The Transmission Grid:
Understanding How It Works to Understand Who Should Pay

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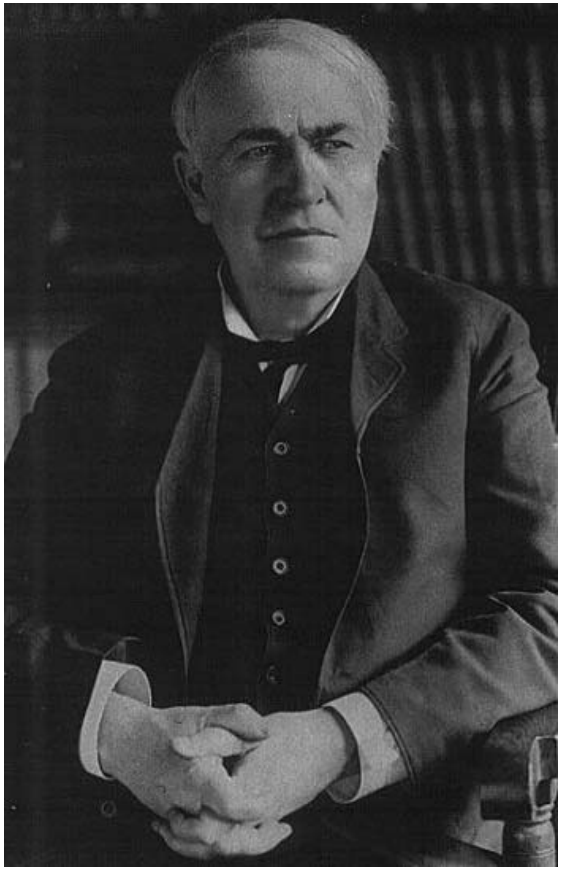
Thanks to:

- Dr. Wayne Galli, Director of Transmission Development for NextEra Energy Resources, for portions of this presentation

What is the Largest, Most Complex Machine Ever Built?

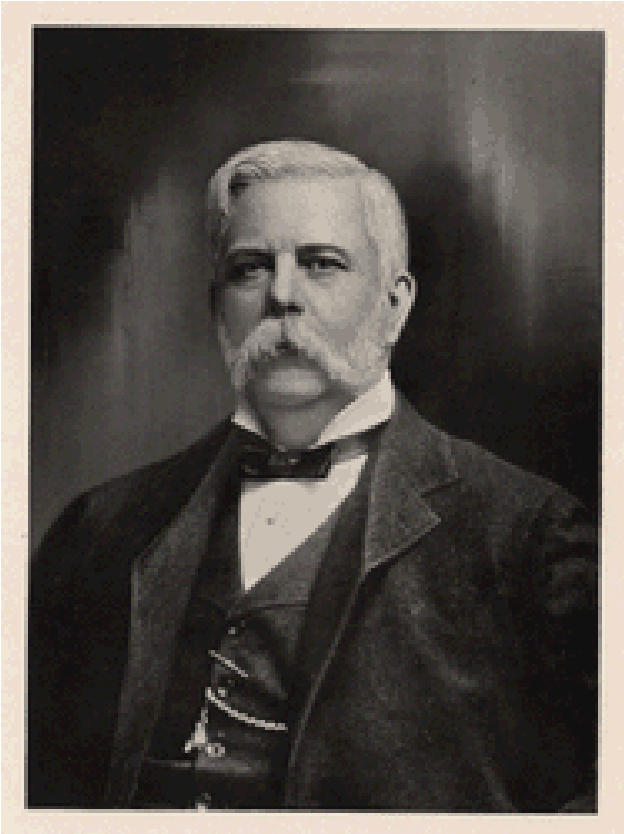
- The space shuttle?
- The Eastern Interconnection?
- The world wide web?
- The Large Hadron Collider?

Thomas Edison



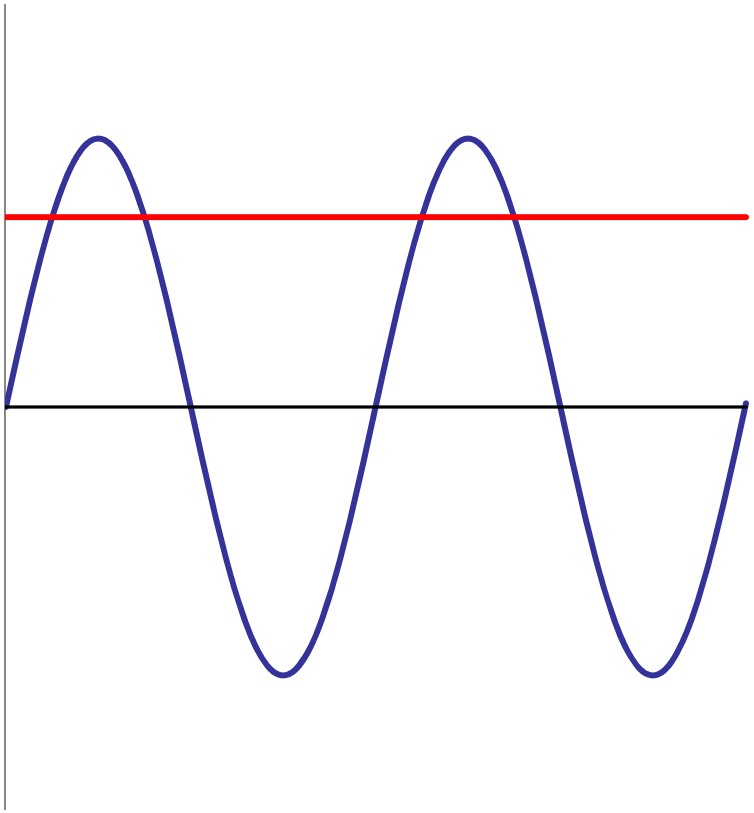
- Advocate of direct current (DC) electric power system
- Founder of General Electric

George Westinghouse



- Advocate of alternating current (AC) electric power system
- Co-founder of Westinghouse Electric

AC vs. DC



- Direct current (DC)
  - Magnitude of current is constant
- Alternating current (AC)
  - Magnitude of current varies with time

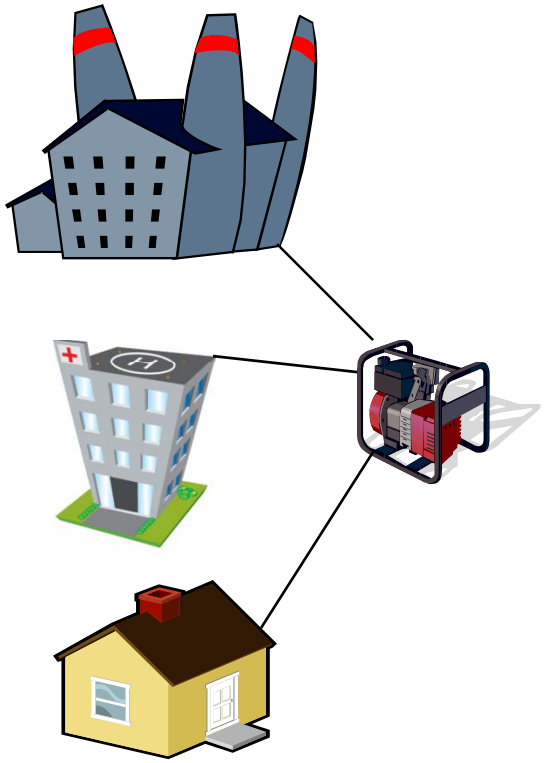
AC vs. DC

- In the late 19th century, an often vicious battle was waged over whether to use AC or DC for electric power systems
- Edison tried to sway public opinion by claiming that AC was dangerous
  - electrocution of animals
  - development of the electric chair

A Winner!!!

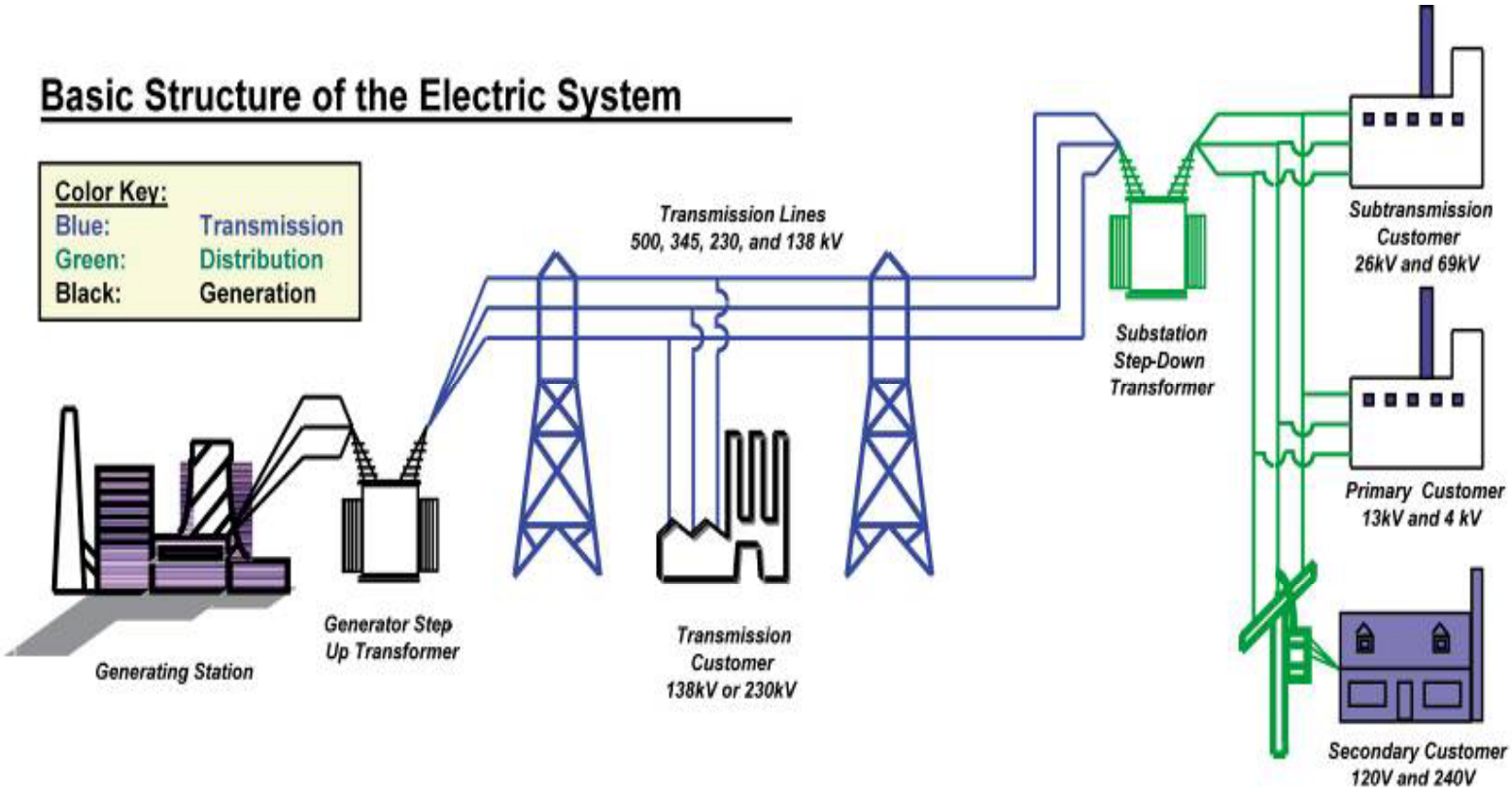
- AC became the current of choice, largely because of the transformer
  - Transformers could easily increase voltage levels to transmit power from the generator and decrease voltage at the load
    - lower losses
- Also, AC is easier to disconnect because the current is equal to zero twice during each cycle

Without a Transmission System



- Loads must be located close to a generator
  - Less than a mile
  - Only cities have access to power
- Small generators
  - High cost

We Add a Transmission Line

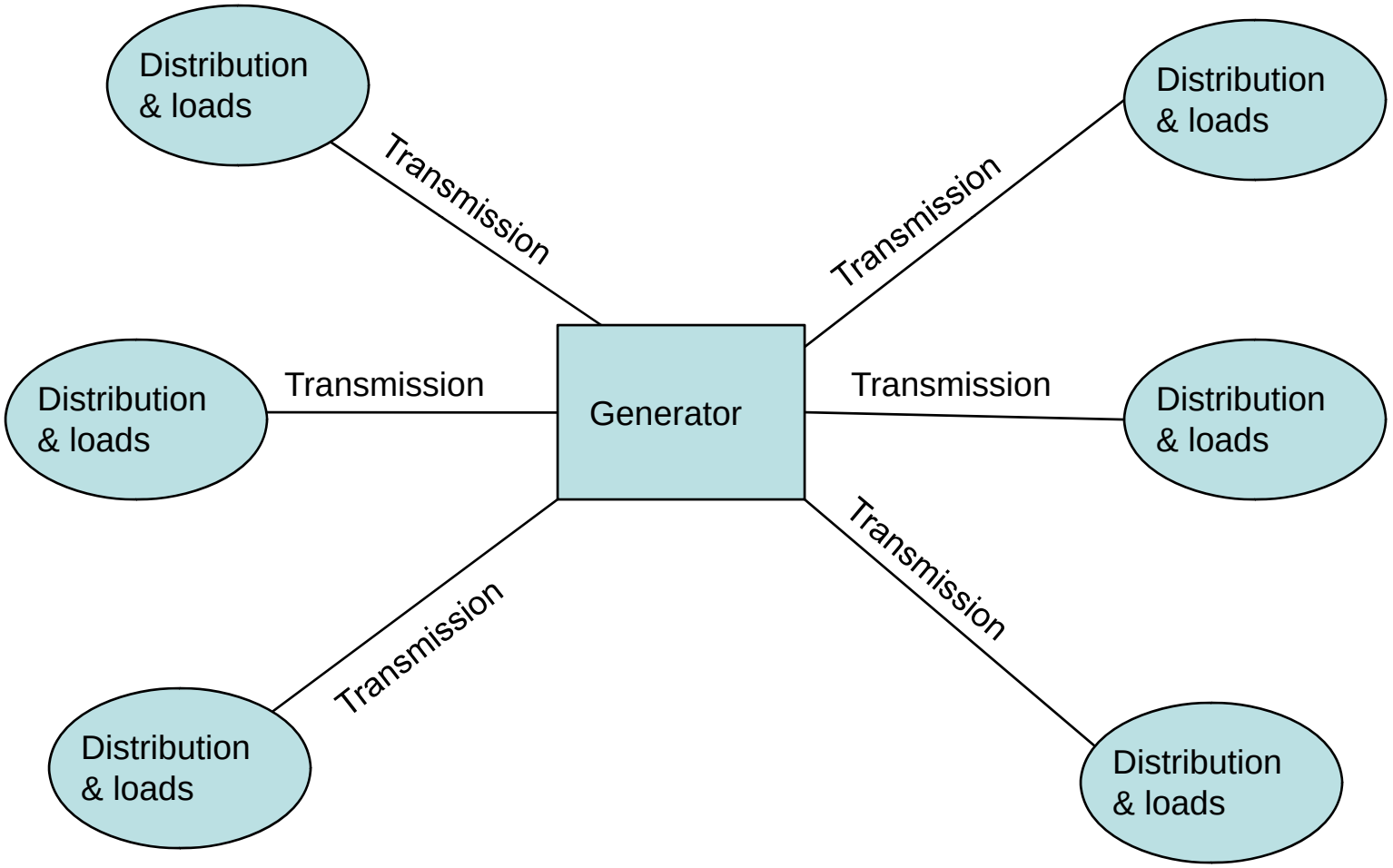


Source: www.nerc.com

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

A Radial System



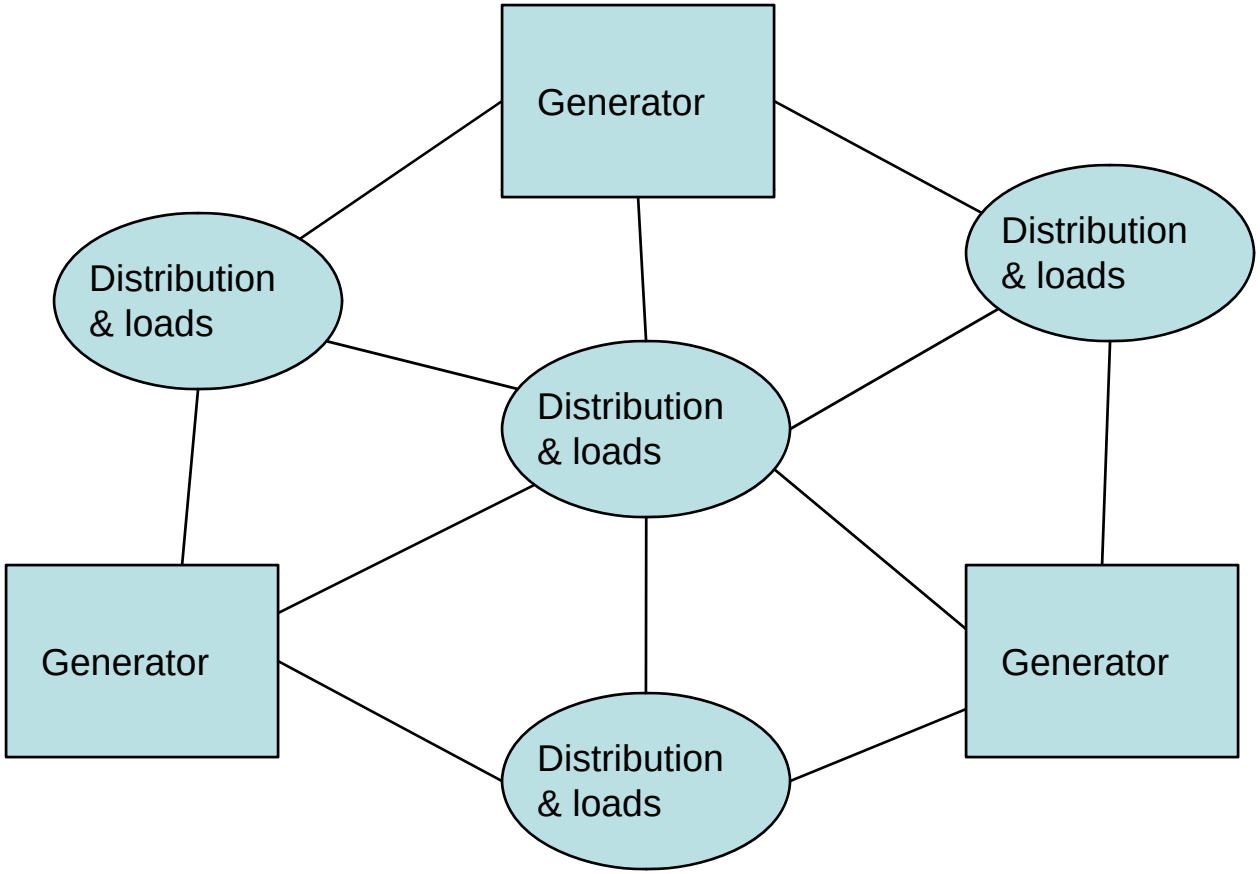
Radial Systems

- Electric power flows from generator to transmission line to distribution system along a single path
- Failure of any component on the path means the lights go out
- This type of system is still used in some developing parts of the world

Parallel Path Systems

- The addition of a second (or more) transmission line increases reliability
  - If a line or transformer fails, power can still flow along another path
- Power losses in the transmission lines are reduced
- But, adding additional lines costs $$$

We Have a Network



Early Utility Systems

- A number of separate utilities operating as islands
- Transmission was built to serve local needs
  - Reliability
  - Allow for larger, more efficient generators located at a distance from the loads

Electrical Isolation

- Maintaining reliability was difficult and expensive with the utilities being electrically separated from each other
  - Each utility would need to build in enough redundancy to handle the problems that might arise, or the customers would have to live with the lights going out
  - It would be difficult for a utility to respond to rapid changes in load levels

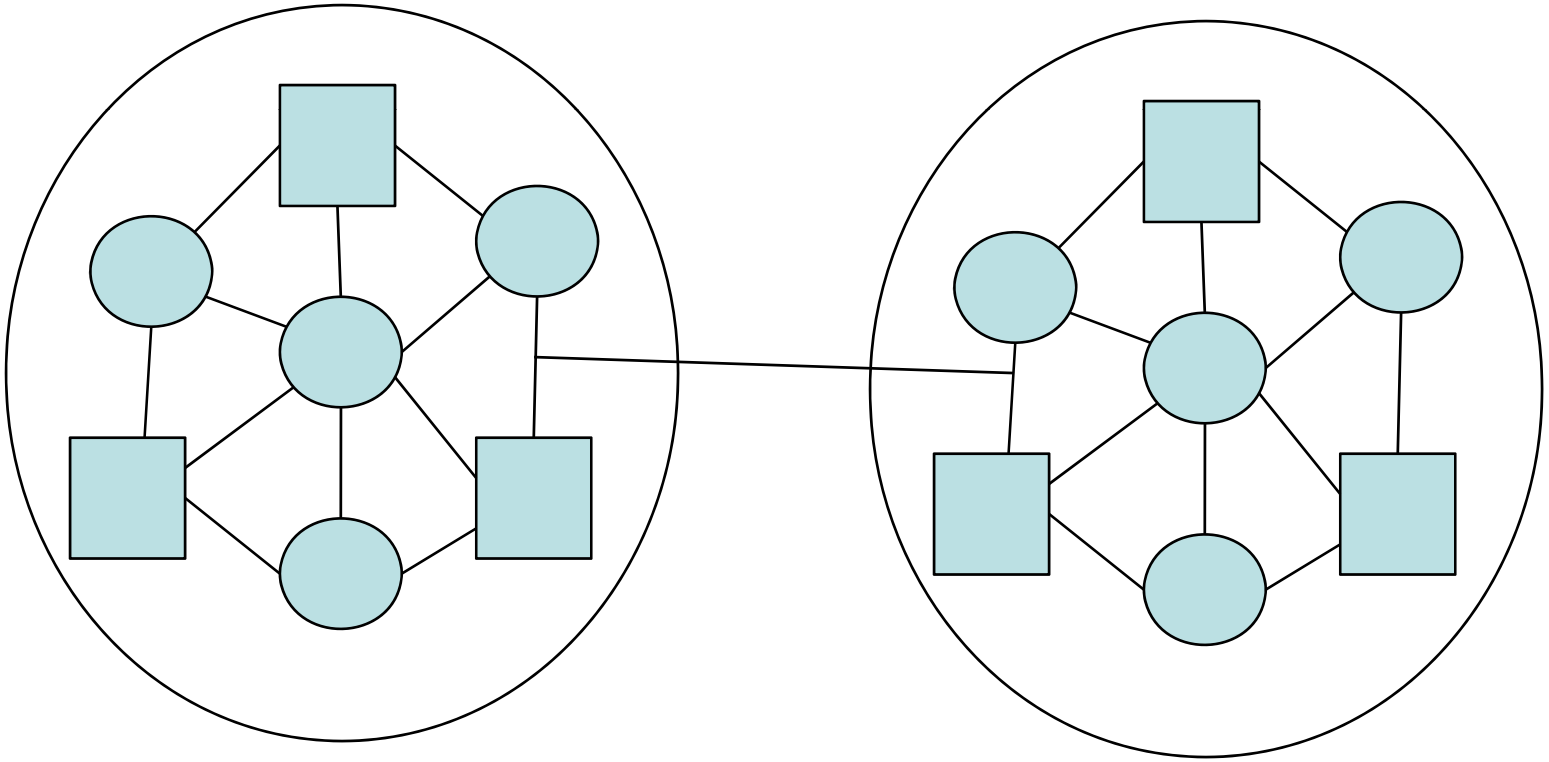
Example

- Suppose I have a utility with 500 MW of load, supplied by three generators
  - 2 are 100 MW each
  - 1 is 300 MW
- In order to handle an outage of the largest generator, I would need 300 MW of excess generation capacity

Example w/ Interconnection

- Suppose my neighbor has an identical system
- If we interconnect, we could each carry 150 MW of extra capacity instead of 300 MW
  - Whichever utility experienced the outage would rely on his neighbor for the rest

Interconnection



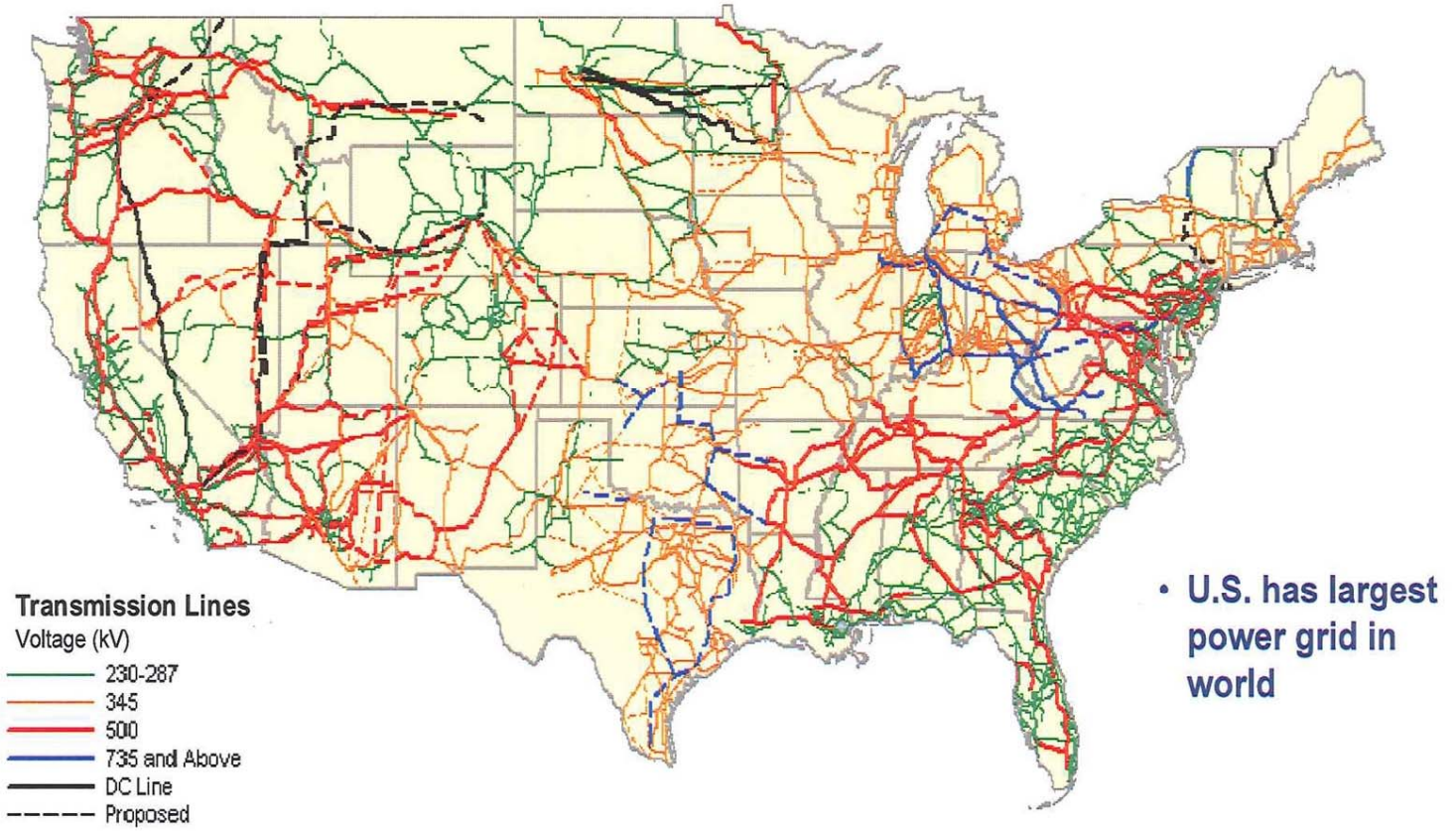
Benefits of Interconnection

- Reserve margins can be reduced
  - Saves $$$
- It is easier to follow load changes (ancillary services)
  - More generators means each can handle a smaller portion of the load change
- Reliability is increased
  - My interconnected neighbor can help me keep the lights on when I experience a problem
- Bulk power transactions, power pools, and markets are possible
  - Saves $$$

Liabilities of Interconnection

- It is difficult to control the path over which electrical power flows (loop flow)
  - "Path of least resistance"
  - "Laws of physics"
- It is also more difficult to analyze
- Cascading outages
  - Instead of my neighbor keeping my system up when I have a problem, I pull his down with me

Interconnected Grid

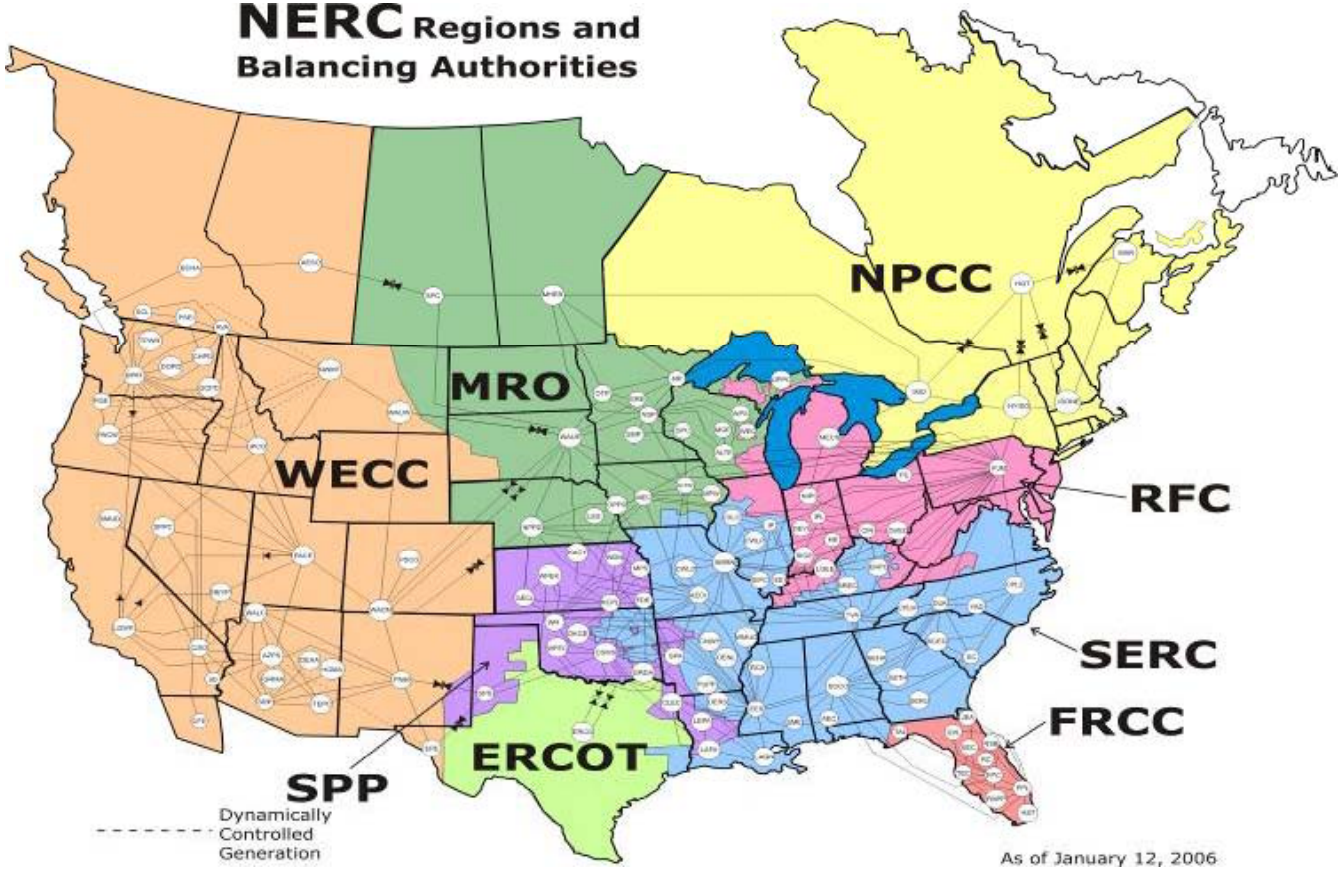


Source: Based on data from Global Energy Decisions, LLC, Velocity Suite, June 2008

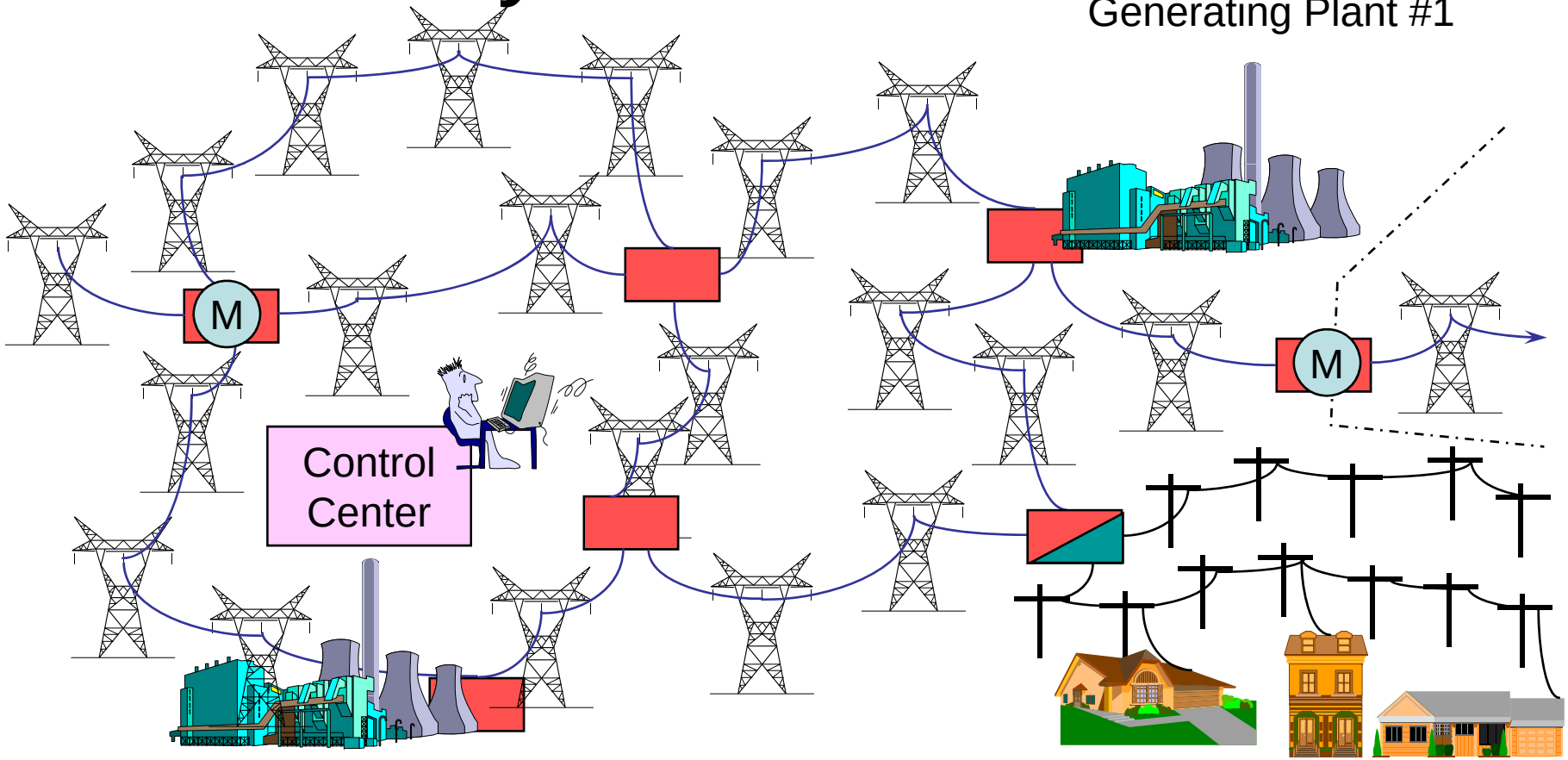
Interconnected Operation

- 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 authority)
- Transmission lines known as tie lines connect the individual utilities to each other

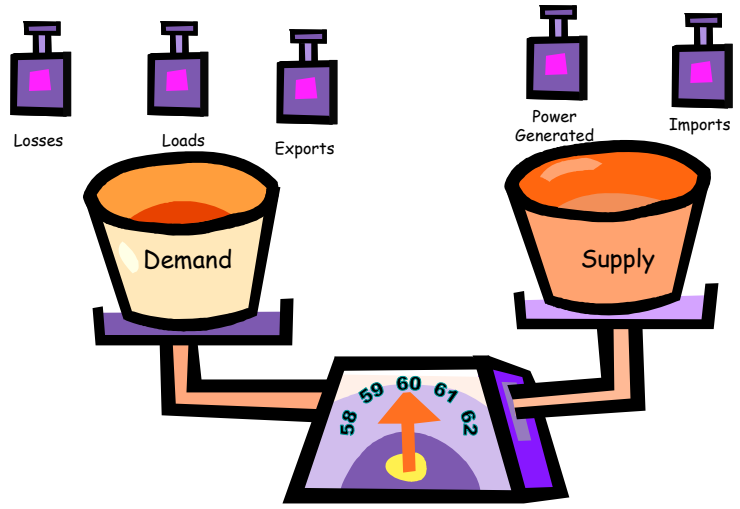
3 Interconnections, 8 Regions, 135 Balancing Authorities



Balancing Authority and System Control



Supply and Demand Balance

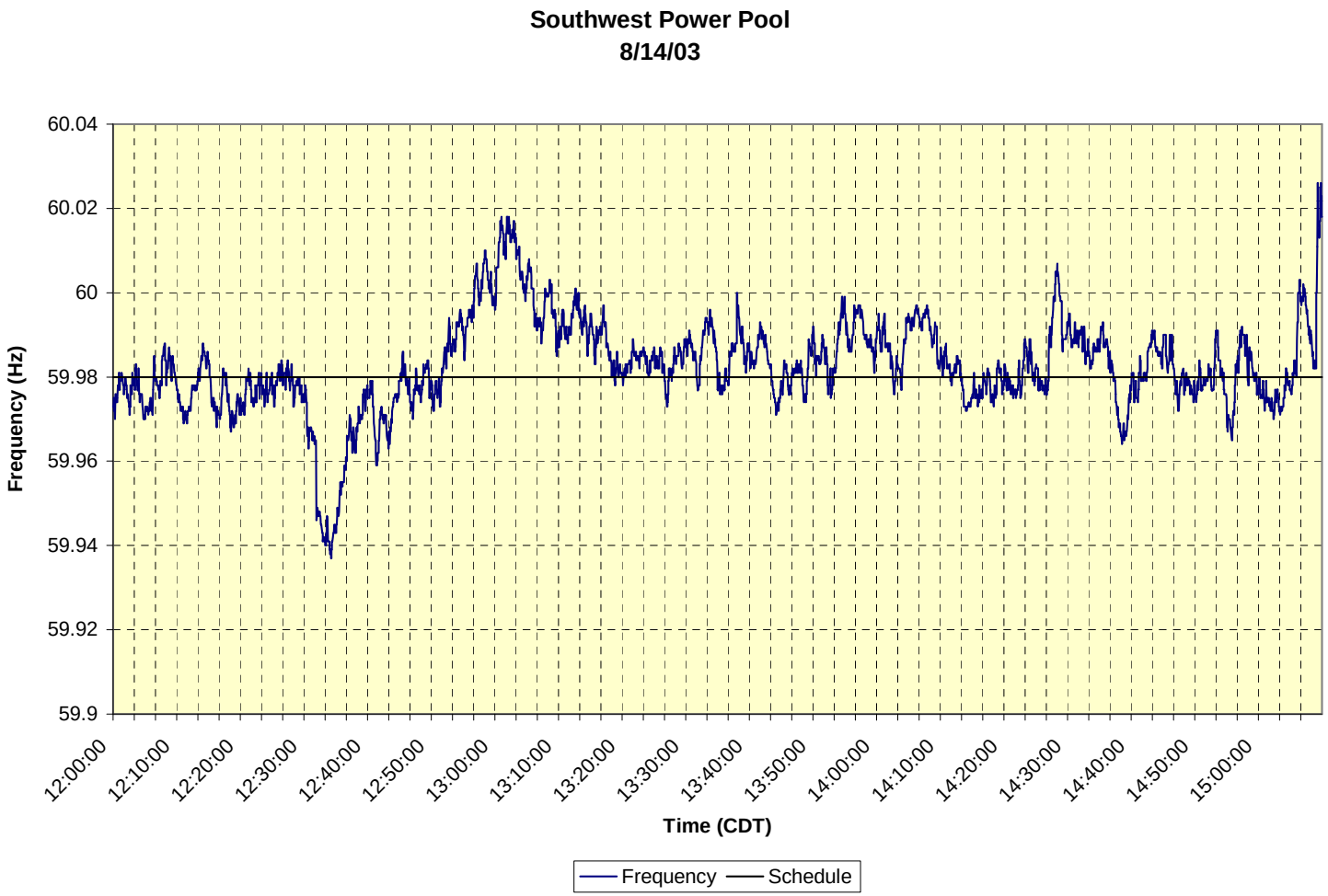


- Electrical energy cannot be stored easily
  - Must be converted to another form
- Thus, supply and demand must always be kept in balance

What Happens in Vegas…

- ….does not stay in Vegas
- Anything that happens in one part of the interconnection affects the rest of the interconnection
- Usually, an event is so small that the impact is lost in the noise of all the other events in the interconnection

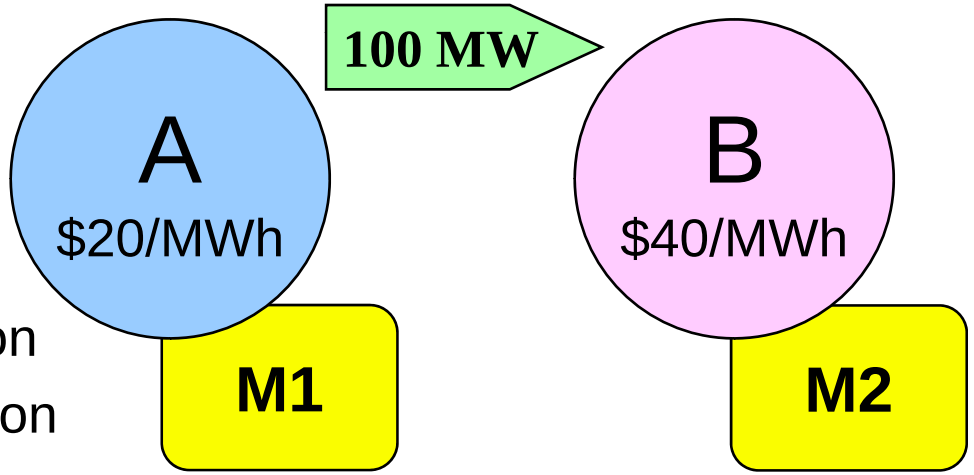
August 14, 2003



Simple Bi-lateral Transaction

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

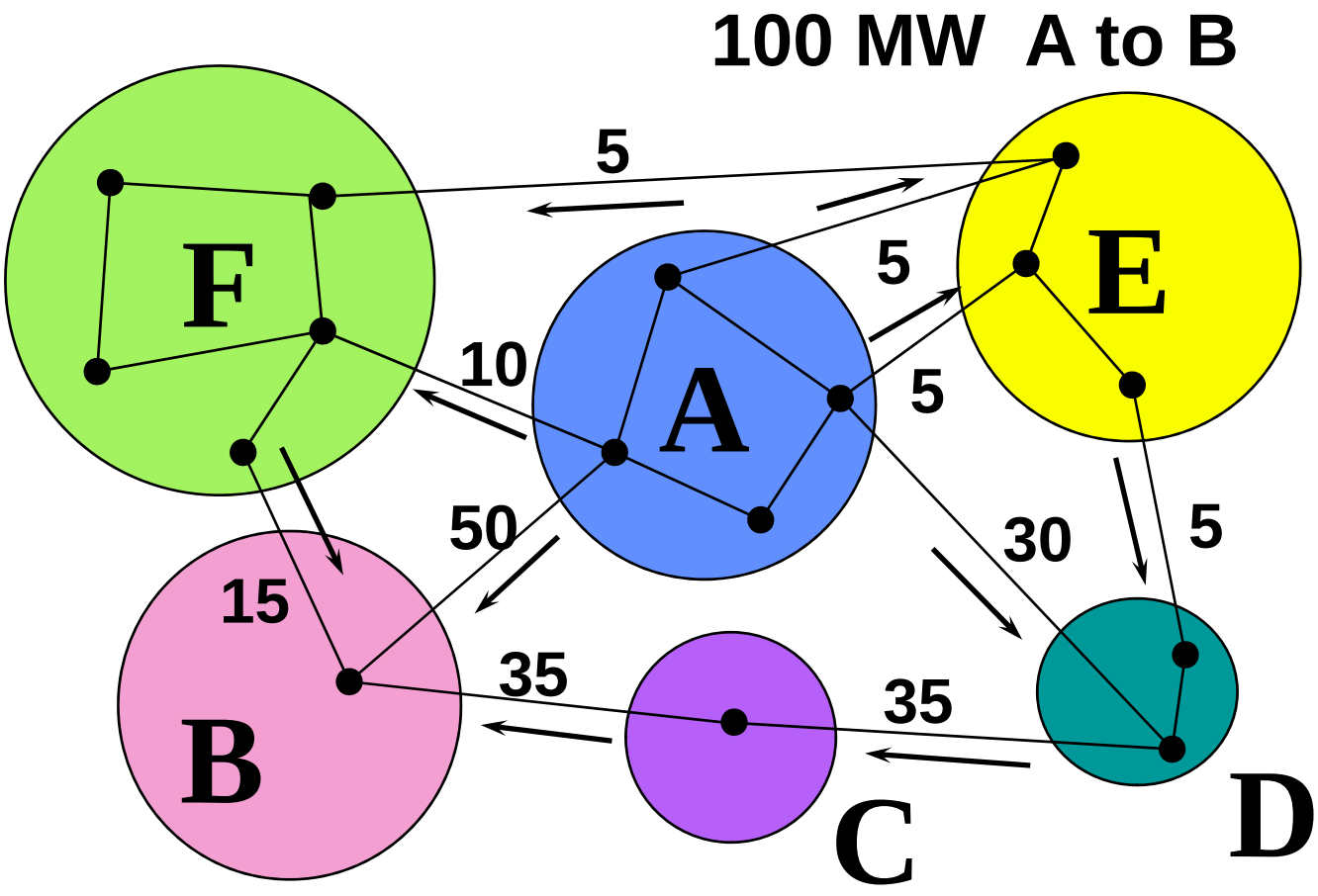
- 3:40 pm Schedule
- 3:55 pm Confirm
- 4:00 pm Begin interchange
  - Seller increases generation
  - Buyer decreases generation
- 5:00 pm End
  - Seller decreases generation
  - Buyer increases generation



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

Power Flows According to Laws of Physics

The power from A does NOT flow directly to B.



Transmission Limitations

- Physical limits of components
  - Overheating of lines and transformers
  - Line sag
- Stability limits
  - Angular
  - Voltage
- Contingencies
  - Some capability left unused to handle outages

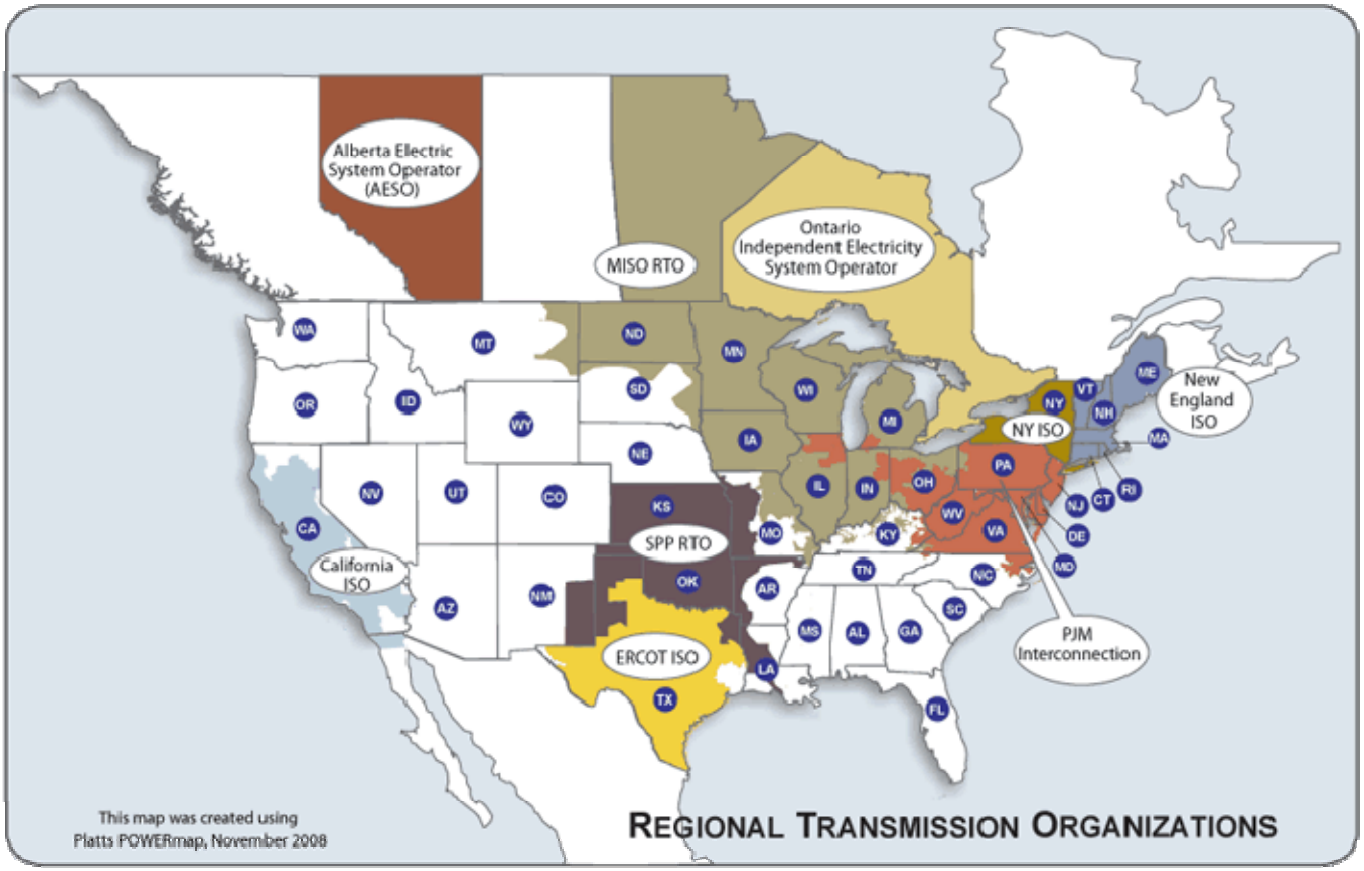
Congestion

- When these limitations become binding, congestion occurs
- Congestion costs $$$
  - Re-dispatch means using less economic generators
  - Reserve margins may need to be higher to maintain adequate reliability
  - Potential for market power increases
  - Ancillary services

Recent Developments

- Open access/regional transmission organizations
  - Increase in economic transactions
- Environmental considerations
  - Increase in renewable generation
- Increasing consumption
- Very little new transmission constructed

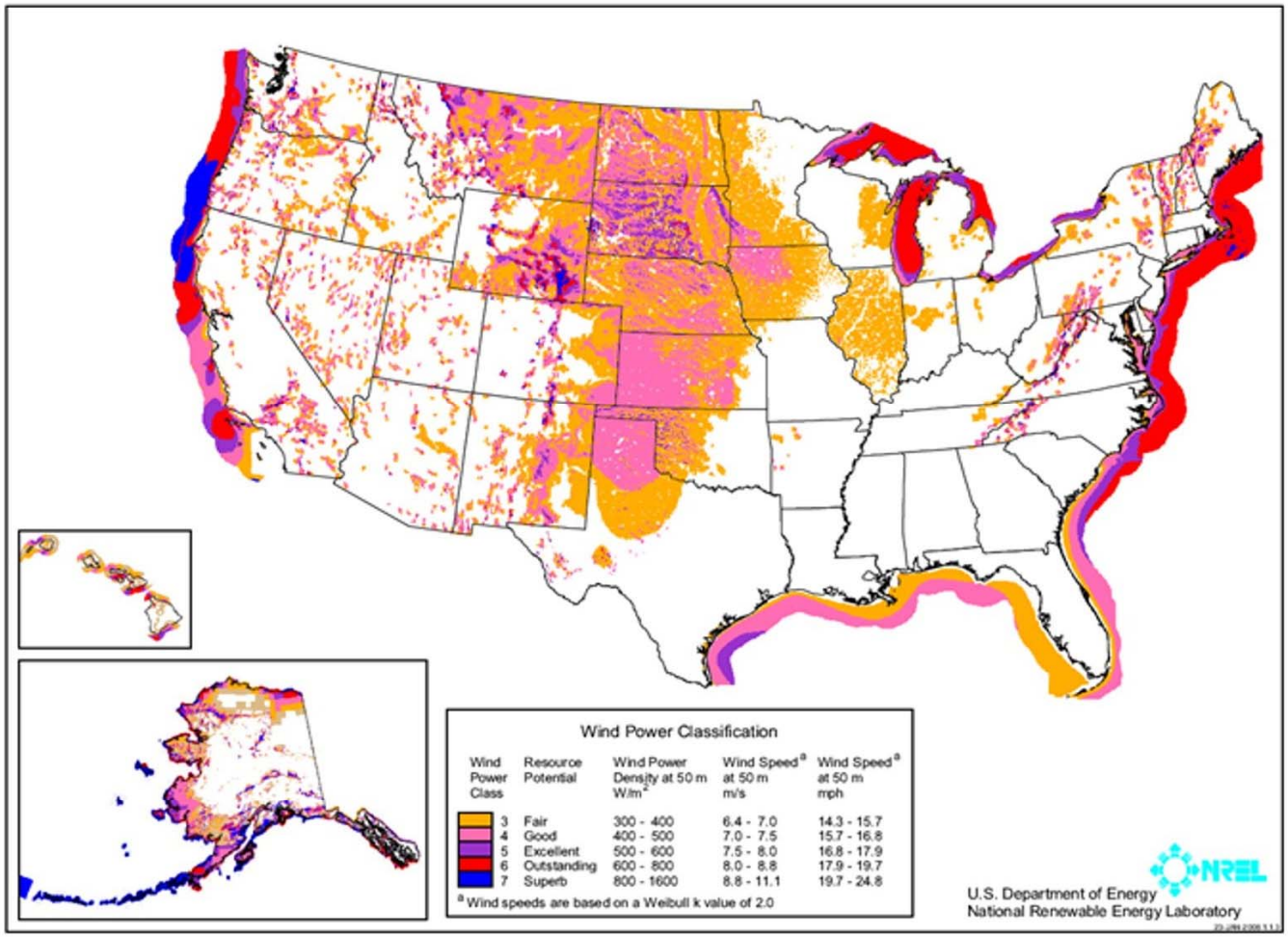
Regional Transmission Organizations



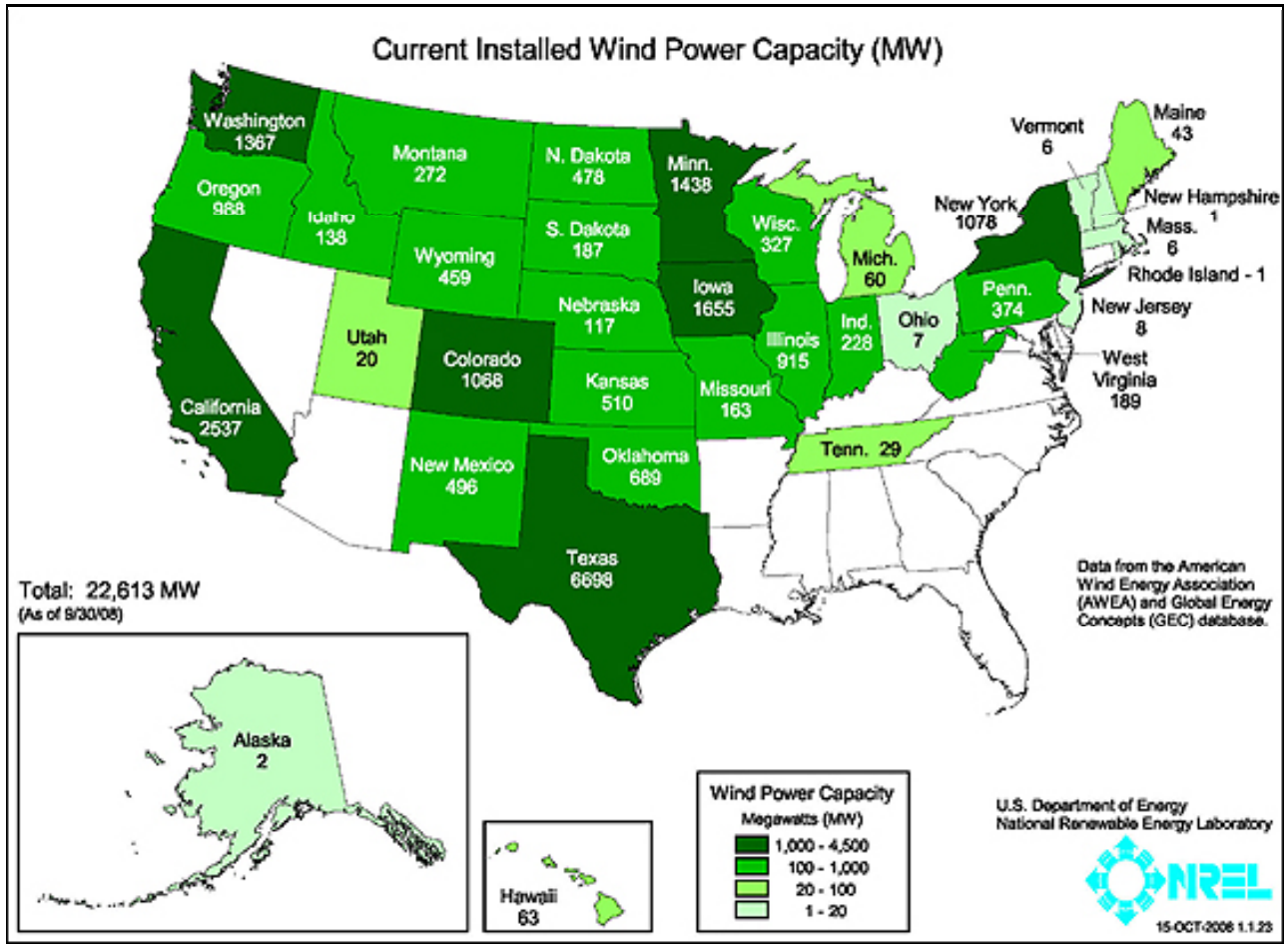
Wind Generation

- Over a tenfold increase in installed wind generation this decade in the U.S.
  - 12/31/00 2,566 MW
  - 9/30/08 22,613 MW
- Best wind sites are often located a long distance from the demand
  - Transmission network is not highly developed
- Wind is intermittent, so it does not always produce at full capacity
  - But the transmission system has to be able to handle full capacity

Wind Resources



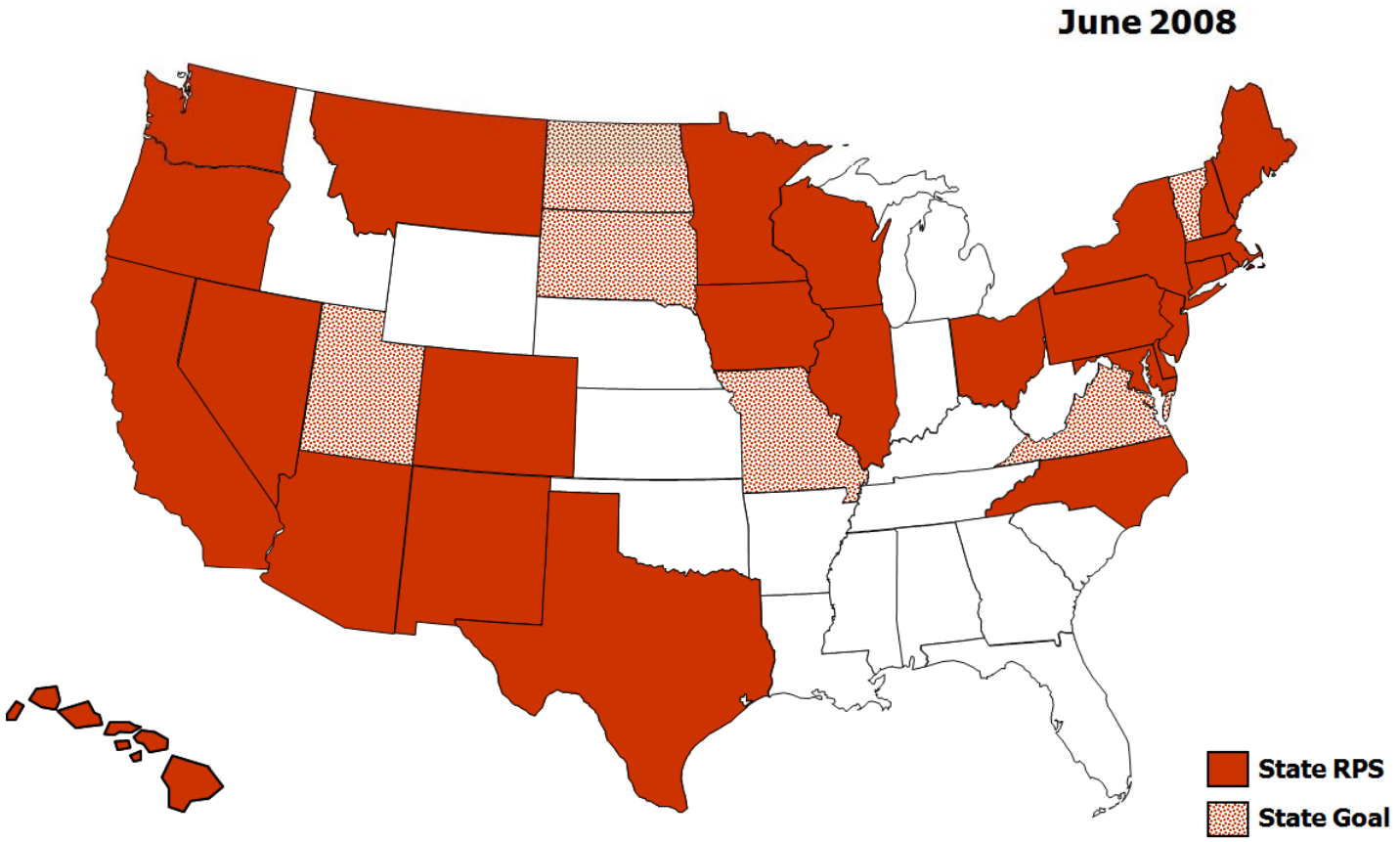
Installed Wind Capacity



Wind Generation is Likely to Increase in the Future

- Renewable Portfolio Standards
- Green consumers
- Future greenhouse gas legislation
- Fossil fuel price volatility

Renewable Portfolio Standards



Source: DSIRE

What Does This Mean?

- We have an aging transmission infrastructure
- It is being relied on more heavily than before
  - Increasing demand for electricity
  - Wholesale competition
  - Power markets
  - Diverse sources of generation
- Scheduling maintenance on existing system becomes more difficult
  - When can I take a line out of service?

Reasons to Build New Transmission Lines

- Largely the same as the reason to build the old ones
  - Save $$$
  - Increase reliability
- And some new ones
  - Allow new generation sources
  - Reduce local market power

New Transmission Affects Many Entities

- Reliability and efficiency benefits are felt throughout the interconnection, not just locally
- The degree to which each entity is impacted can vary greatly

Summary

- The electric transmission system has had tremendous impact on all of us
- It enables us to get electric power at a lower cost with greater reliability
  - Economic development
  - Fuel diversity
  - Reduced price volatility
  - Renewable resources
  - Market power mitigation