ELECTRIC TRANSMISSION 101:

How the High-Voltage Grid Works and Who Regulates It

July 9, 2013

FACULTY:

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Presented by WIRES - a national coalition of entities dedicated to investment in a strong, well-planned and environmentally beneficial electricity high voltage transmission system in the US.

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)

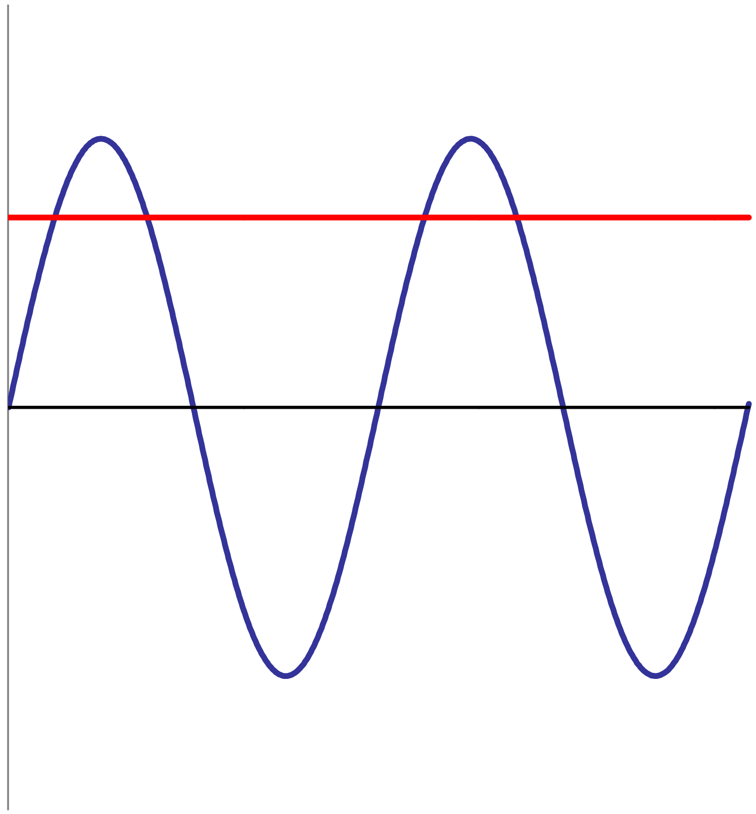
- Power – Rate at which electricity does work. Measured in Watts or more typically kilowatts (kW) or megawatts (MW)

- 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).

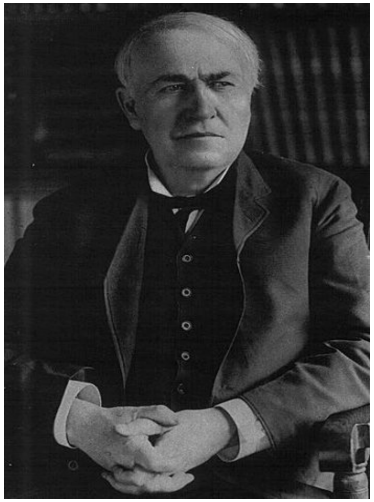
Basic Definitions

- Alternating Current – (AC). Magnitude of current and voltage varies with time. Most of grid is AC

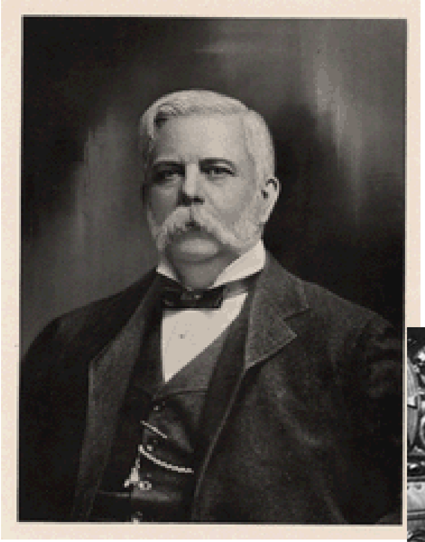
- Direct Current (DC) – magnitude of current and voltage is constant. Applications of high voltage direct current (HVDC) in U.S. and elsewhere.

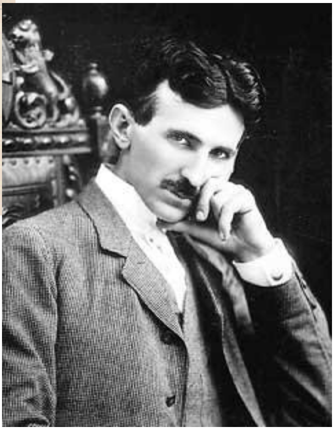


War of the Currents (late 1880s)



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



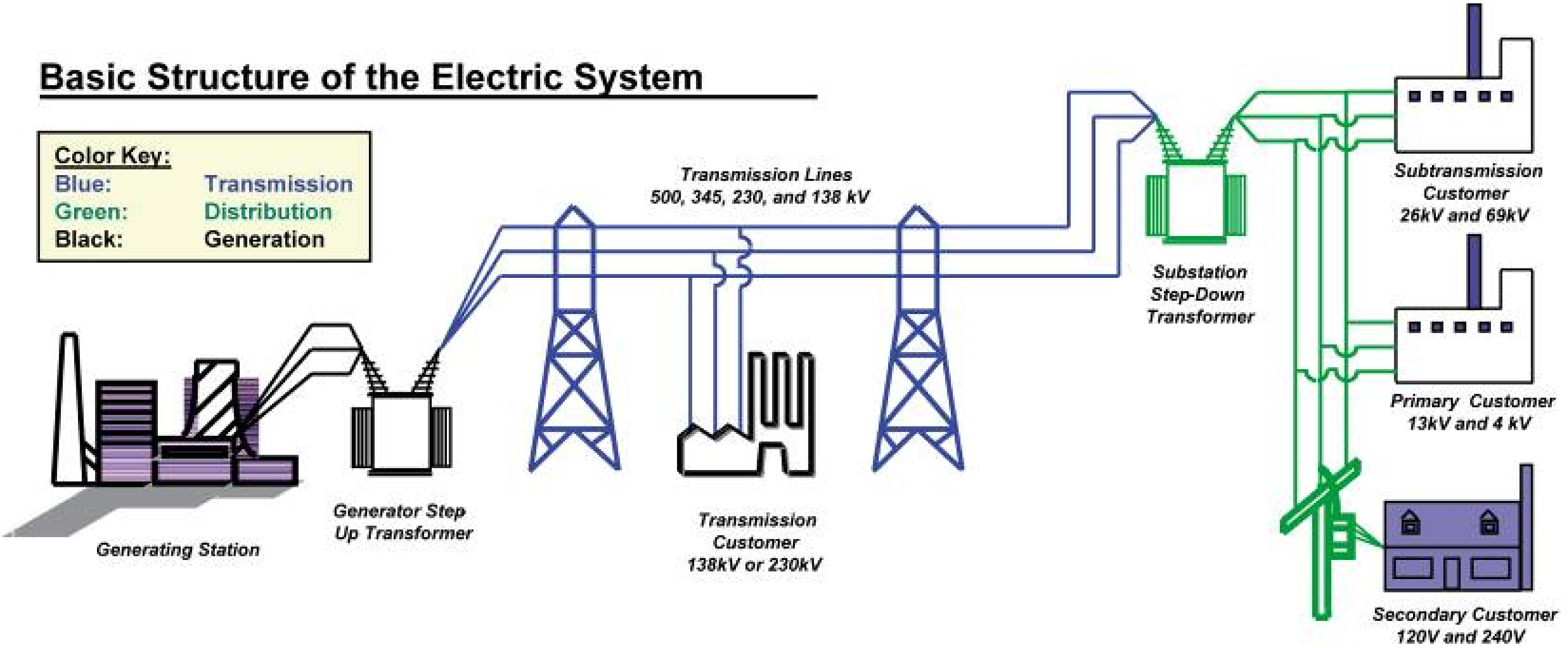


- George Westinghouse(1846-1914)
- Nikola Tesla (1856-1943)
- Advocate of alternating current (AC) power system
- Founder of Westinghouse Electric Corporation
- Licensed polyphase machines from Tesla

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)

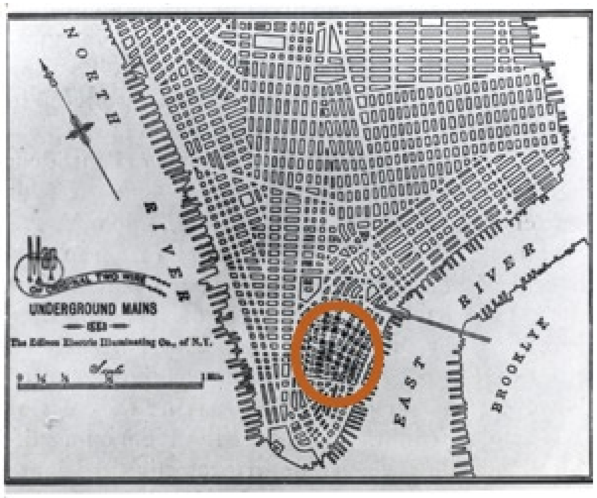
- Generally radial (non-networked) in nature

- Not used for interstate commerce

Components of the Grid: Transmission

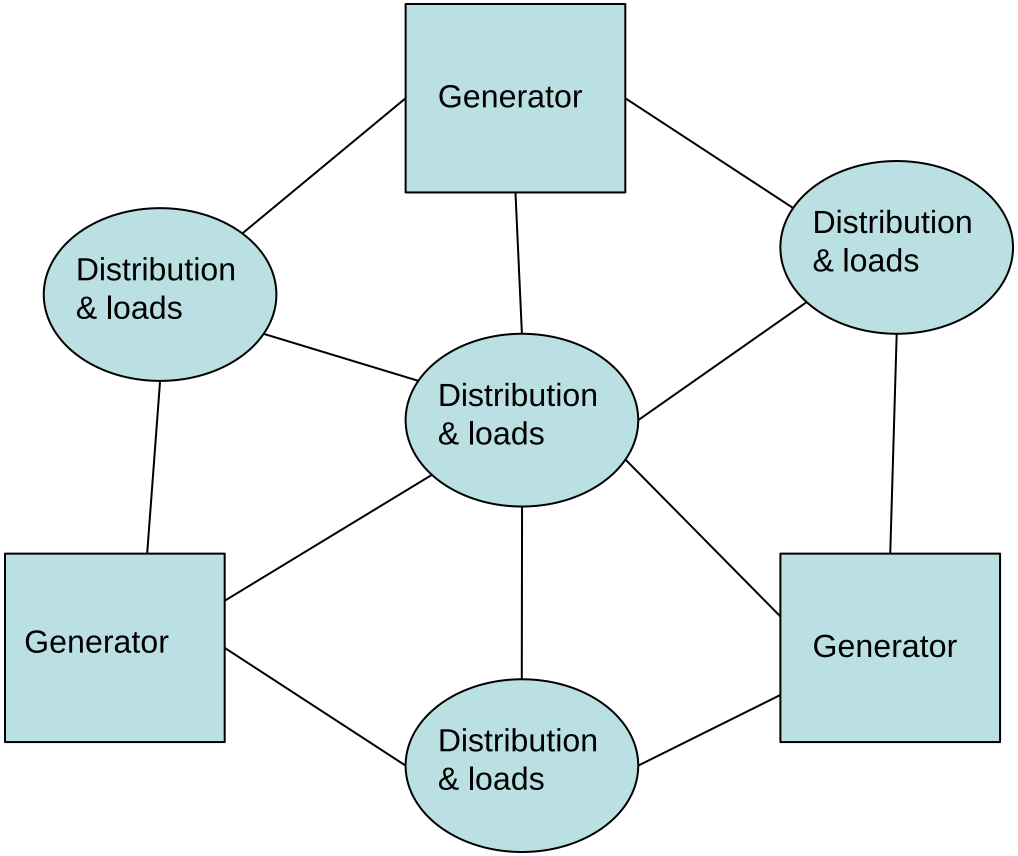
- Used to move power relatively long distances from generators to load with lower losses.
- Highly interconnected for enhanced reliability
- The “interstate system” for electricity
- Traditionally built to enhance reliability for vertically integrated utilities.
- Now a critical part of the electric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

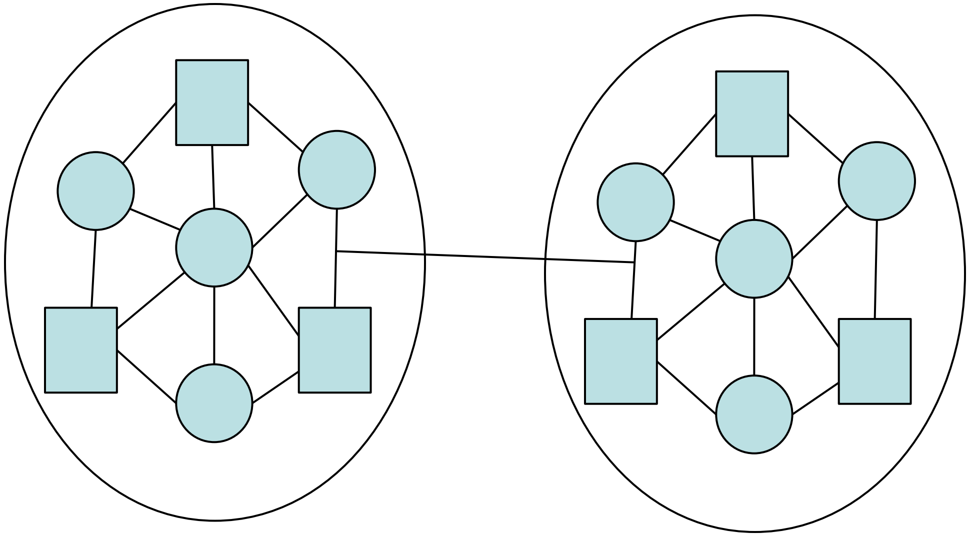
With Transmission



- 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

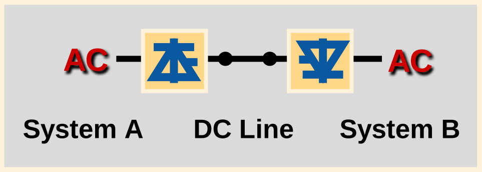
- U.S. has largest power grid in world

Source: Based on data from Global Energy Decisions, LLC, Velocity Suite, June 2008

Components of the Grid: Transmission AC or DC

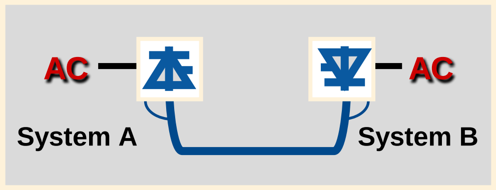
- A function of technological history, the grid is largely AC; however, HVDC has some well defined applications and benefits in the interconnected grid

- **Long Distance**



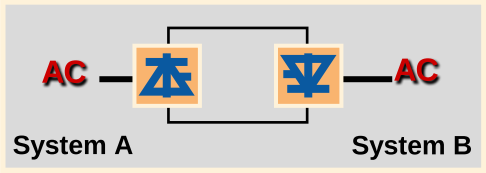
Economical solution for distances greater than ~350 miles.

- **DC Cable**



Solution for long submarine transmission (40+miles)

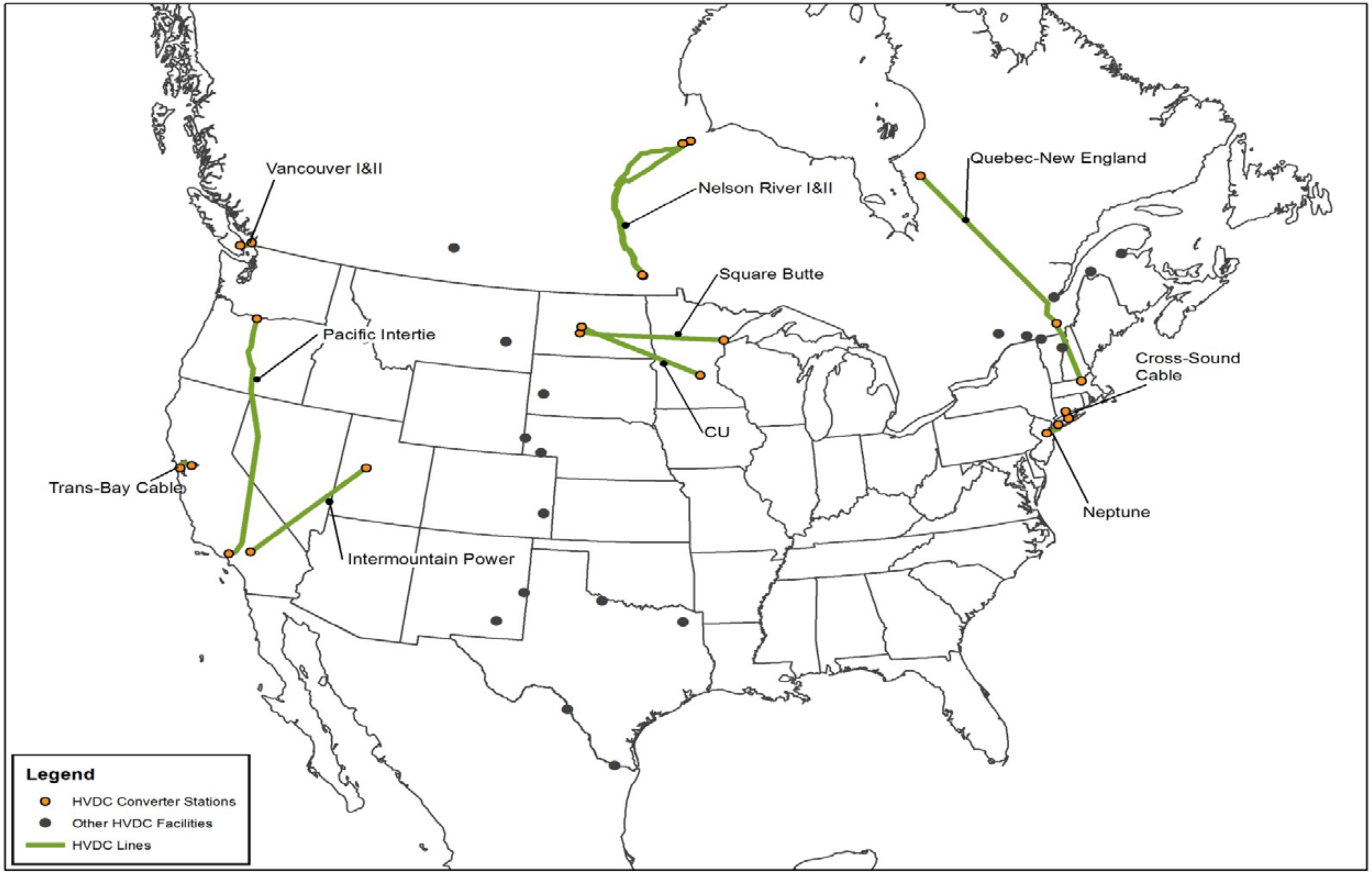
- **Back-to-Back**



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

Graphics courtesy Siemens

HVDC in North America



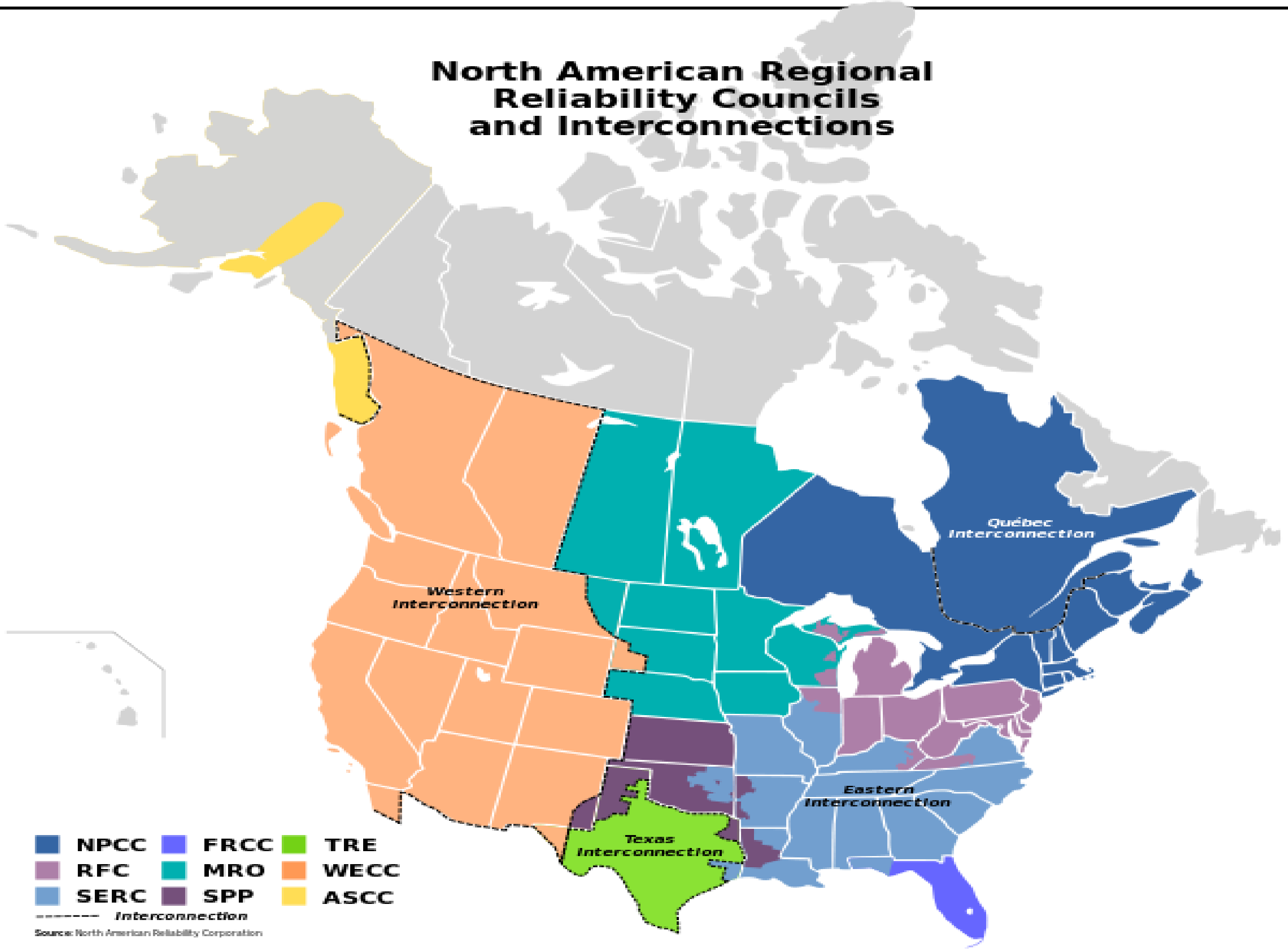
How the Grid Is Controlled

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.

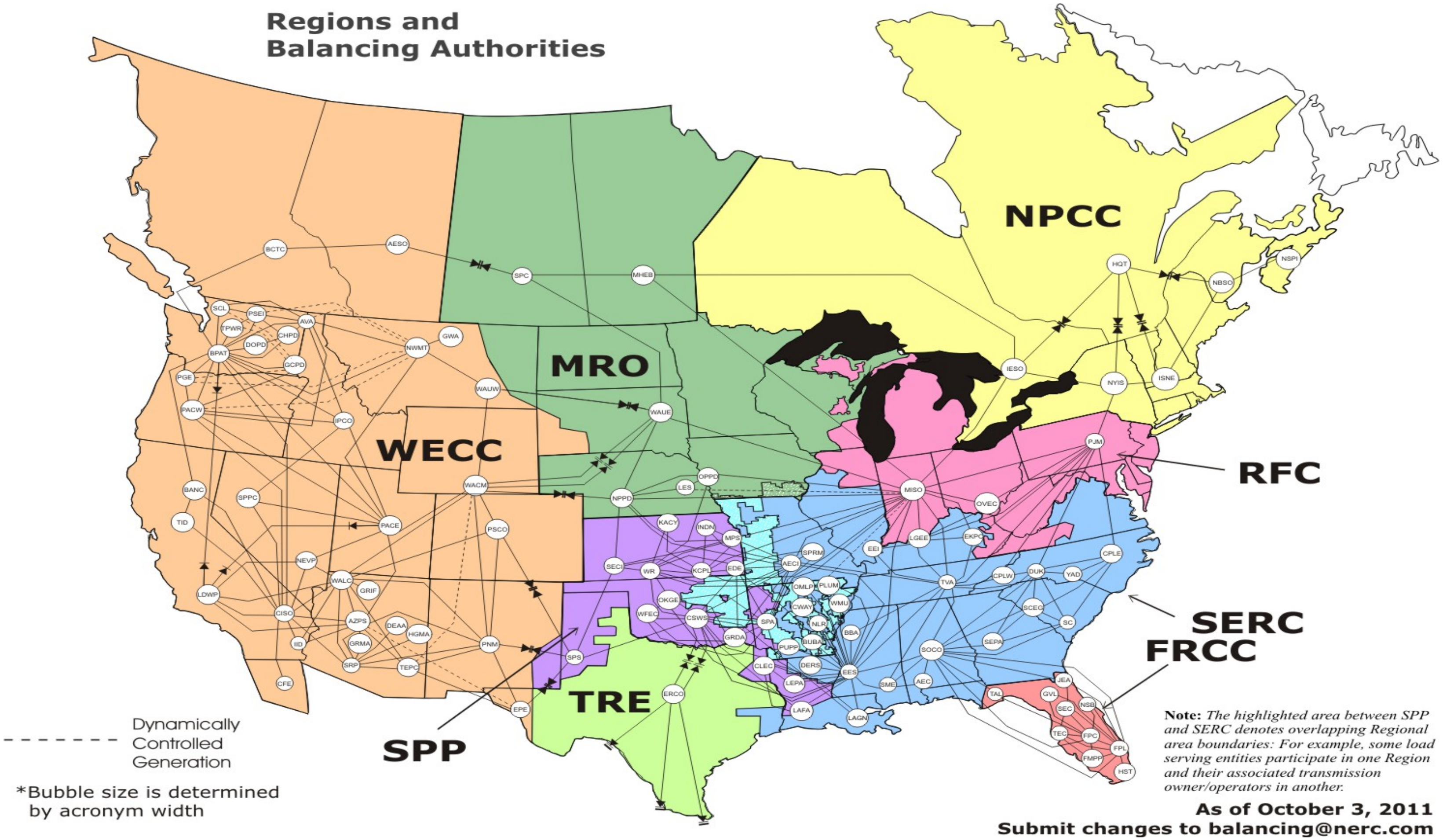
U.S. Grid 345 kV and Above

Interconnections and Reliability Regions



Source: North American Reliability Corporation

3 Major Interconnections, 8 Regions, 135 Balancing Authorities



Regions and Balancing Authorities

*Bubble size is determined by acronym width

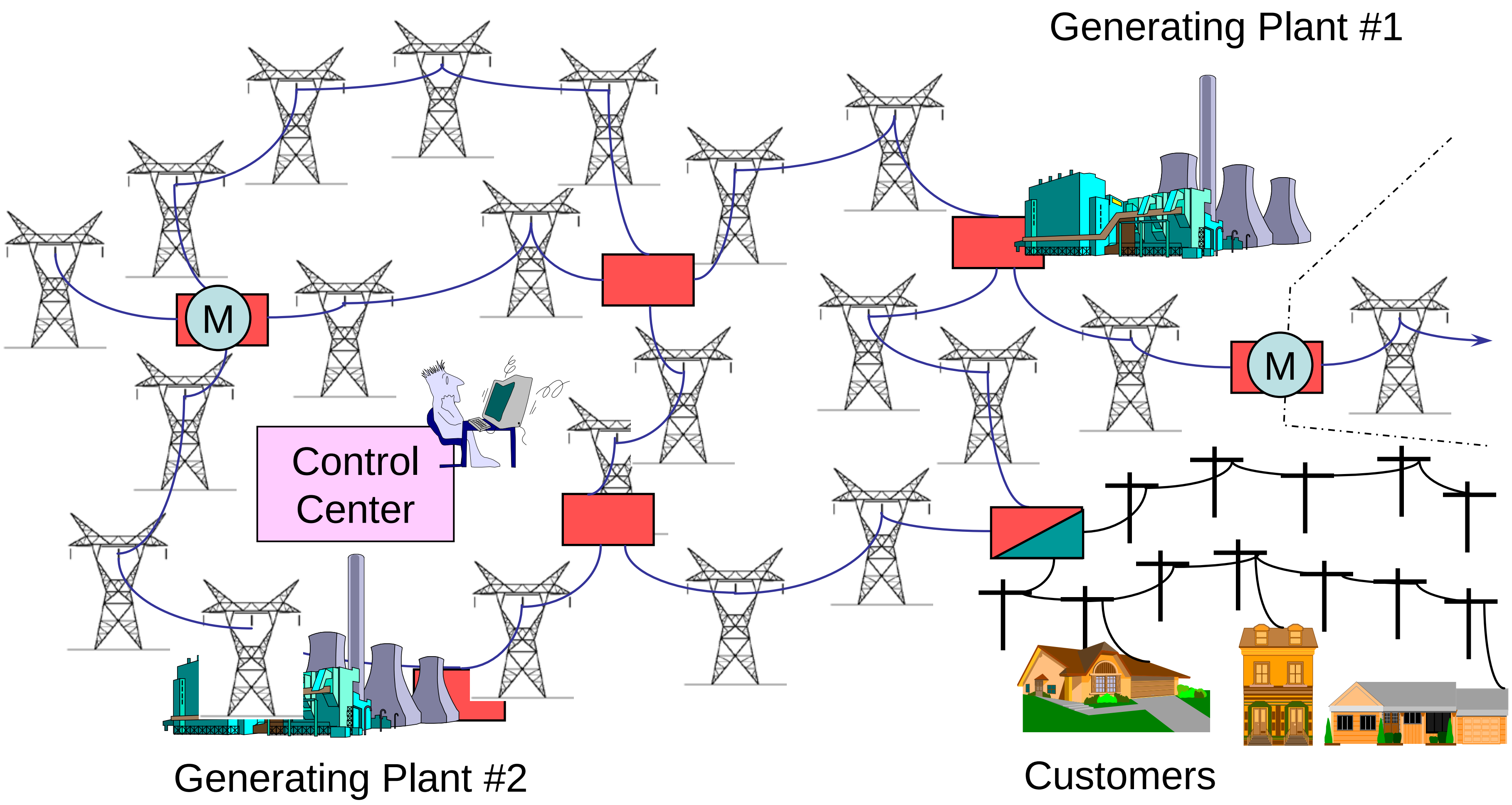
Note: *The highlighted area between SPP and SERC denotes overlapping Regional area boundaries: For example, some load serving entities participate in one Region and their associated transmission owner/operators in another.*

As of October 3, 2011

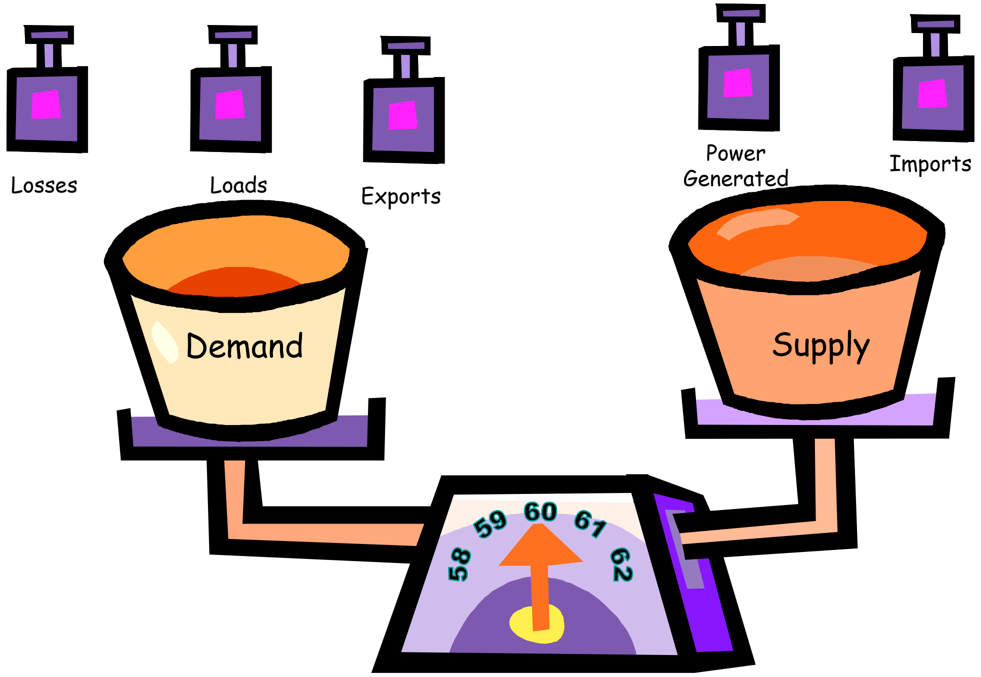
Submit changes to balancing@nerc.com

Source: NERC

The Balancing Authority and System Control



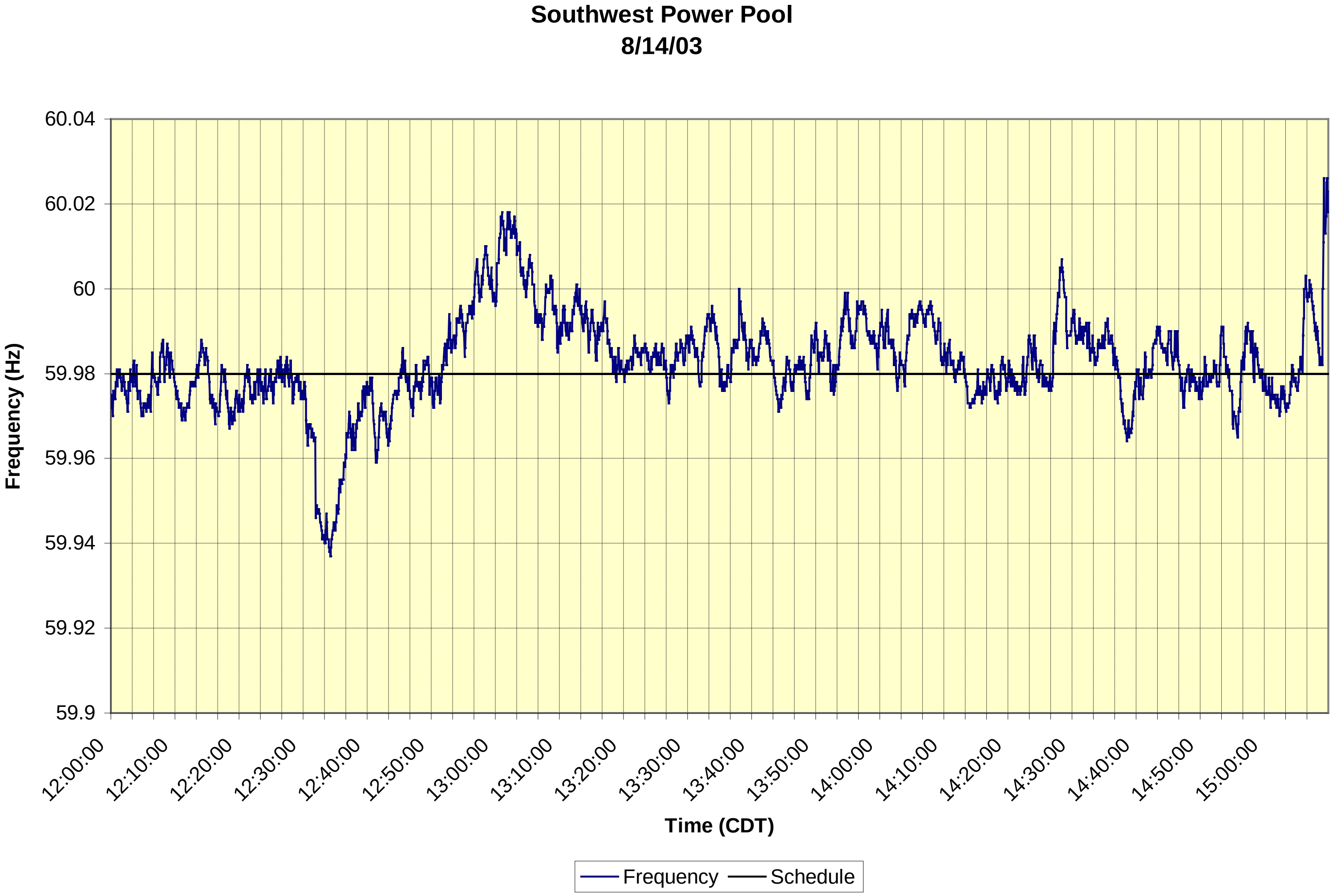
Supply – Demand Balance: The Goal of the System



- 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

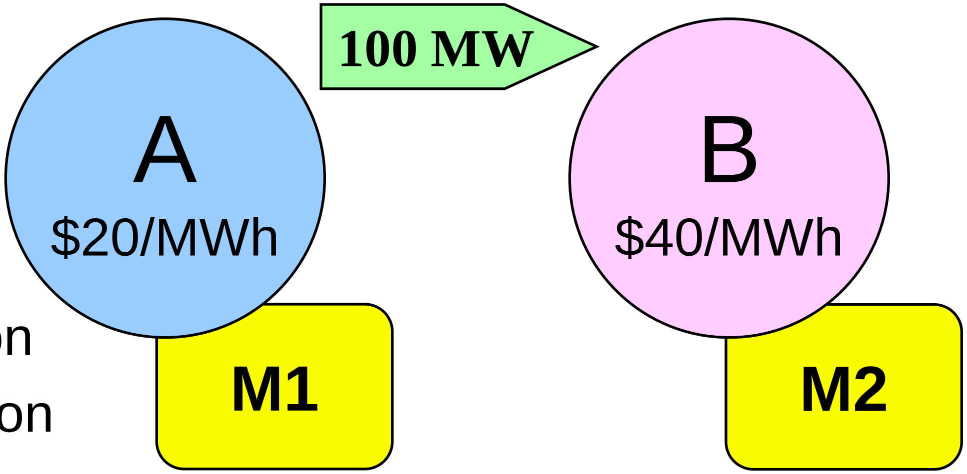


Power Flow Across the Grid

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

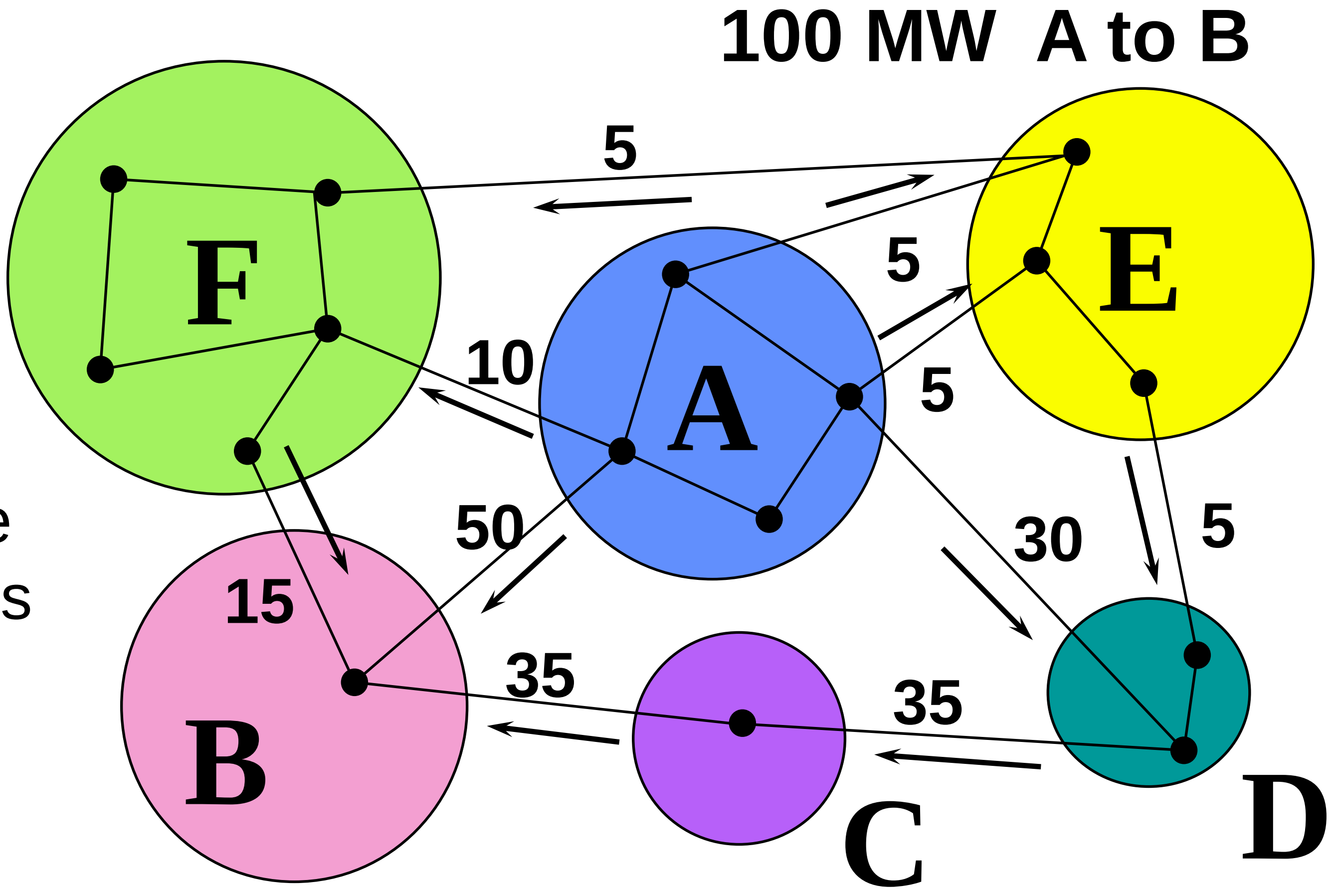
Sale from A to B at 4-5 pm of 100 MW

- 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



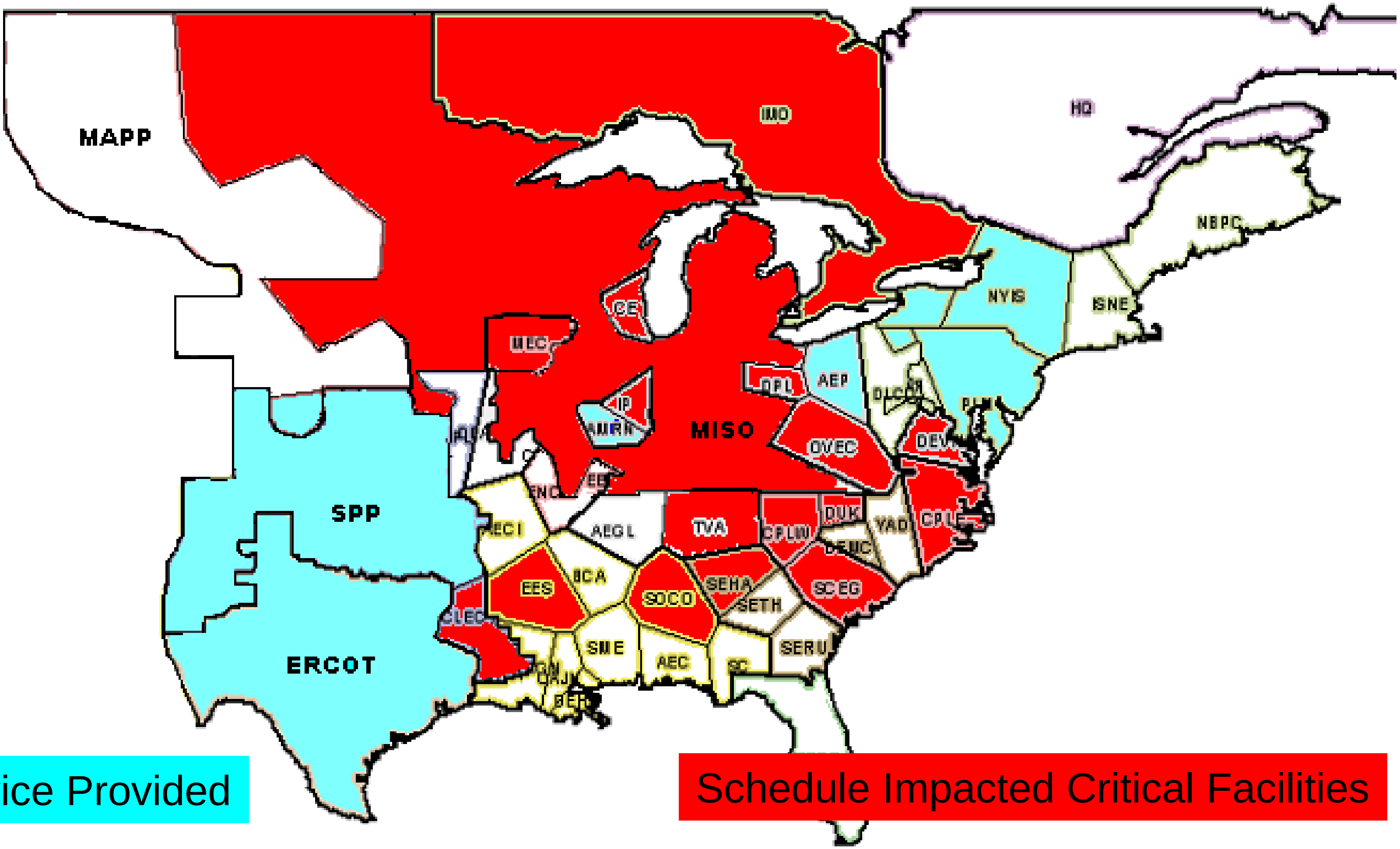
Areas A & B may be separated by thousands of miles. Price may be affected by various factors including transmission congestion

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

ELECTRIC TRANSMISSION 101:

Regulation

Jeff Dennis

Office of Energy Policy and Innovation

Federal Energy Regulatory Commission

Obligatory Disclaimer

Any views expressed in this presentation are my own, and do not necessarily represent the views of the Federal Energy Regulatory Commission or the United States Government.

U.S. Electricity Regulation: Who is Responsible for What?

Federal Regulation (FERC)

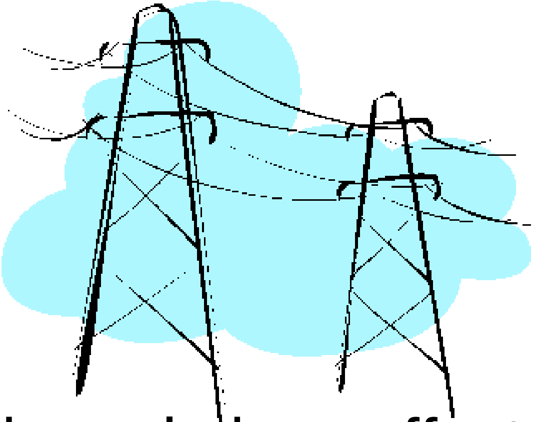
- Wholesale sales of electricity for resale in interstate commerce
- Transmission of electricity in interstate commerce
- (Very) Limited transmission siting authority
- Permitting of hydro plants
  - Otherwise, no generation planning or facility siting authority
- Reliability of transmission grid

State Regulation (PUCs)

- Retail sales to end users
- Low-voltage distribution
- Siting of power plants and transmission lines
- Resource planning; *i.e.* the generation types (coal, natural gas, renewable) used by a utility to serve customers

Transmission Regulation Overview

- Transmission is regulated by a mix of federal, regional, state, and local rules
  - Ratemaking
  - Operation
  - Planning
  - Siting
  - Reliability



- Collectively, transmission-related regulations affect the ongoing reliability of the system, the economic efficiency of delivering energy to consumers, and the ability to add new generation to the overall mix of electricity resources
- A robust national electric grid is key to competitive markets and achievement of public policy goals at the federal and state level (such as the addition of renewable resources like wind and solar)

Transmission Ownership/Operation

- **Ownership of the transmission grid is fragmented - hundreds of discrete owners**
    - Roughly two-thirds of U.S. transmission is owned by investor-owned utilities; roughly one-third is owned by public entities
    - Ownership affects regulatory jurisdiction
- **Many transmission owners have turned operational control over to independent regional operators**
    - Independent regional operators serve roughly two-thirds of electricity consumers in the United States
    - Operational control also affects regulatory jurisdiction

Federal Regulation

- **A number of federal entities have authority over transmission-related matters depending on location and market structure, including:**
  - Federal Energy Regulatory Commission
    - regulation of "public utilities" under FPA - corporate matters, rates and terms of service
    - approval of reliability standards for broader set of utilities
  - Department of Energy
    - policy, data collection and analysis, R&D
  - Department of Agriculture/Forest Service, Department of Interior/ Bureau of Land Management
    - rights of way and land use management
  - Federal Utilities
    - ownership and operation of federally-owned facilities

FERC Authority

- Federal Energy Regulatory Commission regulates interstate transmission rates, terms and conditions of service for public utilities
- **General Ratemaking Principles** assure rates for service are just and reasonable and not unduly discriminatory
    - Largely driven by embedded system costs, not cost of serving the next user
    - Based on “cost of service” principles
    - Revenue requirement is the amount needed to cover operating expenses, taxes, interest, and a reasonable rate of return

Expenses + **Return On** + **Return Of** = **Revenue Requirement**

FERC Authority (cont'd)

- **FERC requires "open access" to jurisdictional transmission facilities**
    - Basic principle: treat others as you treat yourself
    - Non-discriminatory access by generation seeking to deliver to the market
    - Open access applies to transmission used in interstate commerce (including unbundled retail transmission, but not bundled retail transmission)
    - Transmission planning subject to open and transparent rules
    - Must have transparent cost allocation methods in place for regional and interregional projects
- **Adopts and enforces reliability standards**
    - Standards are developed by the North American Electric Reliability Corporation (NERC); apply to all users, owners and operators

Regional Operators

- **Regional Transmission Organizations and Independent System Operators have been created by regional stakeholders in response to FERC's Orders 2000 and 888, respectively, to**:
  - Facilitate competition among wholesale suppliers
  - Provide non-discriminatory access to transmission by scheduling and monitoring the use of transmission
  - Perform planning and operations of the grid to ensure reliability
  - Manage the interconnection of new generation
  - Oversee competitive energy markets to guard against market power and manipulation
  - Provide greater transparency of transactions on the system
- **RTOs and ISOs are subject to FERC jurisdiction**
  - Participation by public entities in an RTO or ISO results in FERC jurisdiction over RTO/ISO-related activities
  - RTO/ISO market structure can affect state jurisdiction (e.g., resource adequacy)

Order No. 1000

- **Regional Transmission Planning Requirements**
  - Establish open and transparent processes to identify projects that can meet regional needs more efficiently or cost effectively than locally-planned alternatives
  - Processes must allow for input by stakeholders (including users of the system, state policymakers, and other affected entities)
- **Planning for Public Policy Requirements**
  - Establish procedures to consider transmission needs driven by local, state or federal public policy requirements (RPS, carbon, etc.), and potential solutions to those needs, in transmission planning processes
- **Requirements for Coordination Between Regions**
  - Regions must share information on transmission needs, and develop procedures to jointly evaluate interregional projects that may be more efficient or cost effective solutions to each region's individual needs.

Order No. 1000 cont.

- **Cost Allocation Requirements**
  - Establish regional cost allocation methods for new transmission projects selected under the regional planning process
  - Methods must satisfy six principles
  - Basic requirement: those who benefit must share in costs, and those who do not benefit may not be assigned costs
- **"Non-Incumbent" Transmission Developer Reforms**
  - Promotes competition in transmission development by removing barriers to participation by new entrants
- **Compliance Process**
  - Filings to comply with regional planning requirements made; Commission has reviewed nearly all of them
  - Filings to comply with interregional planning requirements due July 10

Other FERC Authority

- Monitors energy markets to protect customers from market manipulation
- Authorizes public utility asset dispositions and mergers over $10MM
- Oversees issuance of certain securities
- Resolves disputes among market participants
- Limited backstop siting authority for “national interest electric transmission corridors”

State Regulation

- A number of state entities play a role in transmission issues:
  - Public Service/Public Utility Commissions (retail rates, siting)
  - Environmental agencies (land use, siting, environmental standards)
  - Legislatures
  - Local Authorities (siting)
- States rules and requirements for transmission siting are not uniform and there are no formal compacts; many states have no siting rules and may be governed by local authorities (counties)
- Most states regulate retail electric rates that end use customers pay, including the collection of transmission revenues
- Land use, contracts, corporate matters (e.g., public utility status) eminent domain are usually under state law
- There are entities that are not under state regulation, such as municipal utilities, cooperative utilities and others

ELECTRIC TRANSMISSION 101: Markets, ISO/RTOs and Grid Planning/Operations

Jay Caspary

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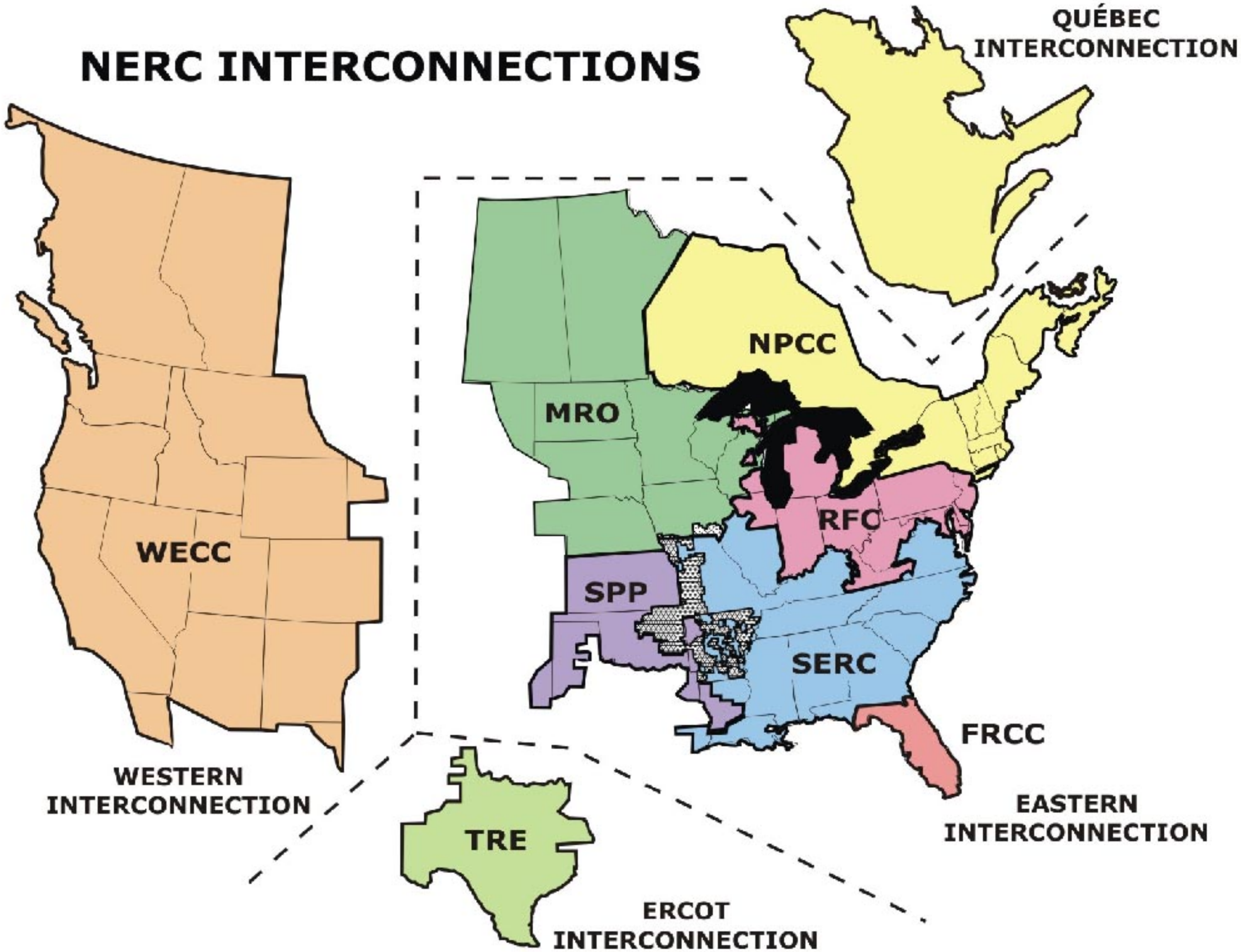
Southwest Power Pool

Organized Markets

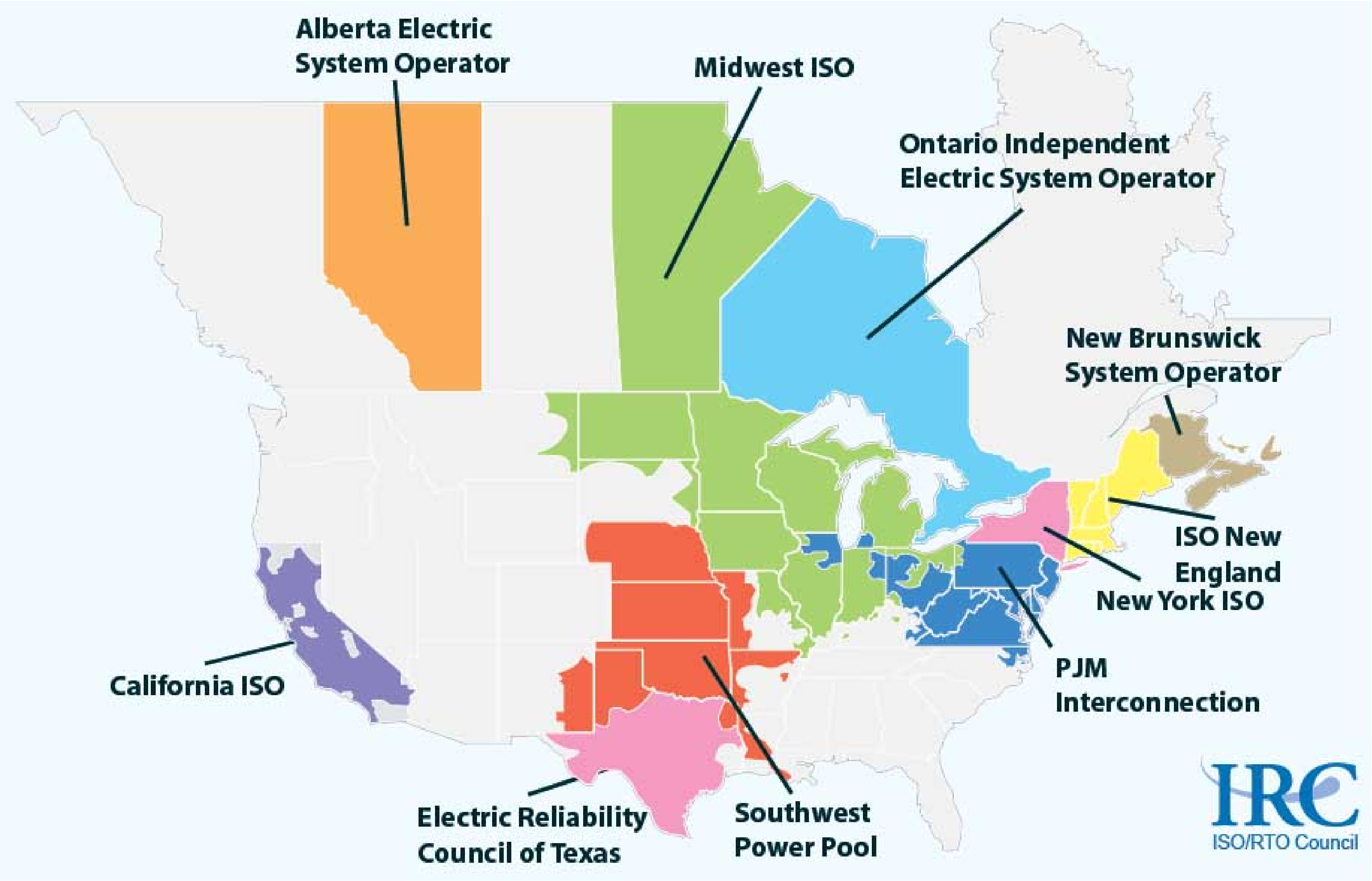
WIRES

- Organized markets are managed by regional oversight entities called Regional Transmission Organizations and Independent System Operators, created by regional stakeholders in response to FERC's Orders 2000 and 888 respectively, to:
  - Facilitate competition among wholesale suppliers
  - Provide non-discriminatory access to transmission by scheduling and monitoring the use of transmission
  - Perform planning and operations of the grid to ensure reliability
  - Manage the interconnection of new resources, e.g., generation, loads…
  - Oversee competitive energy markets to guard against market power and manipulation
  - Provide greater transparency of transactions on the system
- Some are confined to a single state, while some cross multiple states (The terms ISO and RTO often used interchangeably)

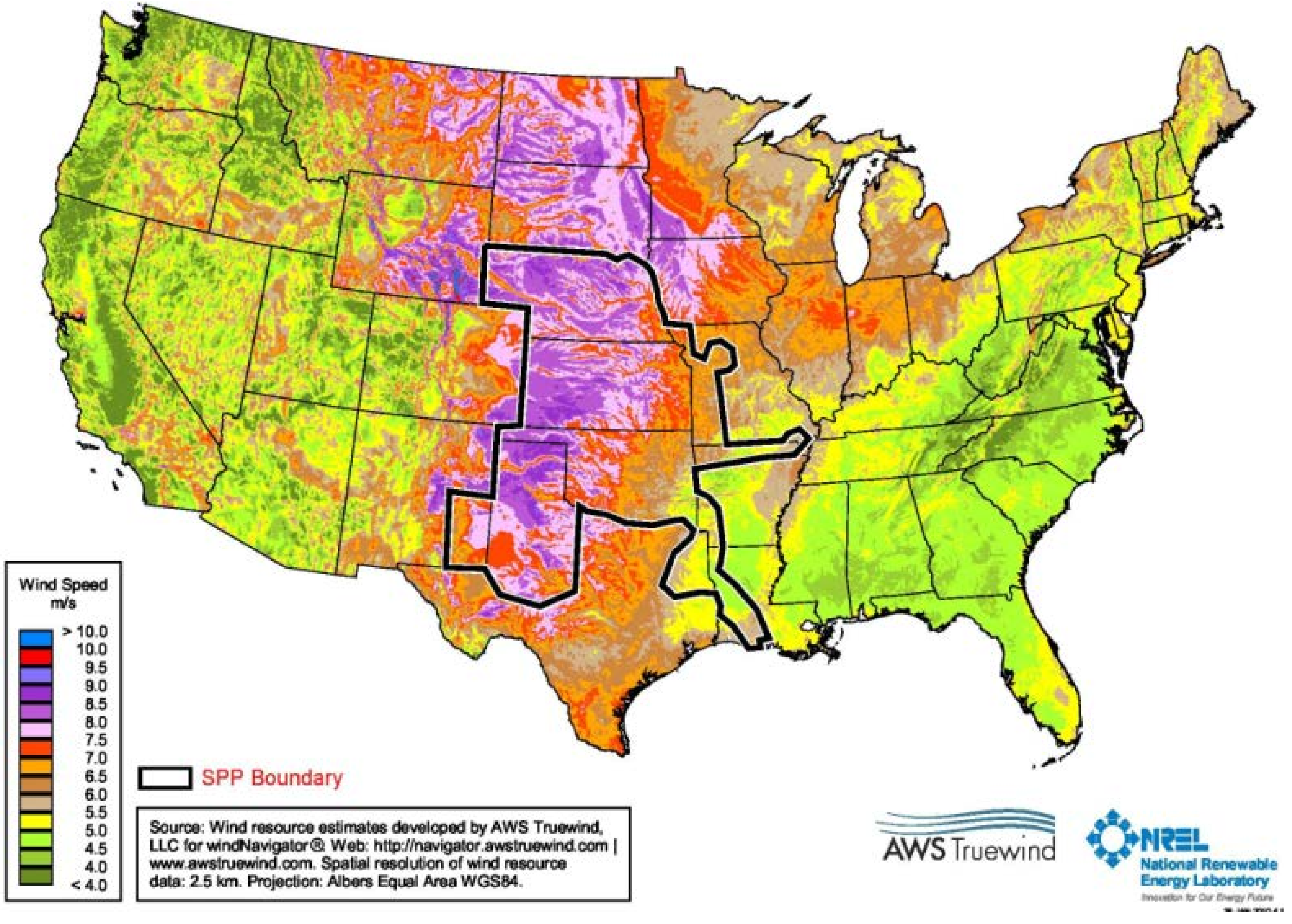
3 Interconnections / 8 NERC Regions



ISO / RTO Map


Alberta Electric System Operator
Midwest ISO
Ontario Independent Electric System Operator
New Brunswick System Operator
ISO New England
New York ISO
PJM Interconnection
California ISO
Electric Reliability Council of Texas
Southwest Power Pool
IRC
ISO/RTO Council

Annual Average Wind Speed - 80 meters

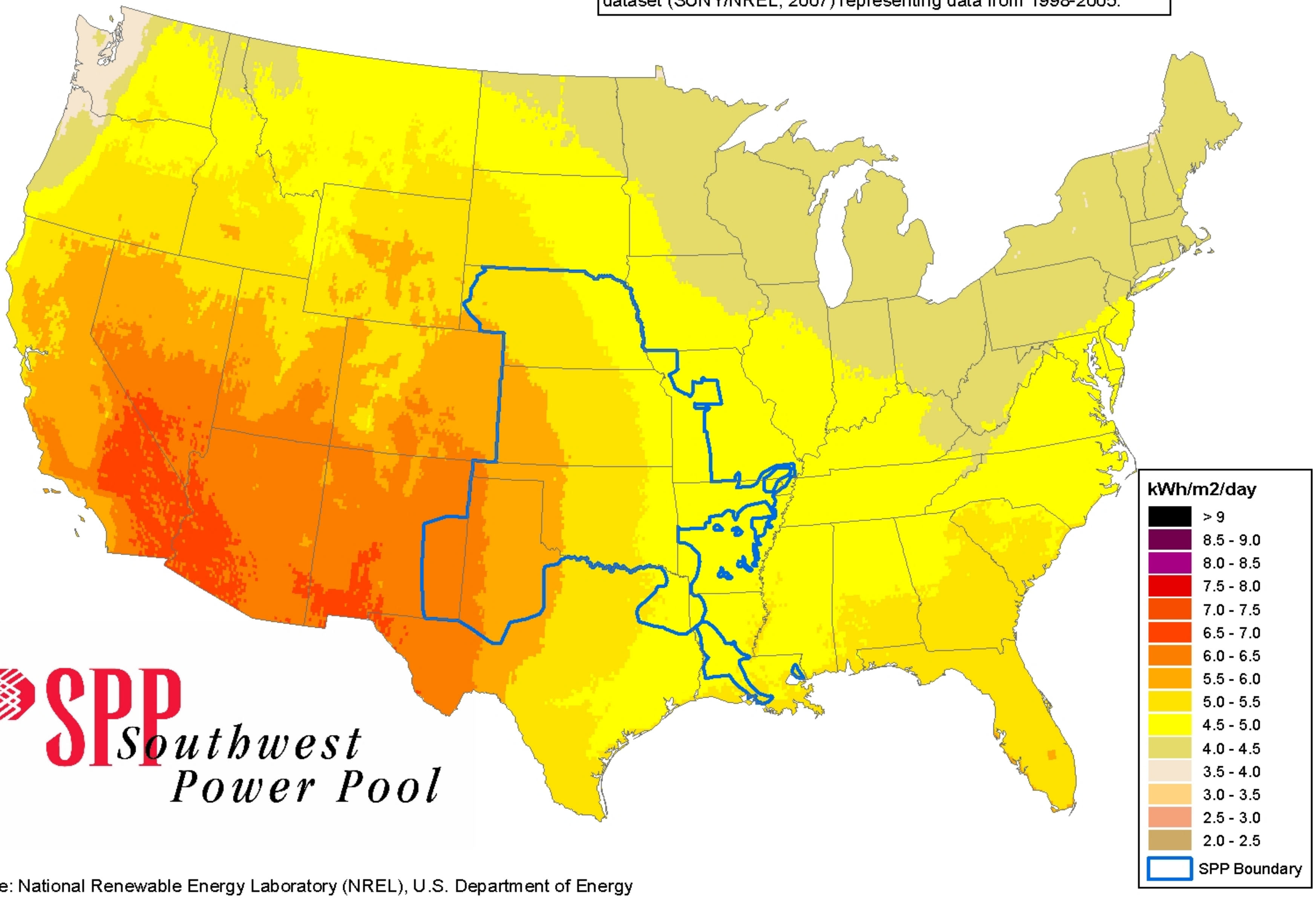


Source: Wind resource estimates developed by AWS Truewind, LLC for windNavigator® Web: http://navigator.awstruewind.com | www.awstruewind.com. Spatial resolution of wind resource data: 2.5 km. Projection: Albers Equal Area WGS84.

PV Solar Radiation
(Flat Plate, Facing South, Latitude Tilt)

Annual

This data represents annual average solar resource potential for 48 Contiguous United States and Hawaii, in High Resolution. The data for Hawaii and the 48 contiguous states is a 10 km, satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005.



SPP Southwest Power Pool

Source: National Renewable Energy Laboratory (NREL), U.S. Department of Energy

Regional Transmission Organizations Independent System Operators

WIRES

- No standard market design for every ISO/RTO
- Manage and provide a central clearing house for transactions (transmission and generation) versus bilateral markets with parties working directly to establish terms and conditions
- Includes allocation of transmission rights, day ahead and spot market purchases
- Participants still negotiate bilateral arrangements as appropriate for business needs
- Provides more efficient grid management
- Participation is officially voluntary though FERC provides incentives to encourage membership

Regional Grid Enlargement in Bilateral Market Areas

WIRES

- Outside RTOs and ISO, there are many types of transmission owners, only some regulated by FERC.
- FERC regulates only wholesale transmission by “public utilities.”
- One-third of U.S. transmission is not owned by public utilities nor subject to full FERC wholesale regulation.
- States regulate most transmission for retail power sales.
- Transmission not fully regulated by FERC includes transmission owned by public power (governments), by most cooperatives, and by most of the utilities in Texas.
- Outside RTOs and ISO, FERC’s ability to promote coordinated enlargement of the interconnected grid is weaker than in RTOs and ISOs because its policies to do not apply to all the owners of the interconnected system.

FERC Authorities and Rules

- **Transmission Reliability**
  - FERC implemented EPAct 2005 authority over transmission reliability.
  - The new authority is to protect existing grid but not to order additions.

- **Regional Transmission Planning**
  - Planning needs to be regional to get some new resources to distant markets and improve grid operations to lower customer costs.
  - FERC requires regional planning by the transmission owners and operators it regulates.

Regional Planning Process

RTO/ISO planning encompasses the regional footprint; stakeholders can provide input and advocate positions throughout the process

Project is submitted to RTO/ISO for modeling to evaluate the impact on the regional system, including costs and benefits

↓

If the data shows the project is beneficial based on the RTO/ISO’s established criteria, it is approved

↓

Approved projects are eligible for cost recovery according to the RTO/ISOs methodology

↓

Projects may proceed outside the planning process but no cost recovery through RTO/ISO will be available

Regional Planning is Expanding

WIRES

- As a result of FERC Order 1000, regional planning and related cost allocation is expanding beyond ISO/RTOs to include other regions
- Certainty regarding cost allocation and cost recovery of transmission investments are critical for grid expansion
  - As you would expect, cost allocation is very challenging given complex and highly interconnected nature of the bulk power system and existing regulatory frameworks, not considering merchant transmission developments and opportunities which can transcend regions

Bilateral vs. Organized Markets

- Bilateral contract – a buyer and seller negotiate directly and sign a two-party contract to trade electric power.
- Outside the RTOs/ISO—mainly the Southeast, the upper Great Plains, and the West outside of California, wholesale power trades occur through bilateral contracts.
- Areas outside RTOs and ISOs are often called "bilateral market" areas.
- In the RTOs and ISOs, there are both bilateral markets and "organized" markets that pool all sellers and buyers.
- In the RTOs, FERC's oversight of transmission is stronger because all transmission owners follow the RTO's or ISO's transmission policies approved by the Commission.

Some Obstacles To Carrying Out Regional Transmission Plans

- **Cost allocation**
  - A major obstacle to carrying out a regional plan is deciding “Who pays?” for it.

- **Transmission Siting**
  - Local transmission siting can be another obstacle to realizing a regional transmission plan.
  - EPAct 2005 gave FERC “backstop” siting authority in DOE designated areas.

- **Interregional Planning is next frontier**
  - DOE funded efforts for each interconnection
  - FERC Order 1000 is providing guidance and direction

ELECTRIC TRANSMISSION 101: Bulk Power System Reliability

David Cook

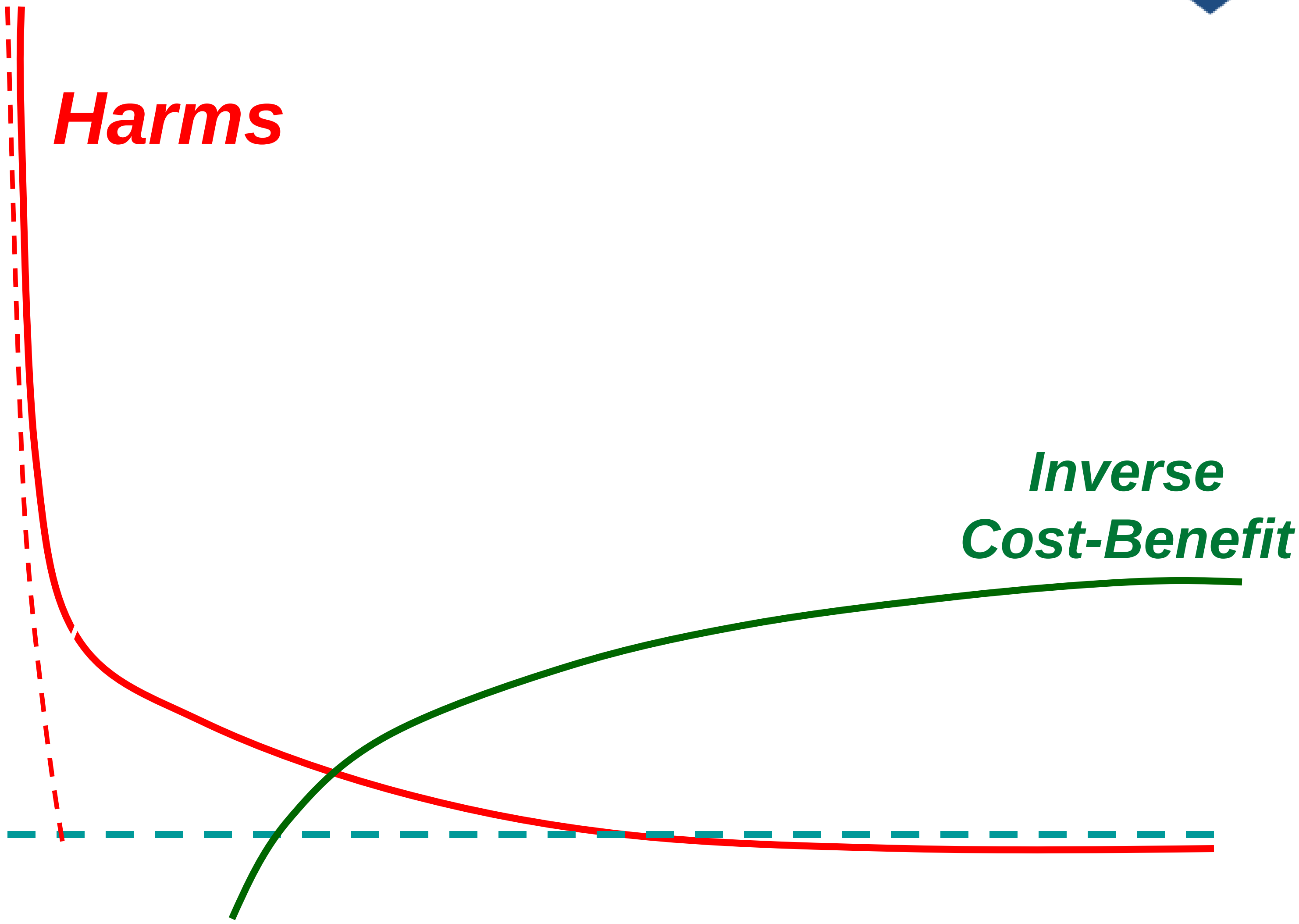
Senior Counsel

North American Electric Reliability Corporation (NERC)

Bulk Power System Reliability

- Meet all expected demand under normal conditions and reasonably foreseeable contingencies
- Maintain balance of generation and demand from second to second
- Plan and operate system so that all elements are within thermal and stability limits
- Plan and operate system so that loss of any element in the system results in remaining elements still being within thermal and stability limits (N-1)
- Protect equipment from physical damage when disturbances do occur, so system can be promptly restored

The Character of Harms



NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

NERC Reliability Risk Metrics

Harms: Load, Line, Generation Loss

Four Pillars

- Reliability – to address events and identifiable risks, thereby improving BPS reliability
- Assurance – to provide assurance to the public, industry, and government for the reliable performance of BPS
- Learning – to promote learning and continuous improvement of operations and adapt to lessons learned for improvement of BPS reliability
- Risk-based Approach – to focus attention, resources, and actions on issues most important to BPS reliability

Program areas

- Developing and enforcing reliability standards
- Assessing seasonal and long-term reliability
- Maintaining system awareness of the bulk power system
- Analyzing disturbances and off-normal events
- Training and certifying industry personnel
- Operating ES-ISAC

Governance and Mission

- A private, nonprofit corporation, governed by an independent board of trustees, elected by the membership

- Ensure and improve the reliability of the bulk power system of North America

- Subject to oversight in U.S. by Federal Energy Regulatory Commission; comparable arrangements with regulatory authorities in Canada

Membership

- Investor-owned utilities
- State/municipal utilities
- Cooperative utilities
- Federal or provincial utilities/Federal PMAs
- Transmission-dependent utilities
- Merchant electricity generators
- Electricity marketers
- Large end-use electricity customers
- Small end-use electricity customers
- ISOs/RTOs
- Regional entities
- Government representatives

Closing

Jim Hoecker

Themes To Think About

- The transmission system is:
  - A massive, highly integrated machine
  - A basic component of a vibrant economy
  - Regional in operation
  - Impacted by many federal, state and local authorities
  - Essential to delivering remote clean energy resources

- Today's challenges to investment:
  - Planning
  - Cost recovery
  - Cost allocation
  - Siting
  - Changing generation/fuel mix
  - Emerging technologies

Questions? Contact us at www.wiresgroup.com

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