

Power System Elements

Generating Unit Basics

PJM State & Member Training Dept.

- Provide an overview of:
 - Major components of a Generator
 - Excitation
 - Governor Control
 - Rotational Speed
 - Generator Limitations
 - VAR/Voltage Relationship
 - MWs and Power Angle

Basic Operating Principles

- *Electromagnetic Induction* is the principle used by a generator to convert mechanical energy into electrical energy
- For this to happen, three things are needed:
 - A magnetic field
 - A current-carrying conductor
 - A relative motion between the two
- This is the fundamental operating principle of generators, motors, transformers, inductors, and solenoids

Basic Operating Principles

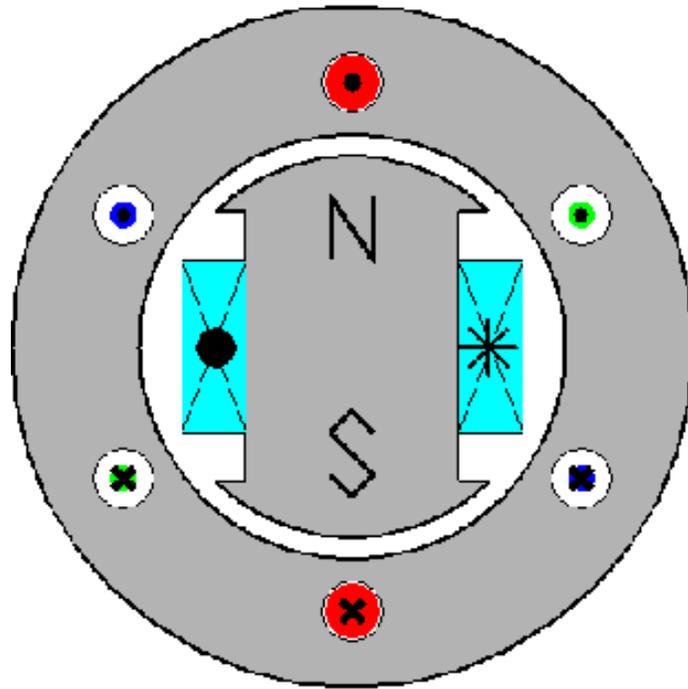
- Generators use energy from the prime mover to turn the generator's **rotor** (moving portion) inside the generator's **stator** (static portion)
 - Steam in a fossil or nuclear unit
 - Water flow in a hydroelectric unit
 - Fuel flow in a combustion turbine unit
 - Wind flow in a wind generator
- A DC current flows through the **field windings** of the **rotor** creating a magnetic field
- As the rotor spins, it acts via electromagnetic induction to induce a voltage in the **armature windings** of the **stator**

Basic Operating Principles

- Output voltage of the generator is controlled by changing the strength of the magnetic field of the rotor
- This is accomplished by controlling the amount of **direct current (DC)** or **excitation current** that is supplied to the rotor's field winding
- The **excitation current** is supplied by the **exciter**
- The stator's output to the system is a three-phase **alternating current (AC)** since the direction of the magnetic field changes in relation to the windings as the rotor turns 360 degrees
- One rotation is equal to a complete cycle of power

Basic Operating Principles

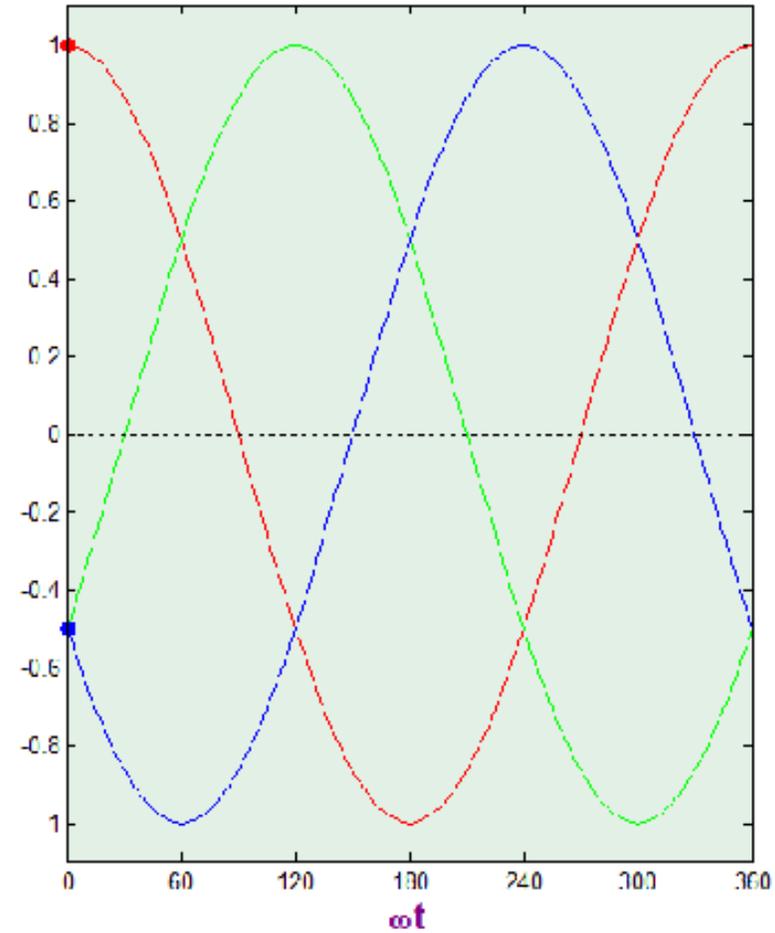
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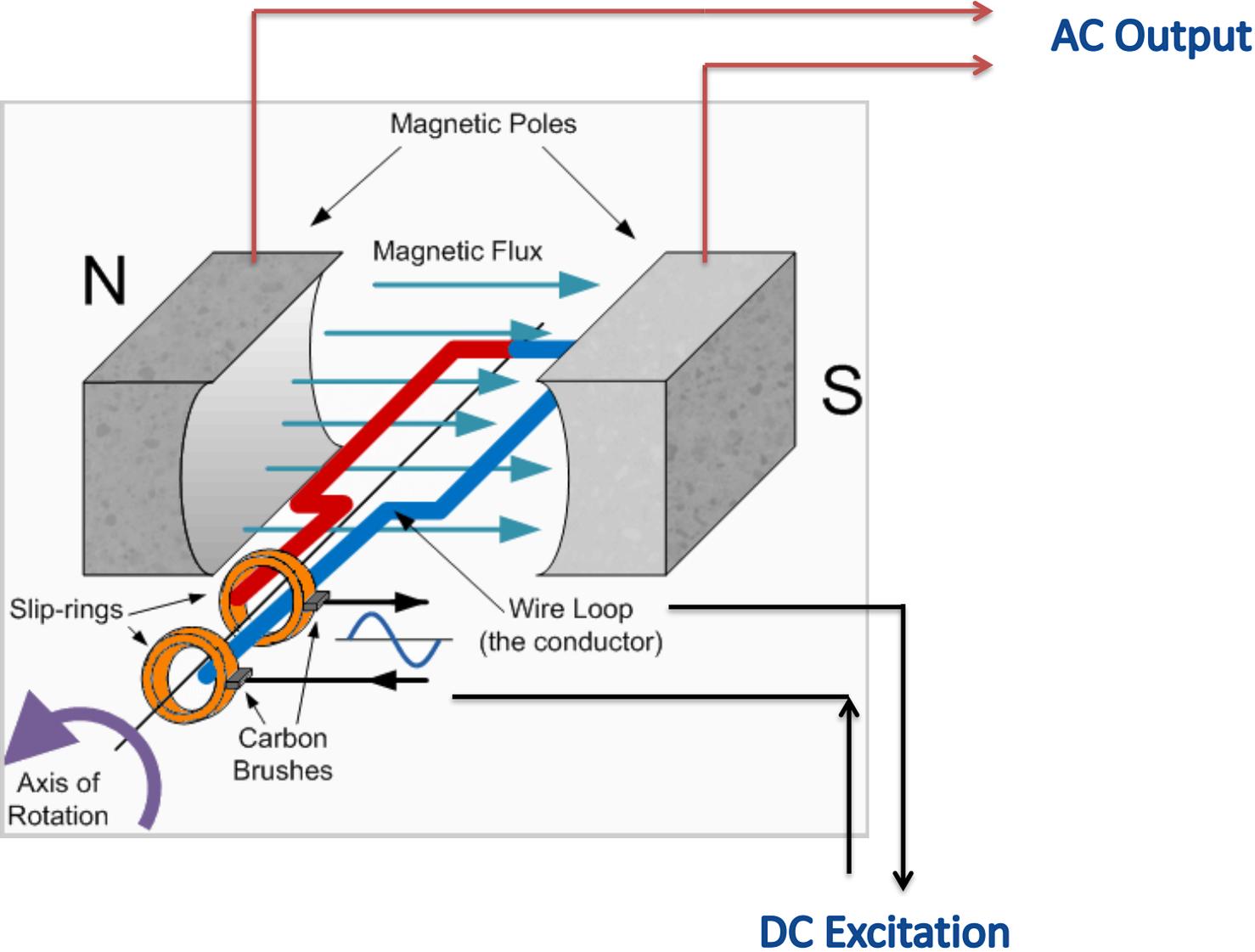
Phase A

Phase B

Phase C



Basic Operating Principles



A.C. Generator Components

- Rotating Magnetic Field (Rotor)
- Series of Stationary Conductors (Stator)
- Source of D.C. Voltage (Exciter)



Rotor

- The basic function of the rotor is to produce a magnetic field of the size and shape necessary to induce the desired output voltage in the stator
- When the rotor is rotated within the stator, alternating current is induced in the stator windings
- The changing polarity of the rotor produces the alternating characteristics of the current

Rotor

- The generated voltage is proportional to the:
 - Strength of the magnetic field
 - Number of coils and number of windings on each coil
 - Speed at which the rotor turns
- Rotor winding is a multi-coil, single circuit, energized with DC power fed through the shaft from the collector rings
- The rotor is a low voltage, low power circuit; a major factor in building a generator with a rotating field instead of a rotating armature

Rotor

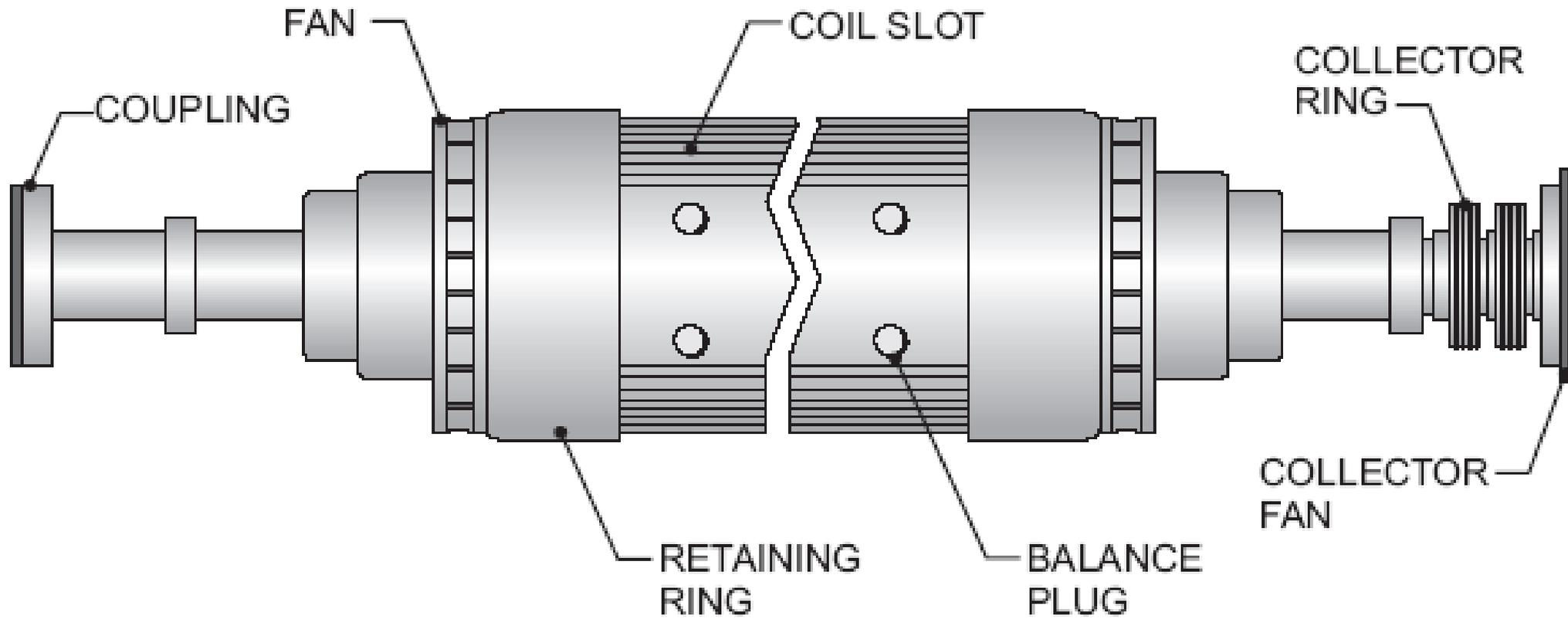


Figure 1. Generator field

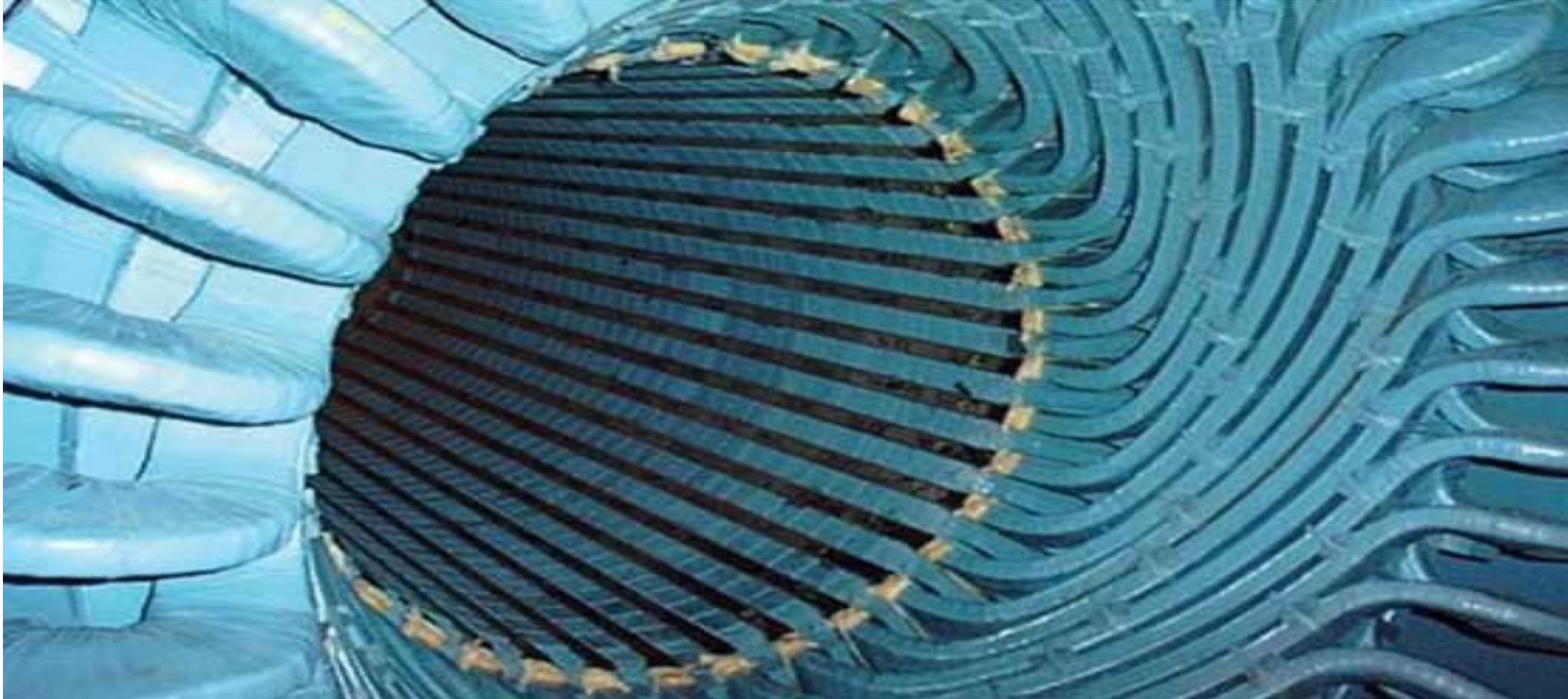
Stator

- The frame assembly of the generator is the main component of the stator
 - The stator core is made of soft iron to provide the magnetic field path with a high permeability
 - The function of the core is to provide a return path for the lines of magnetic flux from the field, and to support the coils of the stator winding
- Insulated windings or coils are placed in slots near an air gap in the stator core
 - The iron is laminated to reduce eddy currents (opposing field) and hysteresis (power losses)

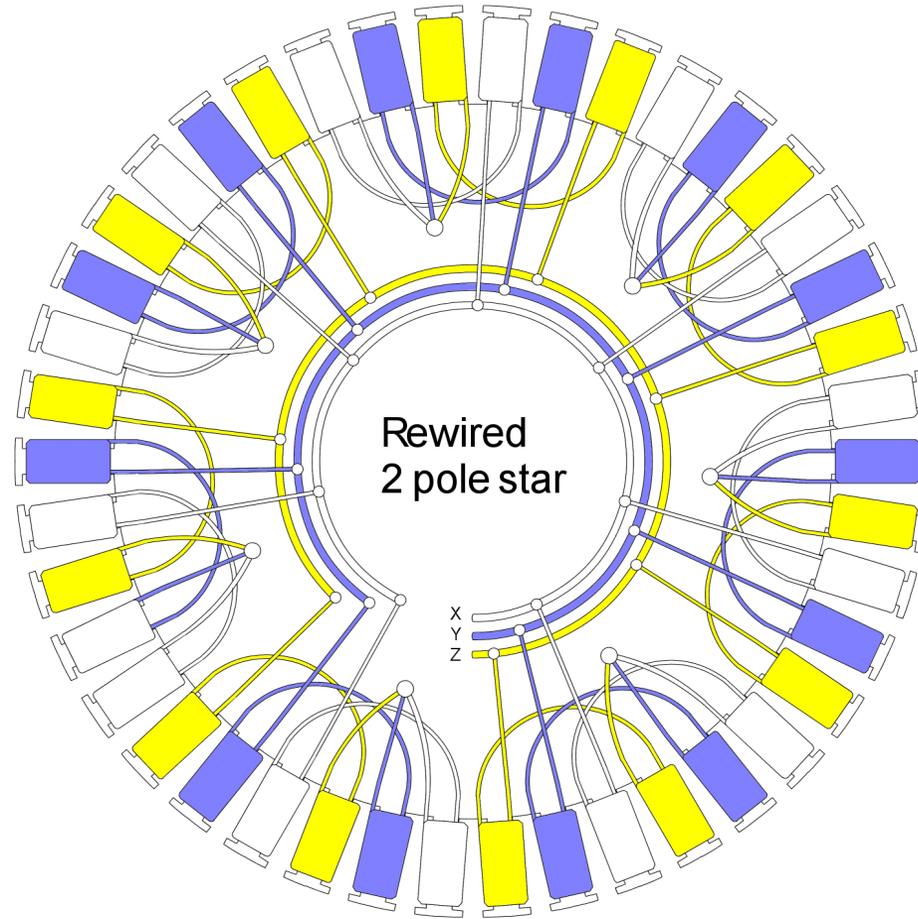
Stator

- Magnitude of voltage induced in the stator is a function of three factors:
 - Total lines of flux (field capability)
 - Frequency of the cutting the lines (operating speed)
 - Number of turns in the coils (stator capability)

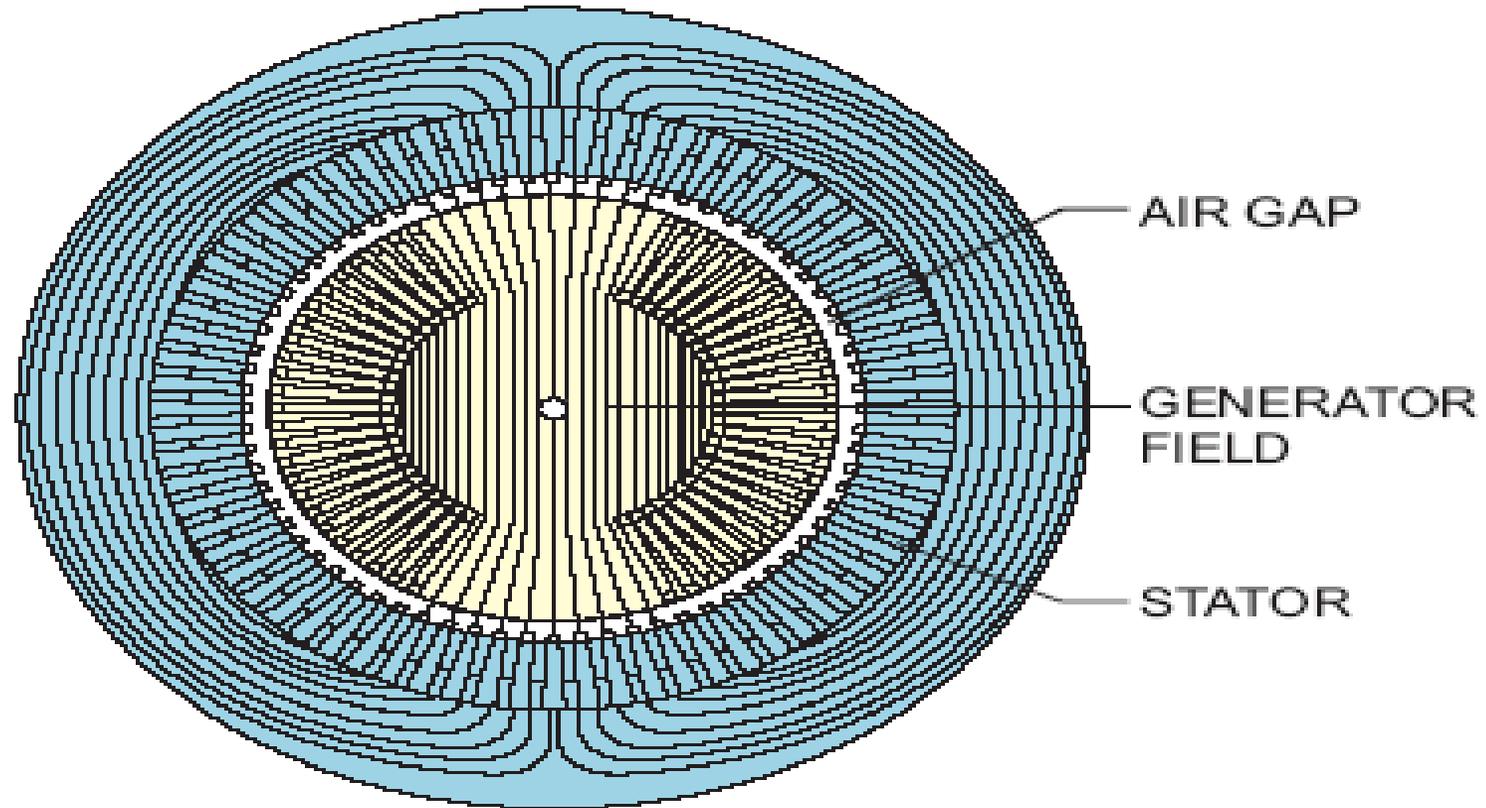
Stator



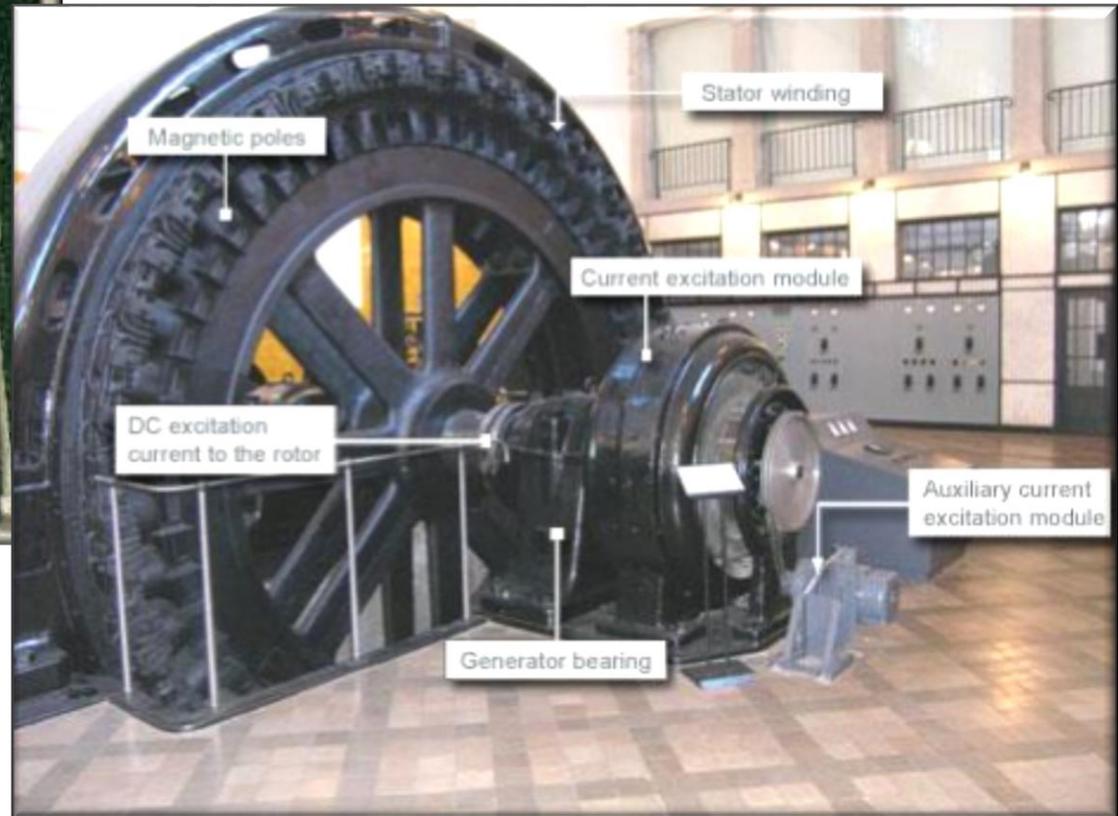
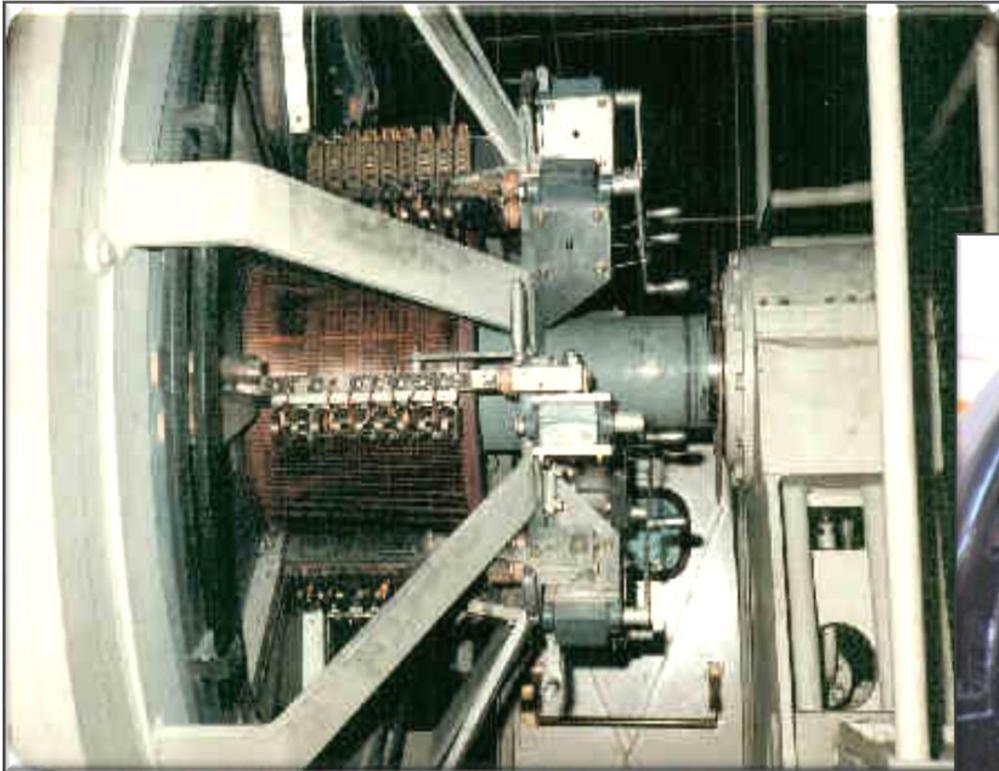
Stator



Stator



Exciter



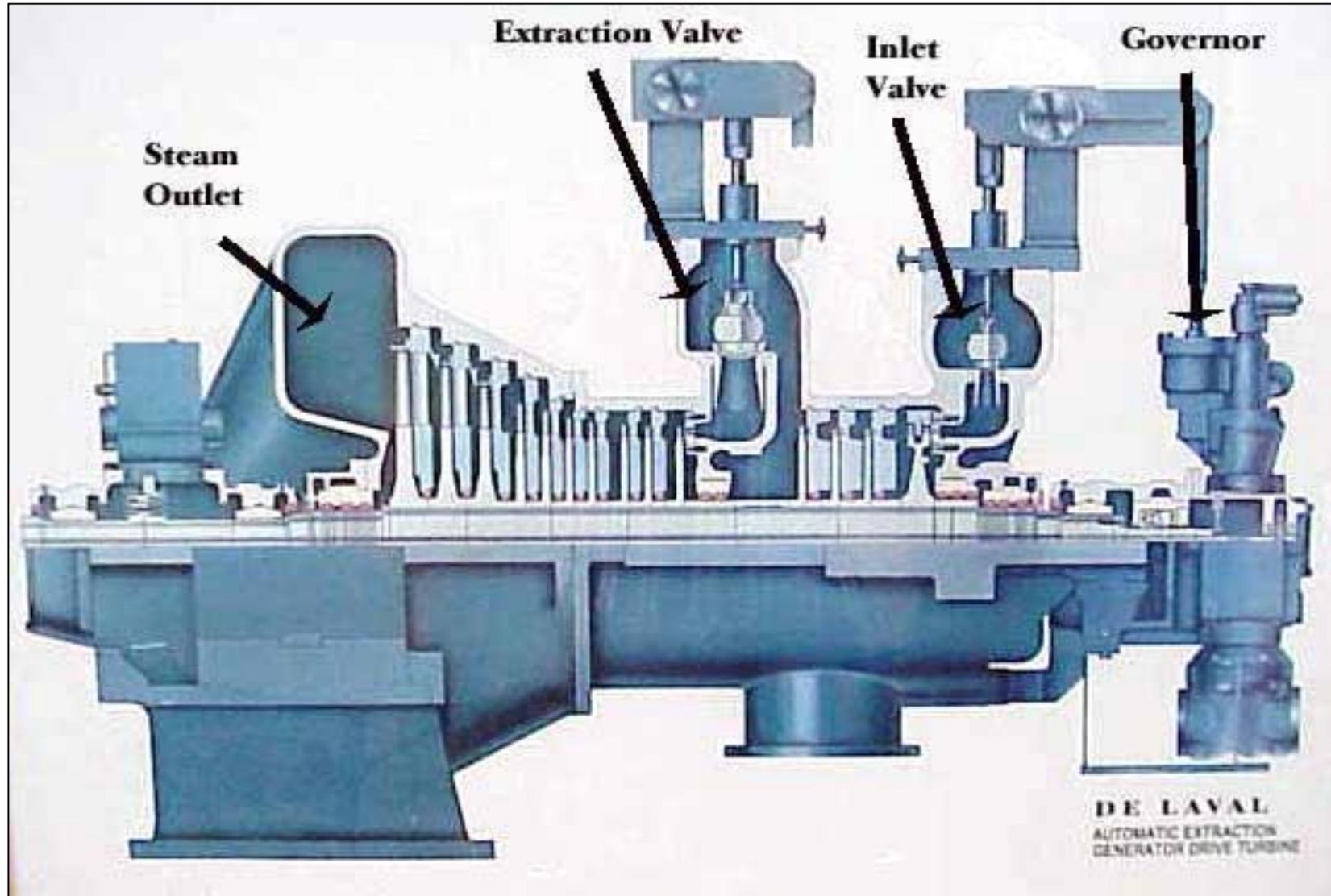
Exciter

- The function of the excitation system is to provide direct current for the generator rotor/field windings through slip rings to produce the magnetic field
- Maintains generator voltage, controls MVAR flow, and assists in maintaining power system stability
- During load changes or disturbances on the system, the exciter must respond, sometimes rapidly, to maintain the proper voltage at the generator terminals

Generator Governor Control

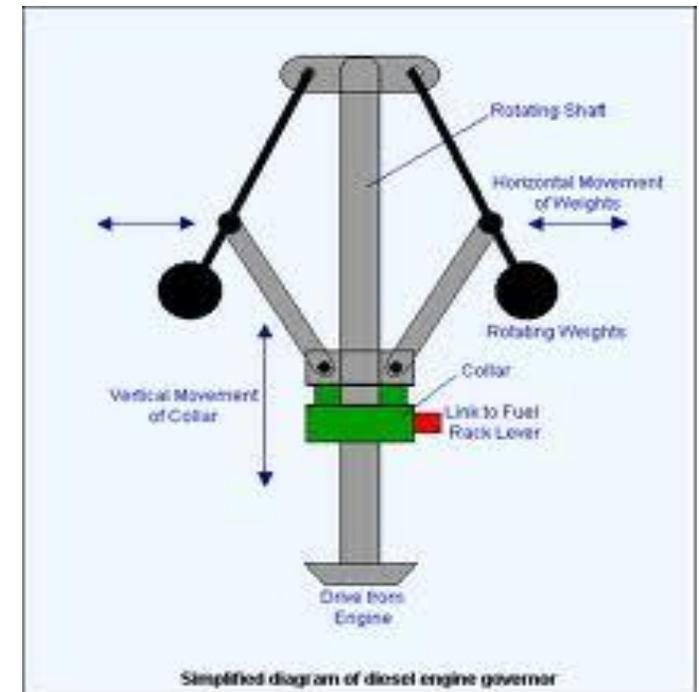
- Governors control generator shaft speed
- Adjust generation for small changes in load
- Operate by adjusting the input to the prime mover
 - Steam flow for fossil
 - Water flow for hydro
 - Fuel flow for combustion turbine
- Amount of governor control varies according to plant design
- Equivalent to a car's cruise control

Generator Governor Control



Generator Governor Control

- The Watt centrifugal governor was the mechanical means for governor control
 - Used weights that moved radially as rotational speed increased that pneumatically operated a servo-motor
 - Electrohydraulic governing has replaced the mechanical governor because of:
 - High response speed
 - Low deadband
 - Accuracy in speed and load control

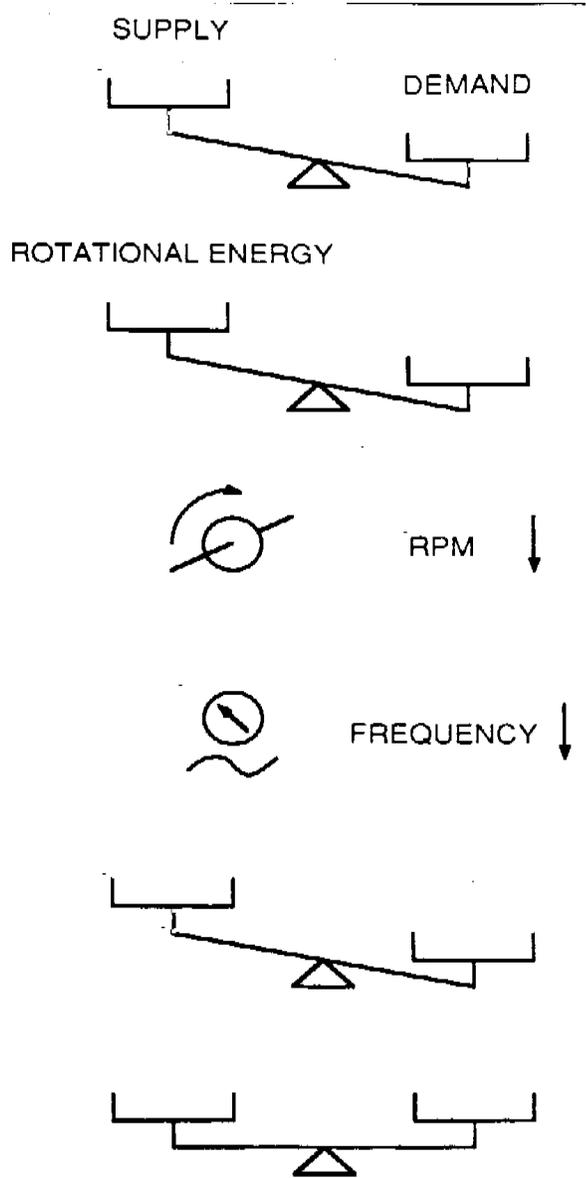


Governor Control

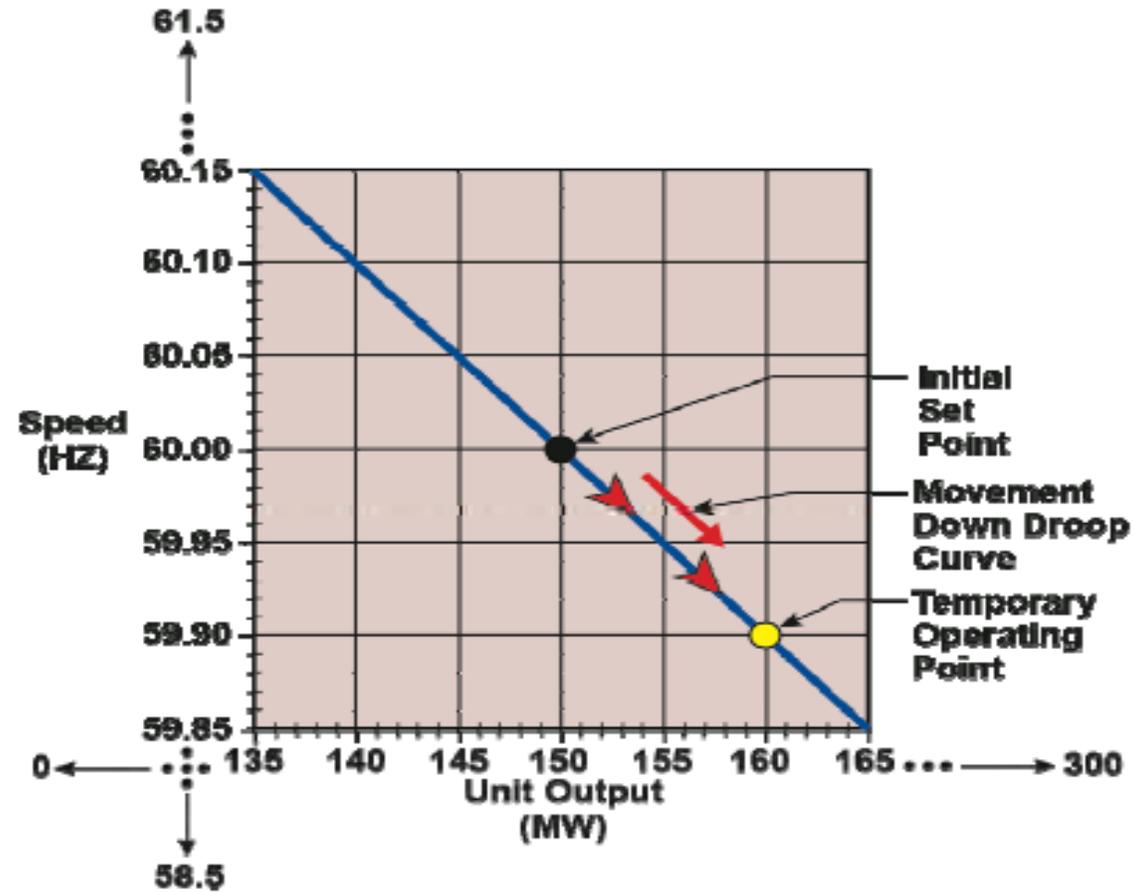
- When a generator synchronizes to the system
 - It couples itself to hundreds of other machines rotating at the same electrical speed
 - Each of these generators have a “droop” feature added to their governor
 - This allows generators to respond in proportion to their size whenever there is a disturbance, or load-resource mismatch

Governor Control

IF DEMAND FOR POWER EXCEEDS SUPPLY
↓
SYSTEM DRAWS ON ROTATIONAL ENERGY
↓
GENERATORS ROTATE MORE SLOWLY
↓
CAUSING A REDUCTION IN AC FREQUENCY
↓
GOVERNOR RESPONDS BY INCREASING GENERATION
↓
TILL BALANCE IS RESTORED

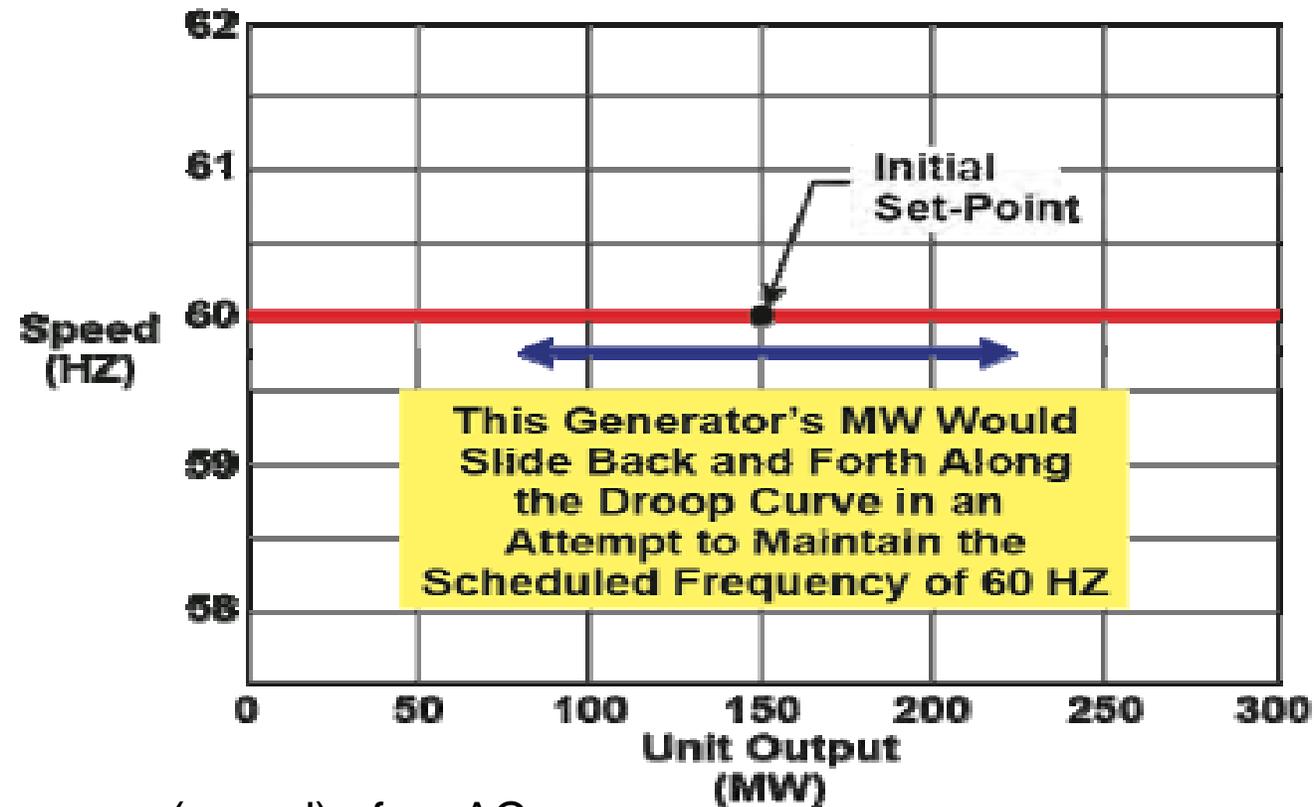


Governor Control – Droop Speed Mode



EPRI

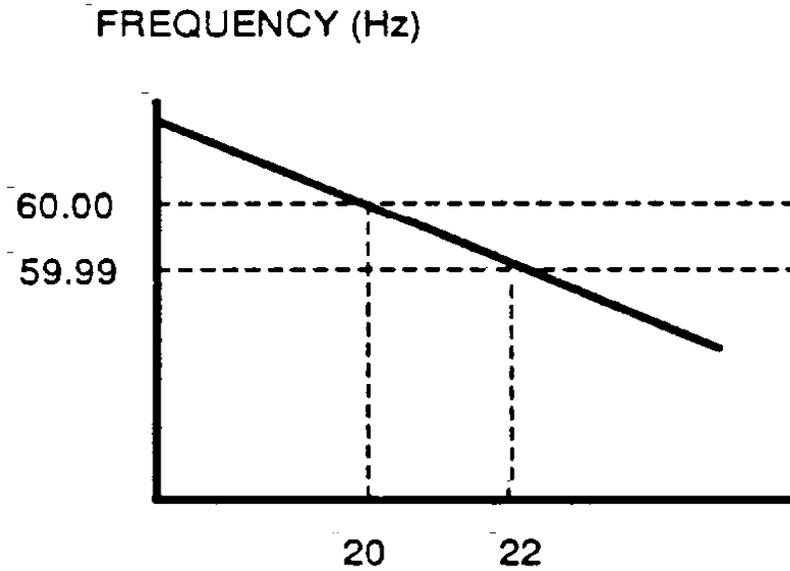
Governor Control – Isochronous Mode



Controls the frequency (speed) of an AC generator

EPRI

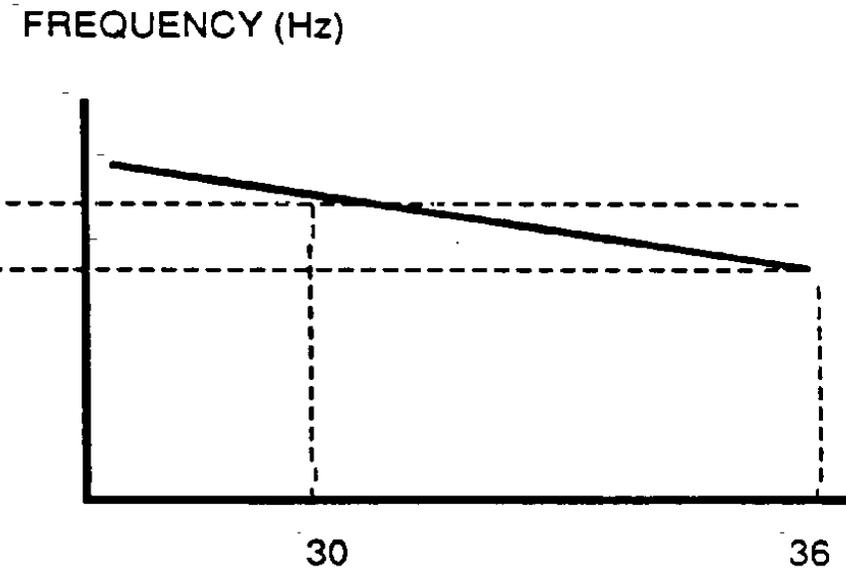
Generator Governor Control: Droop



UNIT A GENERATOR
LOAD (MW)

LOAD PICK-UP FOR A:

2MW FOR 0.01 Hz



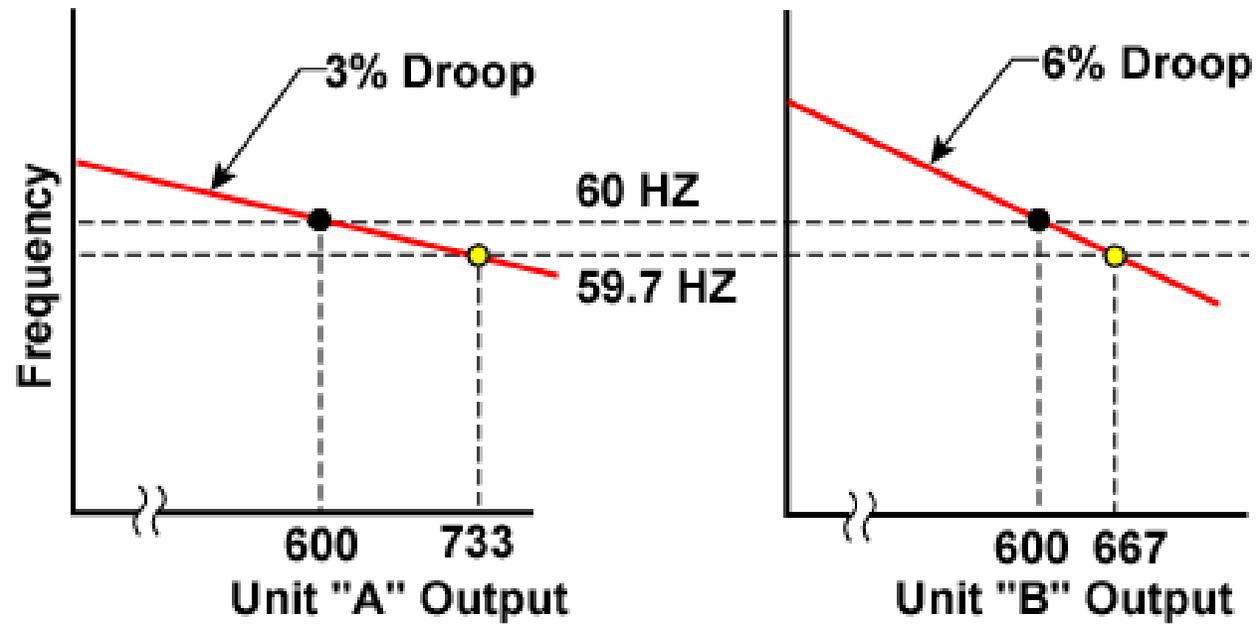
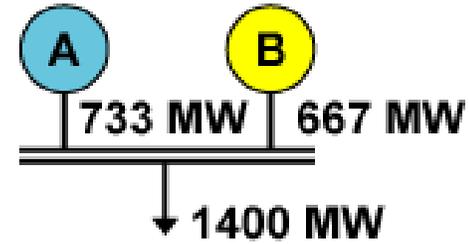
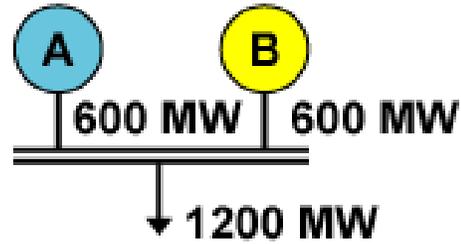
UNIT B GENERATOR
LOAD (MW)

LOAD PICK-UP FOR B:

6MW FOR 0.01 Hz

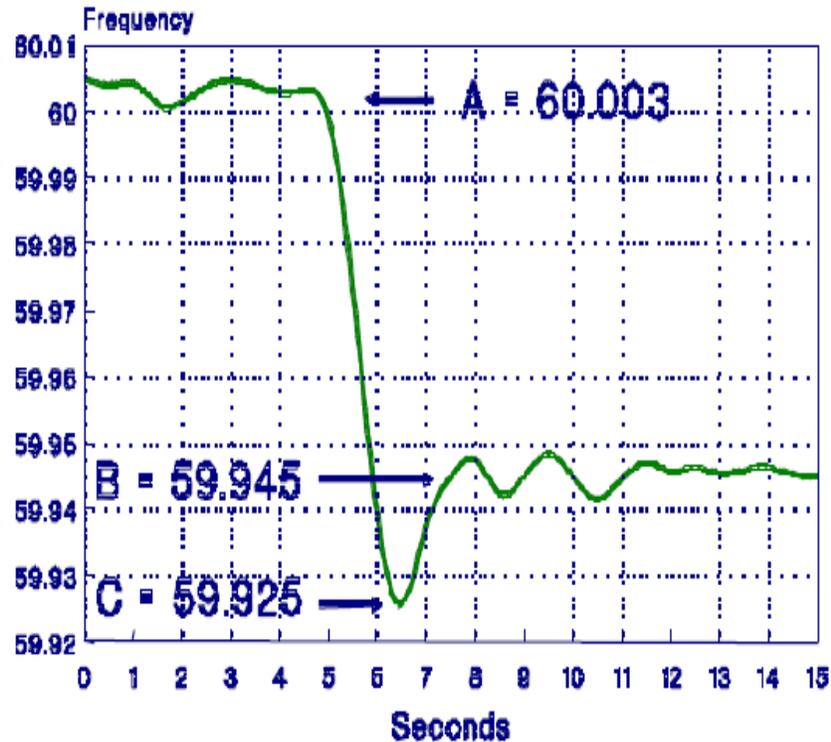
Governor Control

Rating = 750 MW Each



Generator Governor Control

Frequency Response



- Load
 - Rate of frequency decline from points A to C is slowed by “load rejection” and inertia
- Generators
 - Generator governor action halts the decline in frequency and causes the “knee” of the excursion, and brings the frequency back to point B from point C

It is important to note that frequency will not recover from point B to 60 Hz until the deficient control area replaces the amount of lost generation

Generator Governor Control: Droop

- Adding a droop characteristic to a governor forces generators to respond to frequency disturbances in proportion to their size
- Droop settings enable many generators to operate in parallel while all are on governor control and not compete with one another for load changes

Governor Control

- Deadband
 - An additional feature displayed by generators
 - The amount of frequency change a governor must “see” before it starts to respond
 - Natural feature of the earliest governors caused by gear lash (looseness or slop in the gear mechanism)
 - Serves a useful purpose by preventing governors from continuously “hunting” as frequency varies ever so slightly

Generator Rotational Speed

- A generator which is connected to the grid has a constant speed which is dictated by grid frequency
- Doubling the magnets or windings in the stator ensures that the magnetic field rotates at half speed
- When doubling the poles in the stator, the magnets in the rotor must also be doubled

Generator Rotational Speed

- Frequency is dependent on:
 - Number of field poles
 - Speed of the generator

- $f = (N)(P)/120$, where

f = frequency (Hz)

N = rotor speed (rpm)

P = total number of poles

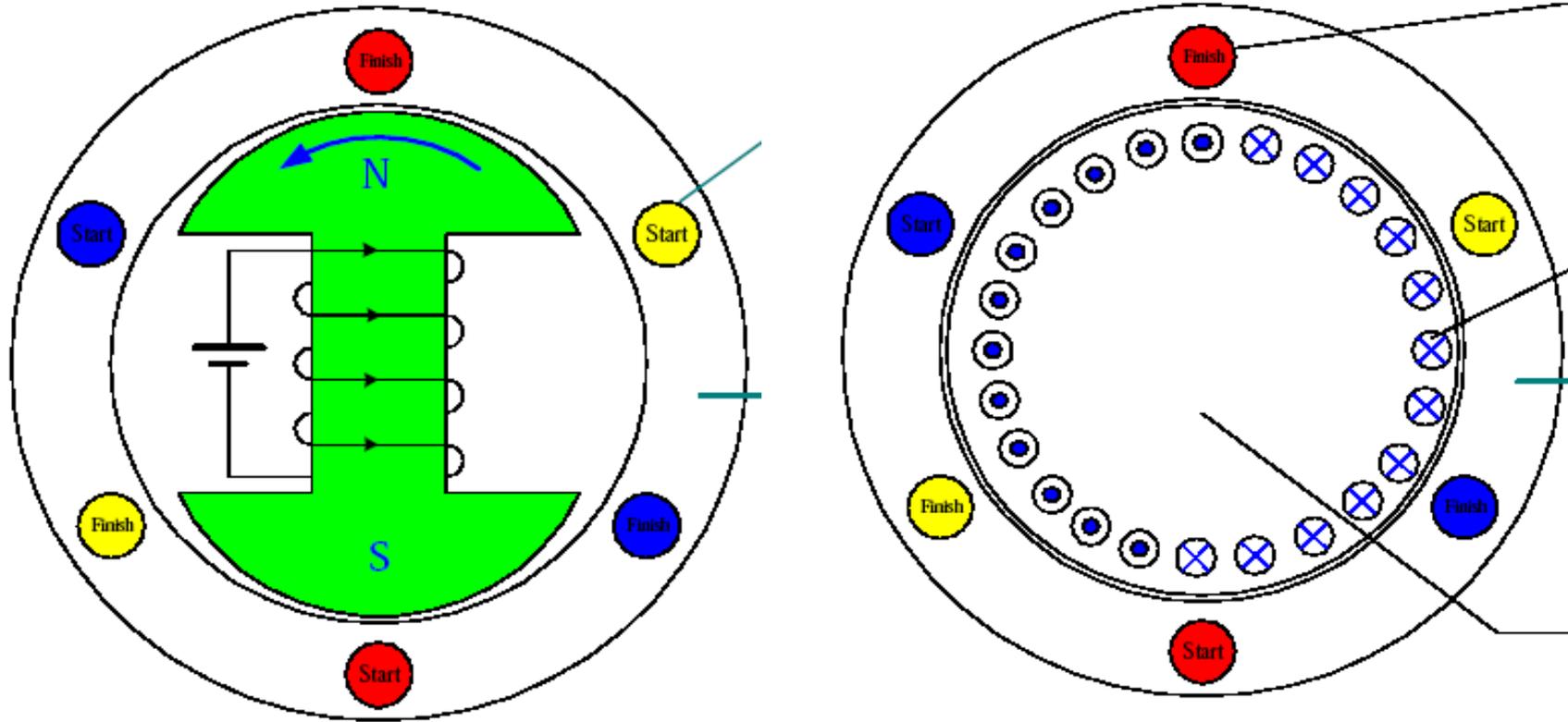
120 = Conversion from minutes to seconds and from “poles” to “pole pairs”

(60 seconds/1 minute) x (2 poles/pole pair)

Generator Rotational Speed

Example: 2 Poles

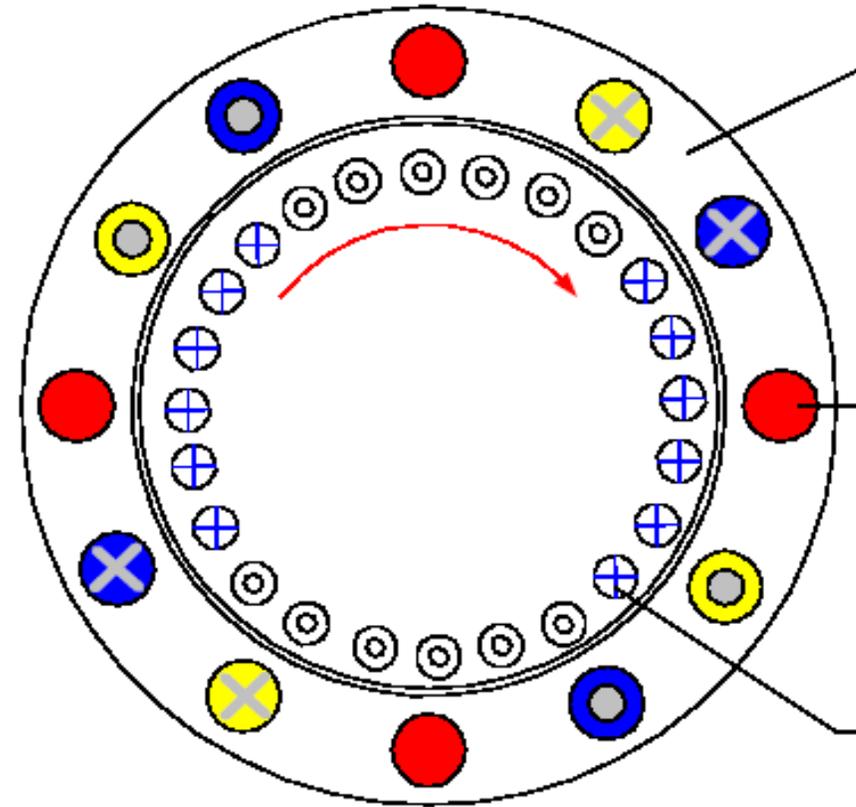
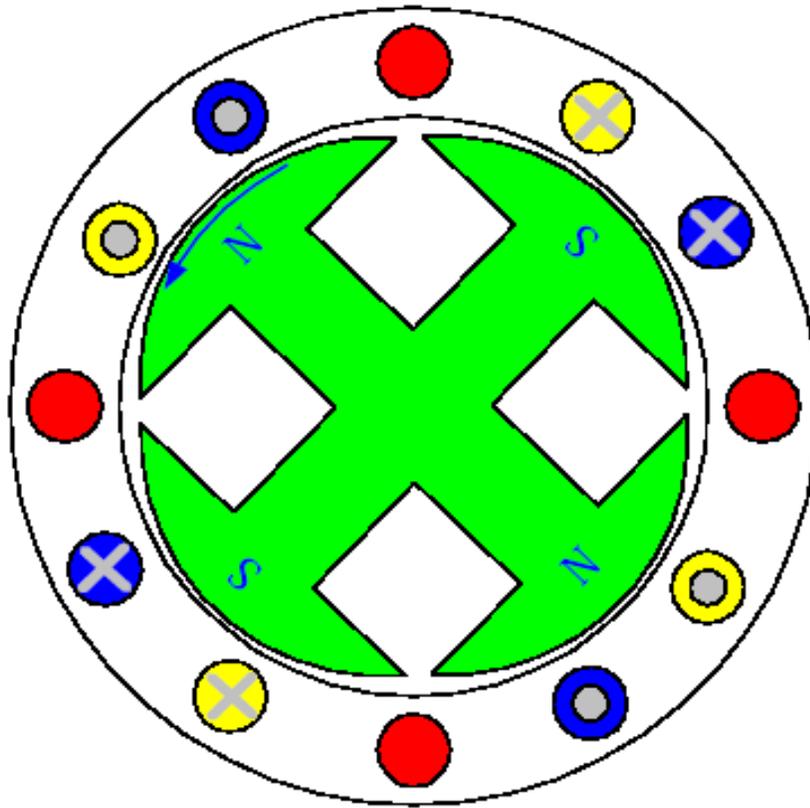
$$60 \text{ Hz} = (3600 \text{ RPM})(2 \text{ Poles})/120$$



Generator Rotational Speed

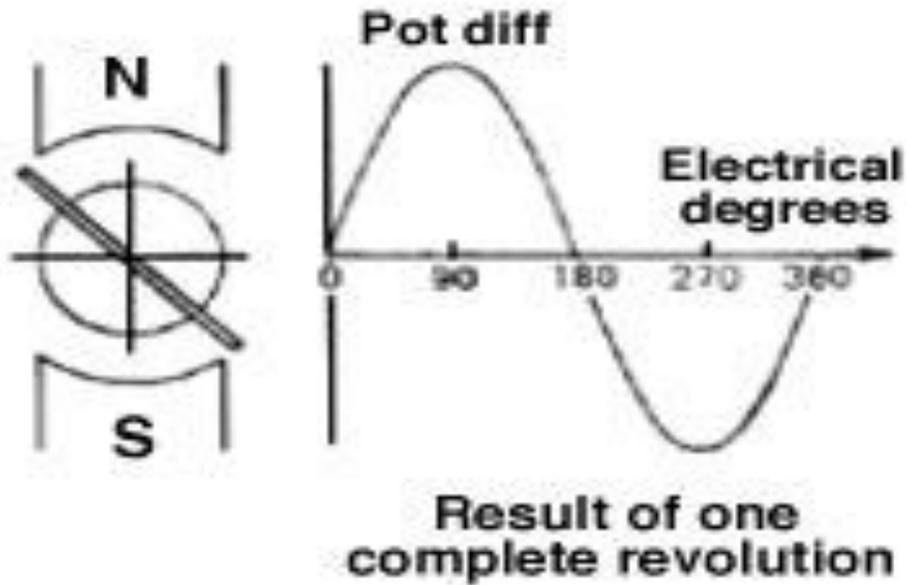
Example: 4 Poles

$$60 \text{ Hz} = (1800 \text{ RPM})(4 \text{ Poles})/120$$

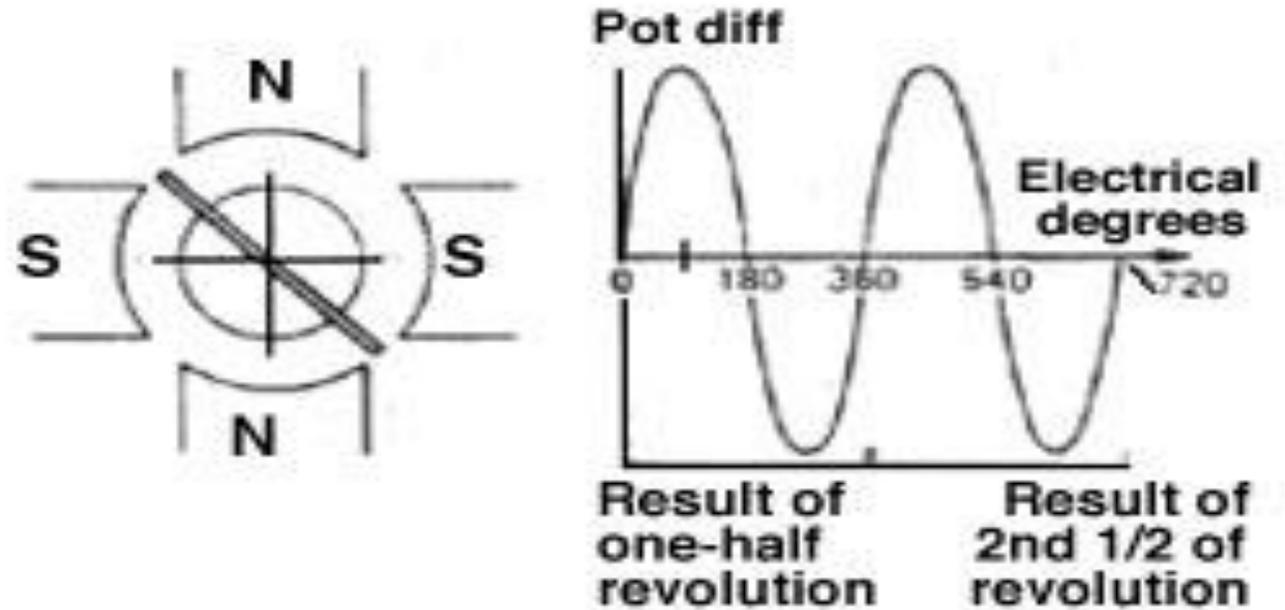


Generator Rotational Speed

Two-pole generator



Four-pole generator



Generator Characteristics

- Generator limitation factors
 - Power capability of the prime mover
 - Heating of generator components (I^2R losses)
 - Necessity to maintain a strong enough magnetic field to transfer power from the rotor to the generator output

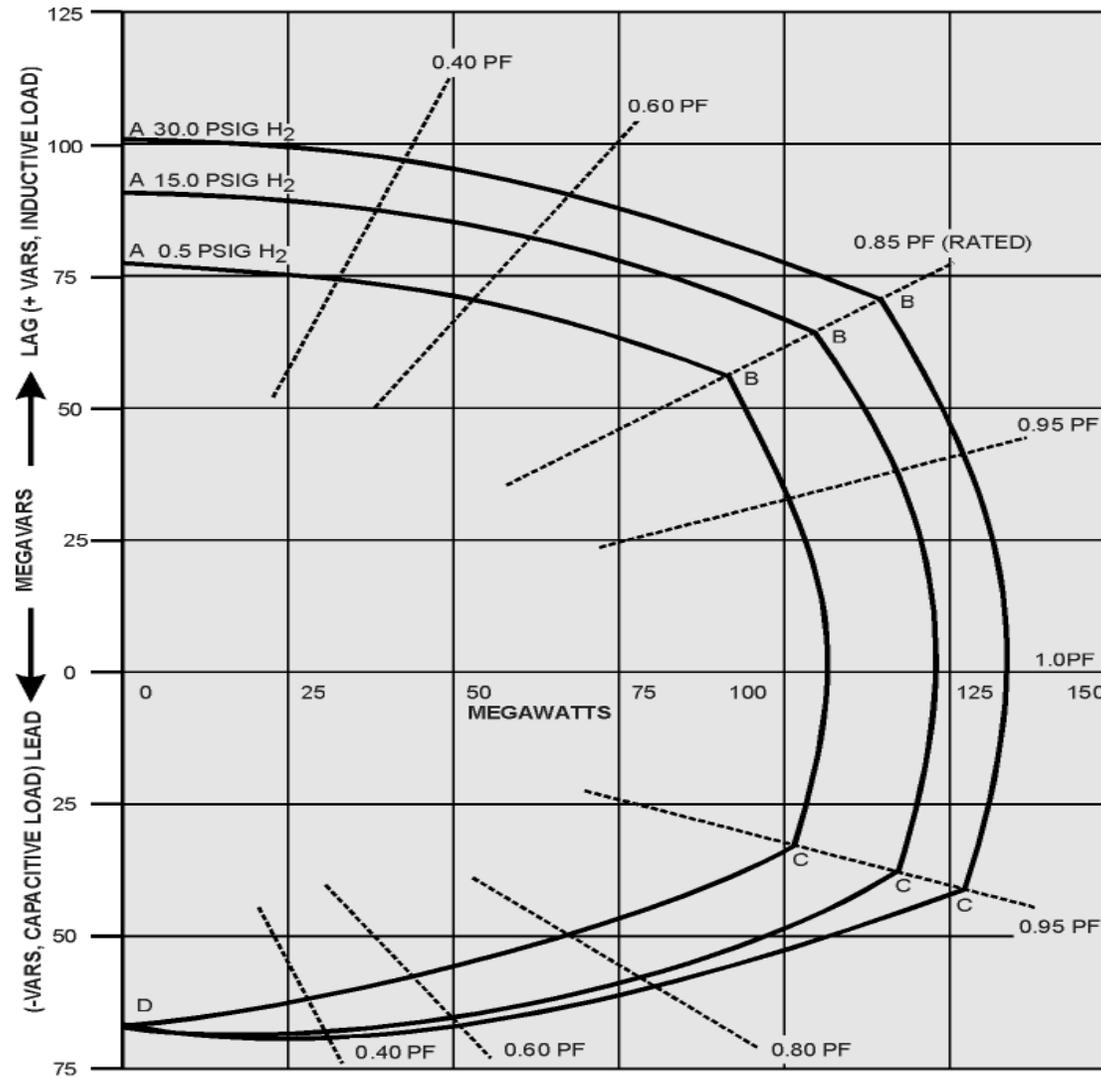
Generator Characteristics

- Heating of generator components
 - Heat generated within the armature windings is directly related to the magnitude of the armature current
 - Heat generated in the rotor is directly related to the magnitude of the field current
 - Heat dissipated by the generator is limited by the cooling system design

Generator Characteristics

- Magnetic field strength
 - Controlled by excitation voltage
 - If excitation voltage is lowered:
 - Voltage induced in A.C. windings is lowered
 - More VARS absorbed by generator from system
 - Undervoltage can cause overcurrent conditions in the stator and lead to armature or stator heating
 - Capability curves provide Max/Min limits

Capability Curve



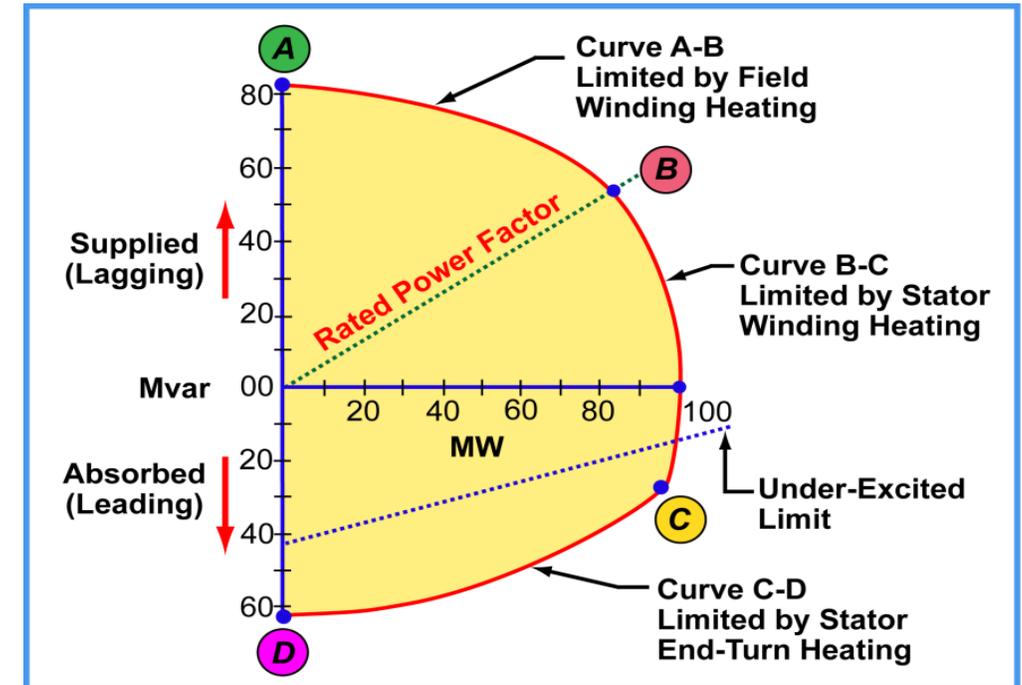
CURVE AB LIMITED BY FIELD HEATING
 CURVE BC LIMITED BY ARMATURE HEATING
 CURVE CD LIMITED BY ARMATURE CORE END HEATING

ND9051\1GEN22

Reactive Capability Curve

Reactive Capability (or "D") Curves

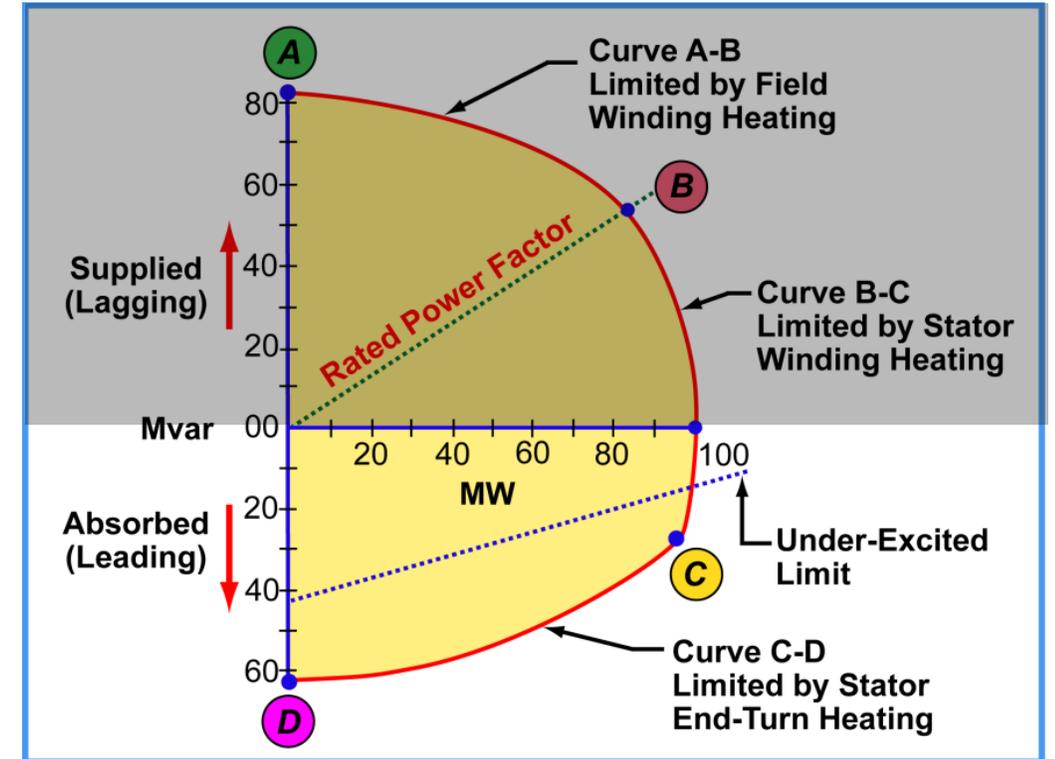
- Generators Report "Continuous Unit Reactive Capability Curve"
 - Realistic usable capability sustainable during continuous unit operation
 - Based on actual operating experience (or testing)
 - Takes into consideration any normal unit or plant restrictions at 95° F ambient or above



Reactive Capability Curve

Generating Unit

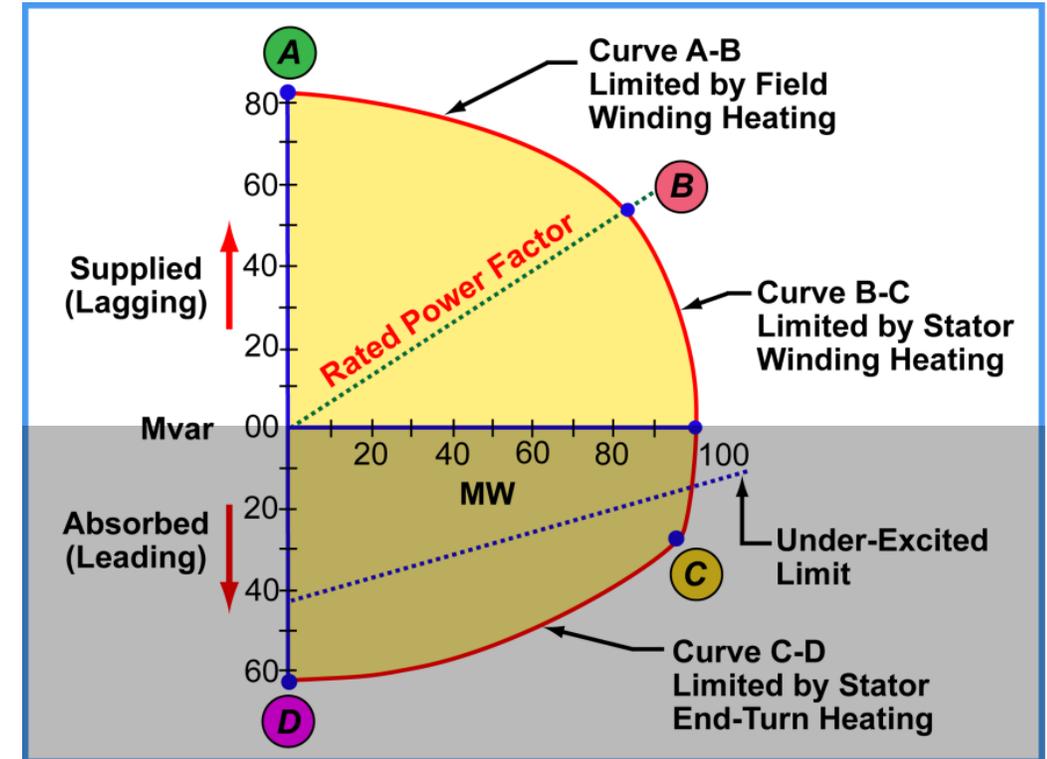
- Unit Over-Excitation
 - Limit on field heating, limits MVAR generation
 - Rotor overheating is I^2R heating caused by DC current over-excitation



Reactive Capability Curve

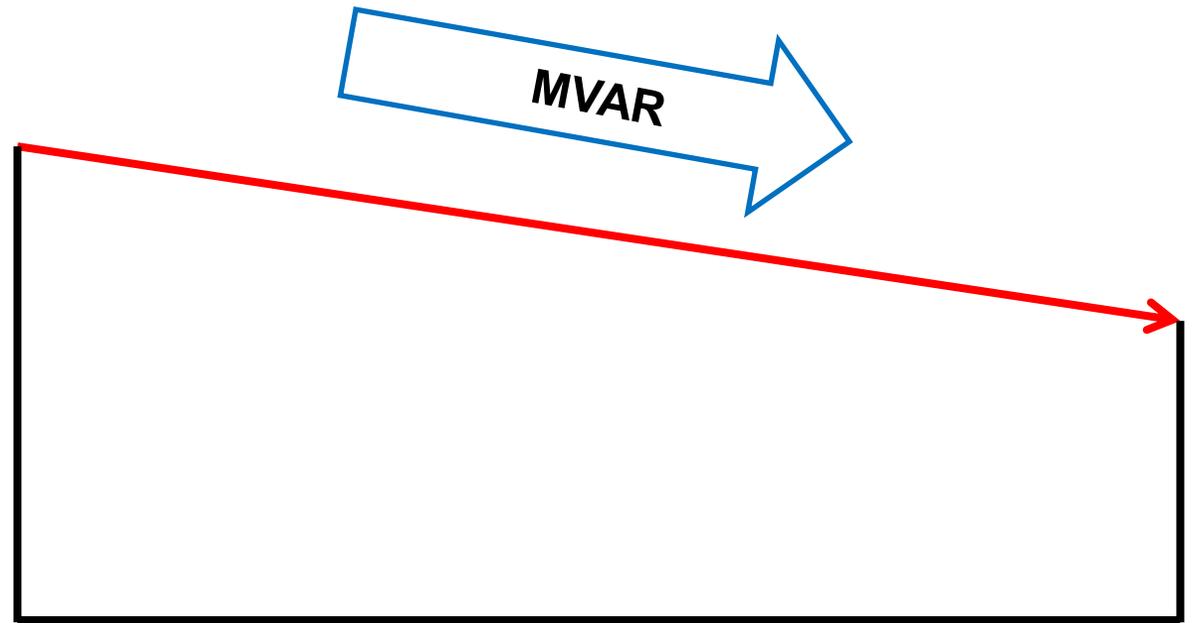
Generating Unit

- Unit Under-excitation
 - Limit on end turn heating
 - Unit instability
 - Field strength too weak, unit goes unstable
 - Area Stability concerns
 - Salem
 - PS South



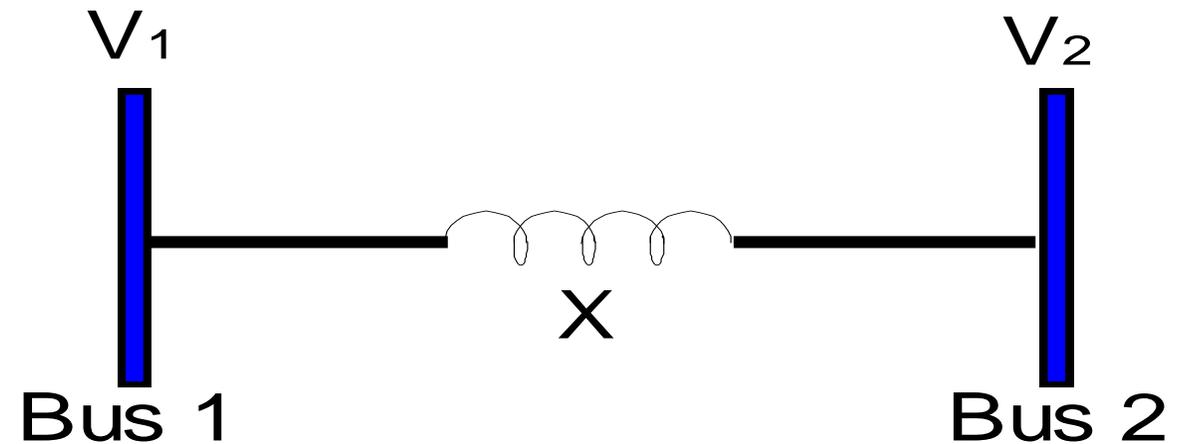
MVAR Flow & Voltage

- MVARs flow “downhill” based on voltage
- Flow from high per unit voltage to low per unit voltage



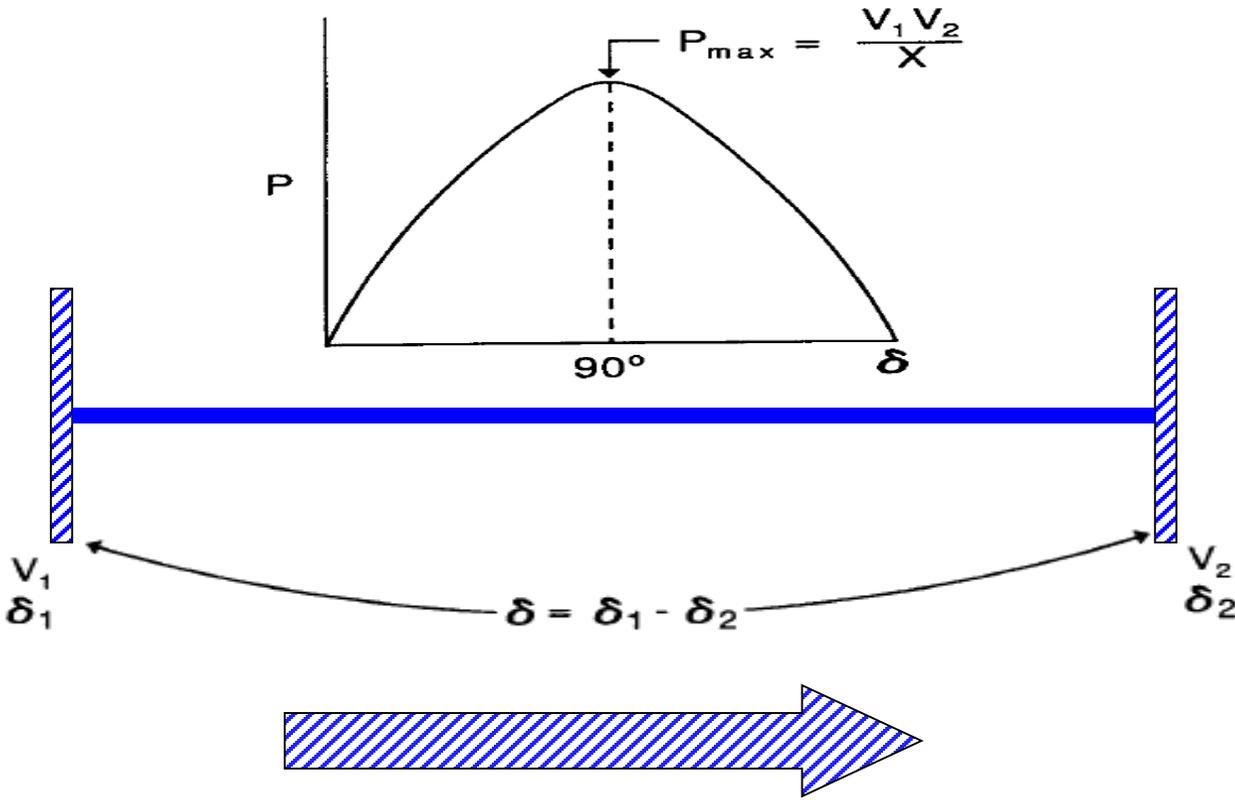
MVAR Flow & Voltage

- MVAR flow between buses is determined by magnitude difference between bus voltages
- Voltage magnitude difference is driving for MVAR flow
- The greater the voltage drop or rise between 2 locations – the greater the MVAR flow



$$\text{VARs} = \frac{V_1 (V_1 - V_2)}{X}$$

MW Flow & Power Angle



$$P = \frac{V_1 V_2}{X} \sin(\delta)$$

MW Flow & Power Angle

- MW flow between buses is determined by phase angle difference between voltages at the buses
- Phase angle difference between voltages is called Power Angle which is represented by the symbol Delta δ

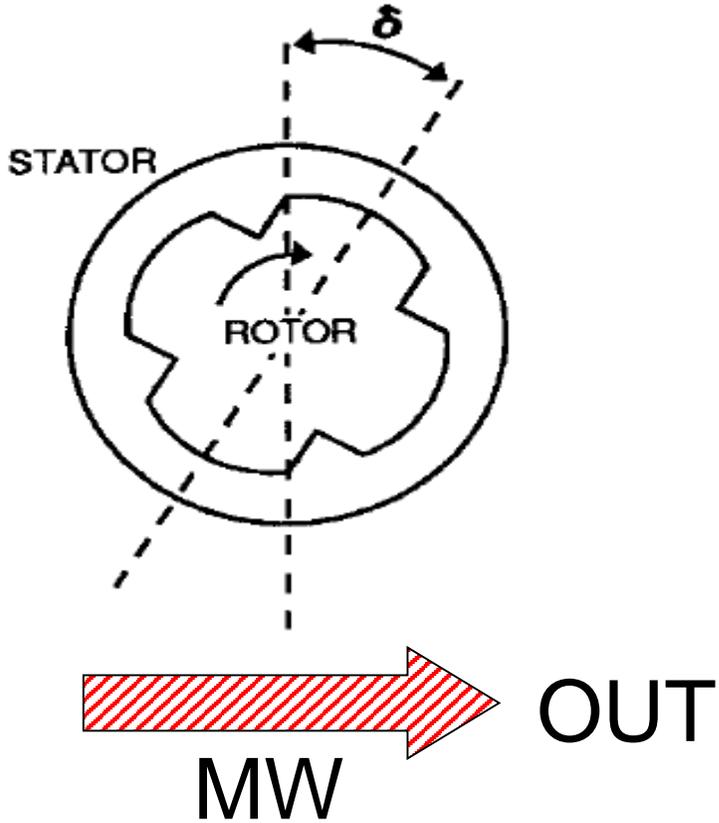
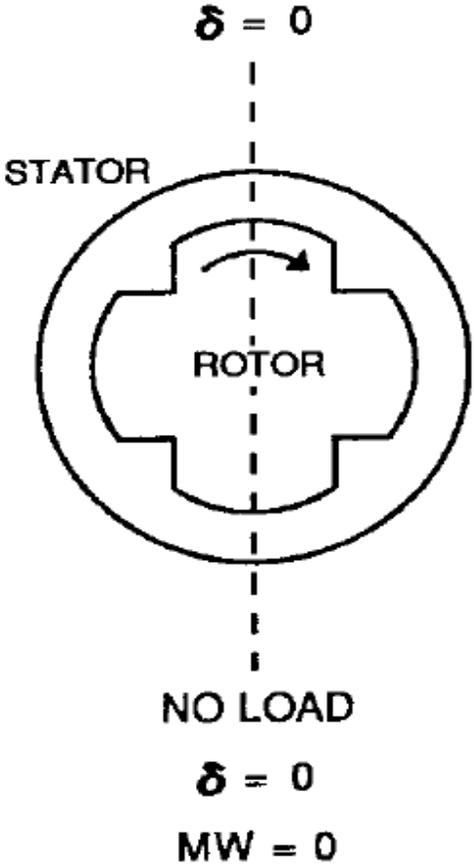
$$P = \frac{V_1 V_2}{X} \sin(\delta)$$

Generator MW Flow & Power Angle

- Rotor Angle
 - On a transmission system is similar to rotor angle
 - Load or Torque angle
 - No Load
 - Field pole of rotor is “in phase” with stator armature windings
 - $\delta = 0$
 - Load Added
 - Rotor advances with respect to the stator
 - MW's flow out of the machine

Bismark Torque Angle Sim

MW Flow & Power Angle



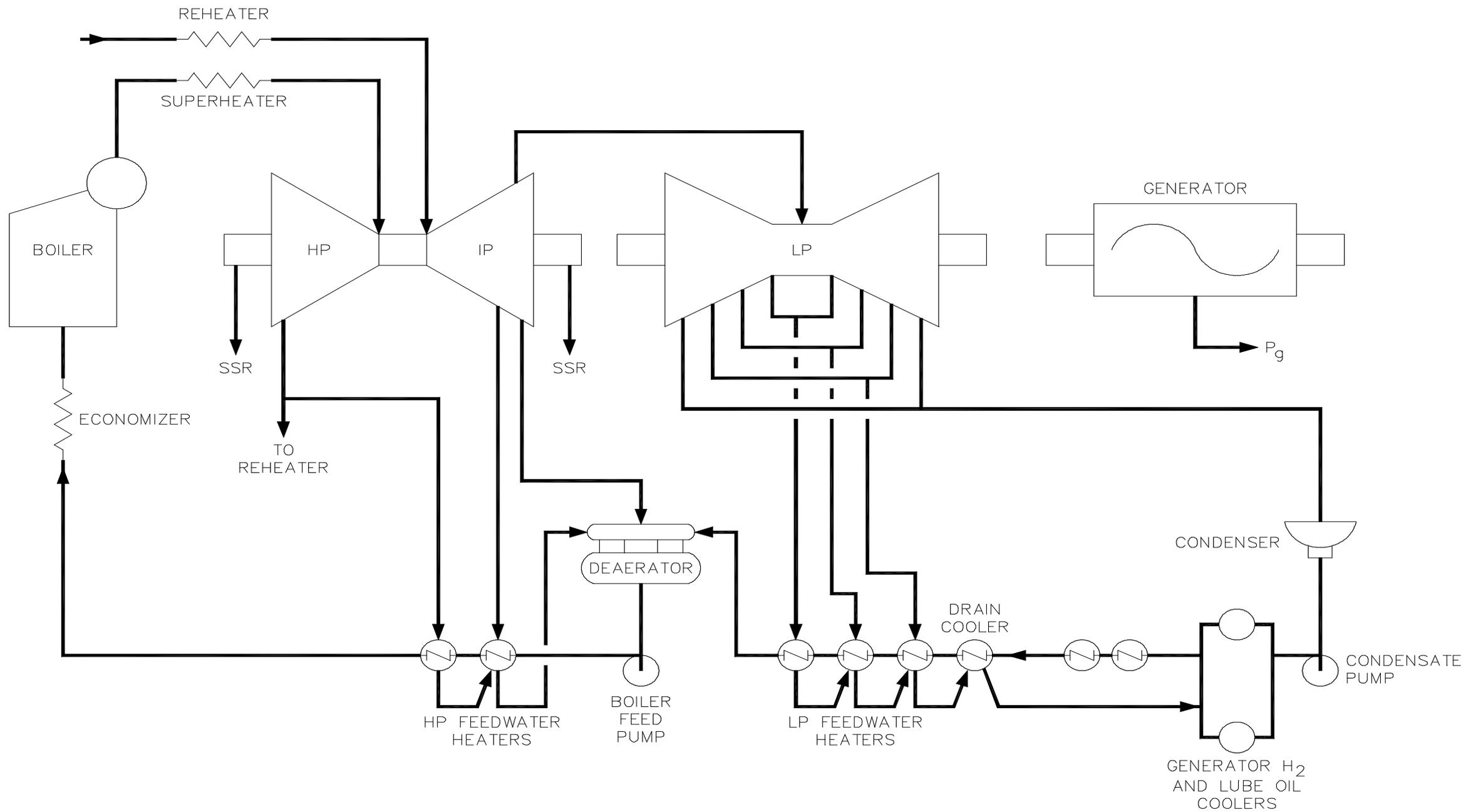
Basic Steam Cycle

Simple Steam Cycle

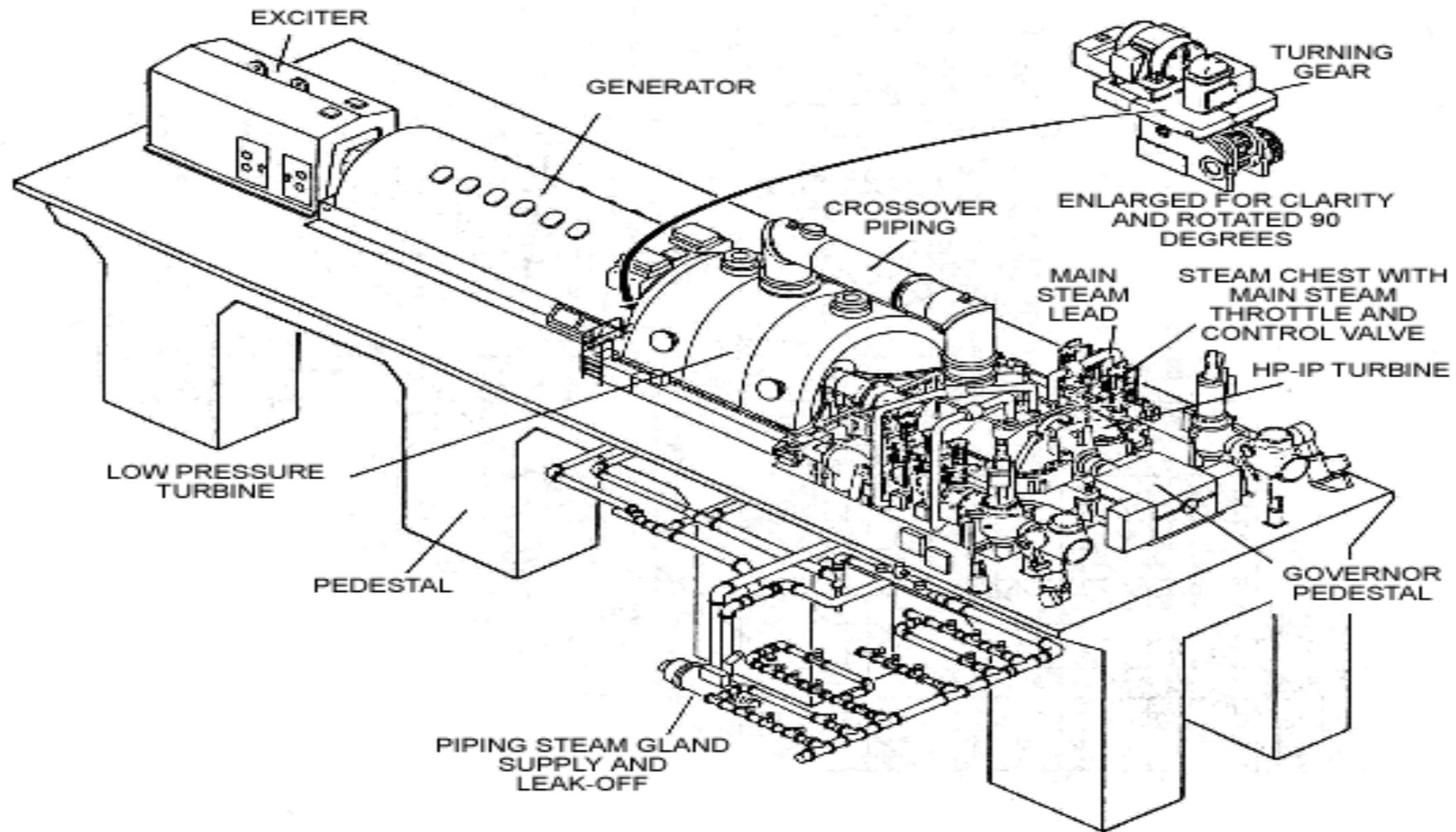
- Four Phases - Steam/Water Cycle
 - **Generation** (Boiler/Reactor/Steam Generator)
 - Heat is produced to change water to steam
 - Changes chemical or Nuclear energy of fuel to thermal energy of steam
 - **Expansion** (Turbine)
 - Nozzles direct steam flow onto blades
 - As the steam expands, the pressure changes cause rotation of the turbine
 - Changes thermal energy to mechanical energy

Simple Steam Cycle

- Four Phases - Steam/Water Cycle (*con't.*)
 - **Condensation** (Condensate System)
 - Remaining low energy steam is condensed to water removing latent heat
 - Recover and clean up the condensate
 - Largest efficiency loss in the cycle
 - **Feedwater** (Feedwater System)
 - Increases energy, both thermal (temperature) and potential (pressure) of water returning to the system
 - Increases overall plant efficiency

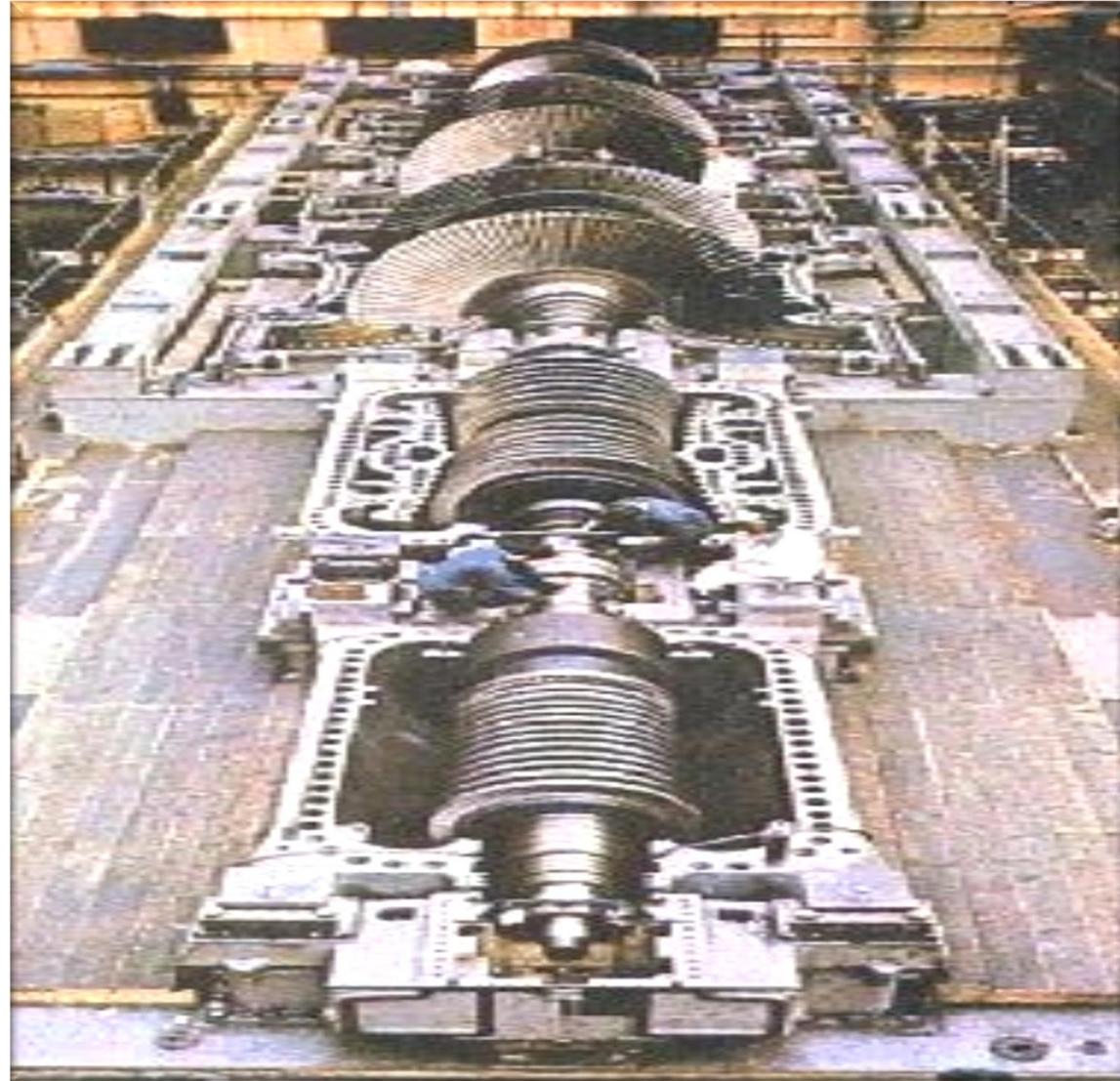


The Steam Turbine



A TYPICAL POWER STATION STEAM TURBINE AND ITS EXTERNAL EQUIPMENT

The Steam Turbine



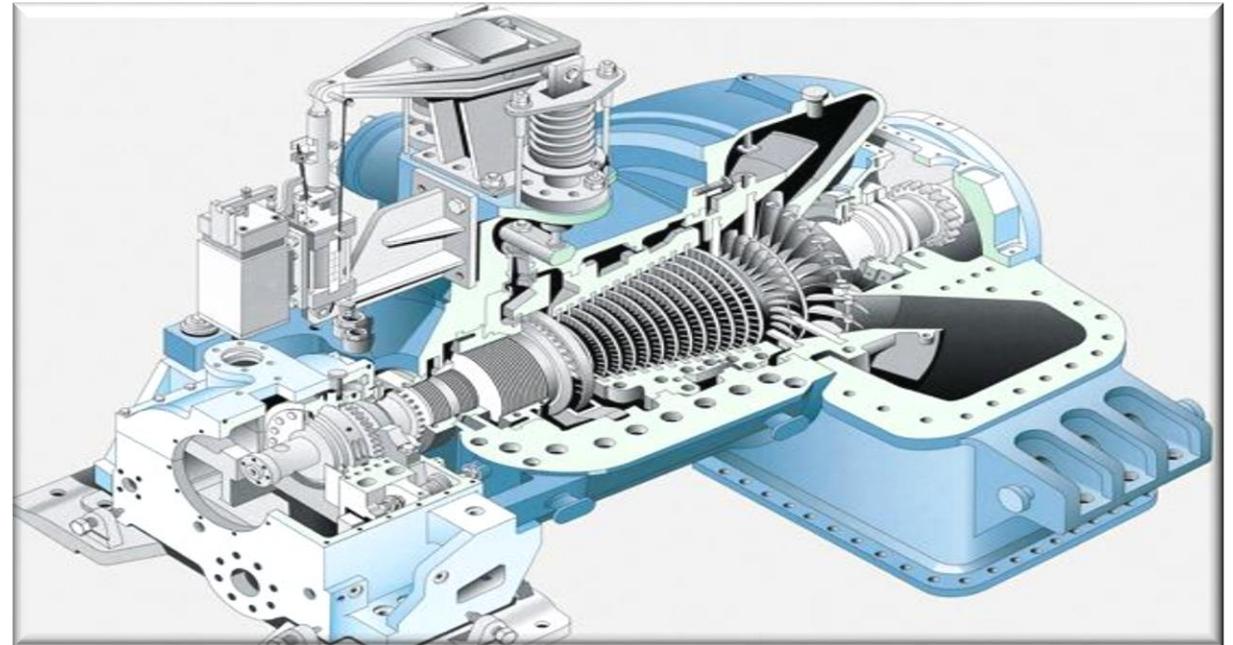
The Steam Turbine

- Steam Turbine: Form of heat engine with the function of converting thermal energy into a rotating mechanical energy
- Two steps are required to convert the thermal energy of the steam into useful work:
 - Thermal energy of the steam is converted into kinetic energy by expanding the steam in stationary nozzles or in moving blades
 - Kinetic energy is converted into work when the steam passes through the moving blades

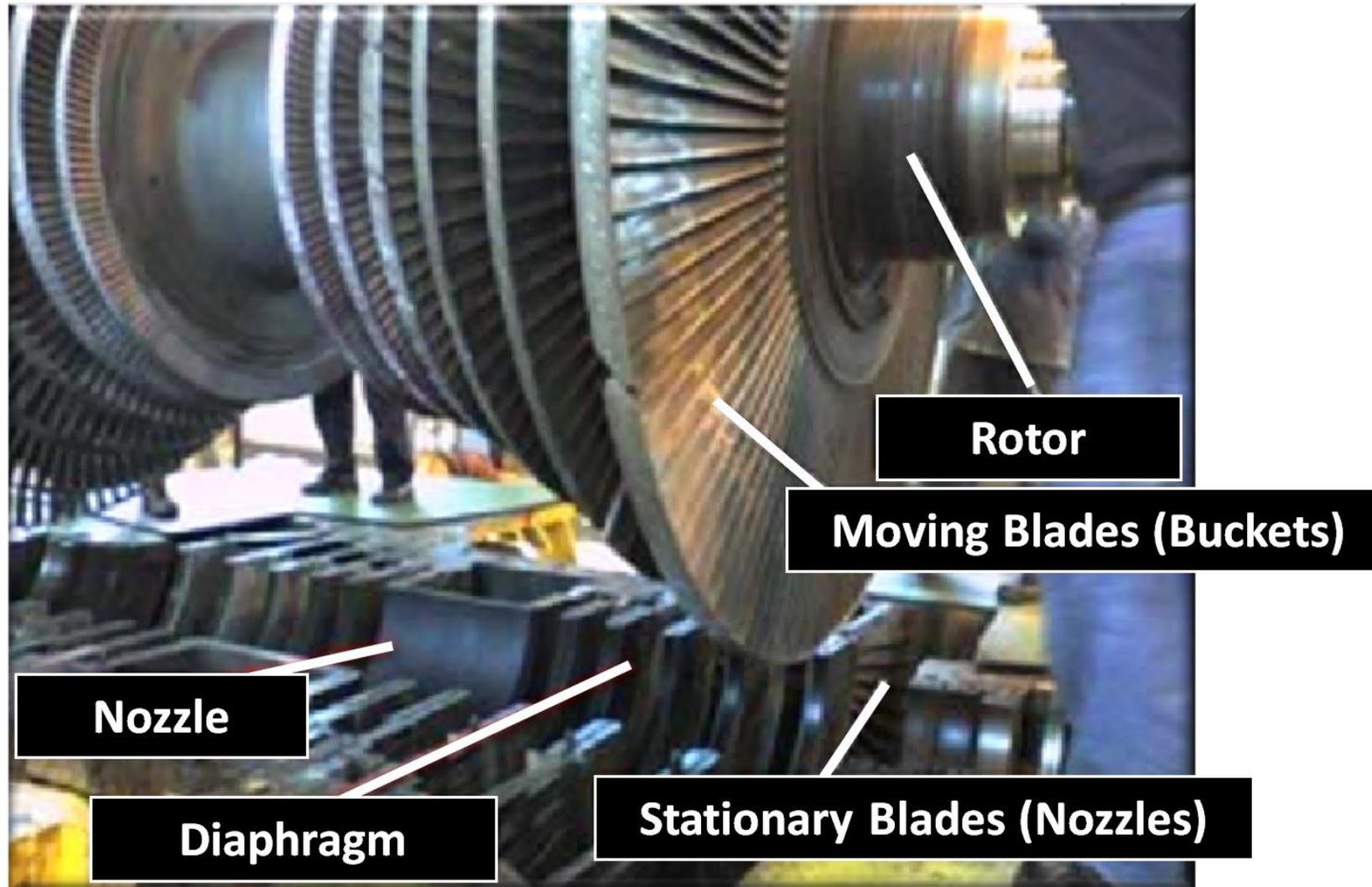
<http://www.youtube.com/watch?v=qvli3JDkADI>

The Steam Turbine

- Turbine is made up of four fundamental components;
 - Rotor: carries the blades or buckets
 - Nozzles: Stationary blades provide flow passages for the steam
 - Buckets: Moving blades
 - Stationary parts: Diaphragms
 - Foundation: support for the rotor & stationary parts



Steam Turbine - Blading



The Steam Turbine

- Turbine Stages
 - High Pressure Turbine (HP)
 - Supplied by Main Steam
 - Exhausts some type of Reheater
 - Intermediate Pressure Turbine (IP)
 - Supplied by Reheated Steam
 - Exhausts to Low Pressure Turbine
 - Low Pressure Turbine (LP)
 - Supplied by IP Turbine exhaust
 - Exhausts to Condenser
- At each stage the steam gives up more energy, and expands, so the turbine stages get progressively larger

The Steam Turbine

- Auxiliary Turbine Equipment
 - **Bearings** - 2 types:
 - Thrust - axially locate the turbine shaft in its correct position
 - Journal - support the weight of the shaft
 - **Shaft Seals** - series of ridges and grooves around the housing to reduce steam leakage
 - **Turning Gear** - slowly rotates the turbine, after shutdown to prevent bowing of the shaft and to even out temperature distribution
 - **Vibration Monitors** - measure the movement of the shafts in their bearings to prevent wear or unbalanced conditions before damage can occur

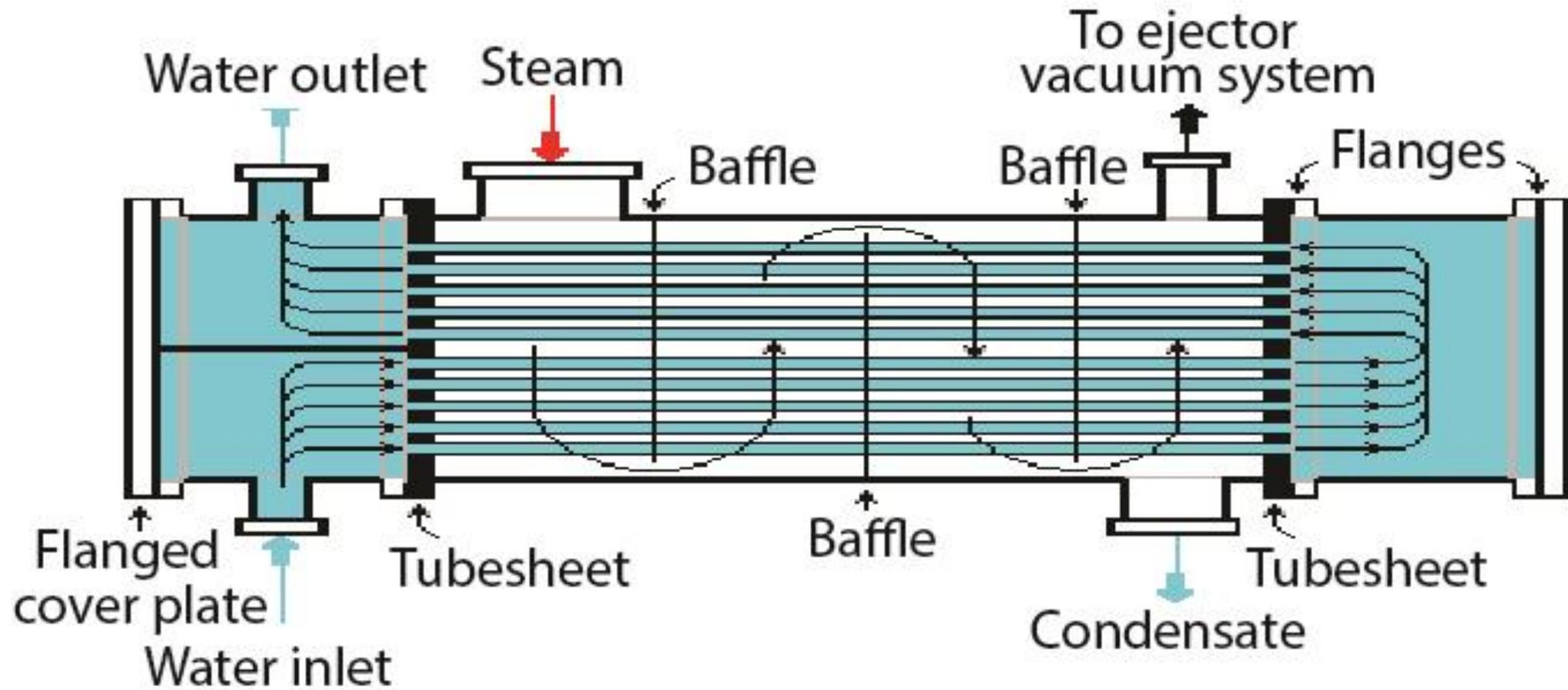
The Steam Turbine

- Turbine Operating Limitations:
 - The Turbine Shaft
 - Eccentricity: shaft out of concentric round
 - Differential expansion: rotor and turbine casing heat up and expand at different rates
 - Bearing vibration limits
 - Critical speed: harmonics due to natural resonance
 - The Turbine Blades
 - Back pressure limitation: fatigue cracks and harmonics on low pressure blades
 - Erosion due to moisture (high moisture content in the steam)
 - Solid particle erosion (carryover from the boiler/SG)
 - Silica plating (can unbalance the blades)

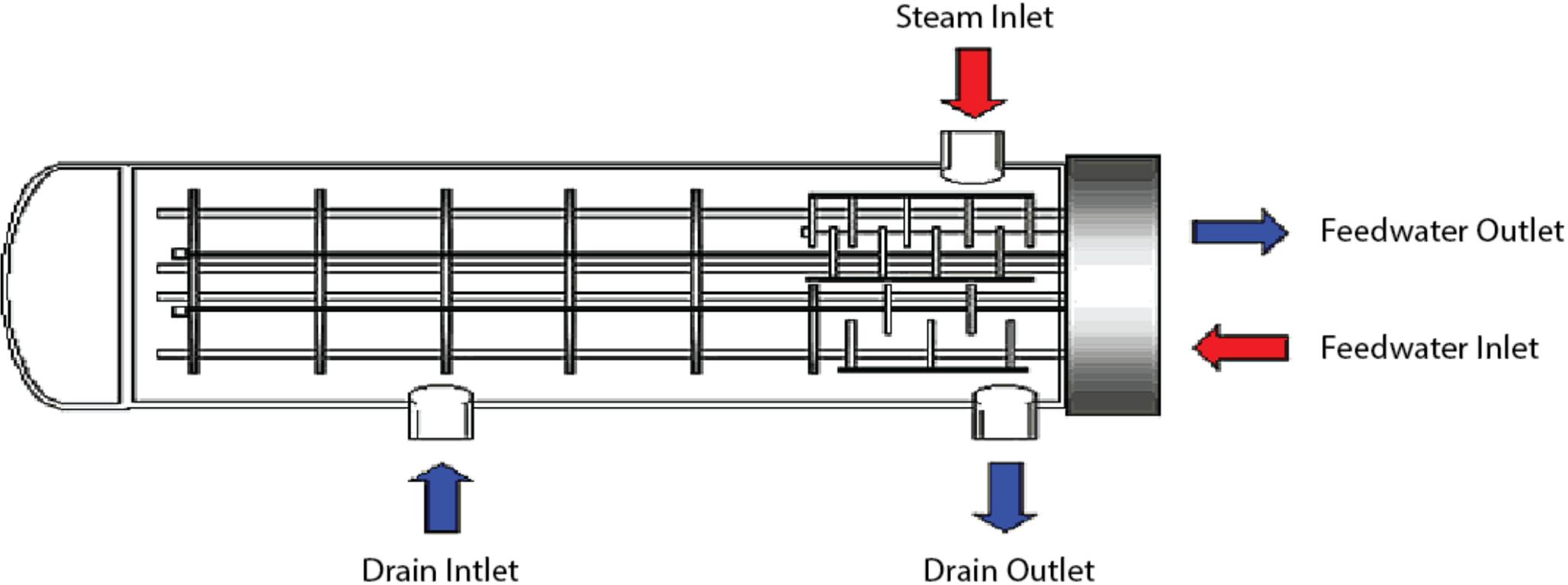
The Condensate System

- Major Components
 - **Condenser:** Converts the exhaust steam into water after it leaves the last stage of the turbine
 - **Hotwell:** Receptacle where water is collected from the condenser
 - **Hotwell Make-up / Draw-off valves:** Compensate for losses or excesses to or from the condensate storage tank
 - **Demineralizers:** Clean up the condensate
 - **Condensate Pumps:** Move condensate up to the feedwater system
 - **Low Pressure Feedwater Heaters:** Preheats the condensate entering the deaerator/boiler feed pump
 - The plant may have multiple “strings” or series of feedwater heaters

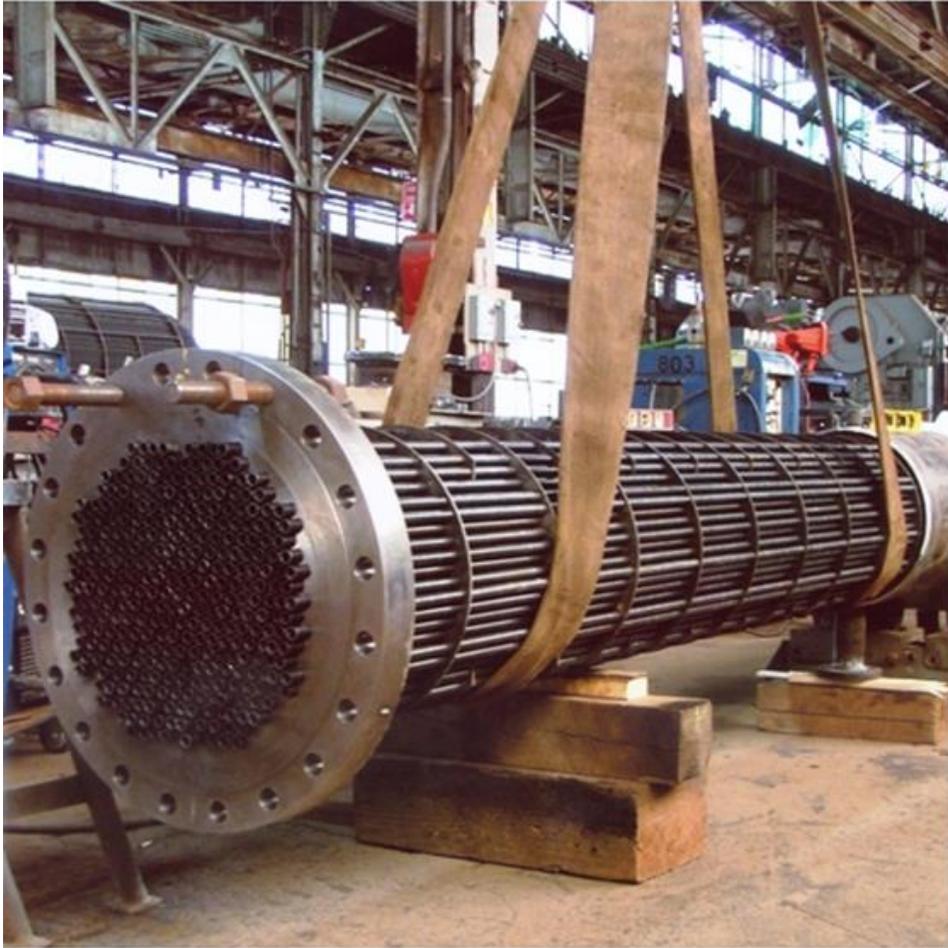
Condenser



Condensate System – Feedwater Heater



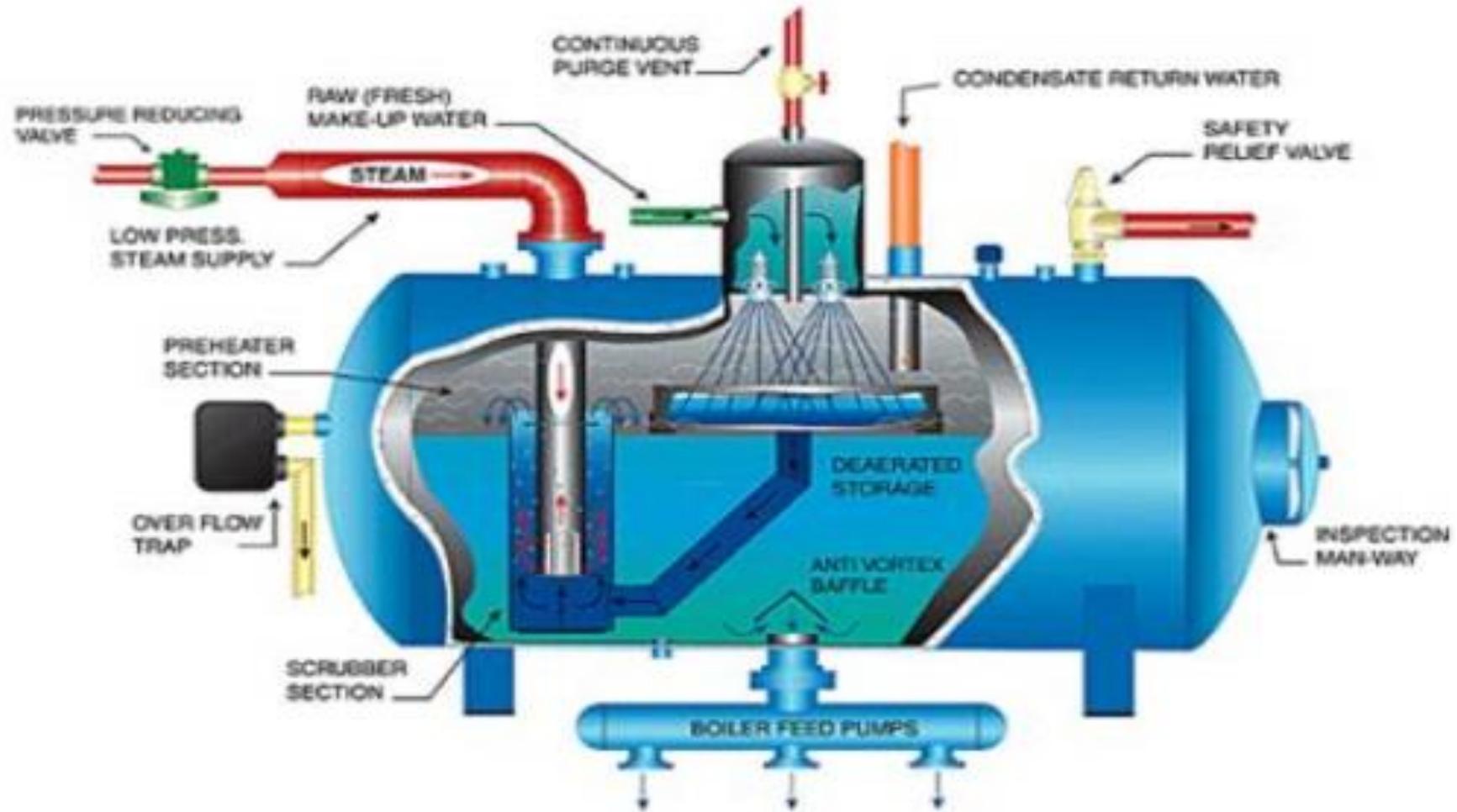
Condensate System – Feedwater Heater



The Feedwater System

- **Deareator:** Removes non-condensable gases (mainly oxygen) from the condensate
- **Boiler Feed Pump:** Supplies water to the boiler/SG and has to overcome boiler pressure, friction in the heaters, piping, and economizer
- **High Pressure Feedwater Heaters:** Preheats the feedwater before entering the boiler/ SG
 - The plant may have multiple “strings” or series of Feedwater heaters

Condensate System - Deaerator



Condensate System - Deaerator

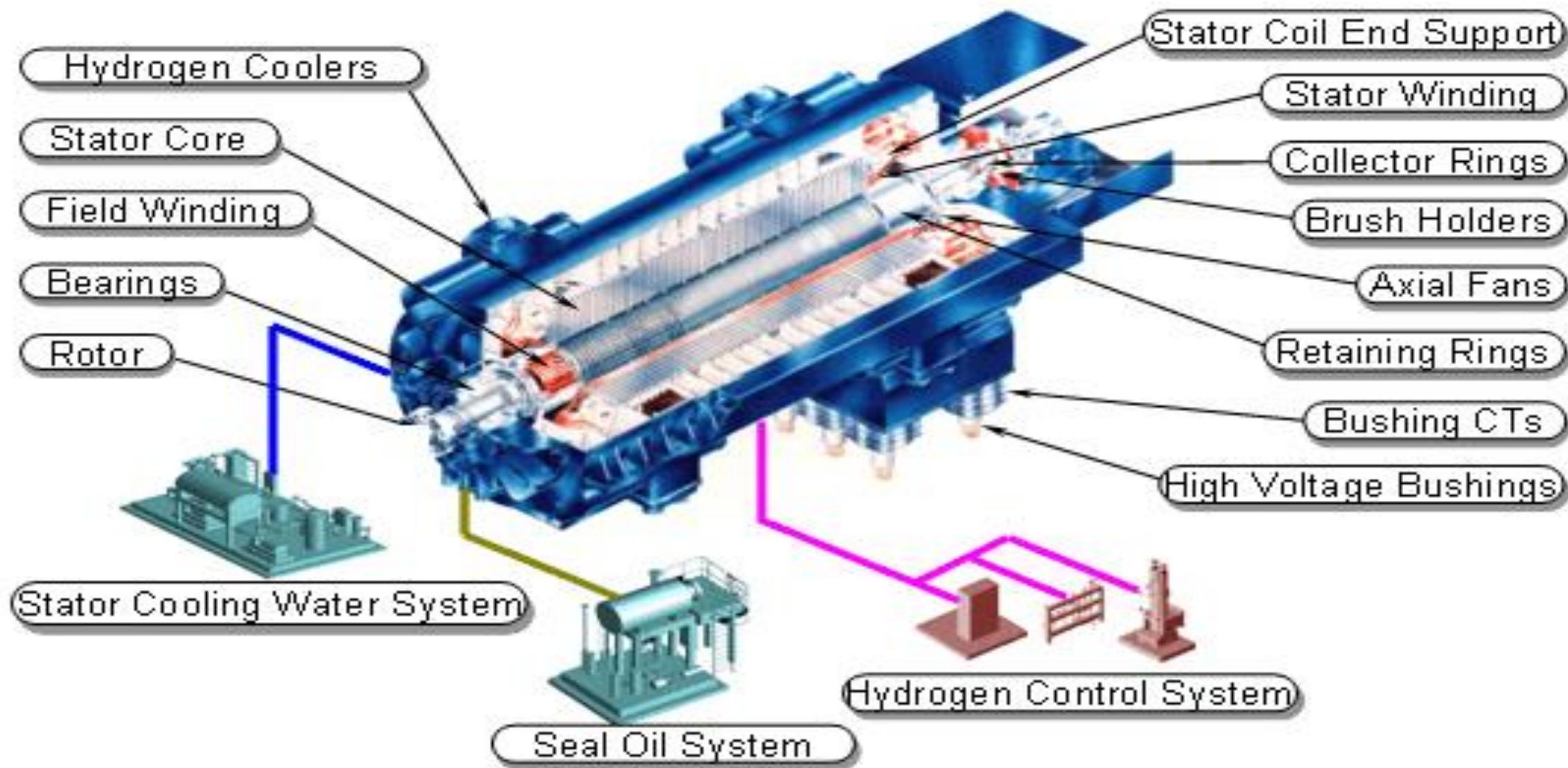


Start-Up Systems

- In order to prevent thermal stress damage, the turbine blades, housing, and other components must be slowly warmed up to normal operational temperatures before the plant can begin producing power
- Plant start-up systems provide a minimum flow path using main steam as the plant begins its start-up process
- This allows a slower, controlled warming process that is less likely to cause damage
- It also provides a steam source for de-aeration of feedwater and a means of heat recovery during plant start-up, which also increases overall efficiency

Other Common Plant Systems

- **Gland sealing:** Enable the turbine to be sealed where the shaft exits the casing (keep air out, steam in)
- **Hydrogen Cooling System:** Cooling water coils in the generator to cool the hydrogen gas
- **Hydrogen Seal Oil System:** Seals the generator where the shaft exits the casing keeping the hydrogen in
- **Cooling Water:** Cools the various component systems
- **Circulating Water:** Primarily provides the cooling water for the condenser
- **Turbine Lube Oil:** Supply clean, pressurized oil at proper temperature
- **Fire Protection**



Other Common Plant Systems

- **Service Air:** Various pressurized air needs within the plant
- **Control Air:** Used on pneumatic or instrumentation applications where moisture cannot be tolerated
- **Waste Water Treatment**
- **Station Batteries:** Supply critical plant loads (turning gear)

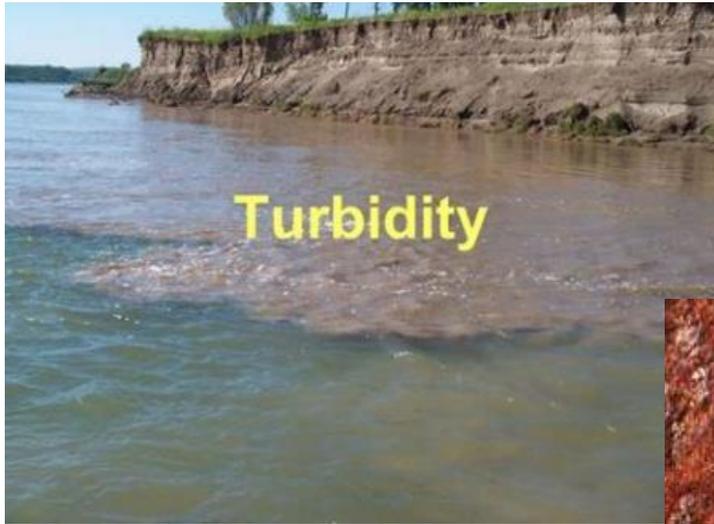
Possible Environmental Limitations on Plant Power Output

- Maximum allowable water temperature of cooling water return to river or lake
- Maximum allowable values of substance discharged to the atmosphere
 - Nitric Oxide - NO_x
 - Sulfur Dioxide - SO₂
 - Carbon Monoxide – CO
 - Carbon Dioxide – CO₂
 - Particulates – Opacity
- pH (solubility) of discharged cooling water
- Turbidity of discharged cooling water -suspended solids such as sediment, mud, and dirt that are in the water

Possible Operational Limitations on Plant Power Output

- **Dissolved Solids:** Minerals picked up by the water that will form hard adherent deposits on the internal surfaces of the boiler or heat exchangers
- **Dissolved Oxygen:** Entrapped in water, could attack metal parts including feedwater, condensate, and boiler tubes
- **Iron:** Concentration must be at a certain level in order to raise temperatures in a supercritical unit, but excess iron deposits can limit the heat transfer rates in boilers, or cause “hot spots”, increasing corrosion
- **Silica:** Found in water as a dissolved solid. Can solidify on components and create scale or reduce heat transfer

Possible Operational Limitations on Plant Power Output



Possible Operational Limitations on Plant Power Output

- **High condenser backpressure** is another factor that may limit power output
 - High cooling water temperatures may not condense the steam as efficiently
 - Condenser tubes may spring leaks and allow air to enter the condenser, compromising the vacuum
 - The condenser tubes may become dirty, preventing adequate cooling of the steam
 - A reduced condenser vacuum limit the amount of steam that can be pushed through the turbine, forcing a reduction in plant power output

Fossil Generation

Generating Unit Principles of Operation

Fossil Conversion Process

Chemical Energy (Fuel)

to

Thermal Energy (Steam)

to

Mechanical Energy (Turbine)

to

Electrical Energy (Generator)

Fossil Generation - Types

- Fossil Plants include those powered primarily by Coal, Oil, Natural Gas, or a combination of these fuels
 - Coal-fired currently provide about 31% of the PJM area generation
 - Total power output can be as low as 15-20 MW or as high as 1,450 MW
 - Ramp Rate, or the rate of change of power output, ranges from a few MW/min. on older units to 10-20 MW/min. for newer units
 - Each fuel type requires a unique set of components to control the ignition and combustion of the fuel, and handle the by-products of that combustion process

Fossil Generation - Components

- In a fossil plant, the combustion of the fuel takes place within the **Boiler**
 - A Boiler is some type of closed vessel in which water is heated, steam generated, and superheated under pressure by the application of additional heat
 - Basic functions of a boiler:
 - Pressure containment
 - Heat transfer
 - Steam separation
 - Two types of boilers:
 - Subcritical (drum type)
 - Supercritical

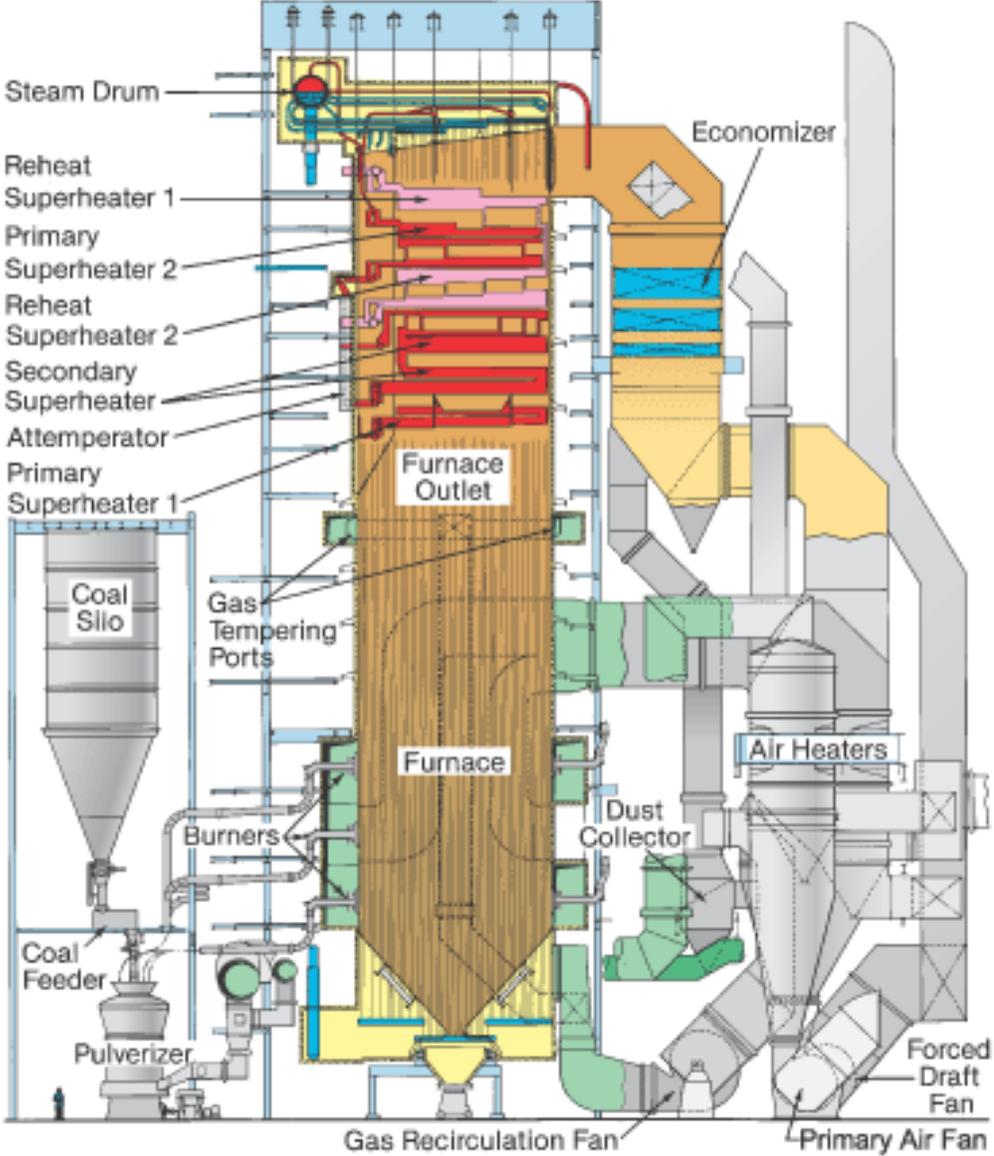
Fossil Generation - Components

- Drum Type Boilers - Components
 - **Economizer** - Improves boiler efficiency by extracting heat from the flue gases and transferring it to the feedwater
 - **Steam Drum** - Separates the water from the steam generated in the furnace walls
 - **Downcomers** – Act as a return path for the feedwater back to the boiler; located away from main heat source
 - **Mud Drum** - Fed from downcomers; collection point for sediment and impurities

Fossil Generation - Components

- Superheater - Increases cycle efficiency by adding heat to raise the steam temperature above its saturation point; located in the flue gas path
 - Adds ~ 3% efficiency per 100°F
 - There are 2 types of Superheaters;
 - Radiant: Direct radiation from the furnace
 - Convection: Absorb heat from hot gases
- Reheater - Adds energy back to the steam that has been passed through the HP turbine
 - Adds 4-5 % efficiency per 100°F

Fossil Generation



Principles of Operation

- Super Critical Boiler (Once Thru)
 - Does not have a boiler drum
 - Consists of many circuits of superheaters
 - Operates in excess of 3206.2 PSIA / 705.4 F
 - Requires a Start-up system (by-pass)
 - More efficient in certain MW ranges

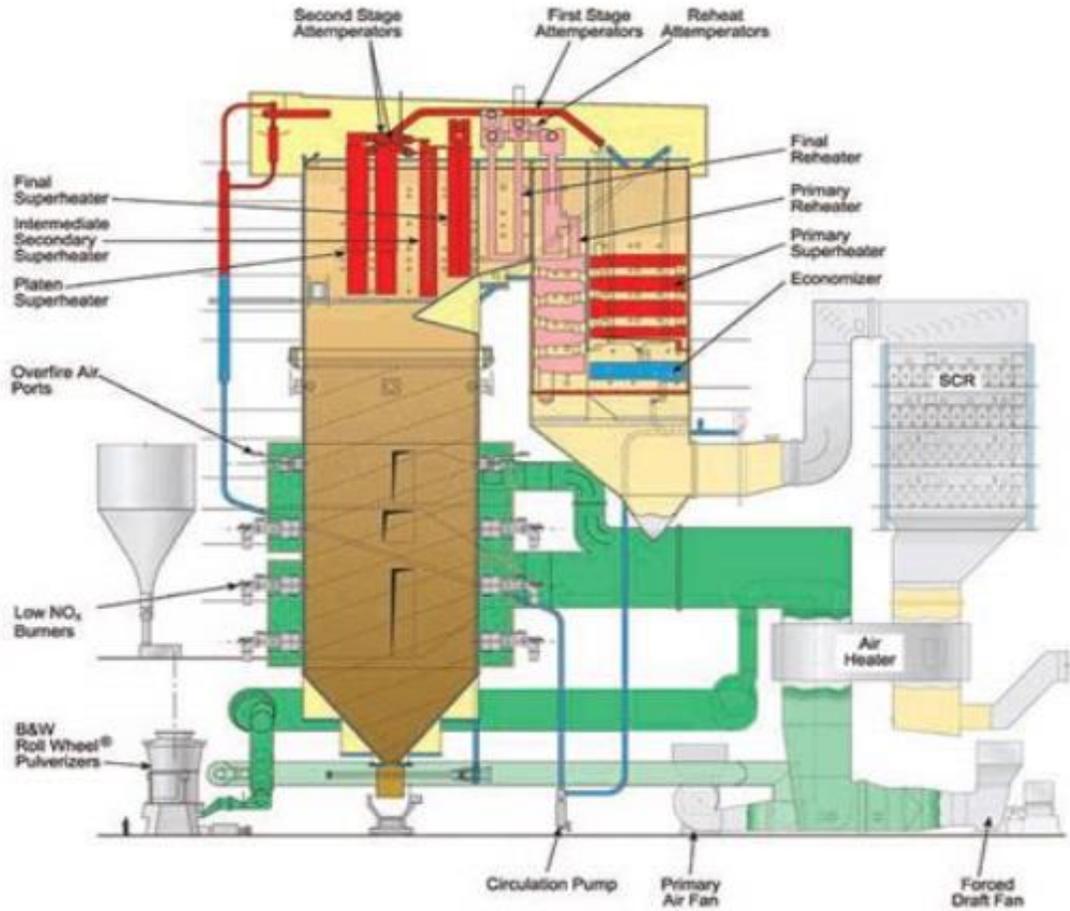
Fossil Generation - Components

- Super Critical Boilers:
 - Operate at significantly higher temperatures and pressures (>3200 psi and over 700 °F)
 - Water is directly converted to steam within the water wall tubes, without going through a boiling process
 - Do not have a boiler drum
 - “Once-thru” design – no recirculation process
 - Many circuits of superheaters
 - More efficient in certain MW ranges

Fossil Generation - Components

- Modifications are needed for the turbines used in supercritical units, due to the higher temperatures and pressures
 - Stronger materials for rotor forgings, casings, steam lines and valves
 - Iron-based materials replaced by nickel based superalloys
 - Last stages of turbine blades also use special alloys

Fossil Generation

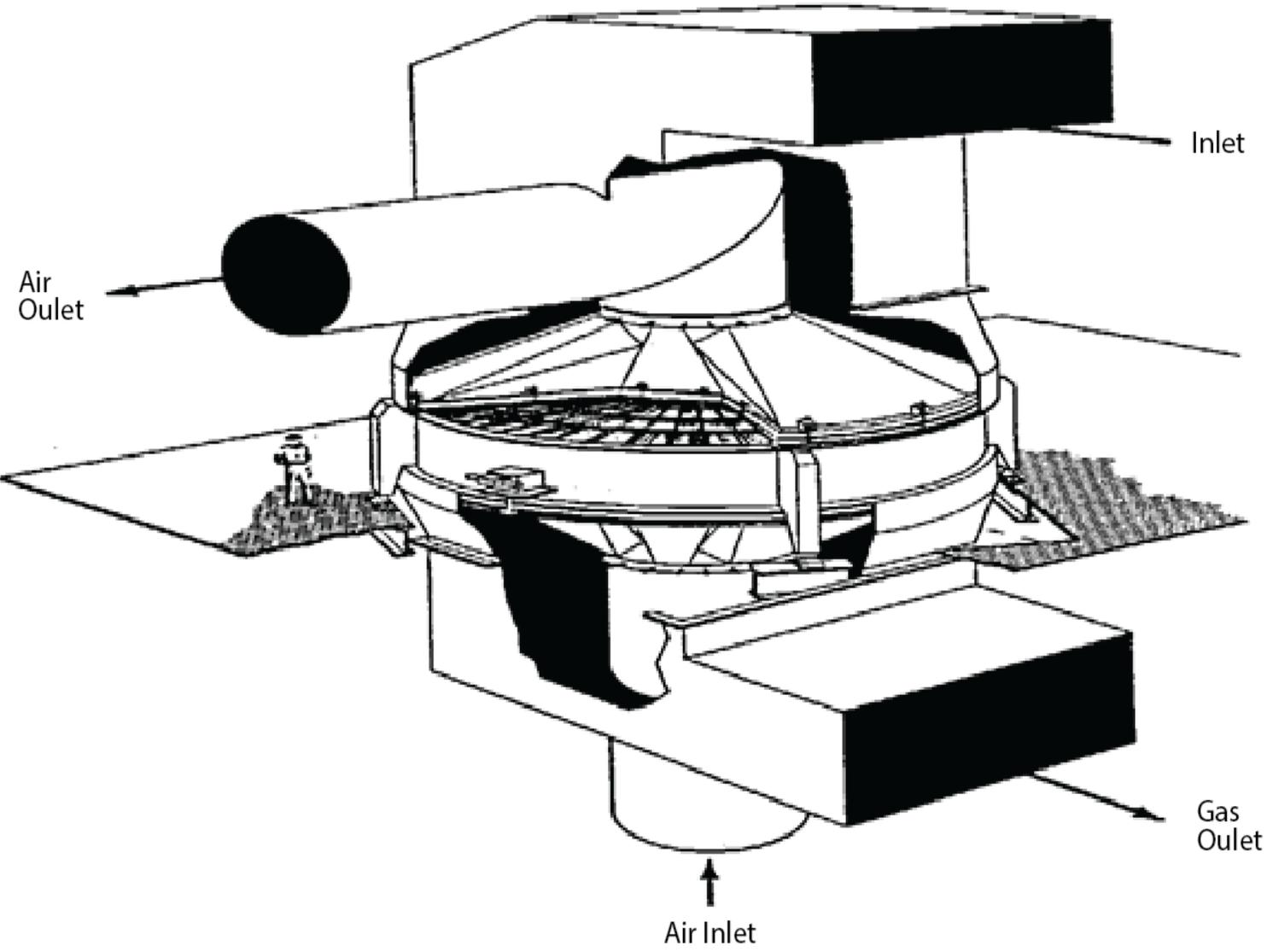


Fossil Generation - Components

- Furnace Air Systems

- **Air Heaters** - Used to transfer heat from stack flue gases to pre-heat the combustion and primary air
- **Forced Draft Fans** - Used to maintain windbox and secondary air pressure to accelerate combustion
- **Induced Draft Fans** - Used to maintain a negative furnace pressure
 - Always larger than FD due to combustion gas expansion

Air Heater

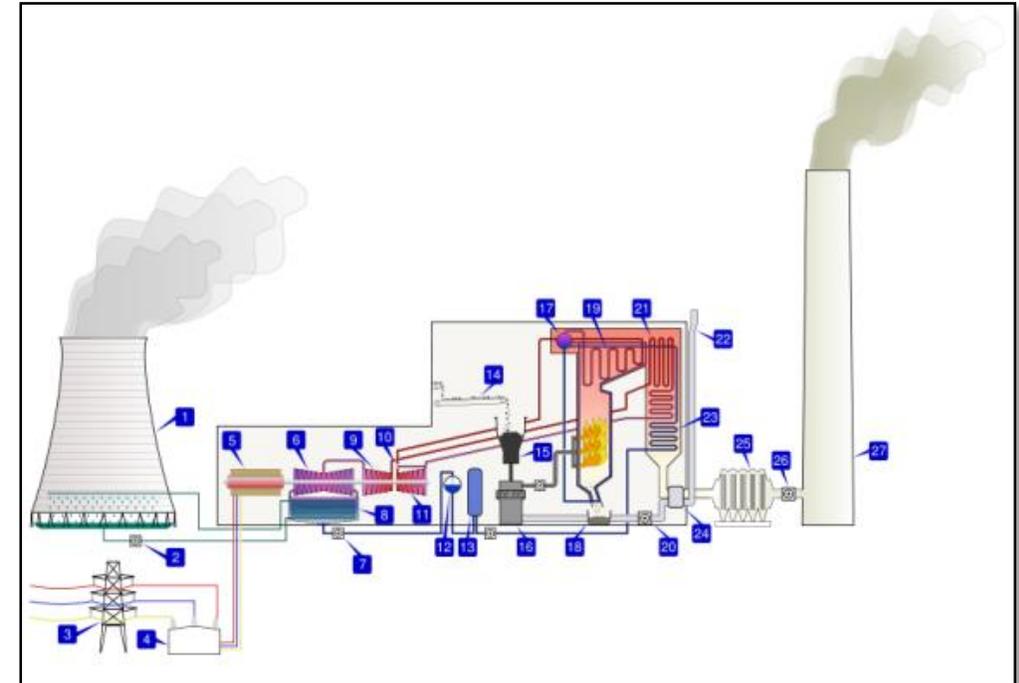


Miscellaneous Fossil Plant Systems

- Bottom Ash (slag) Handling System: remove the coarse, granular, incombustible by-products from the bottom of the boiler
- Fly ash handling system: remove the fine-grained, powdery particulate that is found in flue gas
- Scrubber Facilities: trap pollutants and sulfur that is produced from burning coal and natural gas from escaping into the air

Key

1. Cooling Tower
2. Cooling Water Pump
3. Three-phase Transmission Line
4. Step-up Transformer
5. Electrical Generator
6. Low Pressure Steam Turbine
7. Boiler Feedwater Pump
8. Surface Condenser
9. Intermediate Pressure Stage
10. Steam Control Valve
11. High Pressure Stage
12. Deaerator
13. Feedwater Heater
14. Coal Conveyor
15. Coal Hopper
16. Coal Pulverizer
17. Boiler Steam Drum
18. Bottom Ash Hopper
19. Superheater
20. Forced Draft Fan
21. Reheater
22. Combustion Air Intake
23. Economizer
24. Air Preheater
25. Precipitator
26. Induced Draft Fan
27. Flue Gas Stack



Fossil Generation - Components

- Super Critical Boilers
 - Advantages
 - Greater efficiency (45%)
 - Faster response to changing load
 - Reduced fuel costs due to thermal efficiency
 - Lower emissions (CO₂, NO, SO)
 - Disadvantages
 - Long start-up time
 - Expensive to build (greater press. / temp.)
 - Loss of circulation causes serious boiler damage

Fossil Unit Limitations That May Affect Power Output

- Temperature limits:
 - Temperature limit on the furnace water wall caused by increases in pressure and final steam temperatures to prevent damage to the tubes
 - Corrosion of superheater and reheater tubes caused by the increase in steam temperatures
 - Loss of Air heater thermal efficiency
 - Increasing feedwater temperature to the boiler leads to a rise in air heater gas inlet temperature, and loss of overall efficiency

Fossil Unit Limitations That May Affect Power Output

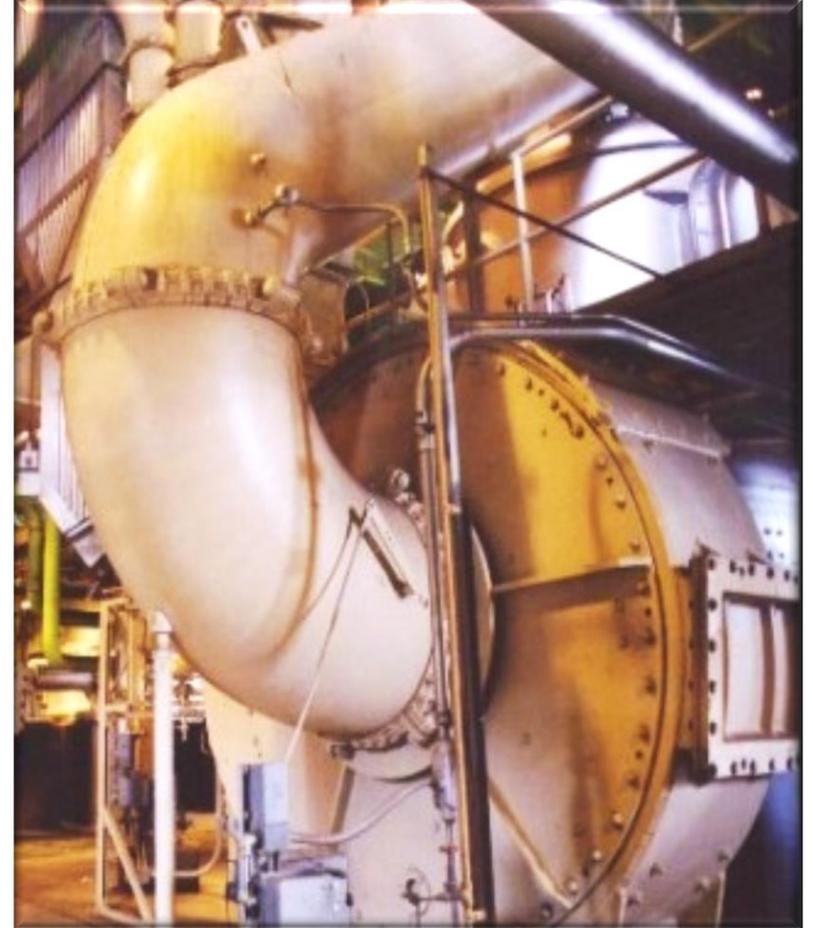
- Auxiliary equipment outages (scheduled or unscheduled)
 - Heaters, condensate or boiler feed pumps
 - Pulverizers (Mills) or oil pumps, gas
 - Fans: ID, FD, or primary air
 - Pumps: circulating water
 - Fuel
 - Ash handling

Fossil Unit Limitations That May Affect Power Output

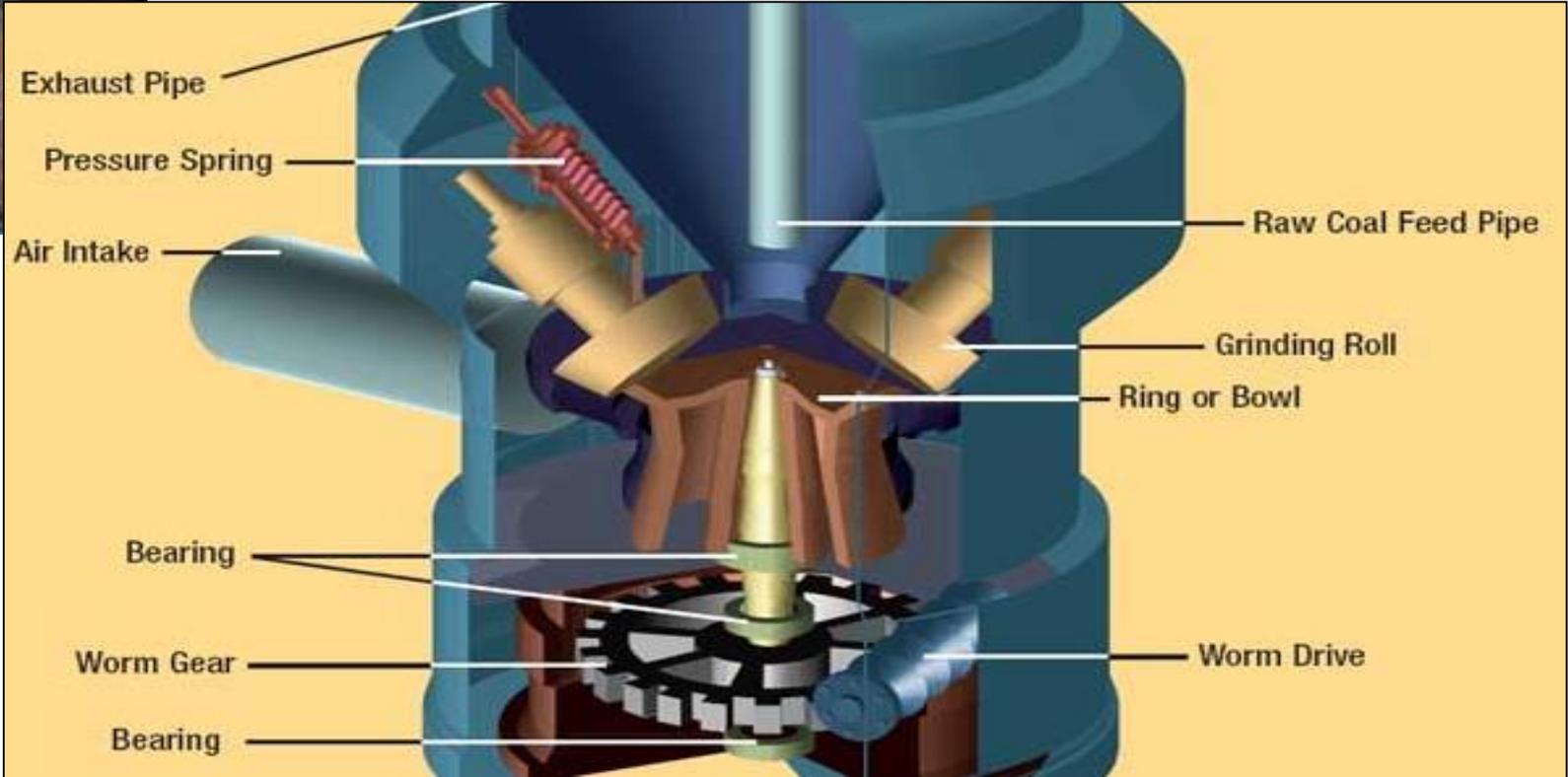
Fuel Limitations - Coal Issues:

- Excessive moisture or bad weather can lead to;
 - Difficulty unloading
 - Sliding on conveyor belts
 - Build-up in chutes
 - Frozen coal
- Poor quality coal can lead to increases in slagging and high ash resistivity
- Coal must be crushed or pulverized to burn efficiently
 - Degree of crushing depends on burner type
 - Pulverized
 - Stoker
 - Cyclone

Pulverizer Mill



Pulverizer Mill



Fossil Unit Limitations That May Affect Power Output

- Fuel Limitations - Oil Issues
 - Moisture deteriorates the performance of oil and increases the probability of corroding components
 - Increased coking
 - More particulates and impurities
 - Fuel oil needs to be pre-warmed to pump properly (150-180 °F) and warmed further to burn efficiently (250-330°F)
 - Oil injectors/guns need to be cleaned and maintained regularly

Fossil Unit Limitations That May Affect Power Output

- Fuel Limitations - Gas Issues
 - When moisture is present, it interacts with impurities in the gas lines to form a corrosive mixture

In all fossil units a major concern is flame detection in the boiler

- Boiler Water Chemistry - Must be maintained within certain levels to ensure the water wall tubes are not damaged
 - Condenser leaks are the major source of impurities

Nuclear Generation

Generating Unit Principles of Operation

Nuclear Conversion Process

Nuclear Energy (Fission)

to

Thermal Energy (Steam)

to

Mechanical Energy (Turbine)

to

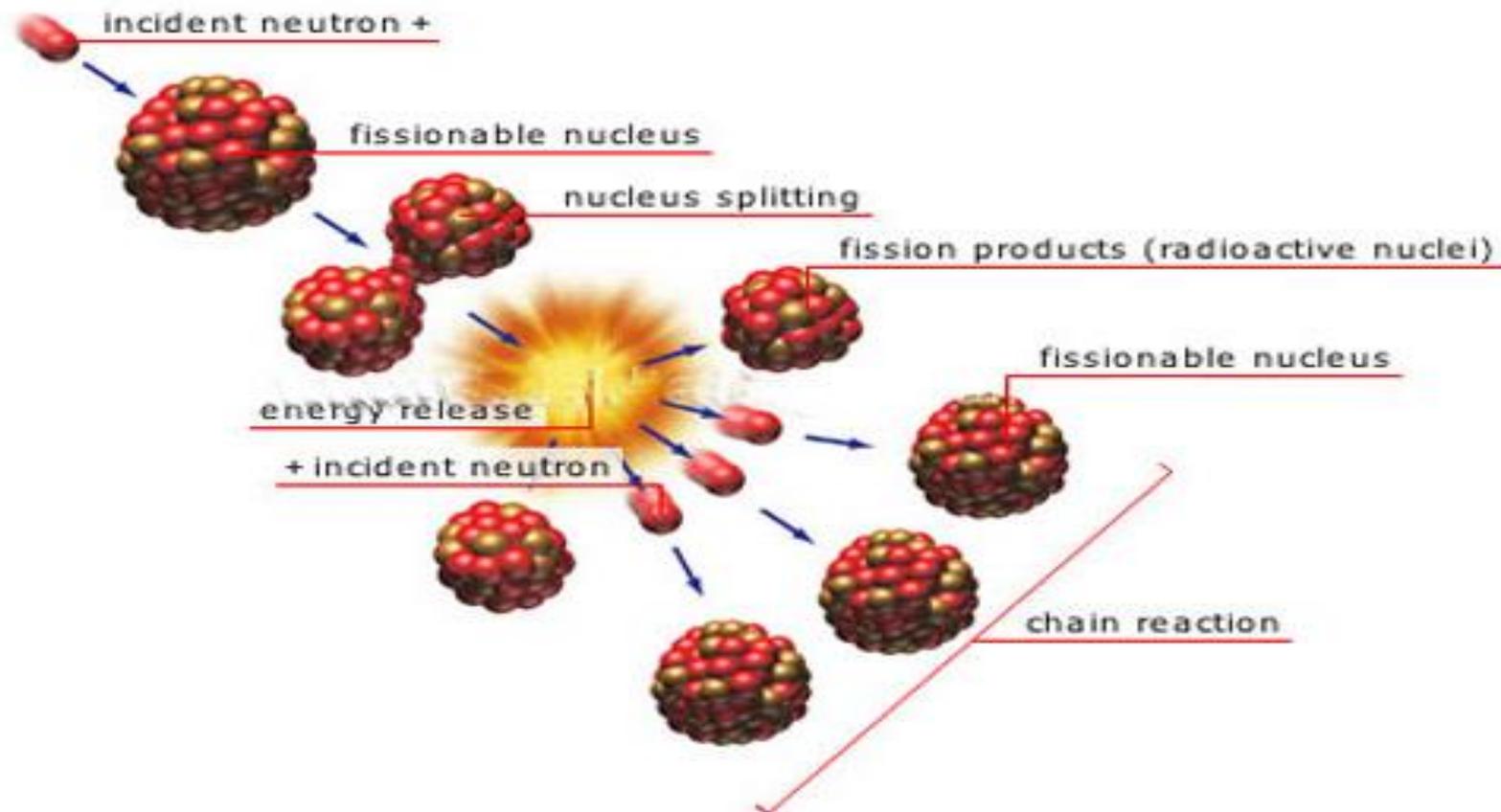
Electrical Energy (Generator)

Nuclear Generation

- Nuclear Fission yields the highest amount of energy produced per mass of fuel “consumed” for any existing fuel type
- Nuclear Generation currently supplies about 18% of the PJM area generation
 - Two types of light-water reactors:
 - Pressurized Water Reactor (PWR)
 - Boiling Water Reactor (BWR)
 - In the US, PWR’s outnumber BWR’s by about 2 to 1
 - Light-water reactors use ordinary water to slow down the thermal neutrons produced in the reaction
 - Light-water reactors use enriched uranium, U235

Nuclear Generation

- The fission process or the “splitting apart” of an atom is what produces heat in a nuclear reactor



Nuclear Generation

- Conventional light water reactors utilize fuel with an initial ^{235}U concentration enriched to at least 3.5%
- Fuel is loaded at 3.5% ^{235}U and replaced once the concentration has fallen to 1.2%
- A 1000 MW plant would consume ~30 tons of fuel per year in comparison to 9,000 tons of coal per day for a fossil plant of the same magnitude
- Nuclear Units require a Coolant, to remove the heat from the fission process (and produce the steam for the turbines) and a Moderator. The Moderator slows down the neutrons to allow the fission process to occur
 - In a light water reactor, water is used as both the Moderator and the coolant

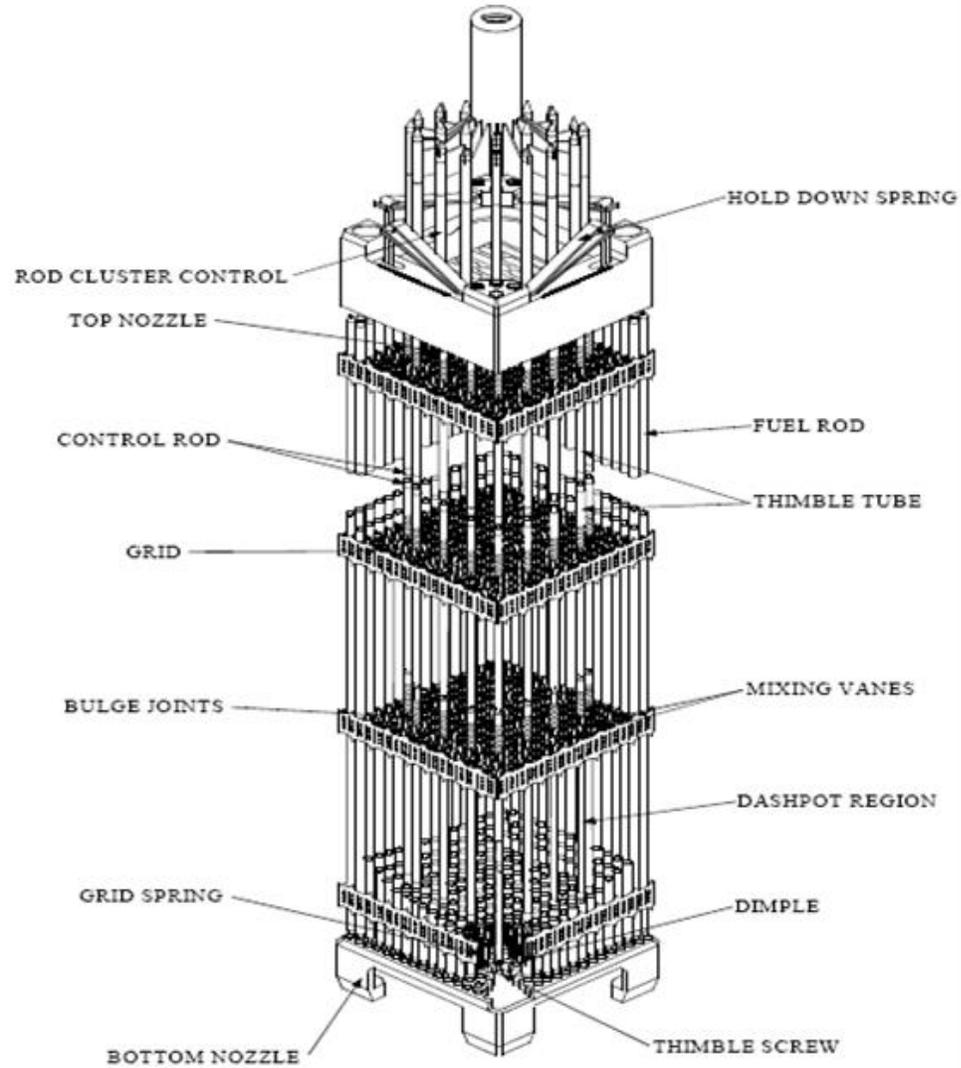
Nuclear Generation

- Once the steam is generated in a Nuclear Unit, it follows the same Cycle as that used in Fossil Units
 - The Steam is directed to Turbine/Generator assembly to produce Power
 - The Used Steam is sent to a condenser to be turned back into condensate, and non-condensable gasses are removed*
 - The condensate is cleaned up, reheated through feedwater heaters, and sent back into the steam cycle*
- * BWR Units modify this component slightly

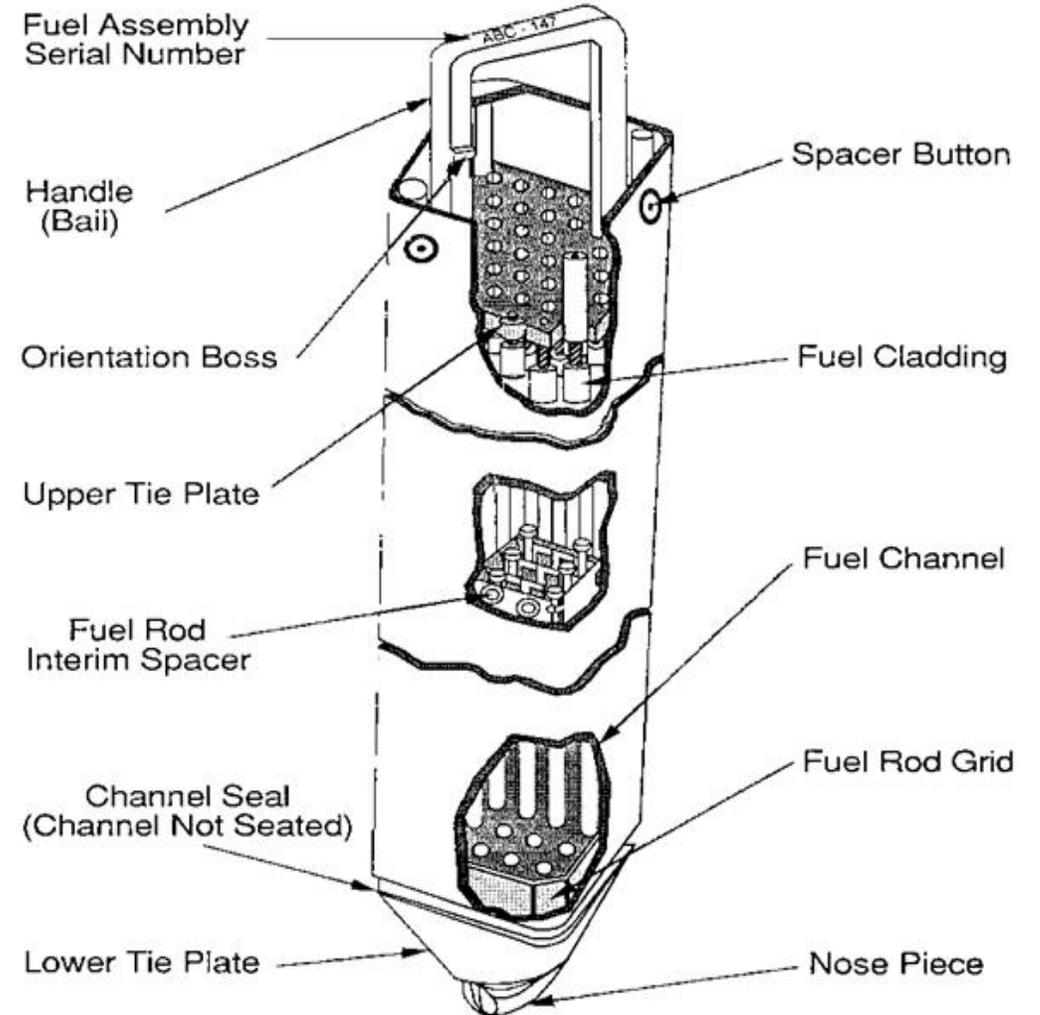
Fuel Assembly

- Both PWR and BWR fuel assemblies consist of the same major components:
 - Fuel Rods - ~ 12 feet long, made up of stacks of ceramic fuel pellets arranged in a square matrix
 - 17 X 17 for PWRs 8 X 8 for BWRs
 - Spacer Grids – provide rigidity for the assembly and allow coolant to flow up around the fuel rods
 - End fittings – the top and bottom structural portions. Also helps direct coolant through the assemblies
 - BWR Fuel Assemblies are also surrounded by a Fuel Channel, to provide more surface areas for steam bubble formation

Fuel Assembly



FUEL ASSEMBLY (Cut-Away)

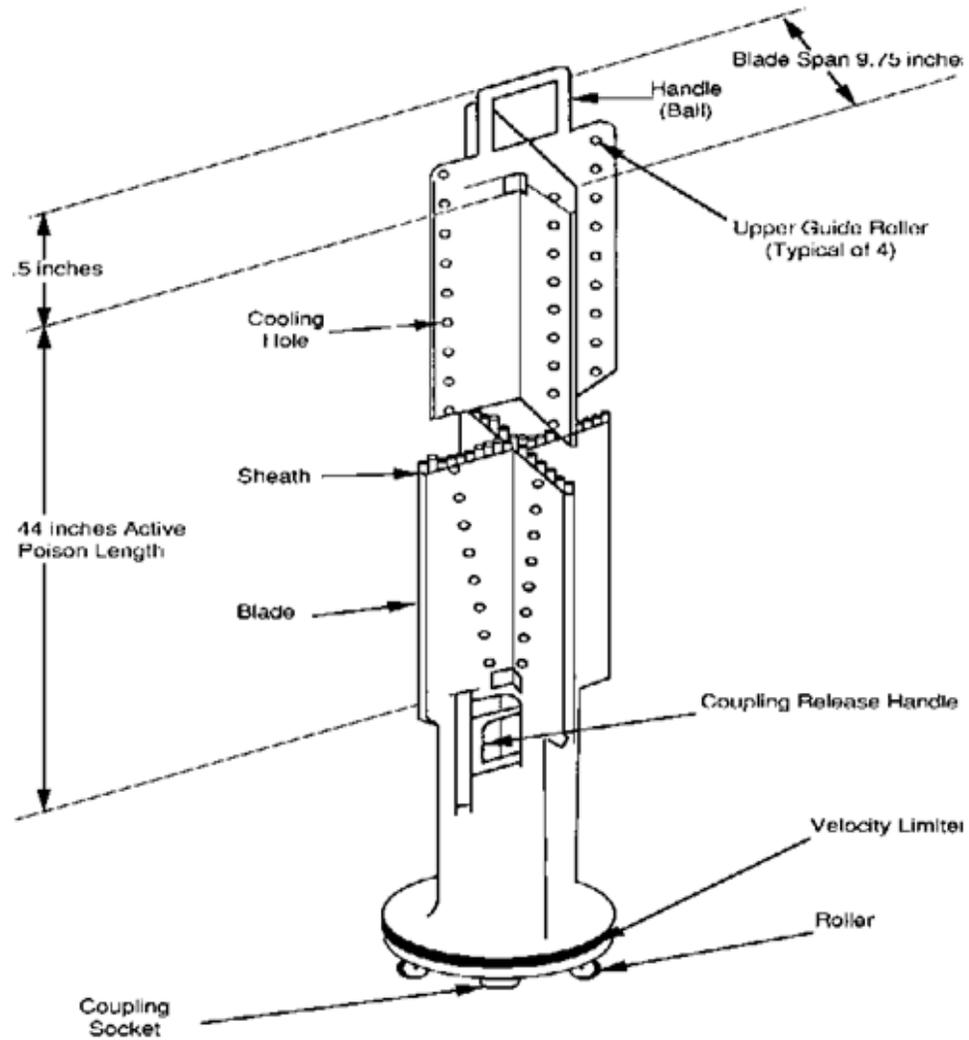


Nuclear Generation

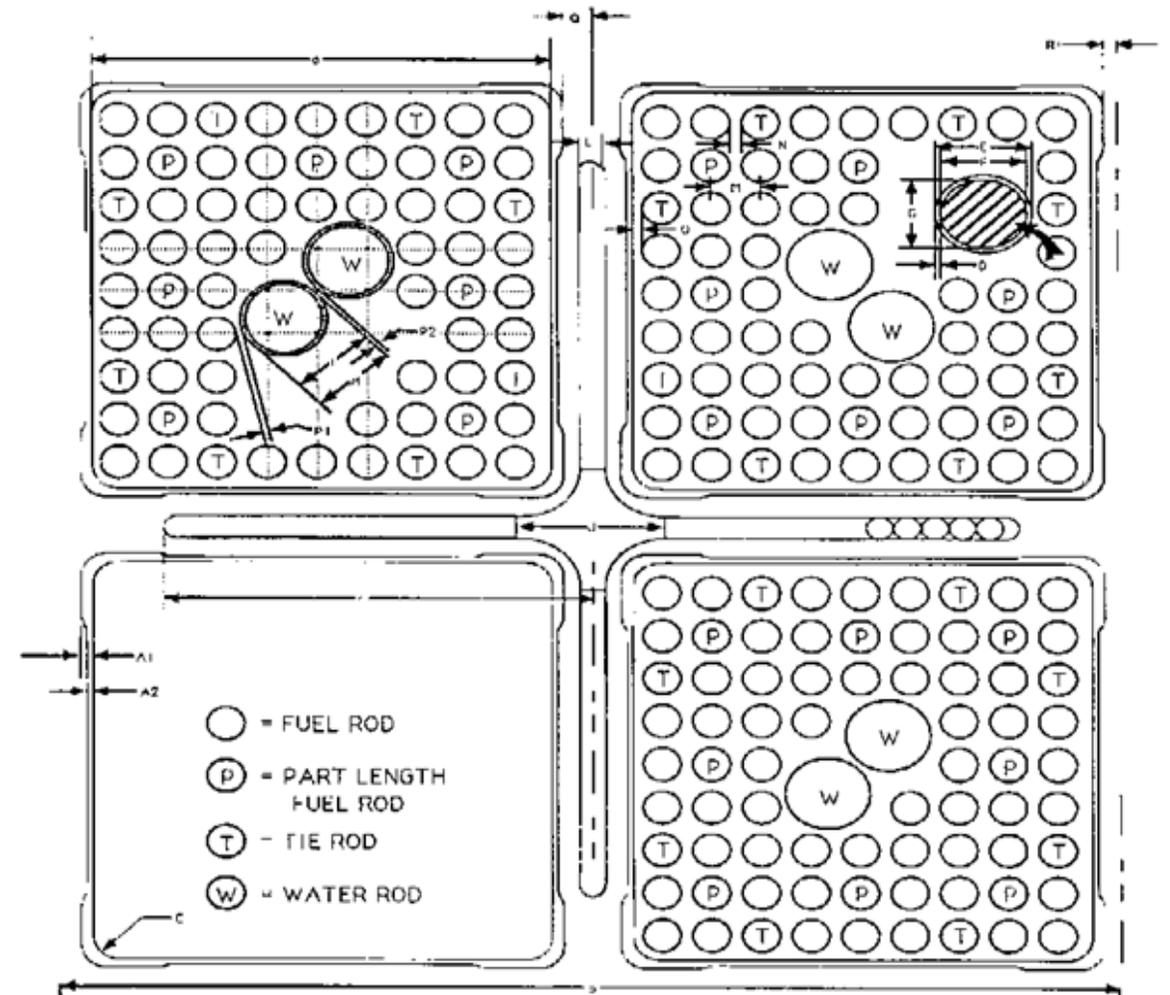
- Nuclear Units also use Control Rods to help moderate (BWRs) or Shut down (both types) the fission reaction
- A Control Rod is a cross-shaped blade made of stainless steel containing Boron or other neutron-absorbing materials
- The Boron will “absorb” the thermal neutrons and slow or stop the Nuclear fission process
- A SCRAM is an automatic process that simultaneously inserts all control rods into the core, to quickly stop the fission process and stop the reaction
 - SCRAMs can also be manually initiated from the control room or other remote locations

Control Rod

CONTROL ROD ASSEMBLY



FUEL ROD ARRANGEMENT GE 11 DESIGN

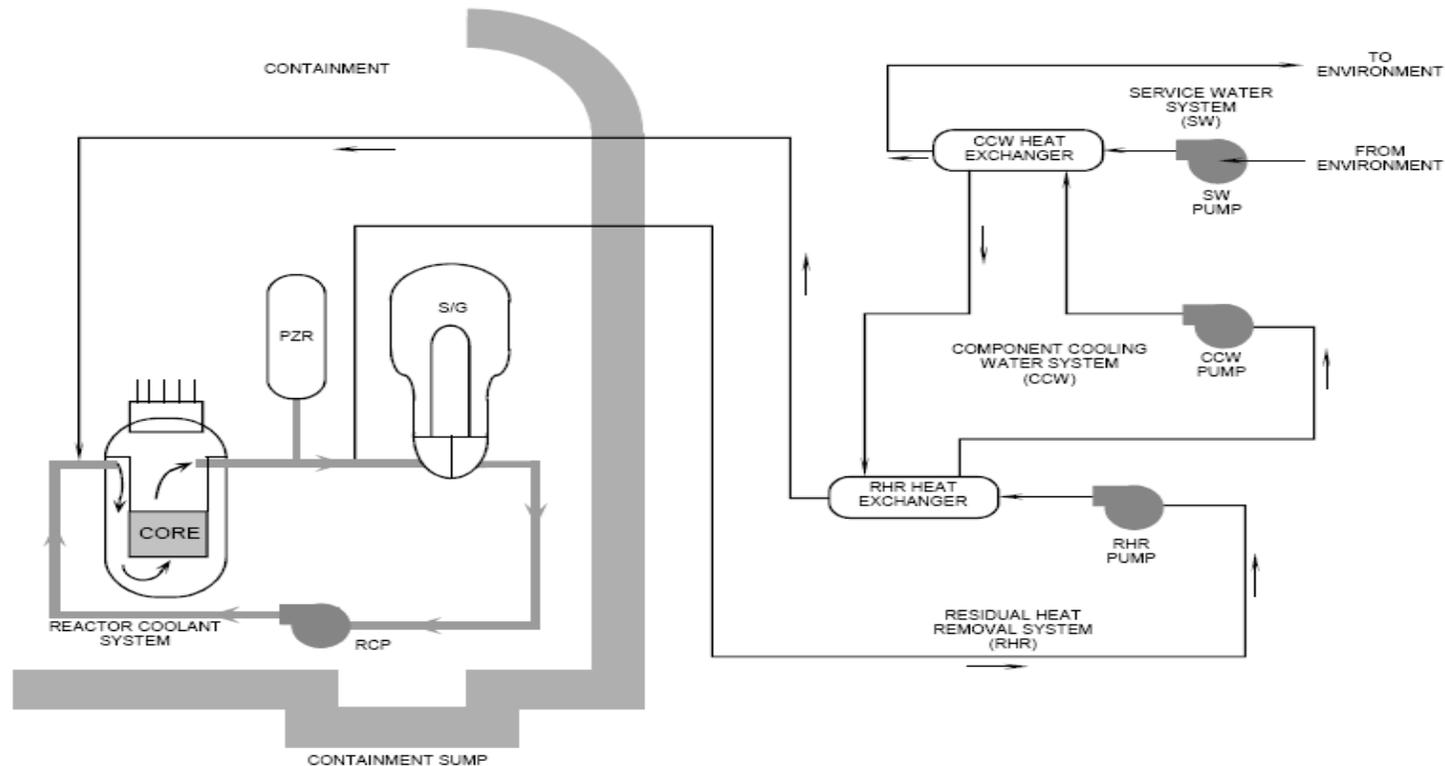


Systems Common to Both Designs

- PWRs and BWRs differ in some critical design elements, but both share some overall design components
- Even if the Nuclear Reaction in the core is shut down, the vibration of the fission products is sufficient to ensure that the core will produce a substantial amount of heat for some time after plant shut down (**Decay Heat**)
- The plants must have some mechanism to remove this heat to prevent damage to the core components at times when the main steam cycle is not available to remove the heat
- **Residual Heat Removal** Systems are used as a secondary means of removing heat from the core and transferring it to the environment

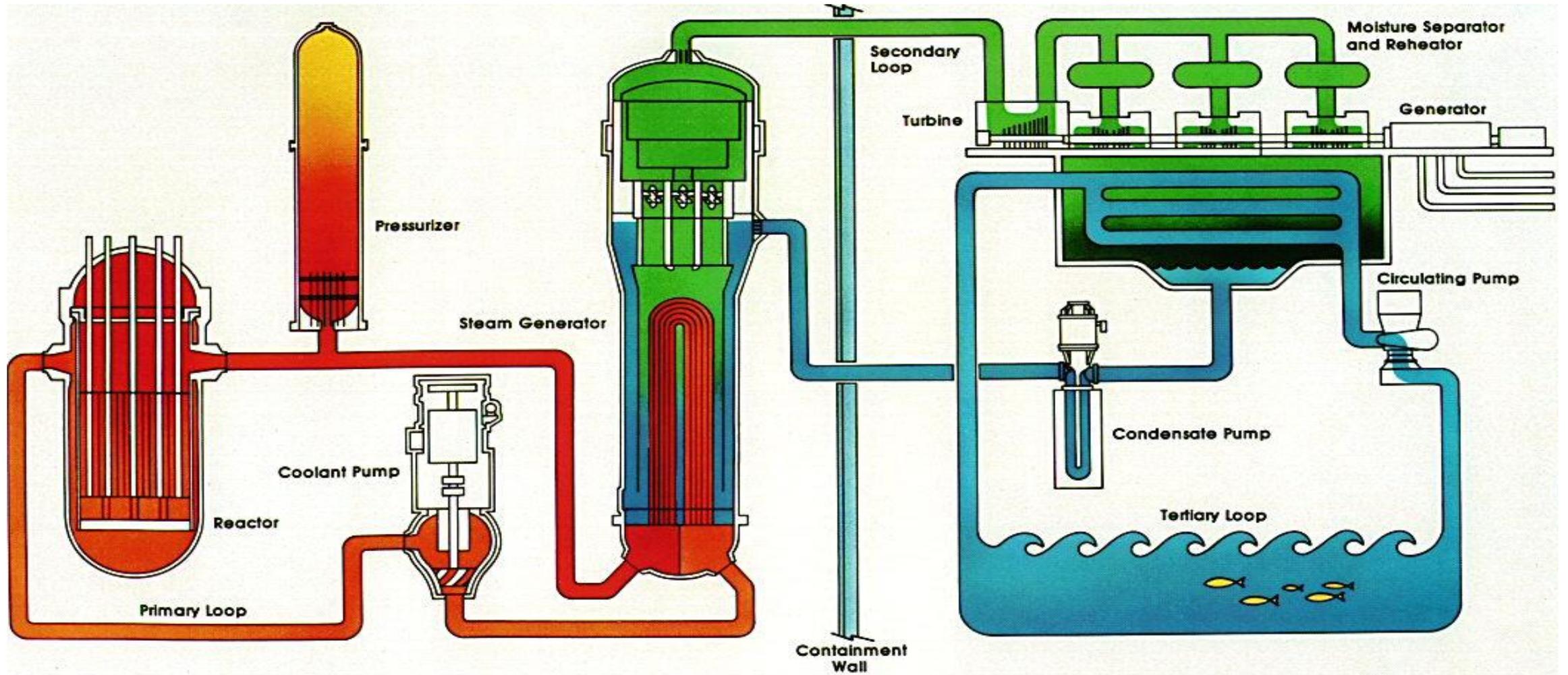
Systems Common to Both Designs

- **Residual Heat Removal** Systems use a series of heat exchangers to bypass the steam generator / condenser and transfer the decay heat to the ultimate cooling source



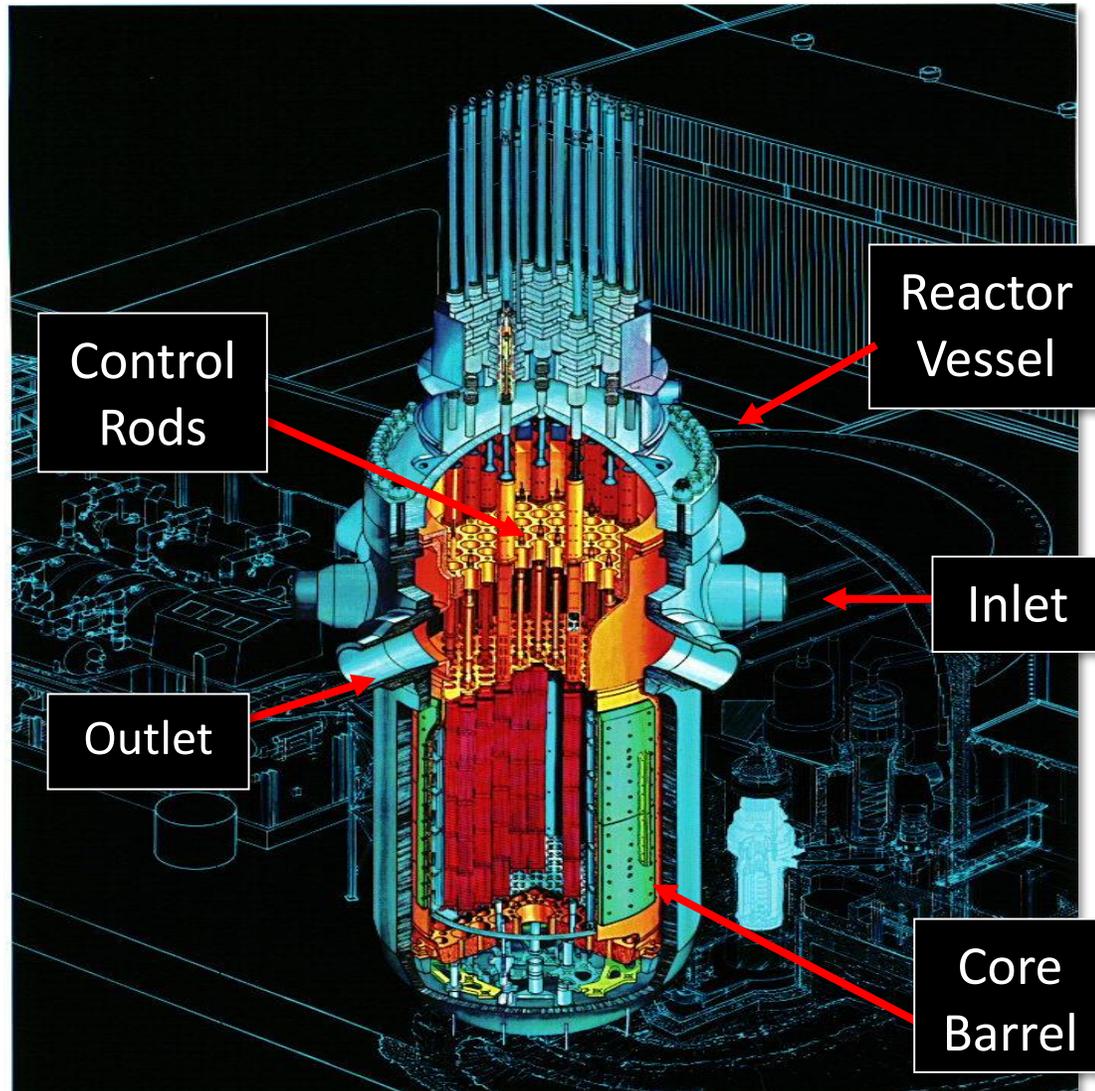
Pressurized Water Reactor

- Major Design Factors for a PWR:
 - The water in the Reactor is not designed to boil. It is maintained under higher temperatures and pressures by the **pressurizer**
 - ~600 °F at 2250 psi
 - The Primary Coolant is sent to a **Steam Generator** where clean (non-contaminated) water is boiled to make steam
 - This means the Generator and Condenser components never come into direct contact with Nuclear materials
 - Power Levels are controlled by adding or removing Boron (in the form of Boric Acid) to the primary coolant
 - This is accomplished by the **Chemical Volume & Control System**
 - Control Rods drop into the core from the top of the Reactor Vessel




Nuclear Steam Supply System
 MB 3618A

Pressurized Water Reactor



Water flows downward on the outside of the core barrel to the bottom of the reactor. The flow then turns upward in between the fuel rods from the bottom to the top of the reactor

The water leaves the reactor on its way to the steam generator

PWR Components

- The **Reactor Coolant Pumps** provide the motive force to pump water through the Reactor vessel, to the Steam generators to remove the heat from the Fission process, and back into the Reactor Vessel
 - Rated for 6,000 to 10,000 HP each – delivering approximately 100,000 gallons of coolant per minute per pump
 - Generally, PWR's have 2 to 4 coolant pumps per Vessel, each feeding a separate Steam Generator

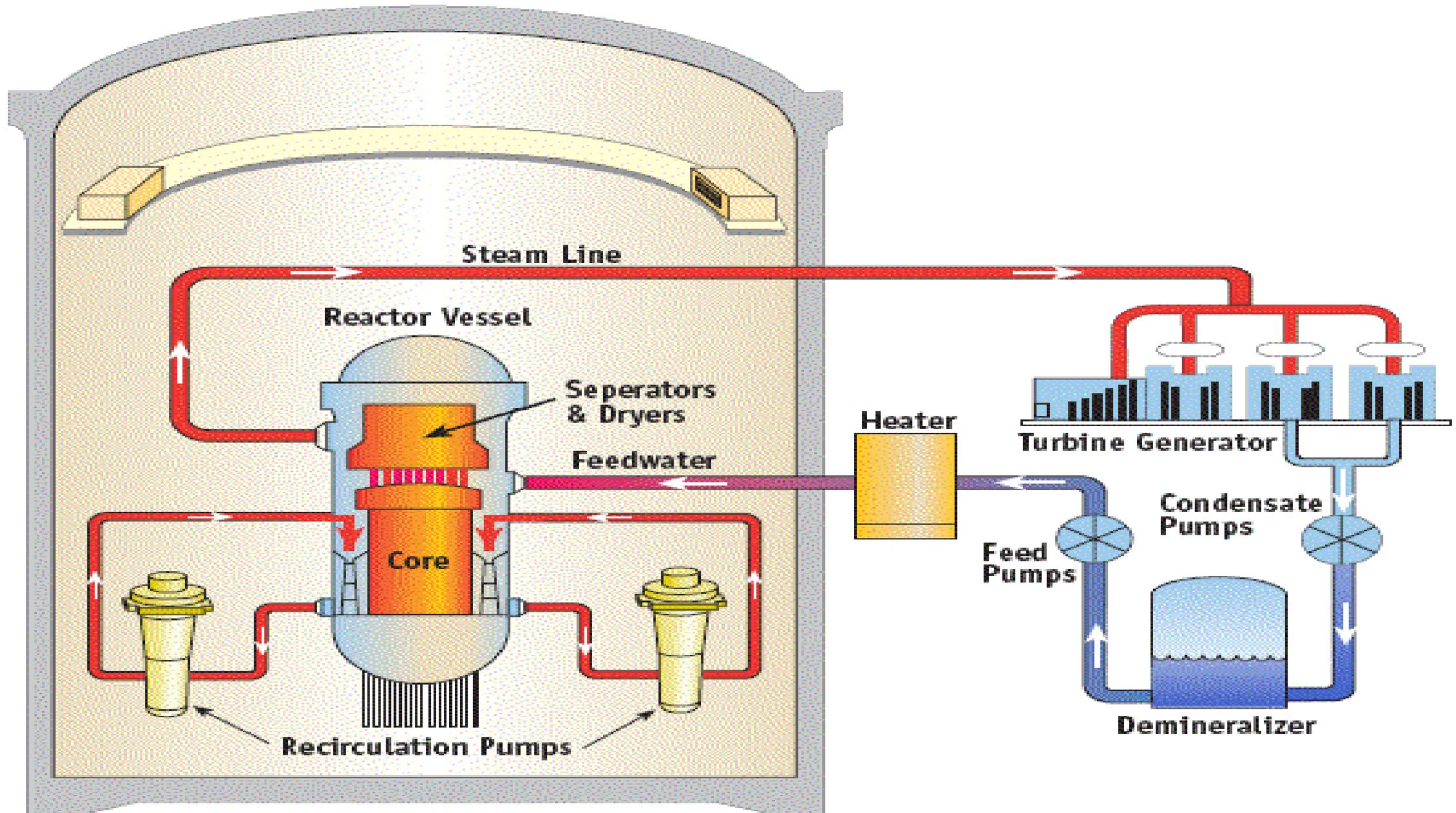
PWR Components

- The **Pressurizer** is the component in the reactor coolant system which provides a means of controlling the system pressure due to changes in coolant temperature
 - The Pressurizer operates with a mixture of steam and water in equilibrium
- The **Chemical and Volume Control System** is a major support system for the reactor coolant system
 - Purifies reactor coolant using filters and demineralizers
 - Adds and removes boron to control Reactor power Levels
 - Maintains the pressurizer level at the required set point

Boiling Water Reactor

Major Design Factors for a BWR:

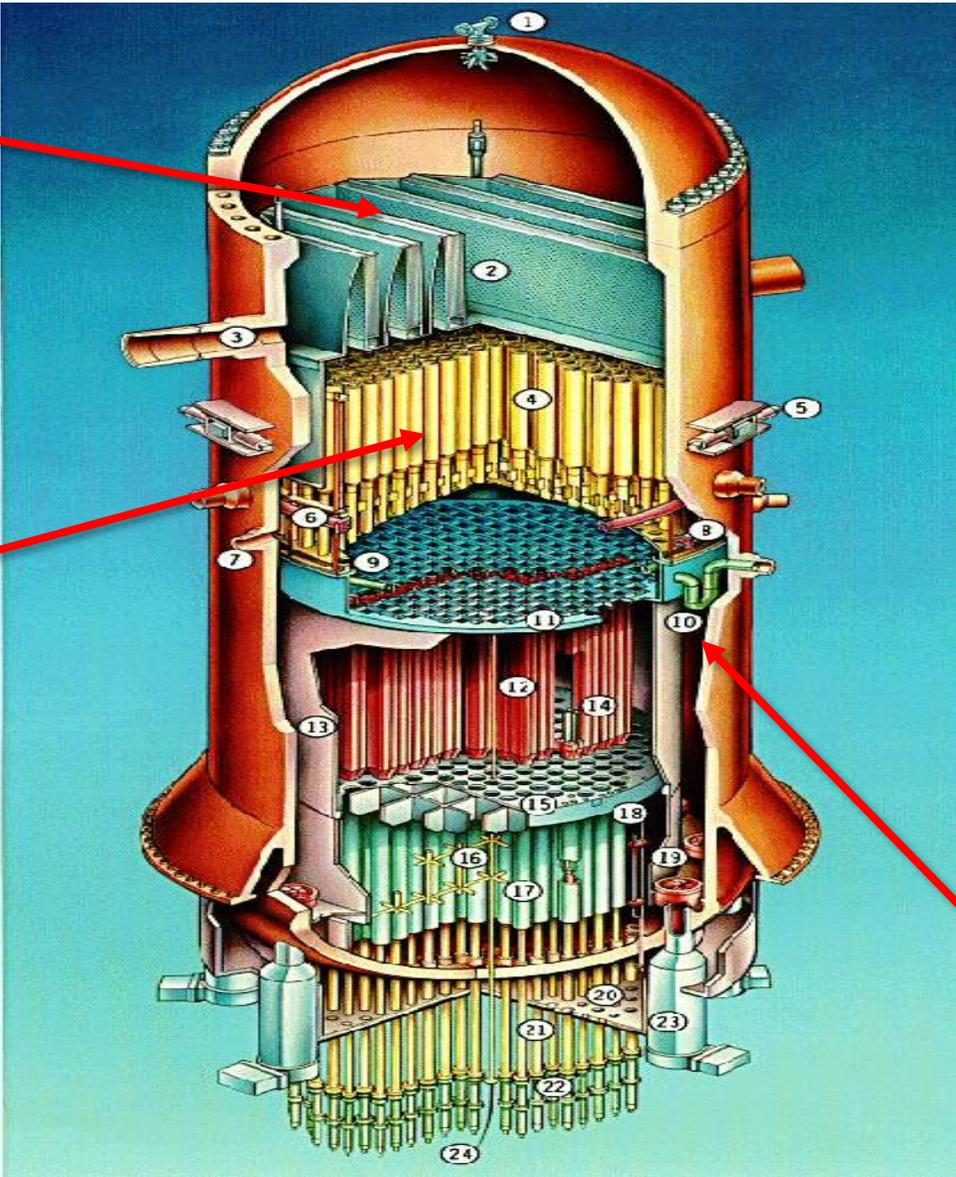
- The water in the Reactor does boil. Lower temperatures and pressures are required
 - ~550 °F at 1000 psi
- A Steam Separator and Steam Dryer are installed above the reactor core to dry the steam prior to sending it to the main Turbine
 - This means the Generator and Condenser components do not come into direct contact with Nuclear materials
- Power Levels are controlled by adjusting the position of the control rods in the core and by adjusting the rate of coolant flow through the core
- Control Rods are inserted into the core from the bottom of the Reactor Vessel



Boiling Water Reactor

Steam Dryers

Steam Separators



Water flows downward on the outside of the core barrel to the bottom of the reactor. The flow then turns upward in between the fuel rods from the bottom to the top of the reactor

Steam is separated at the top from the water

Shroud

BWR Components

- Because the Control Rods on a BWR are inserted from the bottom of the vessel, a failure of the Control Rods to insert would not be helped by gravity alone
- A redundant system called **Standby Liquid Control** provides a tank of highly concentrated boron solution adjacent to the reactor. If the Control Rods fail to shut down the fission reaction when required, an explosive valve if fired, dumping the tank contents into the reactor vessel and shutting down the chain reaction
- Since BWRs do not have the Chemical and Volume control systems of PWRs, this is likely a one-time event for a BWR – it could never be restarted

BWR Components

- In a BWR, the steam coming off the reactor contains other gasses as well;
 - Fission Gas by-products from the core that are carried over
 - Xenon, Iodine isotopes
 - Normal gasses present in the atmosphere that have been “activated” (or made radioactive) by absorbing an additional neutron in the core
 - Hydrogen and Oxygen – produced when the neutron flux in the core breaks apart the water molecules
- These gasses do not condense in the condenser, and if not removed would create backpressure conditions that could lead to turbine damage

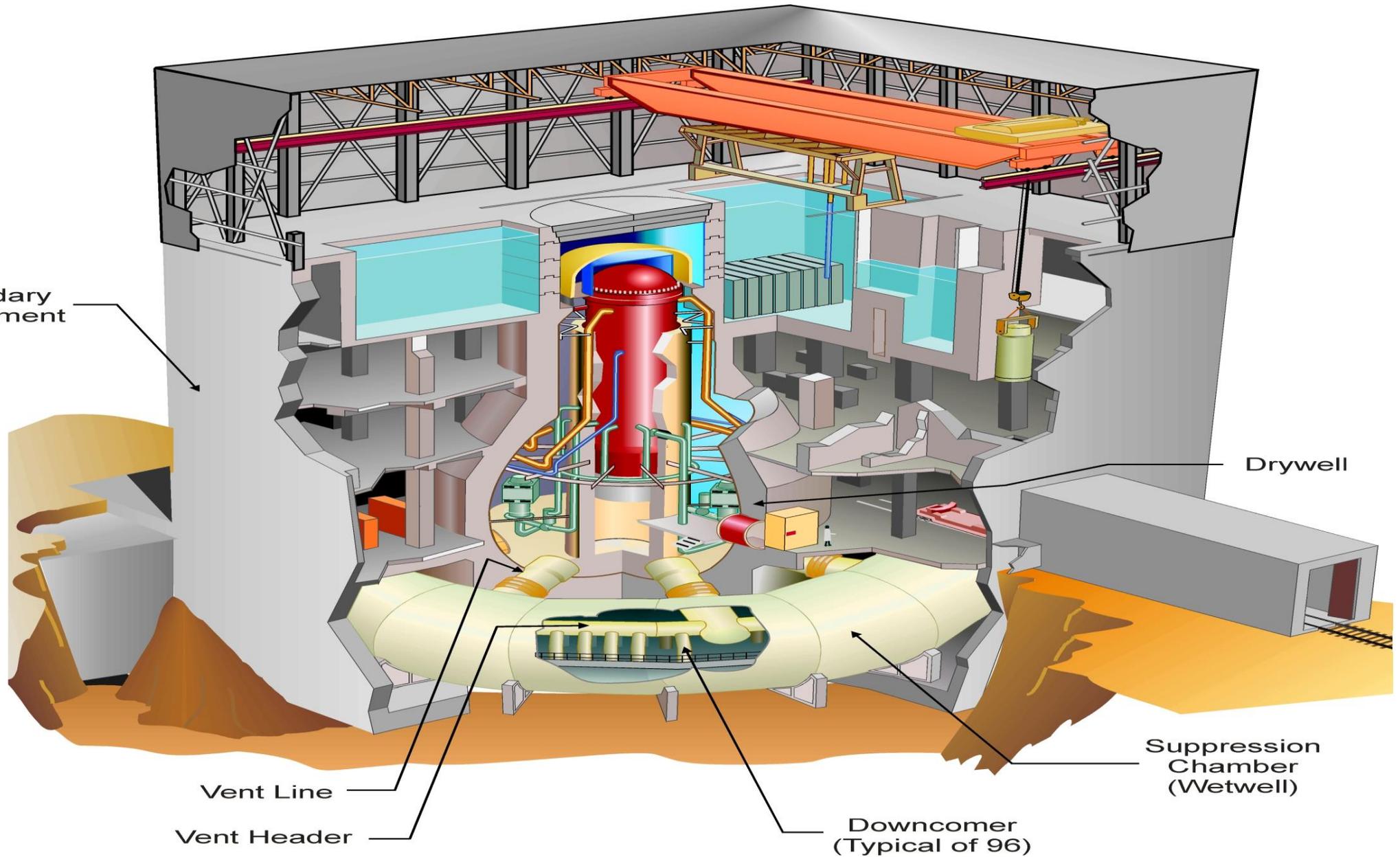
BWR Components

- So BWR operates with an **Offgas System** that takes a suction on the condenser to remove these gasses
- The hydrogen and oxygen exist in percentages that are explosive, so a catalytic **recombiner** is placed in the offgas stream to recombine some of these gasses to water for removal
 - The concentration of hydrogen in the offgas system is constantly monitored and could be a cause for plant shut-down
- The remaining gasses – some of which are radioactive – are passed at a slow rate through a series of charcoal beds. The charcoal “grabs” the gasses and traps them long enough for them to decay below the limits established for them to be released to the atmosphere

BWR Components

- Some plant transients require the isolation of the main Steam lines, to prevent the possible carry-over of radioactive materials
- This would normally leave the BWR without a means of decreasing the pressure and temperature in the vessel, leading to possible damage
- A series of **Safety Relief Valves** are installed before the main steam isolation valves. In the event the core is isolated, these valves direct the steam through a set of downcomers into a specially designed **Suppression Pool** below the reactor vessel where the steam can be condensed and pressure relieved

Secondary Containment



Drywell

Suppression Chamber (Wetwell)

Vent Line
Vent Header

Downcomer (Typical of 96)

Comparison

Plant Issue	BWR	PWR
Temperatures / Pressures	Relatively low, normal carbon steel components can be used	Higher pressures. Primary system components are more costly
Plant Design	All System Components contact radioactive materials – increased safety and cost issues	Only the primary systems contact radioactive materials – lower costs and no disposal issues
Reaction Control	Slow rate of power increase up to 70% - accomplished by slow withdrawal of control rods. 70 – 100% control much faster using jet pumps and altering core flow	Faster control of reaction using boric acid, but this has caused corrosion issues in the reactor vessels and Steam Generators

Nuclear Limitations

- Equipment Vibration
 - Individual component vibration is monitored by a central computer
 - Systems are quickly identified and isolated to prevent damage from excessive vibration
 - A problem area in nuclear plants are the protective relay panels
 - Excessive vibration may cause a system or plant shutdown due to vibration of relays
- Lengthy start-up times
 - Plants – especially BWR's – can require up to 3 days or more to reach full power output. A great deal of testing and “hold” points occur during power ascension

Nuclear Limitations

- With most plants operating on an 18 month or 2 year fuel cycle, the most intrusive maintenance work is done during the short (1-2 month) refueling cycles
- This means that a larger percentage of “routine” maintenance is done while the unit is operating
- Some maintenance activities create a “1/2-SCRAM” Signal due to operating some systems in a compromised manner
- A grid event may cause the second half of the SCRAM signal and cause a unit trip

Nuclear Limitations

- Plant operations are controlled by the **Nuclear Regulatory Commission (NRC)**. The plants must operate by their rules, as well as their license restrictions and individually written Technical Specifications (**Tech Specs**)
- **Tech Specs** specify the actions to be taken if any plant safety component is compromised or out of service. They may require a plant to reduce power, or even affect an immediate shutdown if certain conditions occur
- If a Plant experiences a SCRAM, the cause of the SCRAM must be determined and corrected before the plant can request permission to restart
- NRC permission must be obtained before the plant can be brought online

Hydroelectric Generation

Generating Unit Principles of Operation

Hydro Conversion Process

Kinetic Energy (Falling water)

to

Mechanical Energy (Turbine)

to

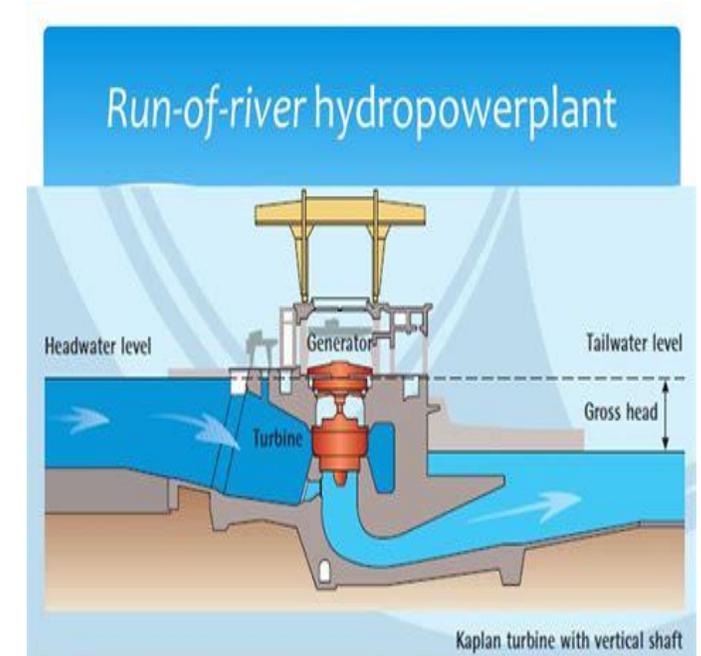
Electrical Energy (Generator)

Hydroelectric Generation

- Hydro once played a significant role in the electric utility industry accounting for 20% to 30% of the total energy produced
- Currently, hydroelectricity produces about 10% of the electricity generated in America (about 4.52% in PJM)
- Because the water cycle is an endless, constantly recharging system, hydro power is considered a renewable energy source
- Two types of hydroelectric generating plants:
 - Run of River
 - Pumped Storage

Hydroelectric Generation

- Basic design elements of hydro facility
 - Water at one elevation, and a dam or reservoir to hold it there
 - A lower elevation to which the water output can be directed
 - A Hydraulic turbine, connected to a generator
 - Converts the potential energy of the water to kinetic energy as it changes elevation, then to mechanical energy as it passes through the turbine, and then into electrical energy

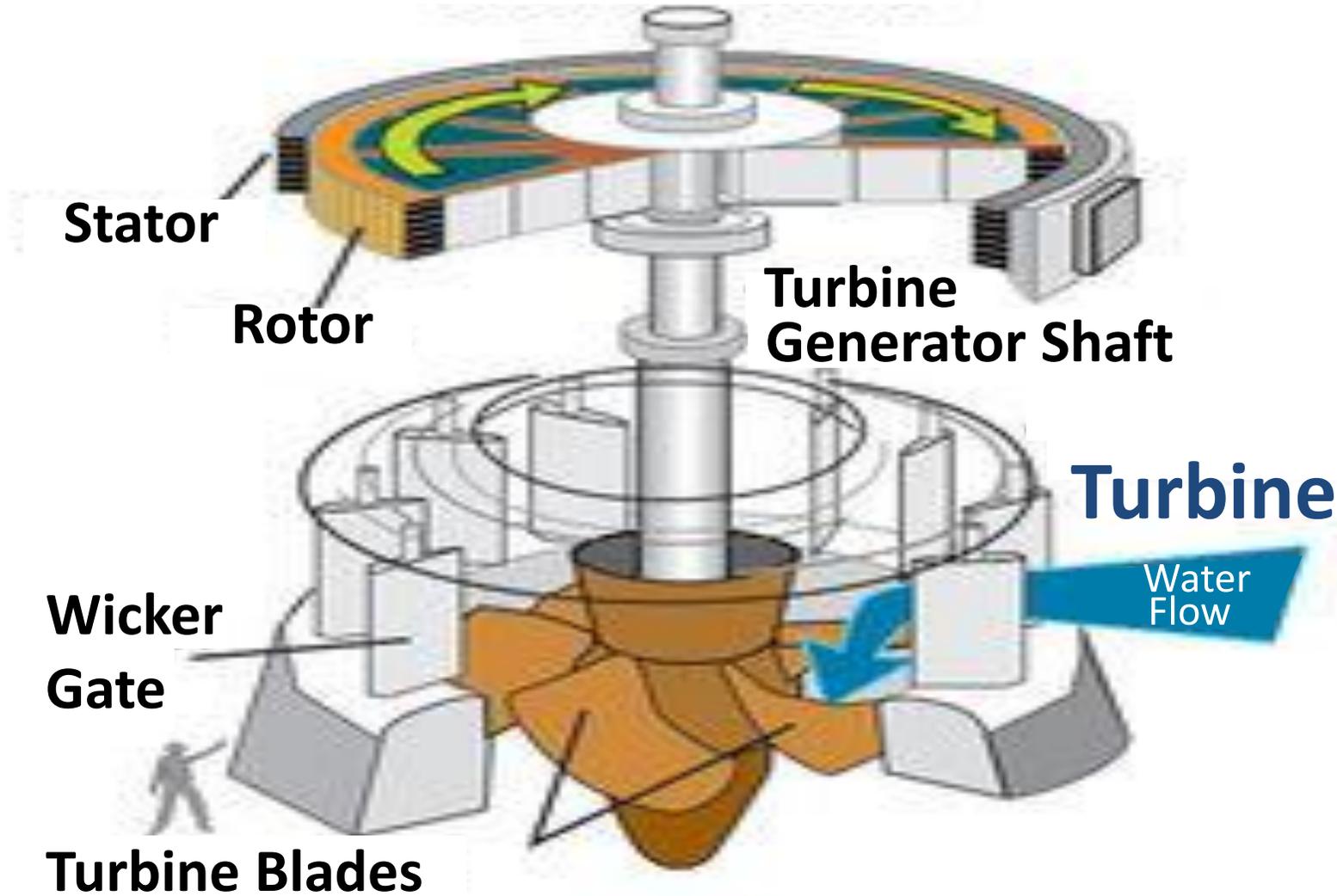


Hydroelectric Generation

- Power capacity of a hydro plant is the function of two variables:
 - Flow Rate of the water (in cubic feet per second)
 - Hydraulic head – the vertical difference between the head water and tail water elevations
- Power output is controlled via the position of the Wicket Gates
 - These are adjustable vanes that control the amount of water that can enter the turbine. These are controlled by the governor by changing the angle of the gates

Hydroelectric Generation

Generator



Hydroelectric Generation

- Safety Considerations:
 - An Extra flywheel effect is built into the generator
 - Dictated by the hydraulic conditions to prevent excessive rate of rise in speed if load is suddenly lost (Changes the moment of inertia)
 - Both Turbine and generator need to be built to stand “runaway” speeds due to the risk of a load loss when the gate-closing mechanism is inoperative
 - Generators at Hydro units are equipped with **Amortisseur Windings**, which:
 - Reduce overvoltage induced in the field caused by surges or imbalances in the stator dampening speed oscillations
 - Reduce overvoltage in the stator caused by unbalanced faults in the machine
 - Aid in stability by reducing power output oscillations

Hydroelectric Generation

- Both **Run-Of-River** and **Pumped Storage** units offer:
 - Rapid start-up, shutdown and loading
 - Long life
 - Low operating and maintenance costs
 - Rapid response to changes in load/ frequency
 - Can be operated as a synchronous condenser for voltage control when not generating

Types of Hydraulic Turbines

- **Impulse Turbine**

- Used in high head plants
- Requires less water volume
- Low velocity head is converted to a high velocity jet then directed onto spoon-shaped buckets
- Less efficient at full load, but more efficient at partial load levels



Repair & Refurbishment of Pelton Wheel Runner - DP Test

Types of Hydraulic Turbines

- Advantages of an Impulse turbine:
 - Greater tolerance for sand/other particles in the water
 - Better access to working parts
 - No pressure seals needed around the shaft
 - Easier to fabricate and maintain
- Disadvantages of an Impulse turbine:
 - Unsuitable for low head sites because of low specific speeds

Types of Hydraulic Turbines

- **Reaction Turbines**

- Two types; Francis and Kaplan (Propeller)
- Runner is fully immersed in water and enclosed in a pressure casing
- Pressure differences impose lift forces, which cause the runner to rotate
- Low to medium head is converted into high speed



Types of Hydraulic Turbines

- Advantages of a Reaction turbine:
 - Will rotate faster for the same head and flow conditions allowing for a more compact machine
 - Eliminates the need for a speed-increasing drive system
 - Simpler to maintain – less cost
 - Higher efficiencies
- Disadvantages of a Reaction Turbine:
 - Requires more sophisticated fabrication
 - Poor efficiency under partial flow conditions

Run-of-River

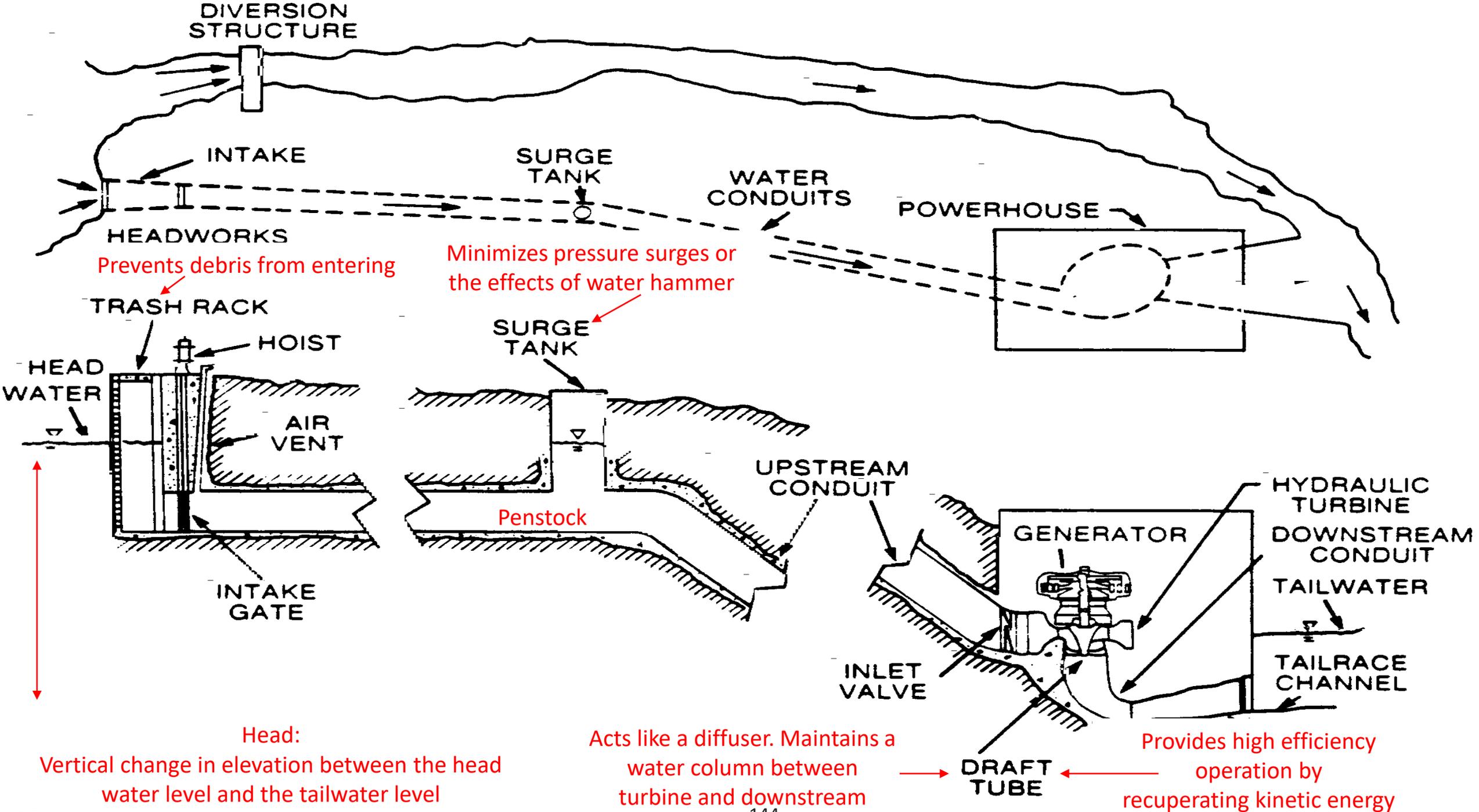


Run-of-River

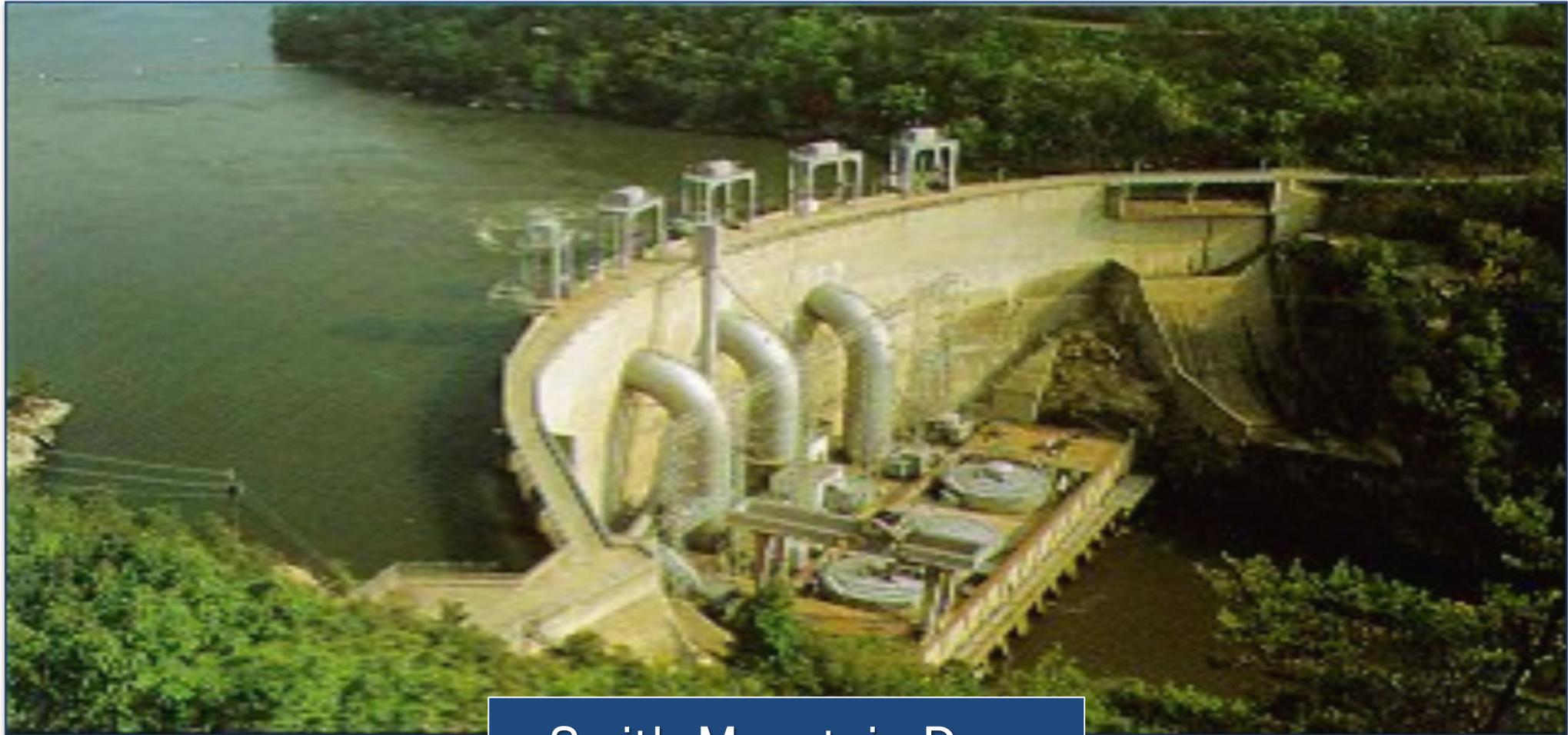
- Low impact method that utilizes the flow of water within the natural range of the river, requiring little or no impoundment
- Produce little change in the stream channel or stream flow
- Plants can be designed using large flow rates with low head or small flow rates with high head
- Advantages:
 - Reduced exposure to price volatility
 - Minimal construction
 - Ecologically sound
 - Reliable
 - Low operating costs

Run-of-River

- Operating Considerations
 - Rainfall in the watershed area
 - River flow and Forebay/tailrace elevations
 - Water Quality impacts
 - Dissolved oxygen, temperature, increased phosphorous and nitrogen content
 - Icing problems during frigid temperatures



Pumped Storage

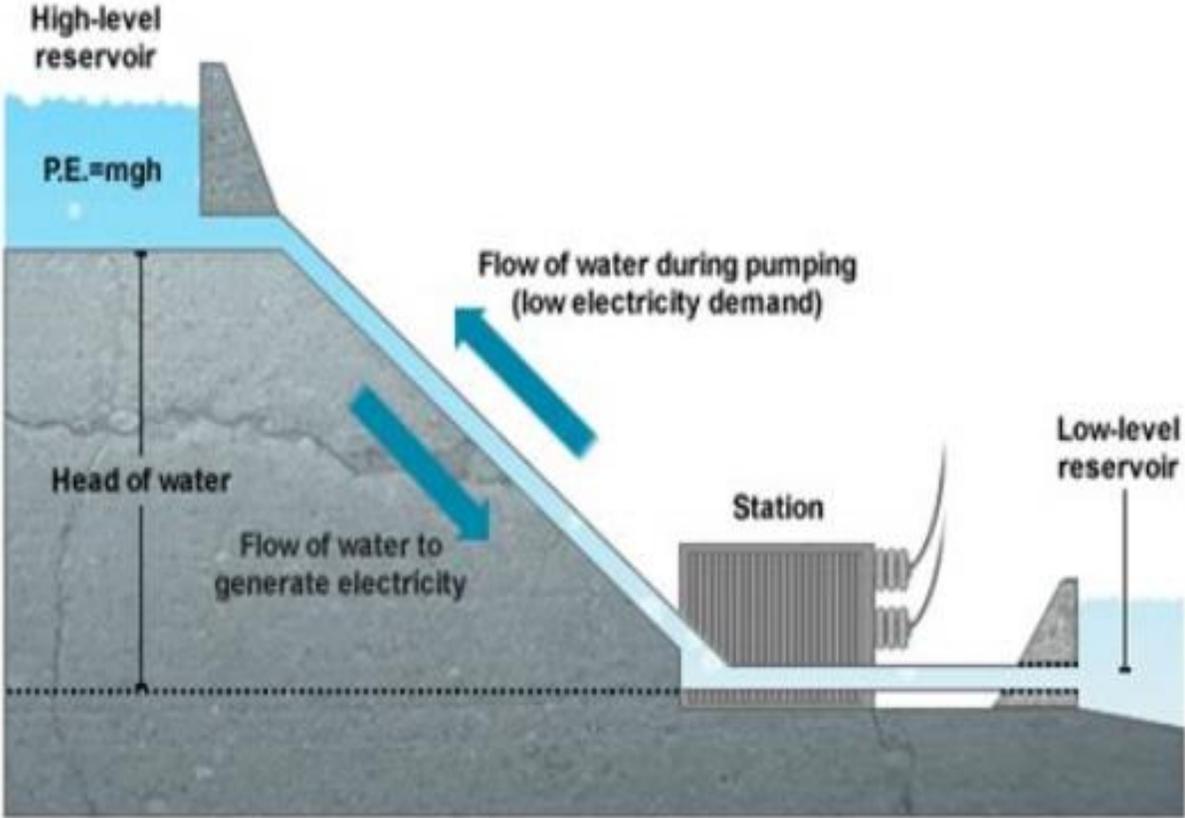


Smith Mountain Dam

Pumped Storage

- Uses off-peak electricity to pump water from a lower reservoir to an upper reservoir
- During periods of high electrical demand, water is released to generate electricity
- Most modern plants utilize a reversible Francis-type turbine which operates in one direction of rotation as a pump, and the opposite direction as a turbine connected to a synchronous generator/motor driving the pump in one direction, and generating power in the other direction

Pumped Storage



Pumped Storage

- Operating Considerations
 - Water Quality impacts
 - Thermal stratification, toxic pollutants, Eutrophication (loss of nutrients)
 - Reservoir Sedimentation
 - Flood Control / Hazard
 - Effects on groundwater levels
 - Ice formation during cold periods

Combustion Turbine

Thermal Efficiency

Generation Type	Efficiency
Combustion Turbine	28% - 34%
Steam (No Reheat)	31% - 35%
Steam (Reheat)	36% - 41%
Combined Cycle	42% - 53%

Thermal Efficiency = BTU Content (Kwh)/Heat Rate (BTUs)

Combustion Turbines

- Combustion turbines play an important role in utility system generation planning (25.3%)
- Combined-cycle units provide most of the advantages of simple-cycle peaking plants with the benefit of a good heat rate; they also requires less cooling water than conventional fossil and nuclear units of the same size
- We will examine both simple (single-cycle) and Combined Cycle CT's

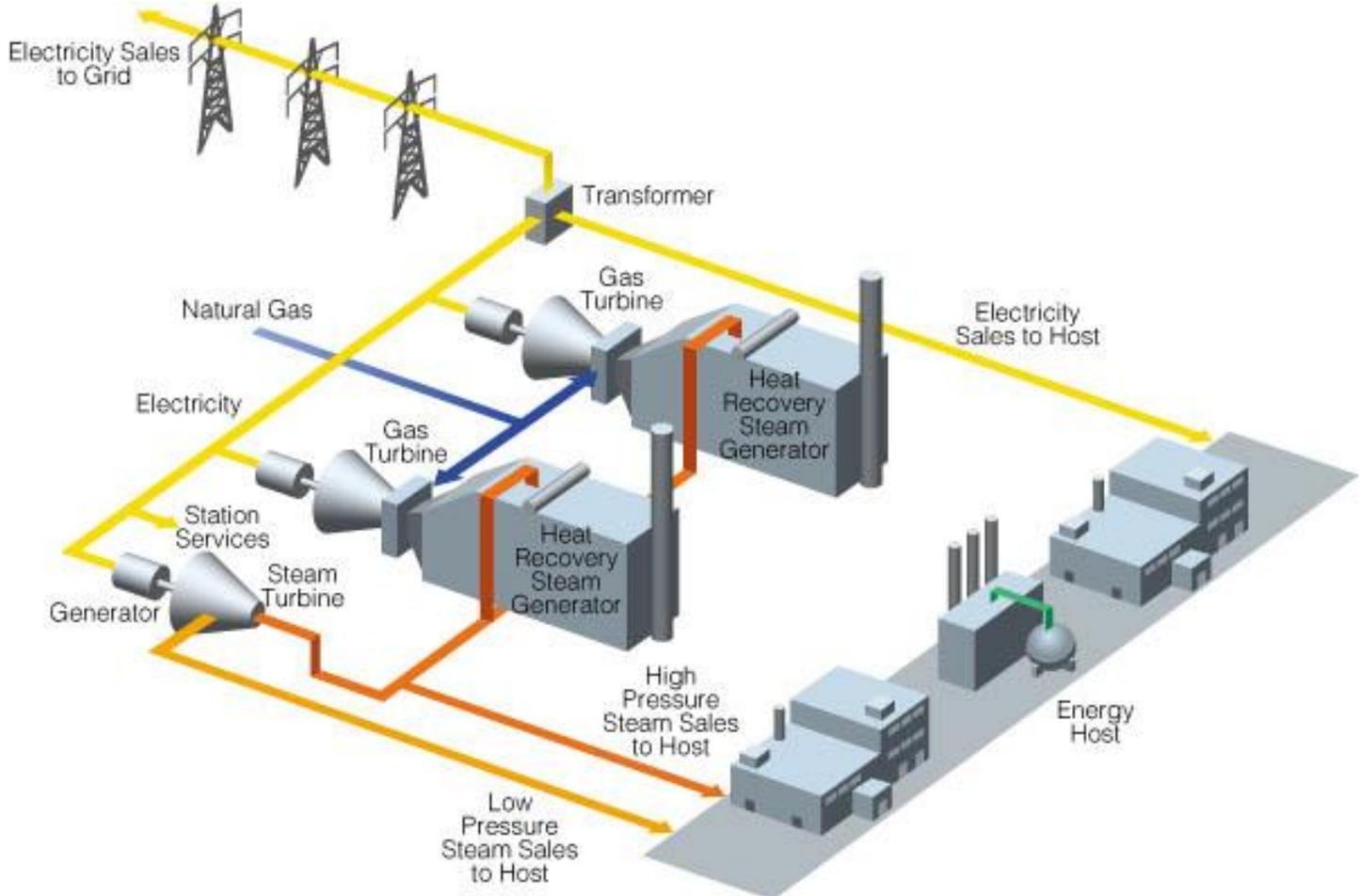
Simple-Cycle Combustion Turbines

- Operation is similar to a jet engine
- Air is compressed, mixed with fuel in a combustor, to heat the compressed air
- It is an internal combustion engine employing a continuous combustion process
- The turbine extracts the power from the hot air flow
- Connecting a generator to the turbine shaft creates electric power
- $\frac{2}{3}$ of the produced shaft power runs the compressor; $\frac{1}{3}$ produces the electric power
- Typical capacity – 15-180 MW

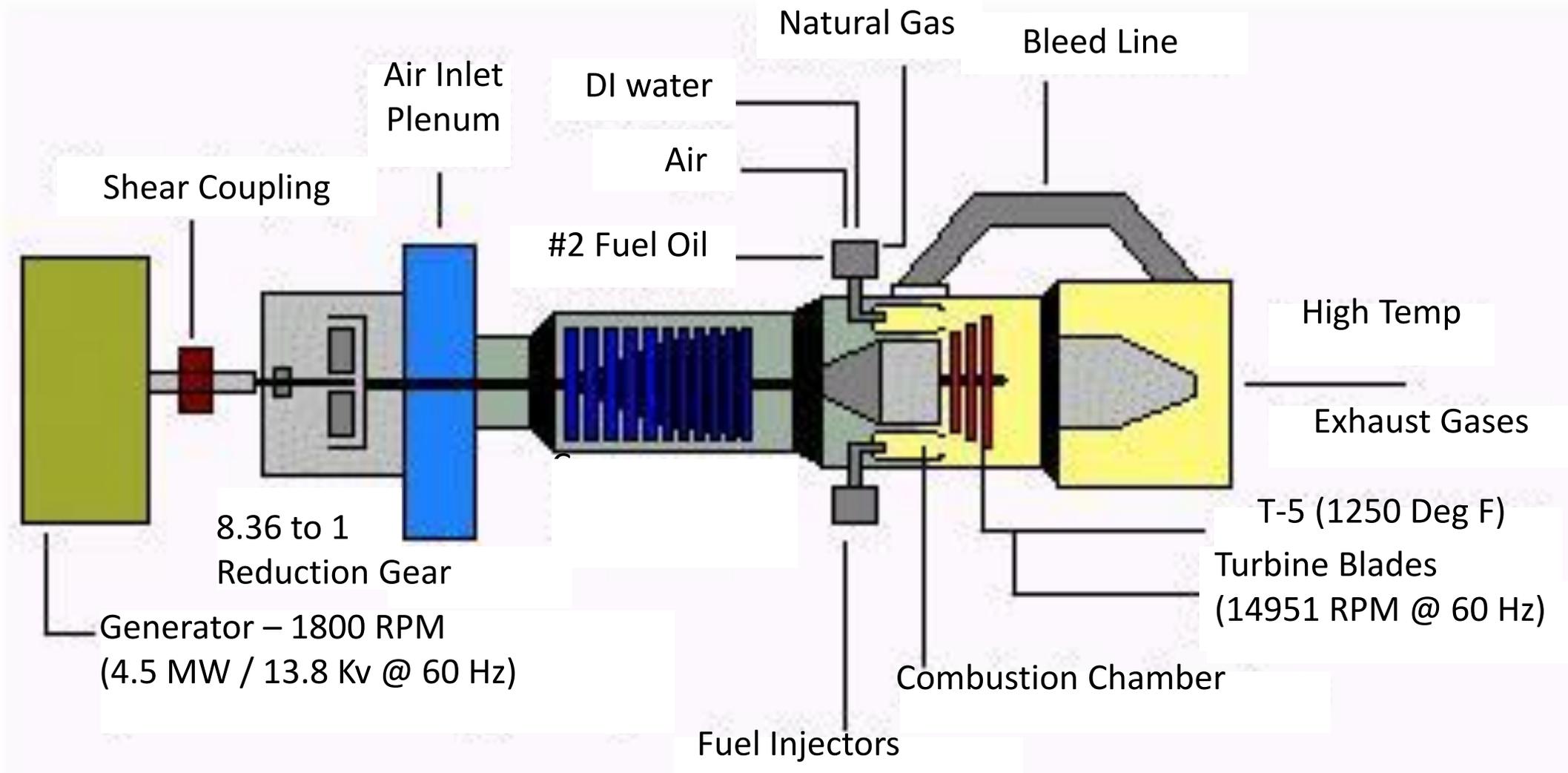
Combined Cycle and Co-Generation

- Uses the excess heat produced by a combustion turbine to power an additional turbine that produces even more electricity
- Combined Cycle units can be used in conjunction with Co-Generation
- Co-Generation (Distributed Generation)
 - A means of generating hot water, and / or high and low pressure steam and electricity at the same time, from the same energy source, yielding a highly efficient power plant

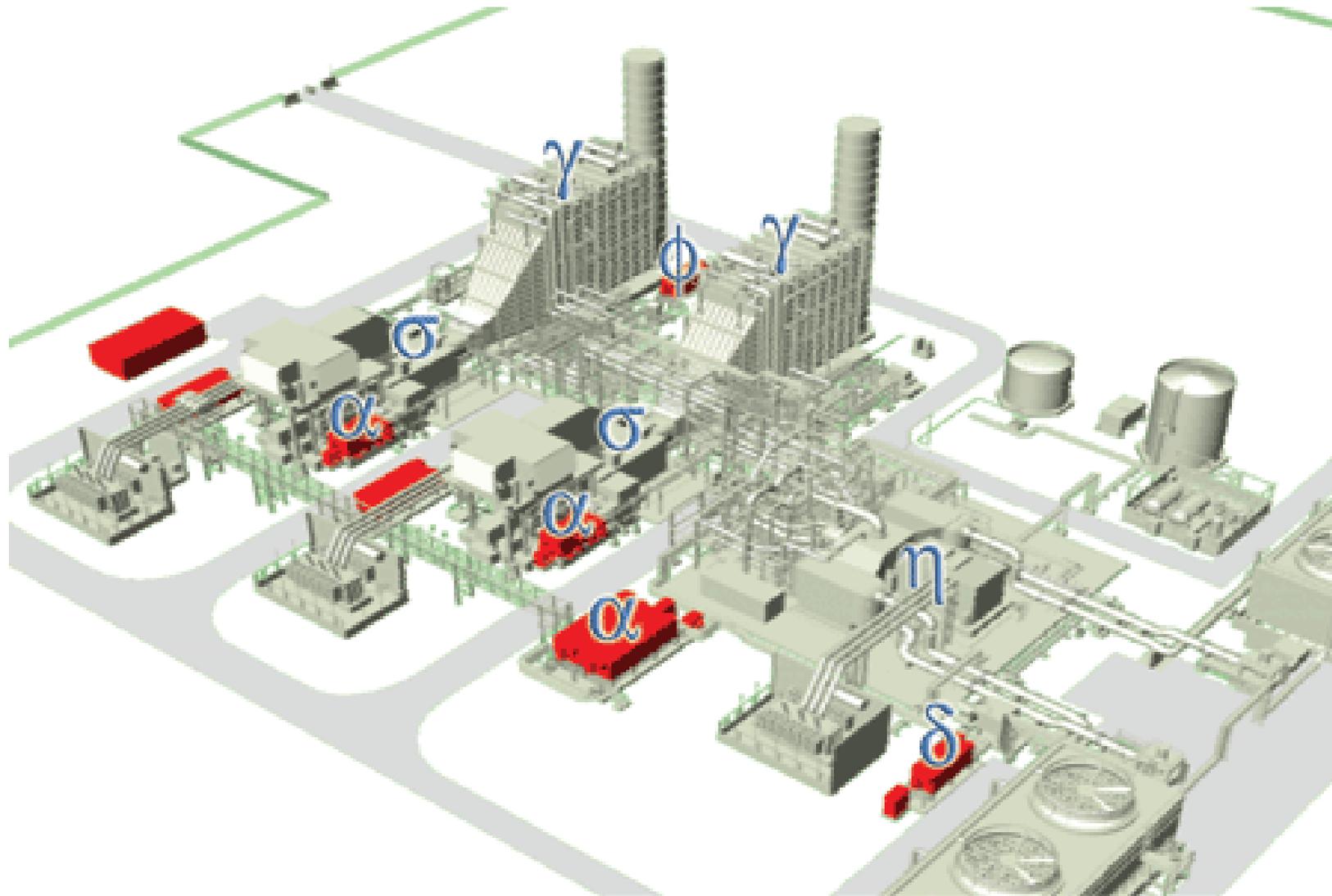
Combined Cycle with Cogeneration



Combustion Turbine



Simple Combined Cycle Unit



Simple Combined Cycle Unit

- One (or more) combustion turbine unit along with an associated generator

AND

- One Heat Recovery Steam Generator (HRSG) along with it's own steam turbine

http://www.youtube.com/watch?feature=player_embedded&v=jQ4yp_0Djvc

Combined Cycle

- The HRSGs convert heat in the CT exhaust gas to steam for use in the steam turbine
- CT's utilizing the HRSG can be operated from 50 to 100% peak load
- HRSG incorporates features of conventional fossil-fired boilers such as:
 - Economizer, Evaporator, and Superheater
 - Auxiliary systems for the steam turbine portion are similar to conventional steam plants
 - Cooling water must be supplied for the steam turbine's condenser
 - Operates with a simple feedwater cycle

Environment

- Gas Fired Combined Cycle Unit Advantages
 - Lower Emissions
 - SO₂ and Particulate emissions are negligible
 - NO emissions are lower than a conventional coal plant
 - No sludge or ash production/emissions
 - Land Use
 - CCPP on the average require five times less land than a coal fired plant (100 acres versus 500 acres)
 - Water Use
 - Lower cooling and condensate water consumption
 - Condensing steam turbine is only about 35% of output

Advantages/Disadvantages

- Disadvantages:
 - Increased chemistry requirements with more complex plants
 - Rapid heating and cooling of critical components
 - Emissions to the environment: nitrogen oxides (NO), sulfur dioxide (SO₂), carbon monoxide (CO), carbon dioxide (CO₂), and opacity
 - Availability and cost of fuel
 - Poor thermal performance, high vibration, tube leaks, and ambient conditions
 - Auxiliary equipment out of service may prevent unit from achieving full load

Combustion Turbines

- **Advantages:**

- Automatic- Some even have remote start capability (unmanned)
- Low initial capital investment - turn-key operation (modular)
- Self contained unit
- Short delivery time
- Fast starting and fast load pickup
- Very good governor response
- Some have Black Start capability
- No cooling water required

- **Disadvantages**

- Fuel operating cost (heat rate)
- Low Efficiency: 25%- 40%
- Thermal stress - high rate of temperature change, short life due to cycling, high maintenance cost

Combustion Turbines

- CT MW Output Limitations:
 - Ambient air temperature & air density
 - Most efficient when using cold, dense air
 - Cold Weather starting problems
 - Lube oil Temperature
 - Moisture in the Fuel
- CT Environmental Limitations:
 - Stack Emissions (NO/CO₂/CO)
 - High operating temperatures in combustion section accelerates nitric oxide formation and emission
 - Particulate emissions can be high (especially older units) – Opacity
 - Noise level limitations

Wind Generation

Generating Unit Principles of Operation

Wind Conversion Process

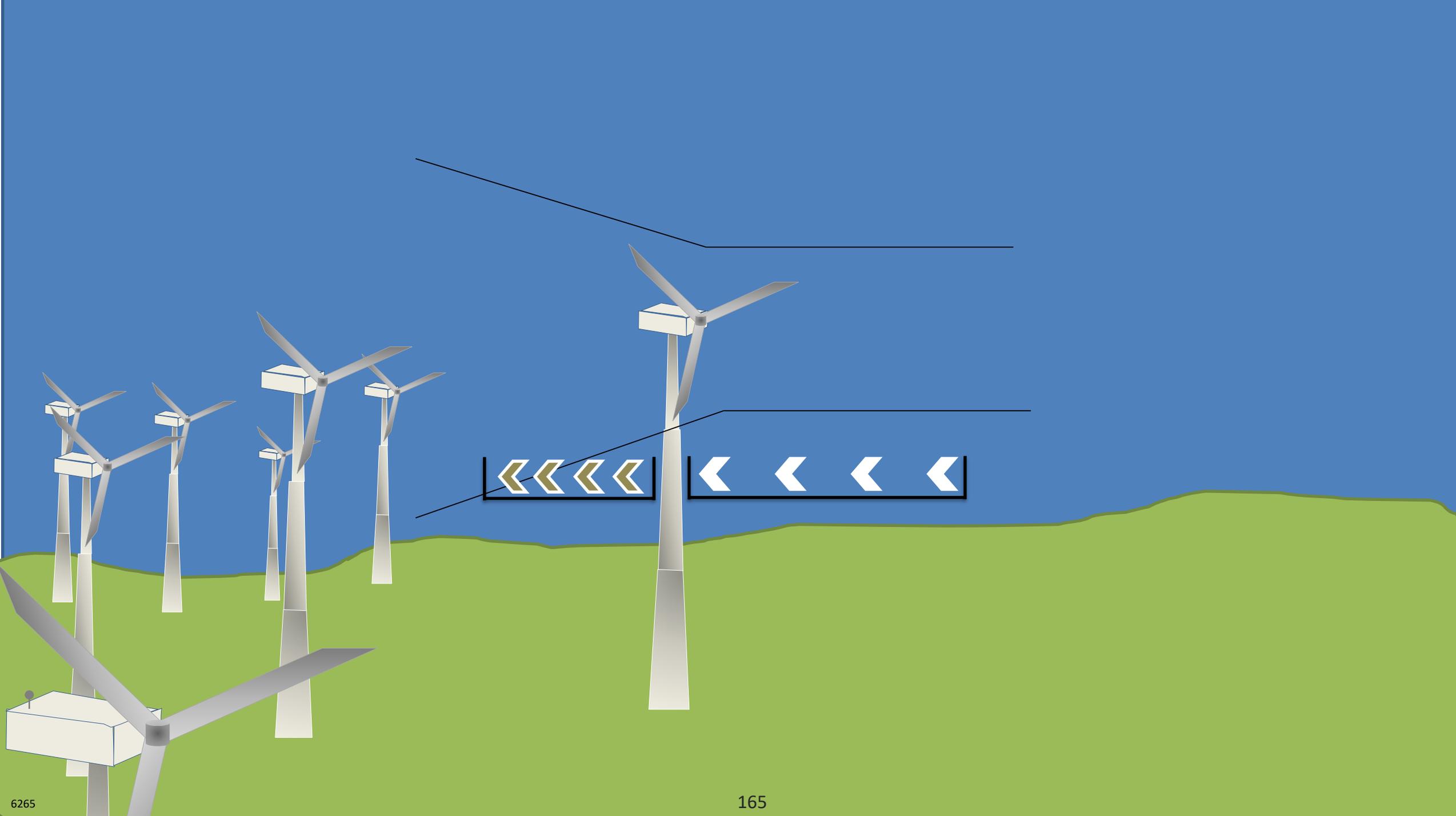
Kinetic Energy (Wind)

to

Mechanical Energy (Turbine)

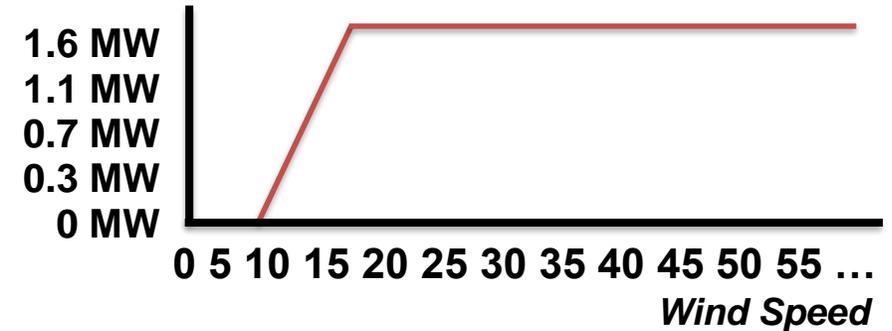
to

Electrical Energy (Generator)



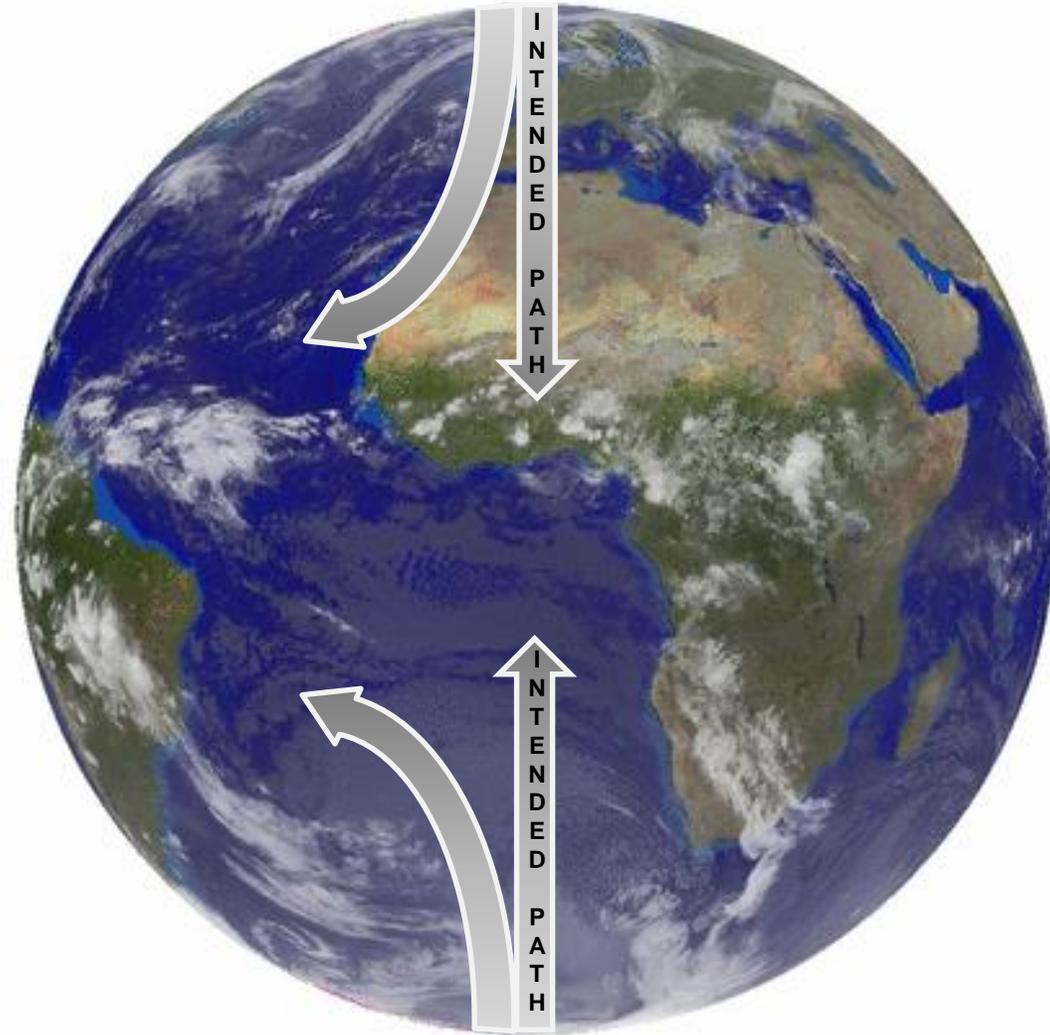
Wind Generation

- Wind is a form of **solar** energy caused by:
 - Uneven heating of the atmosphere
 - Irregularities in the earth's surface
 - Rotation of the earth

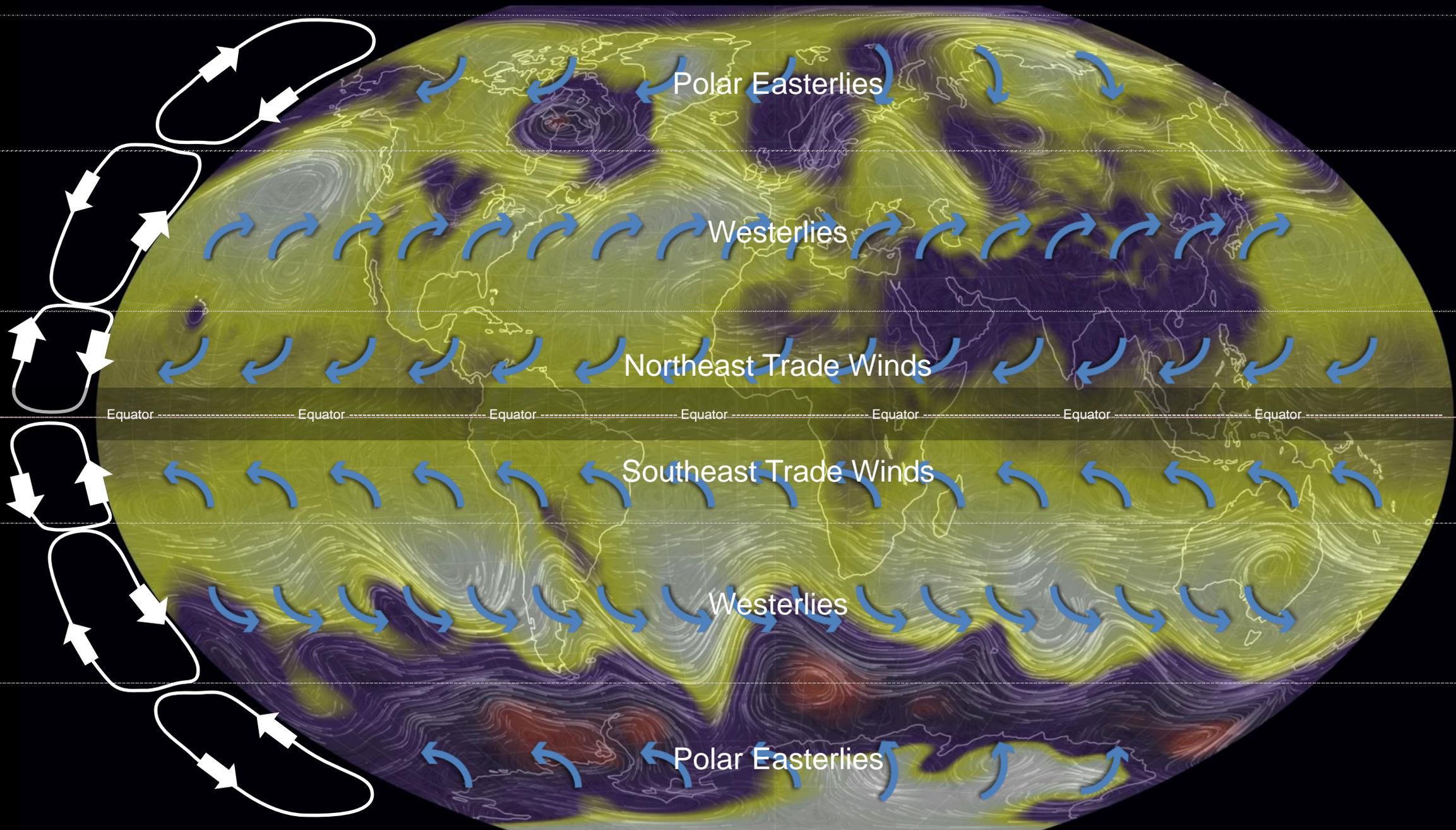


- Wind flow patterns can be effected by; terrain, vegetation, bodies of water, and even the turbines themselves
- Power available in the wind is proportional to the cube of its speed (Double the speed increases the power by a factor of eight)

Coriolis Effect

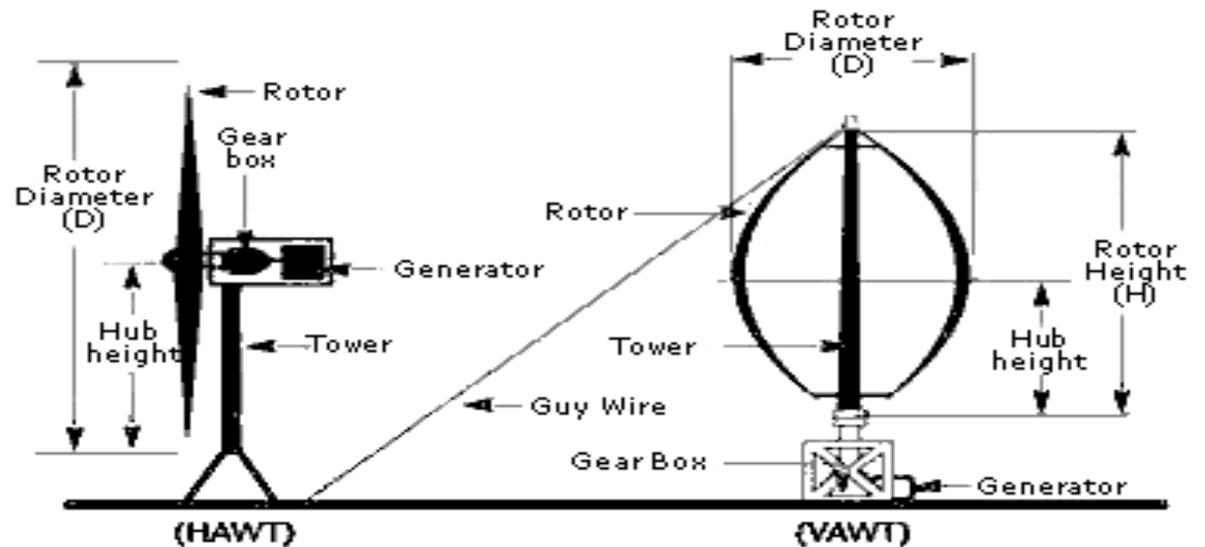


Globe Source: Satellite Applications for Geoscience Education



Wind Generation

- Wind power depends on elevation and wind speed
- It is considered a free and renewable resource just like hydroelectricity
- Wind power currently provides roughly 1.5% of all electricity in PJM
- Two basic types:
 - Horizontal axis turbines
HAWT
 - Vertical axis turbines
VAWT



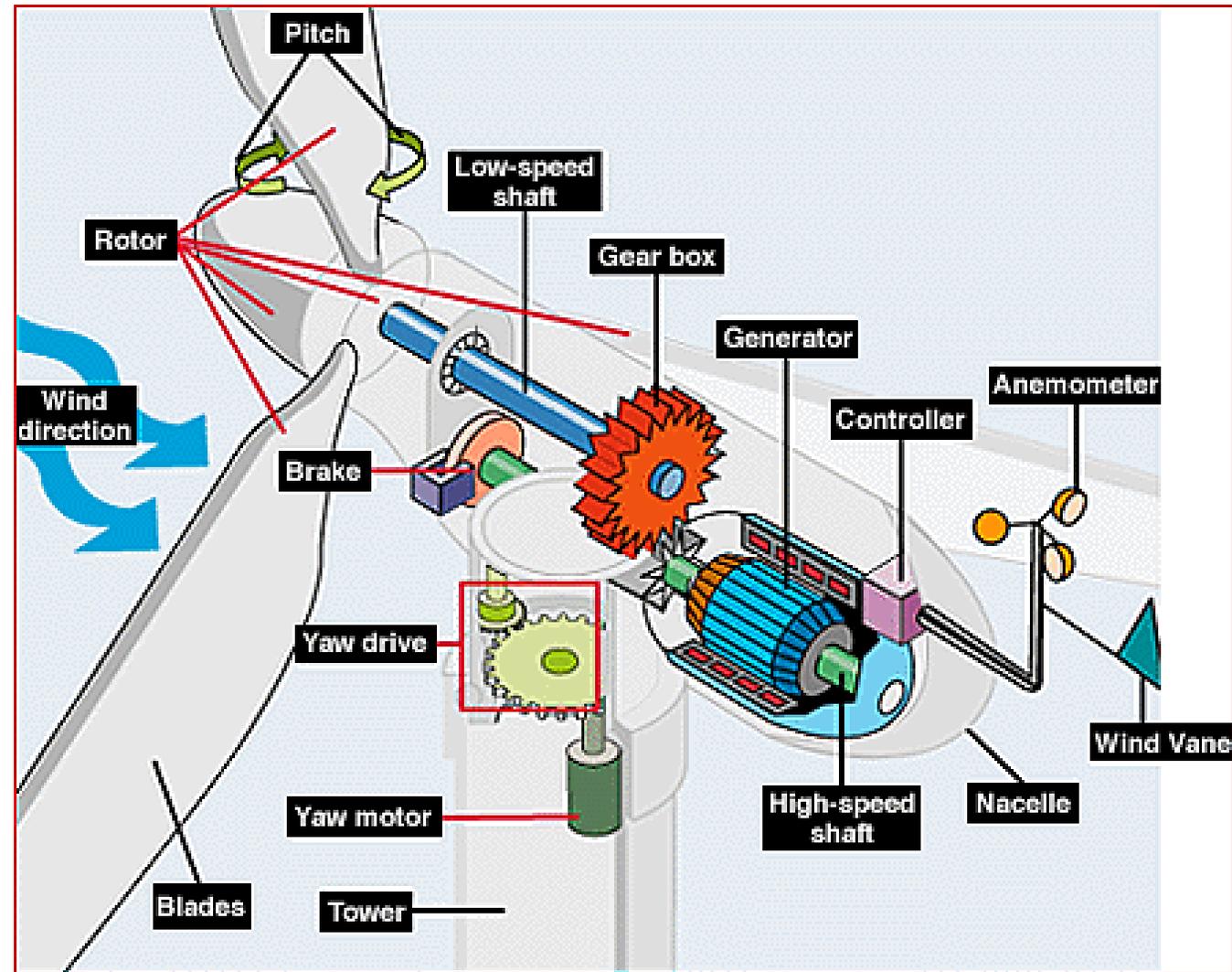
Wind Generation

- Wind Generators come in both:
 - **Asynchronous** – their speed is not locked in step with the grid
 - They produce power when the shaft of the generator is rotated faster than the synchronous frequency of the equivalent induction motor
 - Operate as Induction Generators -the magnetic field of the rotor is supplied from the grid via electromagnetic induction
 - **Synchronous**
 - Frequency of the rotor and stator magnetic fields generated by the coils are the same

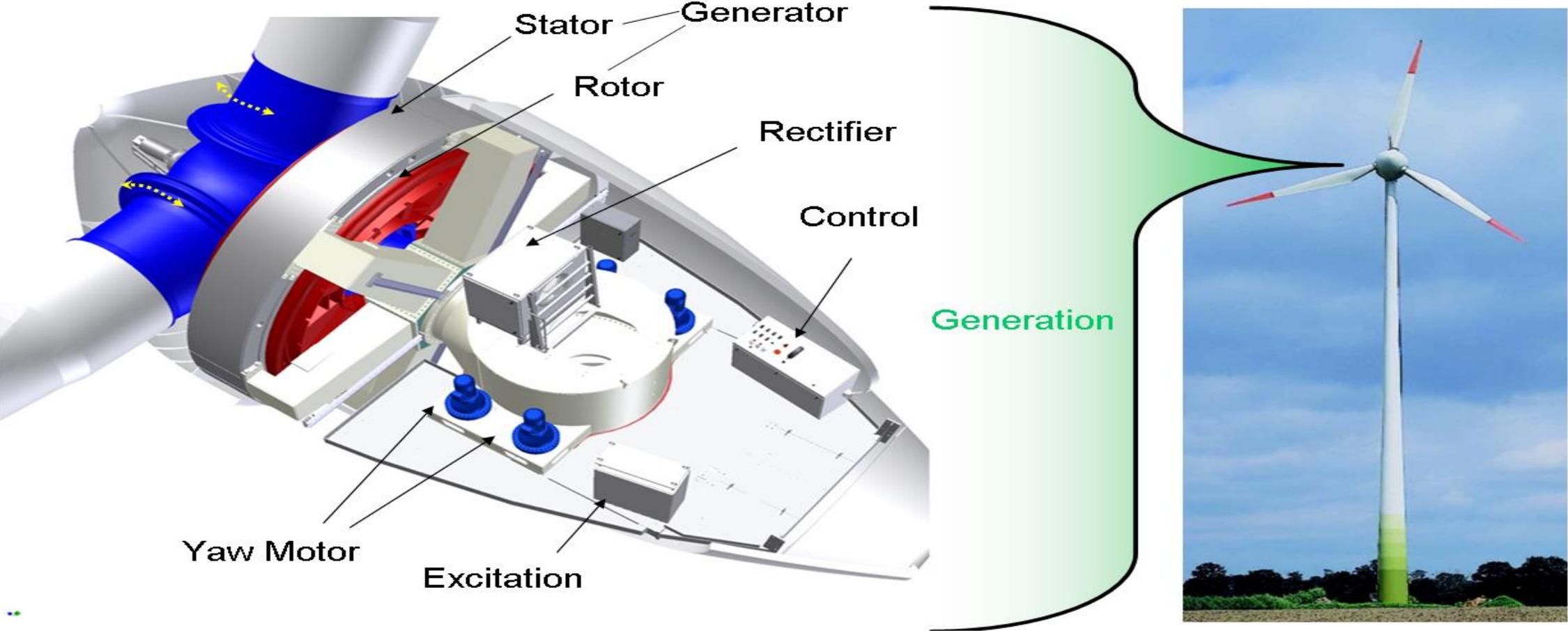
Induction Generator

- Induction generators:
 - Produce useful power at varying rotor speeds
 - Are simpler both mechanically and electrically than other types of generators
 - Do not require brushes or commutators
 - Are not self-exciting; require external excitation (reactive)
 - Require complicated electronic controllers (allows speed of the generator to vary with the speed of the wind)

Wind Power Generation

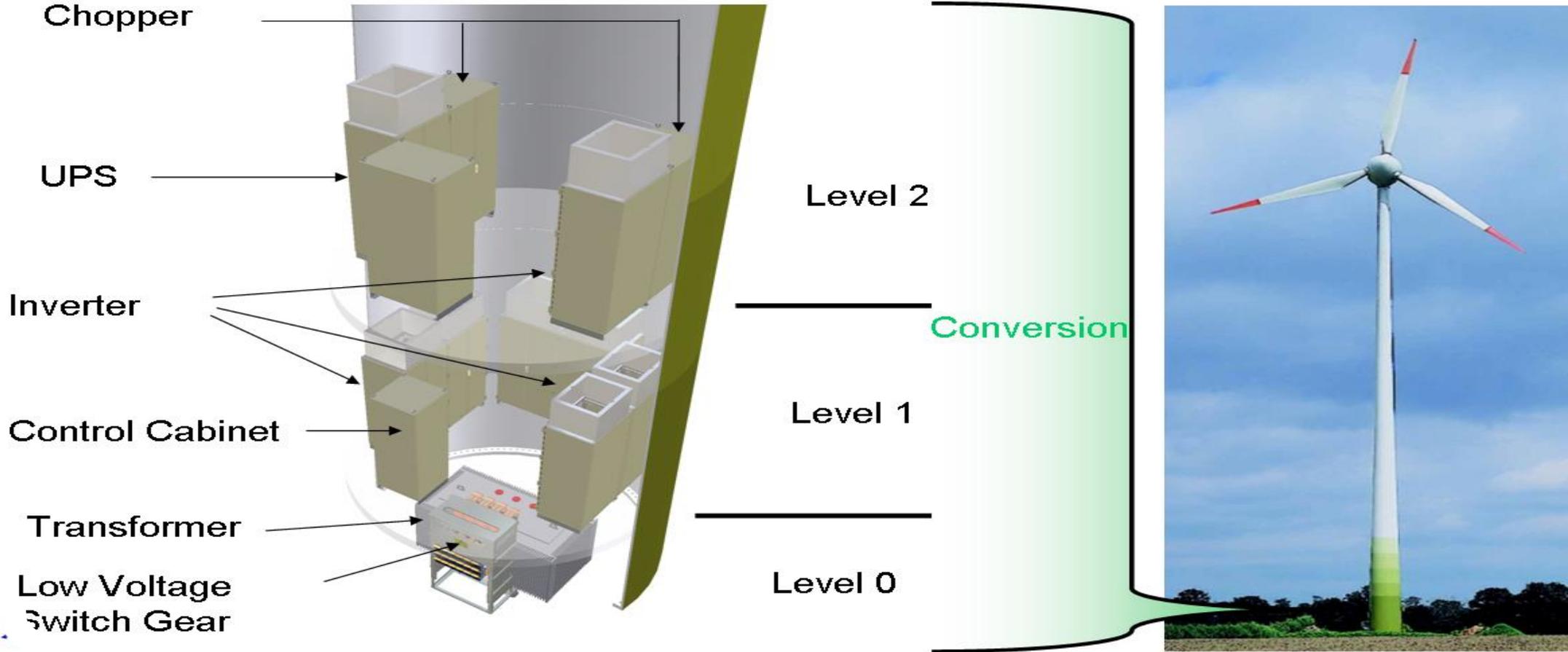


Wind Turbine Major Parts



Other type units may have gear boxes

Tower Components



Wind Unit Components

- **Anemometer:** Measures wind speed and transmits data to the controller
- **Blade:** Catches the wind causing the blades to lift and rotate converting it to rotational shaft energy (2-3 blades)
- **Brake:** Disc brake which can be applied mechanically, electrically, or hydraulically to stop the rotor in an emergency
- **Chopper:** Circuitry used to obtain a controllable DC voltage from wind-driven, self-excited, pole-changing induction generators
- **Controller:** Computer monitoring the turbine conditions such as overheating and power quality. It also starts the turbine, yaws it against the wind, and checks the safety systems
 - Starts at wind speeds of 8-16 mph
 - Shuts down at wind speeds greater than 55 mph

Wind Unit Components *(Con't.)*

- **Gearbox:** Optimizes the power output connecting a low-speed shaft the high-speed shaft increasing rotational speeds from 30 to 60 rpm to 1,000 to 1,800 rpm
- **Generator:** Induction-type producing 60 cycle AC
- **High-Speed Shaft:** Drives the generator
- **Inverter:** Converts incoming DC power into AC power for use on the Interconnection
- **Low-Speed Shaft:** Connected to the rotor
- **Nacelle:** Sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake
- **Pitch Control:** Blades are turned out of the wind to control the speed of the rotor

Wind Unit Components *(Con't.)*

- **Rectifier:** Converts incoming AC power into DC power for excitation
- **Rotor:** Blade and hub assembly. Power available to the blades is proportional to the square of the diameter of the rotor
- **Tower:** Tubular steel, concrete, or steel lattice. Taller the tower, more energy is captured; more electricity is generated
- **Yaw Control:** Used by upwind turbines to rotate parallel to the ground to keep the rotor facing into the wind as wind direction changes

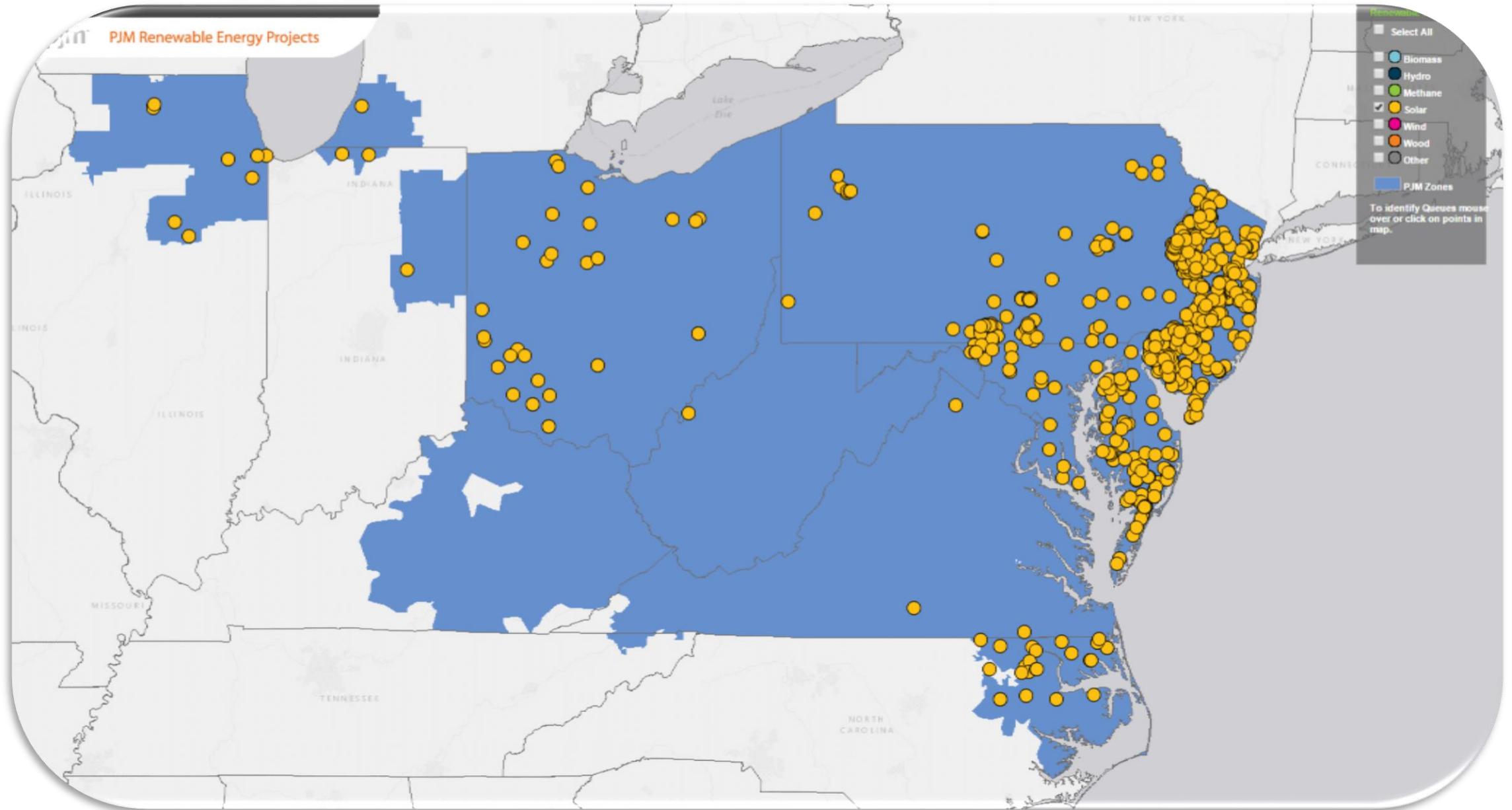
Wind Power Generation

- Wind turbines are available in a variety of sizes:
 - GE-1.5 MW
 - 116 foot blades on a 212 foot tower weighing 164 tons (total height 328 feet)
 - The blades sweep a vertical airspace of just under an acre
 - MHI Vestas V-90-1.8 MW
 - 148 foot blades on a 262 foot tower weighing 267 tons
 - Gamesa G87-2 MW
 - 143 foot blades on a 256 foot tower (total height 399 feet)
 - MHI Vestas V164-9.5 MW
 - 262 foot blades weighing 73,000 lbs

Wind Power Generation

- Wind Power Advantages:
 - Wind is a free, renewable resource
 - Non-polluting energy source
- Wind Power Disadvantages:
 - High initial Investment - 80% Equipment, 20% Site preparation
 - Intermittent resources at best
 - Remote locations
- Environmental Impacts
 - Noise produced by the rotor blades
 - Visual impacts on scenery
 - Wildlife effects

Solar Generation

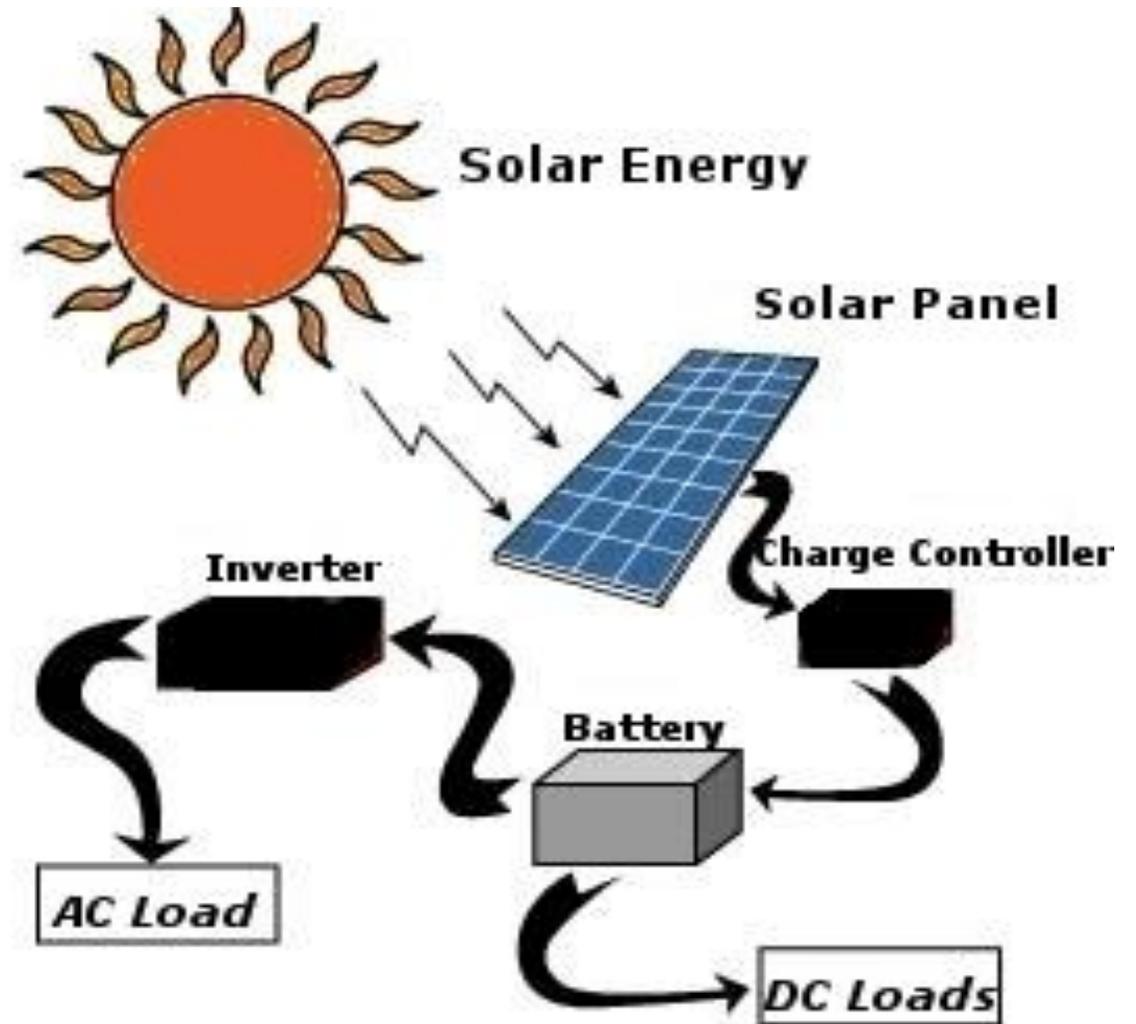


Direct Solar Energy

- One step transformation to useable energy
 - Sunlight striking a solar cell by which electricity is immediately generated
 - Sunlight that is absorbed by the dark surface warms water in solar thermal collectors
 - Sunlight absorbed by a fiber optic cable that is fixed on the exterior of a building and lights the inside

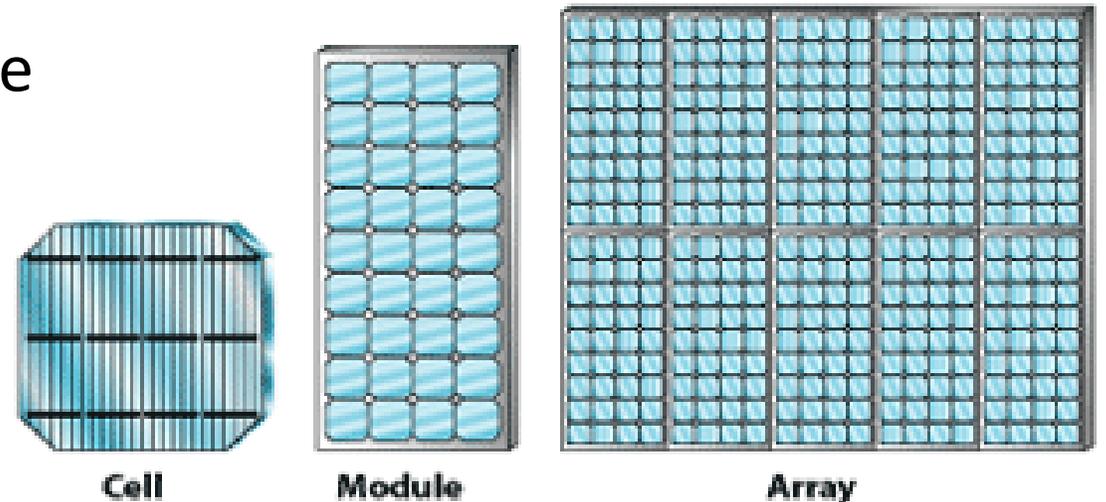
Direct Conversion into Electricity

- A silicon wafer with wires attached to the layers. Current is produced based on types of silicon used for the layers
- The absorbed light (photons) excites the electrons causing them to begin to flow in one direction
- Initially DC, later converted to AC
- Battery needed if storage is desired
- No moving parts, does not wear out
- Environmental conditions limit life to approx. 20 years



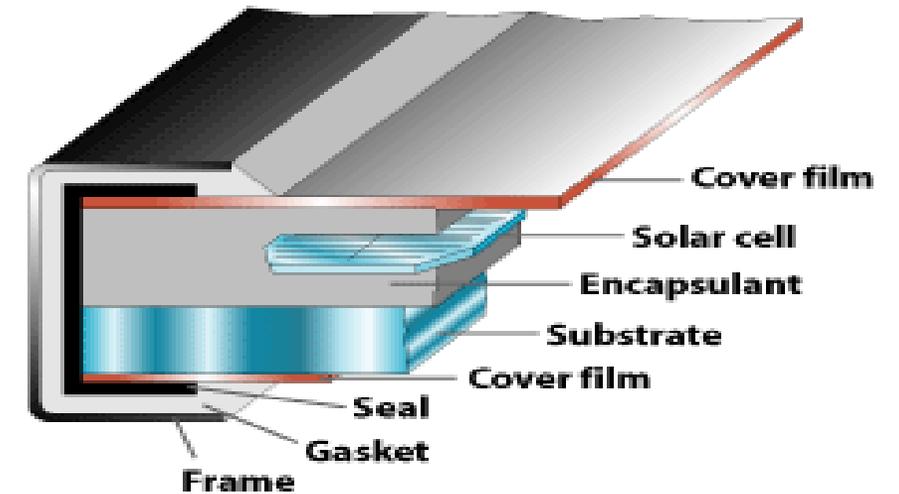
PV Systems

- Made up of several photovoltaic solar cells absorbing sun light, not warmth
- Individual cells are small, typically producing about 1 or 2 watts of power
- Modules are groupings of individual cells
- Modules can be grouped together to form larger units called Arrays
- Arrays can be interconnected to produce more power
- PV systems are flexible and can meet almost any electric power need, small or large



Flat Plate Systems

- Most common photovoltaic (PV) array design
 - Fixed position
 - Moveable (track the movement of the sun)
- The simplest is a fixed position
 - Advantages
 - No moving parts
 - No additional equipment needed
 - Relatively lightweight
 - Suitable for many locations, including most residential roofs
 - Disadvantages
 - Orientation to the sun is usually at an angle that is less than optimal
 - Fixed arrays collect less energy per unit area of array than tracking arrays

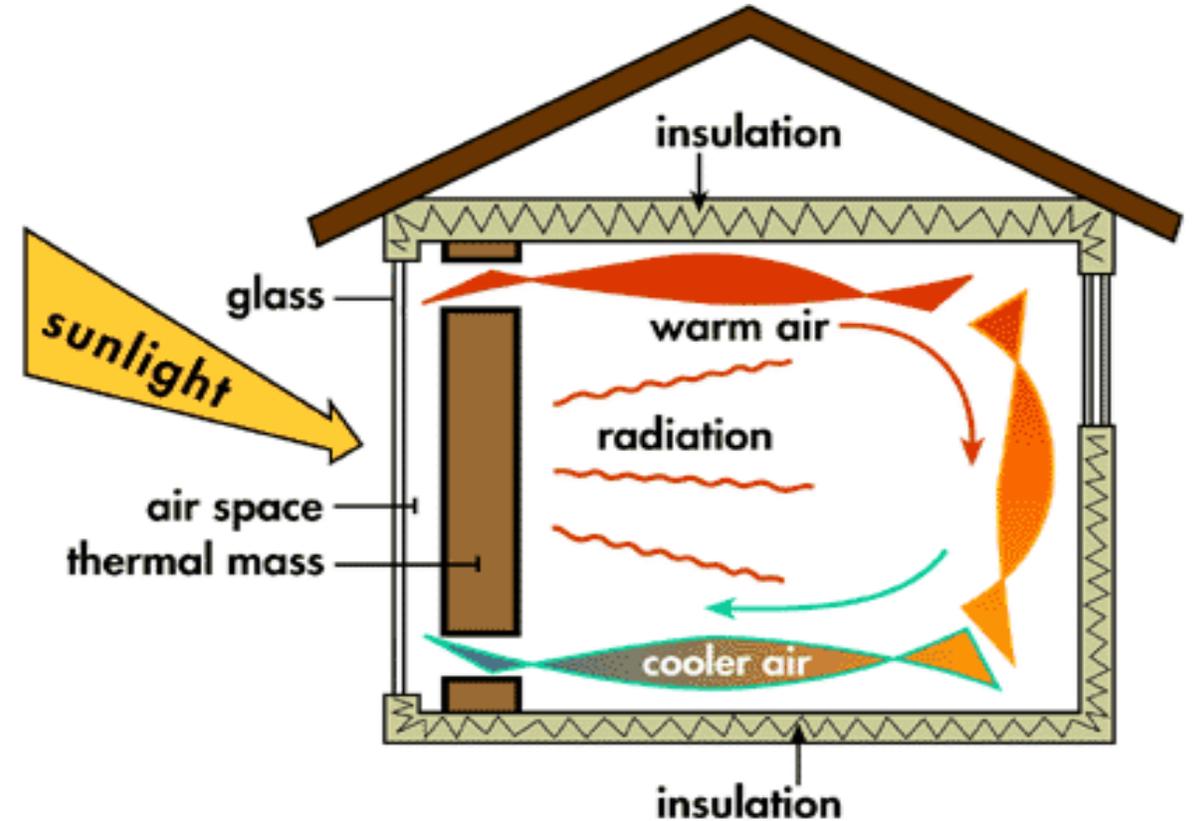


One typical flat-plate module design uses a substrate of metal, glass, or plastic to provide structural support in the back; an encapsulant material to protect the cells; and a transparent cover of plastic or glass.

Passive Systems

Requires Direct Sunlight (Only)

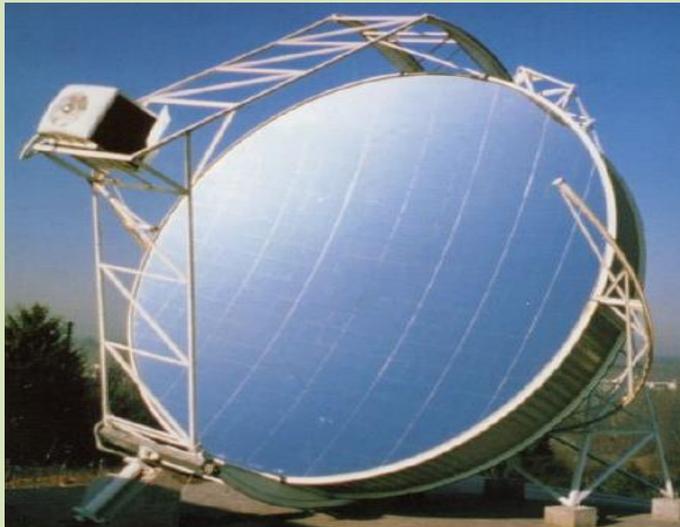
- Sunlight warming an area through a window
- Passive solar water heaters use no pump to circulate its water A passively heated home uses about 60-75% of the solar energy that hits its walls and windows
- The Center for Renewable Resources estimates that in almost any climate, a well-designed passive solar home can reduce energy bills by 75% with an added construction cost of only 5-10%
- About 25% of energy is used for water and space heating



Active Systems

- Active systems use additional energy to make them work
 - Electronic tracking devices to maximize sunlight absorption electric pumps, air blowers, shutters, etc.
 - Can be computer-controlled

Parabolic Dishes and Troughs



Solar-Thermal Electricity: Power Towers

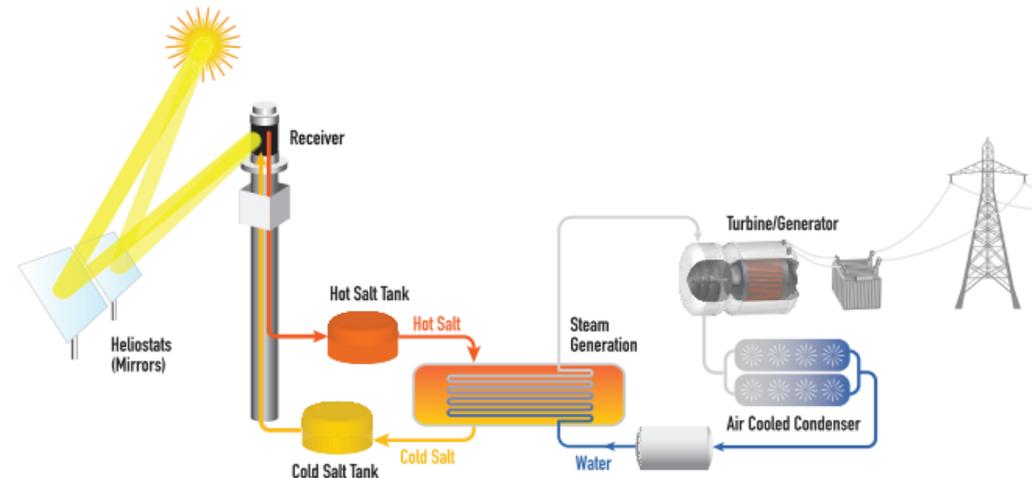


Molten Salt Pillar Generators

- Traditional PV Solar
 - Daytime use
 - No Sun, No Flow
- Traditional Thermal Solar
 - Mostly Daytime use
 - Ramps out quickly
- Molten Salt Pillar Generator
 - Usable @ Night
 - Salt is its own storage
 - Dispatchable



Photo: SolarReserve

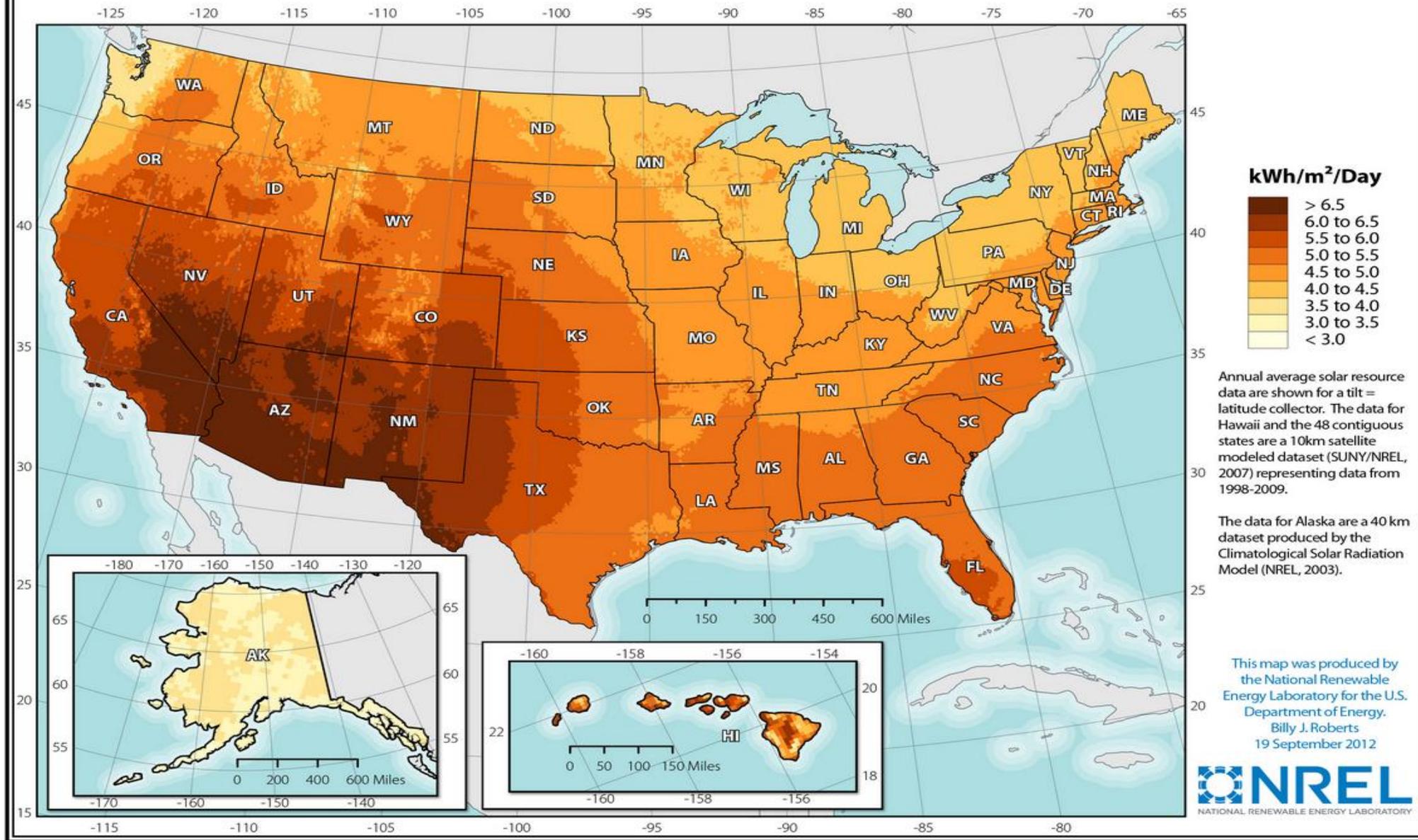


Molten Salt Pillar Generators

- Traditional Thermal
 - Heats oil (400°C) to produce steam
 - Pumps it to a turbine
- Molten Salt
 - Heats molten mixture of nitrate salts (566°C)
 - Stores in insulated tanks
 - Withdraws on demand to produce steam, then turbine
 - Cheaper / More Efficient
- SolarReserve
 - 110 MW
 - 10,000 mirrors (sun trackers)
 - 1,000,000 sq meters
 - Dispatchable up to 10 hours past sunset
 - Tonapah, Nev
 - Purpose?

To energize Las Vegas Strip

Photovoltaic Solar Resource of the United States



Questions?

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