in the continental US?

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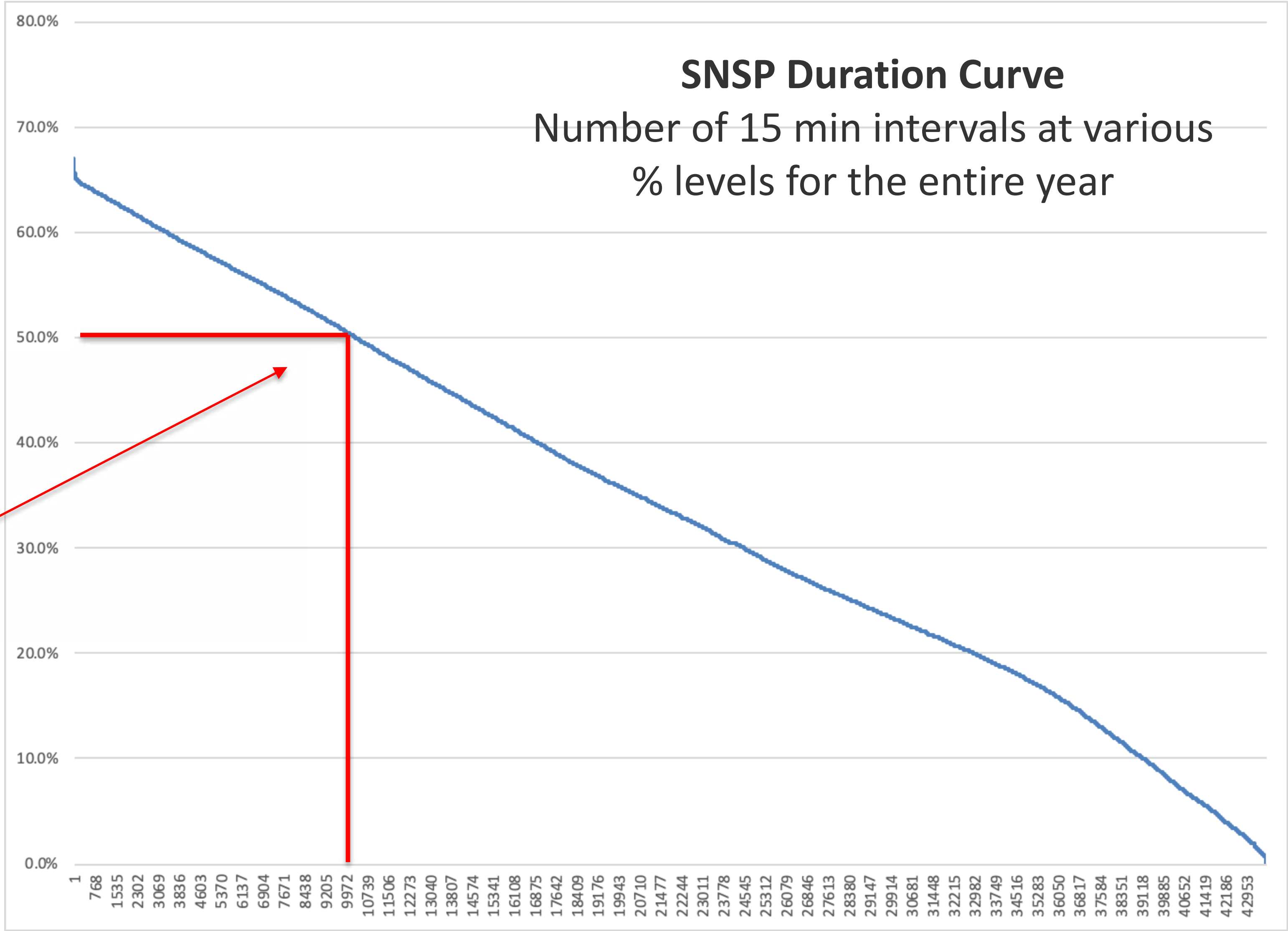
25% of the time, the system is dominated by non-synchronous generation

Ireland Island Wide System Non-Synchronous Penetration 2018



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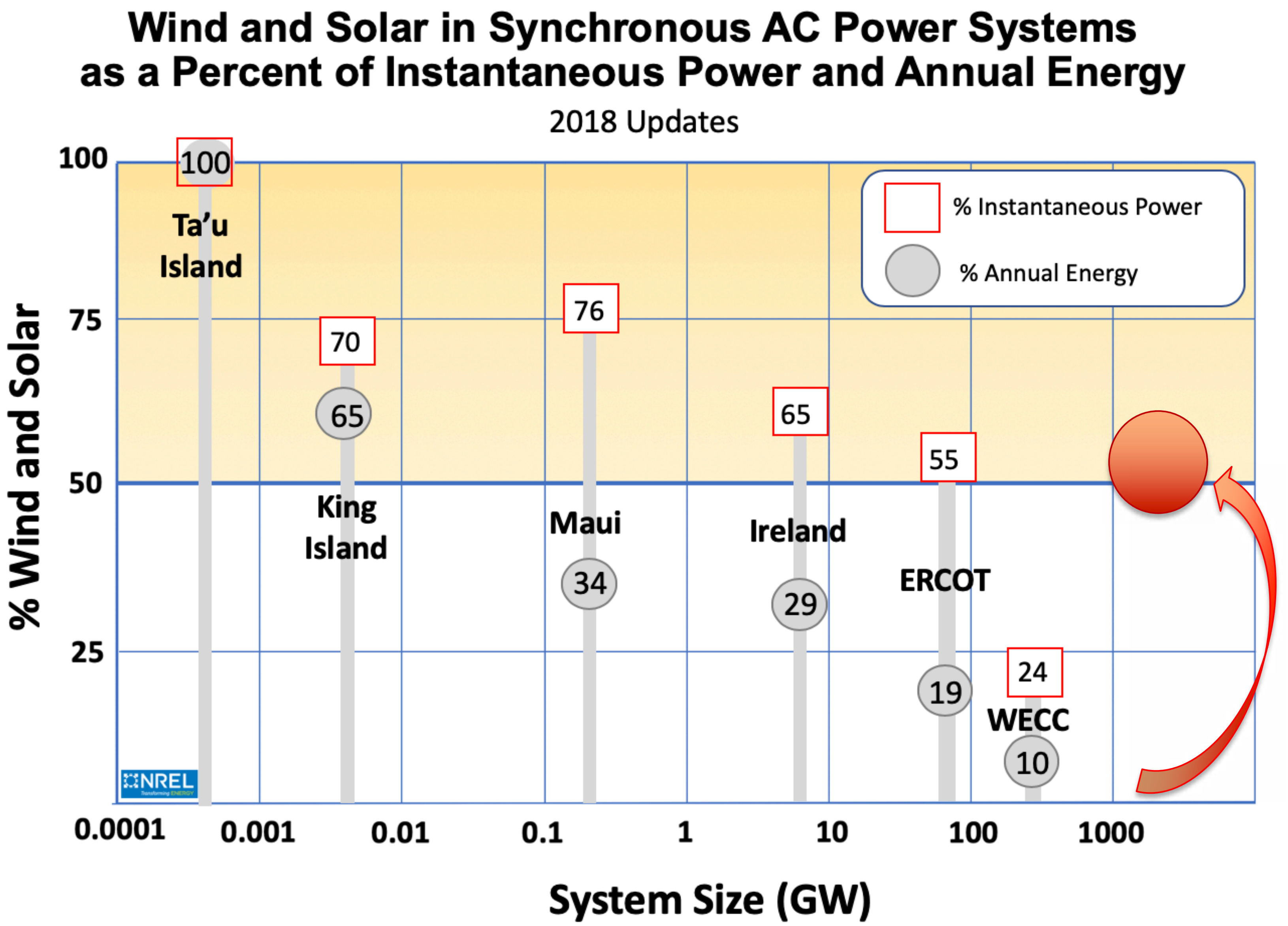
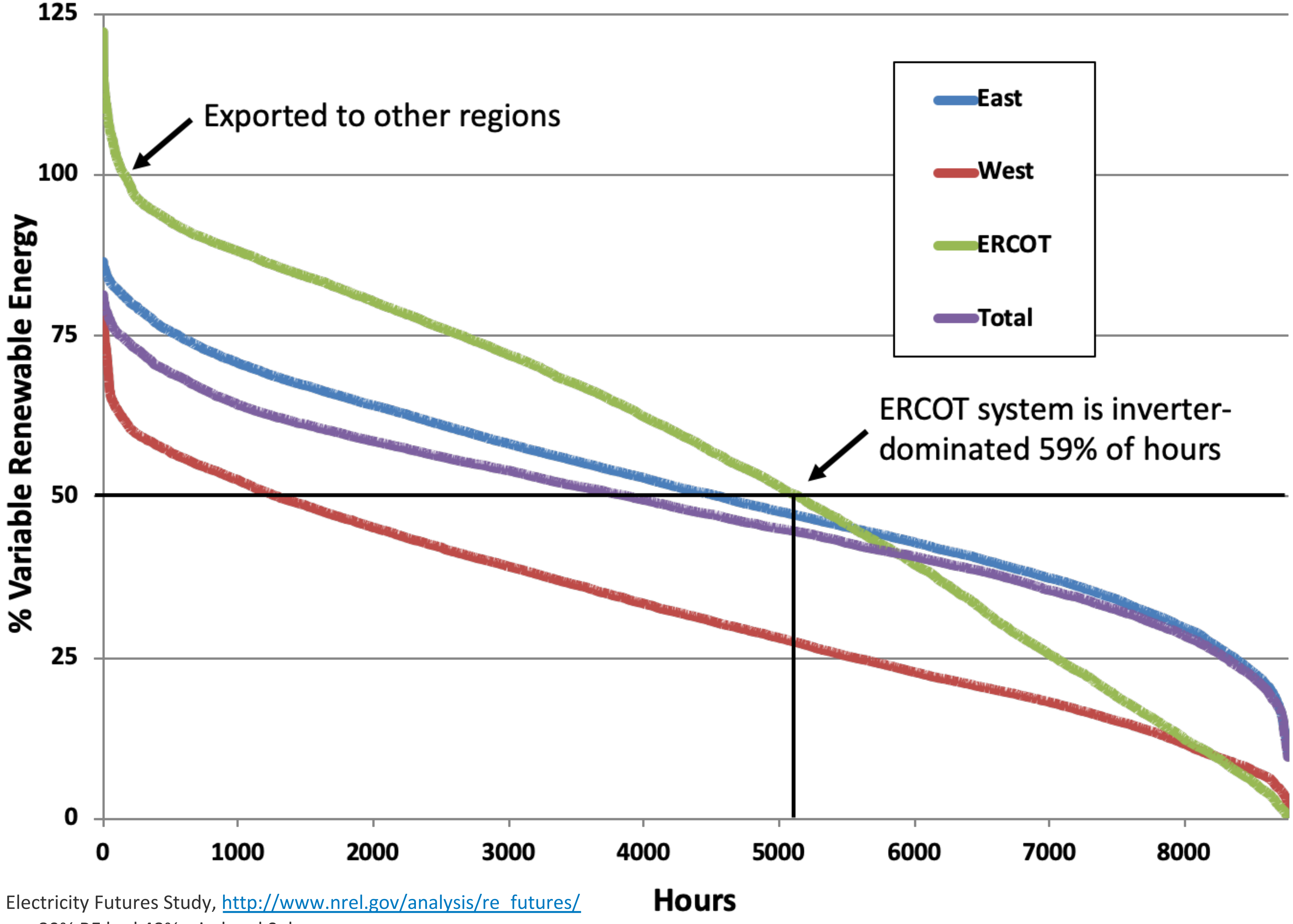
So how do we get to very high levels on very big grids?



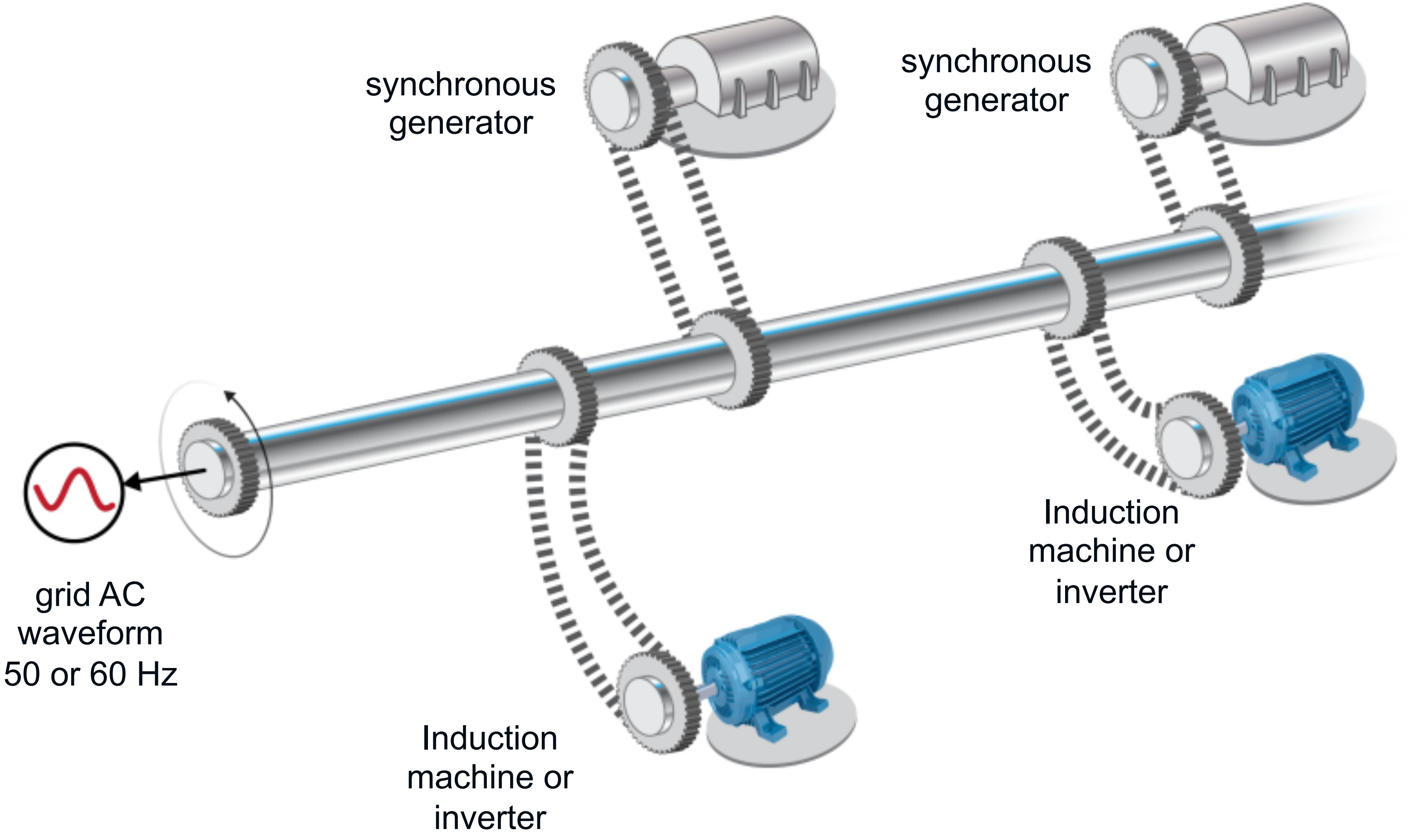
What does it mean to get above 50% in the US mean?

80% RE Case from NREL Renewable Electricity Futures Study



Based on: NREL Renewable Electricity Futures Study, http://www.nrel.gov/analysis/re_futures/
80% RE had 48% wind and Solar

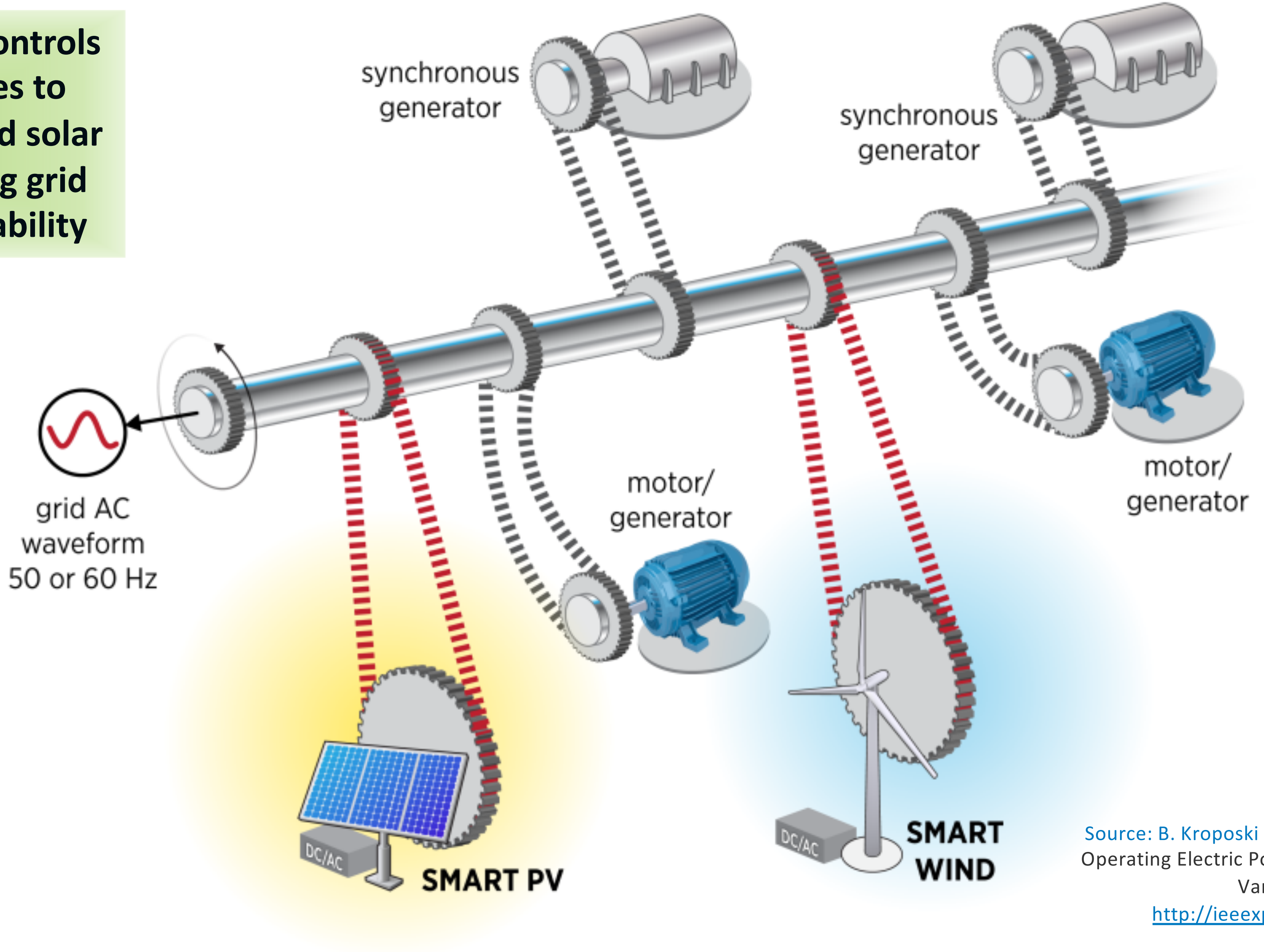
High Renewable Penetrations Require Paradigm Change in Power System Operation



Source: B. Kroposki et al., "Achieving a 100% Renewable Grid – Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy," http://ieeexplore.ieee.org/document/7866938/

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



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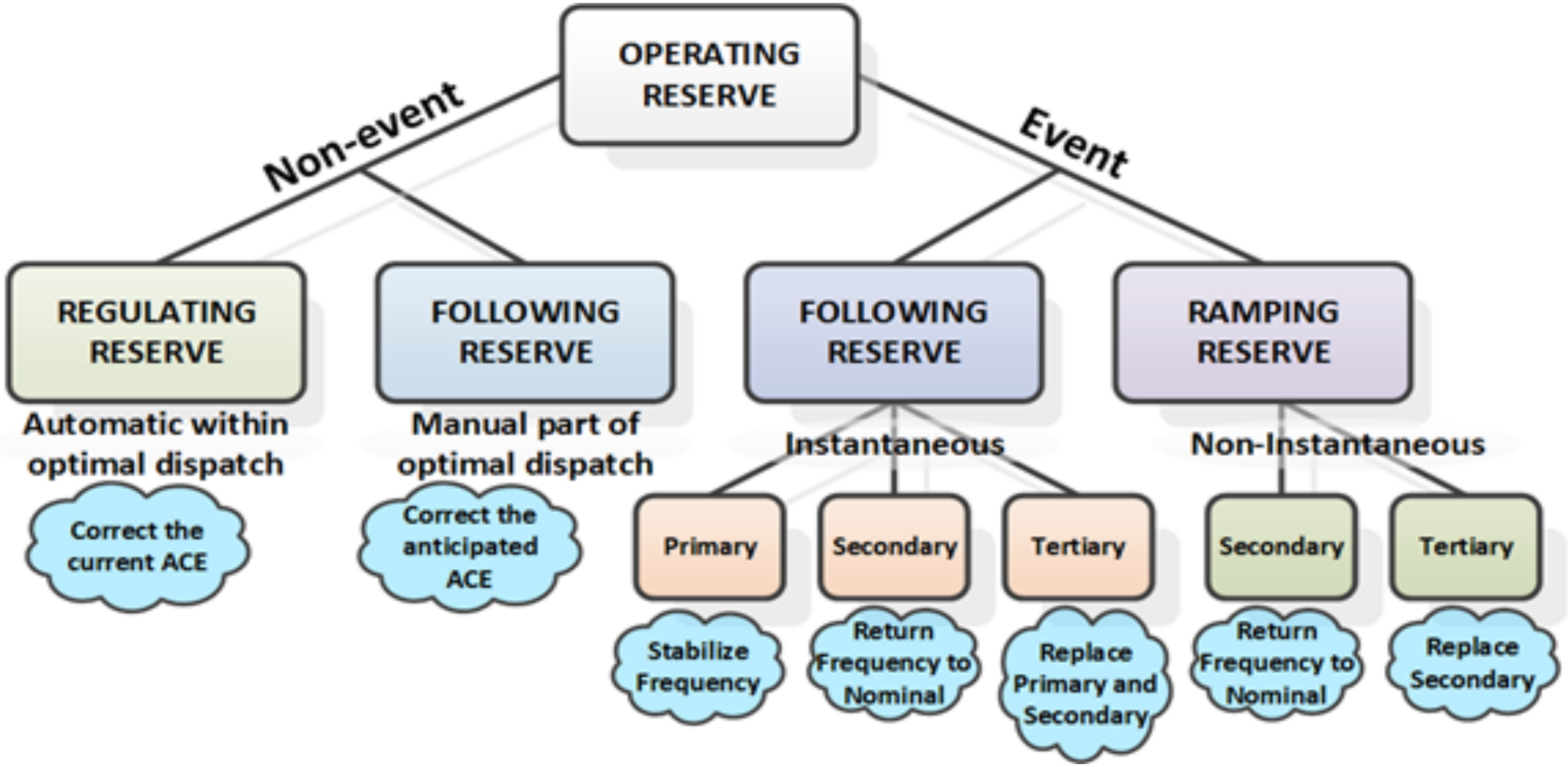
Power System Stability – Providing a Range of Grid Services



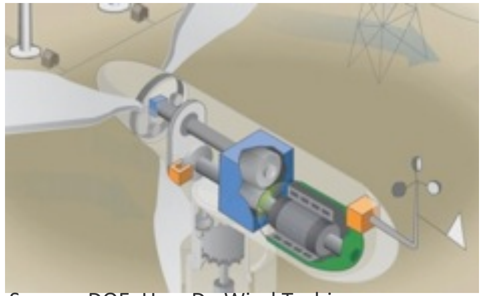
Challenges:

- **Transient and dynamic stability** (loss of system inertia could reduce ability to respond to disturbances—need ride-though 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:

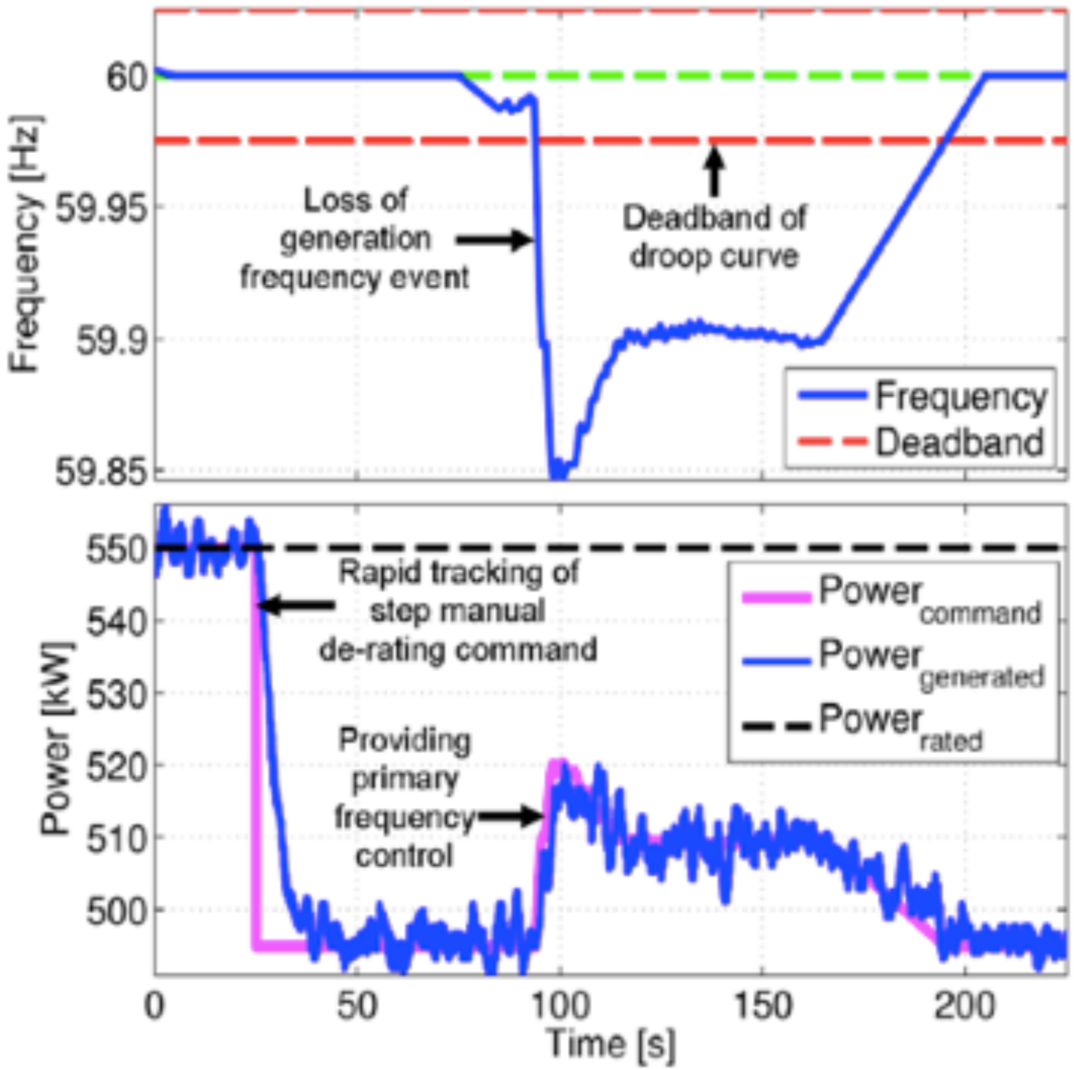
- Understanding how variable generation (wind and solar) can provide primary and secondary reserves



Source: DOE, How Do Wind Turbines Work?,https://energy.gov/eere/wind/how-do-wind-turbines-work

Impact:

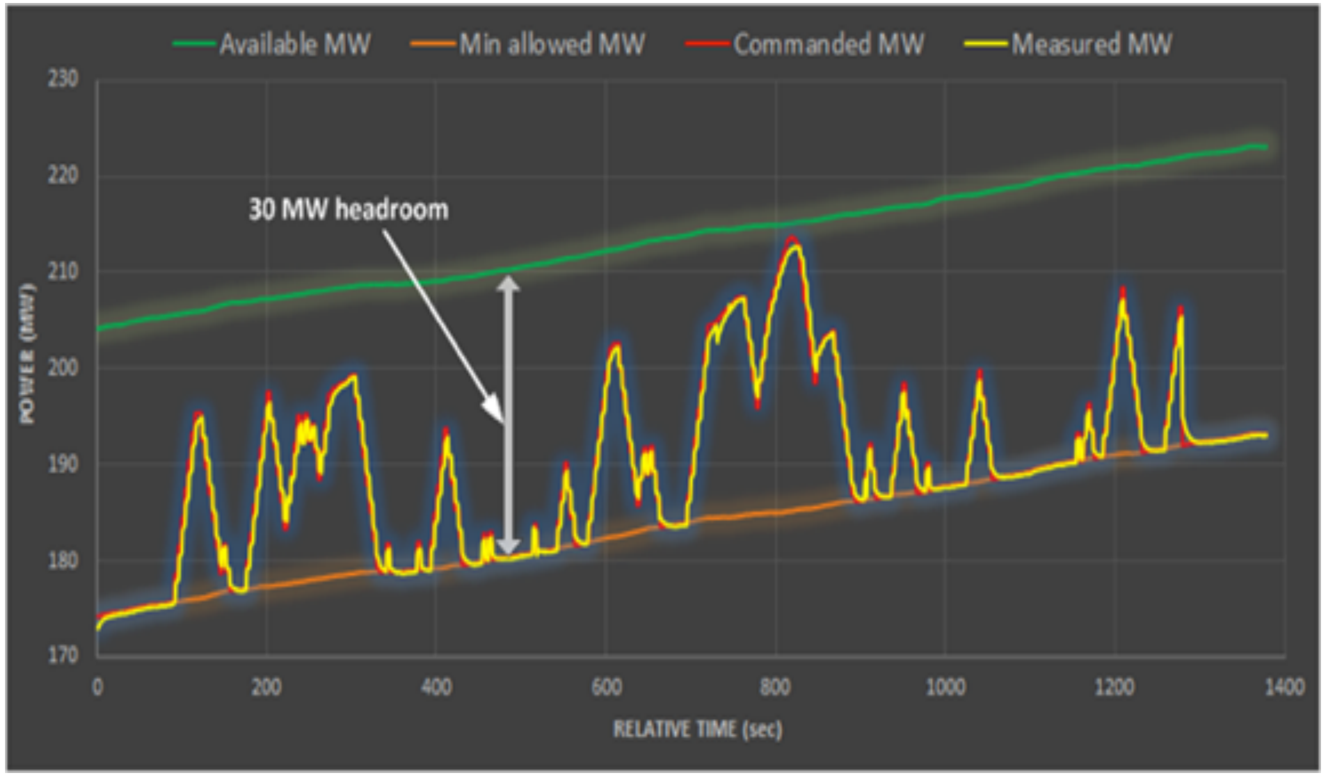
- Inertial control, primary frequency control, and automatic generation control (AGC) from wind and solar are feasible with negligible impacts on loading.



Source: E. Ela et al., *Active Power Controls from Wind Power: Bridging the Gaps*, http://www.nrel.gov/docs/fy14osti/60574.pdf

Grid Services from Solar Plants

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



300-MW PV Plant in California

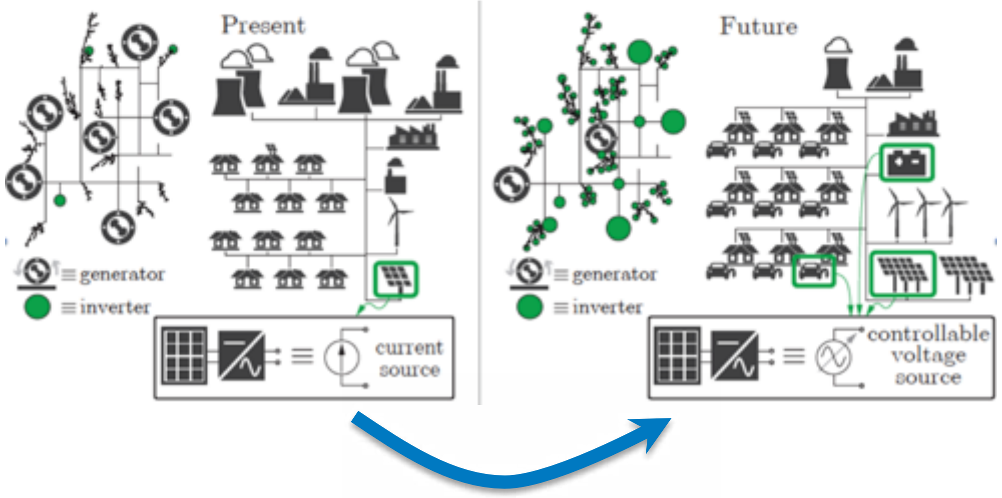
Photo from First Solar

Source: C. Loutan et al., *Demonstration of Essential Reliability Services by a 300-MW Solar Photovoltaic Power Plant*, http://www.nrel.gov/docs/fy17osti/67799.pdf

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?**

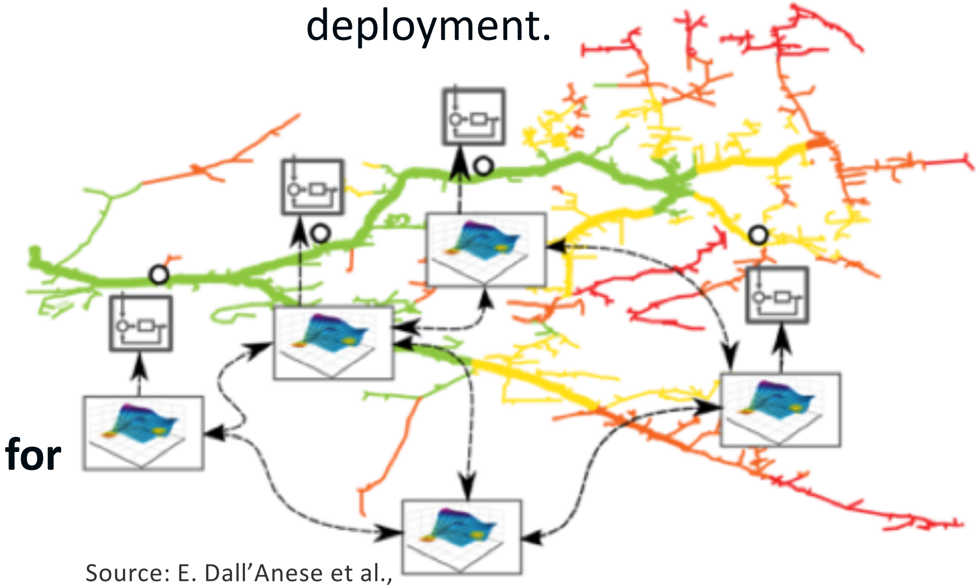
As we migrate from a centrally controlled, synchronous generator-based grid to a highly distributed, inverter-based system…



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

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.

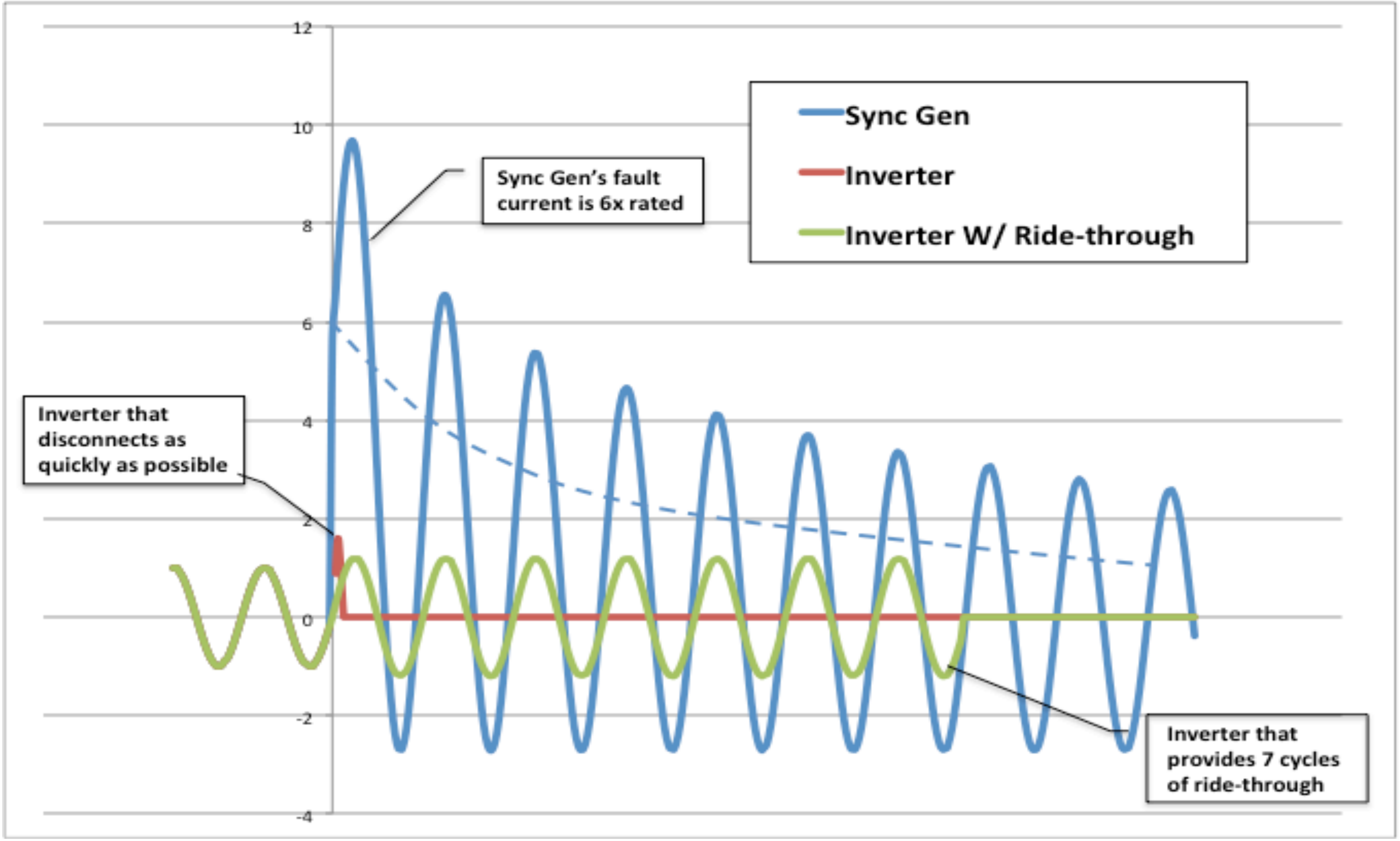


Improved optimization for millions of controllable devices in the grid.

Source: E. Dall'Anese et al., http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6920041

Other Technical Challenges

Protection Coordination



Source: B. Kroposki et al., "Achieving a 100% Renewable Grid – Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy," http://ieeexplore.ieee.org/document/7866938/

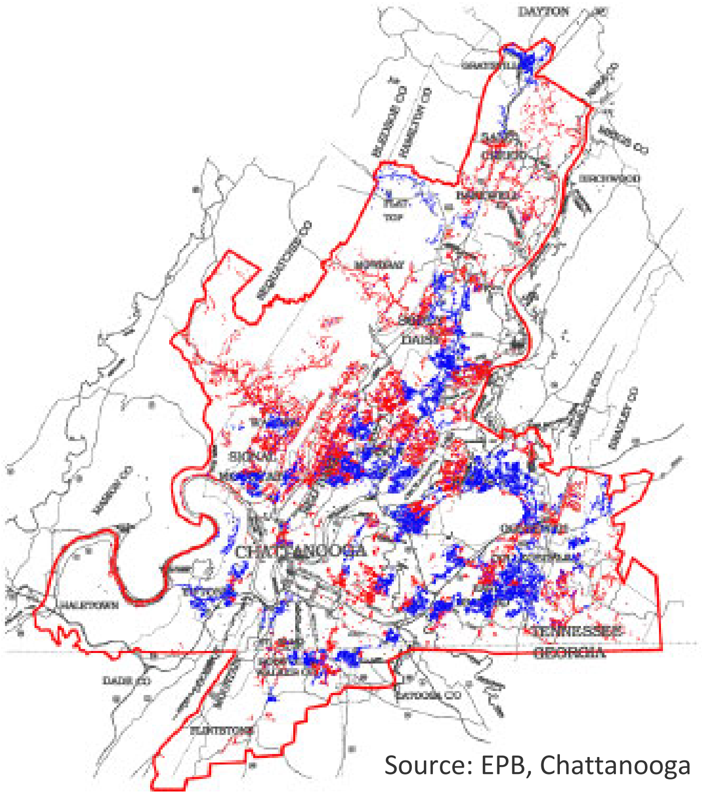
Problem:
Inverters can provide a wide range of fault currents, but typically not more than 1.2x

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

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**?

Utility Outage Map after Storm



Source: EPB, Chattanooga

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.

Needs to achieve grids with high levels of inverter-based resources

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 the 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

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www.nrel.gov/grid

Providing Solutions to Grid Integration Challenges

Thank You!