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ABB

Ensuring Grid Stability as the Power Generation Mix Changes

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Presentation Outline

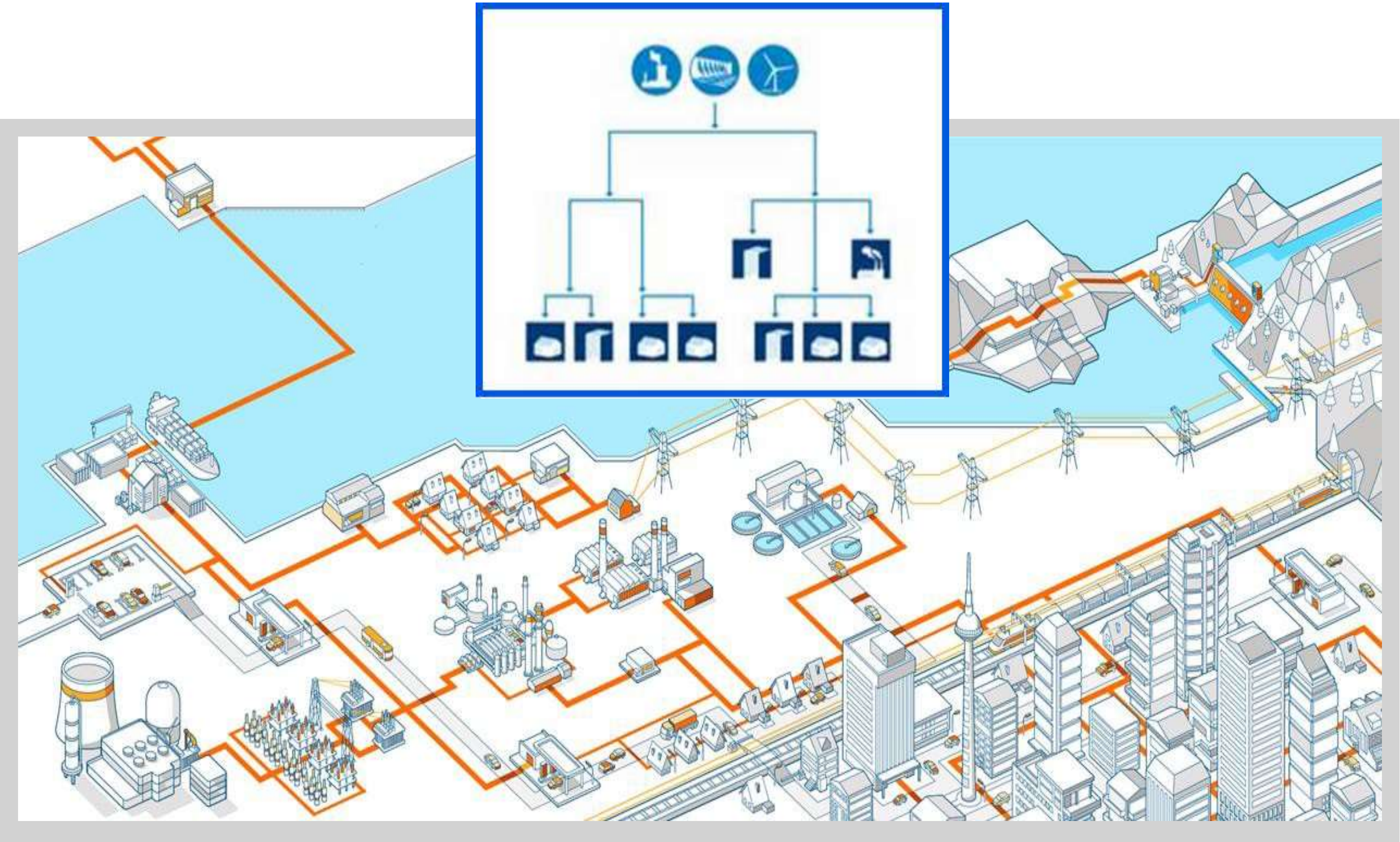
- Generation Mix
- Drivers Behind Changes in the Generation Mix
- Impact on the Transmission System
- FACTS and Technology Options to Manage System Reliability

The future power system

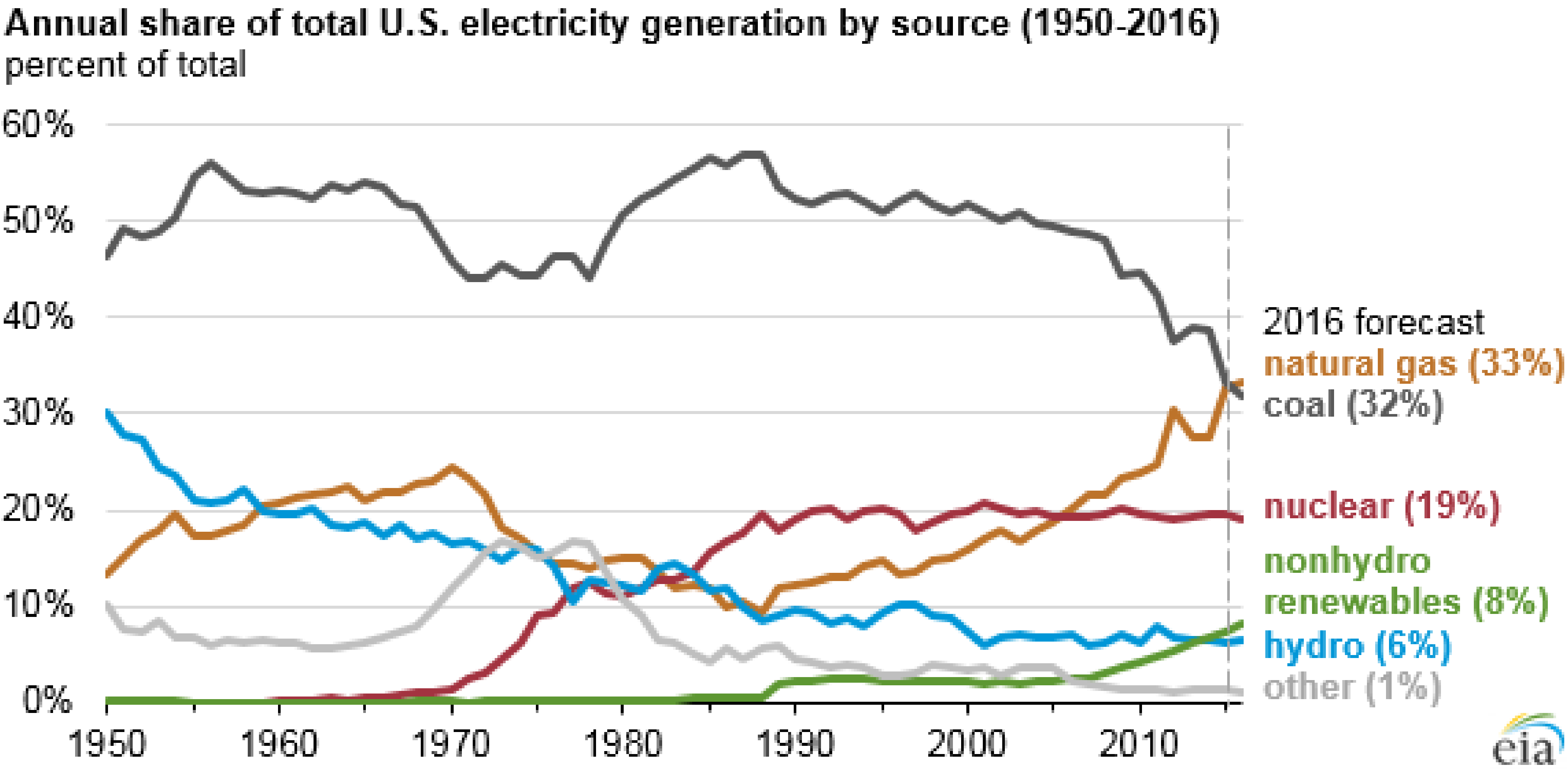
The traditional grid

- Centralized power generation
- Synchronous generators
- Motors connected to the grid
- One-directional power flow
- Generation dispatched to follow load
- Top-down operations planning
- Operation based on historical experience

Evolution

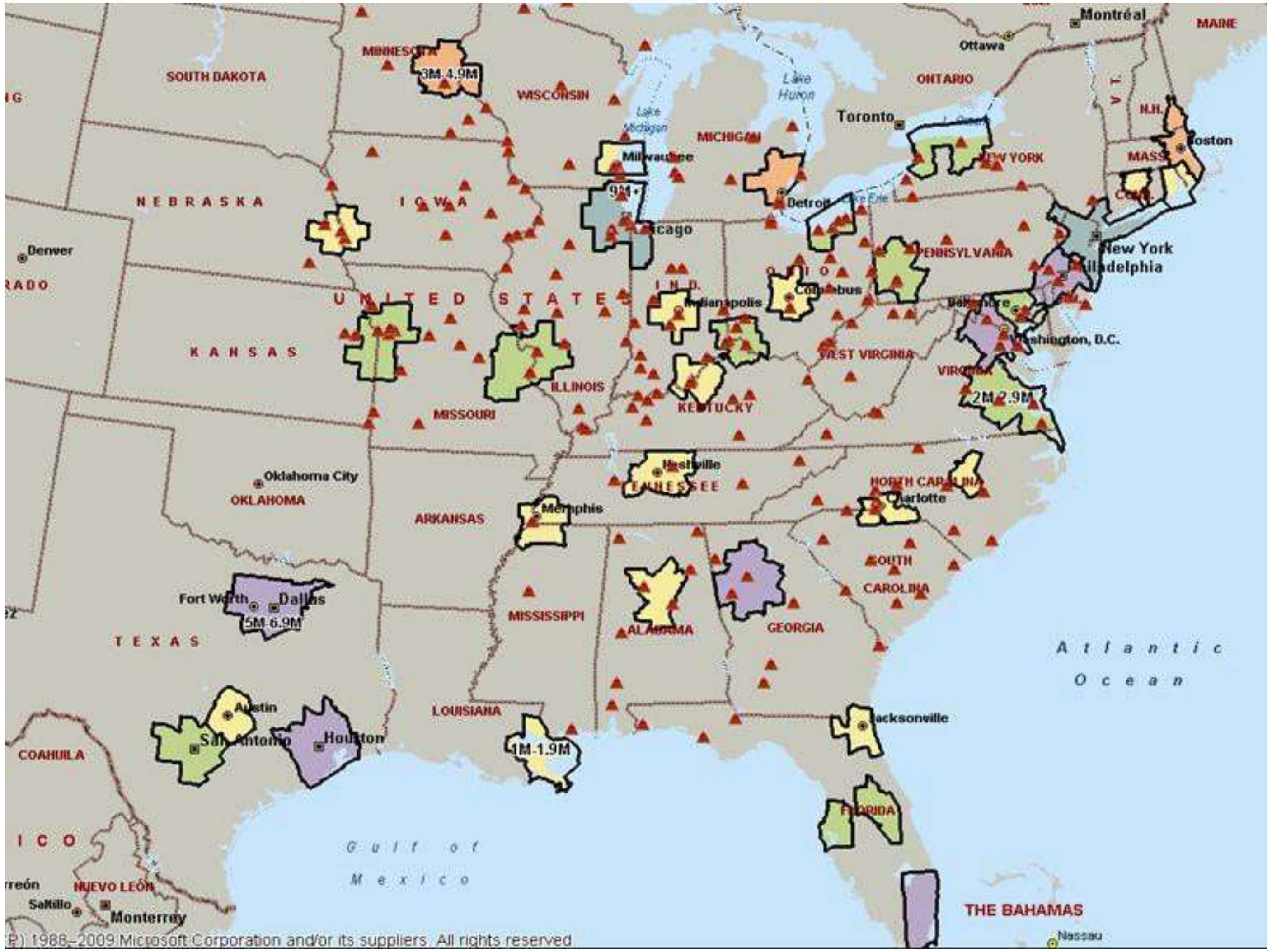


Maintaining Grid Stability as Generation Mix Changes



Source: US Energy Information Administration, https://www.eia.gov

Drivers Behind Coal Retirement

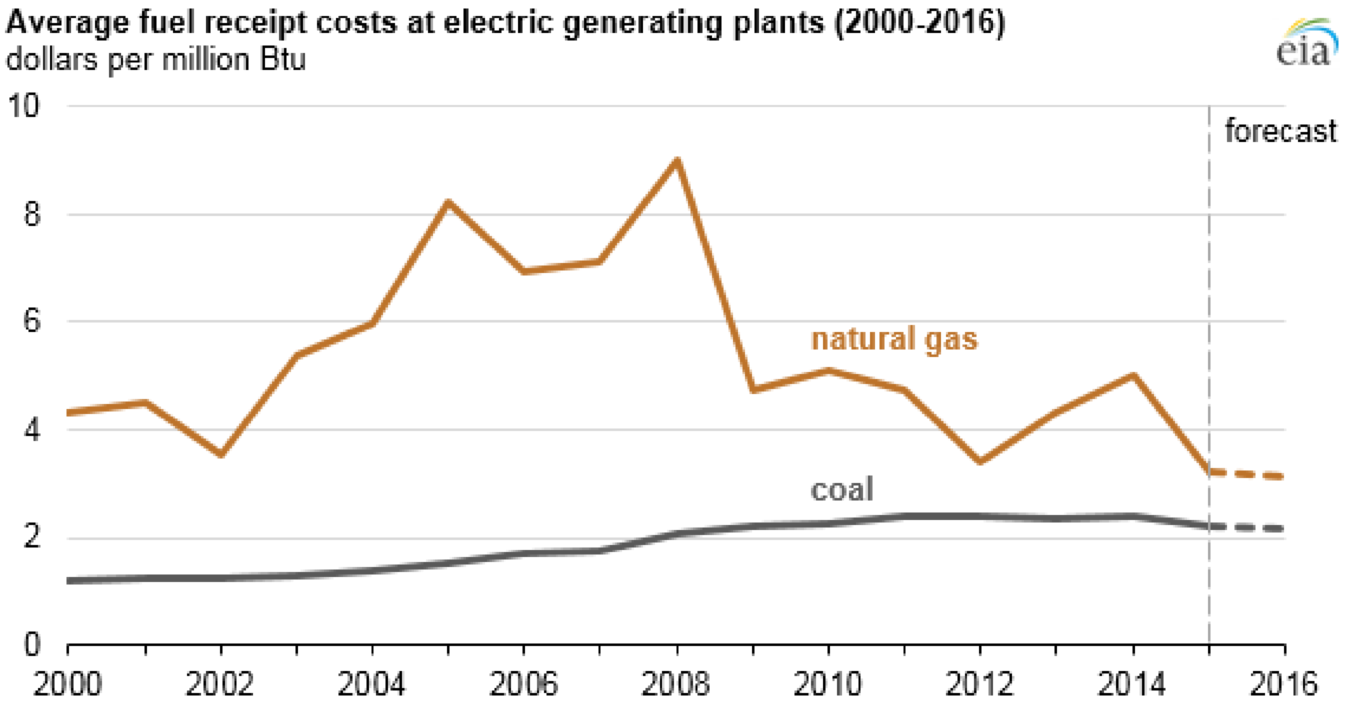


- Aging and inefficient coal fleet
- Rising construction cost
- Stable or falling natural gas price
- Increasing coal price
- Falling cost of renewables
- Slowing load growth
- Coal fired generation fell from 50 % to 37 % from 2008 to 2012 in the US.

Source: Lesley Fleischman, Rachel Cleetus, Jeff Deyette, Steve Clemmer, Steve Frenkel. *Ripe for Retirement: An Economic Analysis of the U.S. Coal Fleet*. The Electricity Journal, Volume 26, Issue 10, December 2013, Pages 51–63.

Drivers Behind Coal Retirement

- **Environmental Aspects** – new air regulatory requirements
- **Aging Baseload Generating Assets**
  Coal gen. high performance lifetime typically 25 – 30 years before outage frequency and maintenance increases
- **Fuel Cost** – reduced profit margins
  Coal price doubled between 2000-2010 while natural gas reduced by 50 %.
- **Dropping Load Growth** – system oversupply
- **Falling Cost for Renewables** – wind and solar PV are reaching the point of grid parity

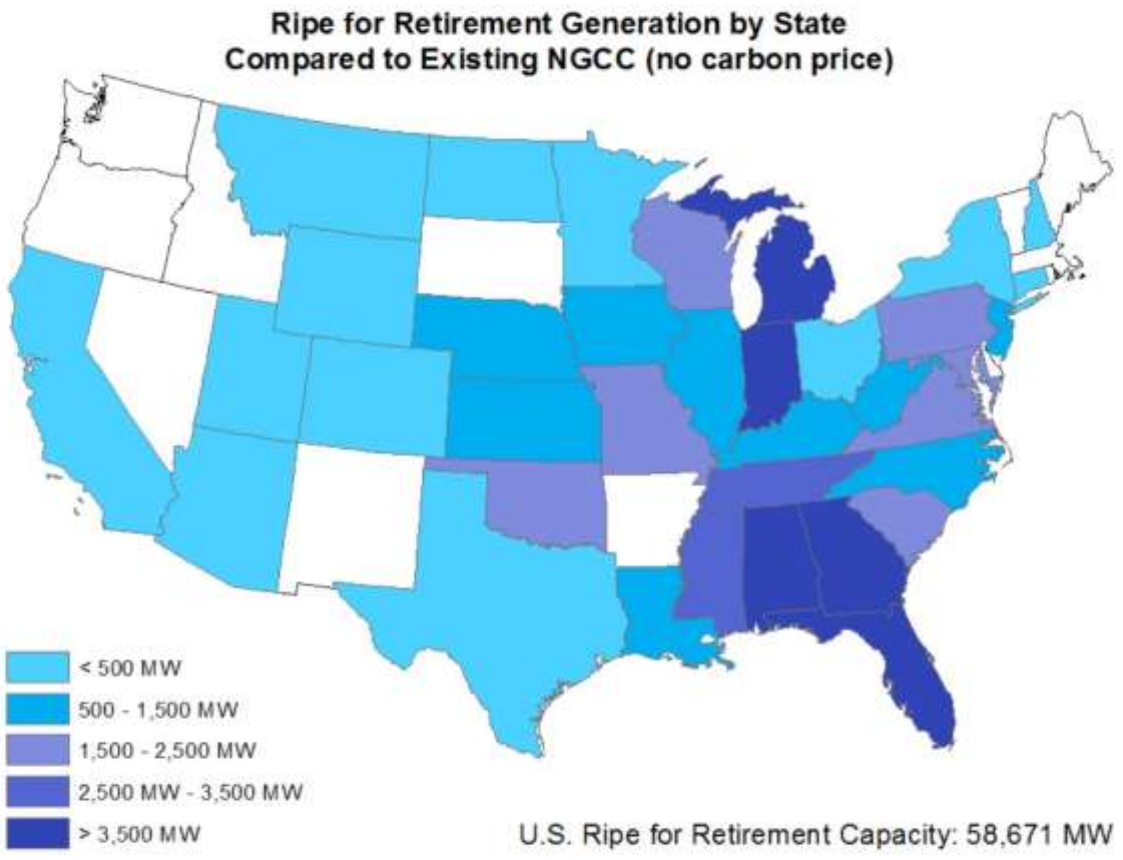


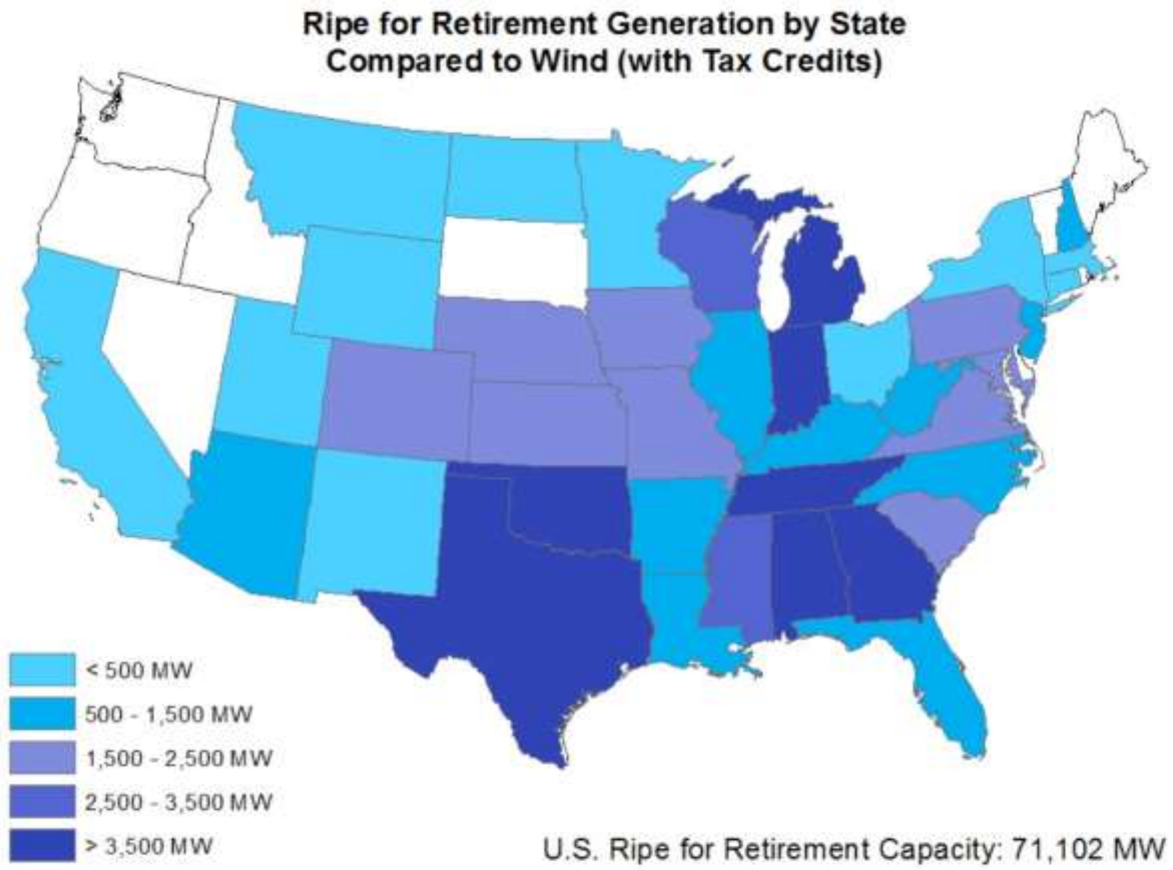
Source: US Energy Information Administration, https://www.eia.gov

BTU = British Thermal Unit, 1 BTU = 1055 J or the amount of heat required to raise the temperature of one pound of water by one degree F.

Renewables

Comparison Coal to NGCC and Coal to Wind





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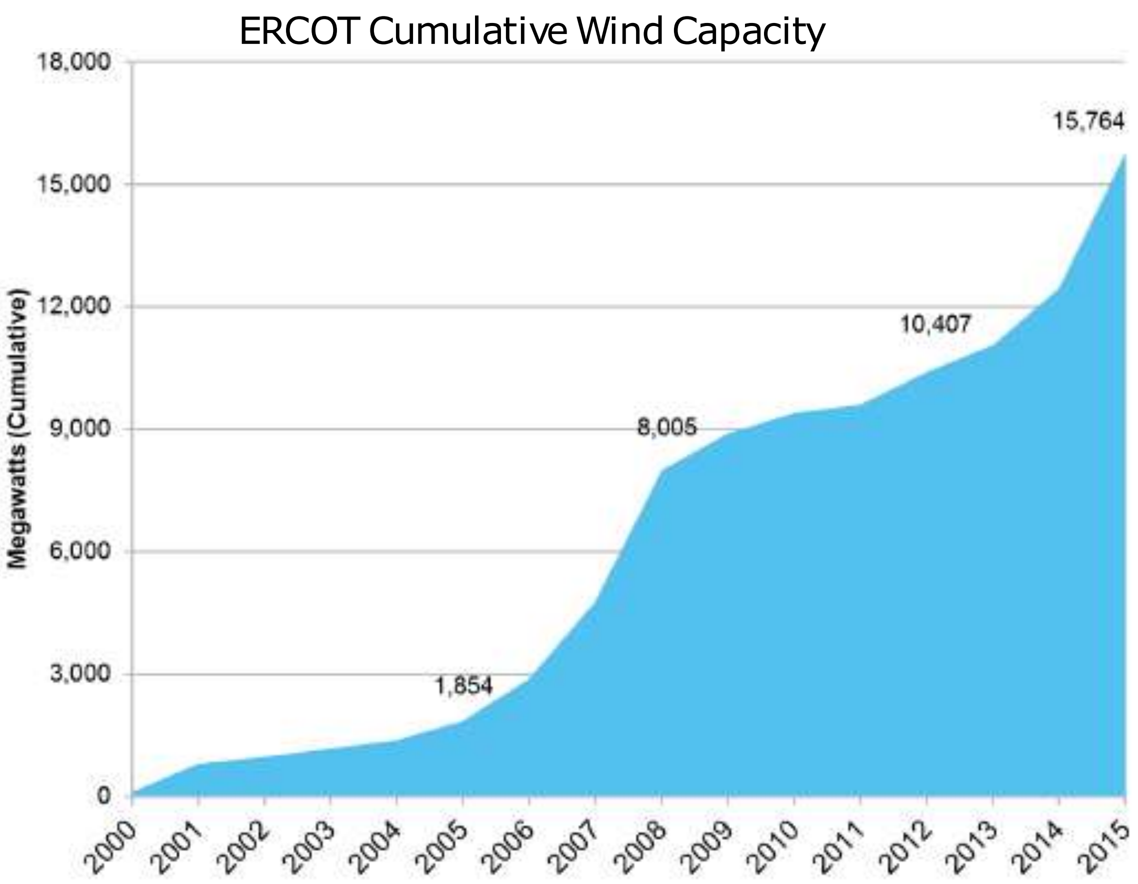
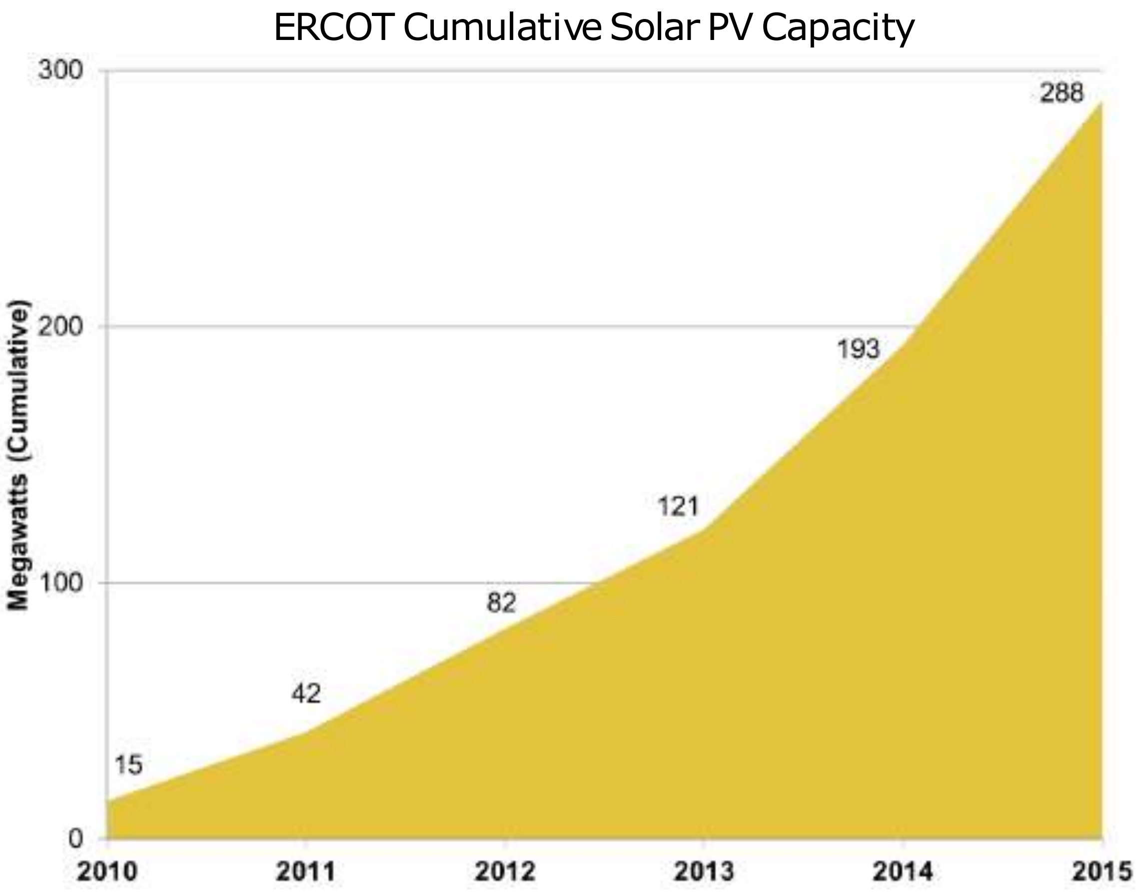
Renewables

Wind and Solar PV

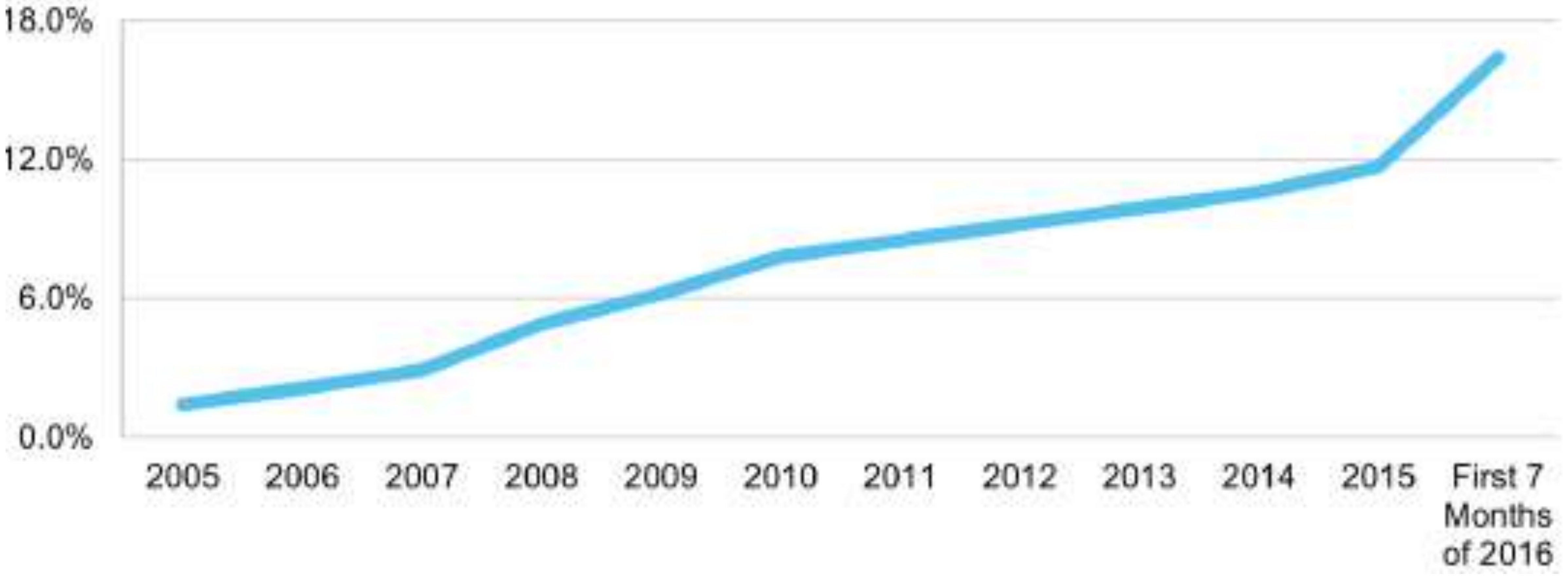




Source: ERCOT state of the grid report 2015

Renewables

ERCOT Annual Wind Generation Percentage of Total Generation

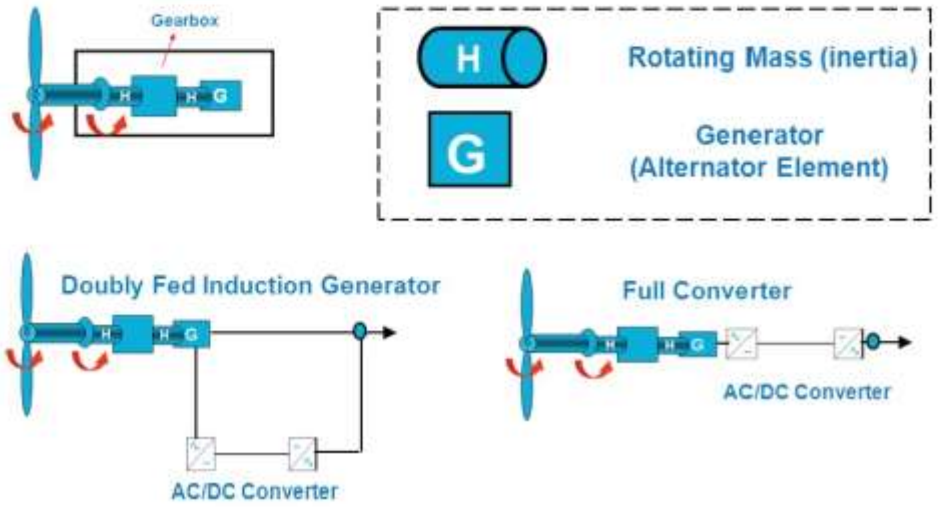


Source: ERCOT Energy by fuel type 2002-2015, available at http://ercot.com/news/presentations

Power System Concerns and Challenges

Integrating distributed renewable energies into the grid

Wind power turbines



Source: National Grid - Electricity Ten Year Statement 2014, Figure 5.21

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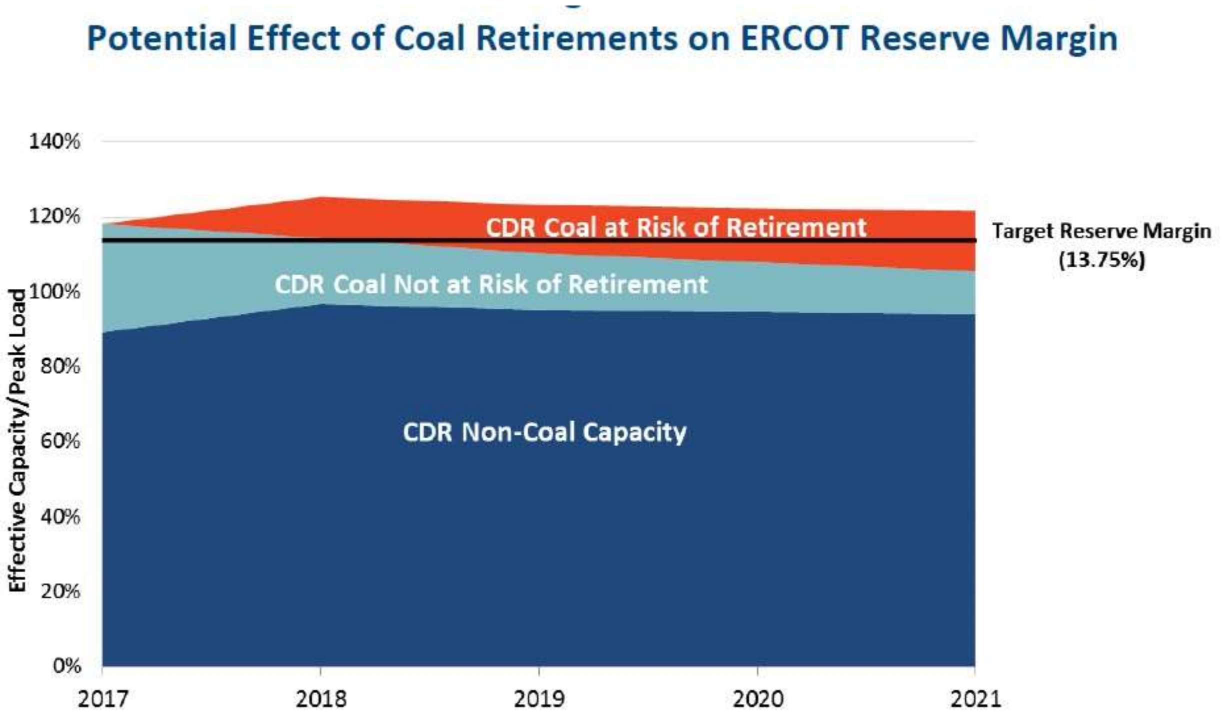
Wind generation deliver low or almost no Inertia

Impact on System Reliability

Planning Reserve Margin

- Generation capacity to meet expected demand and satisfy Resource Adequacy requirements
- Sufficient recourses to provide continuous supply regardless of outages, scheduled or unscheduled
- System ability to withstand unplanned, unexpected contingencies – Transmission Security
- Meet local source requirements – balancing generation and load



Source: Existing and planned capacity are based on ERCOT's May 2016 CDR; coal at risk of retirement is based on Brattle's analysis

Impact on System Reliability

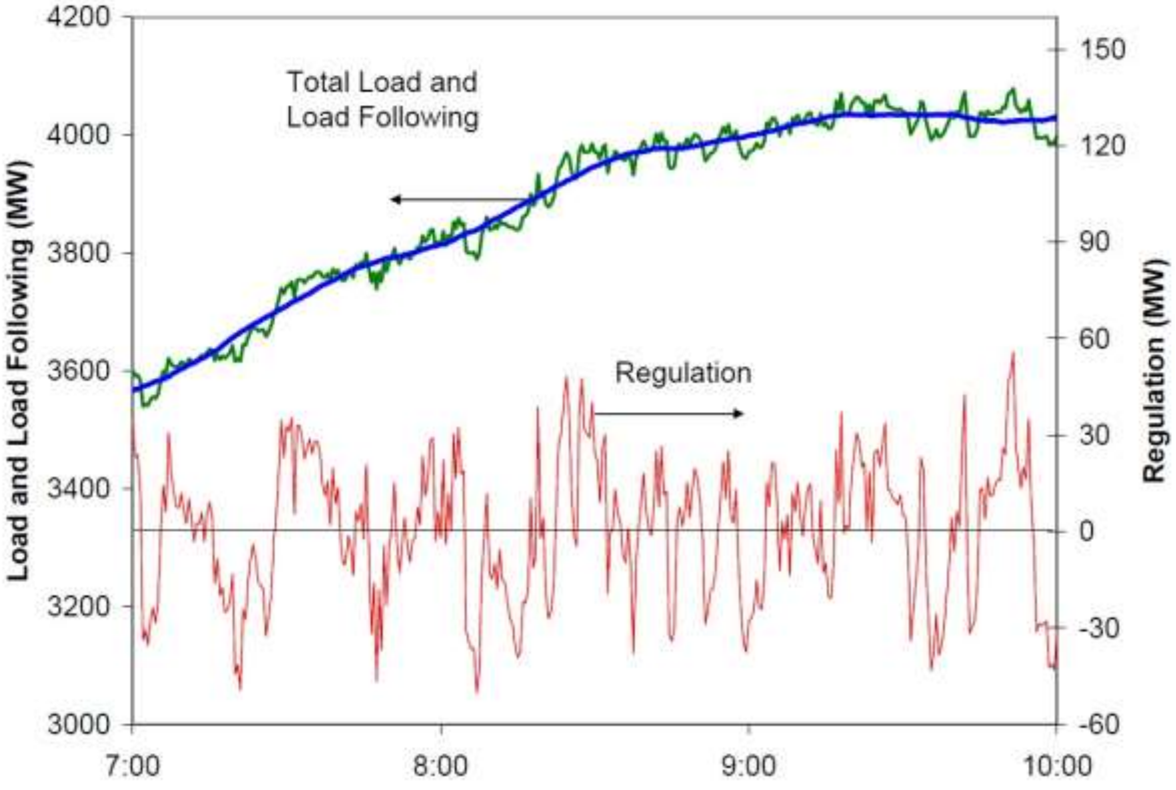
Ramping Power

- Control area load and generation has to be in balance

- Renewables increase need for Agile Ramping Power
  The typical large coal-fired thermal generator is able to
  ramp approximately 1 % of its capacity per minute
  Smaller units and combustion turbines are faster

- Regulation definitions varies between regions
  PJM/ISO-NE➔ 5 min. ramping capability
  ERCOT ➔ 15 min.
  WECC ➔ 10 Min.

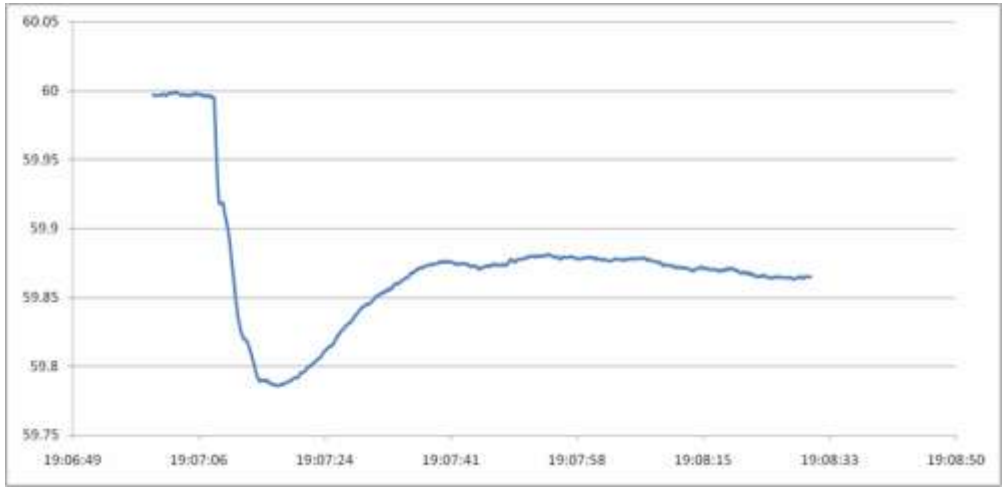
- NERC Control Performance Standard determines the permissible imbalance of a control area on 1 minute and 10 minute basis.

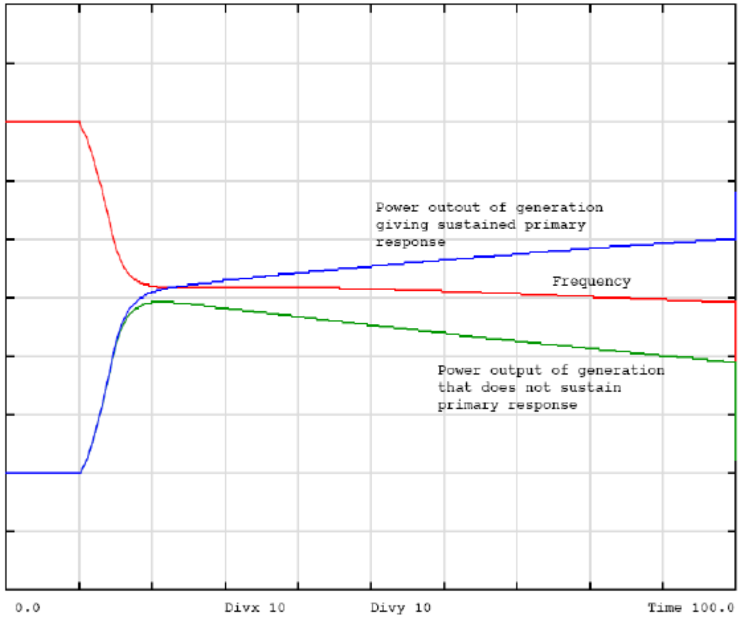


Impact on System Reliability

Frequency Control

- Active Power Deficit ➔ Frequency drop
- Active power surplus ➔ Frequency increase
- Relies on turbine governor control – <u>primary control</u>
- and planning reserve – <u>secondary control</u>
- Renewable Generation will ramp often
- Renewables are typically non responsive to frequency changes or BA load frequency commands



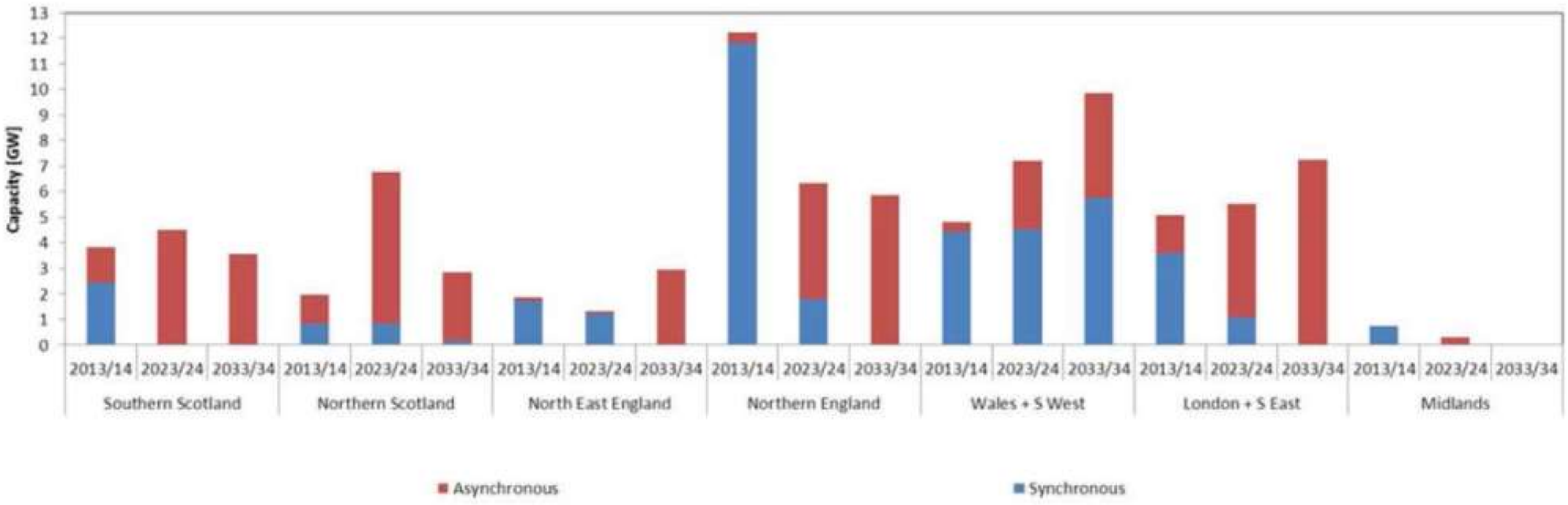


Impact on System Reliability

System Fault Levels

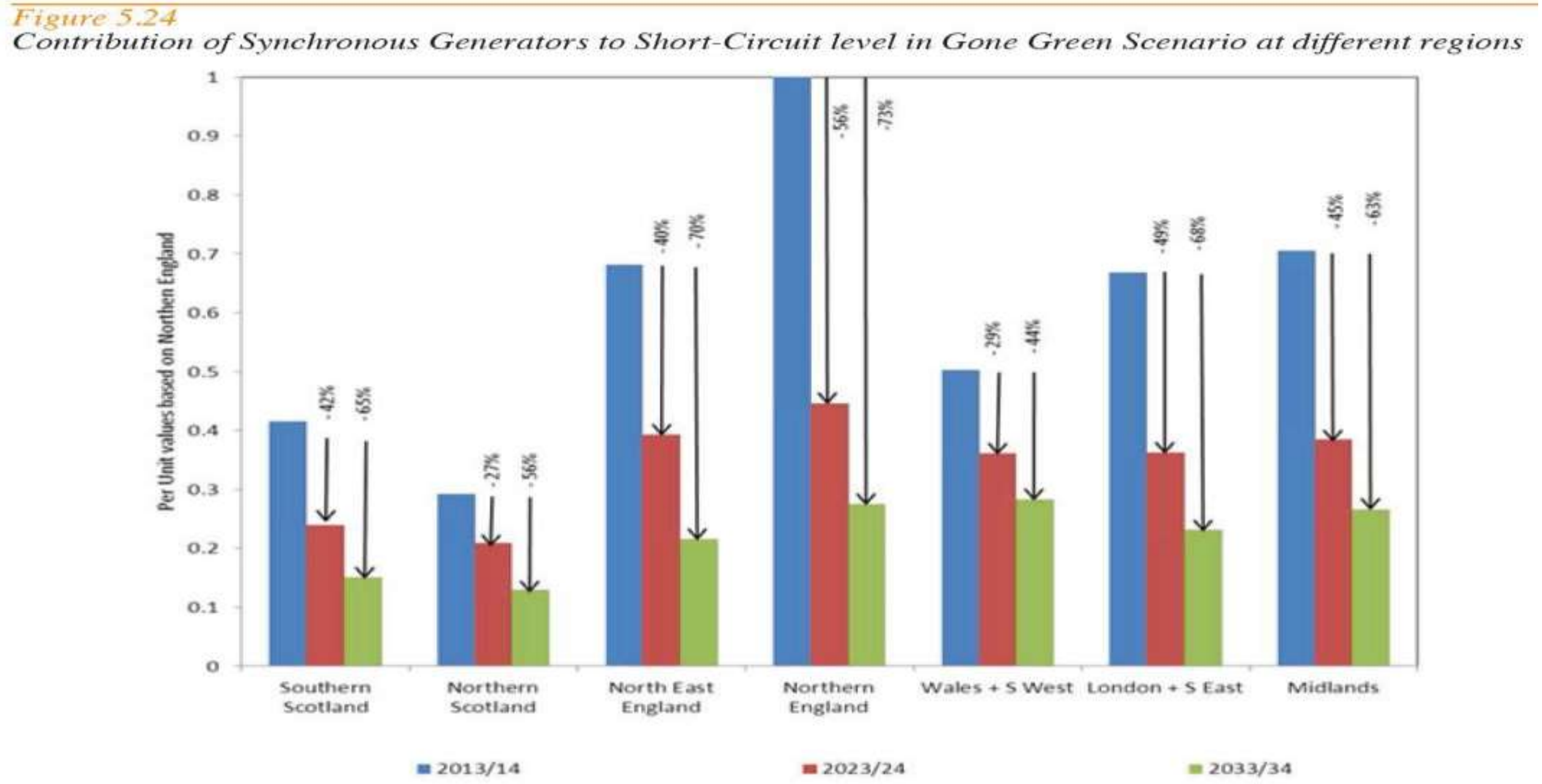
Figure 5.23

Installed Capacity of Synchronous vs Asynchronous Generation Contributing to 30GW demand in Gone Green Scenario at different regions



Source: National Grid Electricity UKTen Year Statement

System Fault Levels



Source: National Grid Electricity Ten Year Statement

Power System Concerns and Challenges

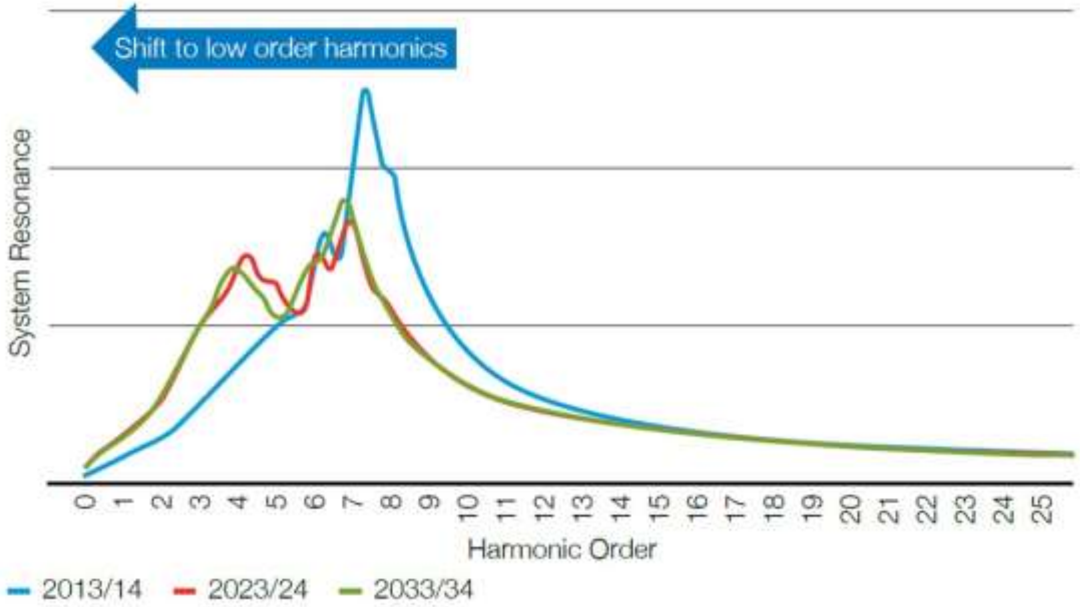
Shift of Resonance to low order harmonics

Implication on power system components

Power quality is an important aspect for power system because it affects the performance of the loads connected to the system;

- Shift in resonance towards lower harmonics means that the voltage distortions will be amplified for the low order harmonics, assuming the current injections are constant
- Increased harmonic stress the stress on existing shunt compensation devices (MSC, harmonic filters).
- Increased stress on power transformers

Harmonic shift

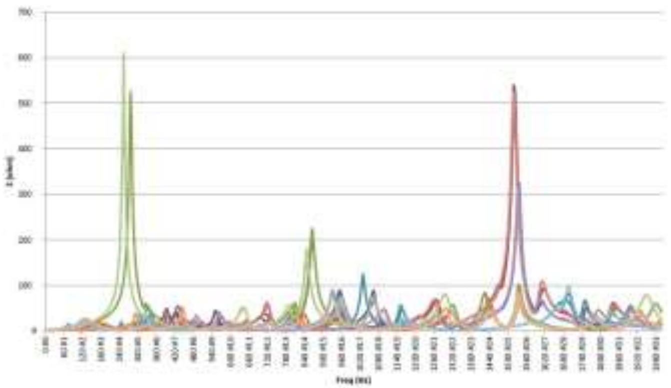


Shift of Resonance to low order harmonics – Amplification of harmonic currents

Power System Concerns and Challenges

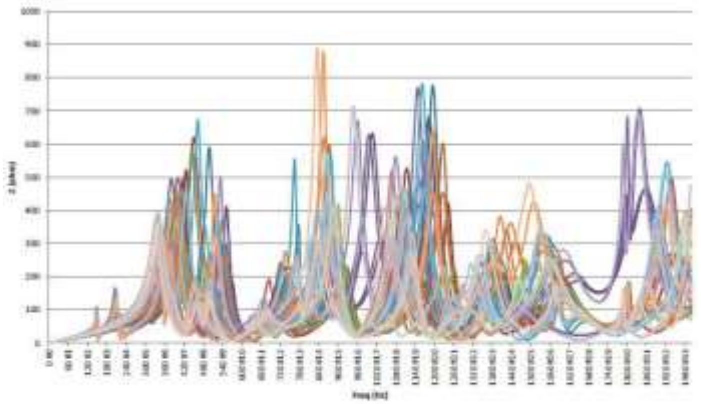
Grid Challenges – Robustness, network dependence

System Impedance - Typical



- Network impedance will change over time; different load scenarios, configurations, contingencies, generation

System Impedance - Future



- Large number of resonances due to fast growing network
- Parallel FACTS and HVDC

System concern and challenges

Resonance frequencies and system damping is affected by;

- Number of connected shunt banks – systems tend to become over compensated
- Cable and T-line charging capacitance
- Harmonic filters
- System loading (active and reactive)

Hybrid STATCOM, and STATCOM are less sensitive and dependent on network conditions

Impact on System Reliability

System Fault Level Considerations

- Fault Level is a measure of system strength
- Transferring Capability
- Angular stability
- Voltage Stability
- Selective system protection
- Susceptibility to harmonic distortion

Traditionally this is provided by synchronous generators driven by turbines at constant speed.

Impact on System Reliability

System Fault Level Considerations

- Fault Level is a measure system strength
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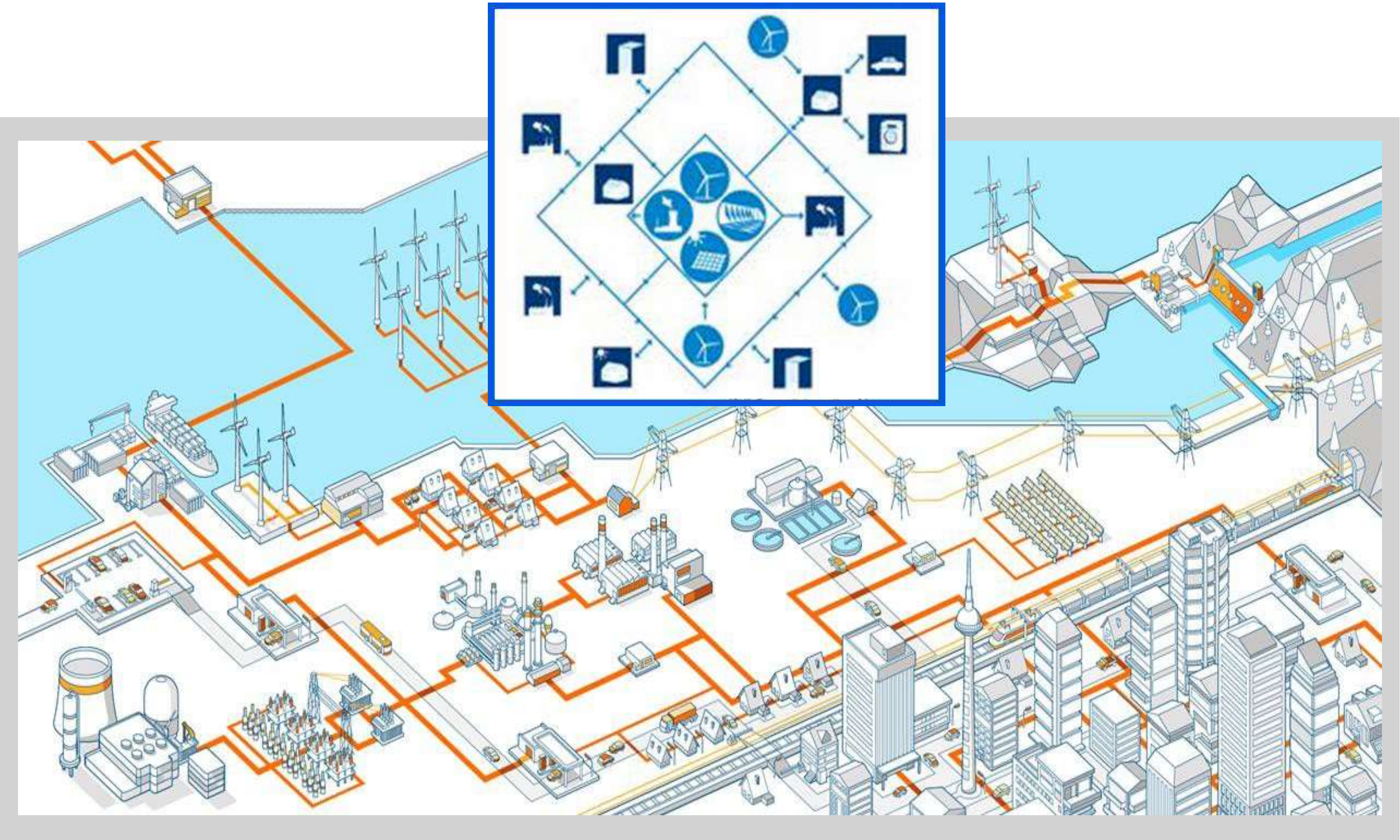
The future power system

The future grid

- Centralized and distributed generation
- Multi-directional power flow
- Intermittent renewable generation
- Consumption integrated in system operation
- More power electronics
- Operation based on real-time data
- Non-synchronous generation

Robust and flexible



FACTS Devices in Transmission

V_1 / δ_1 Power flow P → V_2 / δ_2

$$P = \frac{V_1 V_2}{X_{12}} \sin(\delta_1 - \delta_2)$$

SVC & STATCOM
Control voltage
dynamic reactive reserve

SC & TCSC
Boost Voltage Reduce
line reactance

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The future power system

Solutions - SVC & SVC Light® (STATCOM)

- For enhancement of the transmission grid the dynamic controllable reactive power sources acts in a more robust, flexible and predictable way. They control reactive power injection or absorption, provides dynamic voltage control, increases voltage stability, secures and enhances power supply and increases transmission capacity.

- SVC or SVC Light (STATCOM) are both doing a similar job. SVC is based on thyristor technology and SVC Light is based on transistor (IGCT/IGBT) technology. The requirements and application (network issues) determines what technology to be used.

- Selection of technology can be part of manufacturer's optimization process, this will give the most optimal installation.

Klafastadir SVC, Iceland

The future power system

Solutions - Series Capacitors

Series Capacitor

- More renewable power transmitted through existing lines
- Reduced reactances, leading to angular & voltage stability & increased power flow
- Technology to reduce TRV

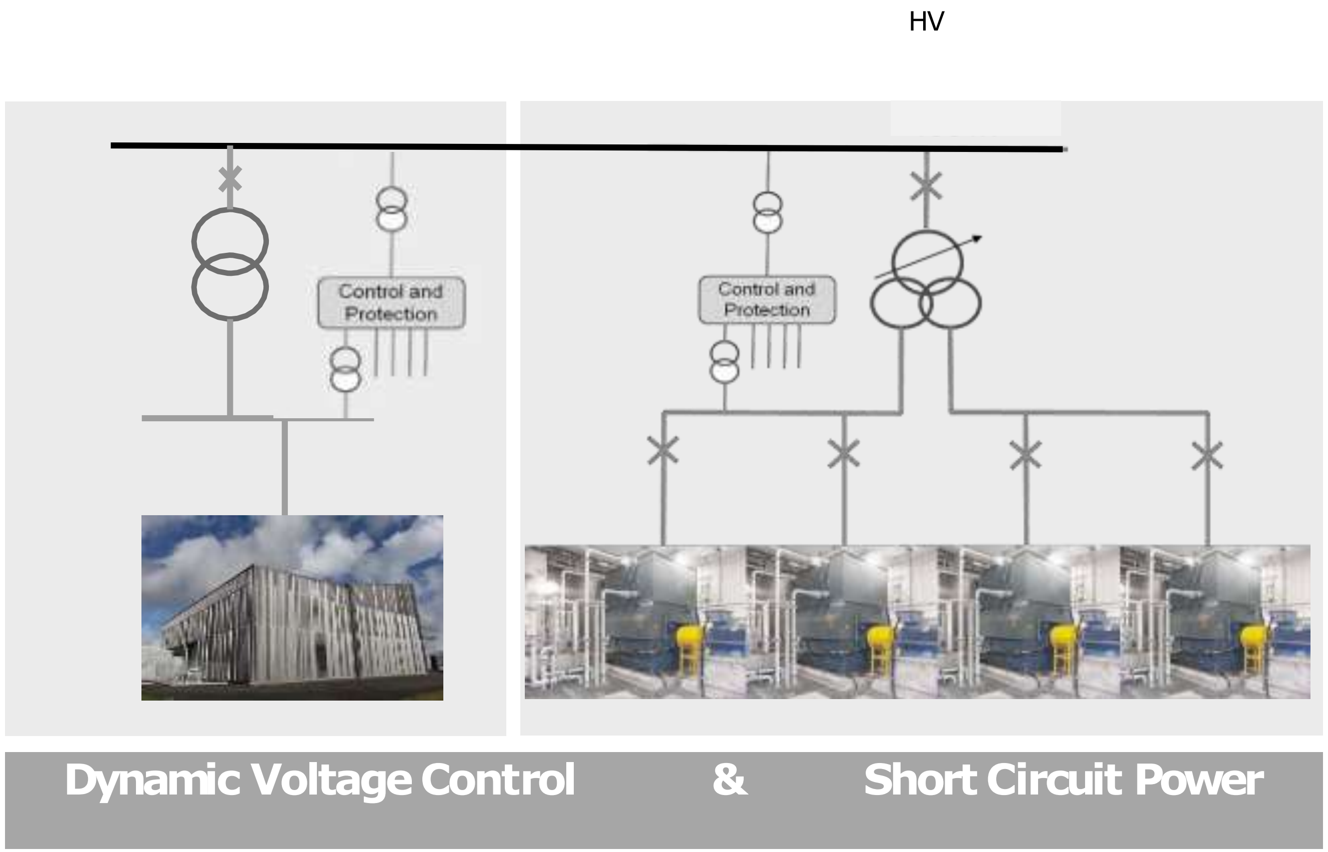
Thyristor Controlled Series Capacitor (TCSC)

- Elimination of sub synchronous resonance risks
- Damping of power oscillations

The future power system

Example - Synchronous Condenser

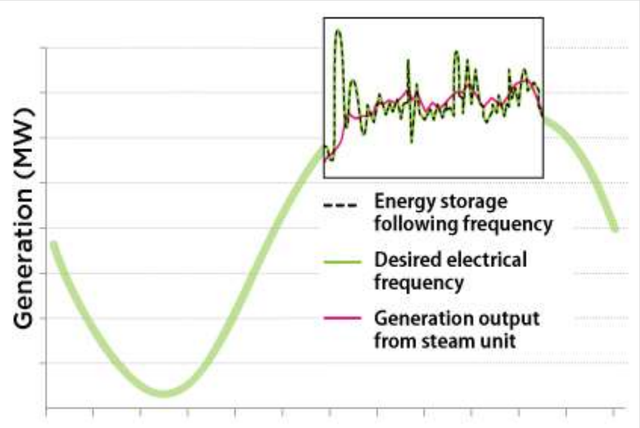
- Synchronous generators have been used from the start of the power system.
- They deliver services that we have, more or less, taken for granted. They provide the power system with voltage control and short-circuit power.
- When we replace synchronous generators, for various reasons, with new production (wind or solar) the connection to the grid is via a power electronic converter and inertia and short circuit contribution is much less.
- Solutions to the potential problems that arise when decreasing system inertia and short-circuit power are today investigated.



The future power system

Example – Energy Storage

- Used to reconcile momentary differences between generation and loads, the energy storage system is charged or discharged in response to an increase or decrease, respectively, of grid frequency
- Requires instant response on a second-by second basis to maintain grid frequency at 60Hz
- Energy storage can instantly respond to changes in frequency by injecting or absorbing real power
- Here is an example of a 20 MW energy storage system that participated in the PJM Frequency Regulation market
- This system used lithium-ion batteries



Frequency Regulation & Energy Storage

The future power system

Example – Energy Storage

- Aliso Canyon natural gas storage facility experienced a catastrophic leak in Oct 2015
- The lack of fuel supply caused sever constraints on the grid which threatened to cause power outages
- To quickly respond to these issues, SCE placed three energy storage systems at the location that totaled 70MW
- a portion of the capacity of the gas storage facility was used to provide hourly peak electric generation demands
- The battery installations were able to absorb low cost energy (from the middle of the day) and discharge during the evening hours when demand is high

Peak Demand & Energy Storage

Power System Concerns and Challenges

Change in System Characteristics

Reduction in system strength

Reduce short circuit levels due to large amount of renewables will have an impact on;

- Relay protection systems;
- Level of harmonics in the grid;
- Level of voltage dips and post fault voltage recovery profiles;
- Increased potential of commutation failure of HVDC

Shift of harmonic resonances

The reduction in strength of the system may potentially cause the network resonance to shift towards lower order harmonics, causing amplification of voltage distortion.

The shift of resonances towards lower harmonics may also increase the stress and robustness of existing shunt compensation devices (MSC, harmonic filters).

Voltage recovery

Recovery of the voltage to pre-fault level for a weak system will require fast acting shunt equipment providing voltage sufficient reactive power support;

- to avoid voltage collapse
- to maintain the grid capability required to meet the demand at different regions

The rising share of renewable energies is influencing the robustness of our grids.

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