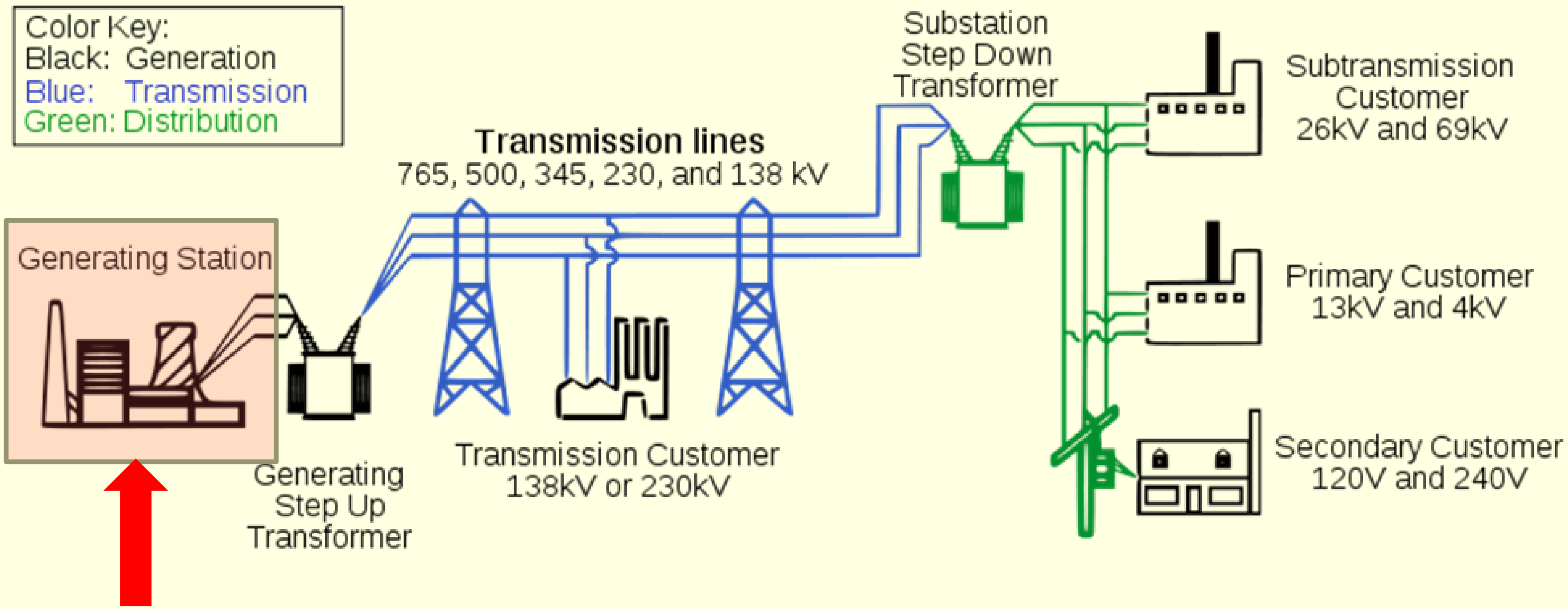
Conventional Energy Sources and Power System Components

Y. Baghzouz
Professor of Electrical Engineering
University of Nevada, Las Vegas

Overview

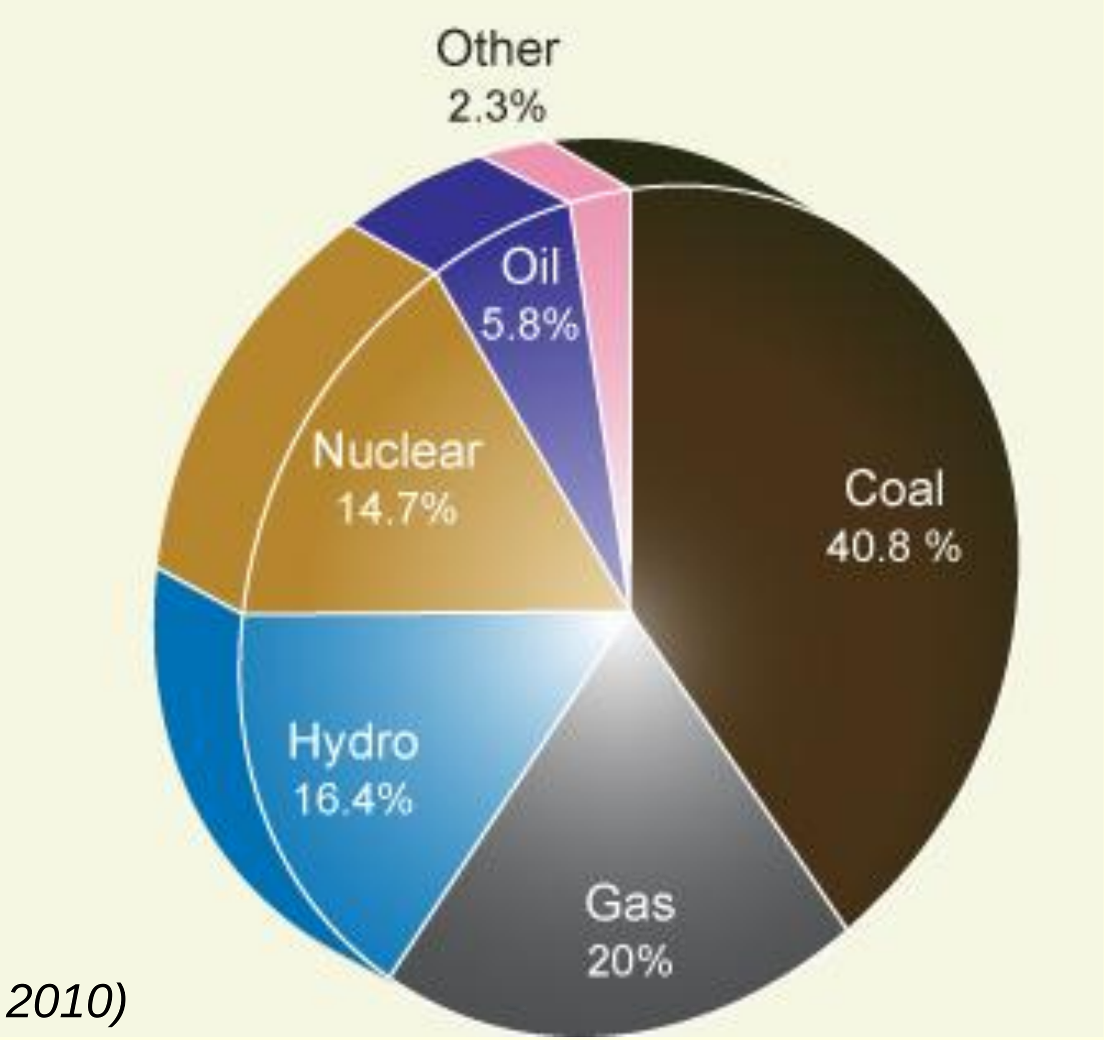
- Power Generation
  - Conventional type of different generation
- Power transmission
  - Cables and other transmission system equipment
- Power Distribution
  - Distribution system equipment
- Power Utilization
  - Demand curves

Basic Conventional Power System Layout



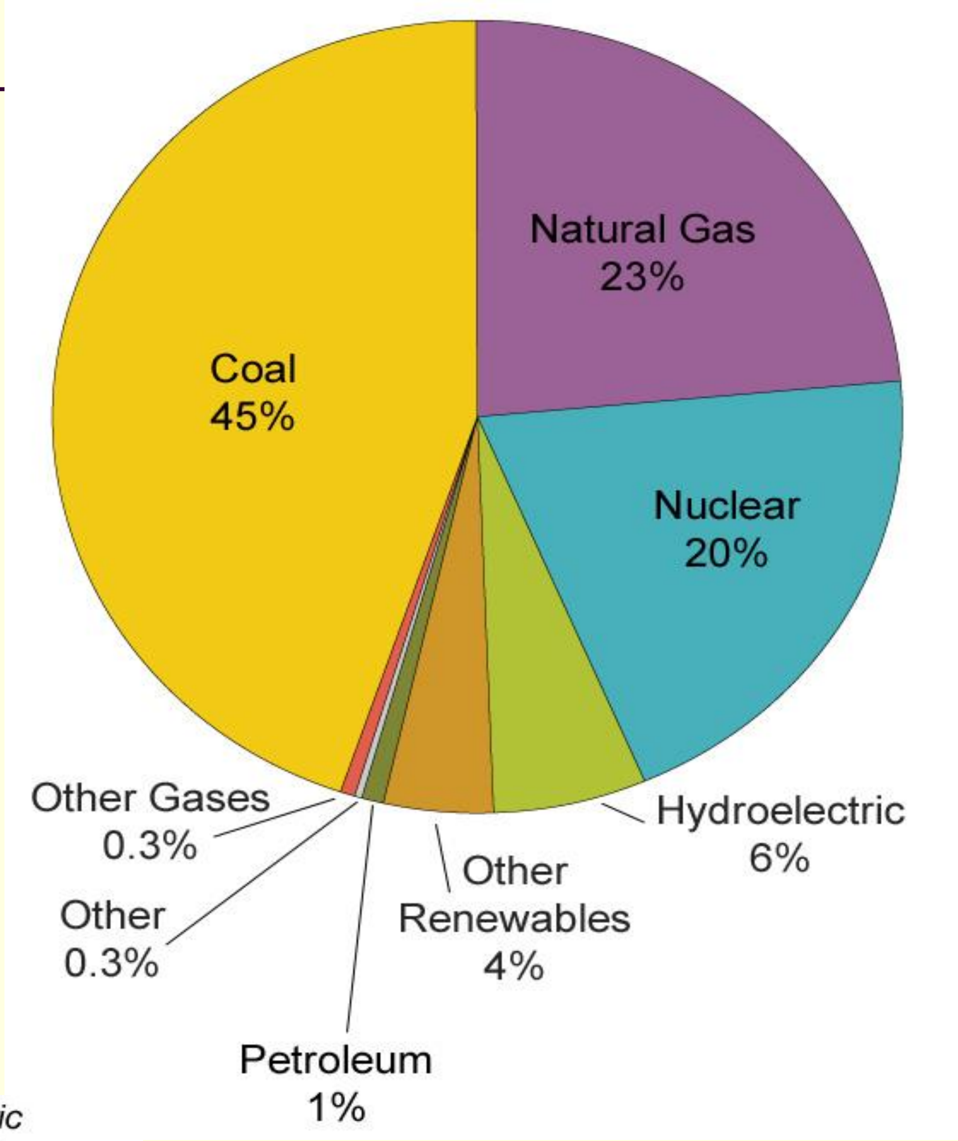
Conventional (non-renewable) primary energy source

World Electricity Generation



(Source: OECD/IEA 2010)

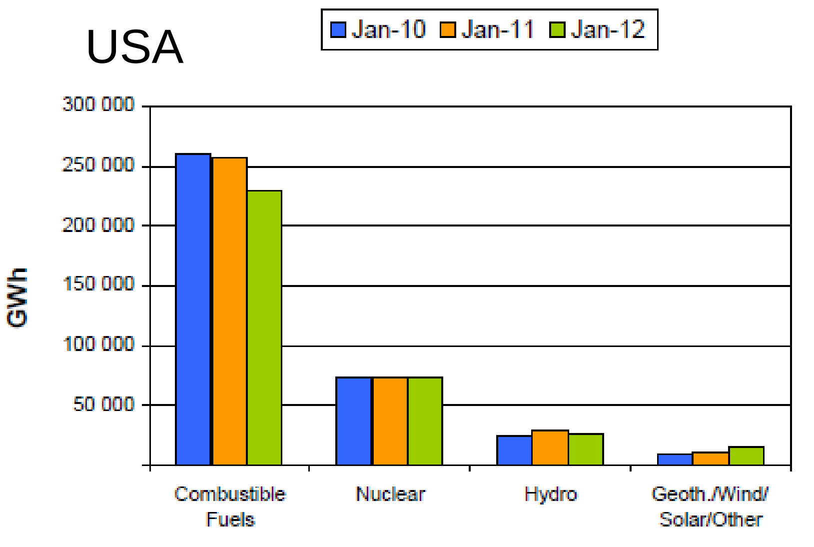
US Electricity Generation by Fuel

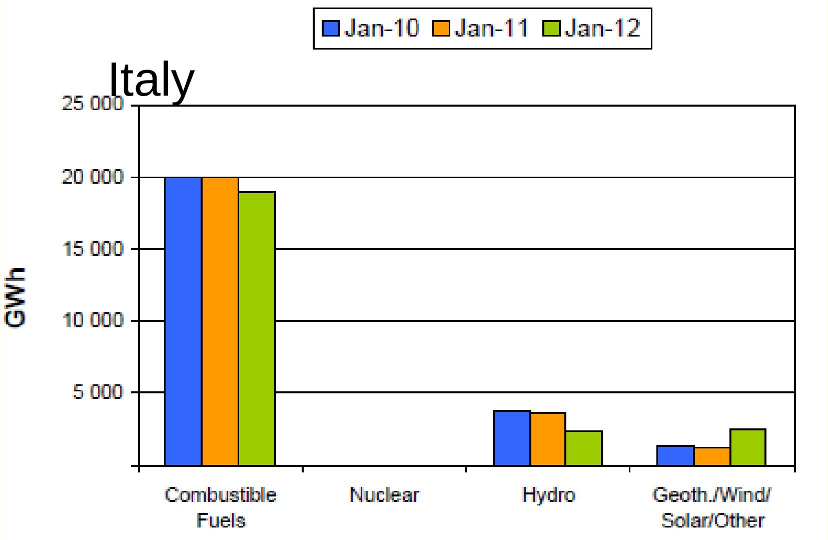


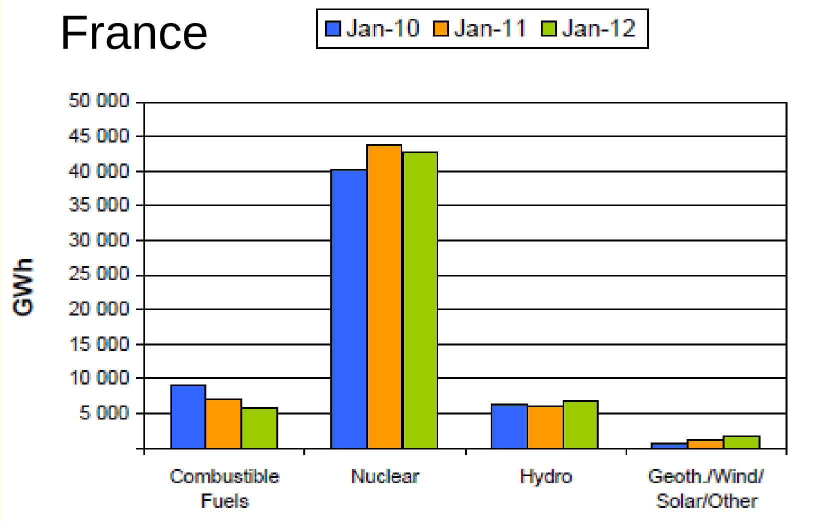
Source: U.S. Energy Information Administration, *Electric Power Monthly,* Table 1.1 (March 2011), preliminary data.

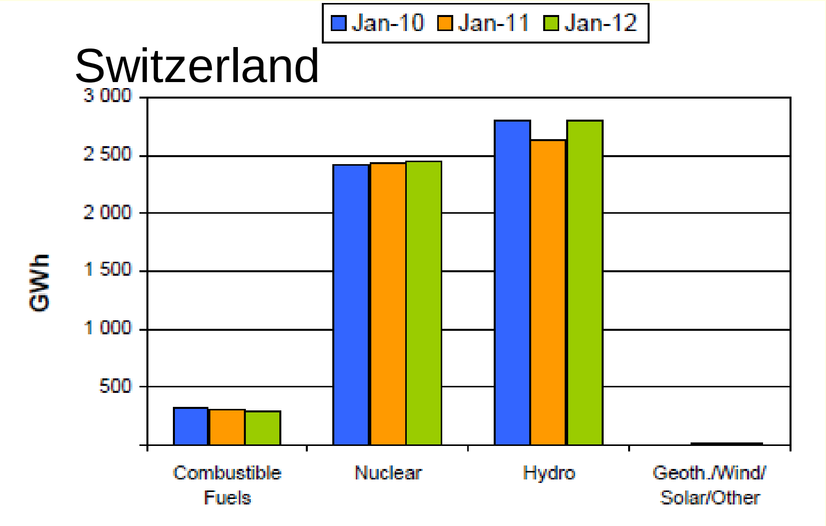
Energy production by country (past 3 yrs.)

(Source: OECD/IEA, 2012)

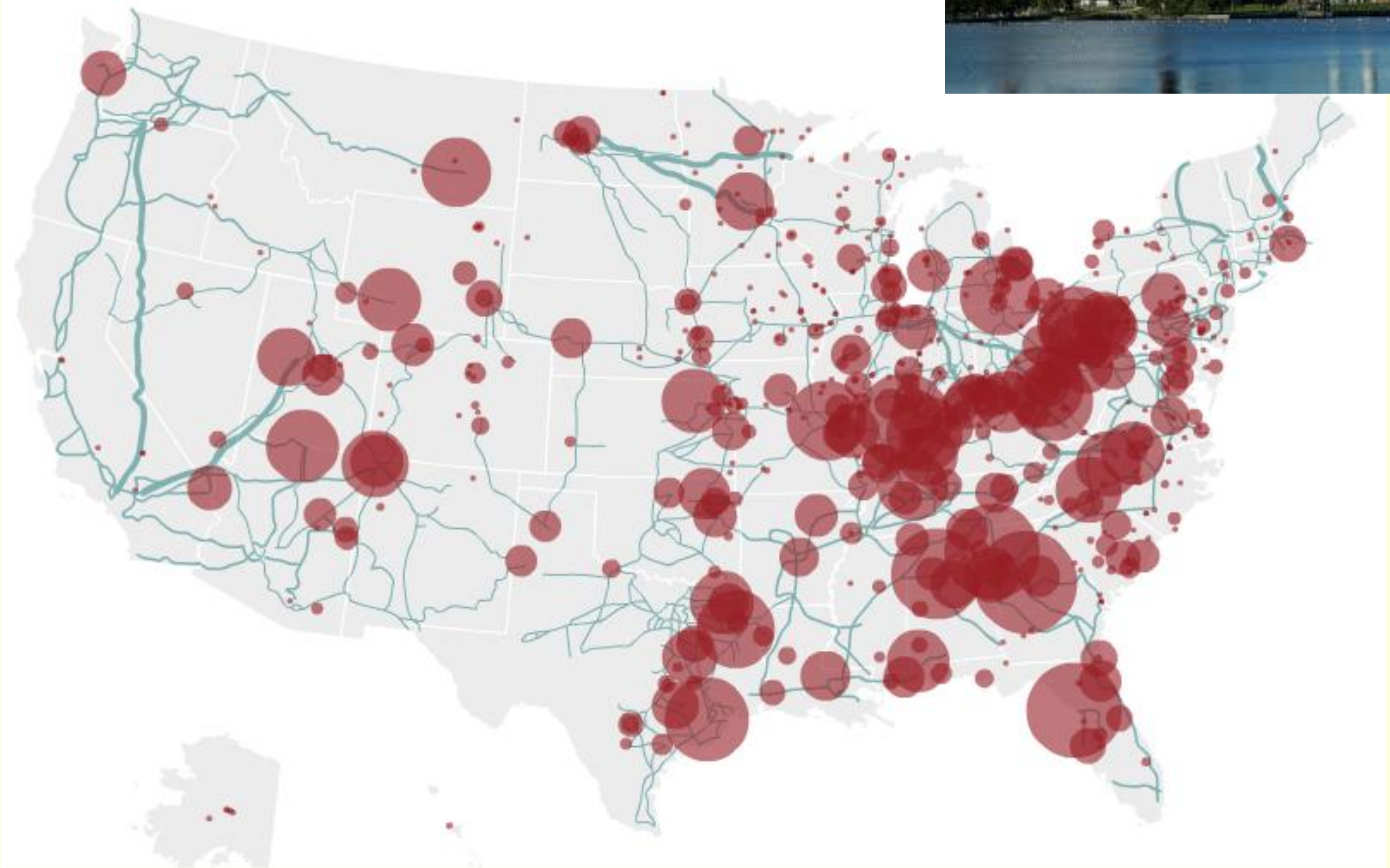








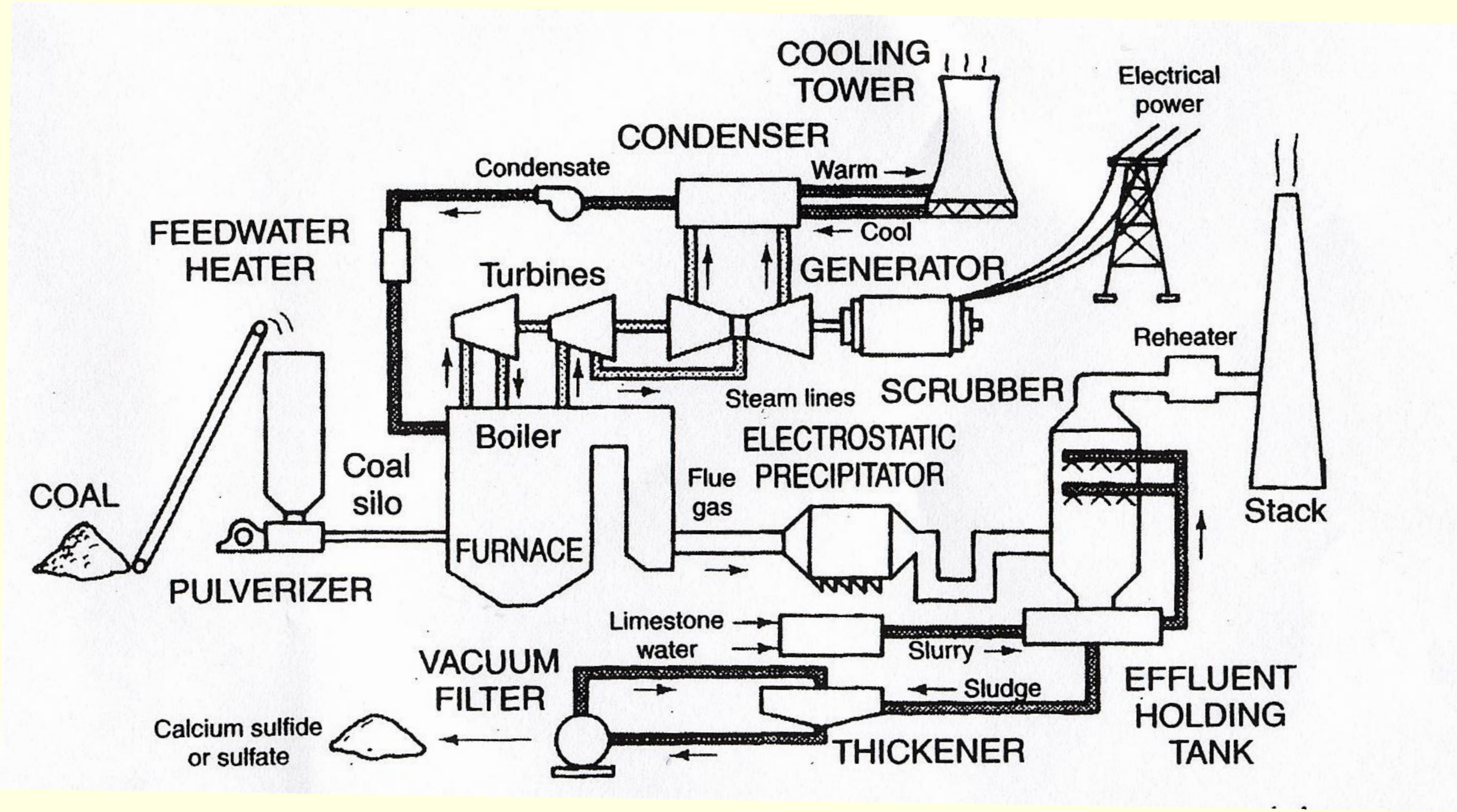
Coal Fired Power Plants:
Number of Generators ≈ 1,450
Total Capacity ≈ 350 GW



(Source: http://www.npr.org)

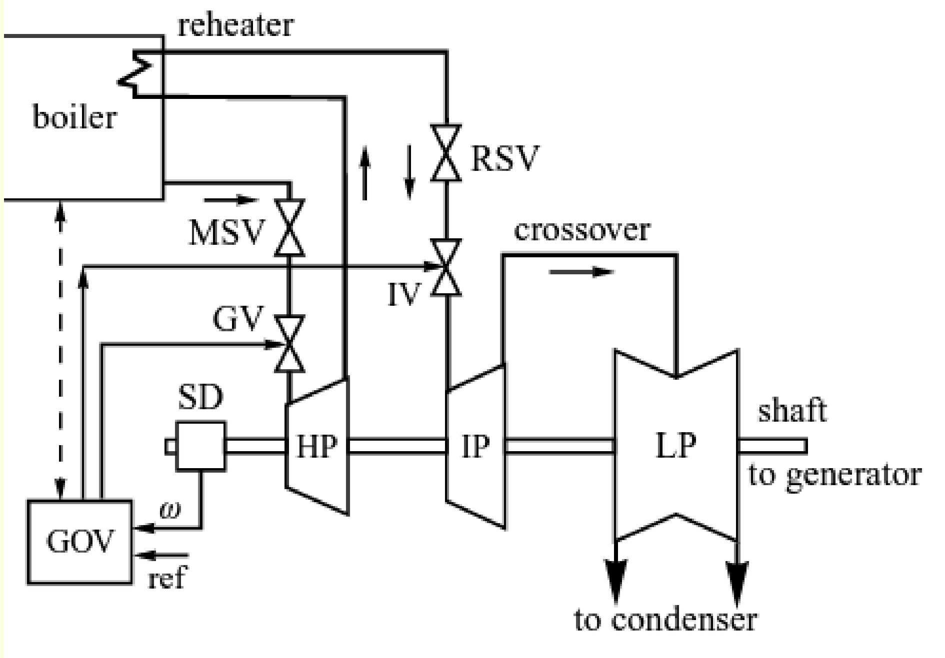
Diagram of a modern coal power plant

(Source: Masters, Renewable and Efficient Electric Power Systems, 2004)



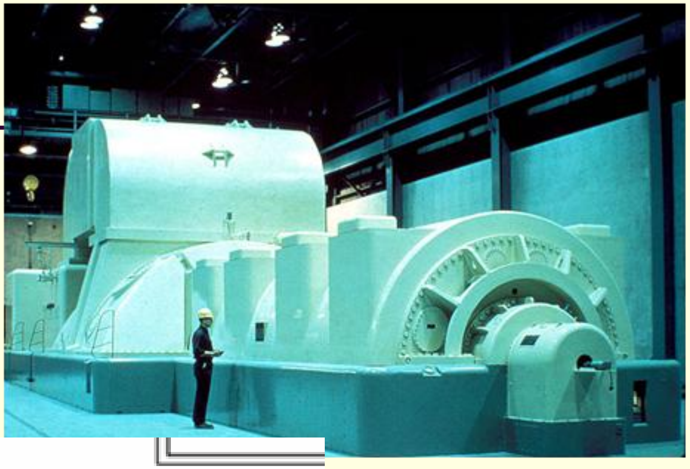
Steam Turbines and their Governors

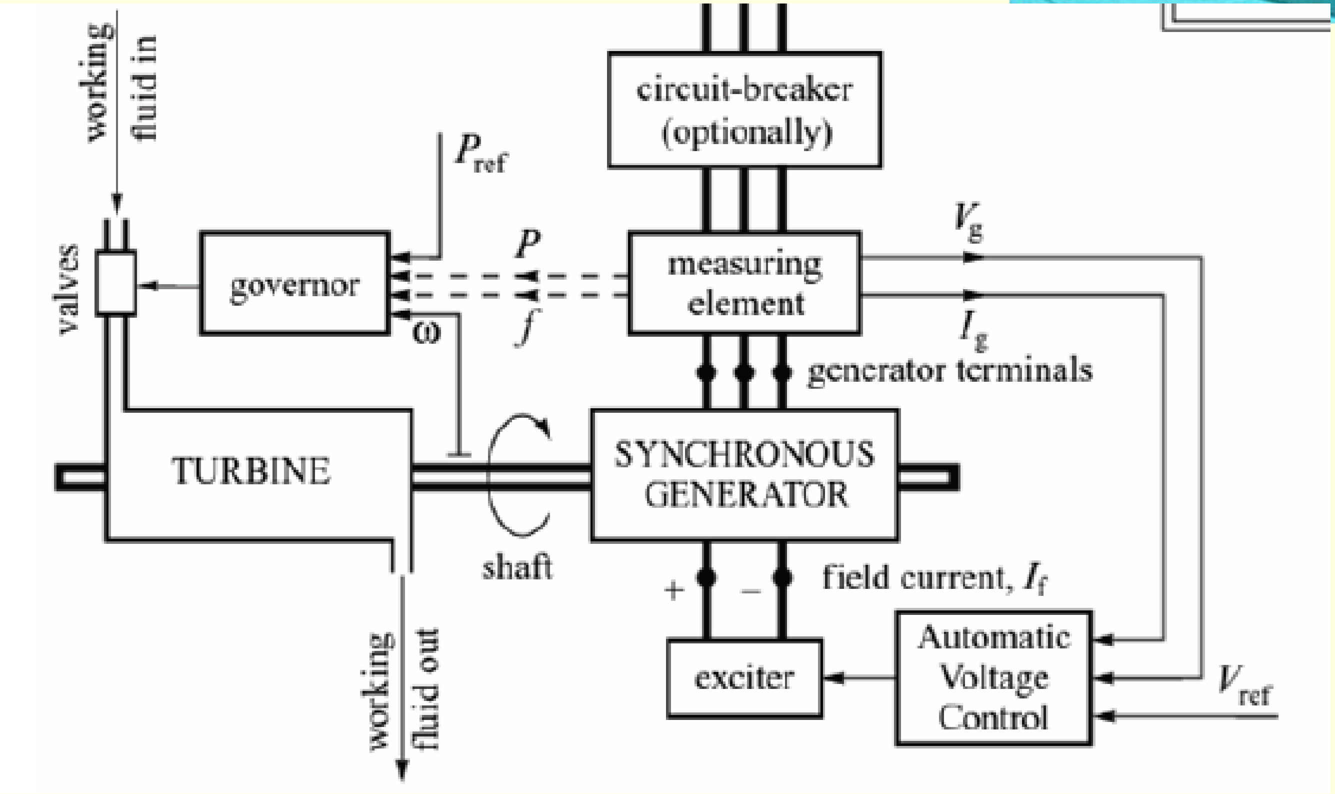
- Steam turbines can have non-reheat, single-reheat or double-reheat.
- The steam flow is controlled by the governor. The main amplifier of the governing system and valve mover is an oil servomotor that is controlled by a pilot valve.
- Main and reheat stop valves are normally fully open - they are used only during generator start-up and shut down.



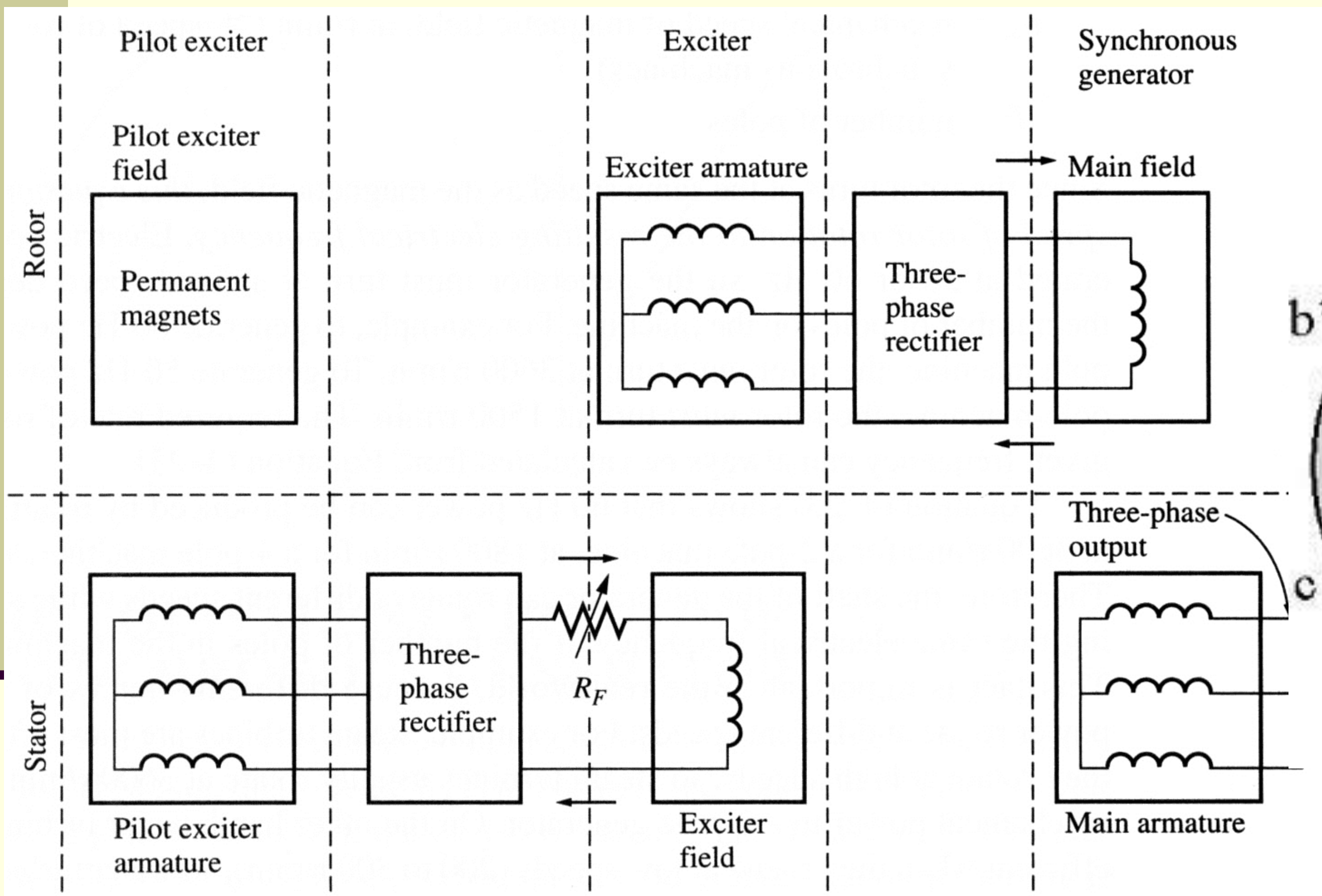
The electric generator

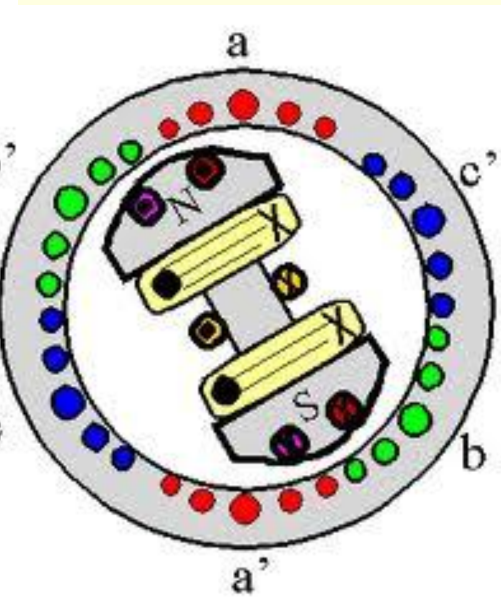
Governor controls turbine torque and power
Exciter controls voltage and reactive power





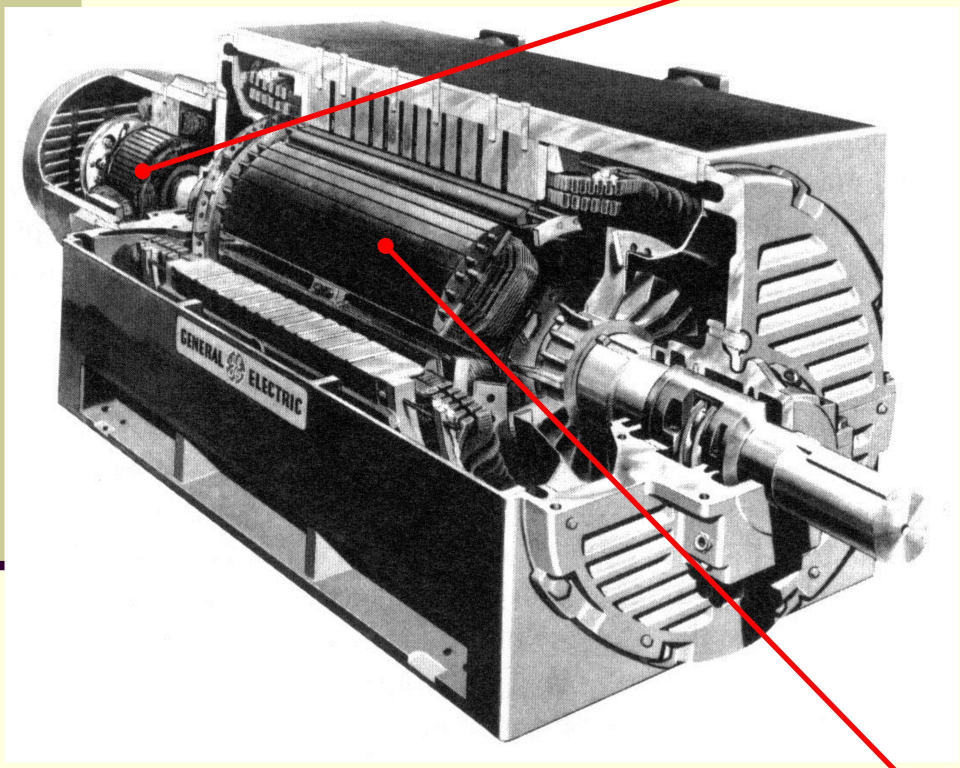
Generator Exciter (brushless)

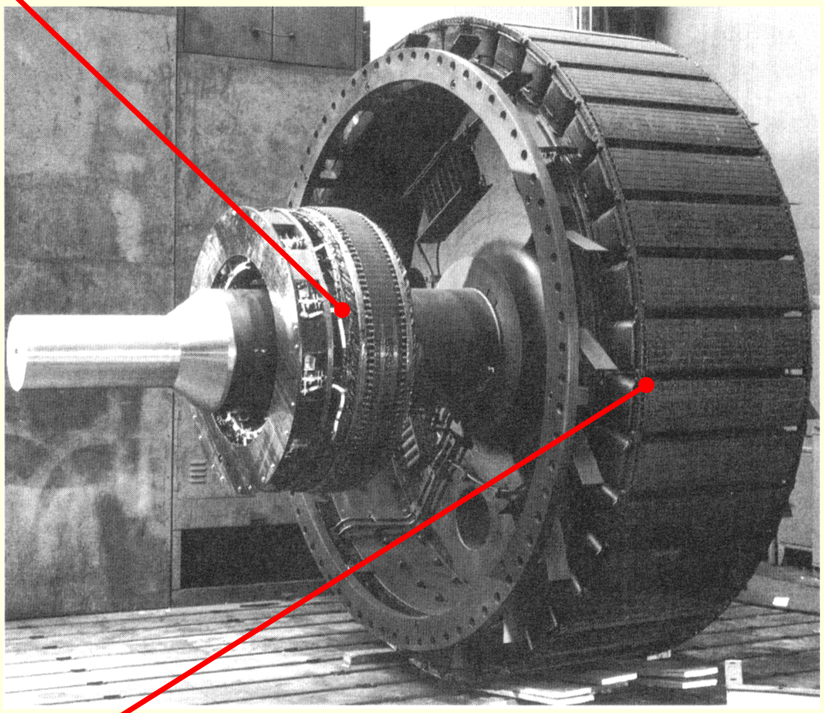




Generator Exciter & Main Field Winding

Generator Exciter





Generator Main Field Winding

Nuclear Power Plants:
Number of Generators ≈ 100
Total Capacity ≈ 100 GW

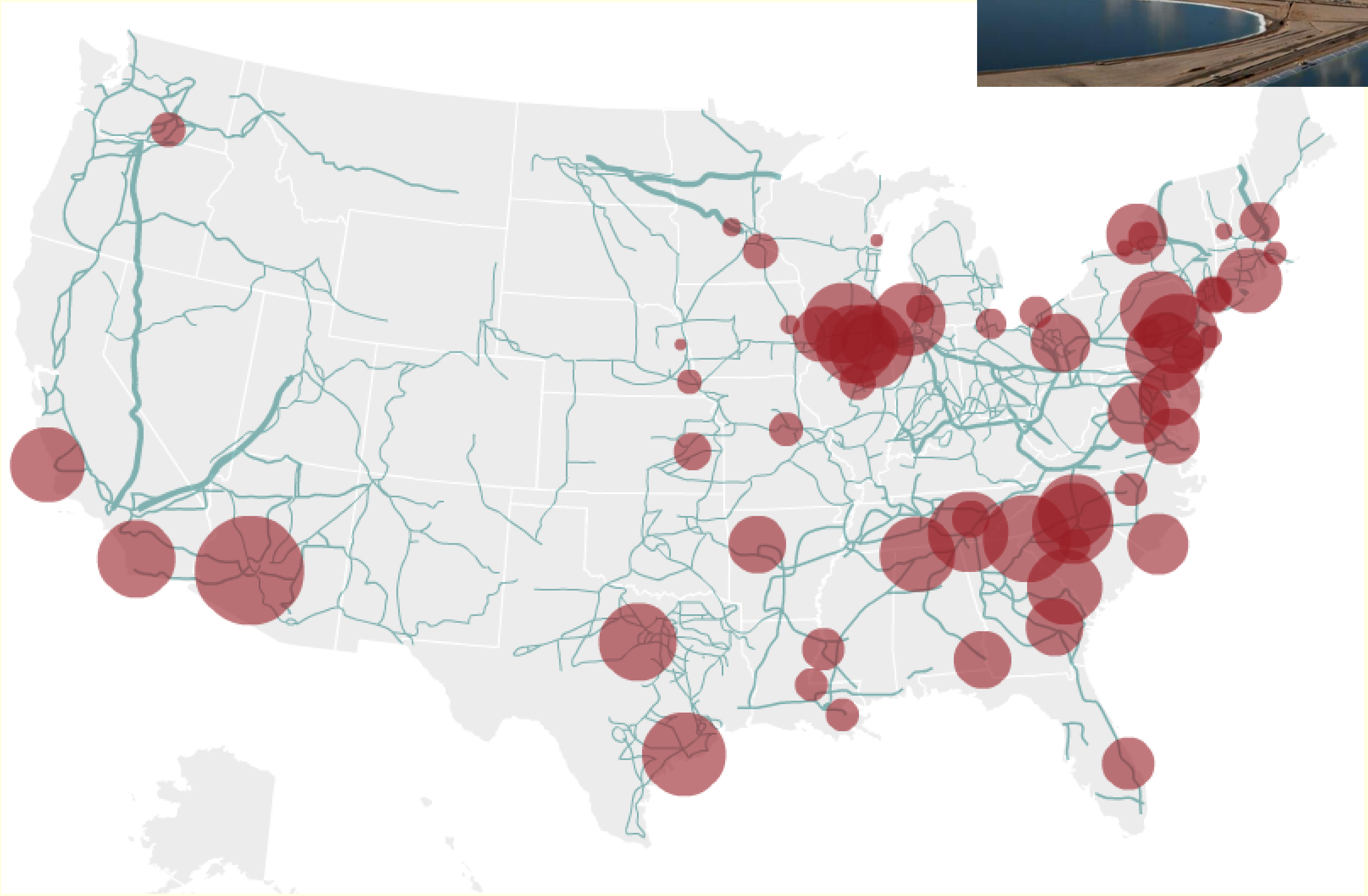
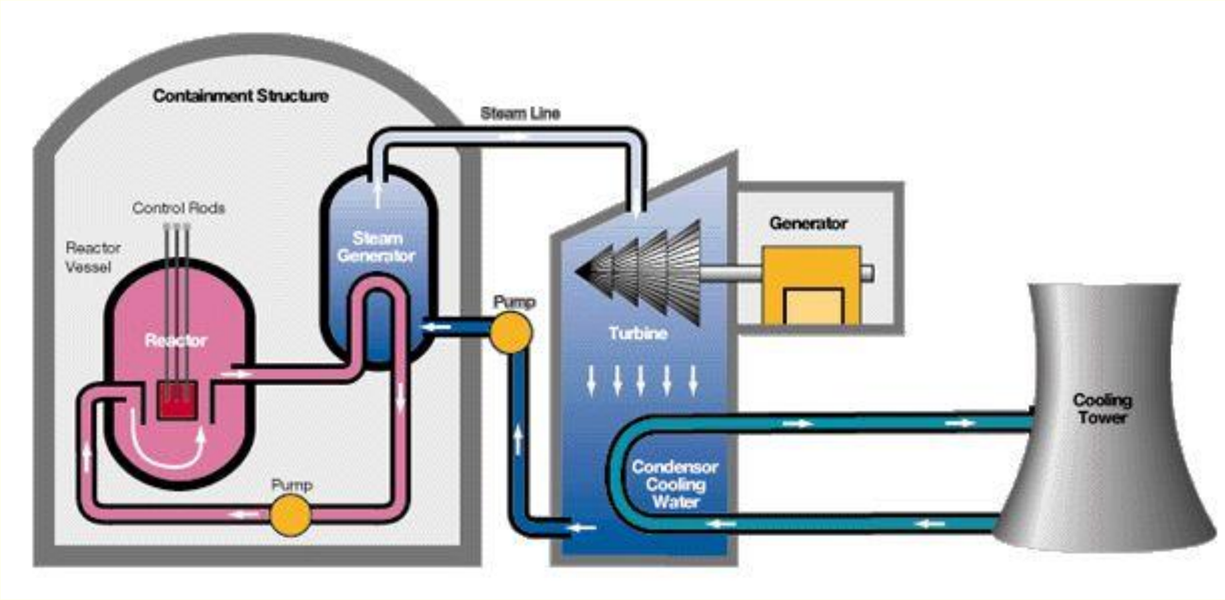
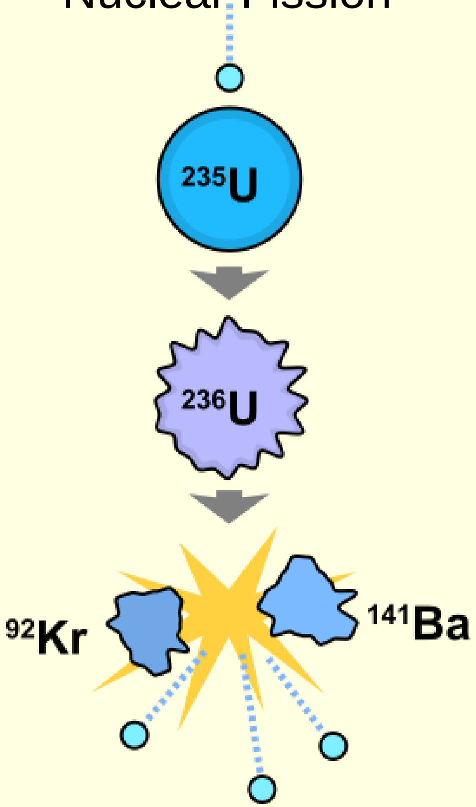


Diagram of a nuclear power plant

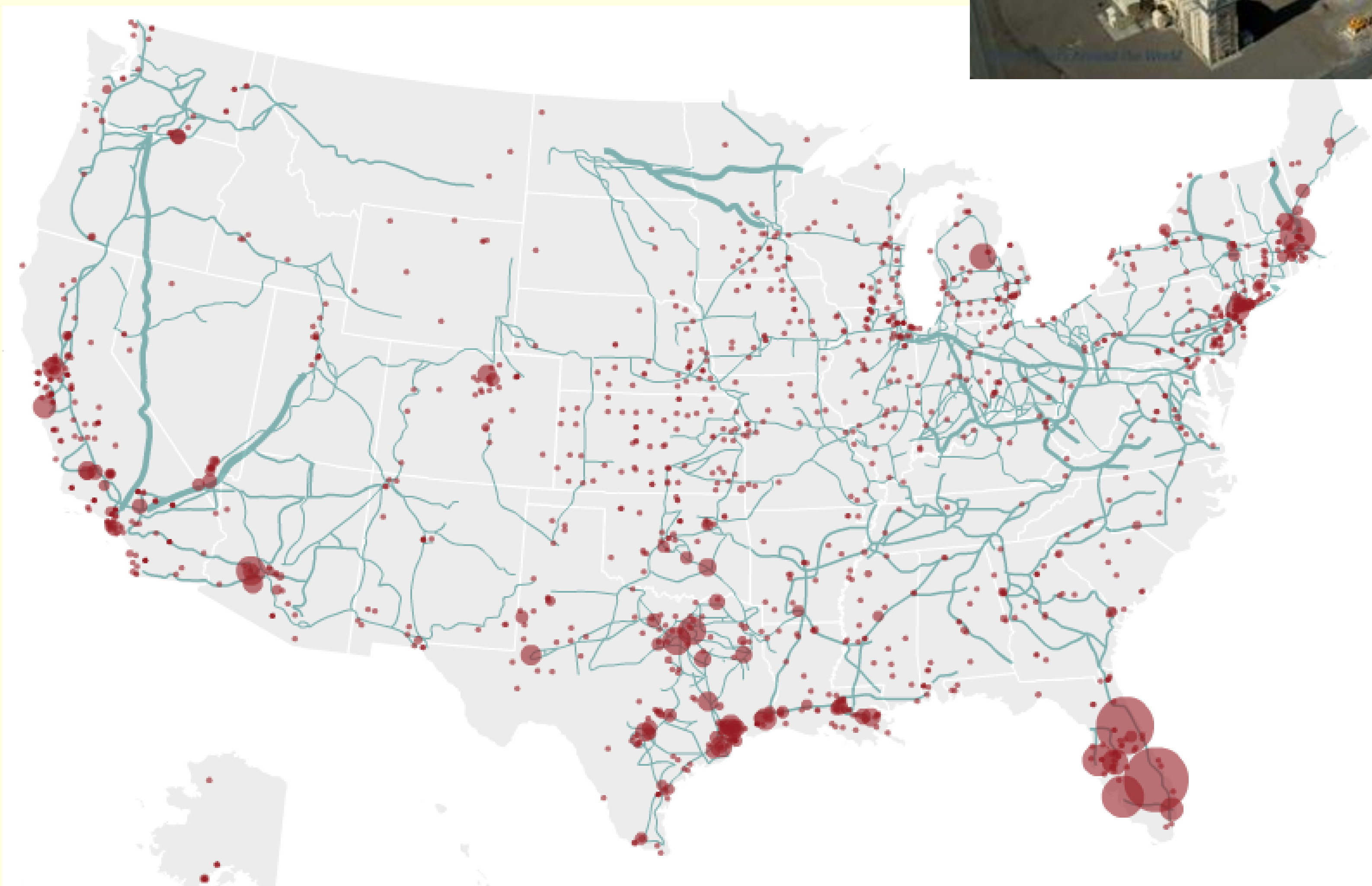
- Types of nuclear reactors:
  - Pressurized Water Reactor (PWR)
  - Boiling Water Reactor (BWR)



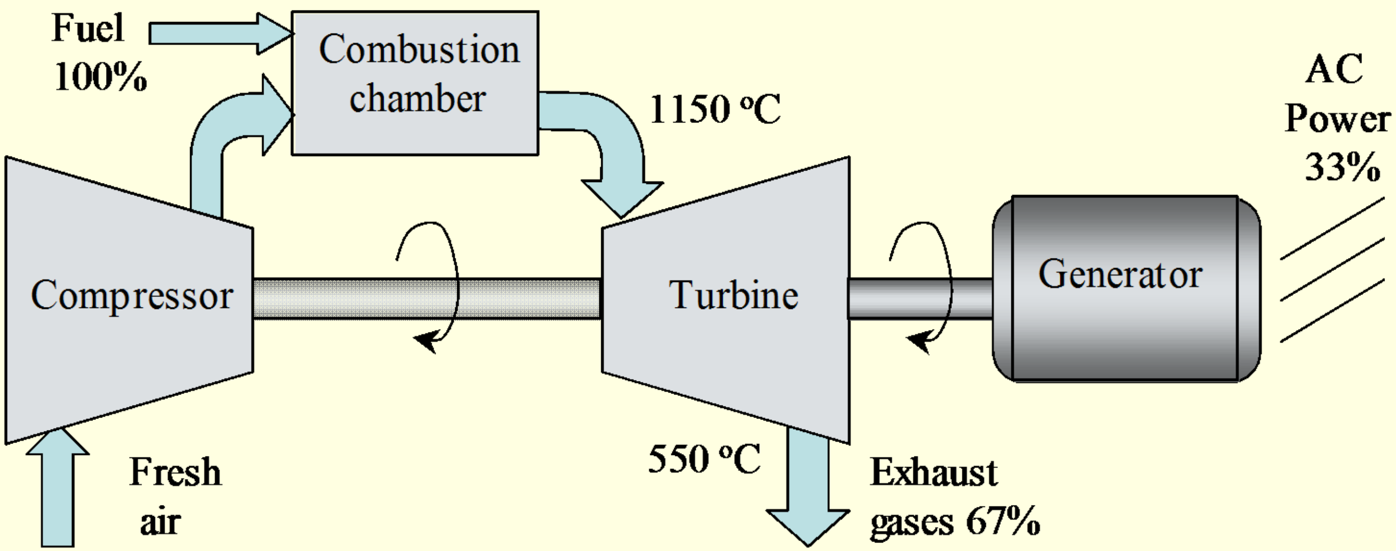
Nuclear Fission



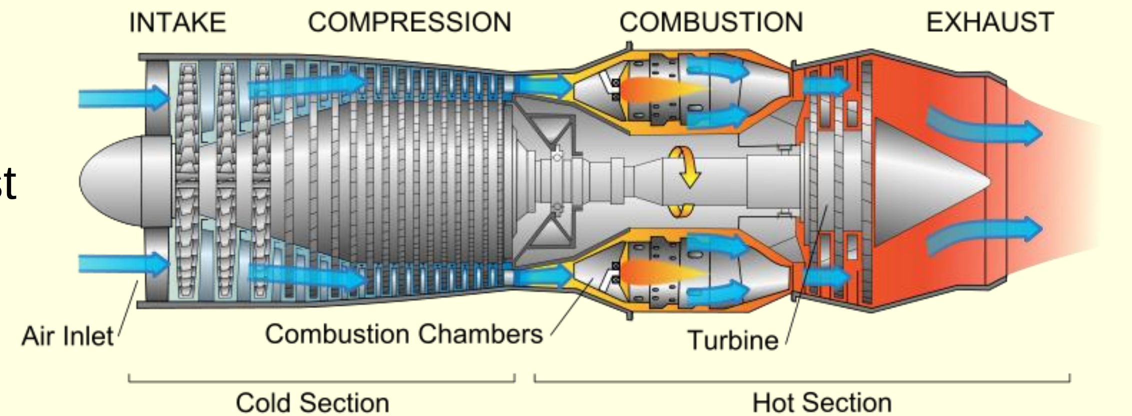
Natural Gas Power Plants:
Number of Generators ≈ 5,500
Total Capacity ≈ 450 GW



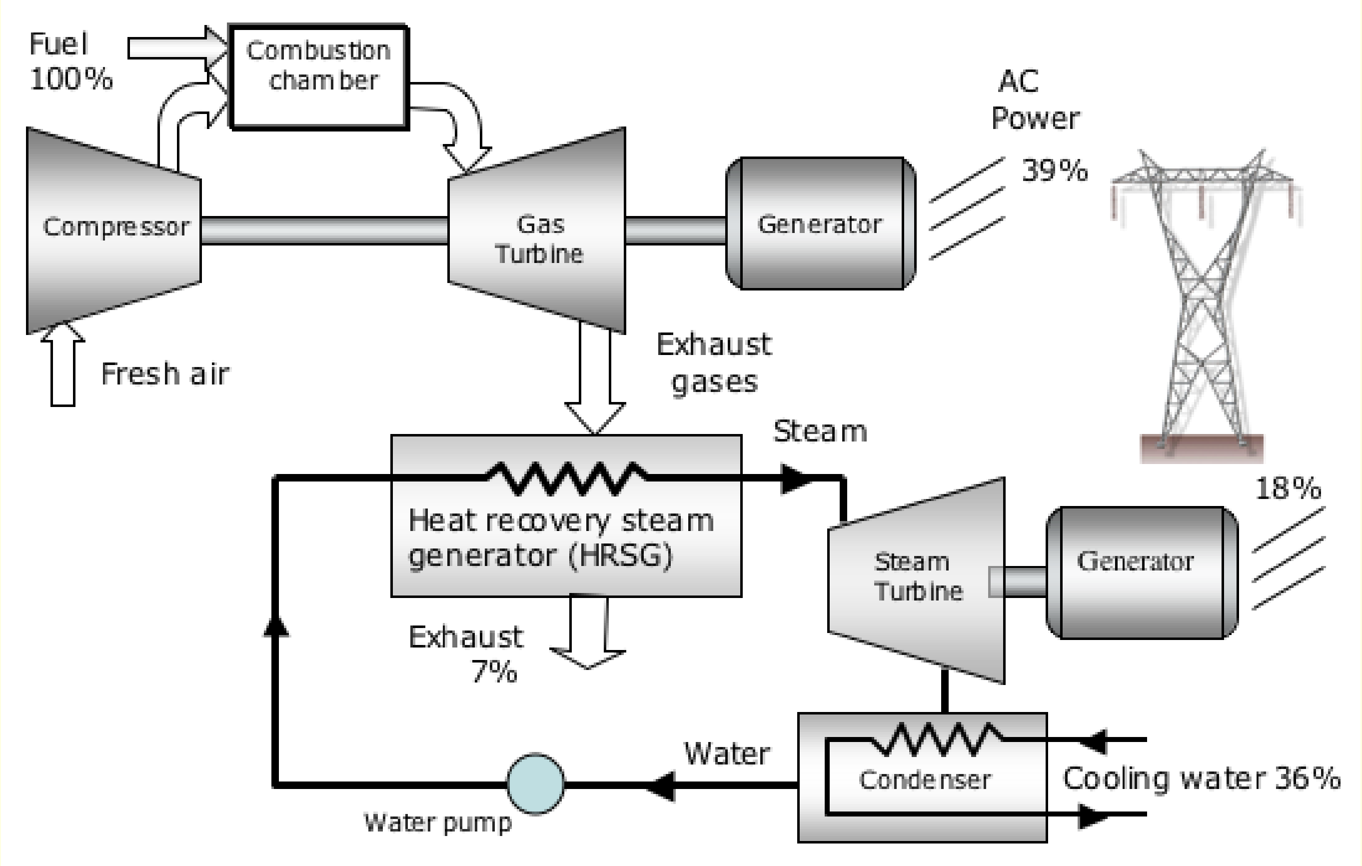
Open cycle gas turbine: Typical efficiency: 30-35%



Air-breathing jet engines are gas turbines optimized to produce thrust from the exhaust gases. In our case, the system is optimized to produce maximum shaft power.

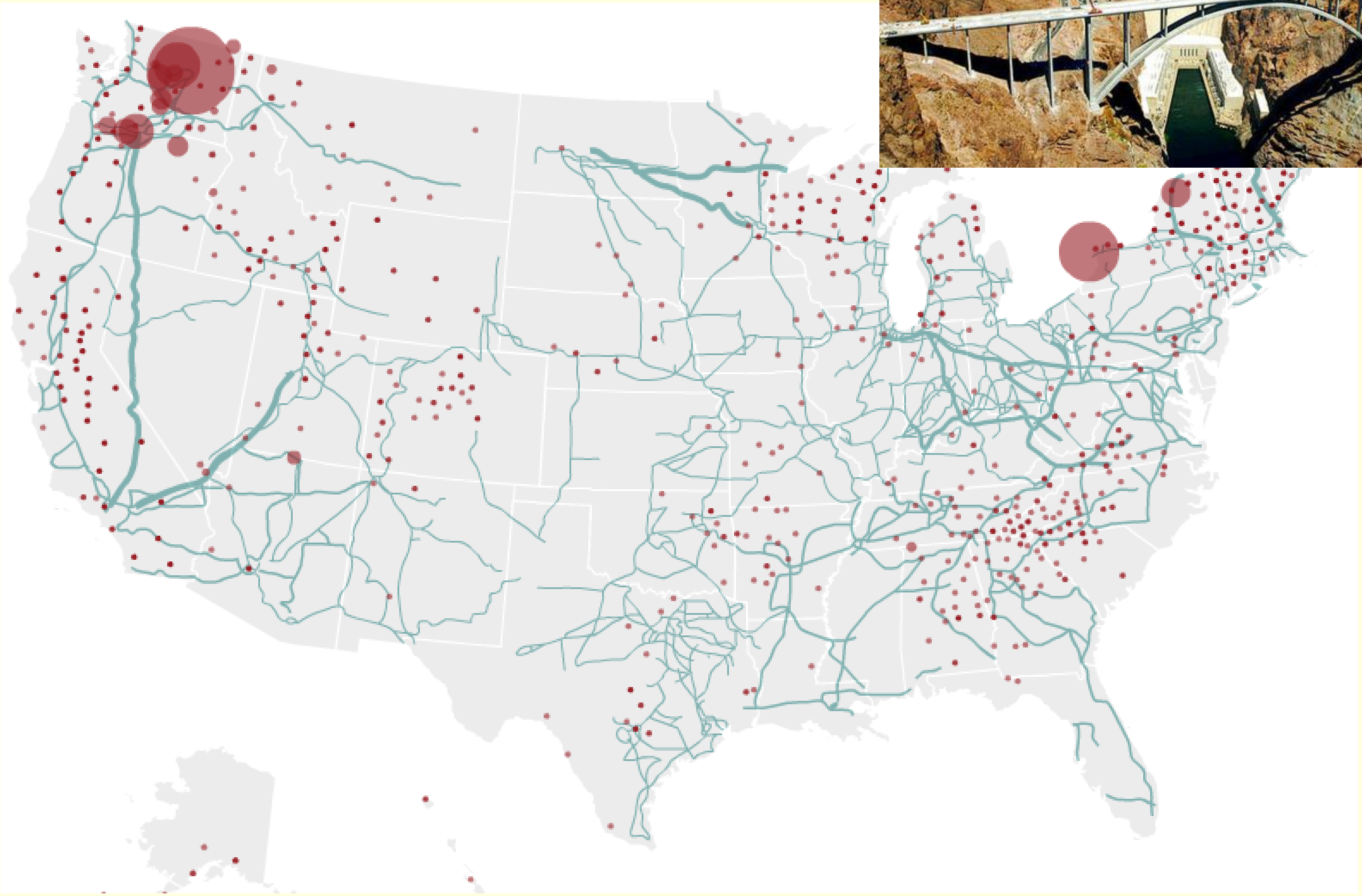


Combined cycle power plant: Typical efficiency: 60-65%



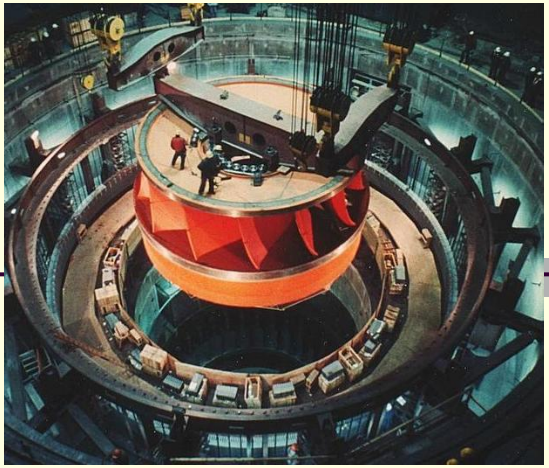
Efficiencies are even higher when the steam is used for district heating or industrial processes.

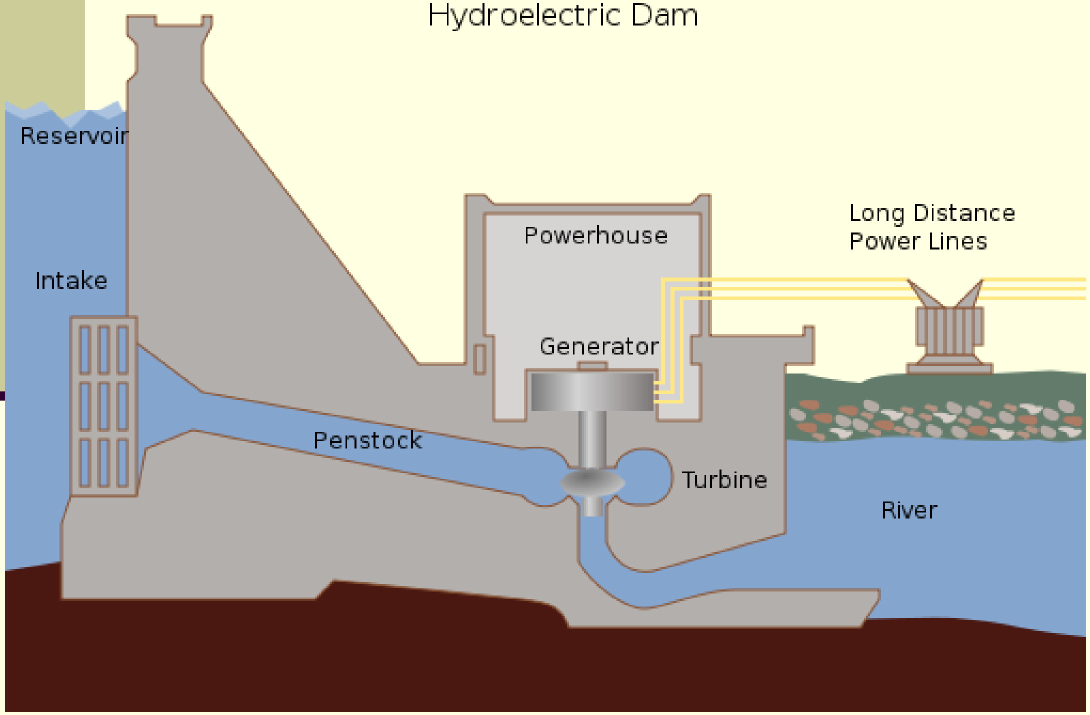
Hydro Power Plants:
Number of Generators ≈ 4,000
Total Capacity ≈ 80 GW

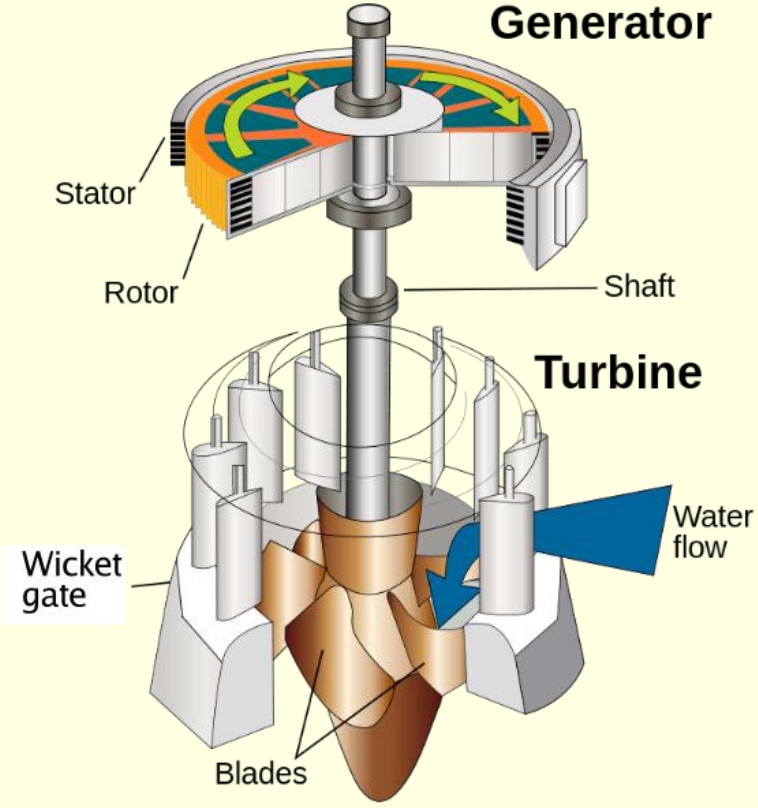


Hydro Power plants

- Low and medium head plants use Francis turbines
- High head plants use Pelton wheel turbines

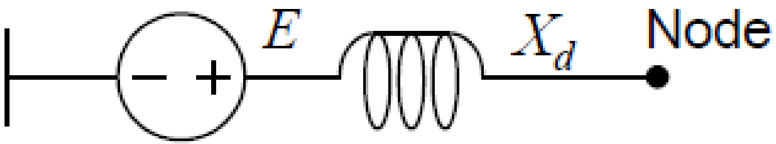




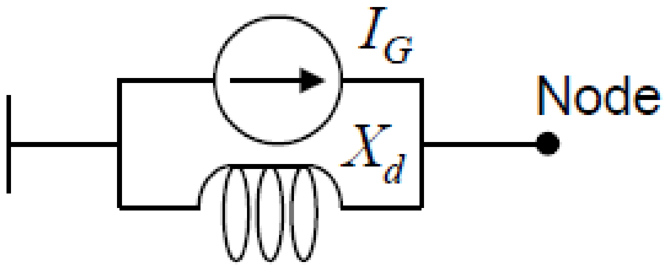


Static Generator Model

- **Generator may be modeled in three different ways**
  - Power Injection Model - the real, P, and reactive, Q, power of the generator is specified at the node that the generator is connected
    - either the voltage or injected current is specified at the connected node, allowing the other quantity to be determined
  - Thevenin Model - induced AC voltage, E, behind the synchronous reactance, X_d

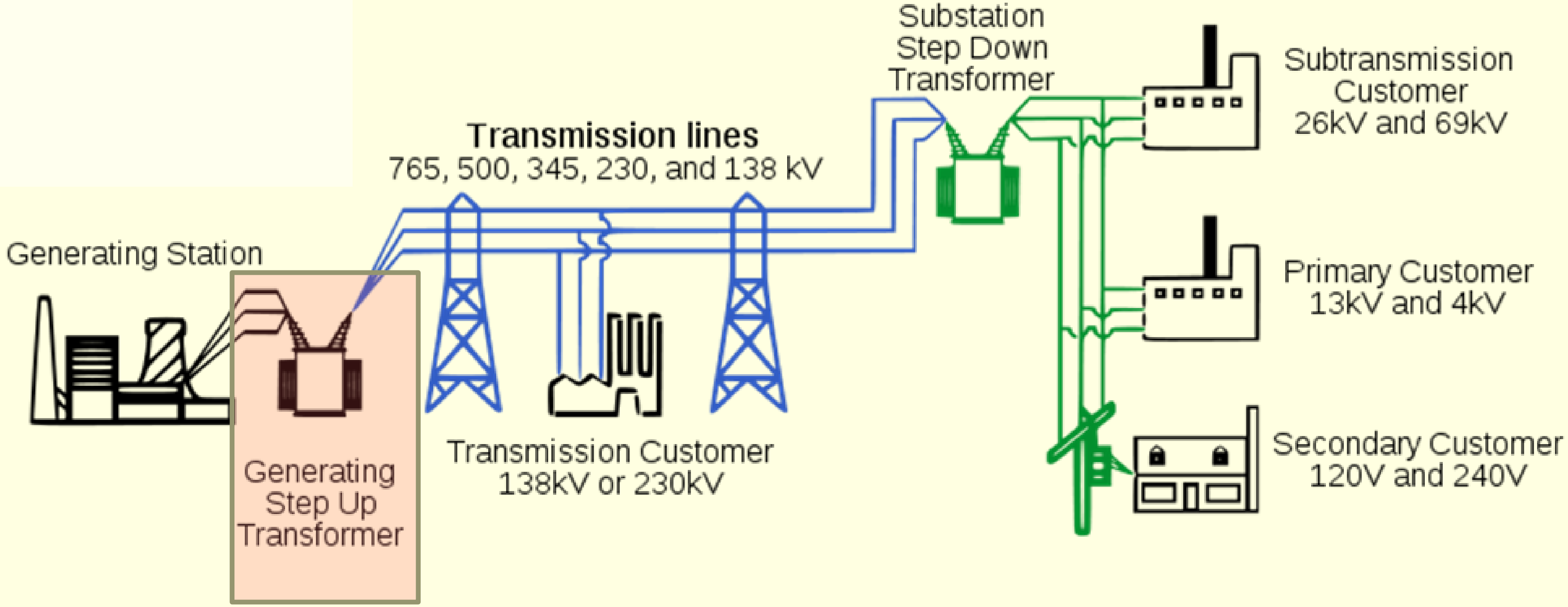


  - Norton Model - injected AC current, I_G, in parallel with the synchronous reactance



- The magnitude of the induced voltage E, and injected current I_G is controlled by the exciter.

Basic Conventional Power System Layout

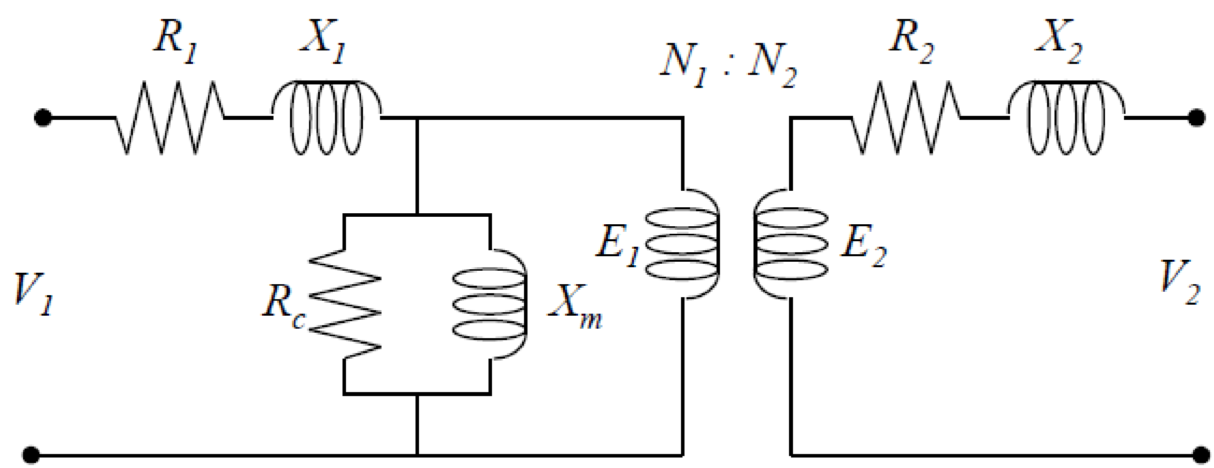


Step-up (Station) transformers:

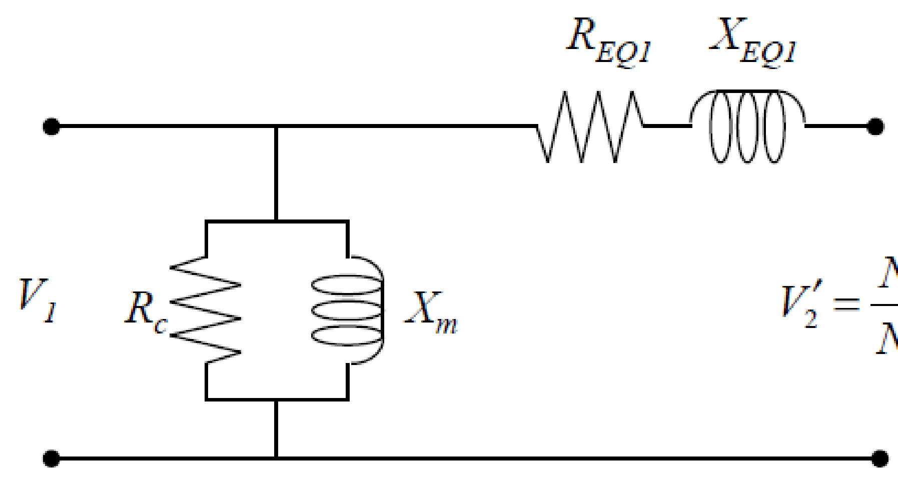
- Size to 1000 MVA
- generator voltage up to 25 kV
- Transmission voltage up to 765 kV
- Forced Air and Forced Oil Cooling.

Two-Winding Transformer Model

- Equivalent circuit of a two winding transformer



- Approximate circuit referred to the primary

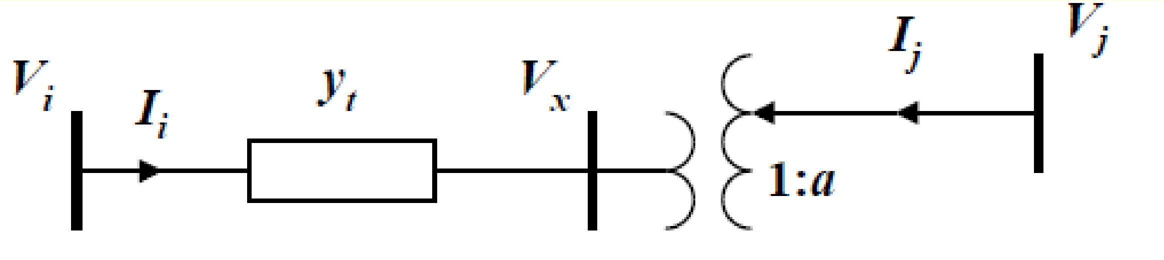


$$V_2' = \frac{N_1}{N_2} V_2$$

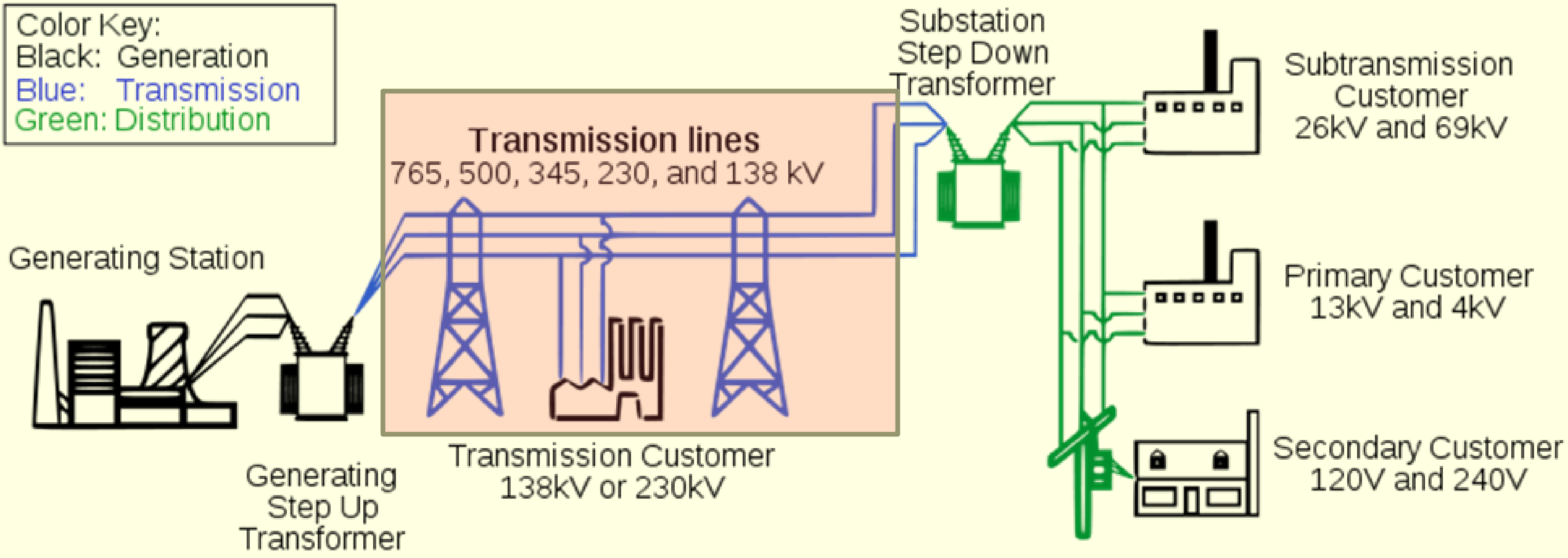
Phase-Shifting Transformer

- Phase shifting transformers change the phase angle between the primary and secondary voltages in order to control the flow of real power.
- They can also be used to control the voltage ratio by small increments, hence reactive power flow.

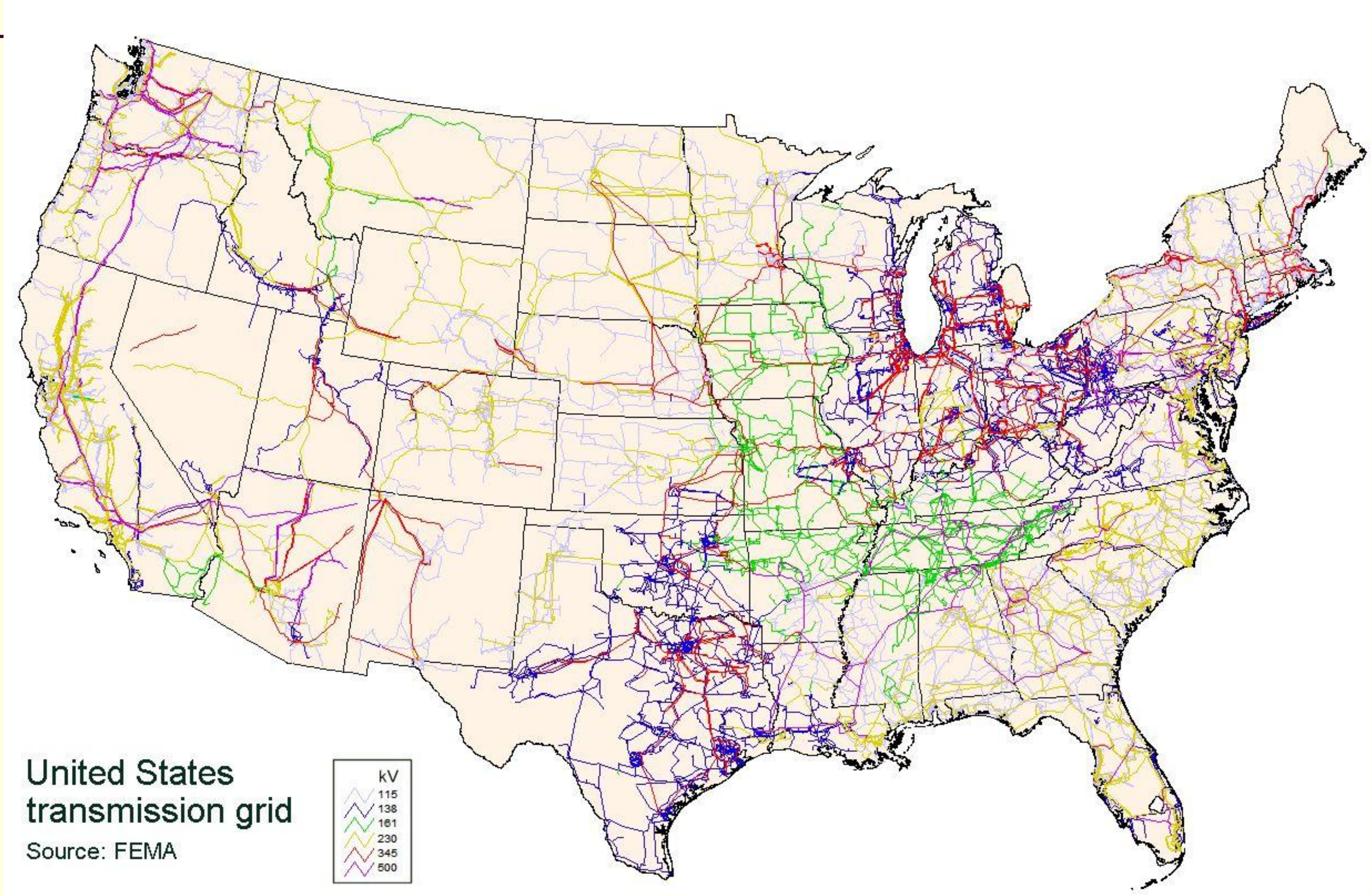
- Phase shifters can be used to prevent inadvertent "loop flow“ and to prevent line overloads.
- These transformers are modeled with a complex turn ratio “a”.



Basic Conventional Power System Layout

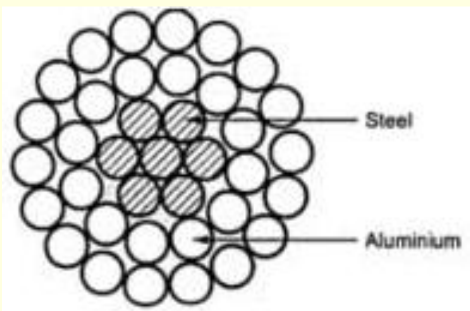


US Power Transmission Grid



High Voltage Power Lines (overhead)

- Common voltages in north America: 138, 230, 345, 500, 765 kV
- Bundled conductors are used in extra-high voltage lines
- Stranded instead of solid conductors are used.



High Voltage Power Cables (underground)

- Cable lines are designed to be placed underground in urban areas or under water. The conductors are insulated from one another and surrounded by protective sheath.
- Cable lines are more expensive and harder to maintain. They also have a large capacitance – not suitable for long distance.



Ground wires and corona discharge

- **Ground wires:** Transmission lines are usually protected from lightning strikes with a ground wire. This topmost wire (or wires) helps to attenuate the transient voltages/currents that arise during a lighting strike. The ground wire is typically grounded at each pole.

- **Corona discharge:** Due to high electric fields around lines, the air molecules become ionized. This causes a crackling sound and may cause the line to glow!

HVDC Transmission

- Because of the large fixed cost necessary to convert ac to dc and then back to ac, dc transmission is only practical in specialized applications
  - long distance overhead power transfer (> 400 miles)
  - long underwater cable power transfer
  - providing an asynchronous means of joining different power systems.

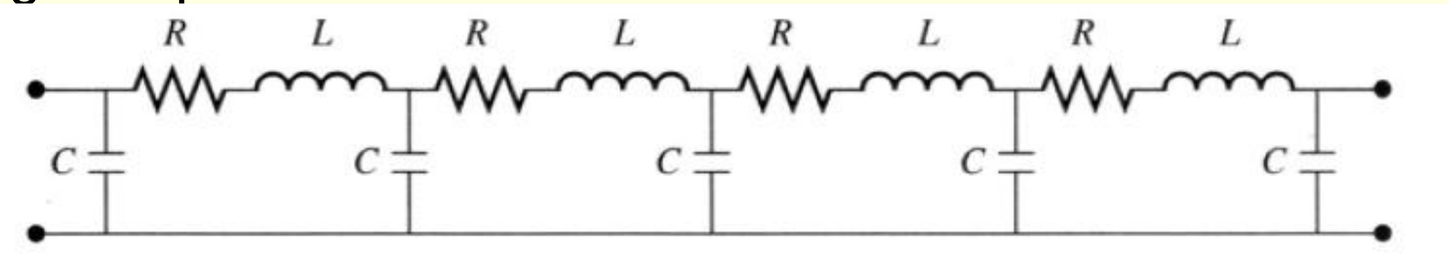
Tree Trimming underneath power lines

Before

After

Transmission line electrical characteristics

- Transmission lines are characterized by a series resistance, inductance, and shunt capacitance per unit length. These values determine the line power-carrying capacity and the voltage drop or rise.

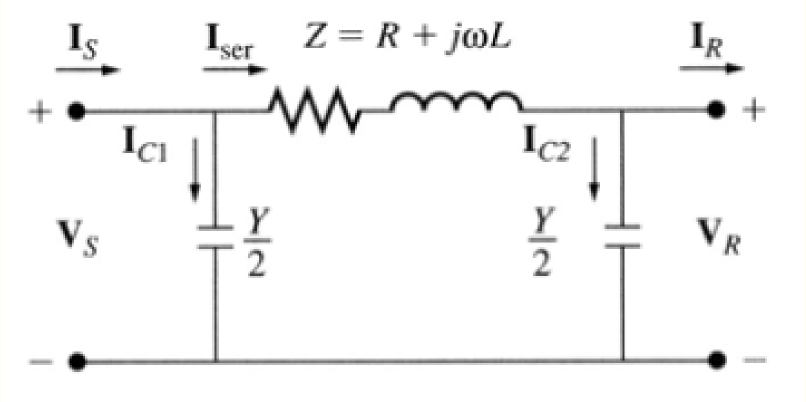


- Equivalent π-circuit

$$R_{DC} = \frac{\rho l}{A} \ \Omega/\text{m}$$

$$C = \frac{2\pi\epsilon}{\ln(\frac{GMD}{r})} \ \text{F/m}$$

$$L = 2x10^{-7}\ln(\frac{GMD}{GMR}) \ \text{H/m}$$



ACSR Conductor Table Data

TABLE A8.1. BARE ALUMINUM CONDUCTORS, STEEL REINFORCED (ACSR) ELECTRICAL PROPERTIES OF MULTILAYER SIZES *(Cont'd)*

Code Word	Size (kcmil)	Stranding Al./St.	Number of Aluminum Layers	Resistance: dc 20°C (Ohms/Mile)	Resistance: ac-60 Hz 25°C (Ohms/Mile)	Resistance: ac-60 Hz 50°C (Ohms/Mile)	Resistance: ac-60 Hz 75°C (Ohms/Mile)	GMR (ft)	Phase-to-Neutral, 60 Hz Reactance at One ft Spacing: Inductive Ohms/Mile X_a	Phase-to-Neutral, 60 Hz Reactance at One ft Spacing: Capacitive Megohm-Miles X'_a
Flicker	477	24/7	2	0.1889	0.194	0.213	0.232	0.0283	0.432	0.0992
Hawk	477	26/7	2	0.1883	0.193	0.212	0.231	0.0290	0.430	0.0988
Hen	477	30/7	2	0.1869	0.191	0.210	0.229	0.0304	0.424	0.0980
Osprey	556.5	18/1	2	0.1629	0.168	0.184	0.200	0.0284	0.432	0.0981
Parakeet	556.5	24/7	2	0.1620	0.166	0.183	0.199	0.0306	0.423	0.0969
Dove	556.5	26/7	2	0.1613	0.166	0.182	0.198	0.0313	0.420	0.0965
Eagle	556.5	30/7	2	0.1602	0.164	0.180	0.196	0.0328	0.415	0.0957
Peacock	605	24/7	2	0.1490	0.153	0.168	0.183	0.0319	0.418	0.0957
Squab	605	26/7	2	0.1485	0.153	0.167	0.182	0.0327	0.415	0.0953

Geometric Mean Radius

Inductive and Capacitive Reactance for 1-foot Spacing

Transmission Line Characteristics

- The ratio of the magnitude of the receiving end voltage to the magnitude of the ending end voltage is generally kept within 5% of the nominal value,

$$0.95 \leq V_S/V_R \leq 1.05$$

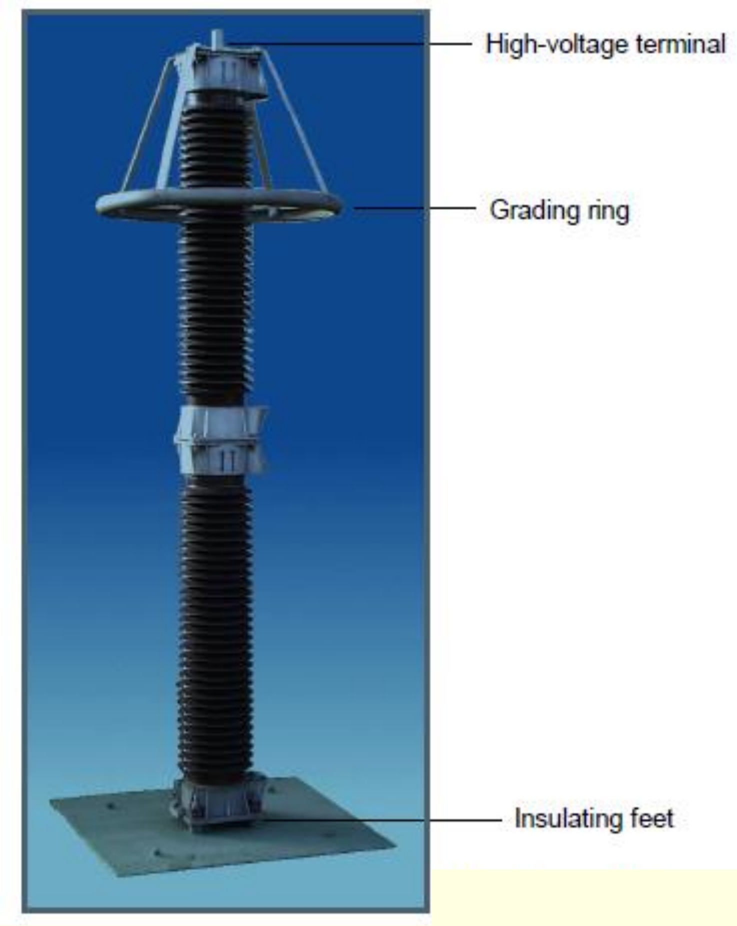
- The angle δ between the two voltages should typically be ≤ 30º to ensure that the power flow in the transmission line is well below the static stability limit.
  - In short lines, where the series reactance *X* is relatively small, the **resistive heating** usually limits the power that the line can carry.
  - In midium lines operating at lagging power factors, the **voltage drop** across the line is usually the limiting factor.
  - In longer lines operating at leading power factors, the **maximum angle δ** can be the limiting f actor.

Transmission lines … some facts

- Highest transmission voltage (AC): 1,150 kV in Kazakhstan
- Longest power line - 500 kV (DC): 1,056 miles in Congo
- Longest submarine cable – 450 kV (DC): 360 miles in Europe
- Note that a transmission line both absorbs and generates reactive power:
  - Under light load, the line generates more reactive power than it consumes.
  - Under “surge impedance loading”, the line generates and consumes the same amount of reactive power.
  - Under heavy load, the line absorbs more reactive power than it generates.

Transmission System Protection

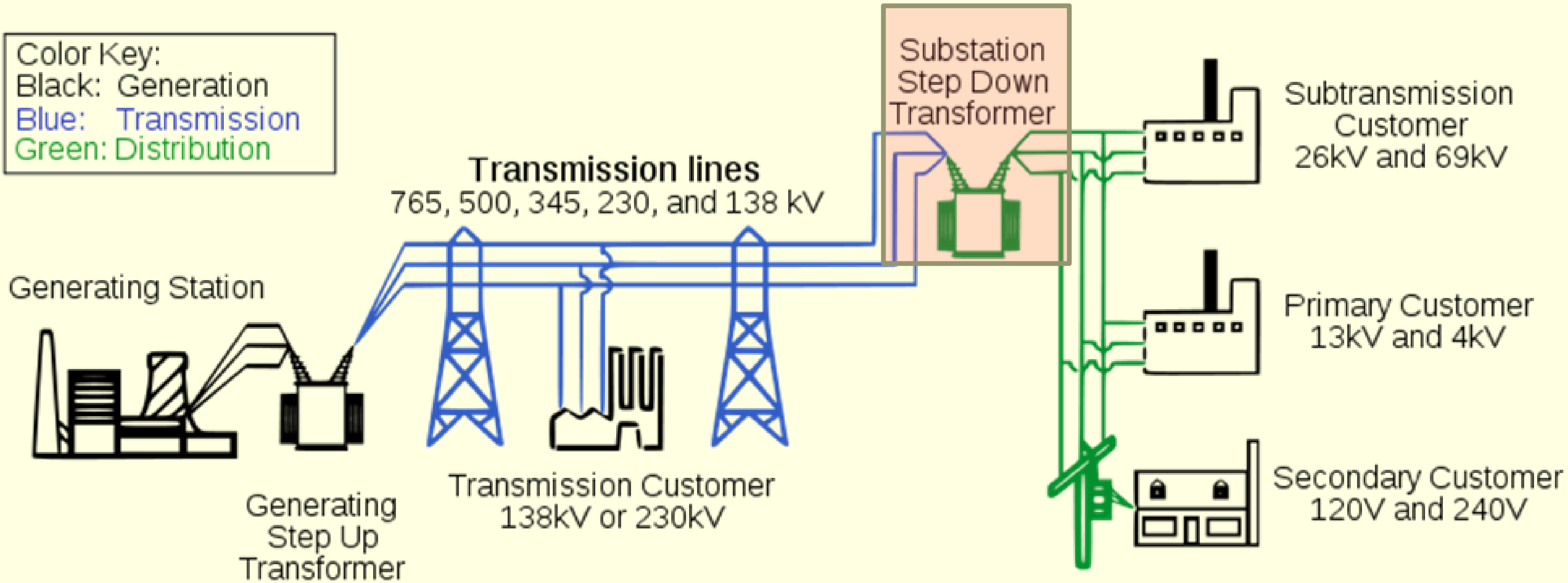
- Protective equipment needs to protect the system from over-voltages (surge arrestors) and over-currents (circuit breakers).



Long line series and shunt compensation

- **Shunt reactors** are used to compensate the line shunt capacitance under light load or no load.
- **Series capacitors** are often used to compensate the line inductive reactance in order to transfer more power.

Basic Conventional Power System Layout



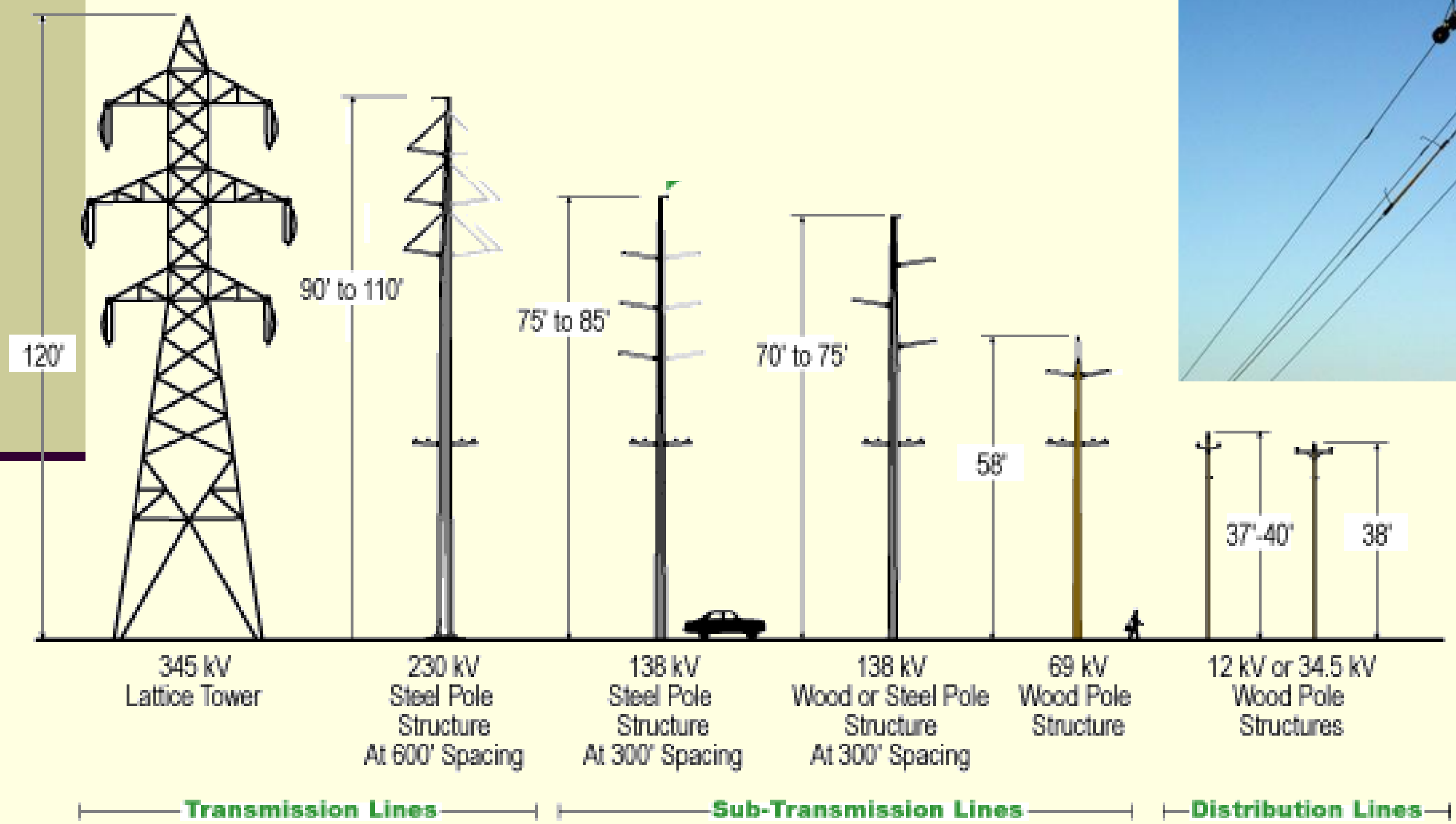
Substation Transformers

- Typical size; 20 MVA
- Primary voltage up to 69 kV
- Secondary voltage down to 4.16kV

Distribution Substation Layout

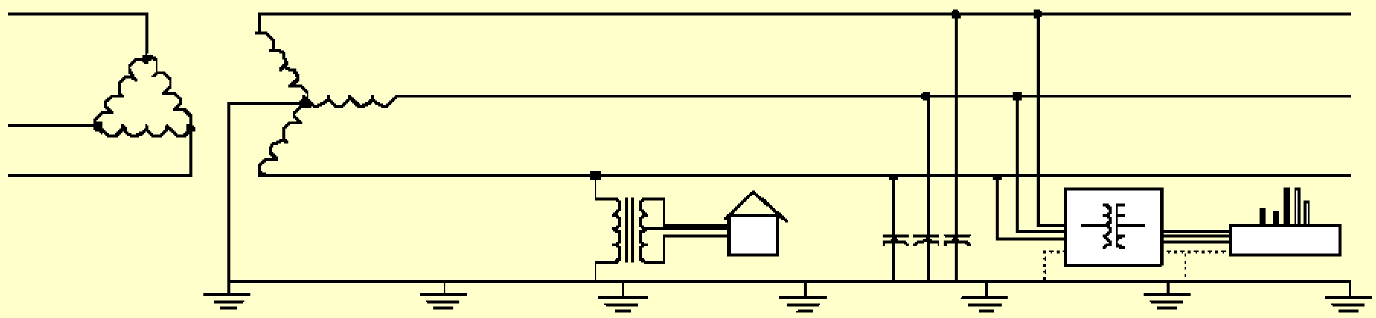
Power distribution lines (placed underground in urban areas)

- Primary Distribution voltages: 4.16, 12.47, 13.2, 13.8, 25, 34.5 kV



Typical North American Distribution System

- Primary system is extensive
- Secondary is short
- 4-5 houses per distribution transformer
  - 120/240V single phase service
- 1 Industrial customer per distribution transformer
  - Or multiple transformers per customer



Typical 4-wire multi-grounded neutral system

Power distribution transformers

- The distribution circuits may be overhead or underground. This will depend on the load density and the physical conditions of the particular area to be served.

Overhead Transformer
Bank & Service

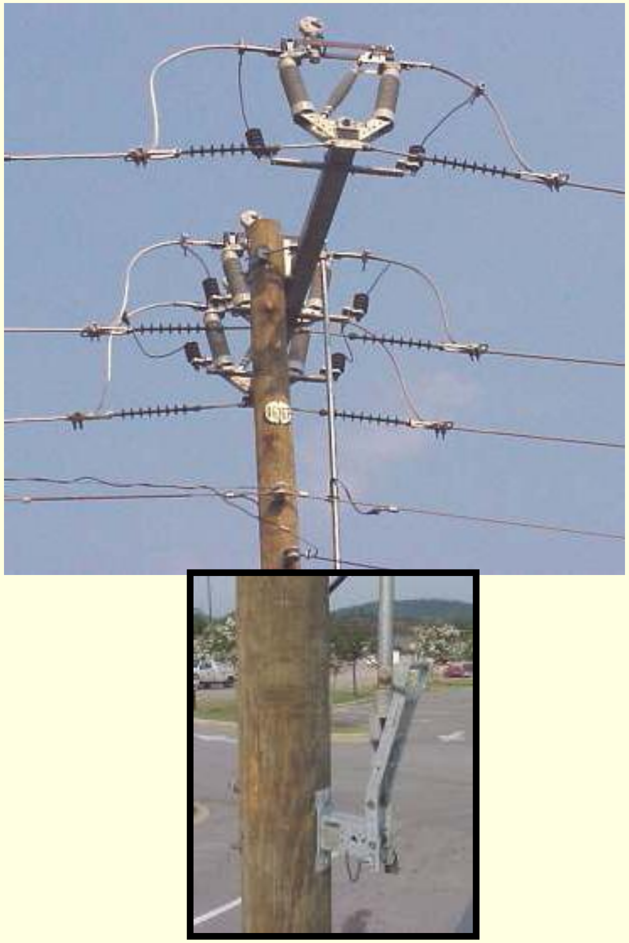
Padmount Transformer
for Underground System

Risers

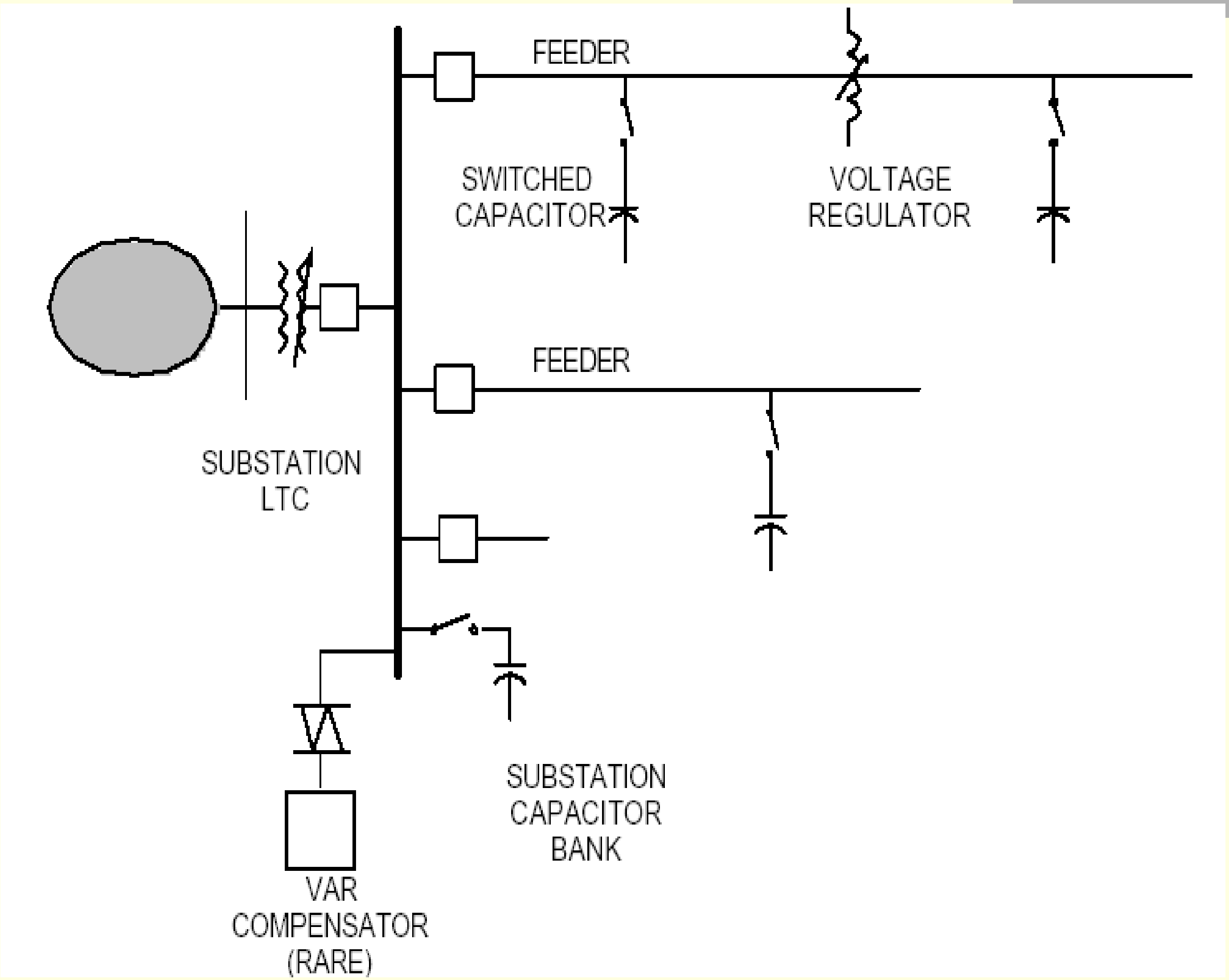
Riser - connects underground cables to overhead lines

Switches

Manual and motorized switches (operated remotely) to disconnect.

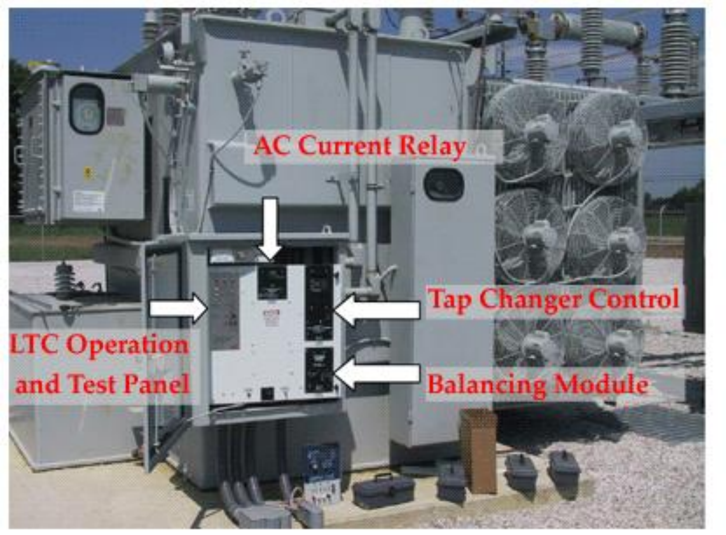


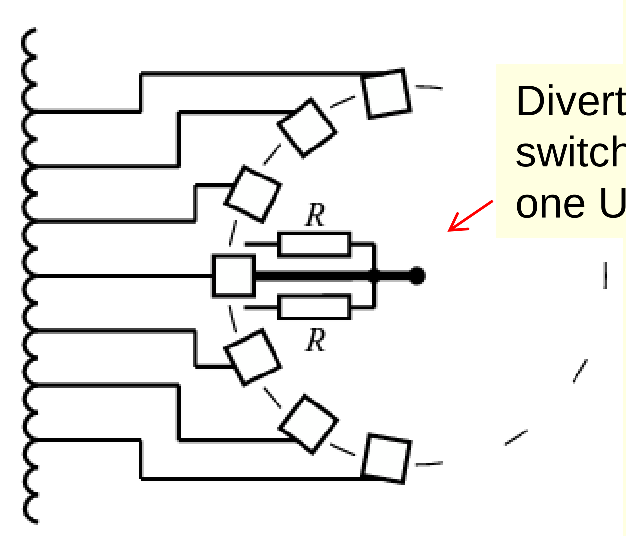
Voltage Regulation Devices



Substation LTC

- The under-load-tap-changing transformer(ULTC), also called the on-load tap Changer (OLTC) or load tap changer(LTC), allows the transformer taps to be changed while the transformer is energized.
- A typical range of regulation is ±10% with 32 steps - each corresponds to (5/8)%.





Diverter and selector switch Combined into one Unit.

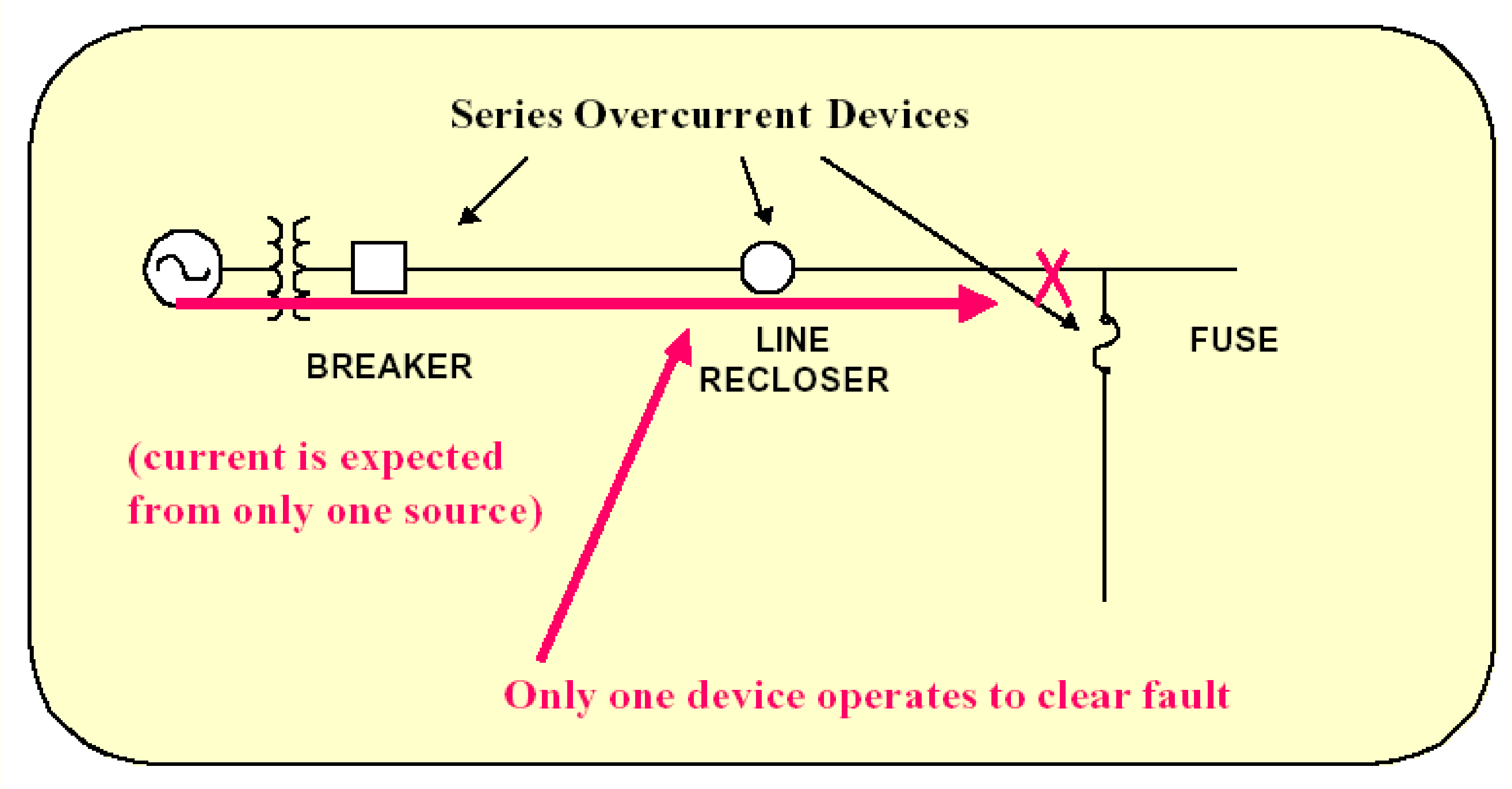
Voltage Regulators

Voltage regulators often installed in long distribution lines to maintain voltage within a specific range

Switched Capacitors

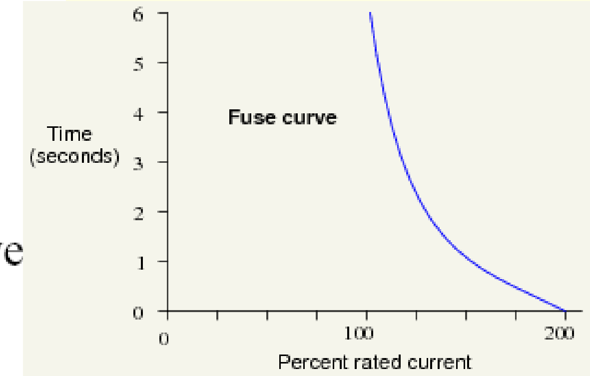
- Least expensive option
  - Improves efficiency as well as voltage
- Typical Sizes: 300, 600, 900, 1200, 1800 kvar
- Changes the voltage approx 2% each step
- Control
  - Quantity: time, temperature, voltage, current, or kvar
    - » Whatever can be best correlated to load
  - Time delay: typically 30 sec or more
- Only two operations expected per day

Over-Current Protection

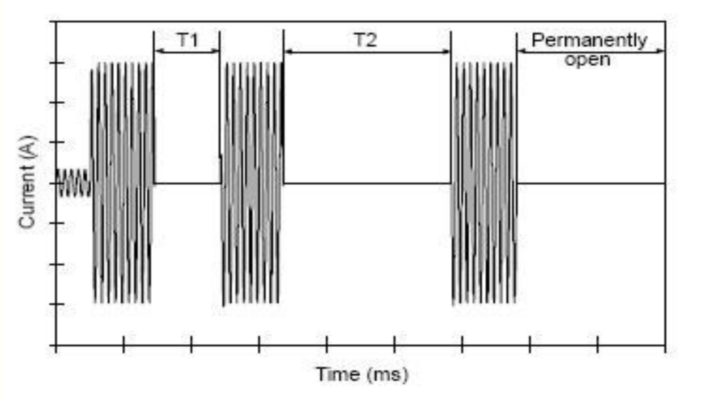


Fuse Characteristics

- A fuse is a one-shot device
- Operates faster for higher currents
- To coordinate with this:
  - Upstream devices have same basic shape
  - Devices closer to substation act slower
    - » Except for "fast" or "instantaneous" tripping where we try once or twice to save the fuse



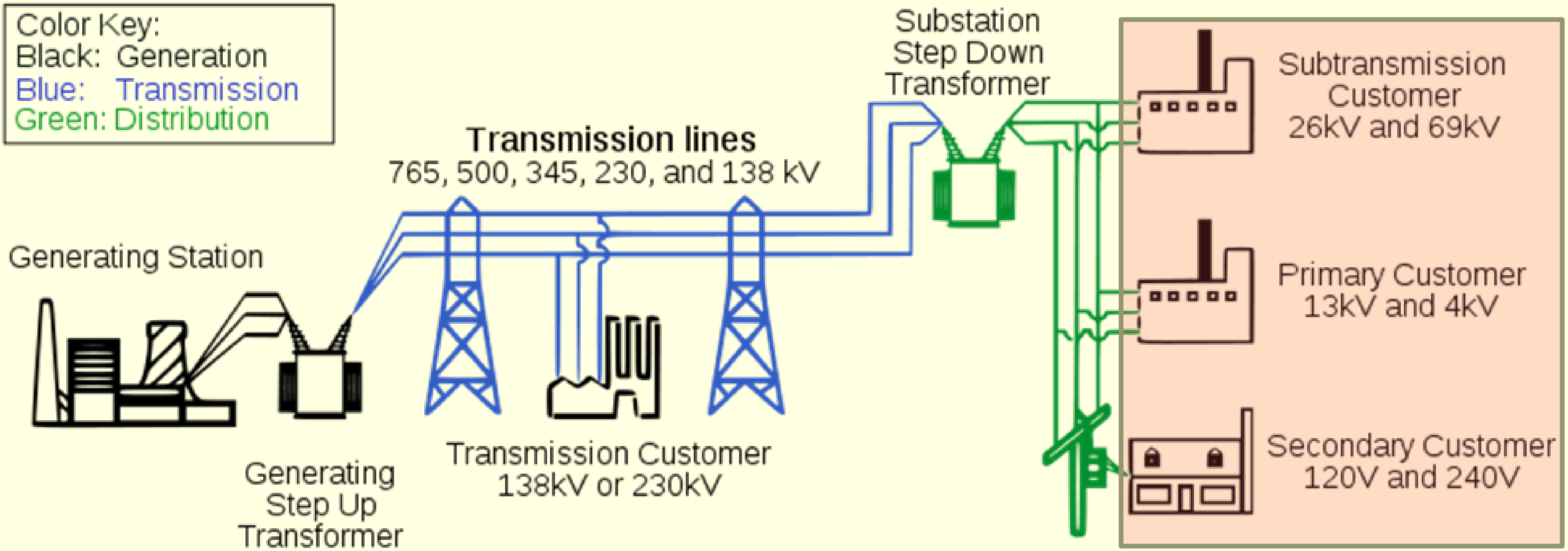
Typical Reclosing Sequence:



Over-Voltage Protection

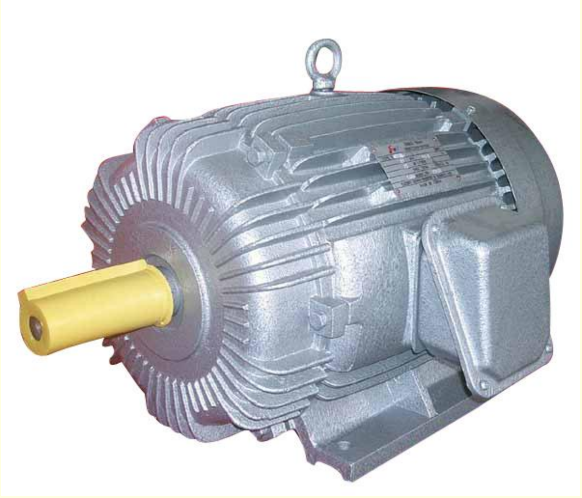
- Surge Arrestors are often placed along distribution feeders and equipment

Basic Conventional Power System Layout



Electrical Power Utilization (electric load)

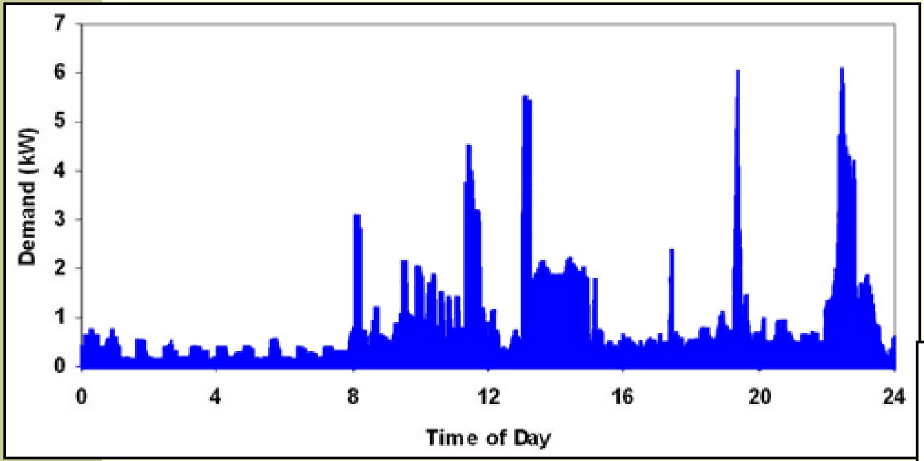
- **Utilization voltage: 120V, 208V*, 240V, 277V, 480V*, 600V***

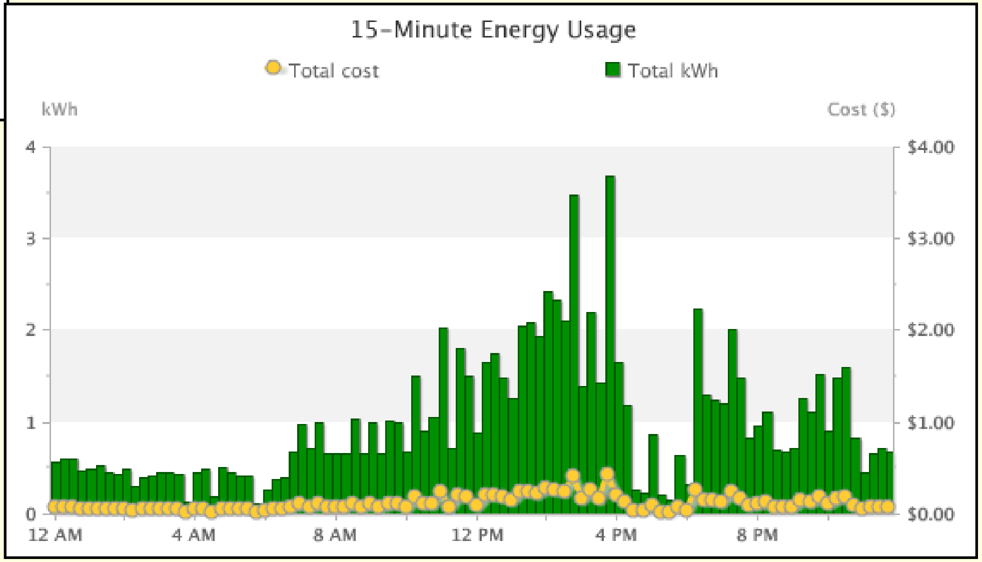


2/3 –3/4 of electricity is consumed by motors

Demand

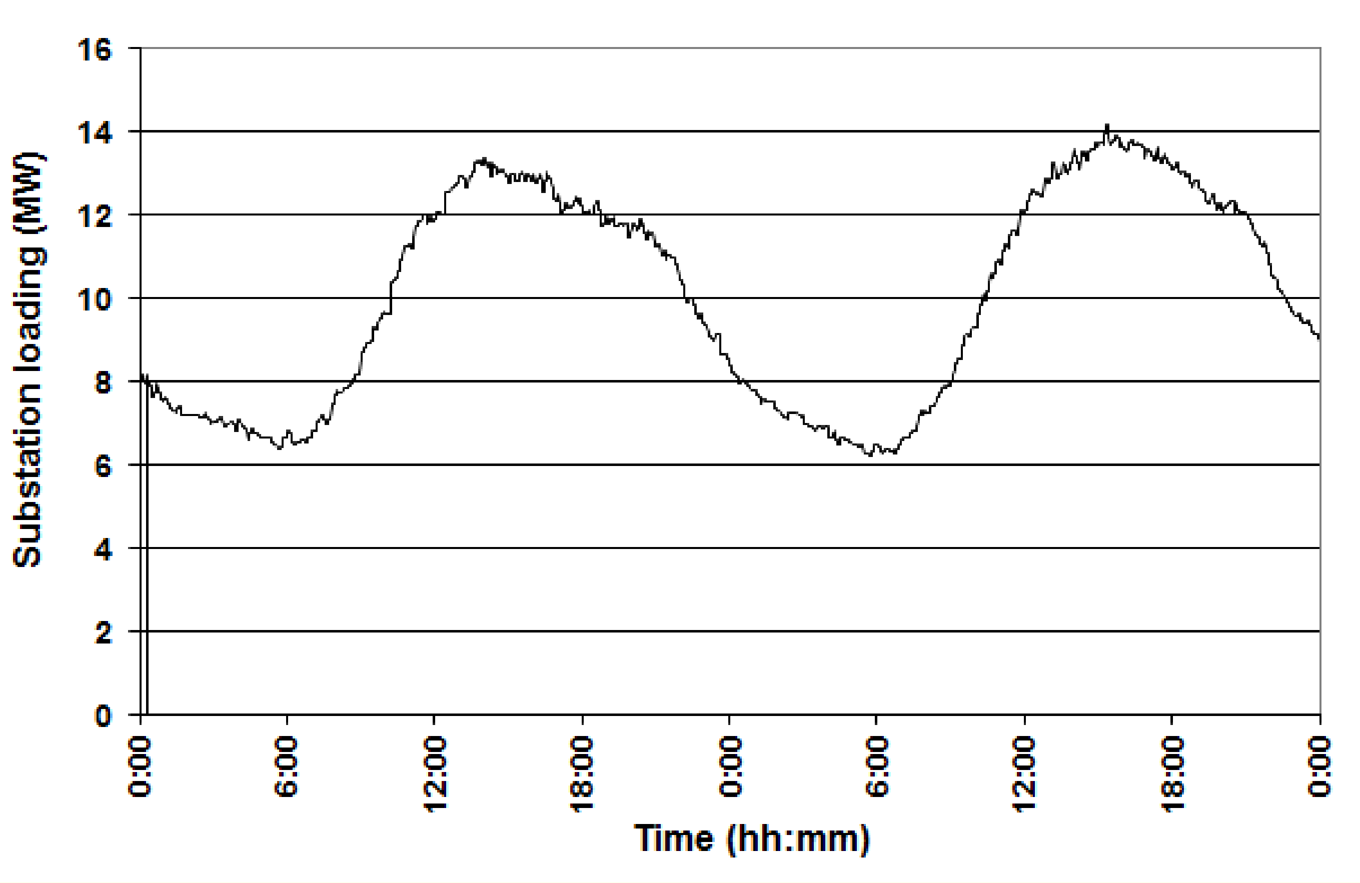
- Changes in demand of individual customers is fast and frequent due to load switching.



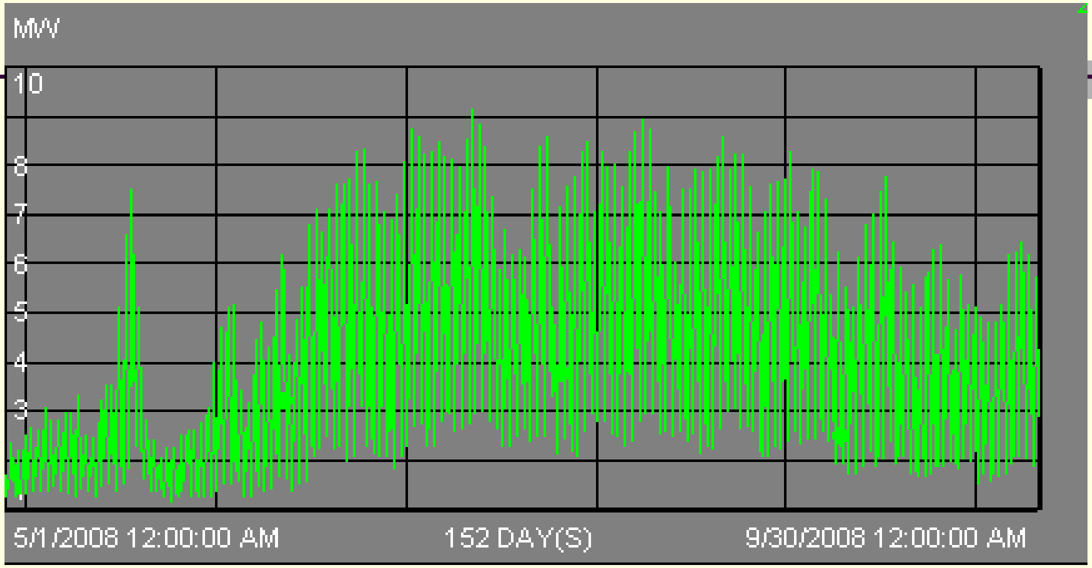


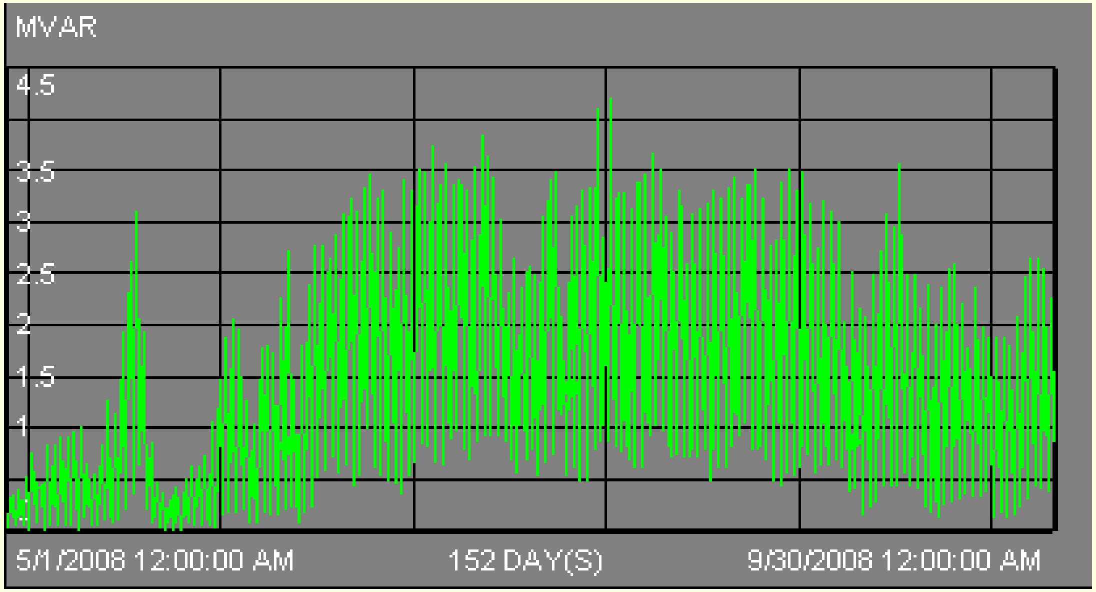
Substation Load: 48 hours

- The aggregated demand at the substation is smoother, and total load fluctuations are usually small.



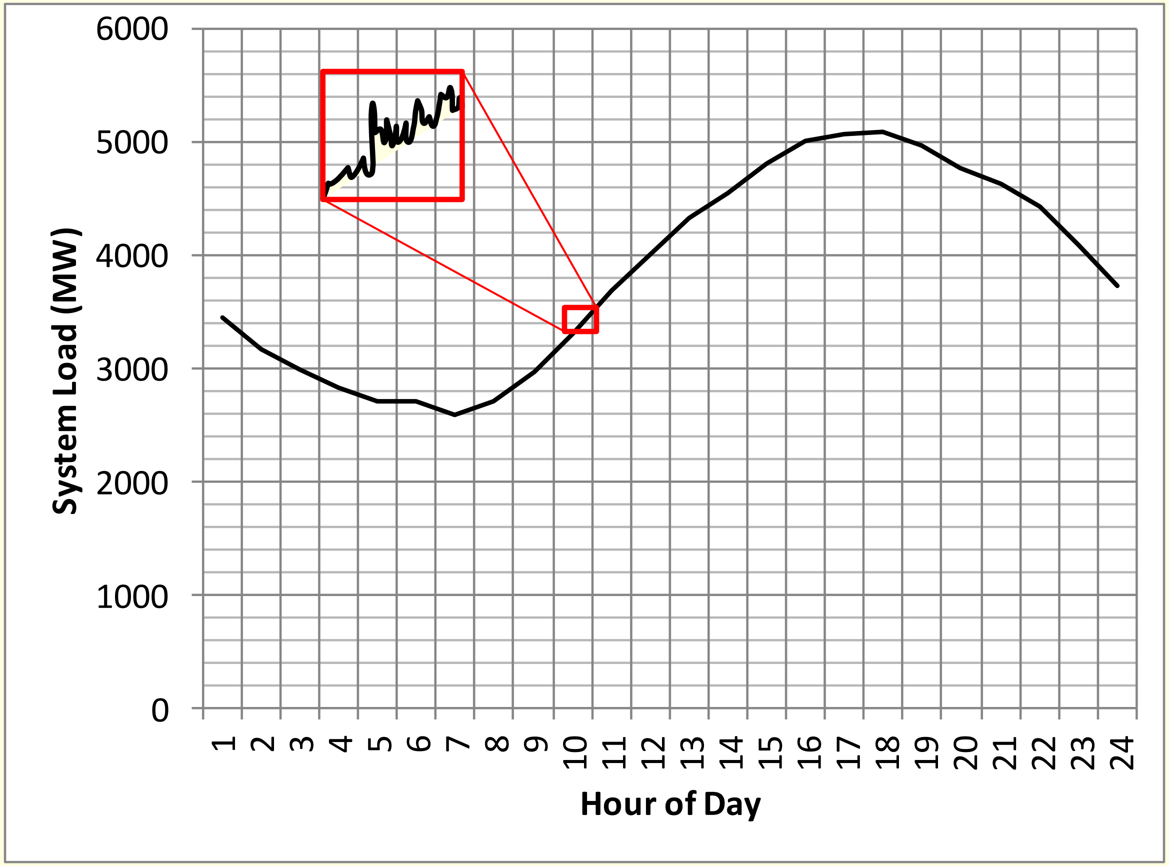
MW and MVAR loading on a feeder – 4 months



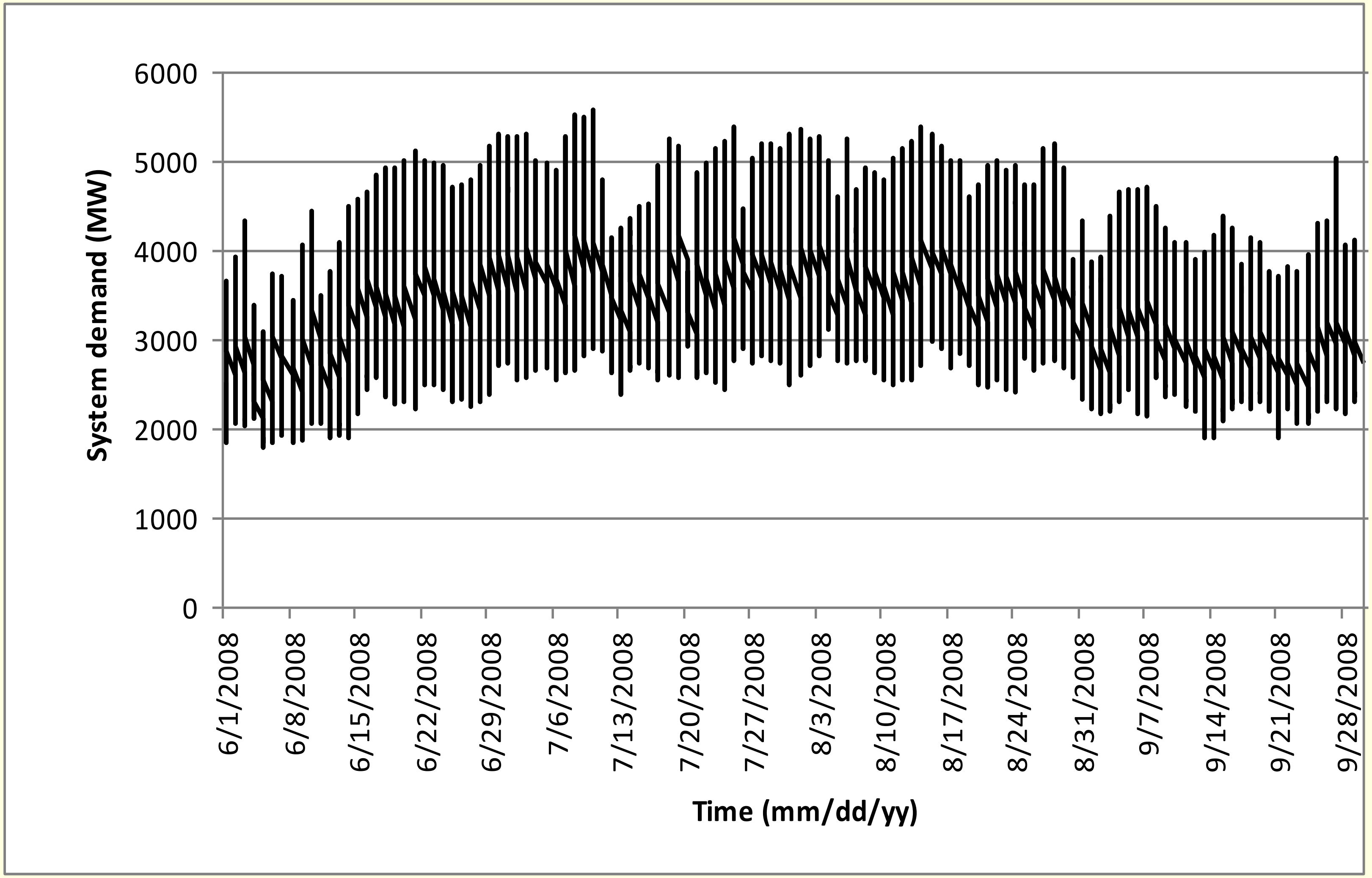


System load: 24-hours

- The aggregated demand on the system is even smoother, and total load fluctuations are very small.

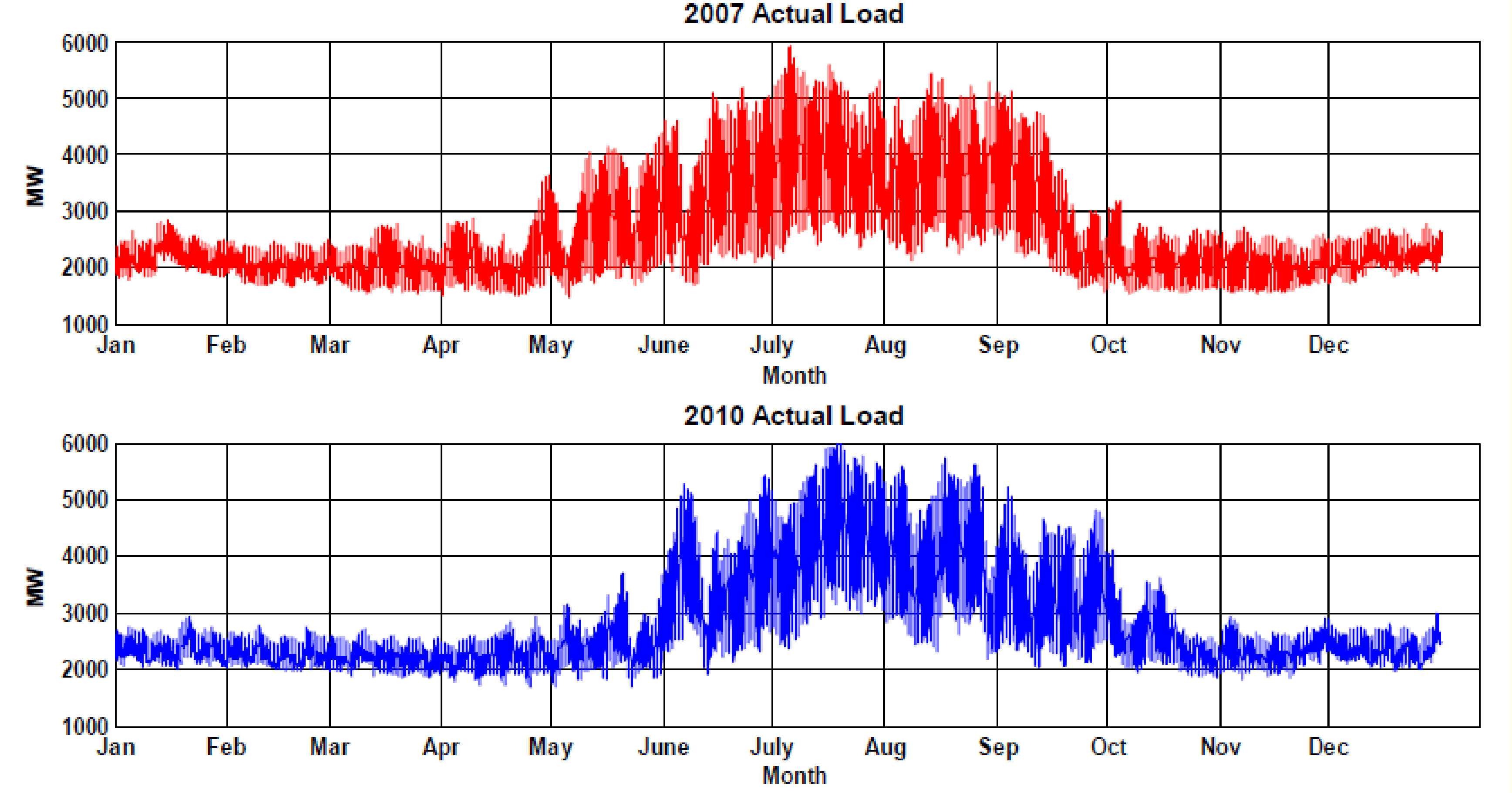


System load: 4-month summer period



Seasonal Load Patterns

NV Energy's service territory loads are dominated by winter and summer patterns, with May and October as shoulder months.

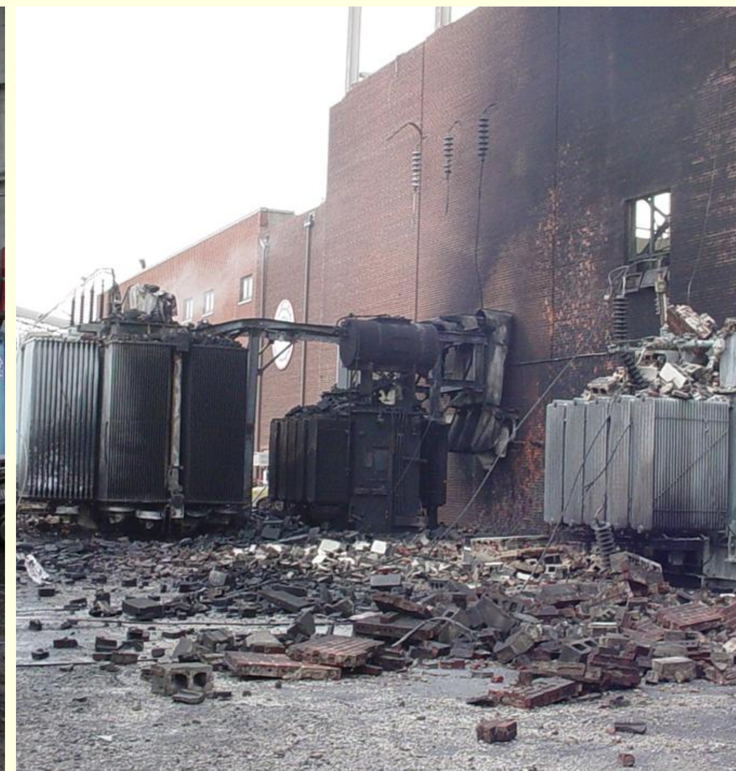


Annual Load Duration Curve (LDC)

- A LDC is similar to a load curve but the demand data is ordered in descending order of magnitude, rather than chronologically. It illustrates the relationship between generating capacity requirements and capacity utilization.

Violent Failure of a steam-driven generator!

The explosion below was caused by a faulty valve that prevented the cutoff of steam into the turbine when the generator went off line, leading the generator to accelerate to over 6,000 rpm. The High speed caused parts of the generator to tear apart. Hydrogen escaped from the cooling system, causing the explosion.



END!