ELECTRIC TRANSMISSION 101: Operational Characteristics

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Objectives

Primary objective is to understand how the power system* operates in 20 minutes or less with emphasis on transmission.

- Understand the elements of the bulk power system
- Understand basic physics and control of the system
- Understand the practical limitations to the system
- Understand what options exist in overcoming the limitations and why they are important.

* Note it is the presenter's opinion that the power system is the largest, most complex machine ever designed by humans so this task is monumental

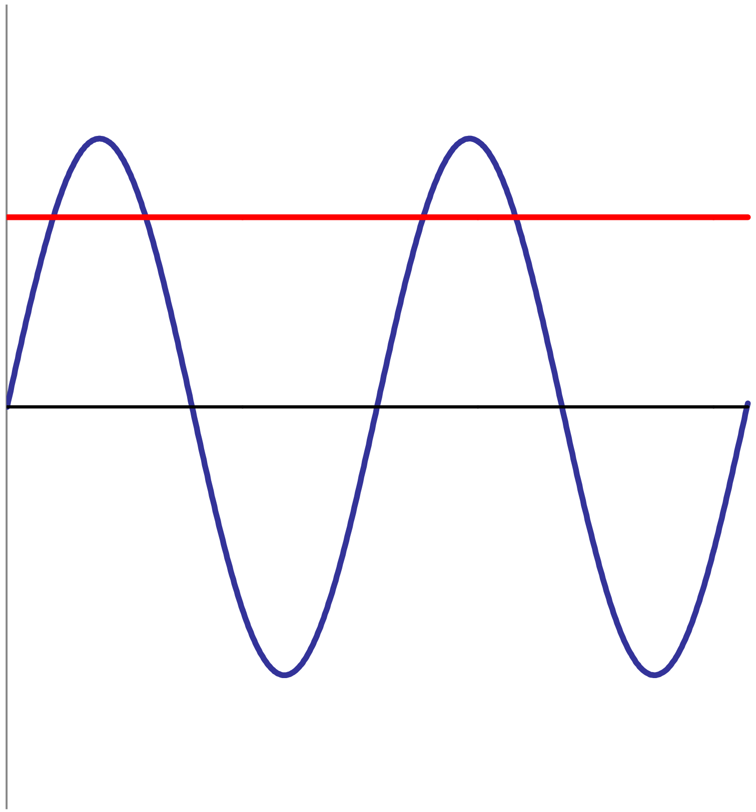
Basic Definitions and Components of the Power System

Basic Definitions

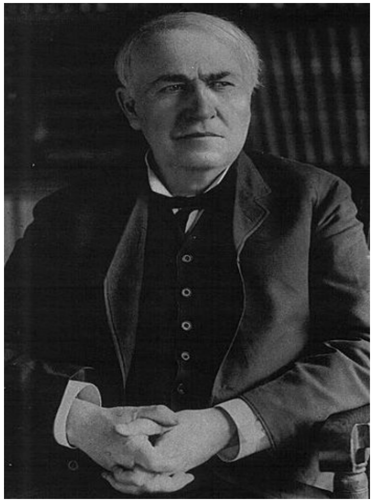
- Voltage – electrical "pressure" measured in volts. For power systems we typically measure in 1000's of volts or kilovolts (kv)
- Current – the movement of charge (electrons) through a conductor. Measured in Amperes (A)
- Power – Rate at which electricity does work. Measured in Watts or more typically kilowatts (kW) or megawatts (MW)
- Energy – The amount of work that can be done by electricity. Measured in Watt-hours or more typically kilowatt-hours (kWh) or megawatt-hours (MWh).

Basic Definitions

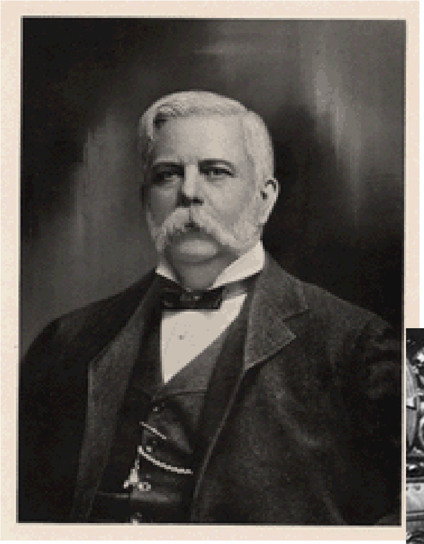
- Alternating Current – (AC). Magnitude of current and voltage varies with time. Most of grid is AC
- Direct Current (DC) – magnitude of current and voltage is constant. Applications of high voltage direct current (HVDC) in U.S. and elsewhere.

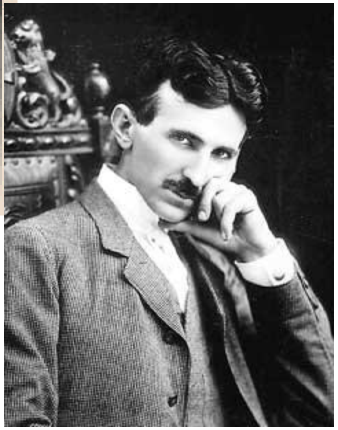


War of the Currents (late 1880s)



- Thomas Edison (1847-1931)
- Advocate of direct current (DC) power system
- Founder of General Electric



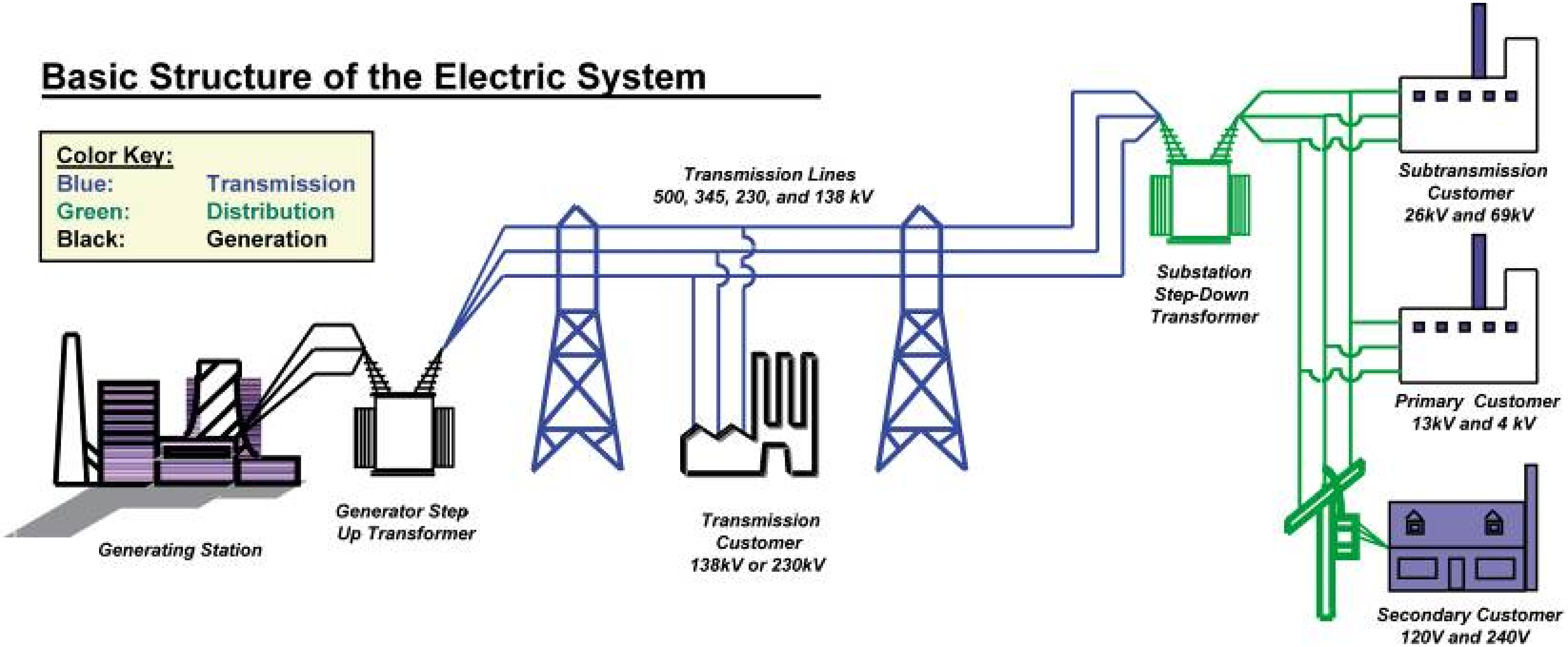


- George Westinghouse(1846-1914)
- Nikola Tesla (1856-1943)
- Advocate of alternating current (AC) power system
- Founder of Westinghouse Electric Corporation
- Licensed polyphase machines from Tesla

Basic Definitions

- **How much is 1 Megawatt (MW)?**
  - 1 MW is one million watts.
  - 1 MW will power 10,000 one hundred watt light bulbs
  - 1 MW will power about 800 “average” homes in North America or about 250 “average” homes during the summer in Phoenix

Components of the Grid: Overview



Source: www.nerc.com

- The “grid” can be broken down in to four main components: Generation, Transmission, Distribution, and Load

- This diagram is a basic overview, but does not truly illustrate the *HIGHLY* interconnected nature of the transmission system.

Components of the Grid: Generation

- "Creates" electric energy
- Generation is fueled by coal, nuclear, wind, gas, biomass, solar, and hydro.

Components of the Grid: Load


- “Consumer” of electric energy
- Loads can be smaller than your cell phone hooked to its wall charger (say 1 watt) or as large as an industrial facility (in the 10’s of millions of watts)

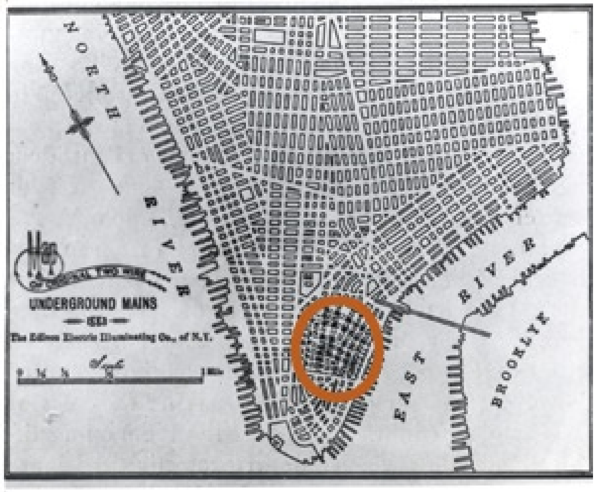
Components of the Grid: Distribution

- Primary purpose is to serve loads (your house is connected to a distribution system)
- Generally radial (non-networked) in nature
- Not used for interstate commerce

Components of the Grid: Transmission

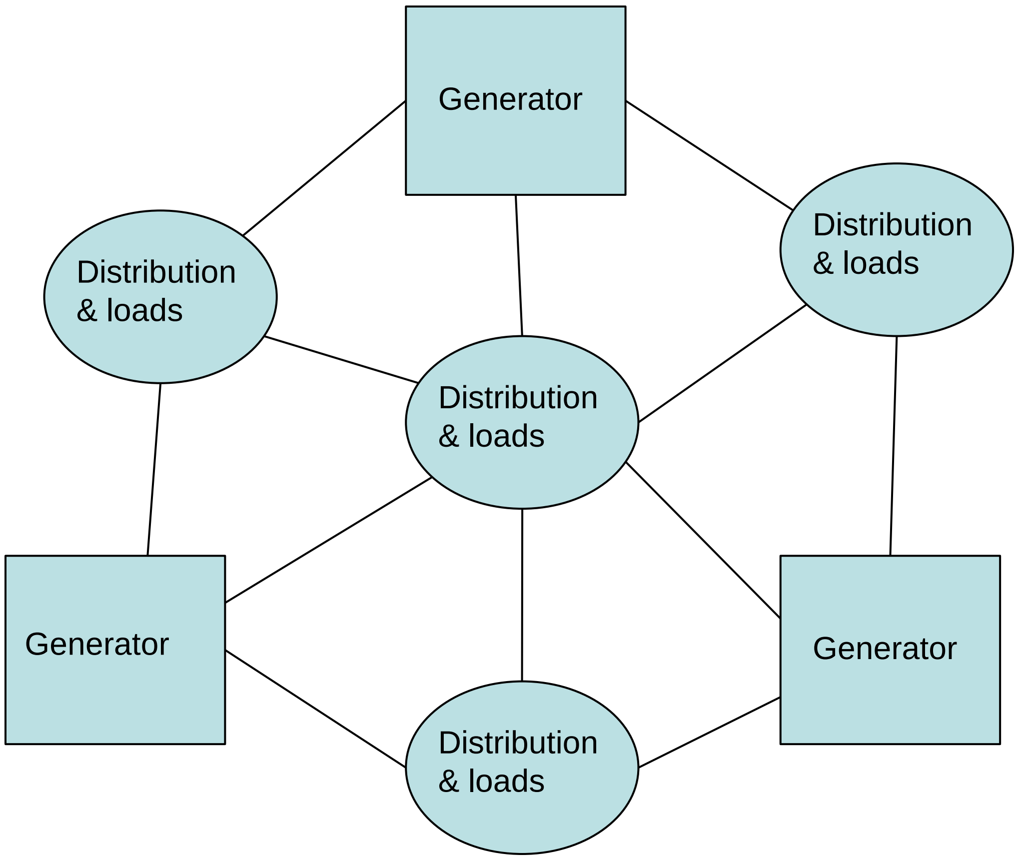
- Used to move power relatively long distances from generators to load with lower losses.
- Highly interconnected for enhanced reliability
- The “interstate system” for electricity
- Traditionally built to enhance reliability for vertically integrated utilities.
- Now a critical part of the electric markets

Without Transmission



- **Pearl Street Station: 255-257 Pearl Street, Manhattan**
  - First central power plant in U.S.
  - Edison Illuminating Company
  - 1882 – 1890
  - Direct current
  - 508 customers
  - 10,164 lamps

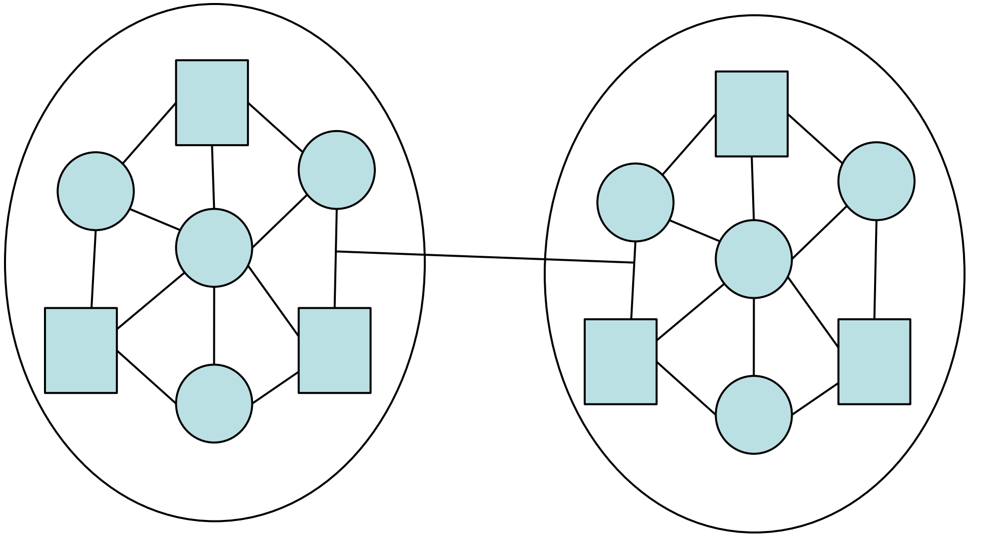
With Transmission



- We can build generation in areas removed from the loads
  - More desirable environmental and fuel factors
- We can build larger, more efficient generators
  - Economies of scale
- We can get power to remote areas with lower losses
  - Rural electrification

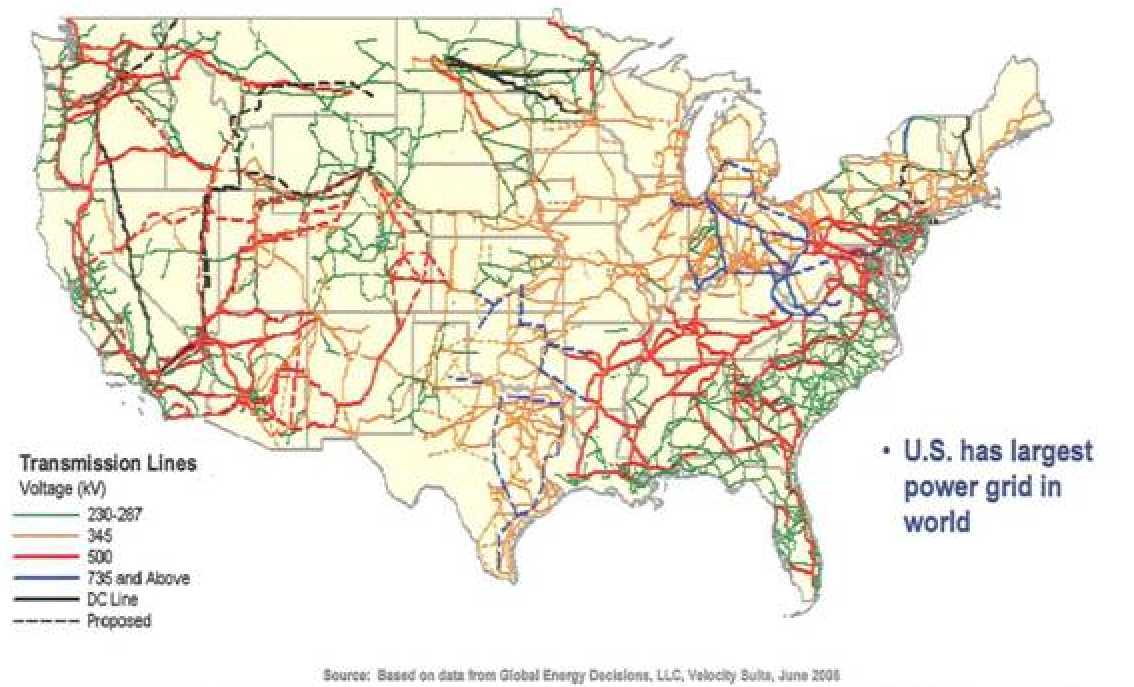
With Transmission

- We can create robust interconnected networks
  - Increased reliability
  - Decreased costs
  - Makes possible power pools, markets, bulk power transactions



Components of the Grid: Transmission

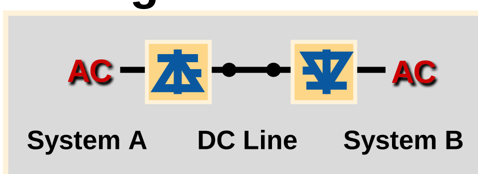
- Unlike highways, pipelines, and telecom, the flow of electricity on the AC grid can not be easily routed or controlled. Power flows via the path of least resistance. This is a critical difference in how the grid differs from other transportation mechanisms



Components of the Grid: Transmission AC or DC

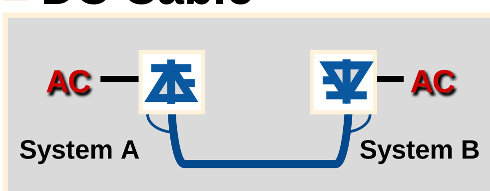
- A function of technological history, the grid is largely AC; however, HVDC has some well defined applications and benefits in the interconnected grid

- **Long Distance**



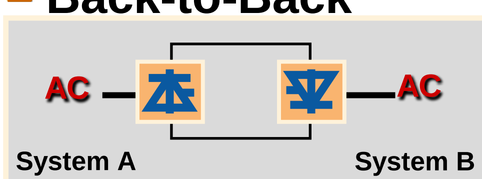
Economical solution for distances greater than ~350 miles.

- **DC Cable**



Solution for long submarine transmission (40+miles)

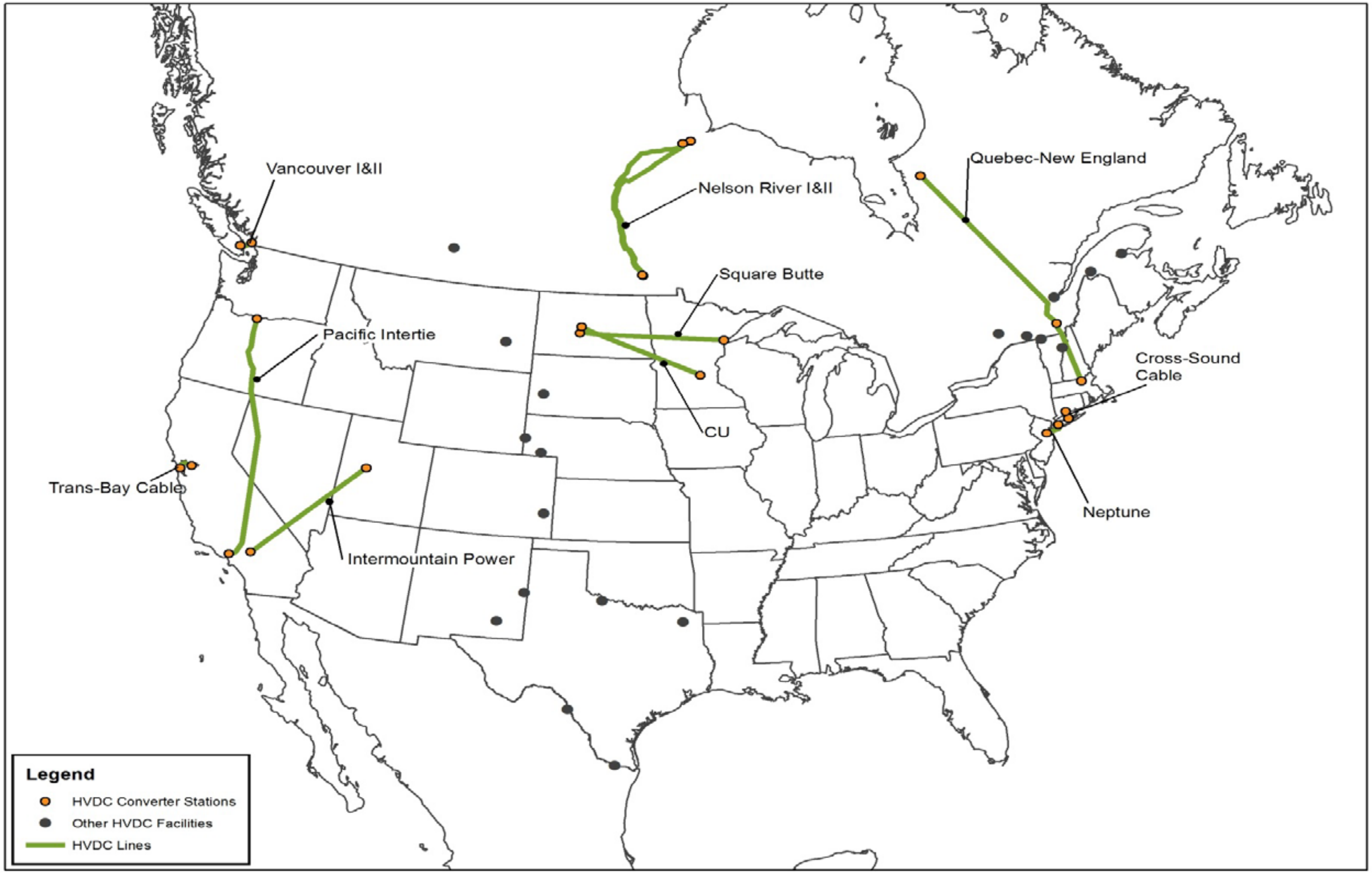
- **Back-to-Back**



Unique solution for power flow control, asynchronous systems, different frequencies.

Graphics courtesy Siemens

HVDC in North America



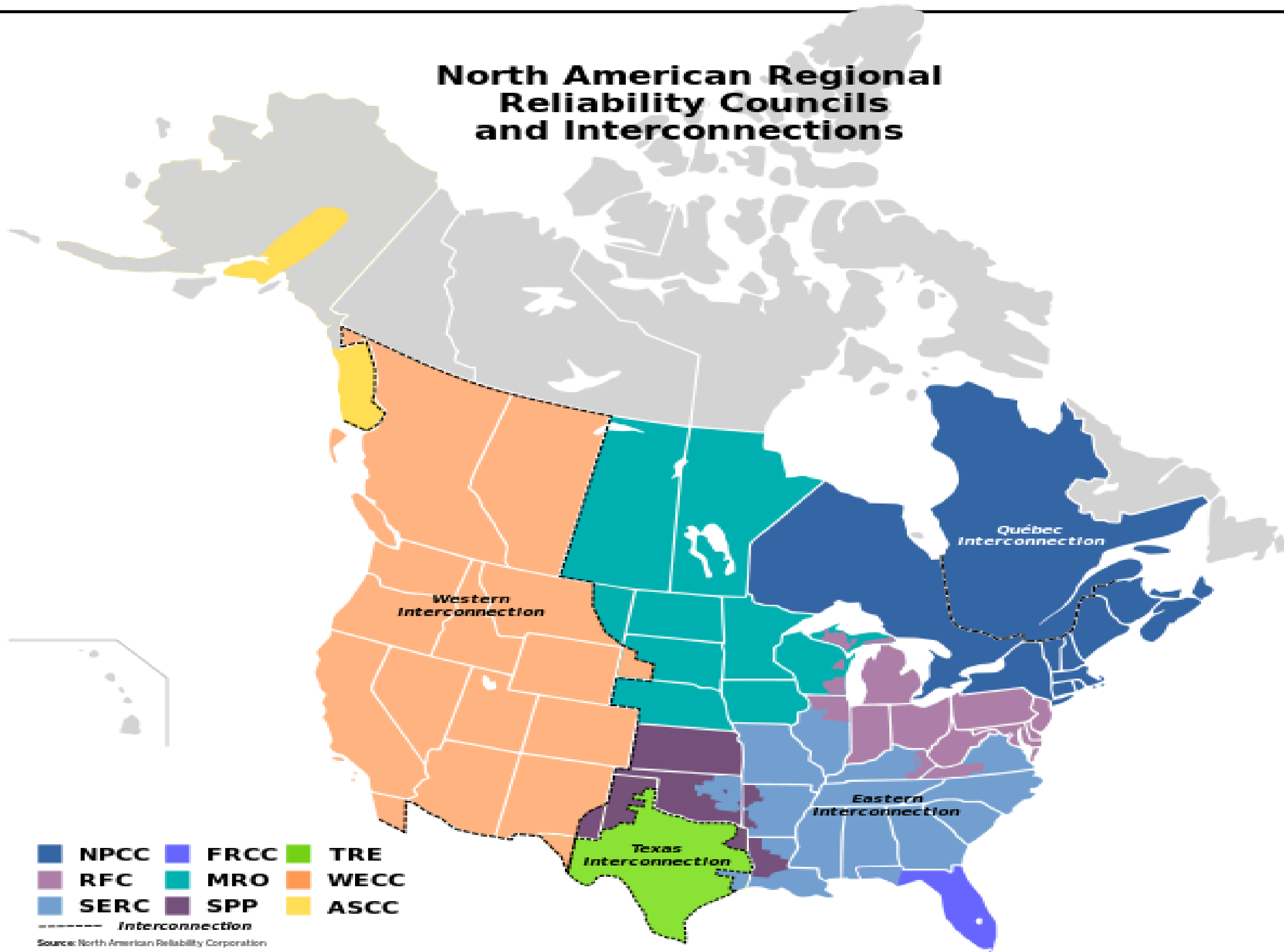
How the Grid Is Controlled

Interconnected Operation

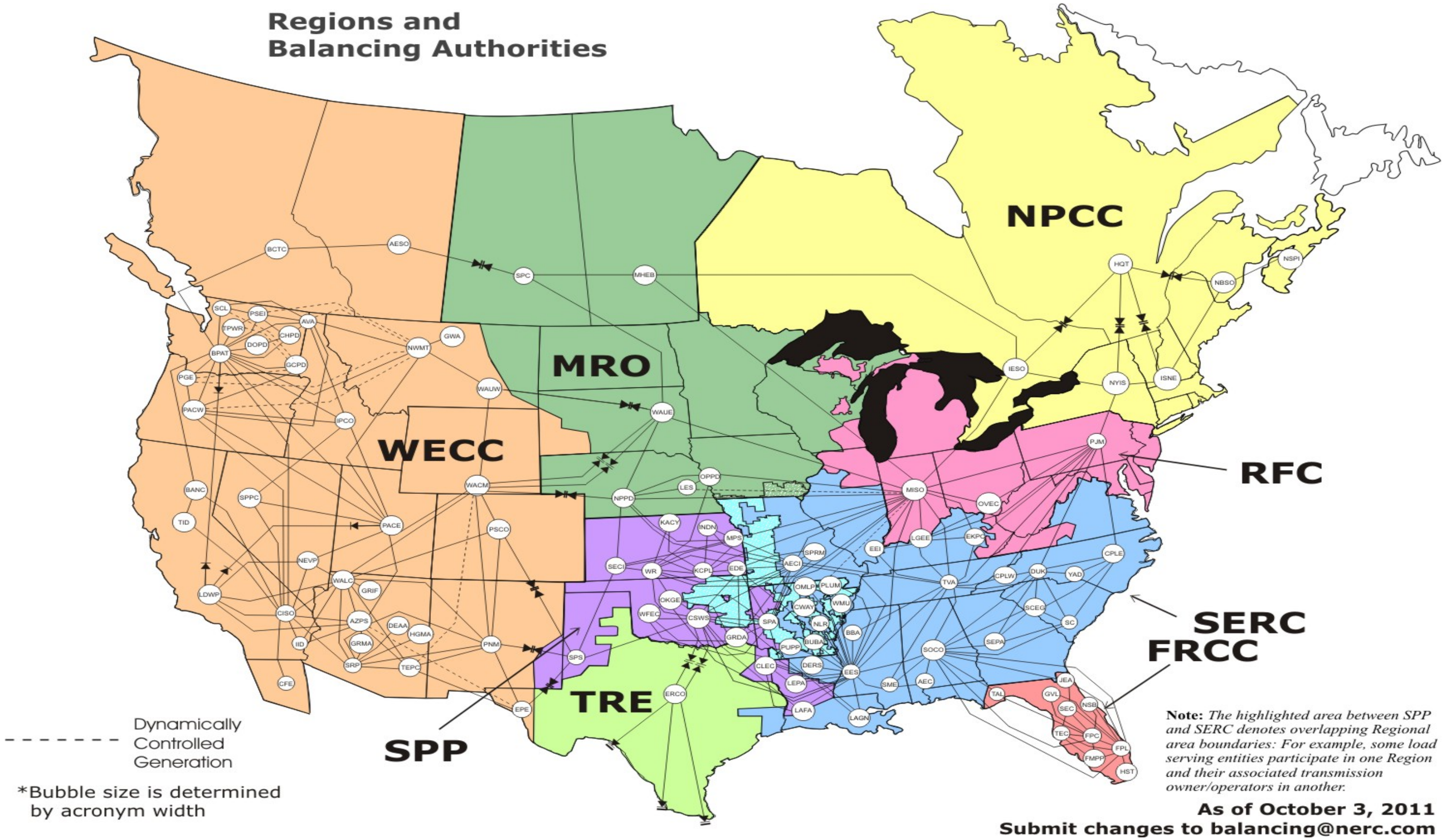
- Power systems are interconnected across large areas. For example, most of North America east of the Rockies (with exceptions for Quebec and most of TX) is an interconnection.
- Individual utilities within each interconnection own and operate a small portion of the system (a balancing area).
- Transmission lines known as “tie lines” connect the individual utilities to each other.

U.S. Grid 345 kV and Above

Interconnections and Reliability Regions

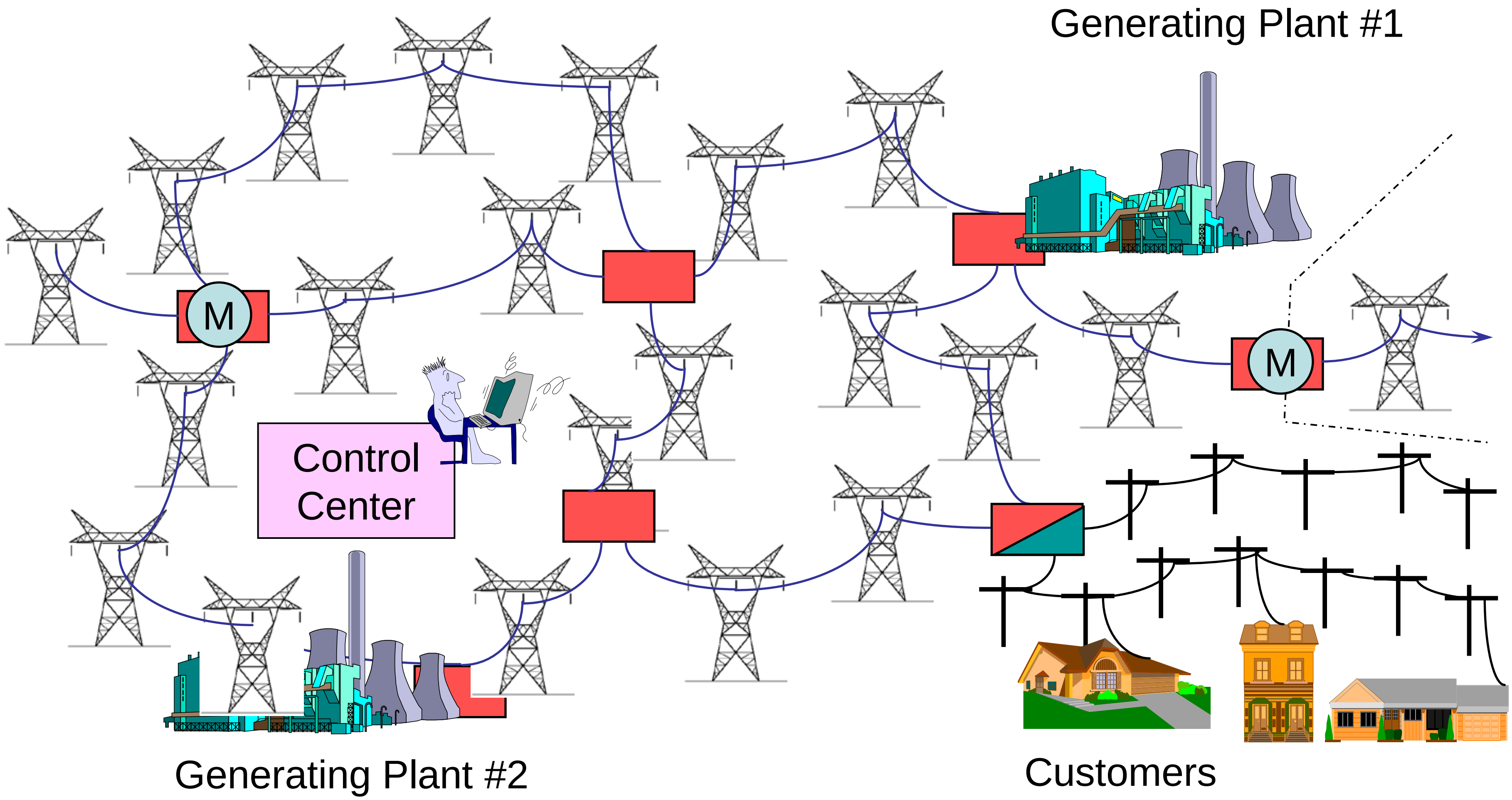


3 Major Interconnections, 8 Regions, 135 Balancing Authorities

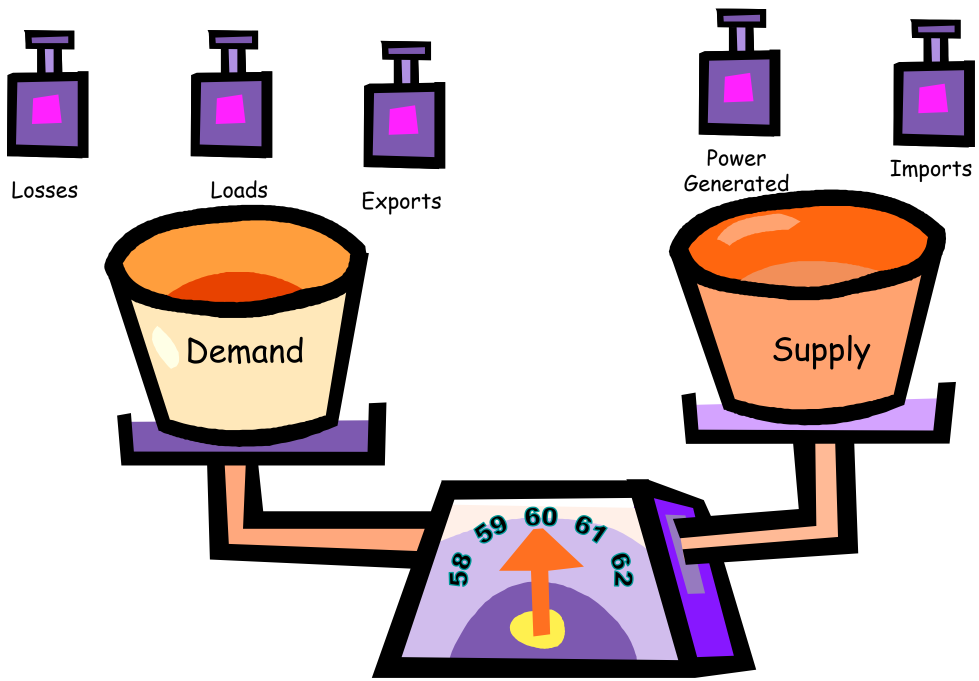


Source: NERC

The Balancing Authority and System Control



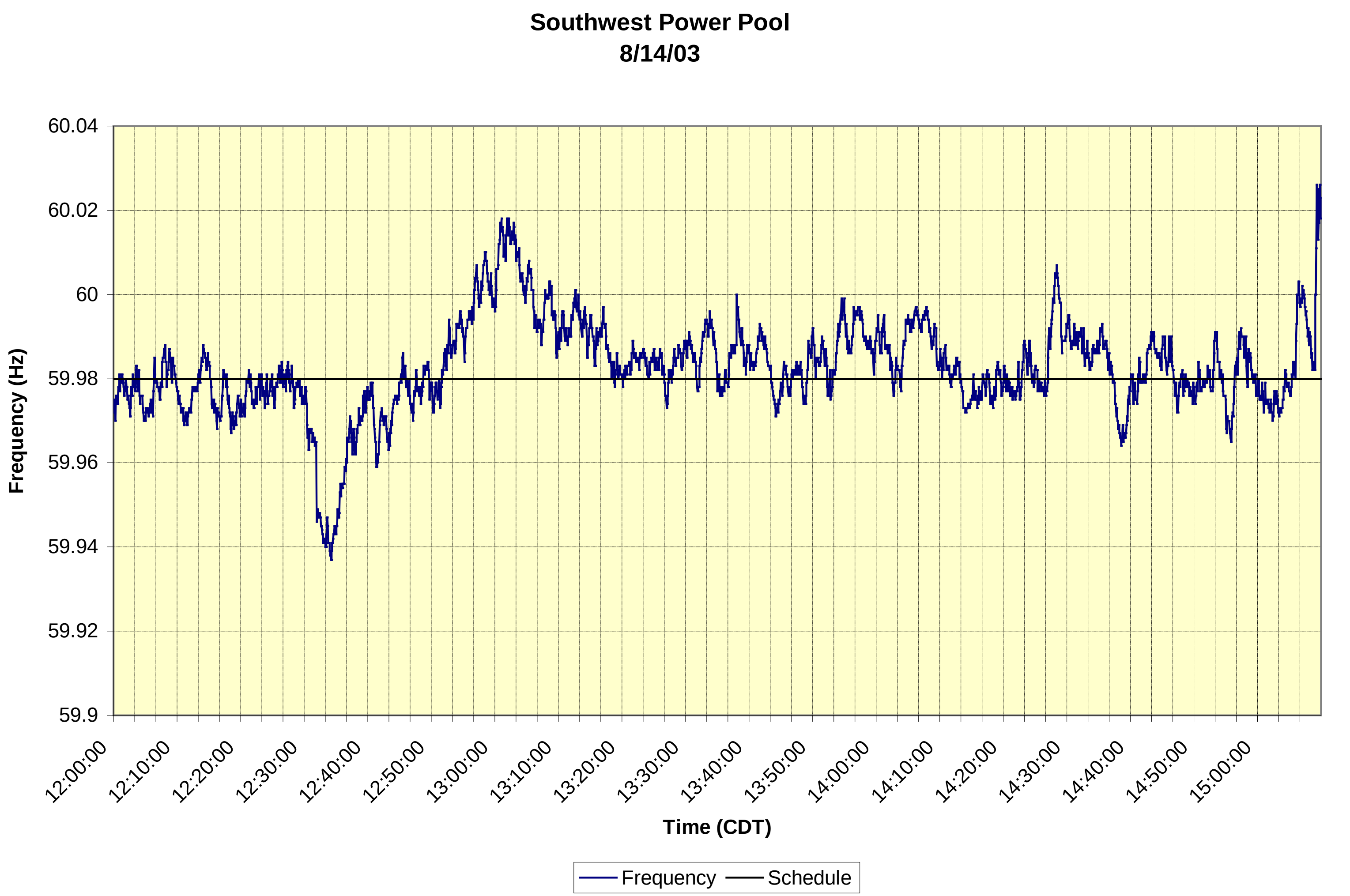
Supply – Demand Balance: The Goal of the System



- Electricity by nature is difficult to store.
- Supply must equal demand at any given instant.

Interconnection frequency needs to be maintained close to 60 Hertz at all times (for any instantaneous demand).

Interconnection Allows for Reliability and Control – August 2003 Blackout example

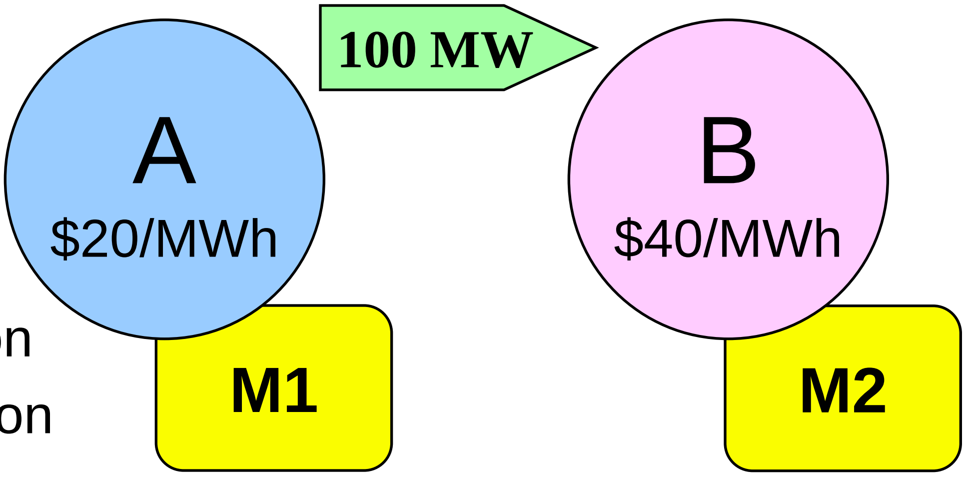


Power Flow Across the Grid

Simple Bi-lateral Transaction – My Best Attorneys Finalized the Contract

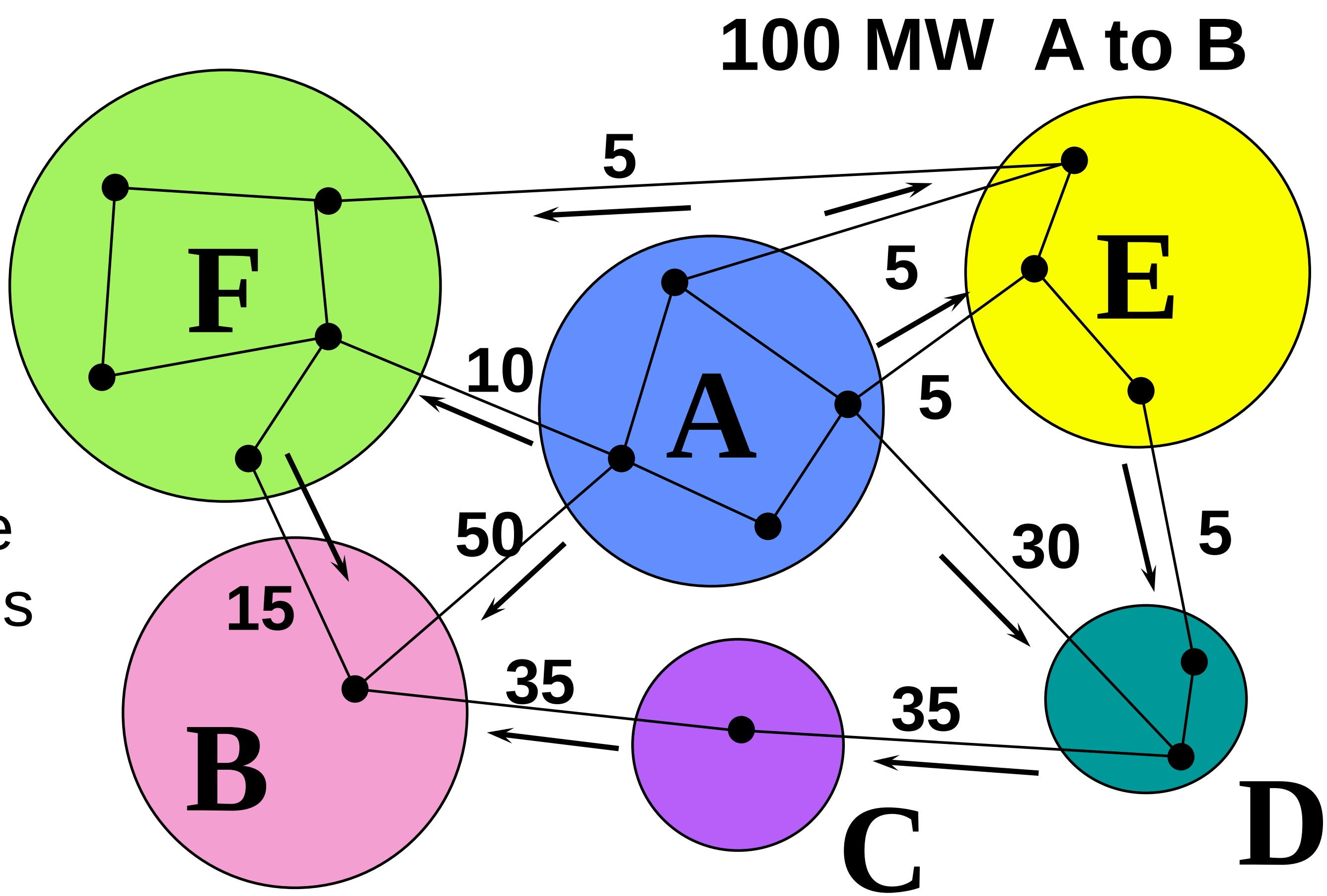
Sale from A to B at 4-5 pm of 100 MW

- 3:40 pm   Schedule
- 3:55 pm   Confirm
- 4:00 pm   Begin interchange
  - Seller increases generation
  - Buyer decreases generation
- 5:00 pm   End
  - Seller decreases generation
  - Buyer increases generation



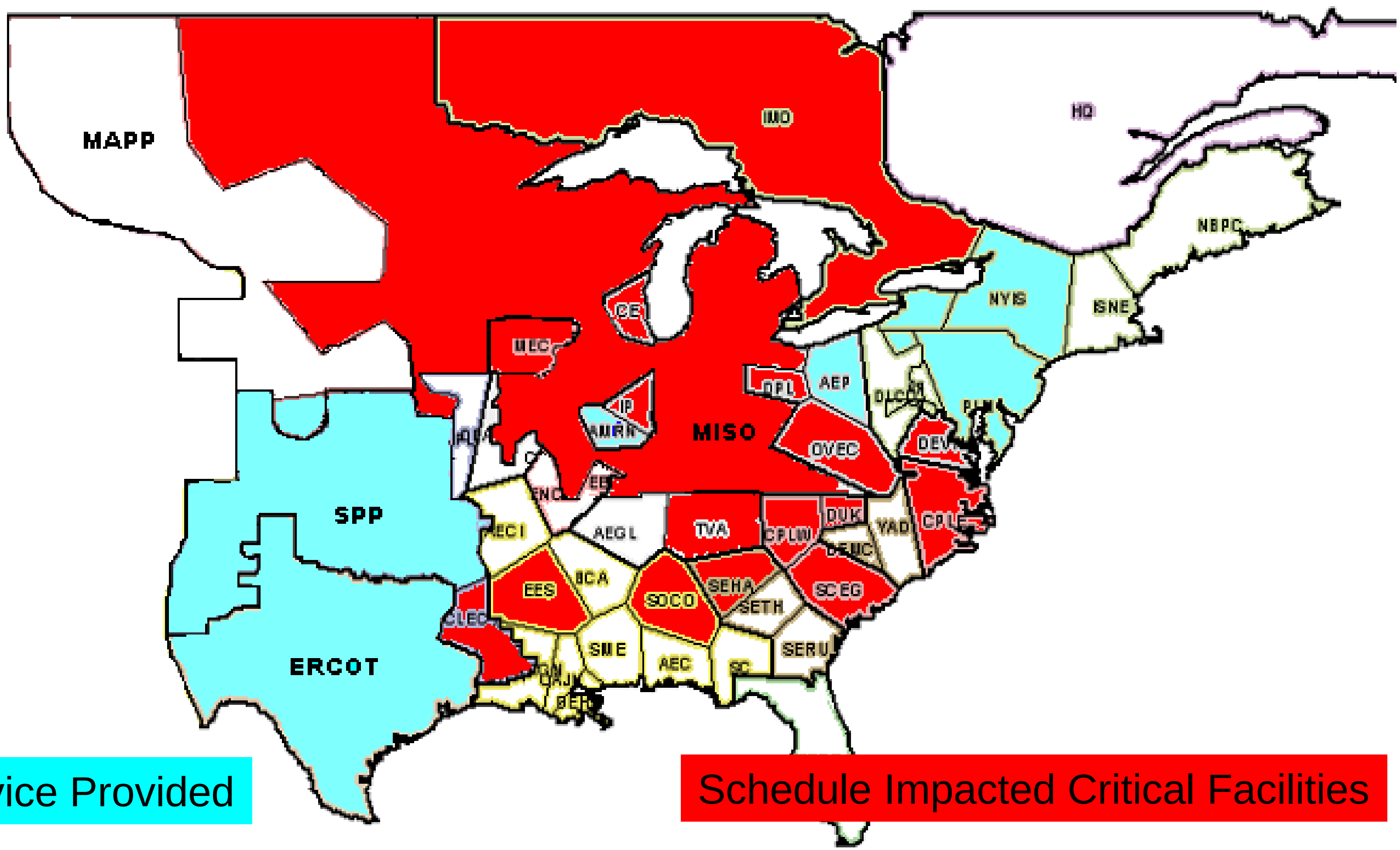
Areas A & B may be separated by thousands of miles. Price may be affected by various factors including transmission congestion

Power Flow Dictated By Laws of Physics, Not My Contract



Contrary to popular belief, the power from A does NOT flow directly to B despite my best contract negotiating skills.

Power Flow Dictated by Laws of Physics – Typical Power Transaction Impacts



Service Provided

Schedule Impacted Critical Facilities

System Limitations

System Limitations

- **Thermal limitations**
  - Overheating of lines, transformers, components
  - Line sag
- **Stability**
  - Angular --disturbances on the system (switching, contingencies, etc) may cause the system to become unstable. Think of controlling a car in an evasive maneuver if your shocks are gone.
  - Voltage -- High demand/loading on transmission can cause voltages to become unstable and difficult to control.
- **Contingencies**
  - Some capability left unused to handle failures

System Limitations Create CONGESTION

- All the aforementioned limitations are worsened by the lack of appropriate transmission.
- The limitations create *CONGESTION* on the system which results in uneconomic use of generation.
  - Re-dispatch means using less economic generators
  - Reserve margins may need to be higher to maintain reliability
  - Potential for market power increases
  - Need for ancillary services