NATIONAL ENERGY TECHNOLOGY LABORATORY

Transmission and Distribution Overview

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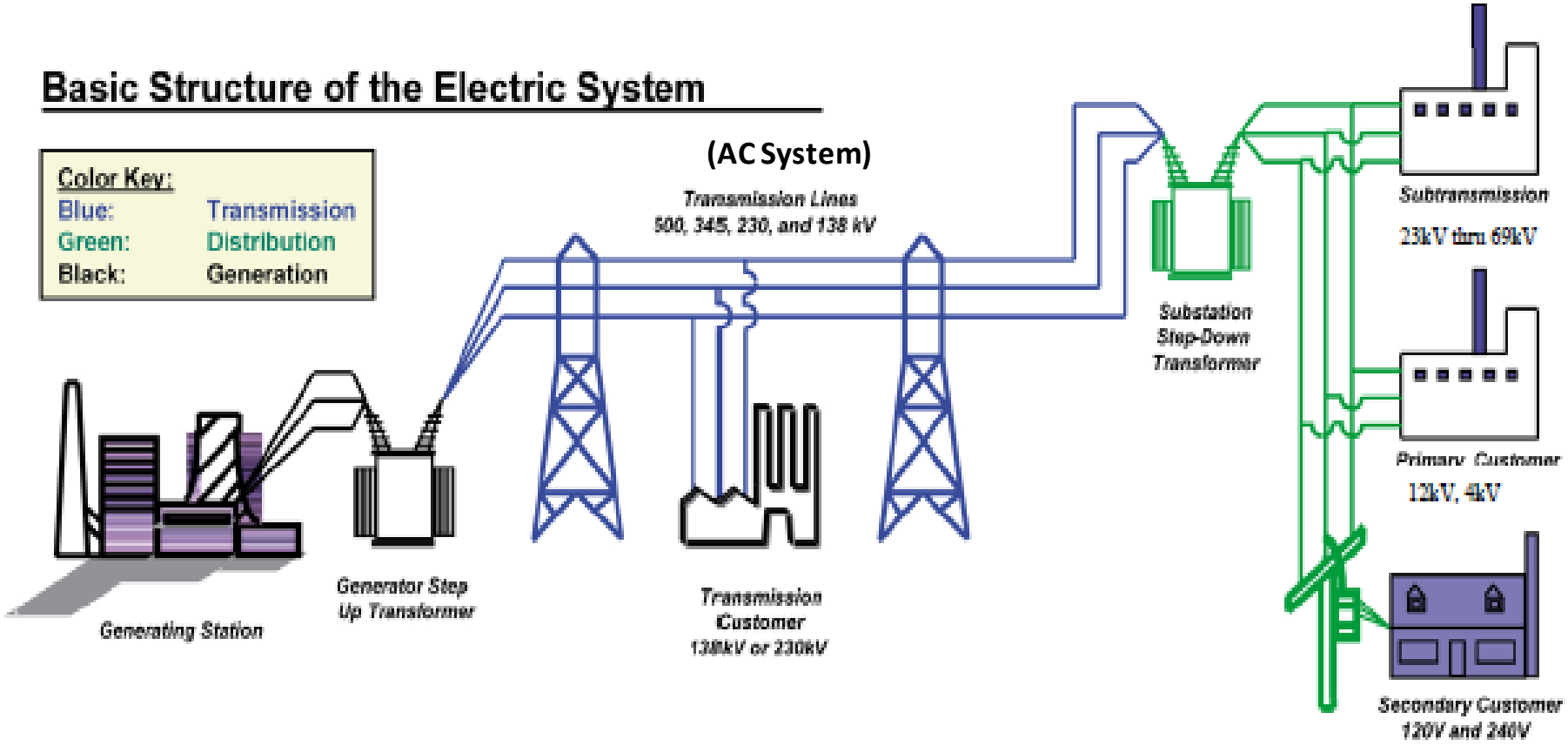
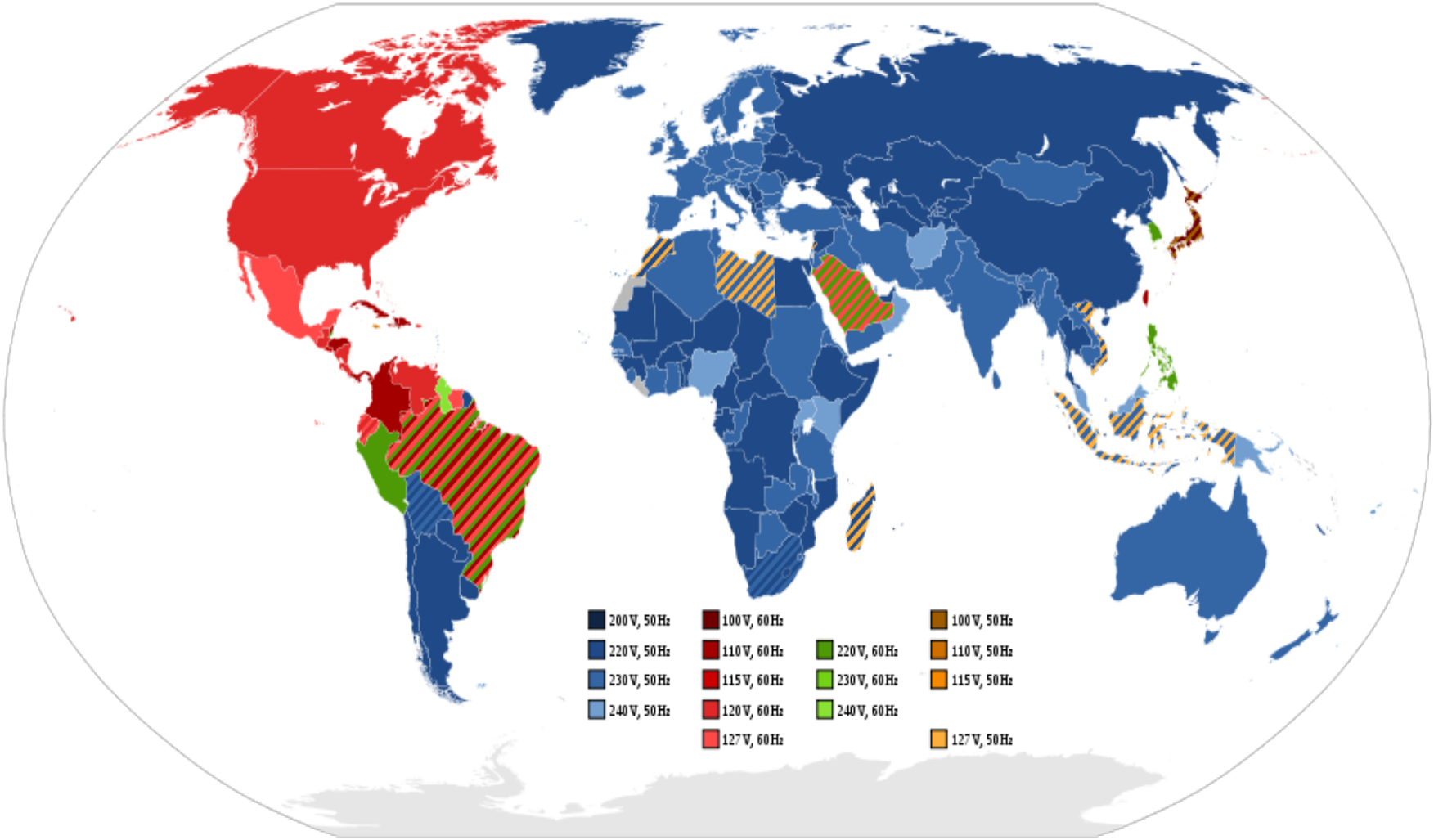
Electric Power System Overview



Source: Allegheny Power

Voltage & Frequency Around the Globe



Source: http://www.vanguardspower.com

60 Hz vs. 50 Hz (Frequency)

- **Many countries use 50 Hertz (Hz)**
  - North America is typically 60 Hz
  - Japan uses both.
- **No technical reason to prefer one over the other and no apparent desire for complete worldwide standardization**

AC vs. DC (Voltage)

- **War of the Currents**
  - Tesla / Westinghouse vs. Edison
- **Technical and economic advantages of AC power transmission won**
- **Electric railways that use a third rail system generally are DC powered**

Transmission System

- **1,000 volts = 1 kilovolt → 10,000 volts = 10 kV**
- **Typical voltages - 69 kV, 138 kV, 230 kV, 345 kV, 500 kV & 765 kV**
  - Bulk Electric System - Voltages of 100 kV or higher
  - High Voltage System is 345 kV and above
- **Used to move large blocks of Power long distances;**
  - AC vs. DC
  - Overhead vs. Underground
- **Analogous to interstate highway systems.**
- **Typically under the Jurisdiction of FERC (Federal Energy Regulatory Commission)**

Transmission – Overhead vs. Underground

OH (Most common):

- Low system Loss
- Lower Install & Maintenance Costs
- Accessible for Maintenance & Problem spotting
- Wider Right of Way (ROW)
- Noticeable
- Enviro Concerns
- EMF/Corona concerns
- Higher Likelihood of physical attack / more vulnerable

UG (Less Frequent):

- Shorter distances
- Increased System Loss
- 10x Cost Differential
- Harder to access / repair
- Narrower ROW
- Inconspicuous
- Enviro concerns
- Few Electro Magnetic Field (EMF) issues

Transmission Lines and Right of Ways

Higher Voltage = Larger Towers, ROW, Siting Issues/Politics, etc

Photo Source: Argonne National Lab, Electrical Engineering Portal

Direct Current / HVDC

- **Generally – more expensive to build.**
  - Higher efficiency, lower losses & no contingencies.
  - No off ramps.
- **Best application for underwater power cables**
- **Point to point – Express Lane analogy**
- **Interconnection Tie Lines**
  - HVDC allows power transmission between unsynchronized AC distribution systems or Interconnections and can increase system stability by preventing cascading failures from one part of a wider power transmission grid to another.

Substations

- **Substations (with transformers) are used to change from one voltage level to another voltage level.**
- **15,700+ transmission substations in U.S.**
- **AC transmission uses step-up / step down transformers**
- **DC Transmission substations in US use converters not transformers**

Distribution System

- **Defined as Voltages less than 69,000 volts (69 kV)**
  - Distribution is often considered to be less than 20,000 volts (20 kV)
- **Converts high-voltage transmission networks through substation transformers into commercial or household voltage to the service drops that carry energy from power lines to residences & commercial sites**
- **Analogous to the off-ramps, feeder routes and side roads;**
- **Typically under the Jurisdiction of a State PUC/PSC**

Overhead: Pole Mount - Residential

Underground: Pad Mount - Residential

Photo Source: Allegheny Power (OH) & OSHA (UG)

Transmission vs. Distribution

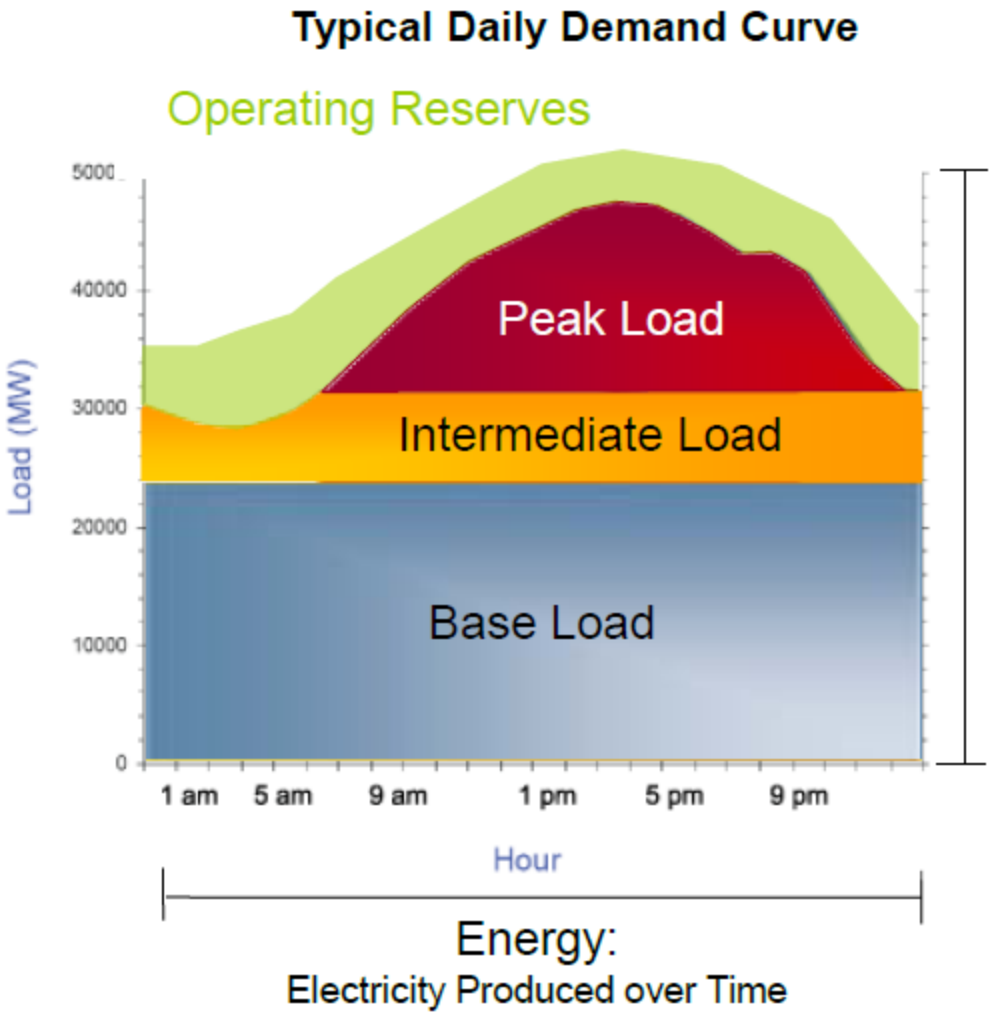
Transmission

- **Bulk Transfer of Energy**
  - **Generator to Substation**
  - **Substation to Substation**
- **Long Distance**
- **High Voltages**
- **Low Line Loss**
- **Networked or Looped**
- **About 10% of customer outage minutes due to G&T system problem – but those are big outage events!**

Distribution

- **Limited Transfer of Energy**
  - Substation to Customer
- **Short Distance**
- **Low Voltages**
- **Higher Line Loss**
- **Looped or Radial Circuits**
- **About 90% of customer outage minutes are due to Distribution problems – small, isolated, local events.**

Bulk Power System Designed to Meet Demand in Real Time



Capacity:
Instantaneous measure of electricity available at peak

Frequency does not change in an Interconnection as long as there is a balance between resources and customer demand (including various electrical losses). This balance is depicted in Figure 3a.

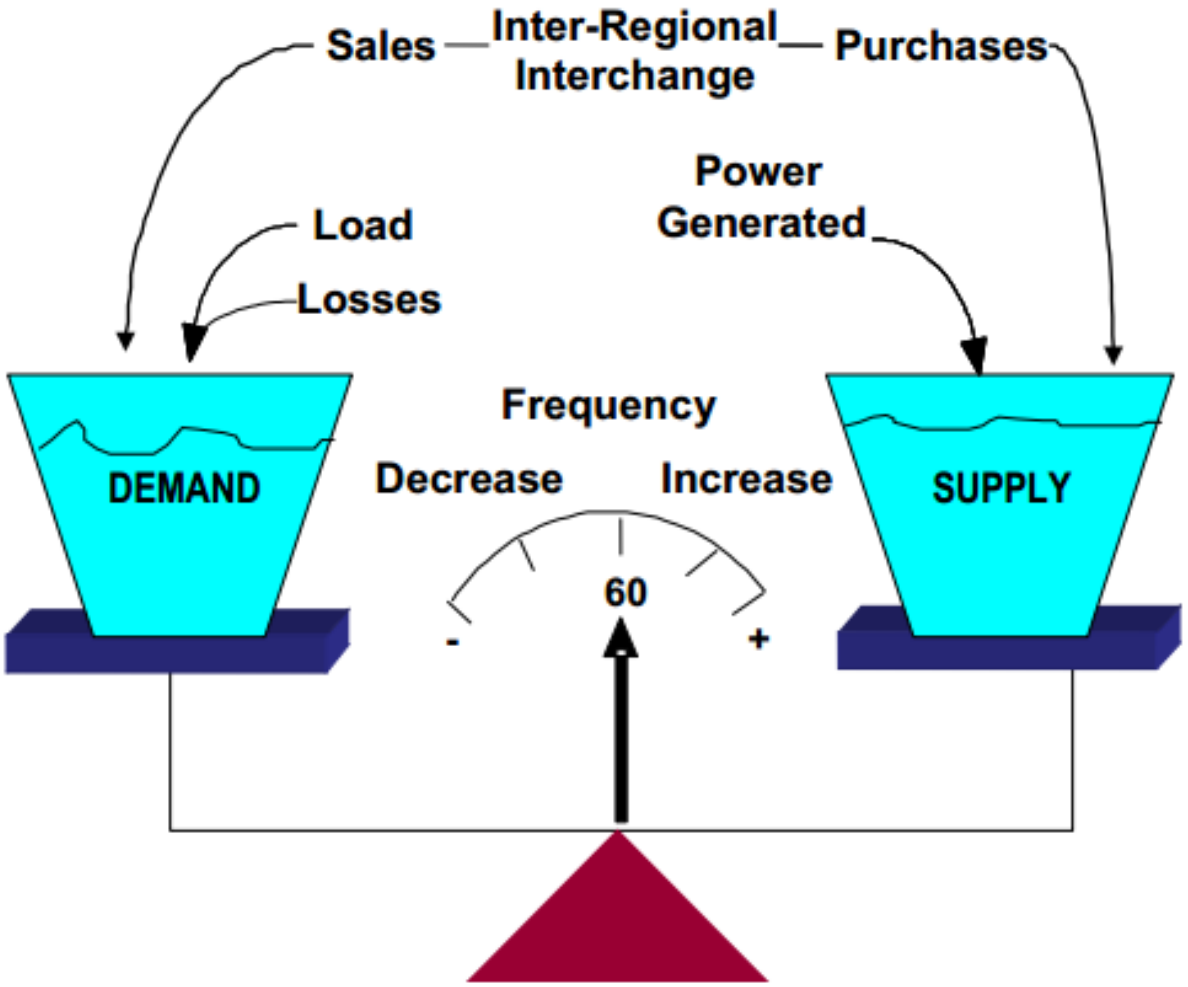


Figure 3a — Generation / Demand Balance

http://www.nerc.com/docs/oc/rs/NERC%20Balancing%20and%20Frequency%20Control%20040520111.pdf

FERC

- **Federal Energy Regulatory Commission**
  - Regulates the interstate transmission of Electricity, Natural Gas & Oil
  - Also reviews proposals to build liquefied natural gas (LNG) terminals and interstate natural gas pipelines as well as licensing hydropower projects.
- **Reliable & Efficient Energy for Customers.**
  - Reasonable cost through appropriate regulatory and market means.
  - On average, total transmission capital and operating costs translated into rates equal less than 5% of a ratepayer's monthly electric bill

North American Electric Reliability Corporation (NERC) - Reliability

- **Voluntary organization formed in 1968**
- **U.S. Energy Policy Act of 2005**
  - Electric Reliability Organization that would span North America
  - FERC oversight in the U.S.
  - Assess current and future reliability
  - Analyze system events and recommend improved practices
  - Encourage active participation by all stakeholders
  - Pursue mandatory standards in all areas of the interconnection
- **The legislation stated that compliance with reliability standards would be mandatory and enforceable.**

NERC Mission

- **Ensure that the bulk electric system in North America is reliable, adequate and secure**
  - Sets standards for the reliable operation and planning
  - Monitors, assesses and enforces compliance with standards for reliability
  - Conducts reliability readiness audits of all reliability coordinators, control areas and other operators to ensure that they are capable of complying with NERC standards
- **US consists of 3 Major Interconnections with 8 Reliability Regions**

NERC Interconnections

Source: NERC


Questions?

Balancing and Frequency Control Basics

- **The power system of North America is divided into four major Interconnections. These interconnections can be thought of as(frequency-) independent islands. The interconnections are:**
  - Western – Generally everything west of the Rockies.
  - Texas – Also known as Electric Reliability Council of Texas (ERCOT).
  - Eastern – Generally everything east of the Rockies except Texas and Quebec.
  - Quebec
- **Each Interconnection is actually a large machine, as every generator within the island is pulling in tandem with the others to supply electricity to all customers. This occurs as the rotation of electric generating units, nearly all in (steady-state) synchronism. The "speed" (of rotation) of the Interconnection is frequency, measured in cycles per second or Hertz (Hz).**
  - If the total Interconnection generation exceeds customer demand, frequency increases beyond the target value, typically 60 Hz1, until energy balance is achieved.
  - Conversely, if there is a temporary generation deficiency, frequency declines until balance is again restored at a point below the scheduled frequency.
  - Balance is initially restored in each case due to load that varies with frequency and generator governors that change generator output in response to frequency changes.
- **Some electric devices, such as electric motors, use more energy if driven at a higher frequency and less at a lower frequency.**

Electricity Markets & ISO/RTOs

- **Generation & Transmission are typically the types of electricity bought & sold in the wholesale market**
  - Bilateral Contracts (Most common in US)
  - Wholesale Markets (Restructured/Deregulated)
  - Self – Supply (Traditional)
- **ISO/RTO – Independent System Operator / Regional Transmission Organization**
  - FERC Jurisdiction
  - Approved independent Transmission Operator (FERC) & Transmission Planner (NERC)
- **Energy / Capacity / Ancillary Services**
  - Day Ahead, Real Time

Types of Transmission Ownership

- **Electric utility –recovers costs through cost-of-service rates to ratepayers and transmission customers or formula rates ….**
  - Investor-owned, vertically integrated or functionally separate wires company subsidiary
  - Municipal utility
  - Cooperative
  - Independent transmission company
  - Merchant transmission (third-party non-utility ownership – recover costs through market-based contracts and fees
- **Other countries have gov't and/or investor owned utilities**