ELECTRIC TRANSMISSION 201: Operational Characteristics

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Smart Wire Grid

Power flow control for the Grid

Objectives

- 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

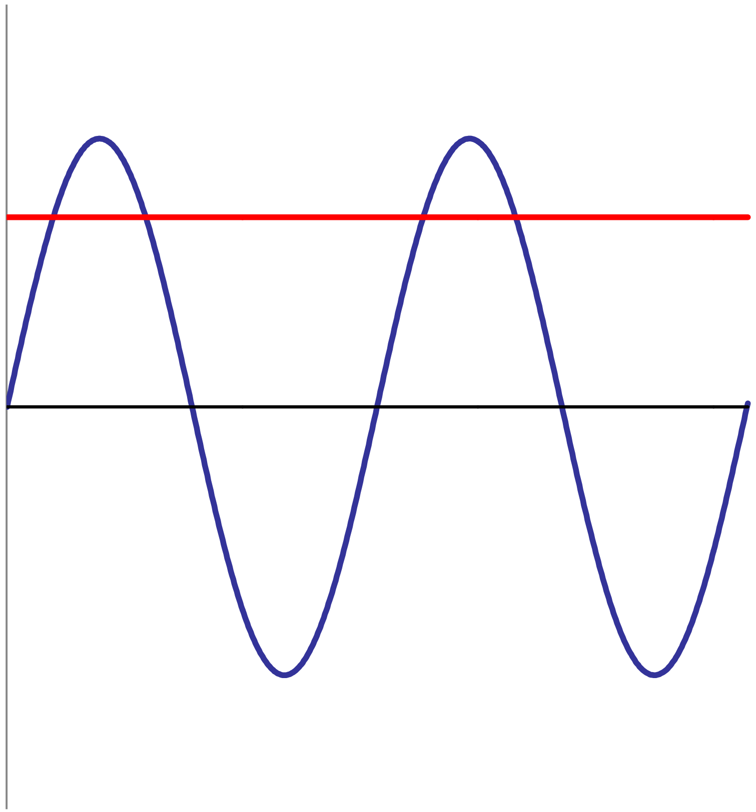
Basic Definitions

- 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

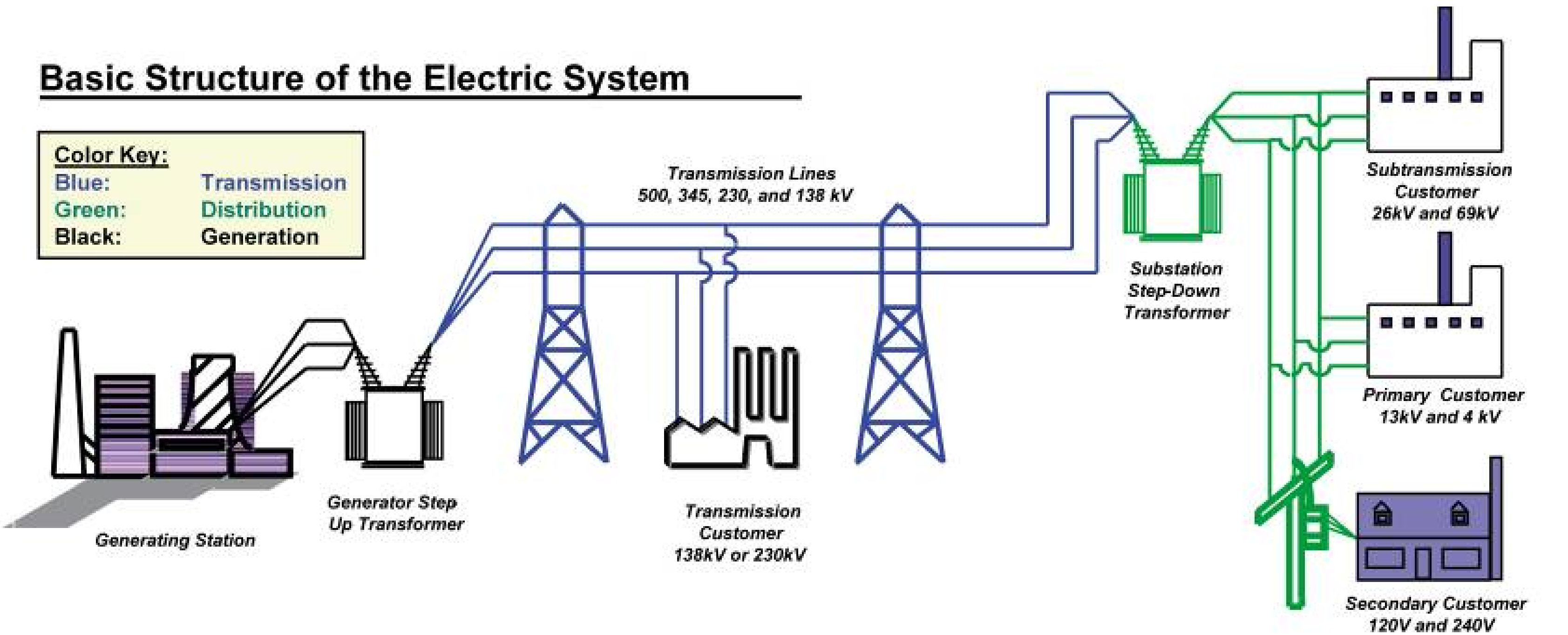
- Direct Current (DC) – magnitude of current and voltage is constant. Applications of high voltage direct current (HVDC) in U.S. and elsewhere.



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 Customers
- This diagram is a basic overview, but does not truly illustrate the *HIGHLY* interconnected nature of the transmission system
- Many large customers have complex grids behind the customer meter which do not appear here

Components of the Grid: Generation Supply

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

Components of the Grid: Customer Demand

- “Consumer” of electric energy
- Loads can be smaller than your cell phone hooked to its wall charger (say 1 watt) or as large as a power plant facility, for example, University of California in San Diego has a microgrid of nearly 50 MegaWatts (MW) or 50 millions 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

Basic Elements of the Electric System Jurisdiction and Cost Allocation

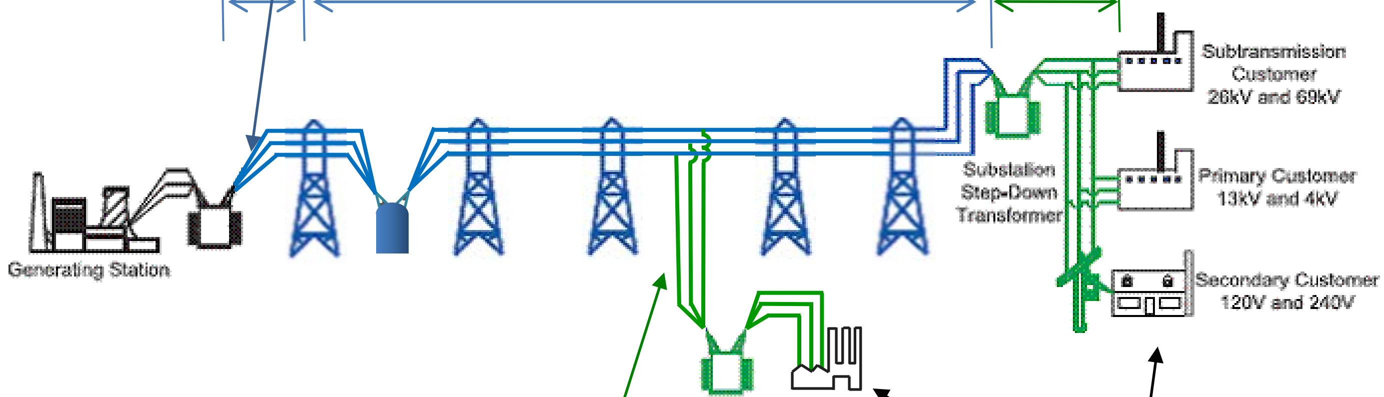
Transmission – FERC jurisdiction*

Distribution Voltage - Local jurisdiction

Gen-tie Cost assigned to Power Production to be paid for by purchasers of the power

Network - cost shared among transmission network users

Distribution - cost shared among distribution users

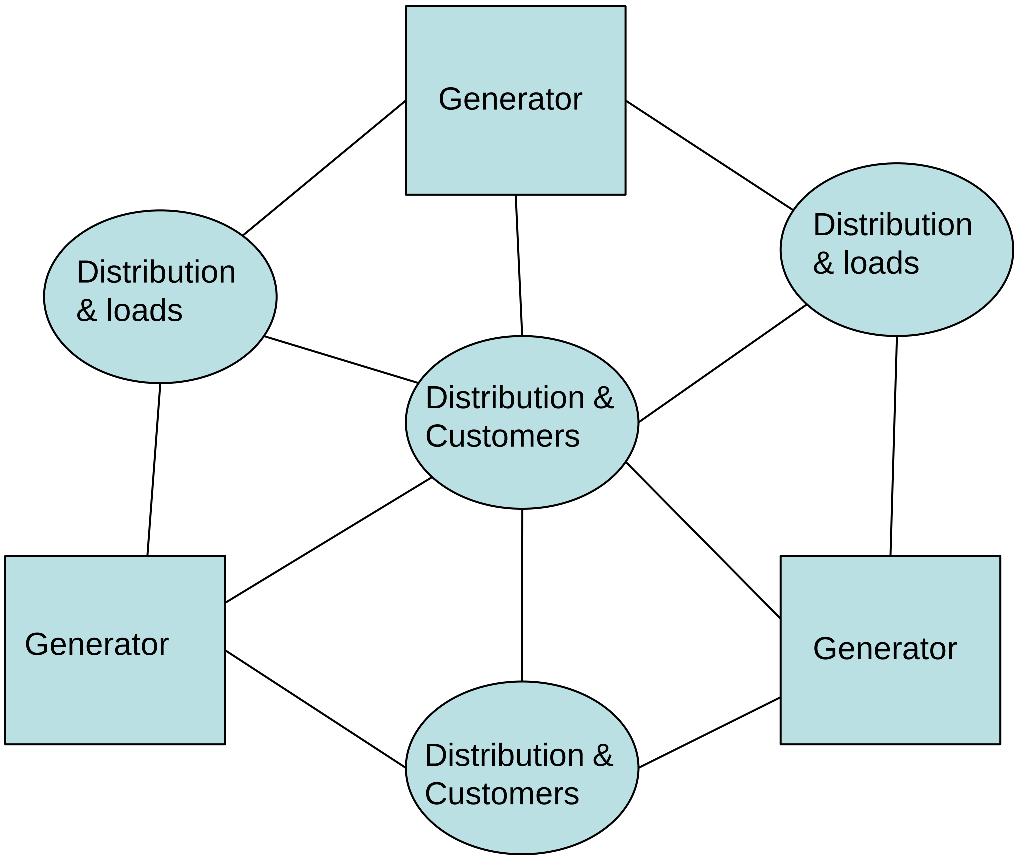


Transmission voltage to end-use customers; can be under local jurisdiction

End-use customer

*Directly for Investor-owner Utilities (IOU); indirectly for Publicly-Owned Utilities (POU)

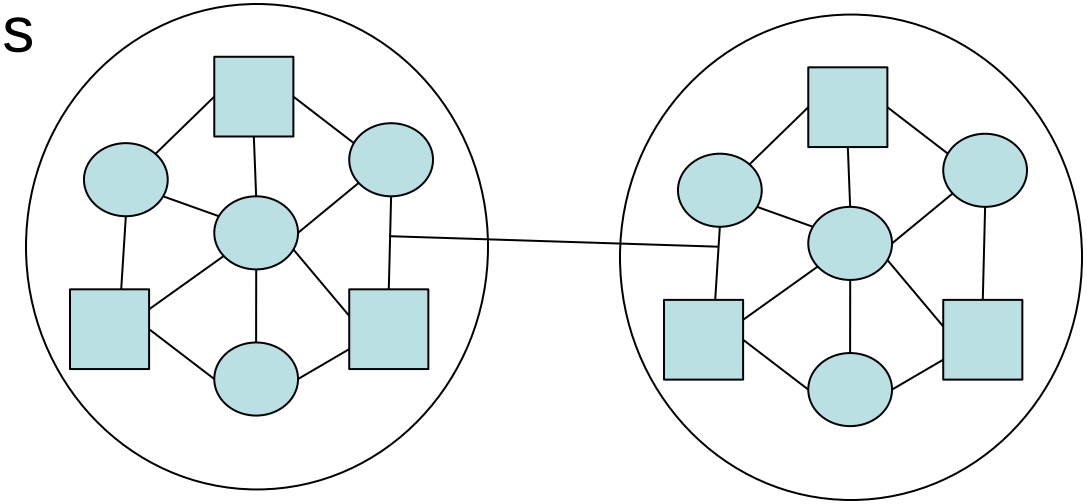
With Transmission



- We can build generation in areas remote from the customers
  - Easier siting, closer to fuel sources, lower losses on high voltage delivery
- We can build larger, more efficient generators
  - Economies of scale
- We can get power to remote areas with lower losses
  - Rural electrification

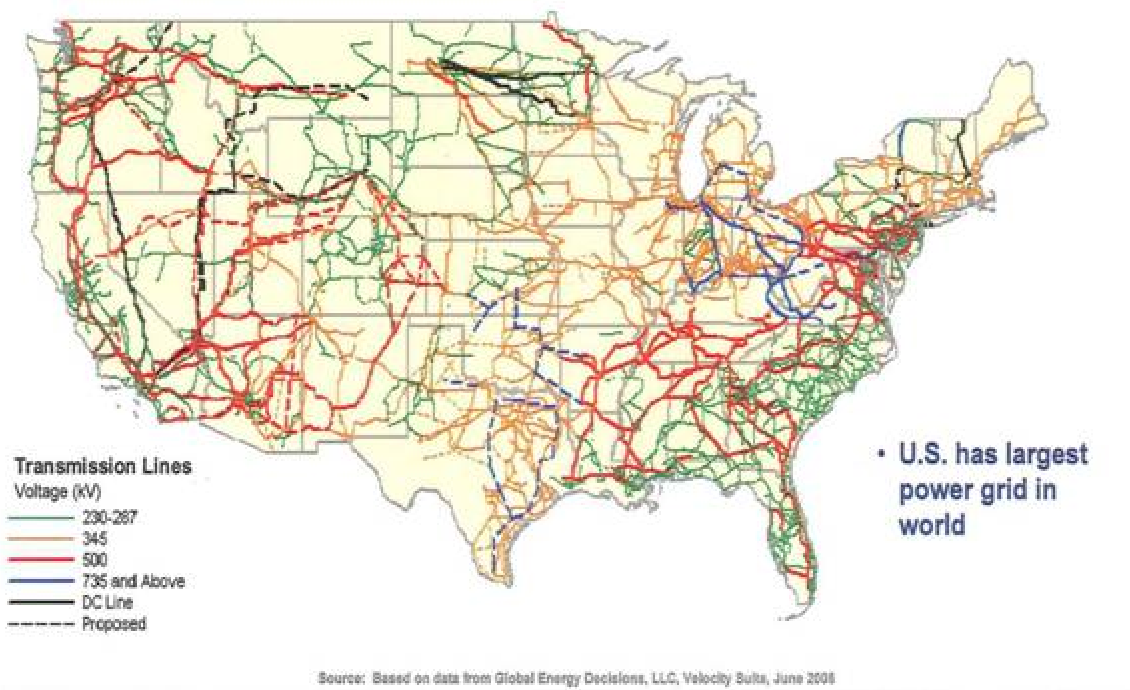
With Transmission

- We can create robust interconnected networks
  - Increased supply portfolio diversity and opportunity to share reserves
  - Decreased costs from economies of scale
  - Makes possible power pools and coordinated operation, wholesale markets, bulk power transactions



Components of the Grid: Transmission

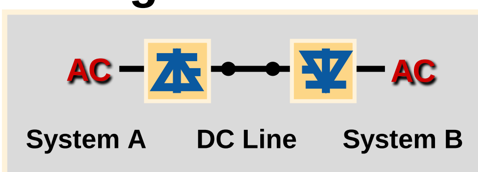
- Unlike highways, pipelines, and telecom, the flow of electricity on the AC grid can not be easily routed or controlled. Power flows via the path of least resistance and is produced as it is consumed. This is a critical difference in how the grid differs from other transportation mechanisms

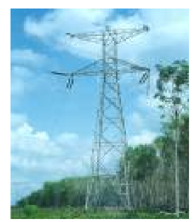


Components of the Grid: Transmission AC or DC

- The grid is largely AC; however, HVDC has some well defined applications and benefits in the interconnected grid

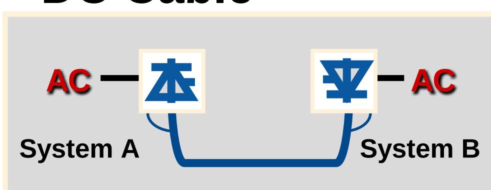
Long Distance





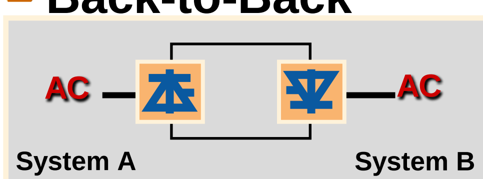
Economical solution for distances greater than ~350 miles.

DC Cable



Solution for long submarine transmission (40+miles)

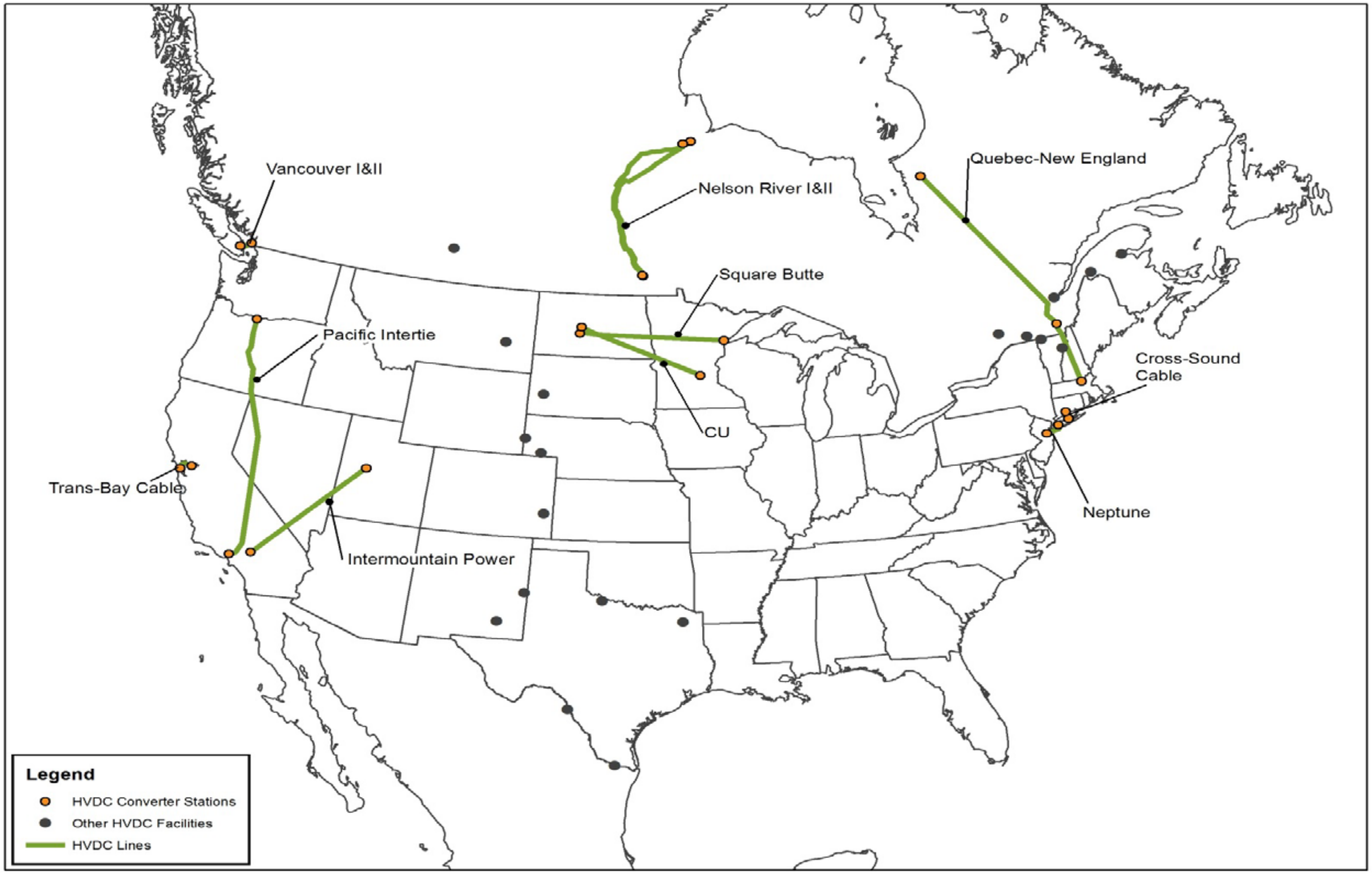
Back-to-Back



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

Graphics courtesy Siemens

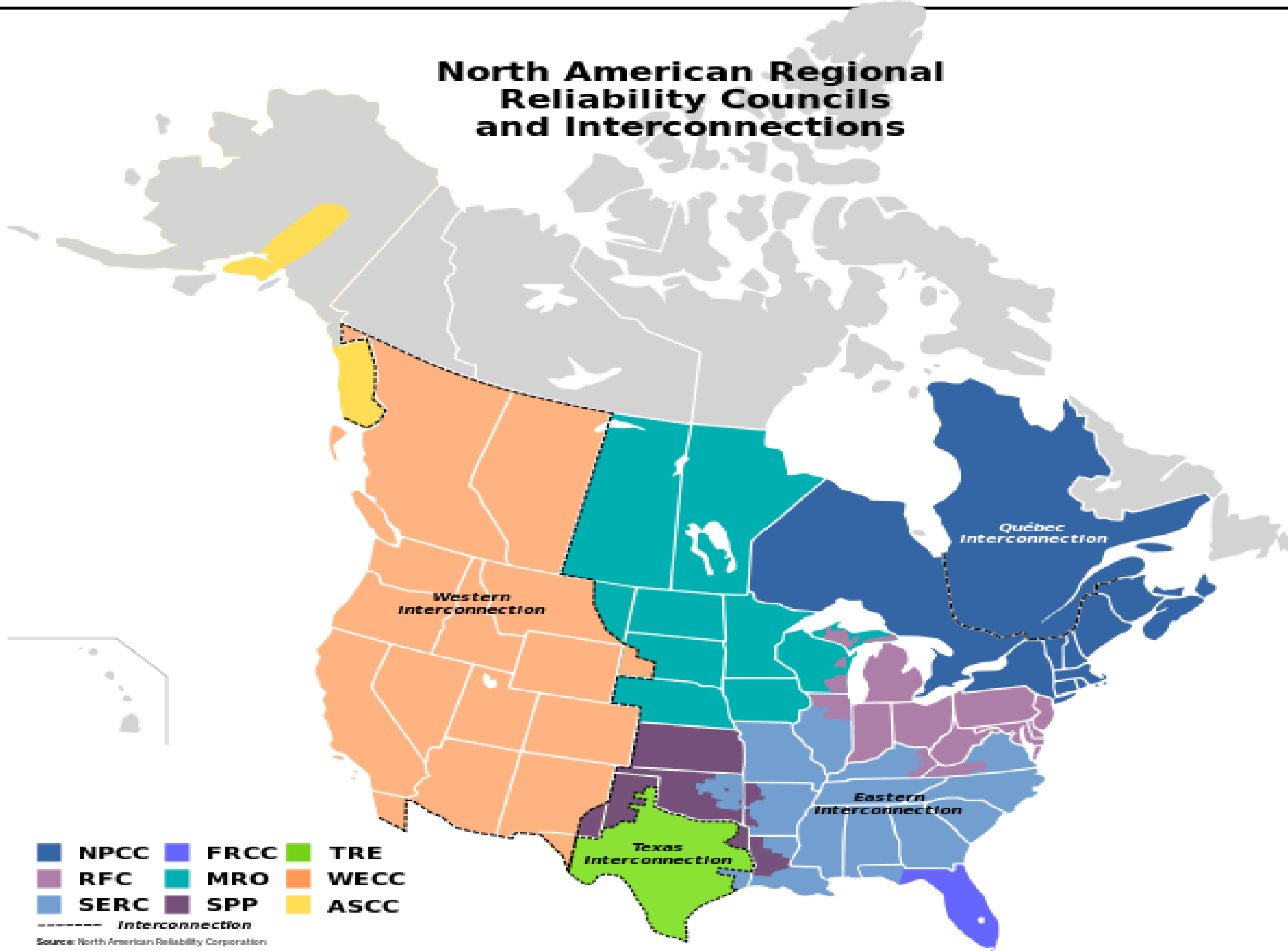
HVDC in North America



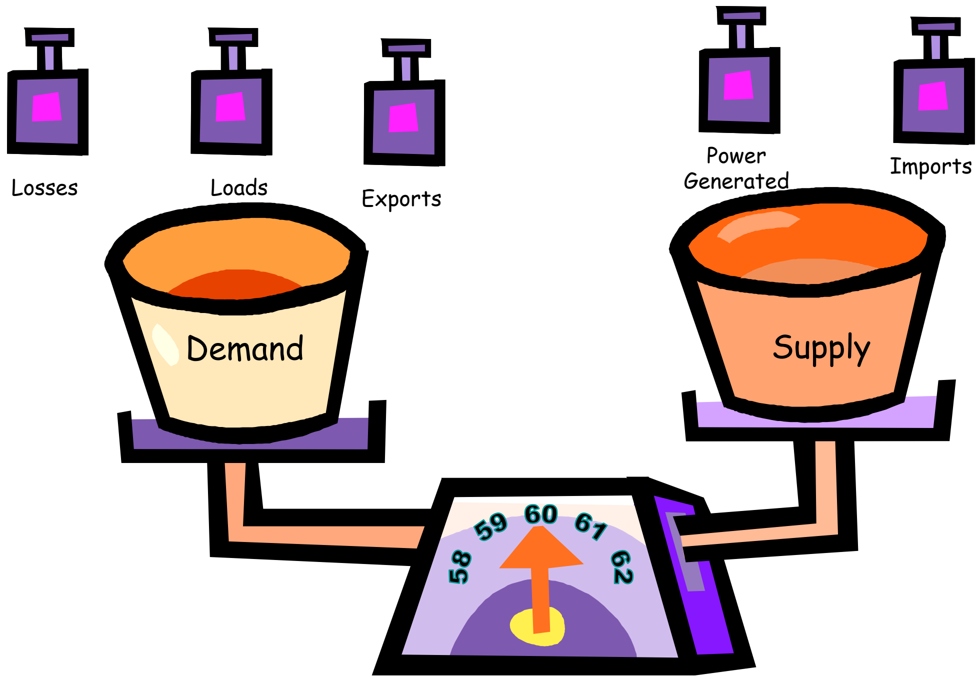
Interconnected Operation

- Power systems are interconnected across large areas. The U.S. has three "interconnections"
  - The Eastern Interconnection east of the Rockies
  - The Western Interconnection west of the Rockies
  - ERCOT most of Texas which does not have free flowing ties with the rest of the U.S.
- Balancing Authorities operate larger subregions within an interconnection acting like air traffic controllers
- Individual utilities operate their local systems

Interconnections and Reliability Regions



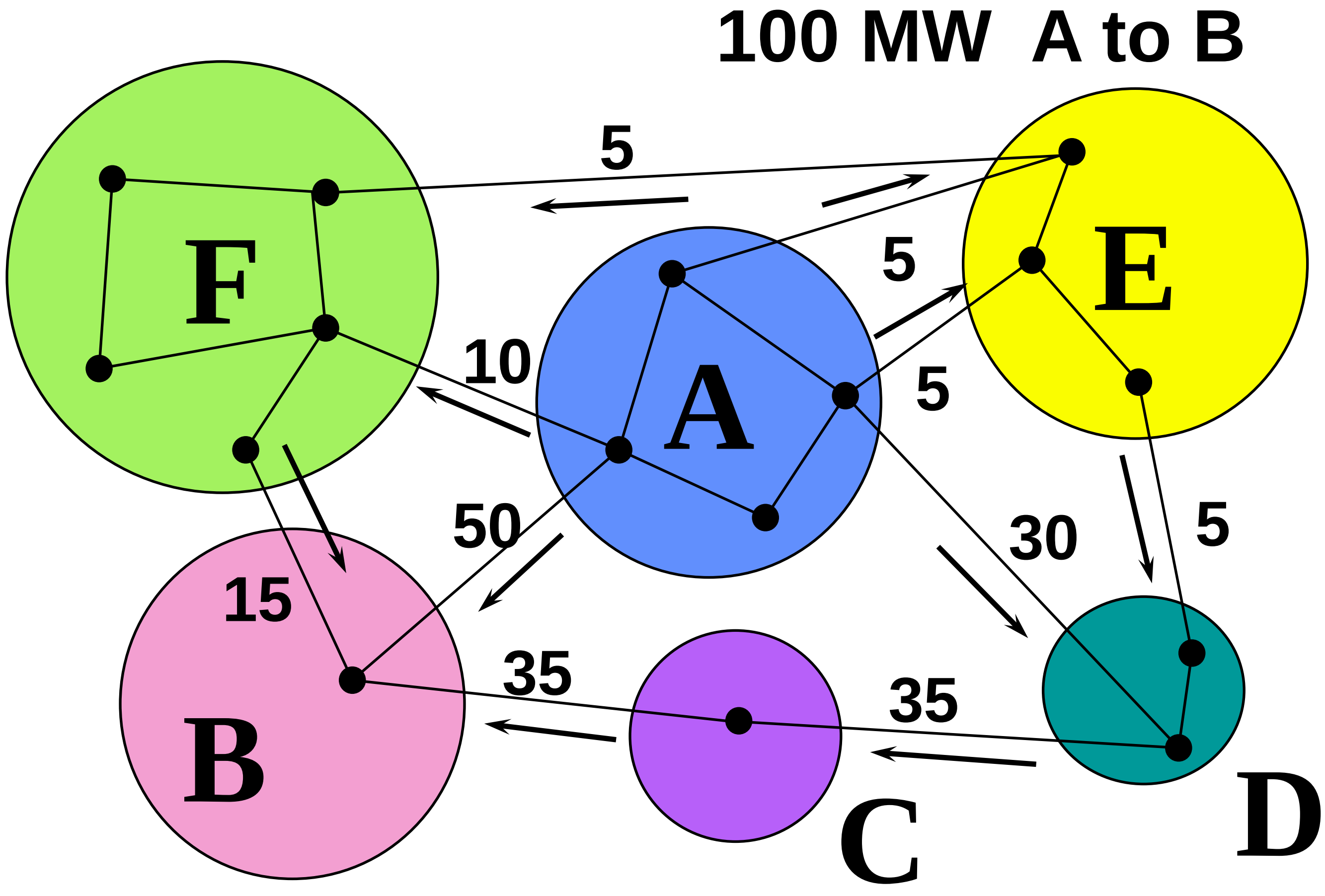
Supply – Demand Balance: The Goal of the System



- At the right time
- At the right location(s)
- With the right characteristics

The business of transmission revolves around operating, preparing and planning

Power Flow Dictated By Laws of Physics, Not By Contracts



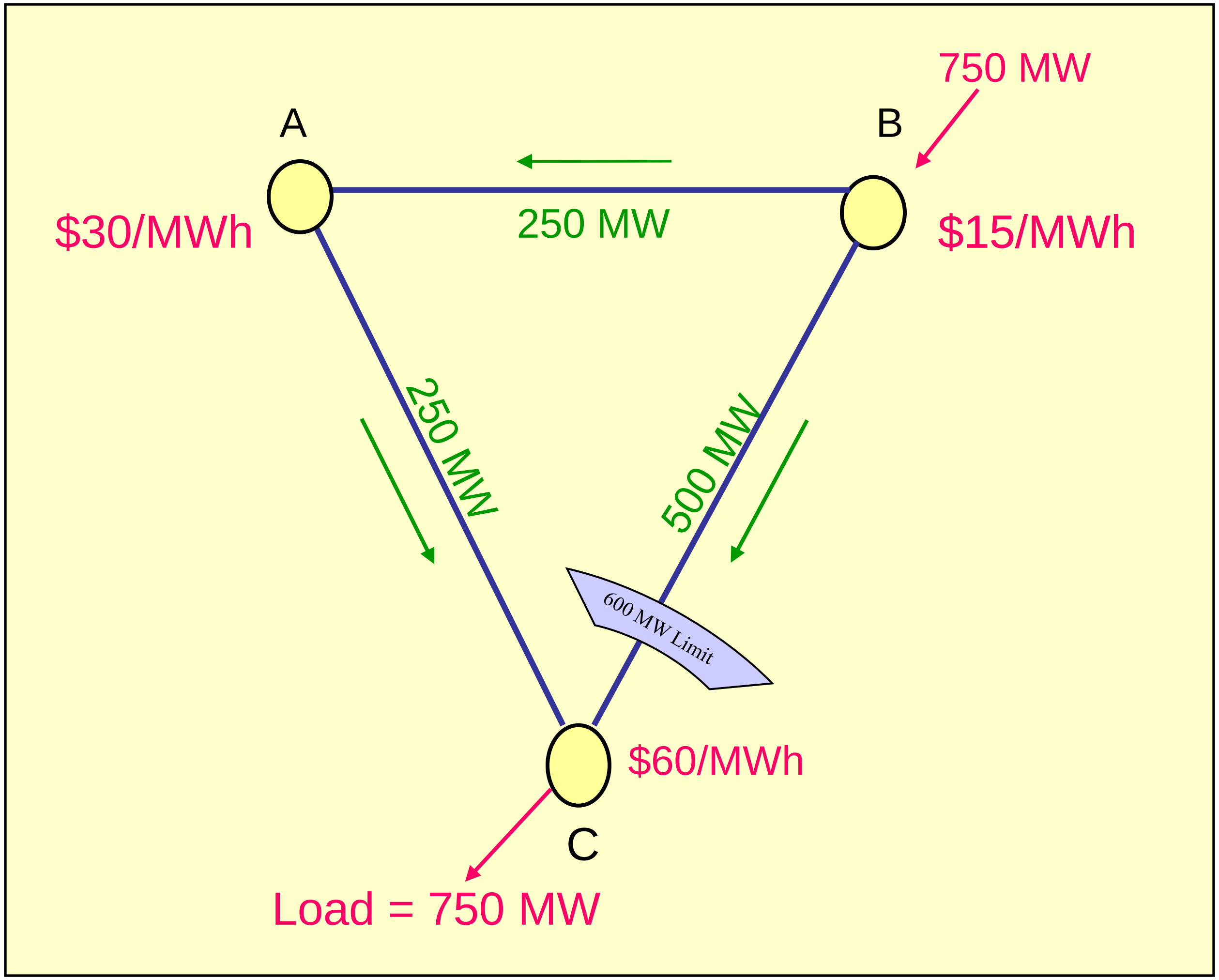
System Limitations

- **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.
  - Voltage -- High demand/loading on transmission can cause voltages to become unstable and difficult to control.
- **Allowance for Contingencies**
  - Some capability left unused to handle failures

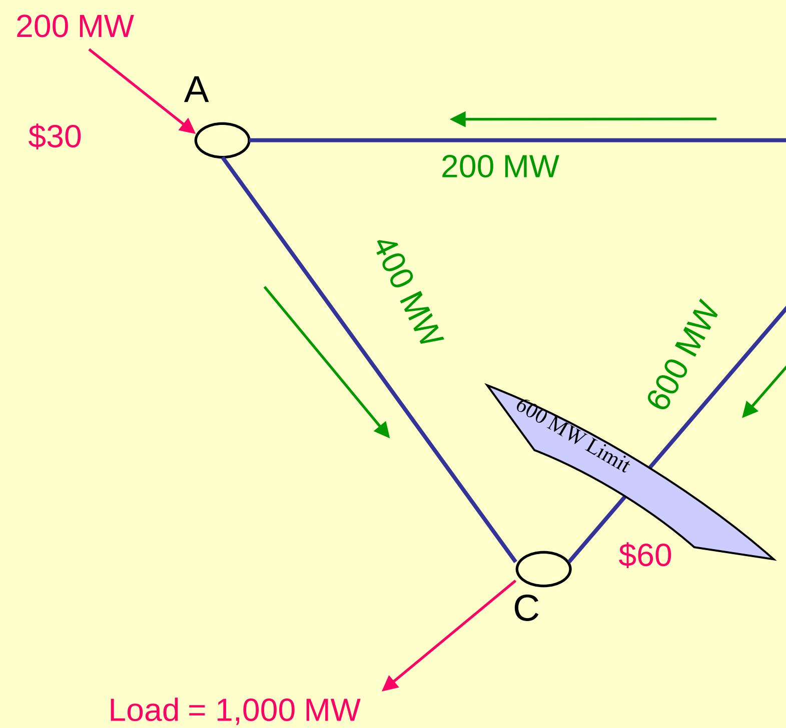
Congestion Management

- When constraints occur on the grid, less expensive generation will not be able to reach loads in the amounts desired.
- To honor the constraint, the system operator must curtail some lower cost generation in an unconstrained area and replace it with more expensive generation located in the constrained region.
- When this occurs, the marginal costs of serving load in each area will differ.
- These differences reflect the reality that transmission constraints create different values for electricity at each location, relative to the constraints handle failures

Three Bus Model



Sometimes Redispatch Out of Economic Merit Order is Required to Maintain System Reliability



Generator B is limited to 800 MW and Generator A produces 200 additional MW.

The system is redispatched to preserve the 600 MW limit

Power injected at B flows 2/3 BC and 1/3 B-A-C. Power injected at A flows 1/3 ABC and 2/3 AC.

System Expansion Drivers

- Under FERC Order 1000 there are three primary drivers of transmission expansion
  - Reliability - meeting national and local reliability criteria, including operational support
  - Economic - where, over time, congestion costs exceed the price of upgrades or technology enhancements
  - Policy – where regional or local considerations change how the grid is used, such as renewable energy mandates