POWER POINT PRESENTATION

ON

POWER SYSTEM - I

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THERMAL POWER PLANT

INTRODUCTION

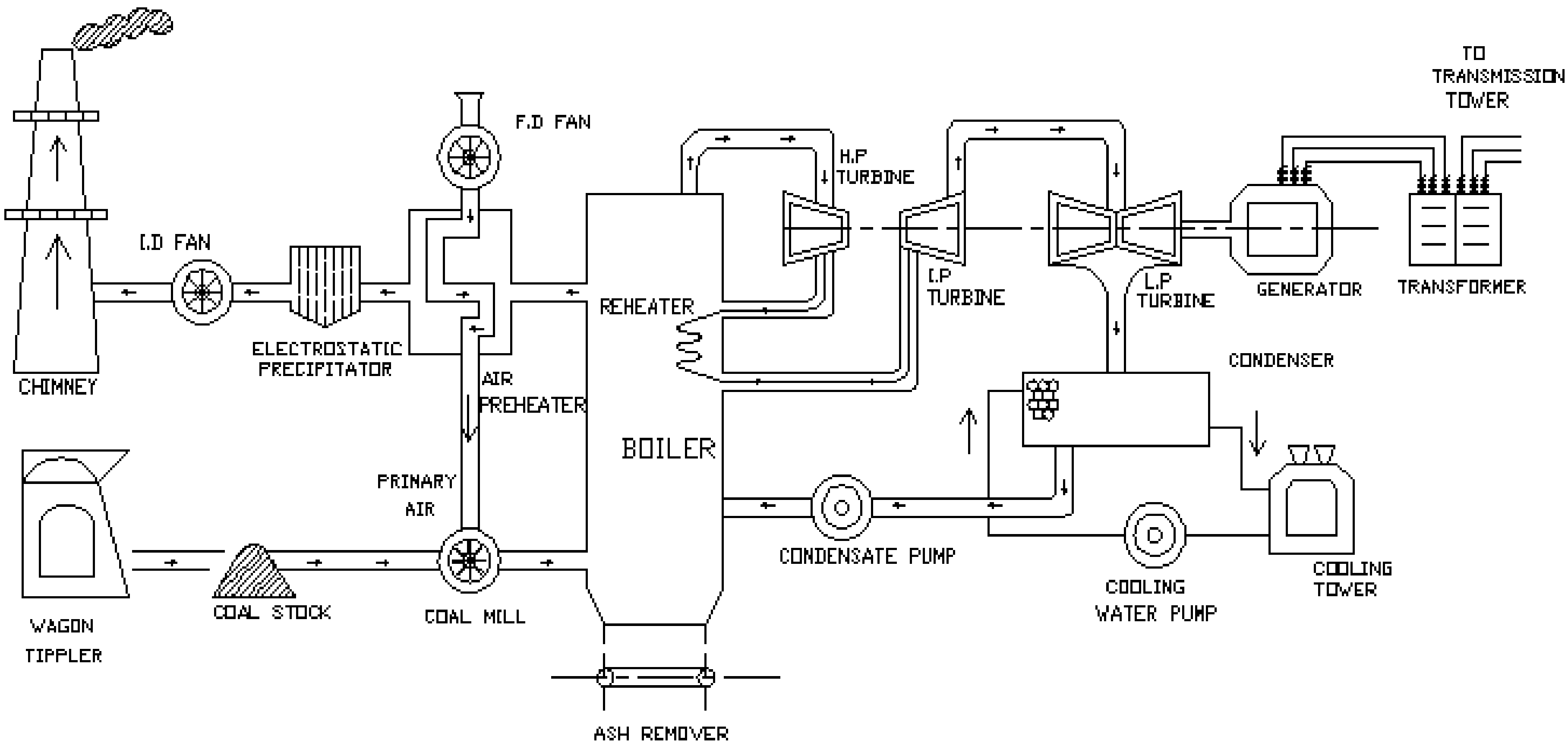
In India 65% of total power is generated by the Thermal Power Stations.

Yamunanagar Thermal Power Project i.e D.C.R.T..P.P(Deen Bandhu ChotuRam Thermal Power Plant) is a project of Haryana Power Generation Corporation limited **(HPGCL).** It is situated at village Kalanor In Yamunanagar. Its total capacity is **600 MW** as at present with two units working with capacity.

Having two unit of **2 x 300 MW = 600 MW**

PLANT LAYOUT

SCHEMATIC DIAGRAM



MECHANICAL DESIGN

- Boiler.
- Furnace.
- Turbine.
- Super Heater & Re- Heater.
- PA,FD & ID Fan.
- Cooling Tower

FUNCTION HELD IN PLANT

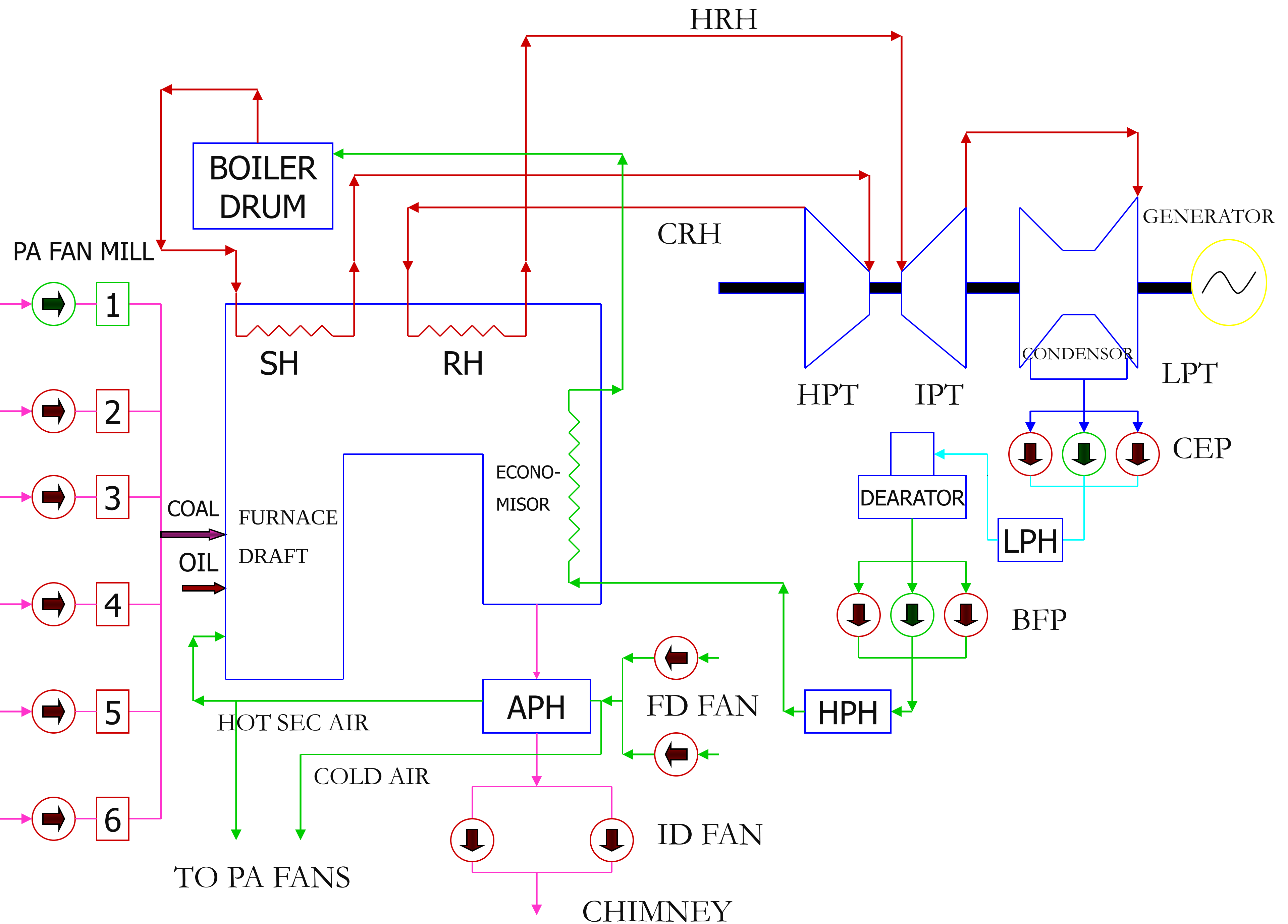
1.COAL FLOW

2.STEAM FLOW

3.WATER FLOW

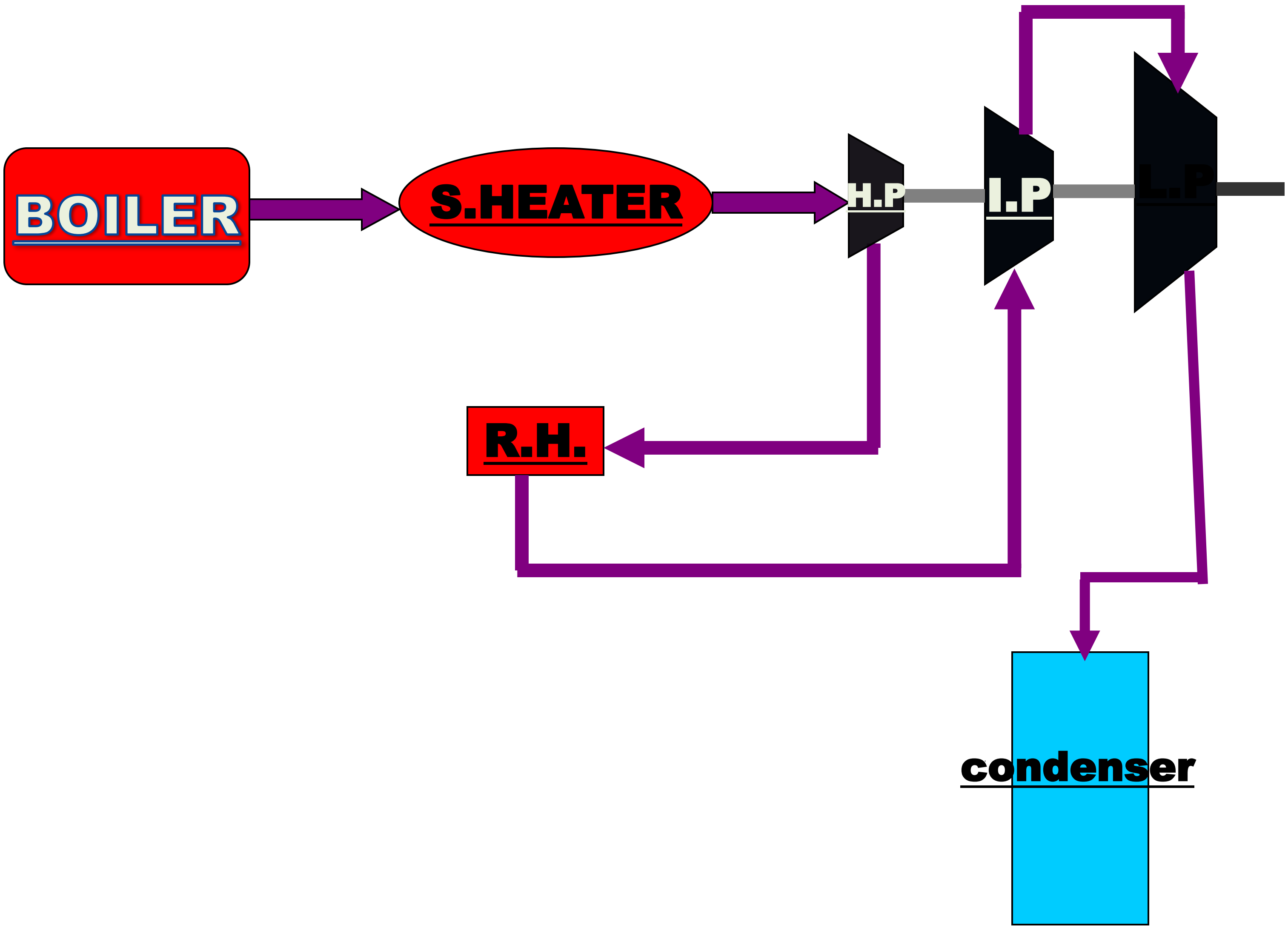
4.ASH HANDLING

OPERATIONAL FEATURES INSIDE THE POWER PLANT

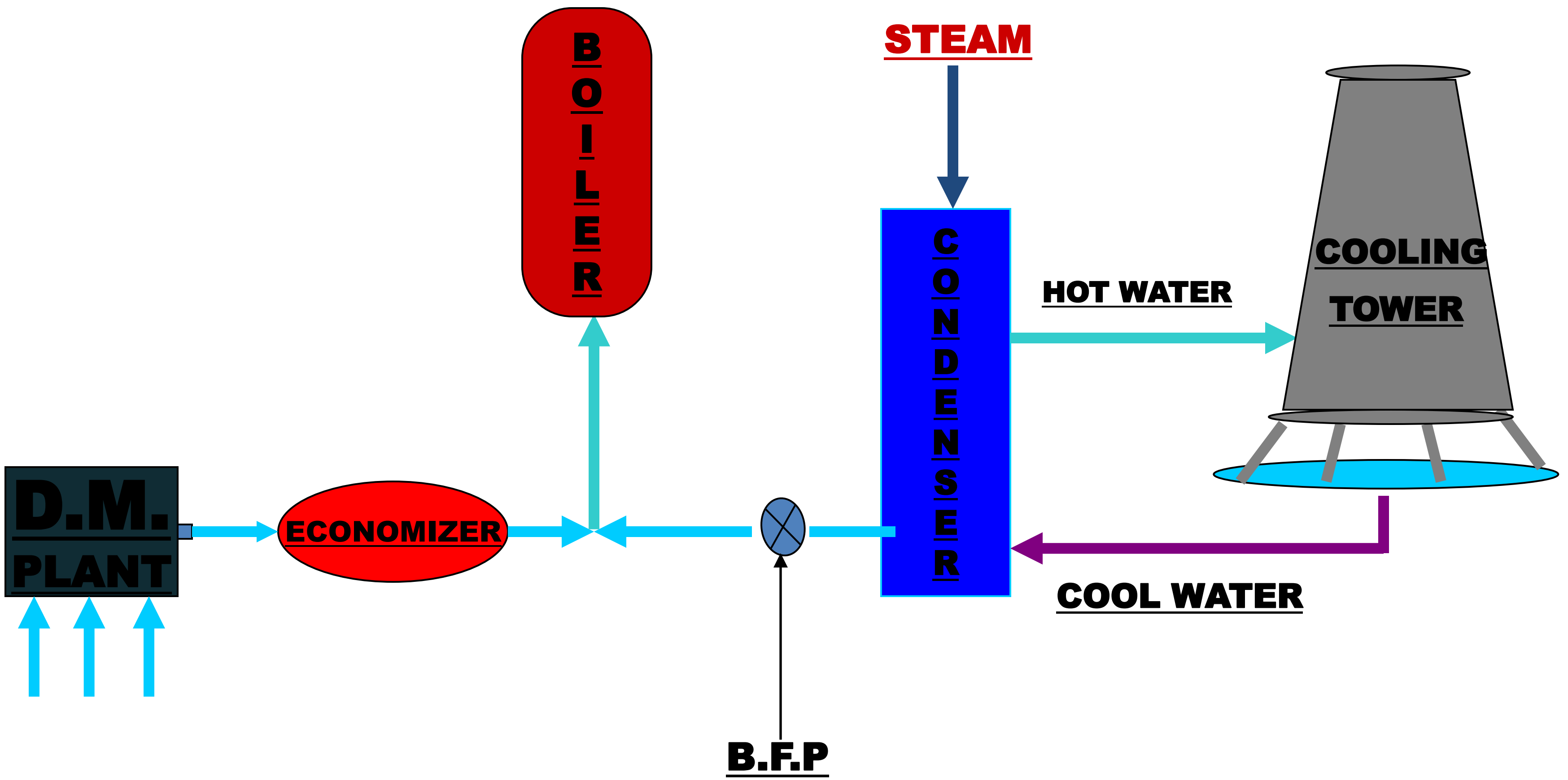


HRH
BOILER DRUM
PA FAN MILL
CRH
GENERATOR
1
2
3
4
5
6
SH
RH
HPT
IPT
CONDENSOR
LPT
CEP
ECONO-
MISOR
DEARATOR
COAL
FURNACE
DRAFT
LPH
OIL
BFP
FD FAN
APH
HPH
HOT SEC AIR
COLD AIR
ID FAN
TO PA FANS
CHIMNEY

STEAM FLOW



WATER FLOW



BOILER
STEAM
CONDENSER
COOLING TOWER
HOT WATER
D.M. PLANT
ECONOMIZER
COOL WATER
B.F.P

TURBINES AUXILIARIES

- **VACUUM SYSTEM:-**

  - **CONDENSER**
  - **EJECTORS**
  - **CW PUMPS**

CONDENSAT DEAERATORE SYSTEM:-

- **CONDENSATE EXTRACTION PUMPS (CEP)**
- **LP HEATERS**
- **DEAERATOR**

FEED WATER SYSTEM

HIGH PRESSURE HEATERS

BOILER FEED PUMP (BFP)

FEED REGULATING STATIOIN

DRIP & DRAIN SYSTEM

BOILER & IT'S ACCESSORIES

- **BOILER DRUM**

SUPER HEATERS

AIR HEATERS

SUPRING LOADED SAFETY VALVES

PRIMARY AIR CYCLE

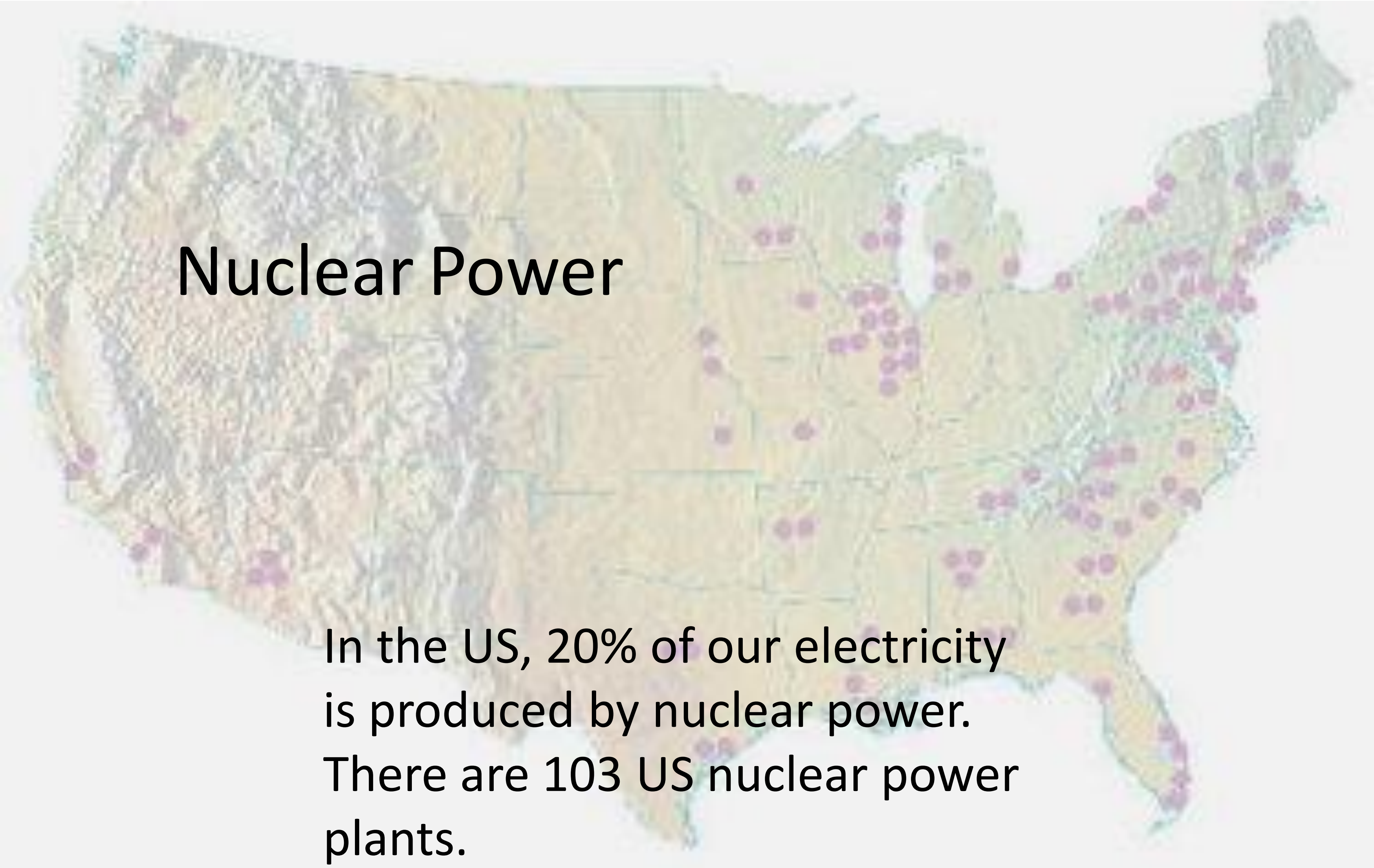
IGNITERS

ECONOMIZER

SUPER HEATERS

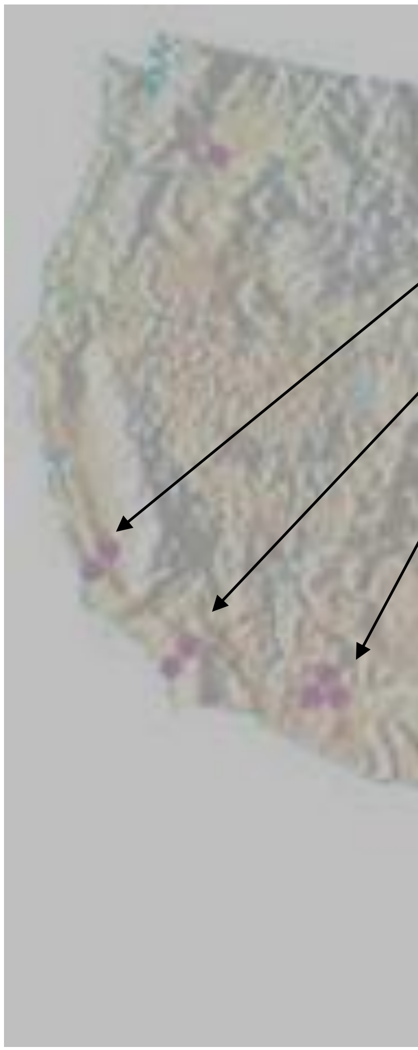
REHEATERS

Nuclear Power



In the US, 20% of our electricity is produced by nuclear power. There are 103 US nuclear power plants.

California related reactors



Diablo Canyon, two reactors

San Onofre, two reactors

⅓ of Palo Verde 1, 2, & 3 in Arizona

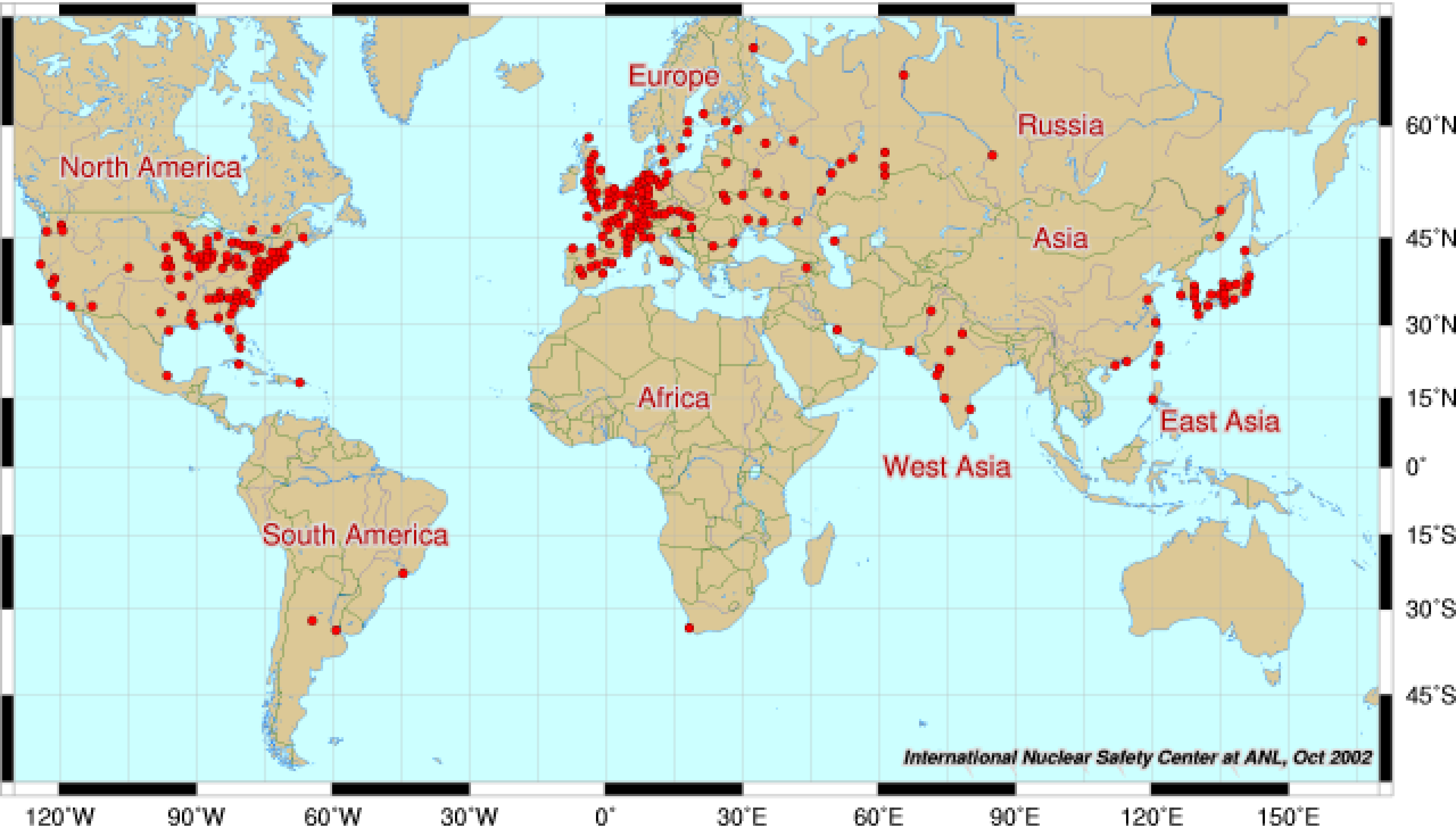
California Nuclear energy

- Each of the five reactors produces about 1,100 million watts (megawatts) of electricity
- This is enough to power one million homes per reactor
- Each reactor’s production is equivalent to 15 million barrels of oil or 3.5 million tons of coal a year.
- The total 5,500 reactor produced megawatts is out of a peak state electrical power of 30,000 – 40,000 megawatts.

Worldwide Nuclear Power Reactors

- There are 440 nuclear power reactors in 31 countries.
- 30 more are under construction.
- They account for 16% of the world’s electricity.
- They produce a total of 351 gigawatts (billion watts) of electricity.

World Nuclear Power Plants



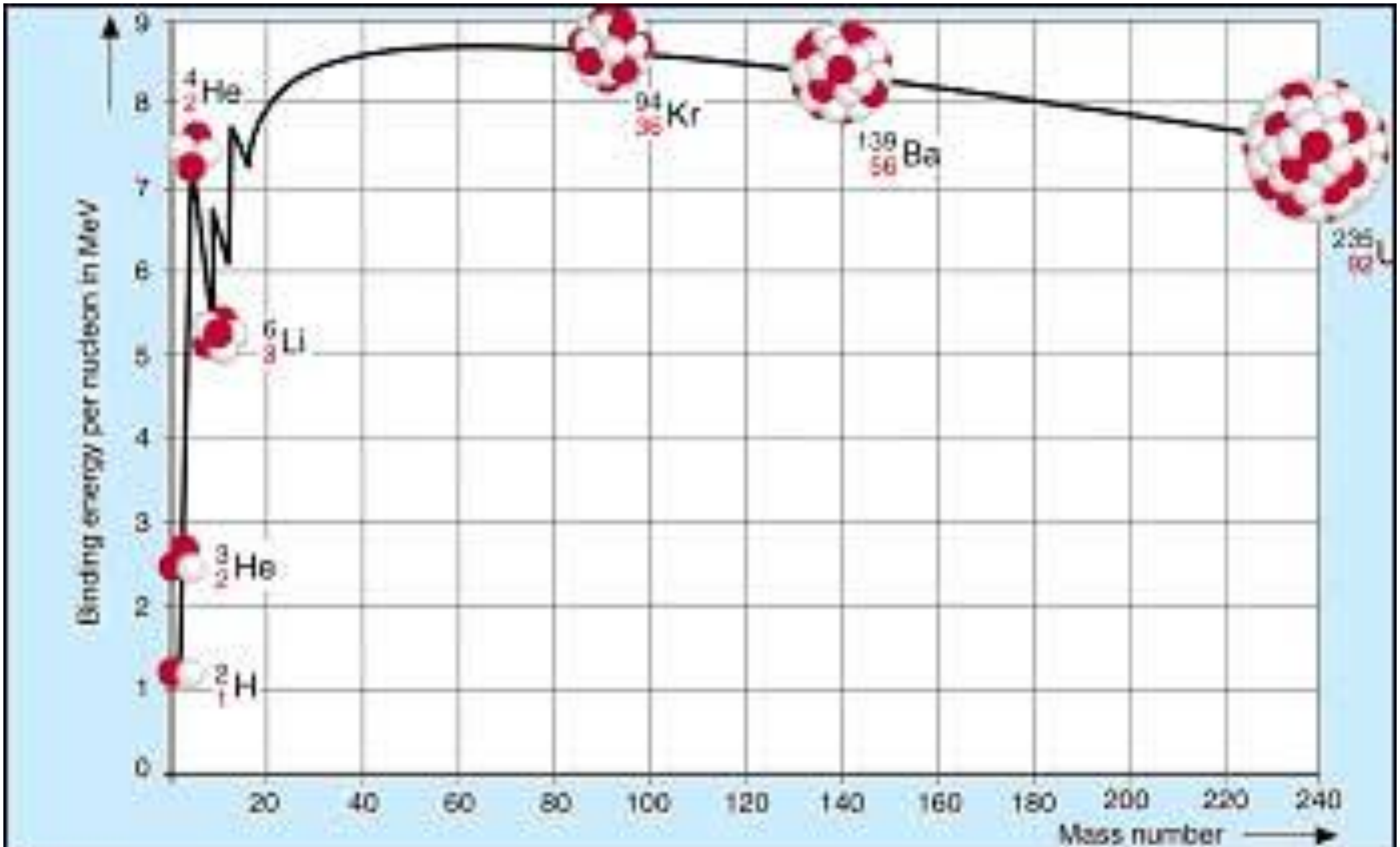
Nuclear Electricity Production by Countries and Regions in Gigawatts (World Total 350 Gigawatts) and percent of electricity

US	97 Trend: declining
North America Region	109
France	63 Increasing
Germany	21 Being phased out
U. K.	12
Western Europe Region	126
Japan	44 Increasing
Asia Region	66 Increasing
Eastern Europe Region	11
Former Soviet U. Region	34

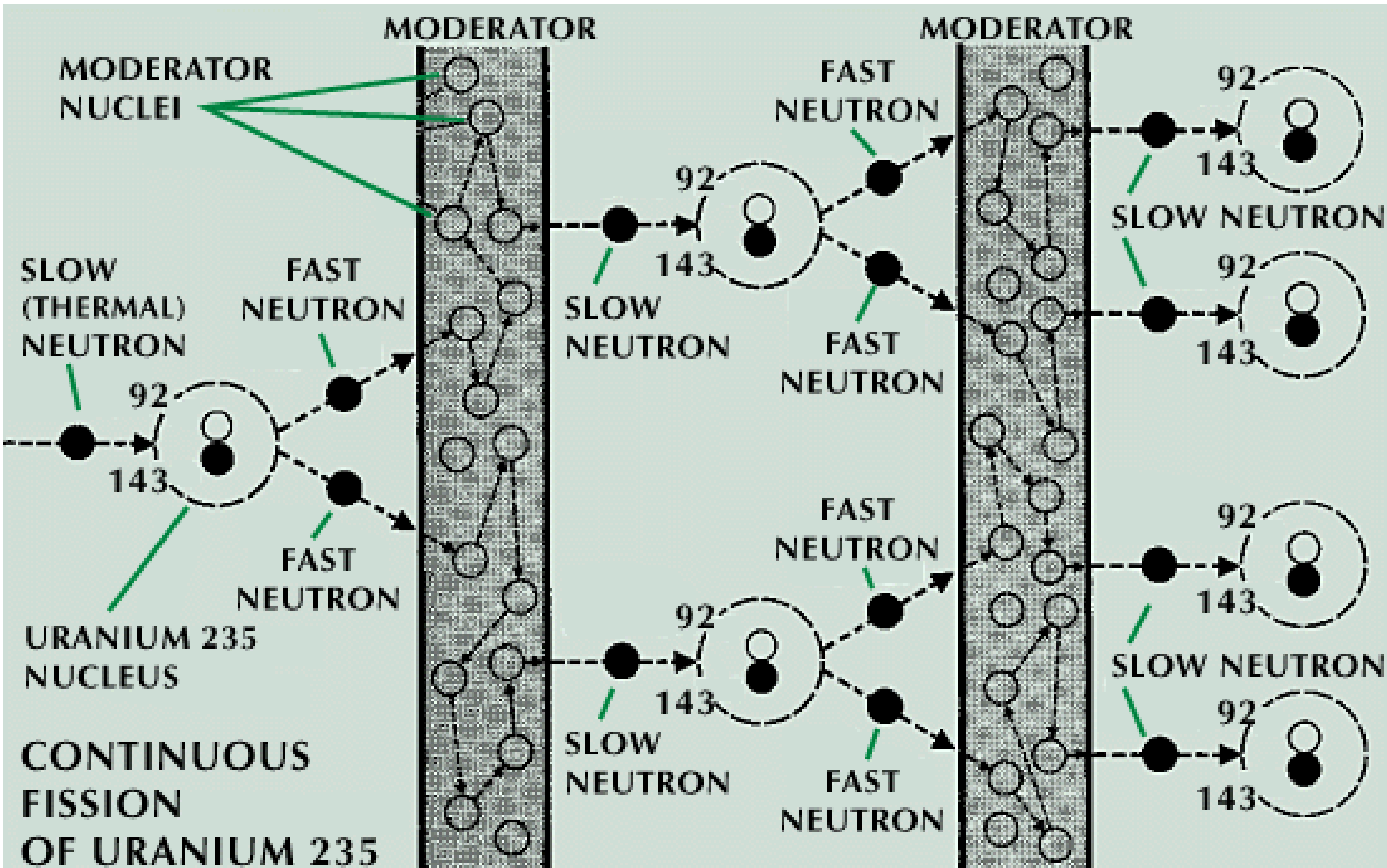
How a Nuclear Reactor works

- ^{235}U fissions by absorbing a neutron and producing 2 to 3 neutrons, which initiate on average one more fission to make a controlled chain reaction
- Normal water is used as a moderator to slow the neutrons since slow neutrons take longer to pass by a U nucleus and have more time to be absorbed
- The protons in the hydrogen in the water have the same mass as the neutron and stop them by a billiard ball effect
- The extra neutrons are taken up by protons to form deuterons
- ^{235}U is enriched from its 0.7% in nature to about 3% to produce the reaction, and is contained in rods in the water
- Boron control rods are inserted to absorb neutrons when it is time to shut down the reactor
- The hot water is boiled or sent through a heat exchanger to produce steam. The steam then powers turbines.

Nucleons more tightly bound in Fission Product Nuclei – Gives 200 Mev Energy per Fission

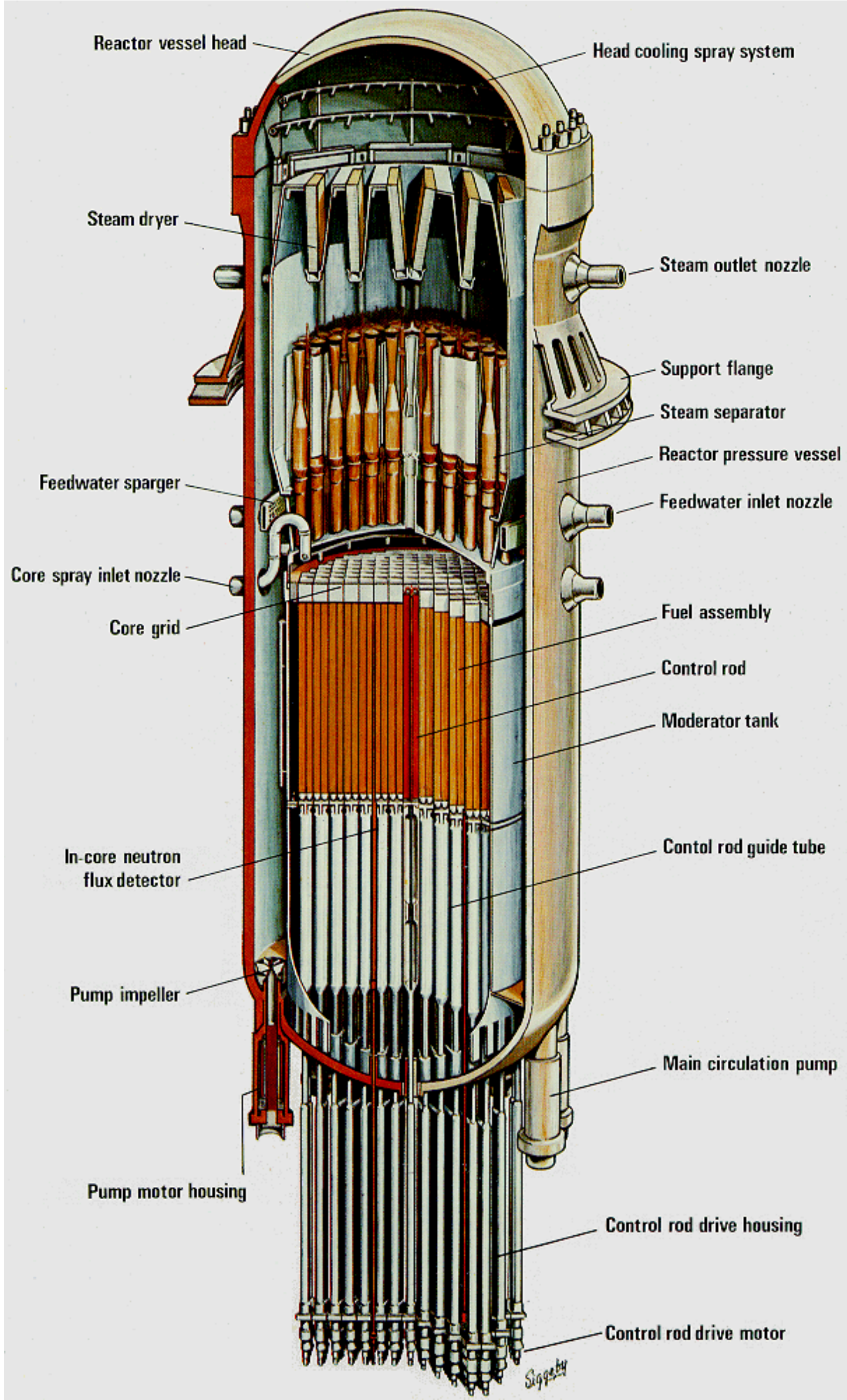


Nuclear Fission from Slow Neutrons and Water Moderator

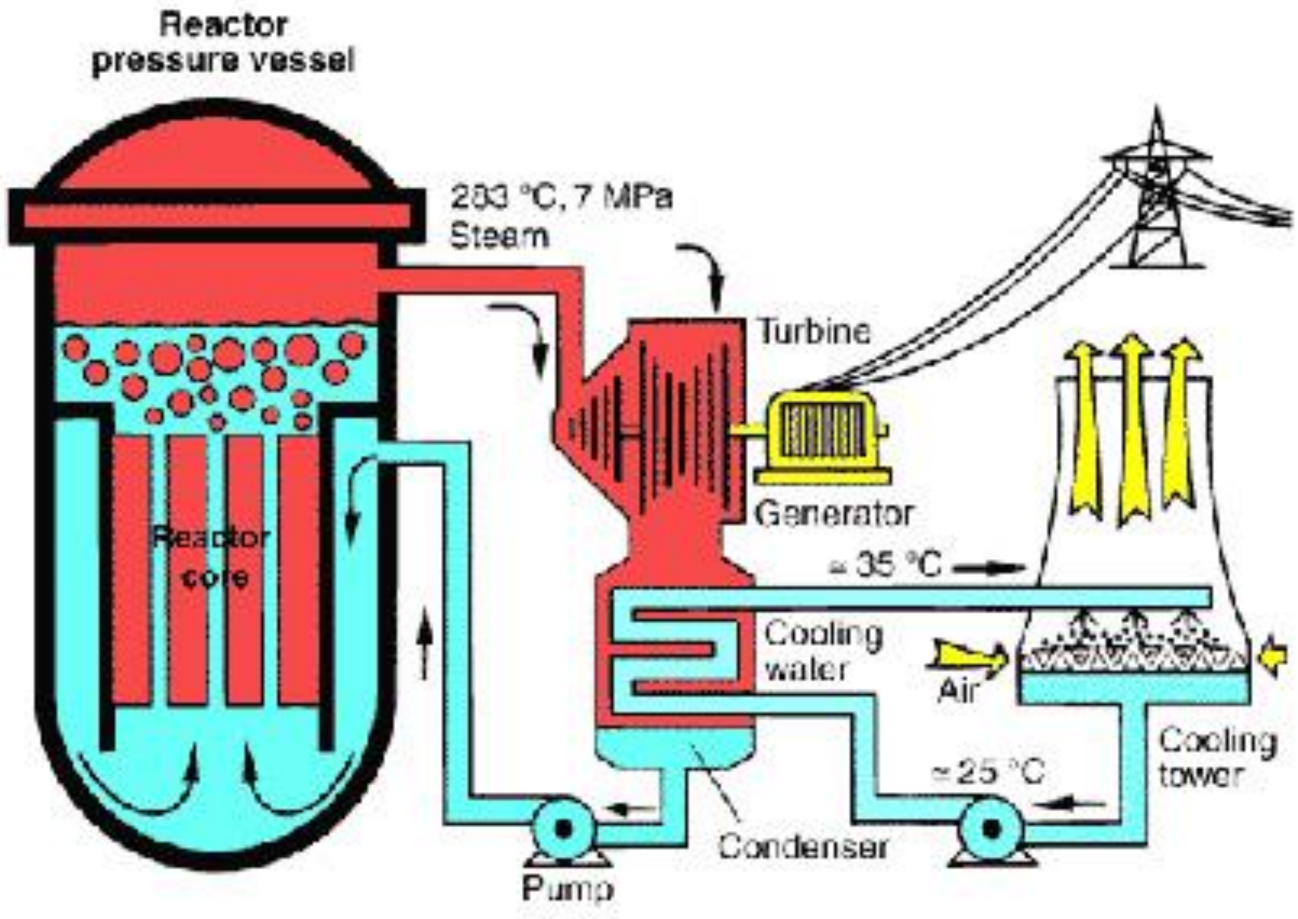


Inside a Nuclear Reactor

- Steam outlet →
- Fuel Rods →
- Control Rods →



Energy Taken out by Steam Turbine



Production of Plutonium (Pu) in Nuclear Reactors

- ^{239}Pu is produced in nuclear reactors by the absorption of a neutron on ^{238}U, followed by two beta decays
- ^{239}Pu also fissions by absorbing a thermal neutron, and on average produces 1/3 of the energy in a fuel cycle.
- ^{239}Pu is relatively stable, with a half life of 24 thousand years.
- It is used in nuclear weapons
- It can be bred for nuclear reactors

Nuclear Weapons to Reactor Fuel

- We are buying highly enriched uranium (20% ^{235}U) from the former Soviet Union's nuclear weapons for 20 years from 1993--2013
- Converting it to low enriched uranium (3% ^{235}U) for reactor fuel
- It will satisfy 9 years of US reactor fuel demand
- It comes from 6,855 Soviet nuclear warheads so far

Nuclear Plant Future

- The countries of the world are each planning their own course of nuclear plant development or decline
- Nuclear power is competitive with natural gas
- It is non-polluting
- It does not contribute to global warming
- Obtaining the fuel only takes 5% of the energy output
- Plant licenses have been extended from 20 years to an additional 20 years

Nuclear Plant Future

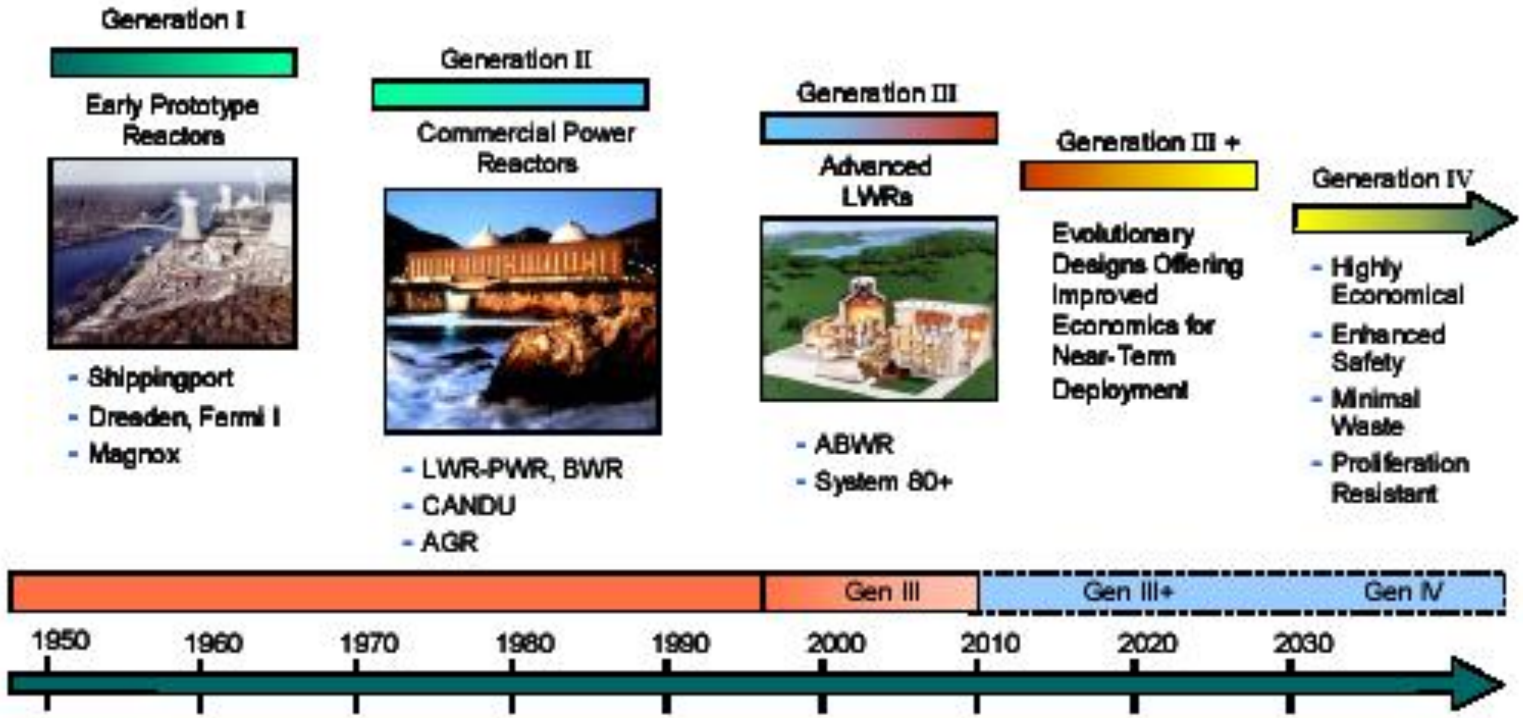
- Newer designs are being sought to make them more economical and safer
- Preapproval of a few designs will hasten development
- Disposal of high level radioactive waste still being studied, but scientists believe deep burial would work
- Because they are have large electrical output, their cost at $2 billion is hard to obtain and guarantee with banks
- Replacing plants may be cheaper using the same sites and containment vessels

Nuclear Problems and Solutions

- Three Mile Island 1979
  - 50% core meltdown, stuck valve with no indicator released water, but containment vessel held
  - More sensors added, better communication to experts in Washington, don’t turn off emergency cooling
  - 28 year US safety record since accident
- Chernobyl 1986
  - Human stupidity turned off cooling system
  - Poor steam cooling reactor design allowed unstable steam pocket to explode
  - Graphite caught fire
  - Design not used in other countries

Yucca Mountain Project: Nuclear Fuel and High Level Waste Repository

- Much more secure repository than leaving high level waste at 60 reactor sites around the country.
- On old atomic bomb testing base, inside a mountain.
- The storage is above the water table.
- The Yucca Mountain site would be 60% filled by present waste.
- US has legal commitment to the reactor industry.
- Site has been studied extensively by scientists for over 20 years.
- Will store waste during its 10,000 year decay time.
- Questions of how to deflect dripping water around and under the storage vessels.
- Questions of radioactive decay weakening storage containers.
- A solution would be to build containers that can be opened and reincased, or to which surrounded casings could be added.



Generation I
Early Prototype Reactors
- Shippingport
- Dresden, Fermi I
- Magnox
Generation II
Commercial Power Reactors
- LWR-PWR, BWR
- CANDU
- AGR
Generation III
Advanced LWRs
- ABWR
- System 80+
Generation III +
Evolutionary Designs Offering Improved Economics for Near-Term Deployment
Generation IV
- Highly Economical
- Enhanced Safety
- Minimal Waste
- Proliferation Resistant
Gen III
Gen III+
Gen IV
1950
1960
1970
1980
1990
2000
2010
2020
2030

Liquid Metal Fast Breeder Reactor

- Uses the fast neutrons from ^{235}U fission on surrounding ^{238}U to produce ^{239}Pu
- In 10-20 years, enough Pu is produced to power another reactor
- No moderators are allowed
- No water, must use liquid sodium coolant
- U must be at 15%-30% enrichment to generate power with fast neutrons while breeding Pu
- This is at weapons grade enrichment, however
- Super-Phenix in France has operated for 20 years

Nuclear Power Proposed Solution?

- Richard Garwin , MIT and industry propose:
- If 50 years from now the world uses twice as much energy, and half comes from nuclear power
- Need 4,000 nuclear reactors, using about a million tons of Uranium a year
- With higher cost terrestrial ore, would last for 300 years
- Breeder reactors creating Plutonium could extend the supply to 200,000 years
- Nonpolluting, non-CO2 producing source
- Need more trained nuclear engineers and sites
- Study fuel reprocessing, waste disposal, and safer designs.
- While nuclear reactors have to be on all day and night, and power use is less at night, they could be used to charge up electric cars.
- Until electric cars or a hydrogen generation economy, they might only be used for the 40% of generation used at night, up from the present 20% that they generate.

Fusion Reactors

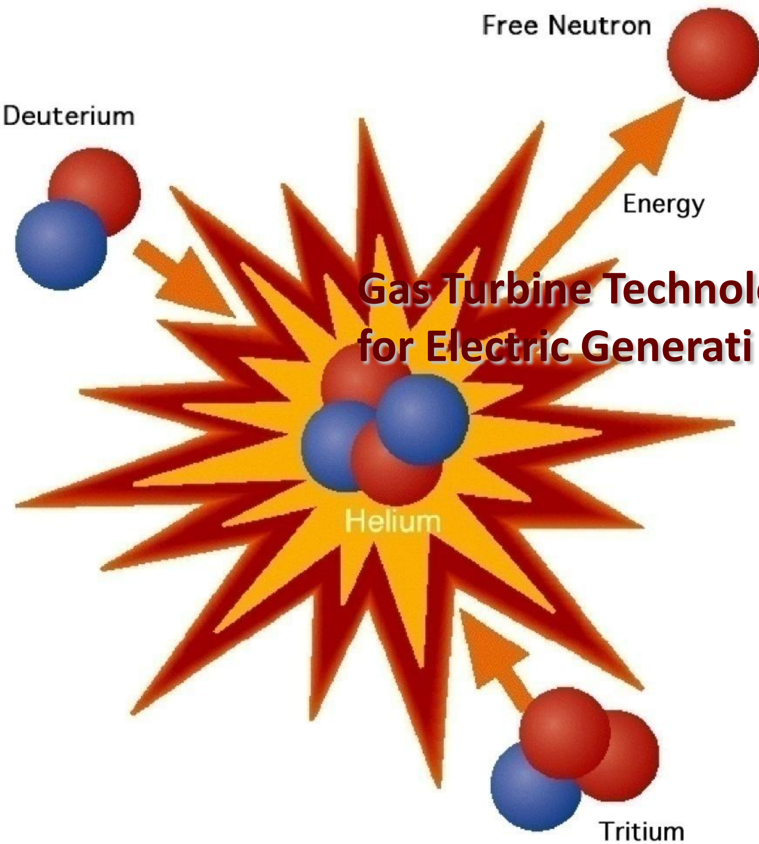
- Fusion easiest for Deuteron (D) + Tritium(T):

  $D(p,n) + T(p,nn) \rightarrow {}^{4}He(pp,nn) + n$

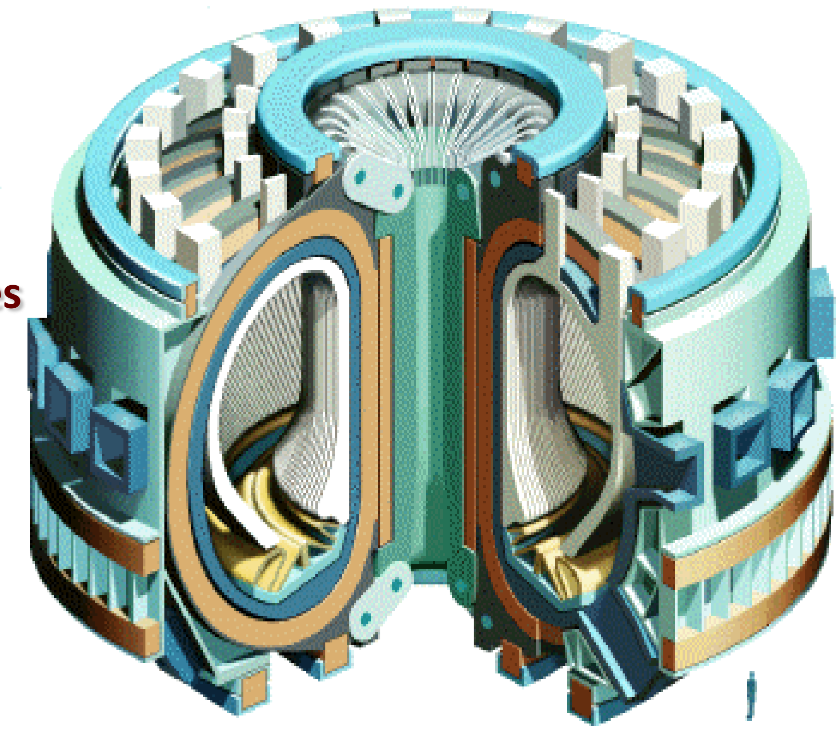
  in a high temperature plasma.
- Replacement T created from Li blanket around reactor

  $n + {}^{6}Li \rightarrow {}^{4}He + T$
- Fusion reactors
  - International ITER in 2012 for research for a decade, costing $5 billion
  - Current stalemate over siting in France or Japan
  - Followed by DEMO for a functioning plant, taking another 10 years.
  - Design and completion of a commercial plant not until 2050.
- US Lithium supply would last a few hundred years.
- Still would be a radioactive waste disposal problem.

International Thermonuclear Experimental Reactor (ITER)



Gas Turbine Technologies
for Electric Generati



DISTRIBUTION SYSTEM

Hello viewers ,in this lecture we shall learn about the distribution system. So that dc as well as ac distribution system also we shall discuss about The components of a pole mounted substation and components fitted on lattice steel tower for transmission of a HT line. some insulators will also be discussed…..

The Transmission system can be divided into two parts:----

Primary Transmission

Secondary Transmission

The Distribution system can be divided into two parts:----

Primary Distribution

Secondary Distribution

A distributor is set to the legal requirement that power must be supplied at a voltage within ± 6% of the declared voltage., whereas a transmission system is not subject to any such restriction . Its voltage can vary as much as 10% to 15% due to variation in loads. any restriction in transmission system is technical and not legal. The transmission system of an area is called GRID.

The different grids are inter connected through the lines to form a regional grid and the different regional grids are further interconnected to form a national grid. Each grid operates independently. However power can be transmitted from one grid to another. The maximum generation voltage in advanced countries is 33 kV while that in India is 11 kV. The amount of power that has to be transmitted through transmission lines is

The amount of power that has to be transmitted through transmission lines is very large and if this power is transmitted at 11kV the line current and power loss will be large. There fore the voltage is stepped to a higher level by using step-up transformers located in sub-stations.

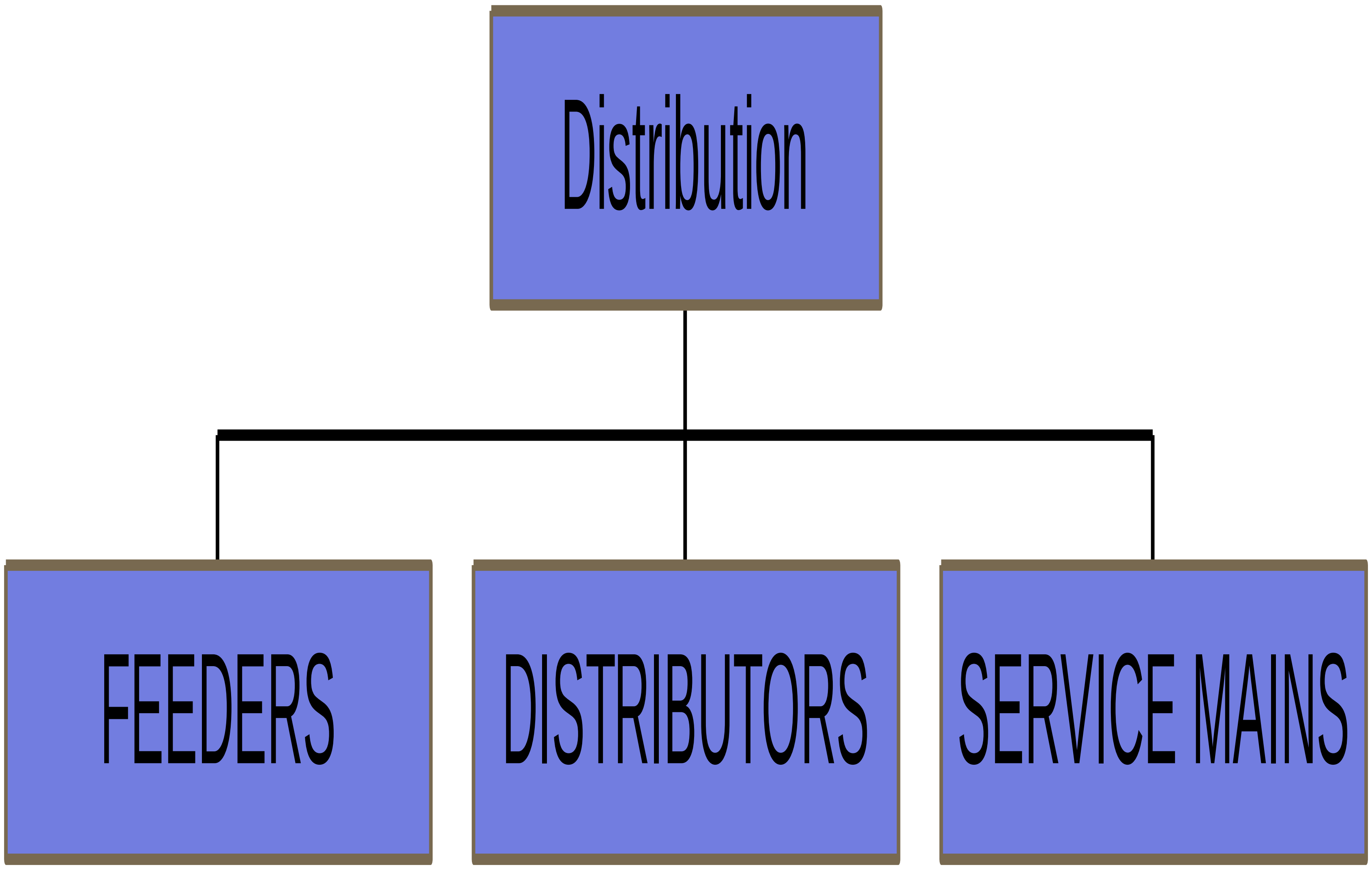
Also volume of conductor used in transmission lines depends upon the voltage and current.

The three phase transmission and distribution system may consist of

Overhead lines

Underground cables

The main advantage of underground system are that it is less prone to electric hazards like rain , wind & lightning. and that it does not interfere with other amenities.


Distribution
FEEDERS
DISTRIBUTORS
SERVICE MAINS

FEEDERS

- These are the cables supplying power in bulk to a selected number of points called feeding points The feeders run along streets overhead (or underground, in some cases) and power the distribution transformers at or near the customer premises.

DISTRIBUTORS

- Distributors are used for current Tapping for the various consumers these cables are generally having the main street for there route .

SERVICE MAIN

- Service mains are the small cables teed of off from the distributors and taken into the premises of the various consumers these are low tension cables.

EFFECT OF SUPPLY VOLTAGE ON THE SIZE OF DISTRIBUTOR

The allowable current density for given type of cable laid is not constant but decreases somewhat as the cable size increases. If voltage of the system is increased N folds then for a given power delivered The current is reduced to 1/Nth.

Size of cable is reduced to 1/Nth.

BALANCERS

The generators supplying a three-wire feeder are all connected in parallel across the outers, and it is therefore necessary to fix the potential of the middle wire midway between that of the outers, otherwise voltages will not be equal, unless the currents taken from the outers are equal.

POLE-MOUNTED SUBSTATION

The substation consisting of a transformer and other apparatus installed on the pole structure is known as
<u>pole mounted substation</u>
As the name implies such substation are installed on H-pole structure many times

COMPONENTS OF
11kV/ 400V POLE MOUNTED SUB-STATION

It is an out-door type substation and is erected on a pole structure. this erected pole is also called H-pole structure

The various components of such a sub-station numbered as under:-

1)---R.C.C. Pole Structure
2)--Platform for transformer
3)--Transformer
4)--Pin-Type insulator
5)-Jumpers
6)--Strain insulator
7)--Fuses
8)--Gang Operating switch
9)--P.G. Clamps

10)-Earthing

11)--Caution Plates

12)--Stay wire

13)-Anchor road

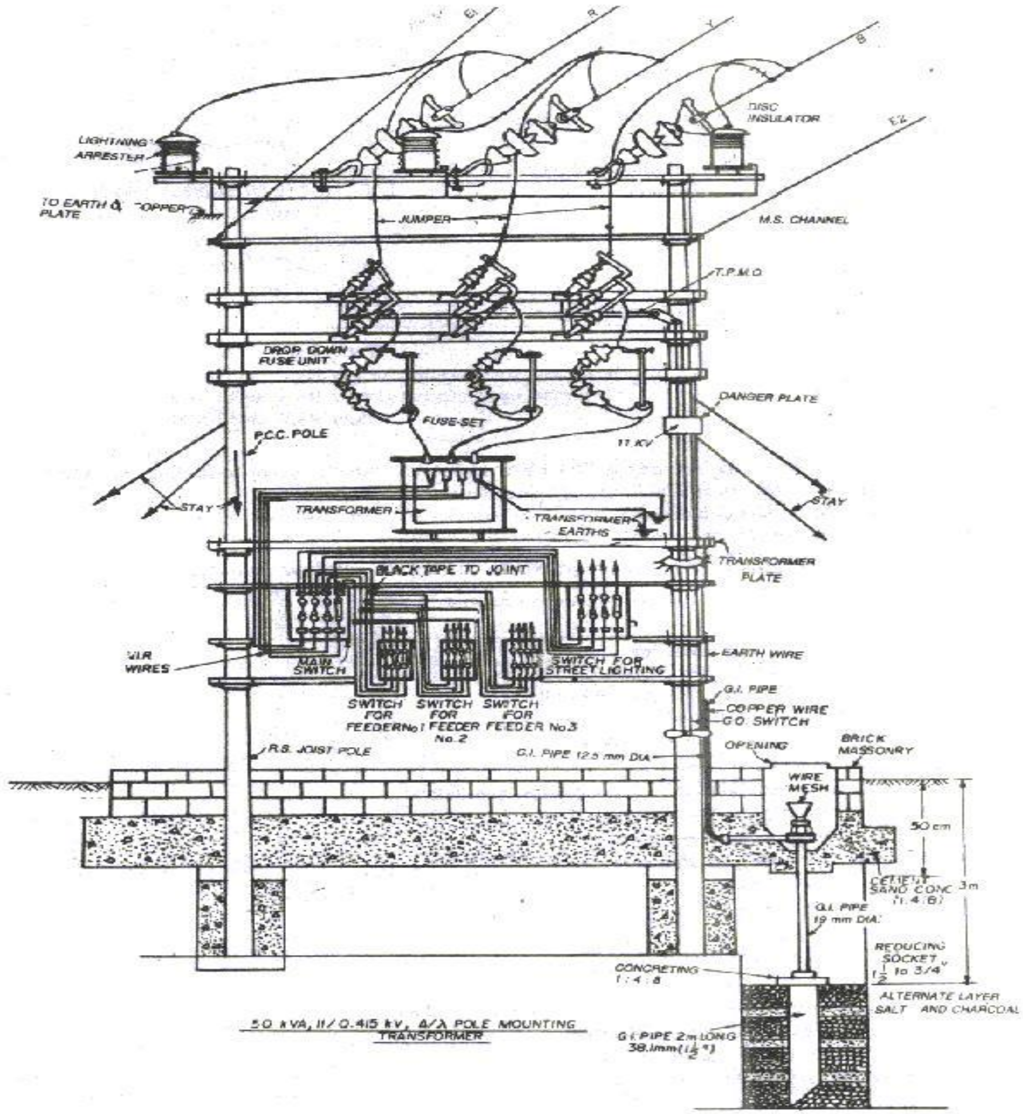
14)-Stay insulators

15)-Anti-climbing devices

16)-G.I. Pipe and bends

17)-V.I.R. Cable

18)-T.P.I.C. Switch



50 kVA, 11/0.415 kV, Δ/λ POLE MOUNTING TRANSFORMER

ESTIMATING OF 11KV/440V POLE MOUNTED OUTDOOR SUBSTATION

M.S.channel for cross arm	10cm x 5 cm x 1.5mt long	1no
H.T. 11 kV disc insulators with fittings	11kv grade, porcelain body, glazed	3nos
H.T. 11 kV pin insulators with fittings	11kv grade, porcelain body, glazed	3nos
Stay sets complete	Stay clamp ,stay insulator, stay bow, egg insulator	2 sets

Earth wire clamp.	**M.S flat with nut & bolt**	**1no**
Binding wire	**Aluminum wire**	**500 gm**
Total Conductor	**ACSR gopher 6/1/2.36 mm diameter: length 50 x 3=150mts sag allowed1% = 1.5mt**	**150+ 1.5 = 151.5 mts**
Galvanized steel wires	**8 SWG ,galvanized steel**	**50.5 mt or 6 kg**
R.S joist poles	**R.S joist, 175 mm x 100 mm x 10 mts long**	**2nos**

substation plate	**100 mm x 50 mm x 6mm long**	**1no**
dropper angle iron	**75mm x 75mm x 8mm x 2mts long long**	**1no**

Stay sets complete

a) Stay clamp	**40x6 mm,M.S flat with nut & bolt.**	**2nos**
b) Stay insulator	**H.T grade, , porcelain body, glazed**	**2nos**

Disc insulator	**11kv grade, porcelain body, glazed**	**3nos**
Pin insulators with pins	**11kv grade, porcelain body, glazed**	**3nos**
Danger board with clamp	**Written in local, national, English language**	**1no**
Jump wire for jumpering	**ACSR gopher 6/1/2.36mm dia**	**1kg**

T.P.M.O switch	**Iron clad Switch with handle**	**1no**
Painting for poles and other attachments		**2 ltr**
Fuse set	**415v,60amp,copper or tinned alloy**	**1set(3 Nos)**
Transformer	**50 KVA 11/0.4 kV**	**1no**
Cross channel for transformer	**75x40x6cm M.S channel, 0.7mtr long**	**1no**
Earthing complete **a) salt** **b) charcoal** **c) Earthing set**	**Complete Earthing set**	**25kg** **25kg** **1set**

1) Transformer	**50 KVA 11/0.4 kV**	**1**
2) Cross channel for transformer	**75x40x6cm M.S channel, 0.7mtr long**	**1**
Main switch	**TPICN (Triple Pole ironclad and Neutral) main switch with 3 fuses & with one neutral link, 100 amp, and built in HRC fuse unit.**	**1no**
Earthing for transformer	**Complete earthing**	**1**
Feeder	**3 phase, 4 wire, 50 cycles, 400/440 volts**	**3 Nos**
Transportation & labour charge		**As requi red**
Lightning arrester	**11 kV grade ,glazed**	**3 Nos**

Dimensions of Danger Plate

Two sizes of Danger Notice Plates as follows are recommended:

For display at 415 V installations – 200x150mm---

For display at 11 KV (or higher voltages) installations – 250x200mm

The corners of the plate shall be rounded off.

The location of fixing holes is provisional and can be modified to suit the requirements of the purchaser.

Lettering of Danger Plate

All letterings shall be centrally spaced.

The dimensions of the letters, figures and their respective position shall be as shown in figs on next slide

The size of letters in the words in each language and spacing between them shall be so chosen that these are uniformly written in the space earmarked for them.

FIG:-1

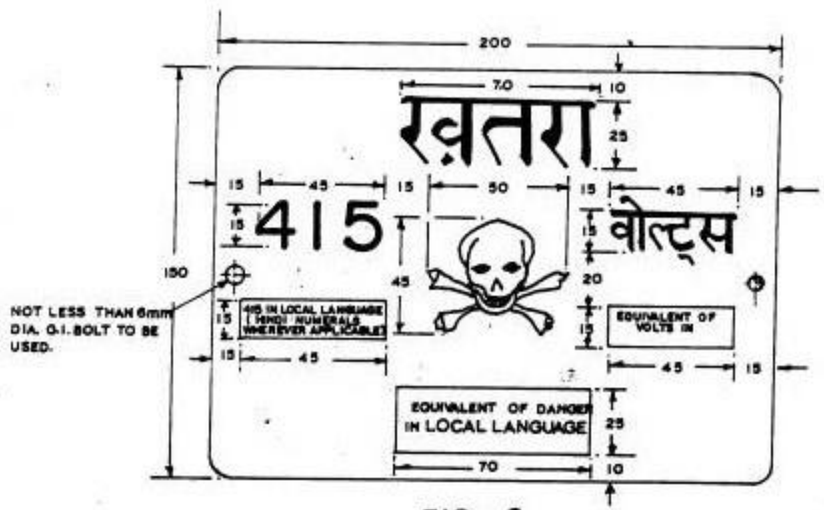


FIG. -2

ALL DIMENSIONS ARE IN mm.

Languages of Danger Plate

Under Rule No. 35 of Indian Electricity Rules, 1956, the owner of every medium, high and extra high voltage installation is required to affix permanently in a conspicuous position a danger notice in Hindi or English and, in addition, in the local language, with the sign of skull and bones.

The type and size of lettering to be done in Hindi is indicated in the specimen danger notice plates shown in Fig. 2 and those in English are shown in Figs.

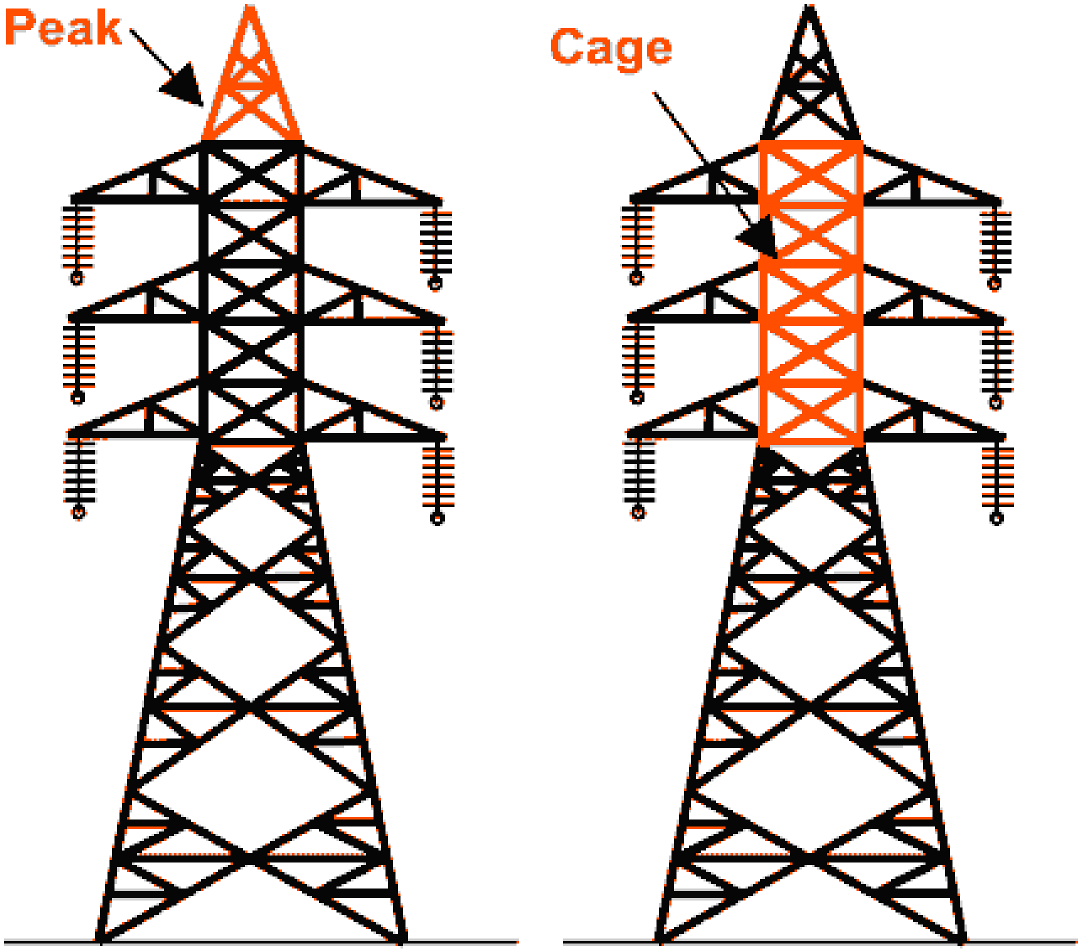
Now let us discuss about the components Regarding the lattice steel tower for distribution the ac voltage. The main supporting unit of overhead transmission line is transmission tower. Transmission towers have to carry the heavy transmission conductor at a sufficient safe height from ground. In addition to that all towers have to sustain all kinds of natural calamities

- So transmission tower designing is an important engineering job where all three basic engineering concepts, civil, mechanical and electrical engineering concepts are equally applicable.

- Main parts of a transmission tower A power transmission tower consists of the following parts,

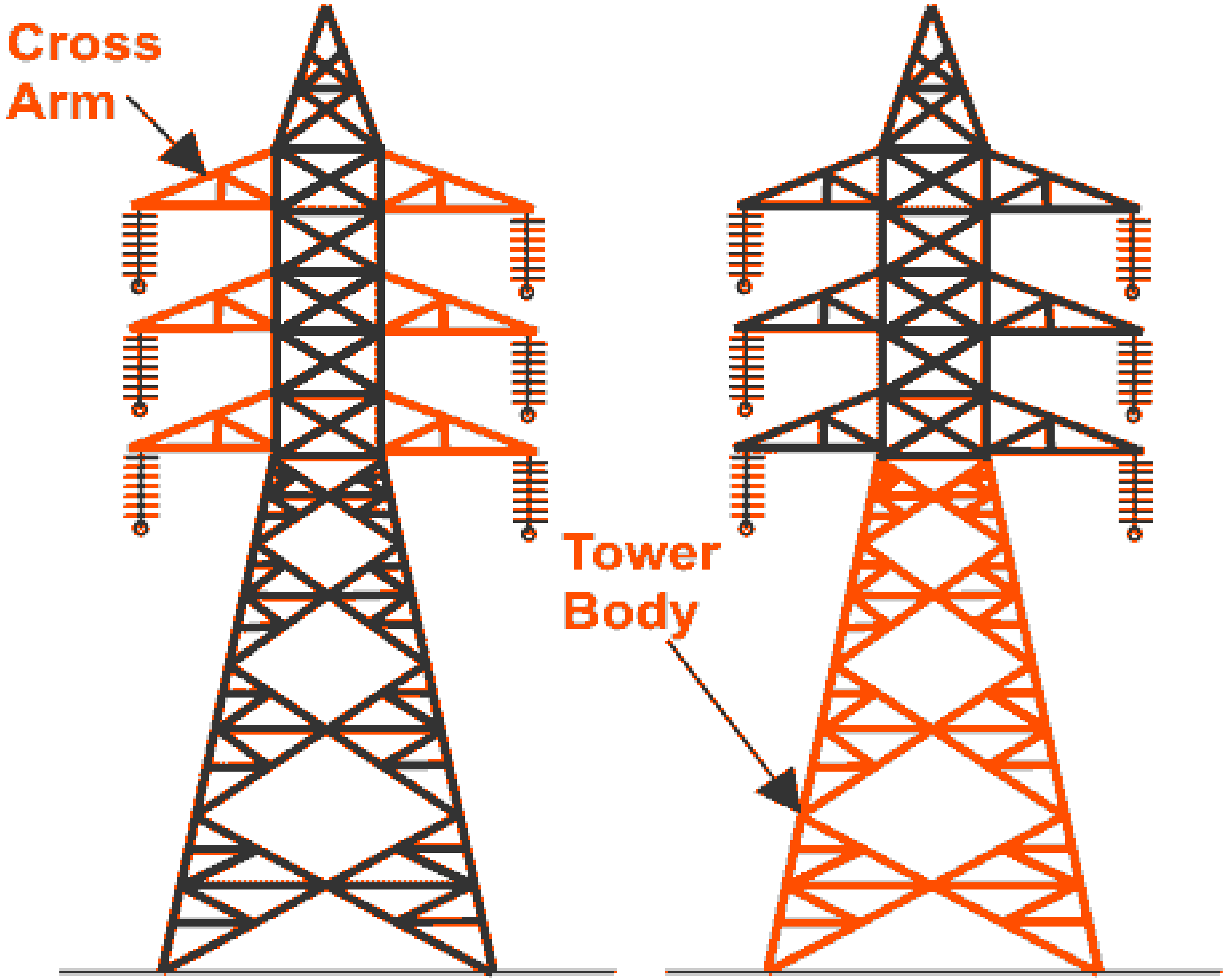
- 1) Peak of transmission tower
2) Cross Arm of transmission tower
3) Boom of transmission tower
4) Cage of transmission tower
5) Transmission Tower Body
6) Leg of transmission tower
7) Stub/Anchor Bolt and Base plate assembly of transmission tower

Lattice steel tower

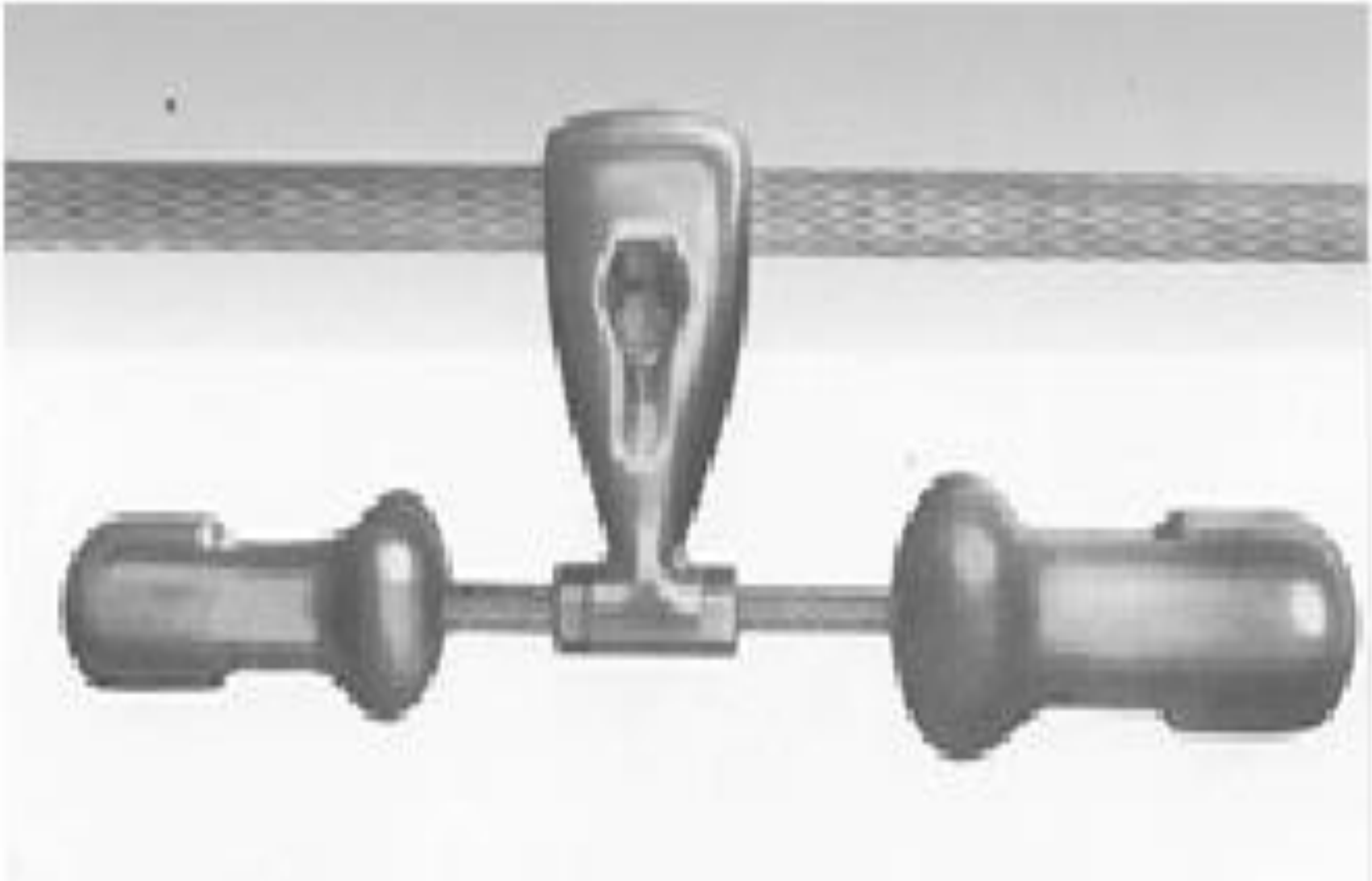


- **Peak of transmission tower**
- The portion above the top cross arm is called peak of transmission tower. Generally earth shield wire connected to the tip of this peak.
- **Cross Arm of transmission tower**
- Cross arms of transmission tower hold the transmission conductor. The dimension of cross arm depends on the level of transmission voltage, configuration and minimum forming angle for stress distribution.

- **Cage of transmission tower**
- The portion between tower body and peak is known as cage of transmission tower. This portion of the tower holds the cross arms.
- **Transmission tower body**
- The portion from bottom cross arms up to the ground level is called transmission tower body. This portion of the tower plays a vital role for maintaining required ground clearance of the bottom conductor of the transmission line.


Cross
Arm
Tower
Body

The "Stockbridge" type vibration damper is commonly used to control vibration of overhead conductors and OPGW. The vibration damper has a length of steel messenger cable. Two metallic weights are attached to the ends of the messenger cable. The centre clamp, which is attached to the messenger cable, is used to install the vibration damper onto the overhead conductor.



Ring Distributor

A ring distributor is a distributor which is arranged to form a closed circuit and which is fed atone or more than one points. For the purpose of calculating voltage distribution, it can be looked uponas consisting of a series of open distributors fed at both ends. By using a ring distributor fed properly, great economy in copper can be affected. If the ring distributor is fed at one point then, for the purposes of calculation, it is equivalent to a straight distributor fed at both ends with equal voltages There are 3 type of power distribution namely loop,network and radial.Radial distribution is the type of power distribution where the power is delivered from the main branch to sub-branches then it split out from the sub-branches again. it is the cheapest but least reliable network configuration.

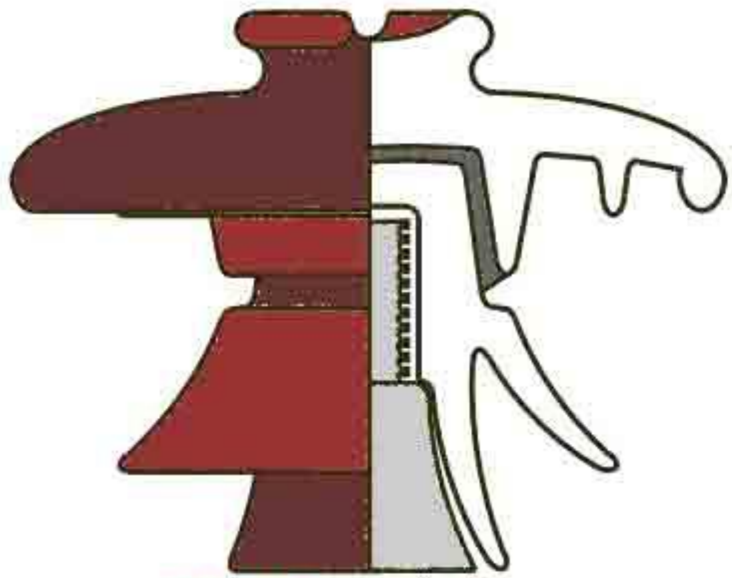
Ring main system In this system, various power stations or sub-stations are interconnected alternate routes, thus forming a closed ring. In case of damage to any section of the ring, that section may be disconnected for repairs and power will be supplied from both ends of the ring. A radial system has a single simultaneous path of power .

The distribution systems are typically radial because networked systems are more expensive.

ADVANTAGES OF OUT-DOOR SUBSTATIONS

- Fault location is easier.
- Extension of the installation is easier.
- Less time is required foe their erection.
- The cost of civil engine4ering work is less.
- Practically no danger of a fault which appears at one point being carried over to another point.

Now let us discuss some insulators used
In distribution systems
Pin type insulators
Post type insulators
Disc type insulators
D-Shakle type insulators
Egg type insulators
Reel insulators ....etc



33KV Pin Insulator

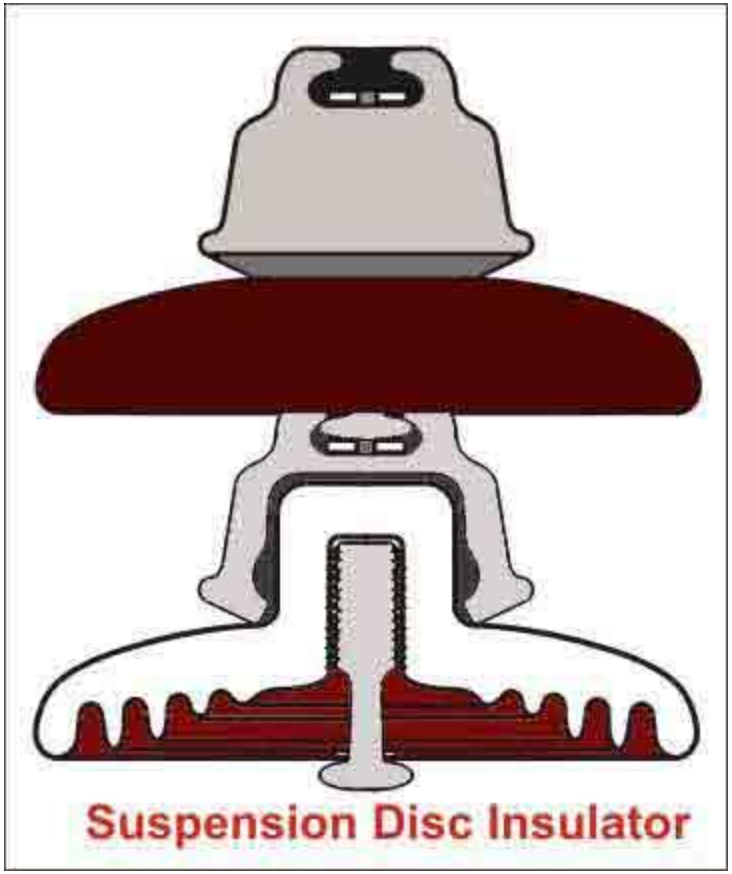
Pin Insulator is earliest developed **overhead insulator**, but still popularly used in power network up to 33KV system. Pin type insulator can be one part, two parts or three parts type, depending upon application voltage. In 11KV system we generally use one part type insulator where whole pin insulator is one piece of properly shaped porcelain or glass. As the leakage path of insulator is through its surface

In higher voltage like 33KV and 66KV manufacturing of one part porcelain pin insulator becomes difficult. Because in higher voltage, the thickness of the insulator become more and a quite thick single piece porcelain insulator can not manufactured practically. In this case we use multiple part pin insulator, where a number of properly designed porcelain shells are fixed together by Portland cement to form one complete insulator unit. For 33KV tow parts and for 66KV three parts pin insulator are generally used.

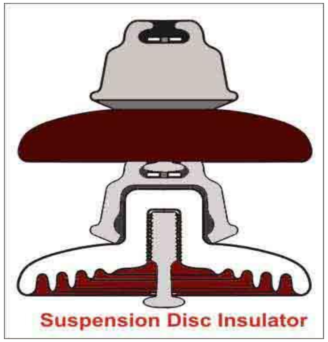
Post Insulator--

Post insulator is more or less similar to Pin insulator but former is suitable for higher voltage application. **Post insulator** has higher numbers of petticoats and has greater height. This type of insulator can be mounted on supporting structure horizontally as well as vertically. The insulator is made of one piece of porcelain but has fixing clamp arrangement are in both top and bottom end.

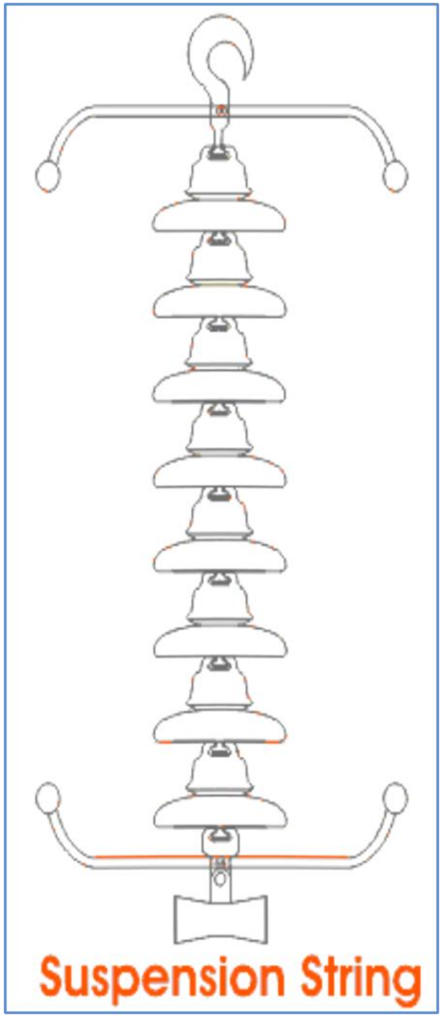
Suspension Insulator

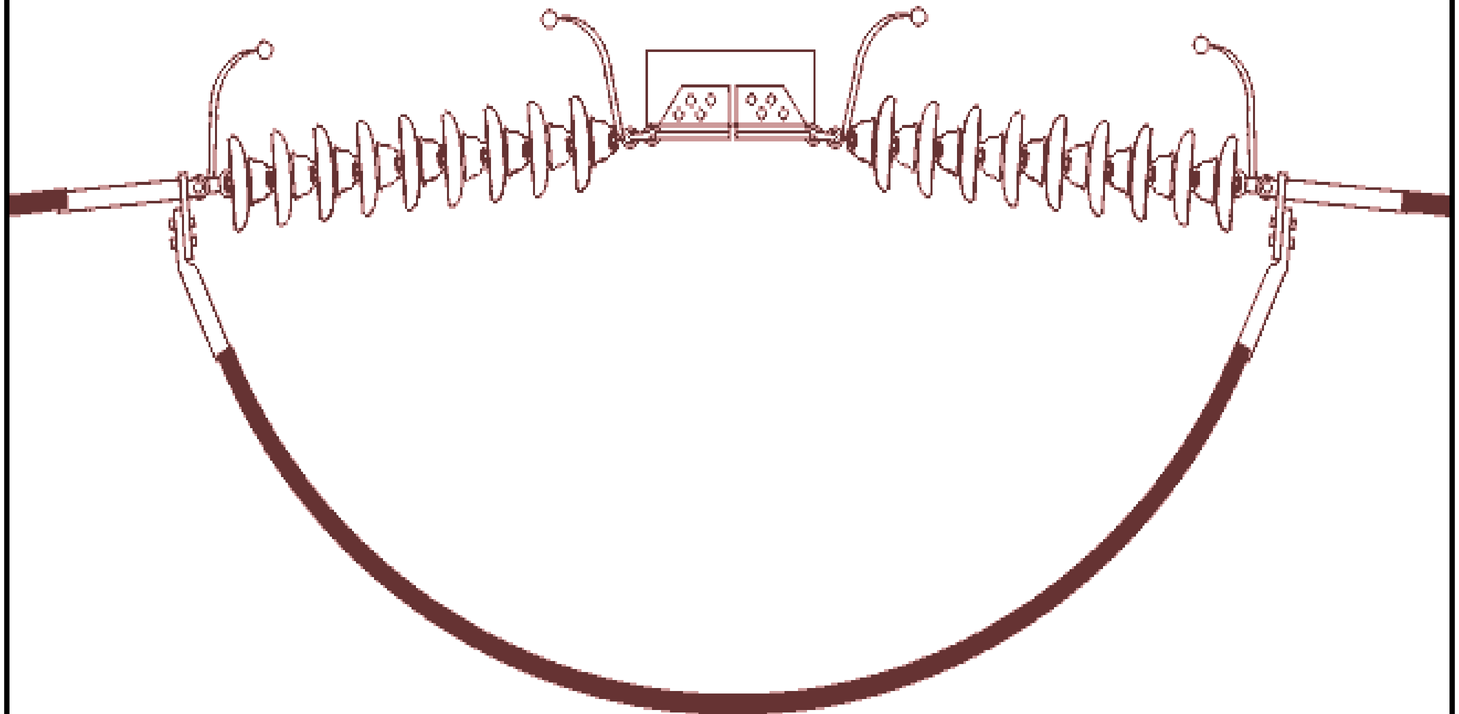


In higher voltage, beyond 33KV, it becomes uneconomical to use pin insulator because size, weight of the insulator become more. Handling and replacing bigger size single unit insulator are quite difficult task. For overcoming these difficulties, **suspension insulator** was developed.



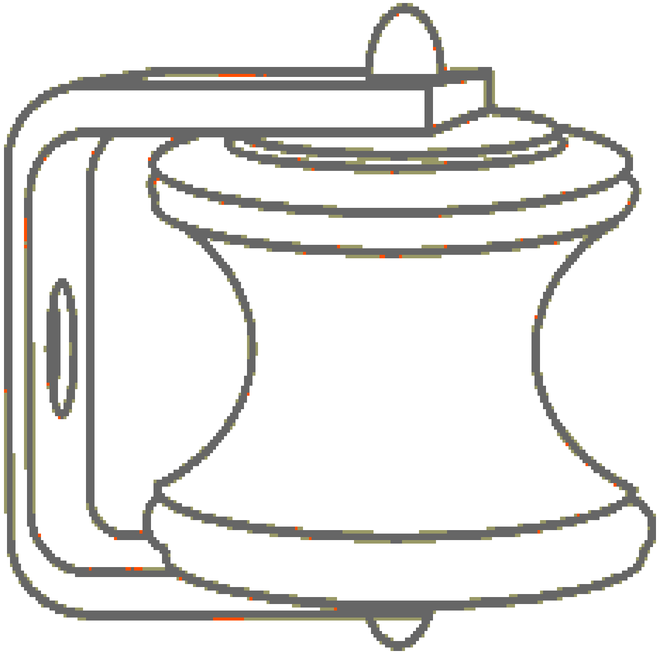
In **suspension insulator** numbers of insulators are connected in series to form a string and the line conductor is carried by the bottom most insulator. Each insulator of a suspension string is called disc insulator because of their disc like shape.



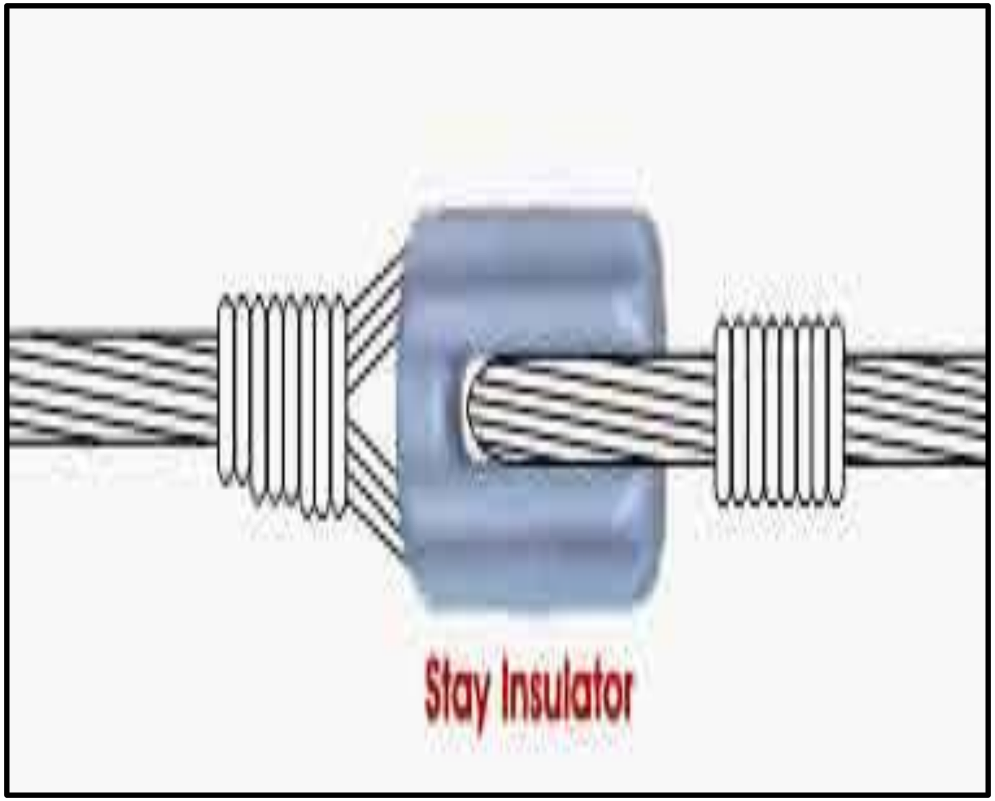


STRAIN INSULATOR

When suspension string is used to sustain extraordinary tensile load of conductor it is referred as **string insulator**. When there is a dead end or there is a sharp corner in transmission line, the line has to sustain a great tensile load of conductor or strain. A **strain insulator** must have considerable mechanical strength as well as the necessary electrical insulating properties.



Shackle or Spool Insulator


Stay Insulator

Glass Insulator (Disc)

Polymer Insulator
(Supension)

Gas Turbine Technologies for Electric Generation

Gas Turbine Basics

- Gas Turbines
  - Types
  - How They Work
  - Applications
  - Components of Plant
  - Flow Paths
  - Operation

Gas Turbine Applications

- Simple Cycle
- Combined Cycle
- Cogeneration

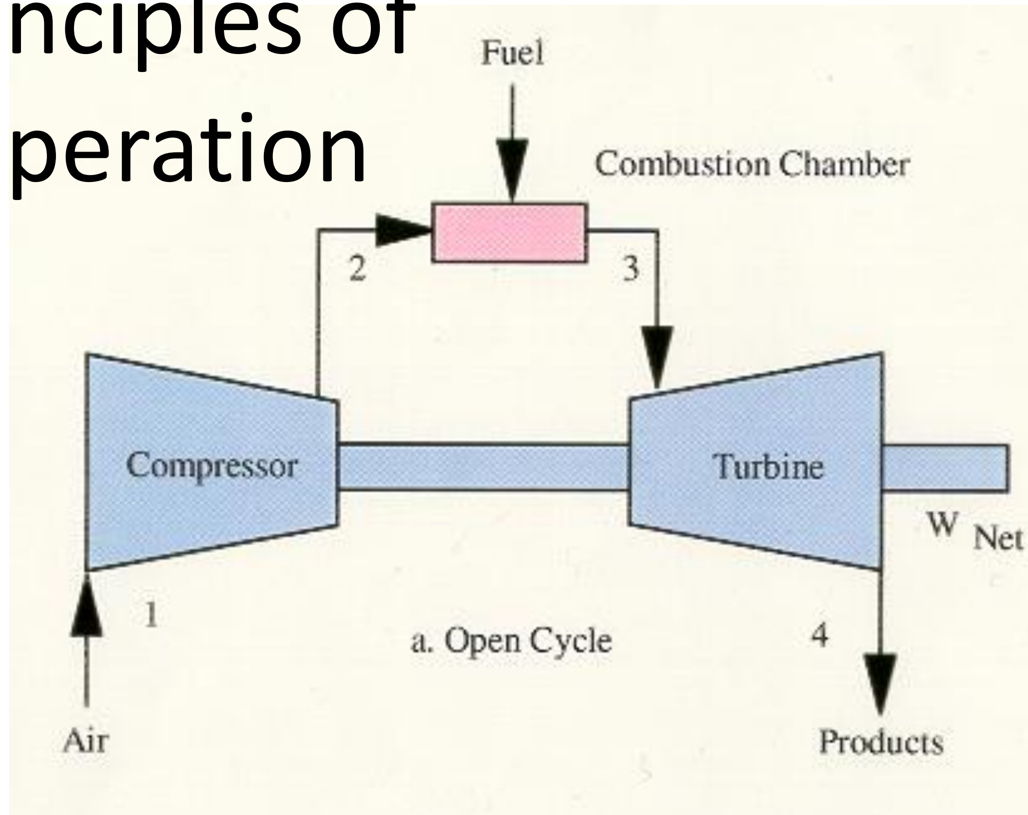
Types of Gas Turbine Plants

- Simple Cycle
  - Operate When Demand is High – Peak Demand
  - Operate for Short / Variable Times
  - Designed for Quick Start-Up
  - Not designed to be Efficient but Reliable
    - Not Cost Effective to Build for Efficiency
- Combined Cycle
  - Operate for Peak and Economic Dispatch
  - Designed for Quick Start-Up
  - Designed to Efficient, Cost-Effective Operation
  - Typically Has Ability to Operate in SC Mode

Principles of Operation

- Open Cycle

Also referred to as simple cycle)



- The energy contained in a flowing ideal gas is the sum of enthalpy and kinetic energy.
- Pressurized gas can store or release energy. As it expands the pressure is converted to kinetic energy.

Link to picture

Brayton Cycle – Gas Turbine Cycle

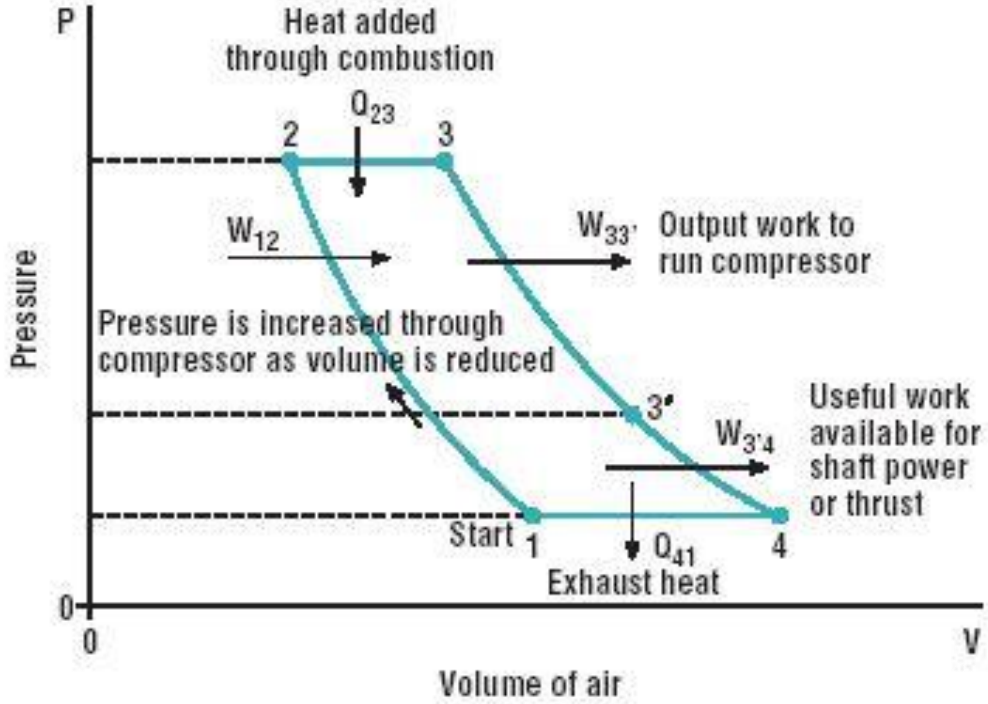
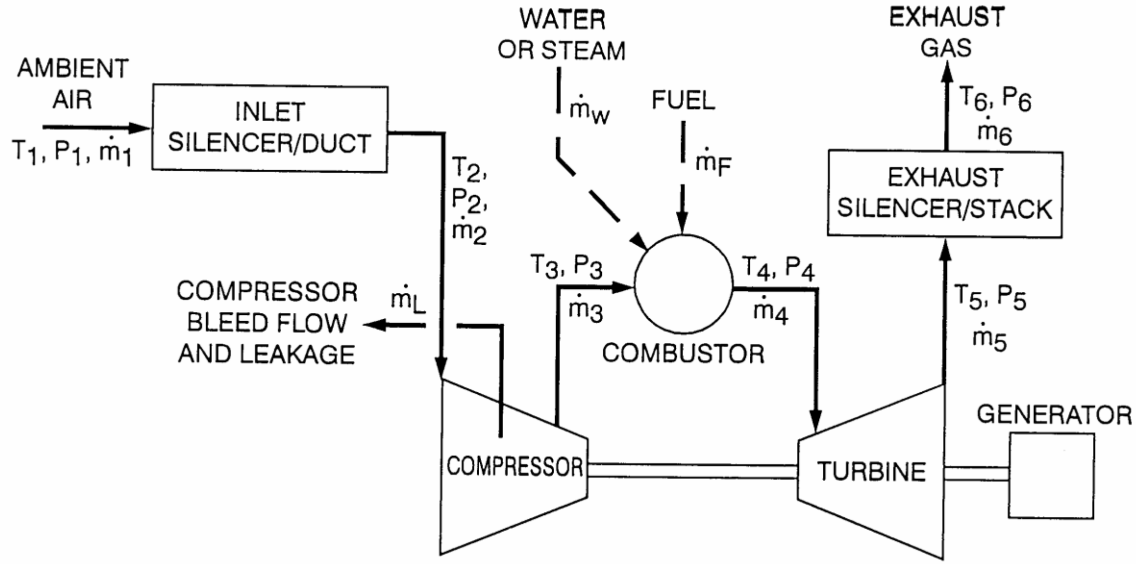


Figure 3. Idealized gas turbine heat cycle (Energy Solution Center)

Thermodynamic Fundamentals

- Pressure Ratio & CT Components



COMPRESSOR INLET TEMPERATURE = T_2
PRESSURE RATIO = P_3/P_2
TURBINE INLET TEMPERATURE = T_4
EXHAUST TEMPERATURE = $T_5 \cong T_6$
EXHAUST GAS FLOW = $\dot{m}_5 = (\dot{m}_1 + \dot{m}_F + \dot{m}_W - \dot{m}_L)$
EXHAUST HEAT = $\dot{m}_5 \cdot T_5 \cdot$ SPECIFIC HEAT OF EXHAUST GAS
INLET PRESSURE DROP = $P_1 - P_2$
EXHAUST PRESSURE DROP = $P_5 - P_6$

Figure 20-15. GAS TURBINE GENERATOR PERFORMANCE PARAMETERS

Combustion or Gas Turbine

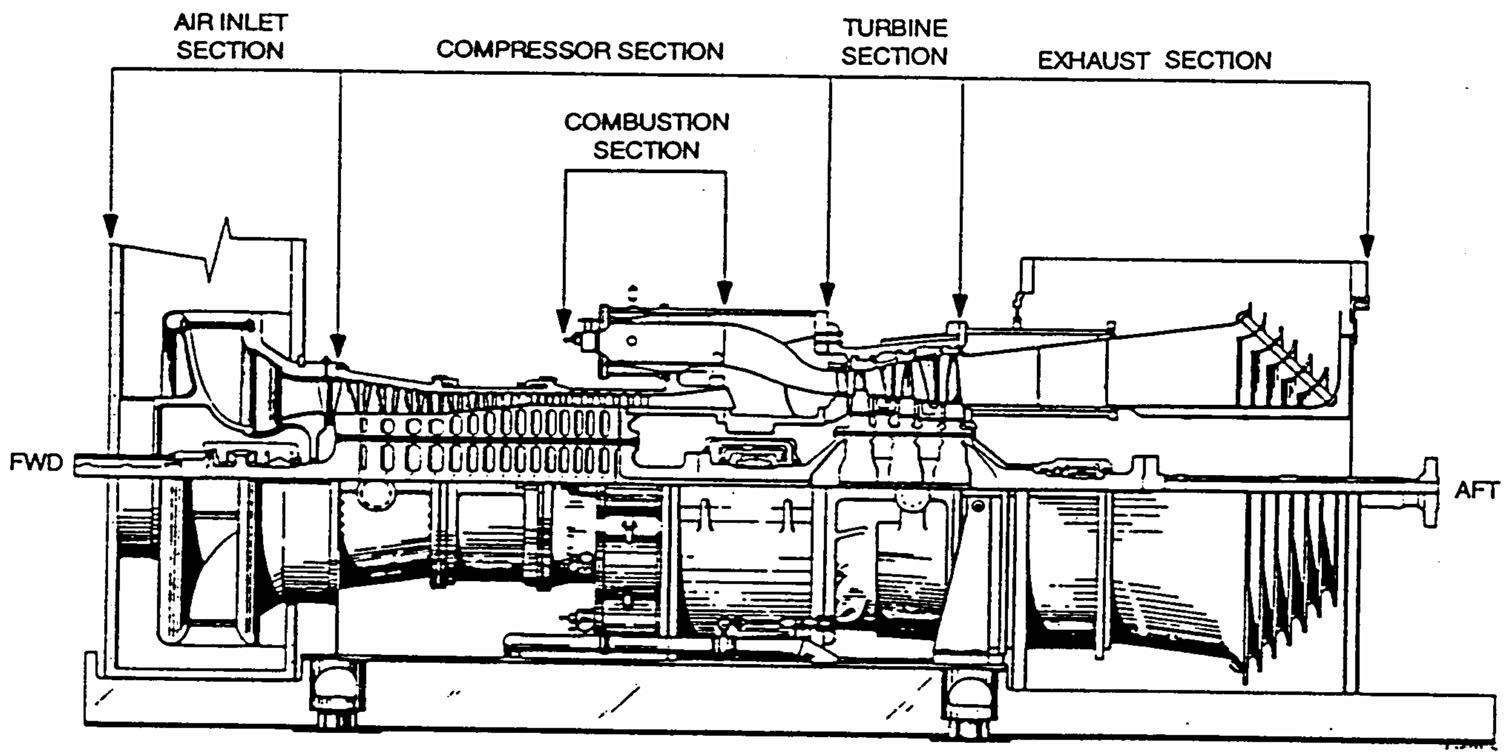


Figure 20-12. MAJOR SECTIONS OF THE MS-7000 GAS TURBINE ASSEMBLY (FROM GENERAL ELECTRIC. USED WITH PERMISSION.)

Principles of Operation

Compressor

- As air flows into the compressor, energy is transferred from its rotating blades to the air. Pressure and temperature of the air increase.
- Most compressors operate in the range of 75% to 85% efficiency.

Combustor

- The purpose of the combustor is to increase the energy stored in the compressor exhaust by raising its temperature.

Turbine

- The turbine acts like the compressor in reverse with respect to energy transformation.
- Most turbines operate in the range of 80% to 90% efficiency.

Principles of Operation

Overall Energy Transformations (Thermal Efficiency)

- Useful Work = Energy released in turbine minus energy absorbed by compressor.

The compressor requires typically approximately 50% of the energy released by the turbine.

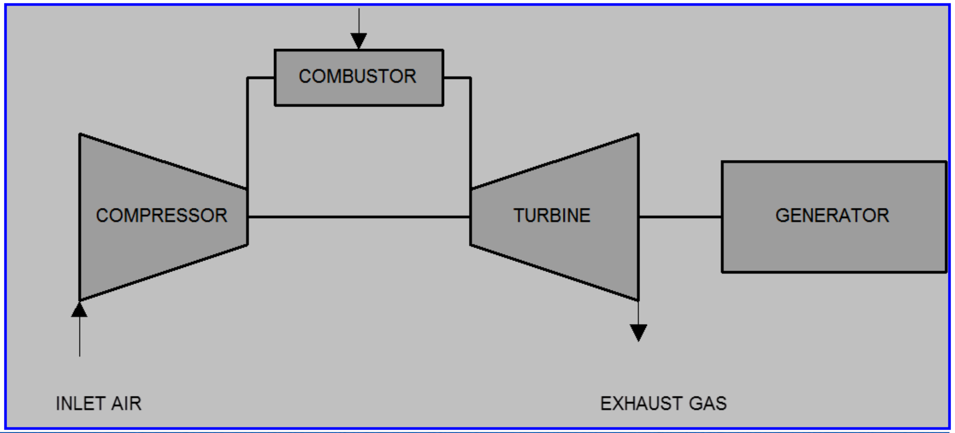
- Overall Thermal Efficiency =

Useful Work/Fuel Chemical Energy *100

Typical overall thermal efficiencies of a combustion turbine are 20% - 40%.

Gas Turbine Applications

- Simple Cycle

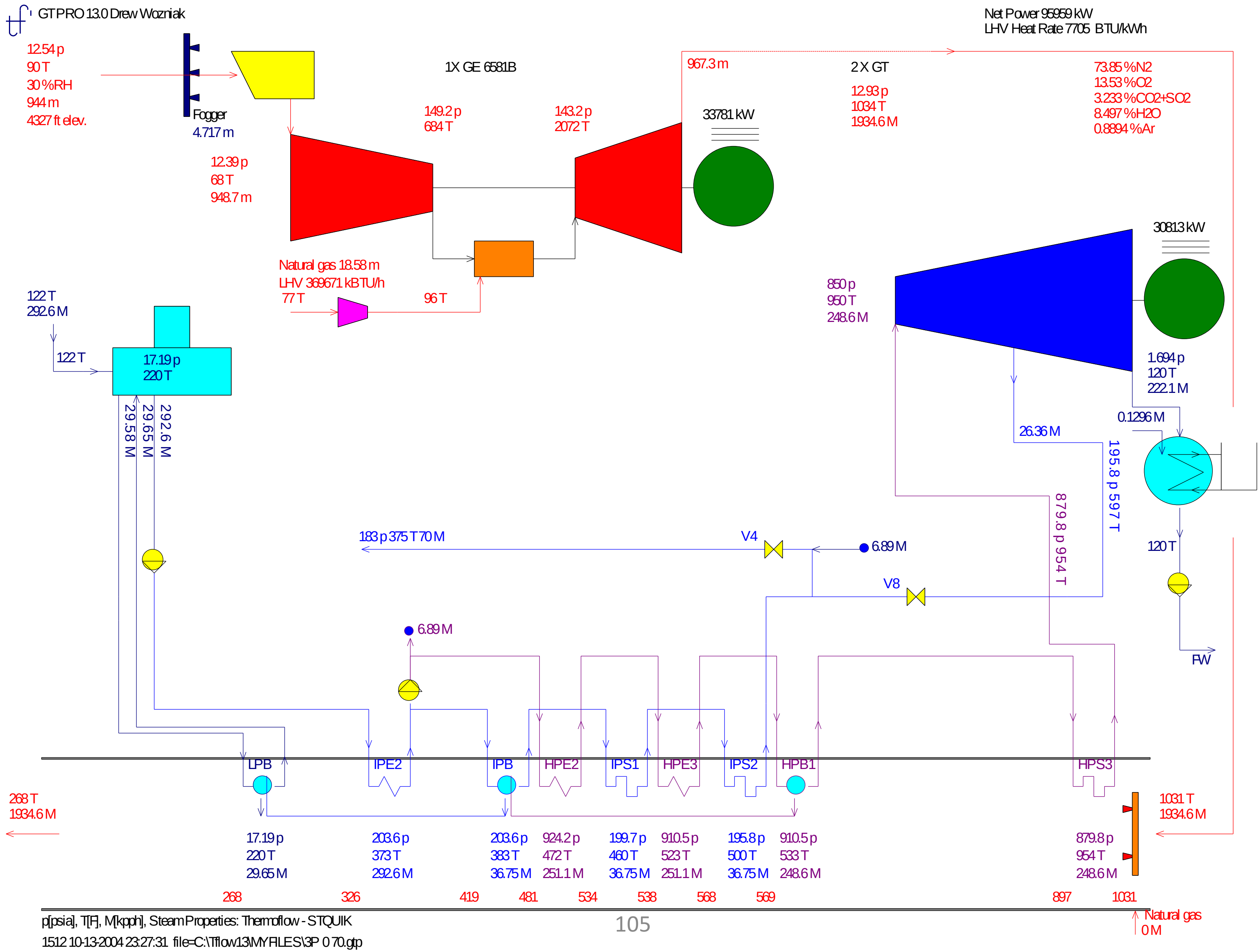


ture

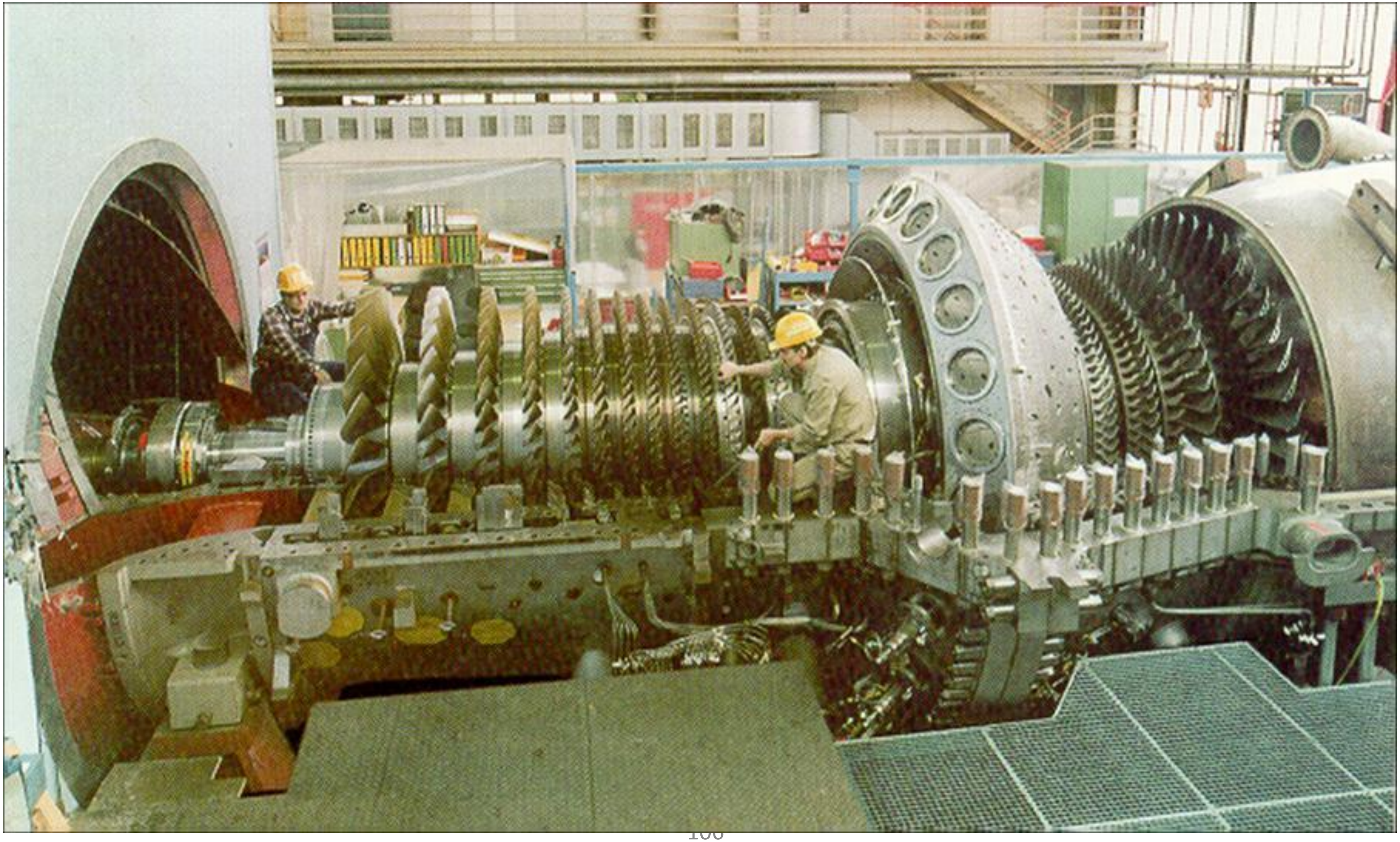
Simple Cycle Power Plant
Westinghouse 501D5 – 340 MW

Combined Cycle Power Plant

Combined Cycle Plant Design



Gas Turbine Components
Compressor – Combustor - Turbine



Gas Turbine Components & Systems (cont'd)

- Combustion System
  - Silo, Cannular, Annular
  - Water, Steam, DLN
- Turbine
  - Multiple Shaft, Single Shaft
  - Number of Stages
  - Material and Manufacturing Processes

- Exhaust System
  - Simple Cycle Stack
  - Transition to HRSG
- Generator
  - Open-Air cooled
  - TEWAC
  - Hydrogen Cooled
- Starting Systems
  - Diesel
  - Motor
  - Static

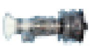
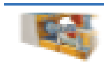
Paper Towel thru compressor

Combustion Turbine Fuels

- Conventional Fuels
  - Natural Gas
  - Liquid Fuel Oil
- Nonconventional Fuels
  - Crude Oil
  - Refinery Gas
  - Propane
- Synthetic Fuels
  - Chemical Process
  - Physical Process

GE Combustion Turbine Comparisons

Generator Drive (ISO conditions - natural gas - electrical generator terminals)

		ISO RATED POWER	HEAT RATE	EFFIC.	PRESSURE RATIO	EXHAUST FLOW		TURBINE SPEED	EXHAUST TEMPERATURE	
		kW	kJ/kWh	%		kg/sec	lbs/sec	RPM	°C	°F
	GE10-1	11,250	11,489	31.4	15.5	47.5	104.7	11,000	482	900
	PGT16	13,720	10,295	35.0	20.2	47.3	104.3	7,900	491	919
	PGT20	17,464	10,238	35.2	15.7	62.5	137.7	6,500	475	887
	PGT25	22,417	9,919	36.3	17.9	68.9	151.9	6,500	525	976
	PGT25+	30,226	9,084	39.6	21.5	84.3	185.9	6,100	500	931
	PGT25+G4	33,057	9,047	40.0	23.2	89.6	197.7	6,100	510	950
	LM6000*	42,262	8,787	41.1	28.0	125.0	275.0	3,600	455	851
	LMS100*	98,196	7,997	45.0	40.0	206.9	456.0	3,600	417	782
	MS5001	26,830	12,687	28.4	10.5	125.2	276.1	5,094	483	901
	MS5002E*	31,100	10,285	35.0	17.0	102.0	225.0	5,714	511	952
	MS6001B	42,100	11,230	32.1	12.2	141.1	311.0	5,163	548	1,026
	MS7001EA	85,400	10,990	32.7	12.6	292.0	643.0	3,600	537	998
	MS9001E	126,100	10,650	33.8	12.6	418.0	921.0	3,000	543	1,009

(*) DLE Combustion

Gas Turbine Types

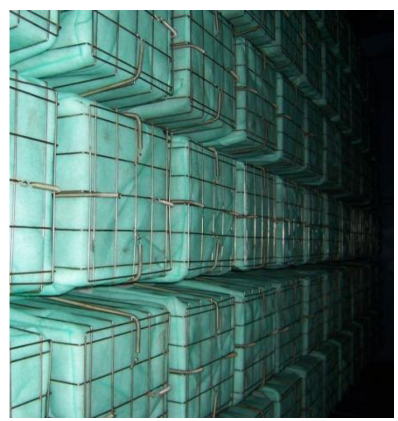
- Advanced Heavy-Duty Units
- Advanced Aeroderivative Units

Parameter	Heavy Duty	Aero-Derivative
Capital Cost, $/kW	Lower	Higher
Capacity, MW	10 - 330	5 – 100
Efficiency	Lower	Higher
Plan Area Size	Larger	Smaller
Maintenance Requirements	Lower	Higher
Technological Development	Lower	Higher

Gas Turbine Major Sections

- **Air Inlet**
- **Compressor**
- **Combustion System**
- **Turbine**
- **Exhaust**
- **Support Systems**

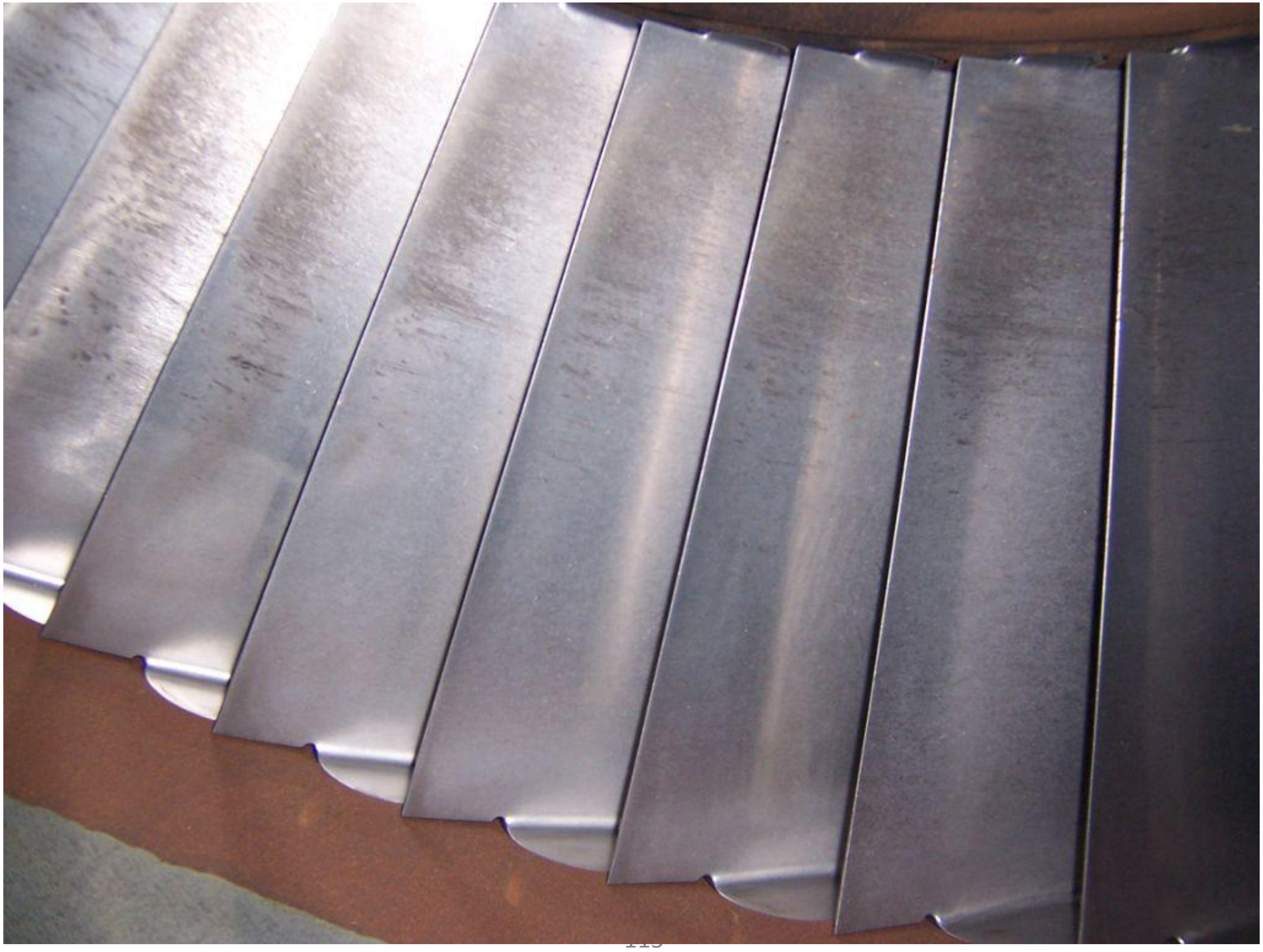
Gas Turbine Barrier Inlet Filter Systems



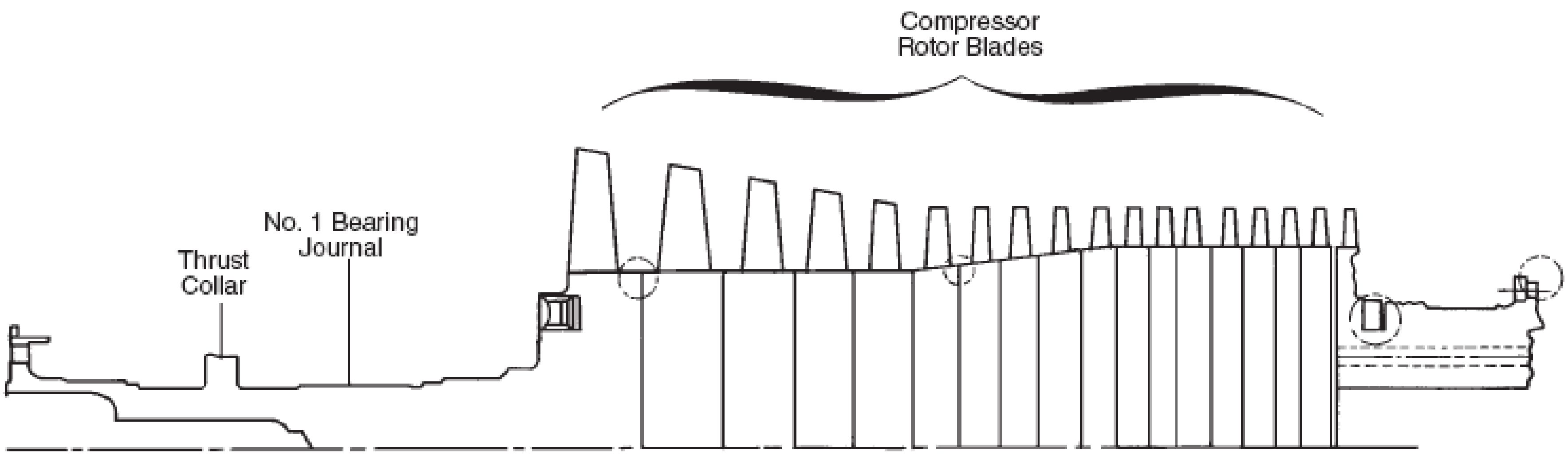
Gas Turbine Pulse Inlet Filter System

Inlet Guide Vanes

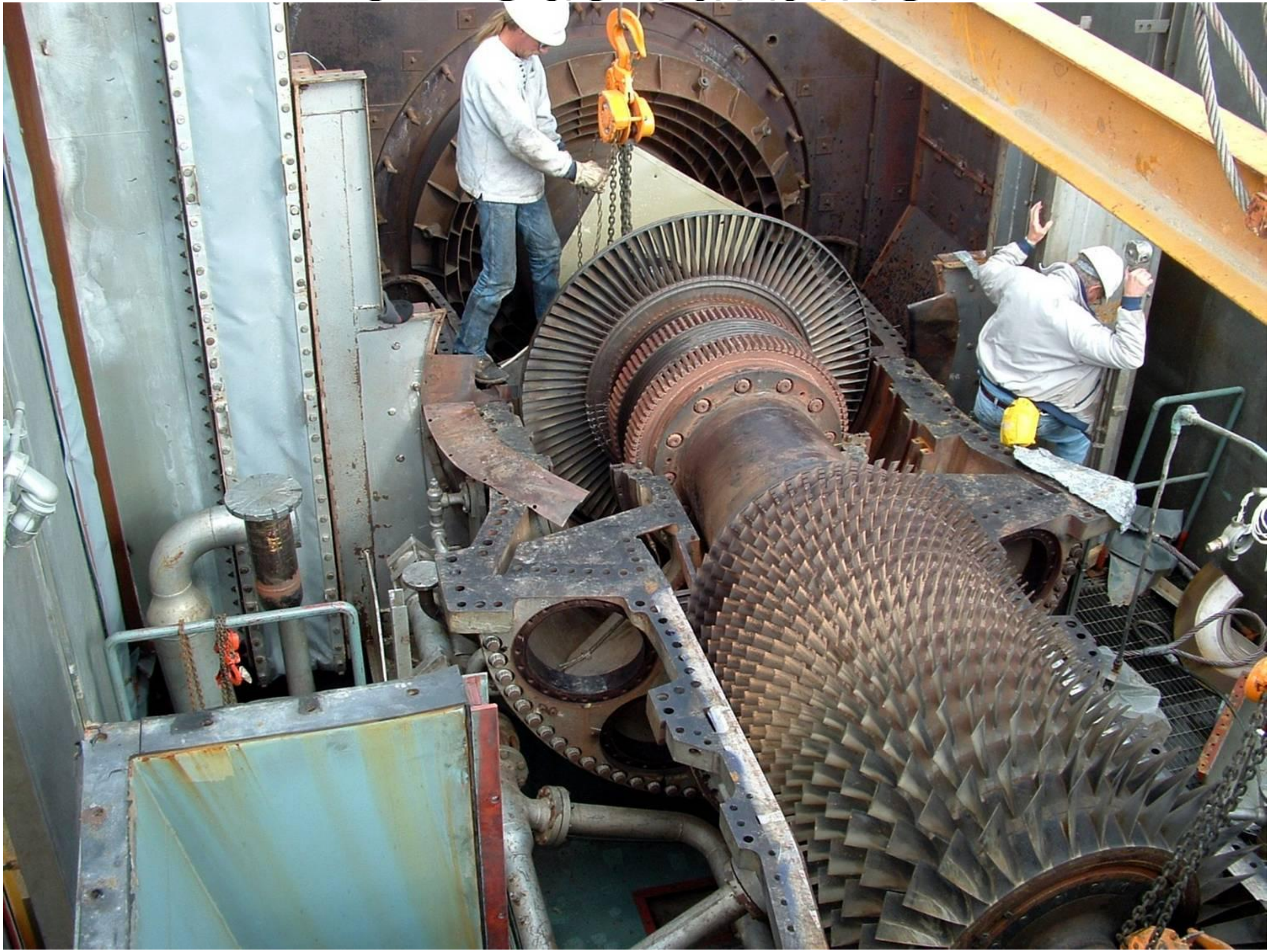
Inlet Guide Vanes



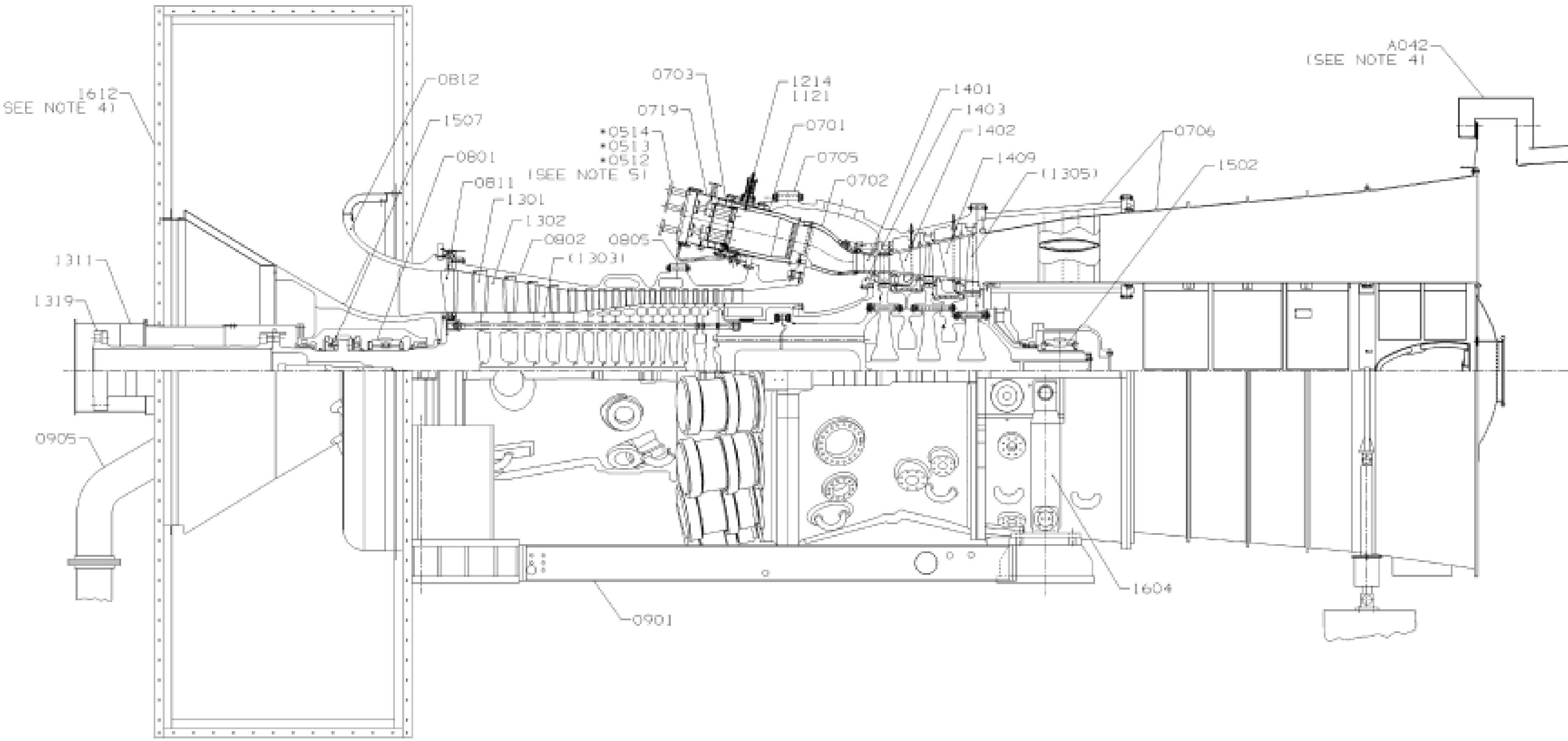
Gas Turbine Compressor Rotor Assembly



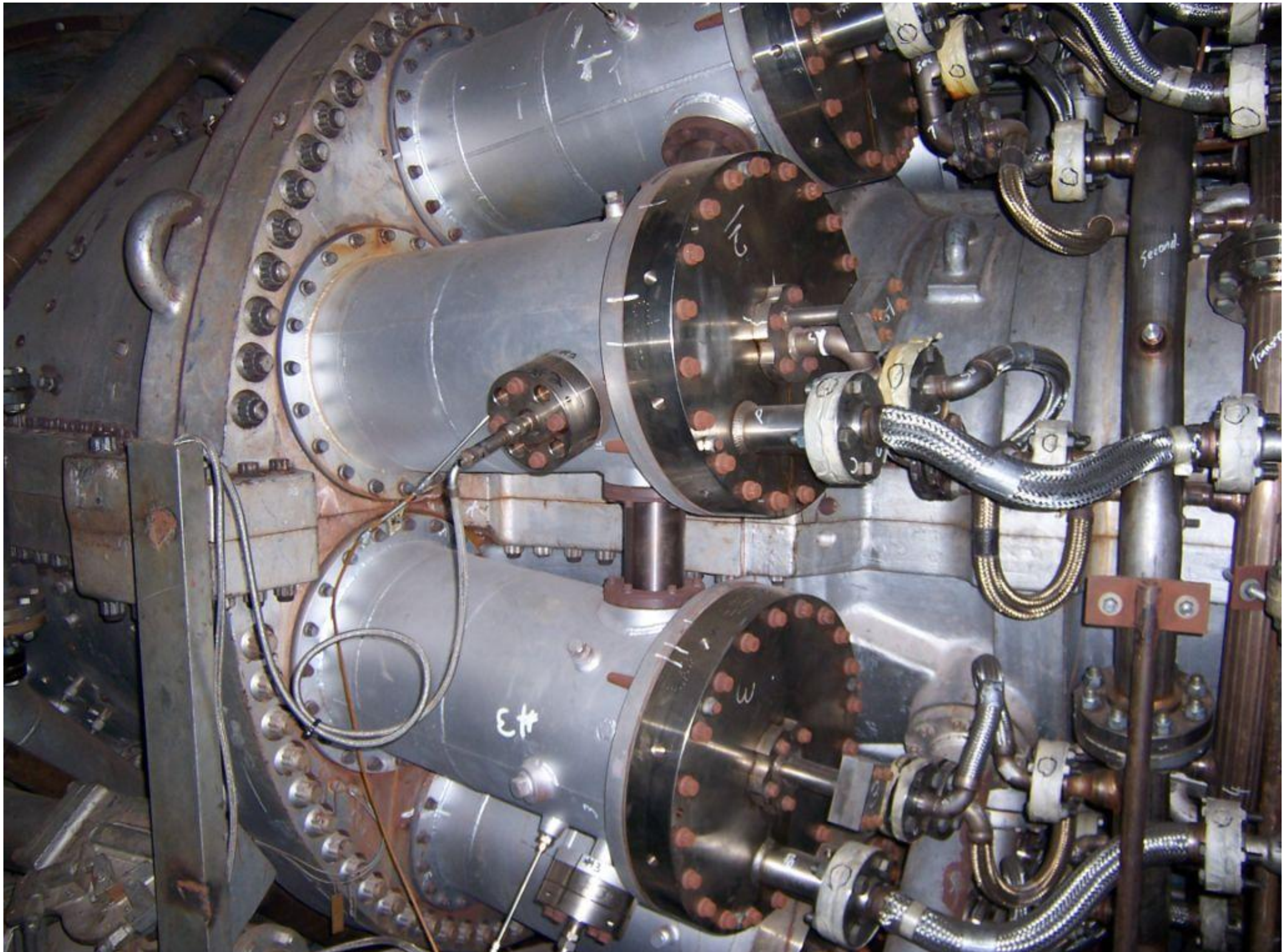
6B Gas Turbine



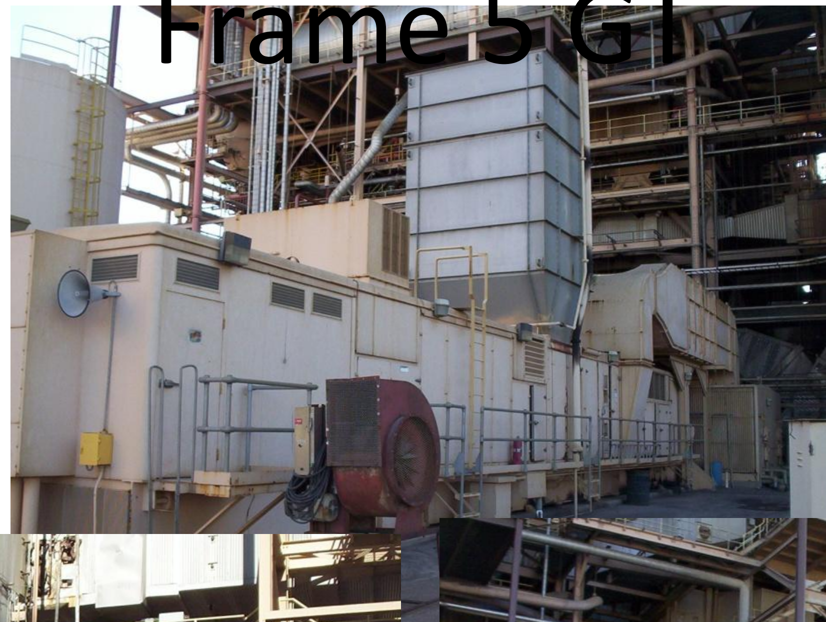
Gas Turbine Cut Away Side View



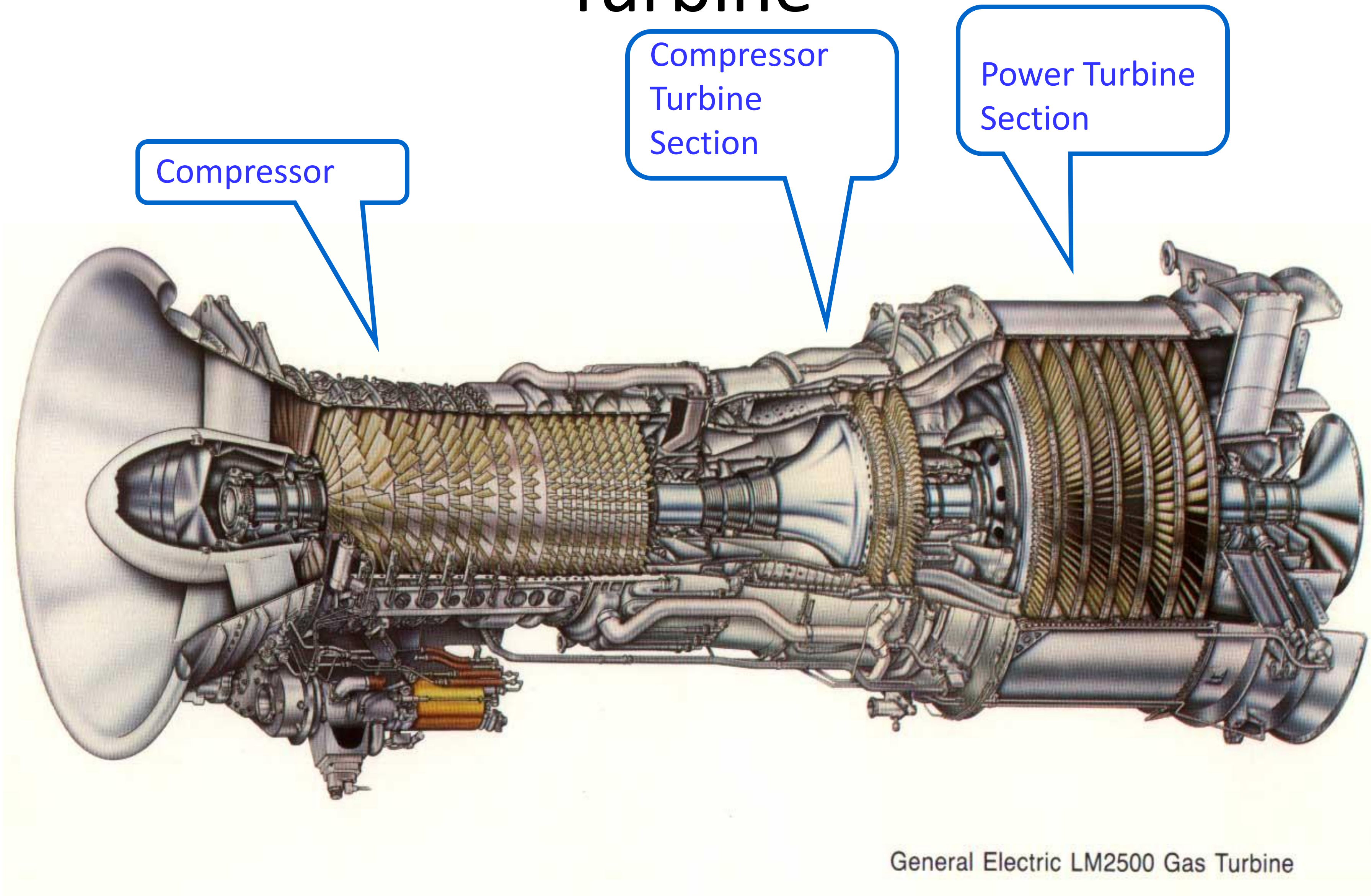
Gas Turbine Combustor Arrangement



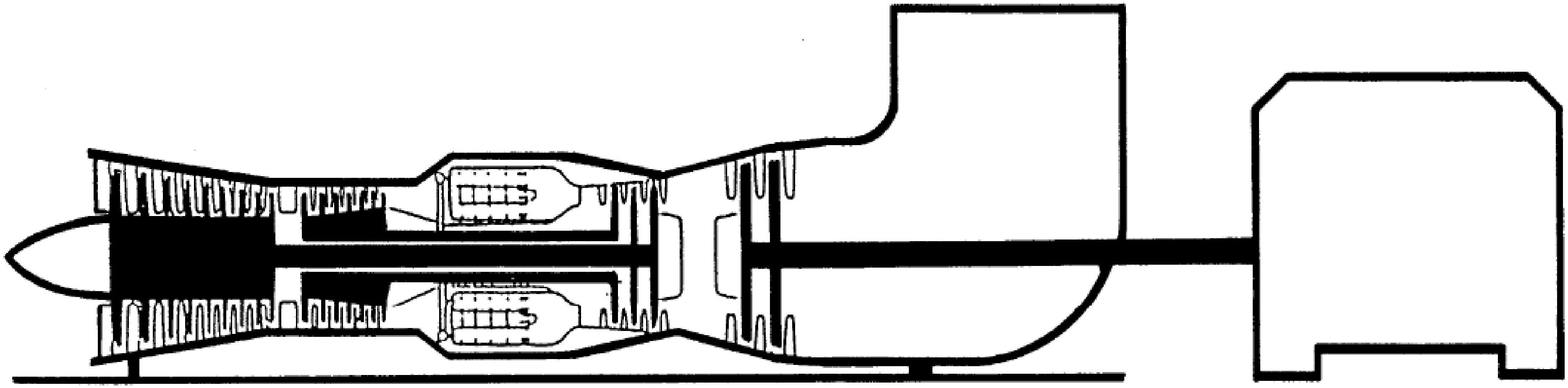
Frame 5 GT



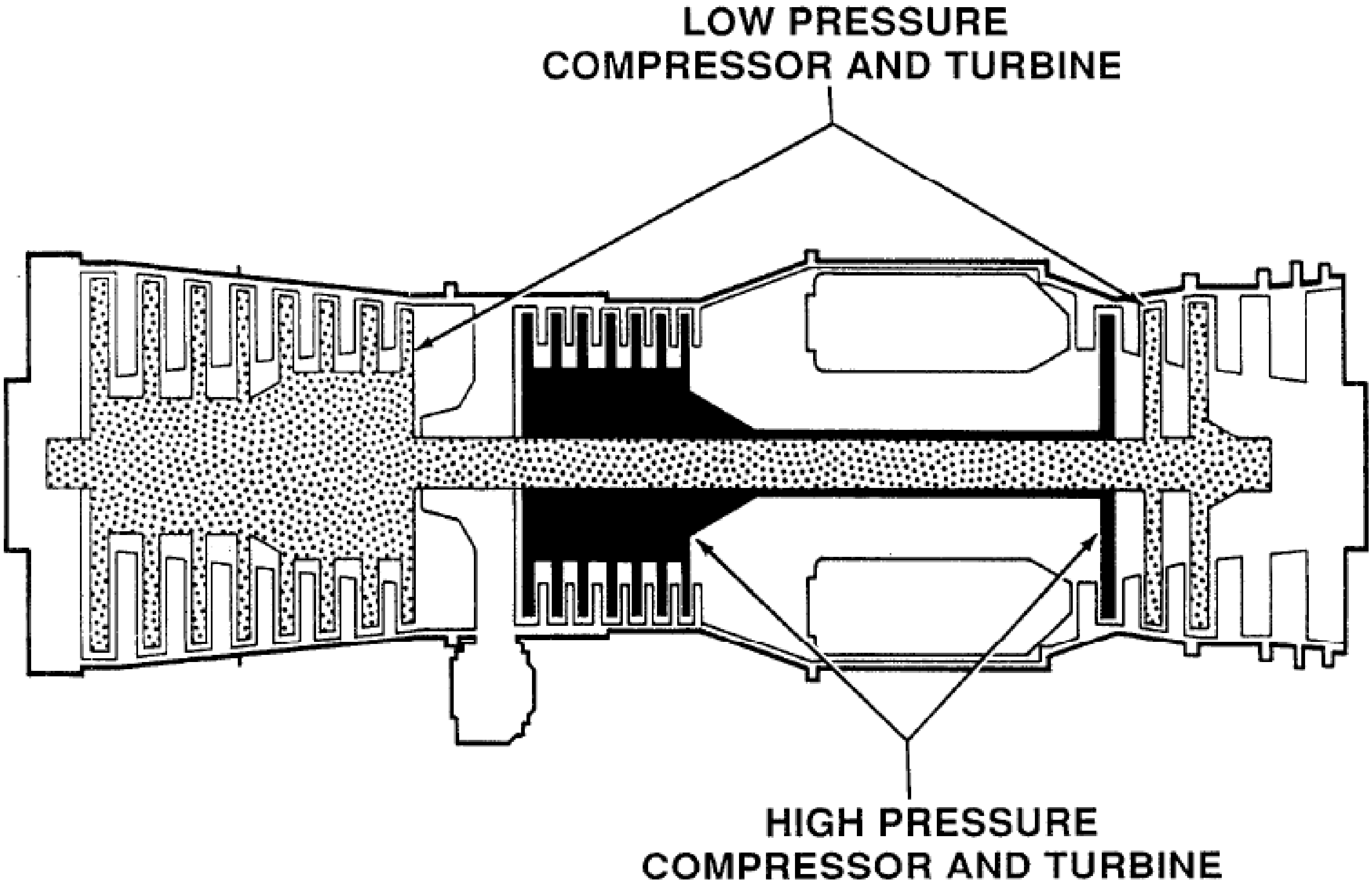
GE LM2500 Aeroderivative Gas Turbine



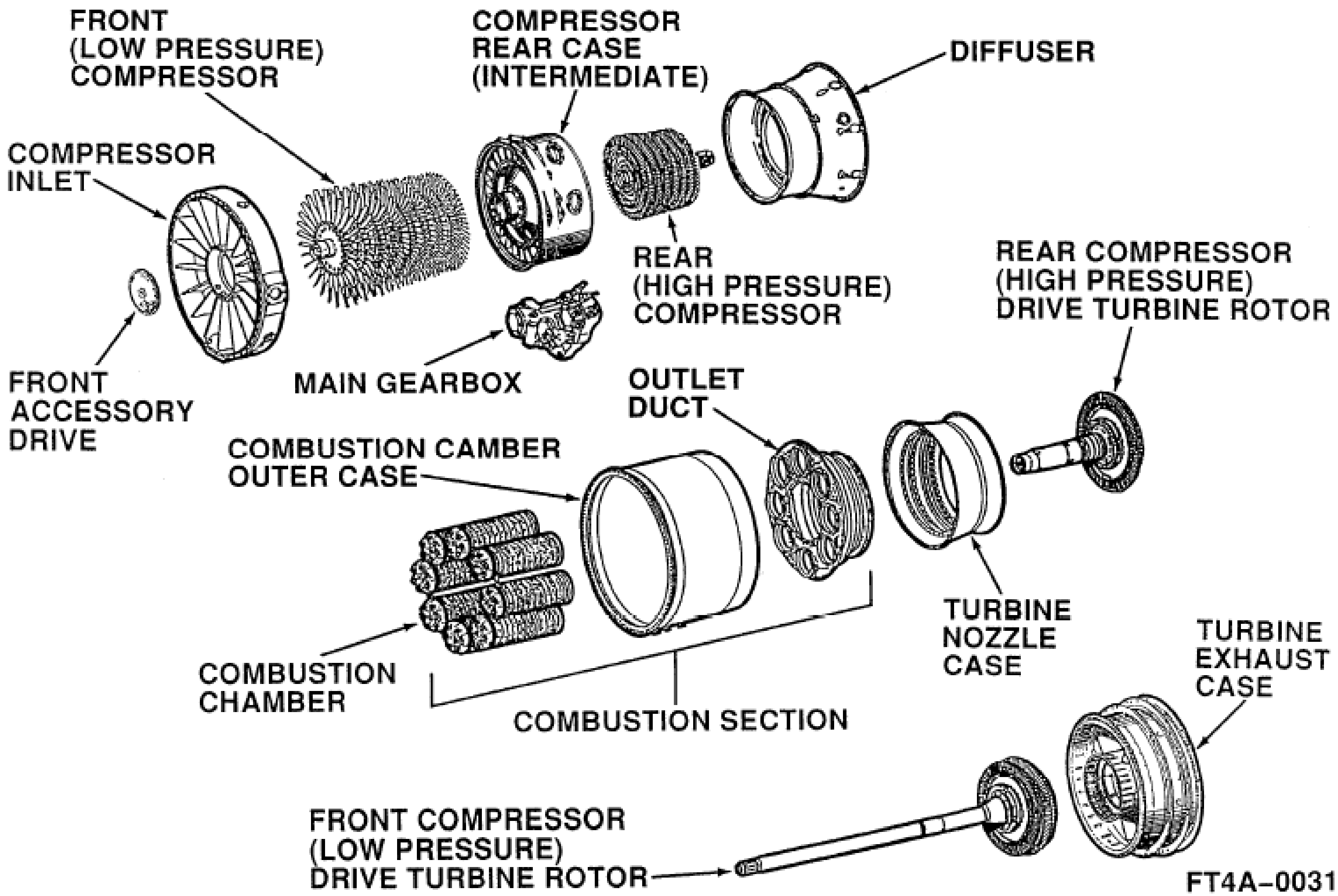
FT4 Gas Turbine



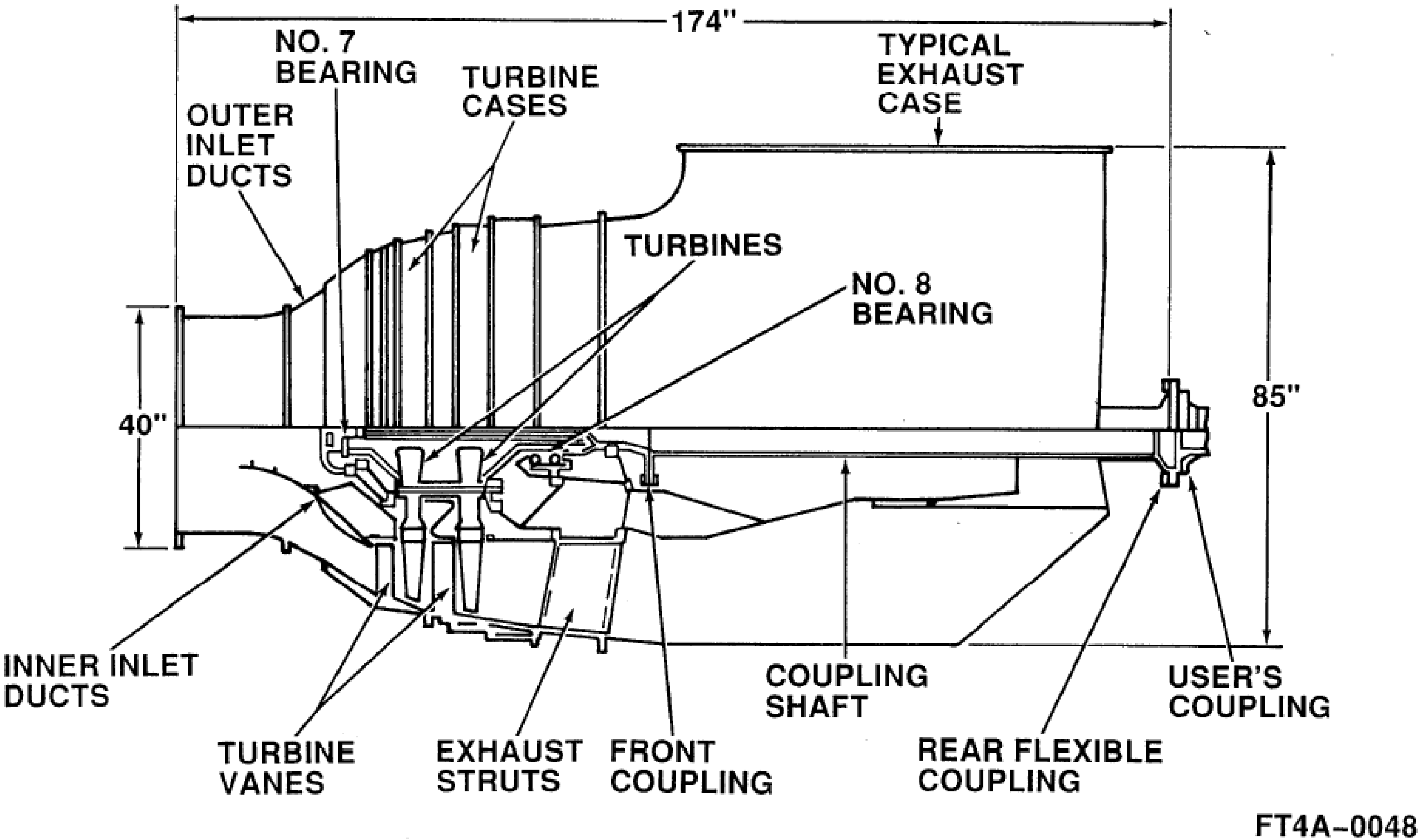
FT4 Gas Turbine – Gas Generator (Compressor)



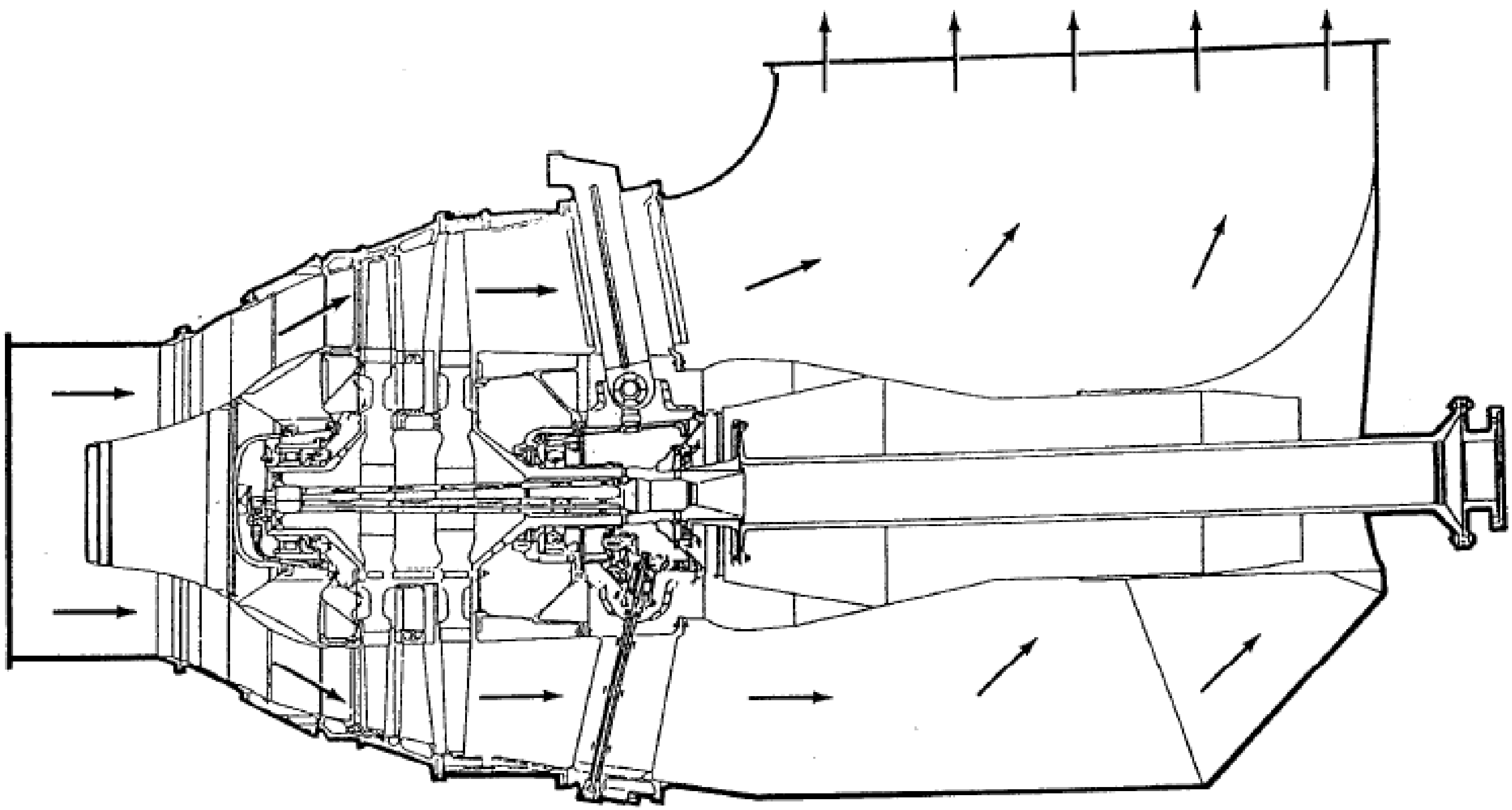
FT4 Gas Turbine – Gas Generator (Compressor)



FT4 Gas Turbine – Free Turbine



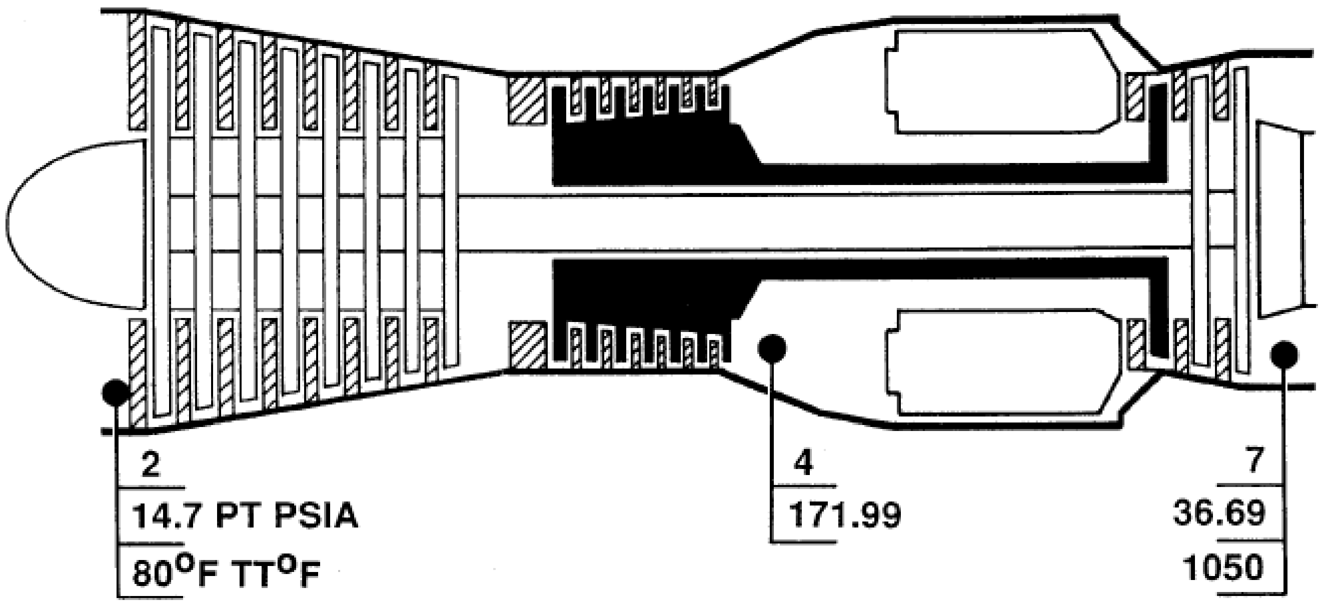
FT4 Gas Turbine – Free Turbine Gas Path



FT4 Gas Generator Performance

ENGINE MODEL FT4A

OPERATING CONDTION BASE LOAD

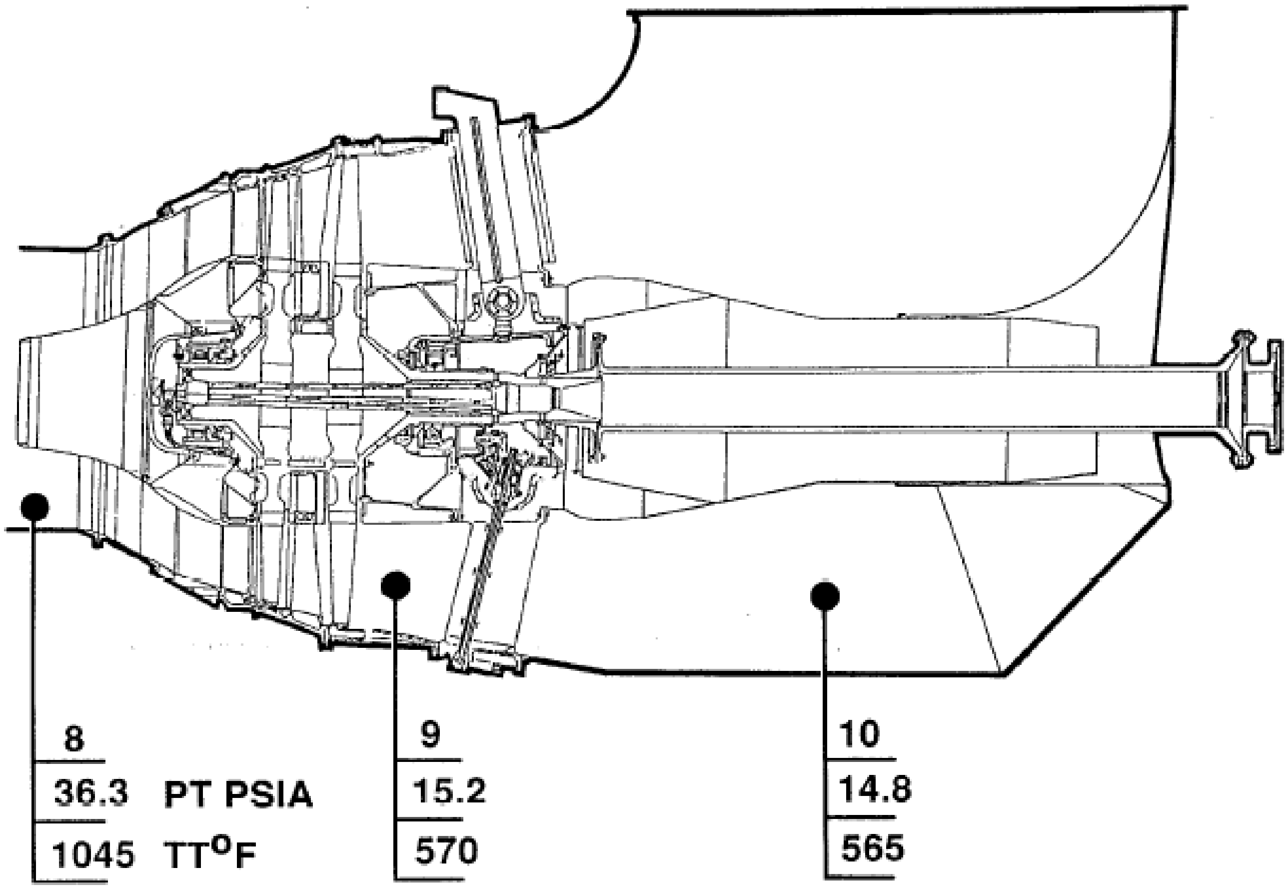


TYPICAL OPERATING PARAMETERS

N_1	6,200	RPM
N_2	8,600	RPM
WF	LIQ 12,750	LB/HR
EGT	1050	°F
EPR	2.496	

FT4A

FT4 Free Turbine Performance



TYPICAL OPERATING PARAMETERS

NP 3600 RPM

SHAFT OUTPUT 23500 SHP AT 16.7 MW

Aeroderivative Versus Heavy Duty Combustion Turbines

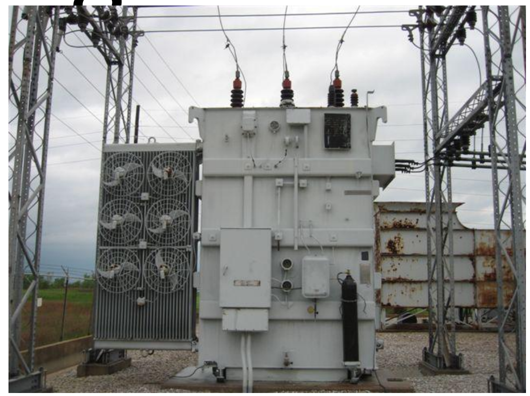
- Aeroderivatives
  - Higher Pressure Ratios and Firing Temperatures Result in Higher Power Output per Pound of Air Flow
  - Smaller Chilling/Cooling Systems Required
  - Compressor Inlet Temperature Has a Greater Impact on Output and Heat Rate
  - Benefits of Chilling/Cooling Systems are More Pronounced

Typical Simple Cycle CT Plant Components

- Prime Mover (Combustion Turbine)
- Fuel Supply & Preparation
- Emissions Control Equipment
- Generator
- Electrical Switchgear
- Generator Step Up Transformer
- Starting System (Combustion Turbines)
- Auxiliary Cooling
- Fire Protection
- Lubrication System

Typical Peaking Plant Components

Lube Oil System



GSU

Generator

Switchgear / MCC

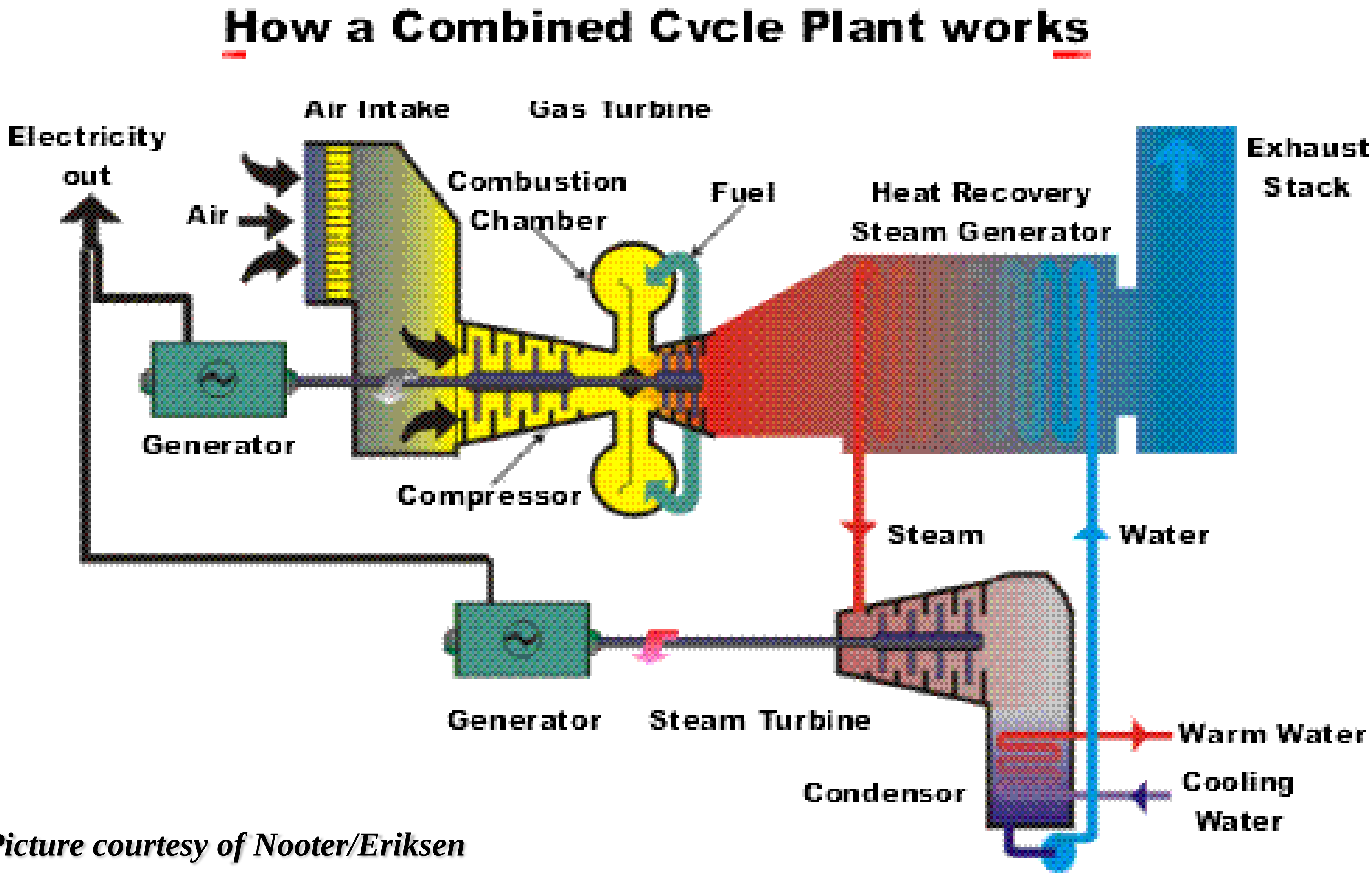
Starting Engine

Fire Protection

Combining the Brayton and Rankine Cycles

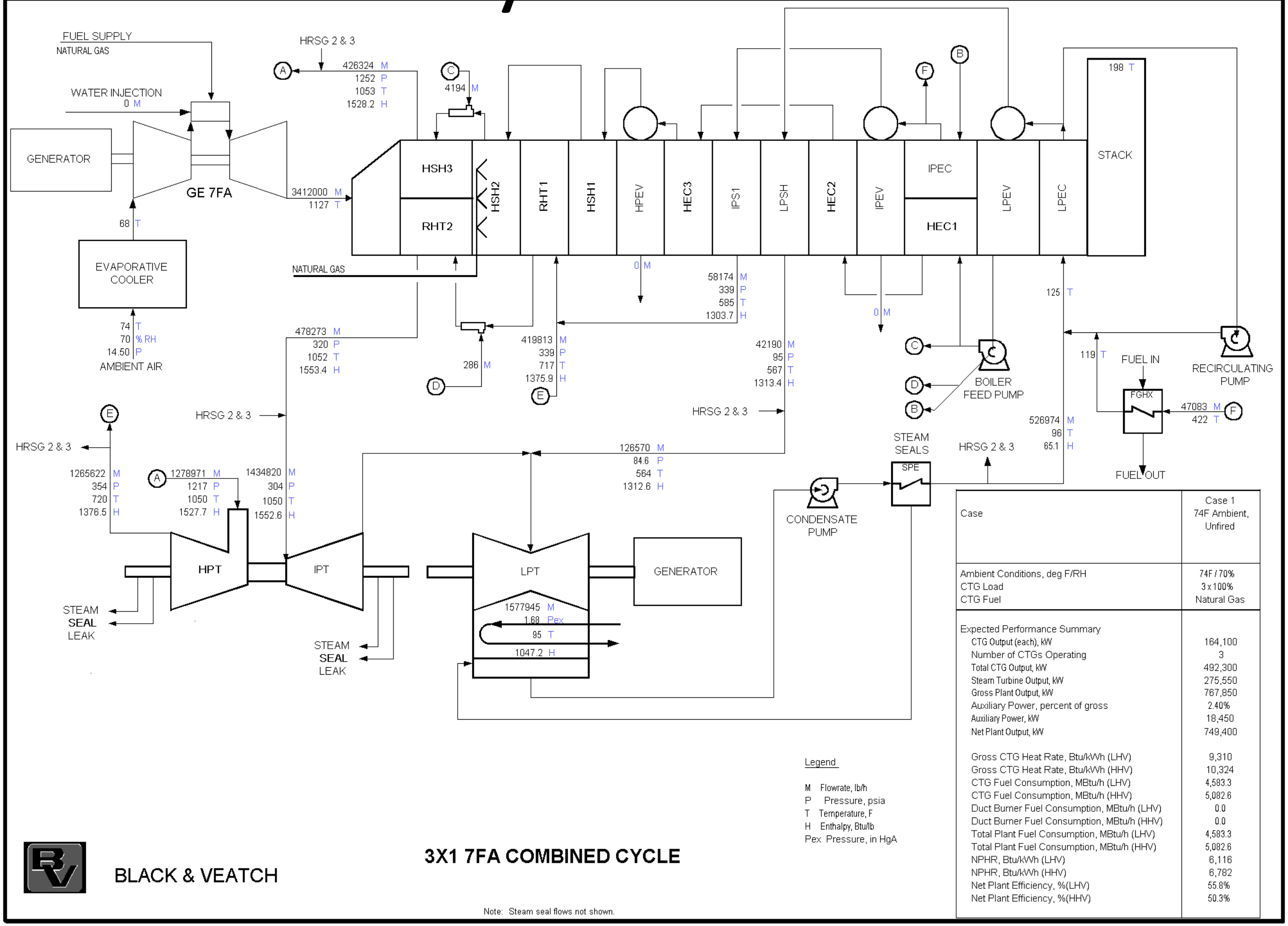
- Gas Turbine Exhaust used as the heat source for the Steam Turbine cycle
- Utilizes the major efficiency loss from the Brayton cycle
- Advantages:
  - Relatively short cycle to design, construct & commission
  - Higher overall efficiency
  - Good cycling capabilities
  - Fast starting and loading
  - Lower installed costs
  - No issues with ash disposal or coal storage
- Disadvantages
  - High fuel costs
  - Uncertain long term fuel source
  - Output dependent on ambient temperature

How does a Combined Cycle Plant Work?



Picture courtesy of Nooter/Eriksen

Combined Cycle Heat Balance



Case	Case 1 74F Ambient, Unfired
Ambient Conditions, deg F/RH	74F / 70%
CTG Load	3 x 100%
CTG Fuel	Natural Gas
Expected Performance Summary	
CTG Output (each), kW	164,100
Number of CTGs Operating	3
Total CTG Output, kW	492,300
Steam Turbine Output, kW	275,550
Gross Plant Output, kW	767,850
Auxiliary Power, percent of gross	2.40%
Auxiliary Power, kW	18,450
Net Plant Output, kW	749,400
Gross CTG Heat Rate, Btu/kWh (LHV)	9,310
Gross CTG Heat Rate, Btu/kWh (HHV)	10,324
CTG Fuel Consumption, MBtu/h (LHV)	4,583.3
CTG Fuel Consumption, MBtu/h (HHV)	5,082.6
Duct Burner Fuel Consumption, MBtu/h (LHV)	0.0
Duct Burner Fuel Consumption, MBtu/h (HHV)	0.0
Total Plant Fuel Consumption, MBtu/h (LHV)	4,583.3
Total Plant Fuel Consumption, MBtu/h (HHV)	5,082.6
NPHR, Btu/kWh (LHV)	6,116
NPHR, Btu/kWh (HHV)	6,782
Net Plant Efficiency, %(LHV)	55.8%
Net Plant Efficiency, %(HHV)	50.3%

Combined Cycles Today

- Plant Efficiency ~ 58-60 percent
  - Biggest losses are mechanical input to the compressor and heat in the exhaust
- Steam Turbine output
  - Typically 50% of the gas turbine output
  - More with duct-firing
- Net Plant Output (Using Frame size gas turbines)
  - up to 750 MW for 3 on 1 configuration
  - Up to 520 MW for 2 on 1 configuration
- Construction time about 24 months
- Engineering time 80k to 130k labor hours
- Engineering duration about 12 months
- Capital Cost ($900-$1100/kW)
- Two (2) versus Three (3) Pressure Designs
  - Larger capacity units utilize the additional drums to gain efficiency at the expense of higher capital costs

Combined Cycle Efficiency

- Simple cycle efficiency (max ~ 44%*)
- Combined cycle efficiency (max ~58-60%*)
- Correlating Efficiency to Heat Rate (British Units)
  - η= 3412/(Heat Rate) --> 3412/η = Heat Rate*
  - Simple cycle – 3412/.44 = 7,757 Btu/Kwh*
  - Combined cycle – 3412/.58 = 5,884 Btu/Kwh*
- Correlating Efficiency to Heat Rate (SI Units)
  - η= 3600/(Heat Rate) --> 3600/η = Heat Rate*
  - Simple cycle – 3600/.44 = 8,182 KJ/Kwh*
  - Combined cycle – 3600/.58 = 6,207 KJ/Kwh*
- Practical Values
  - HHV basis, net output basis
  - Simple cycle 7FA (new and clean) 10,860 Btu/Kwh (11,457 KJ/Kwh)
  - Combined cycle 2x1 7FA (new and clean) 6,218 Btu/Kwh (6,560 KJ/Kwh)

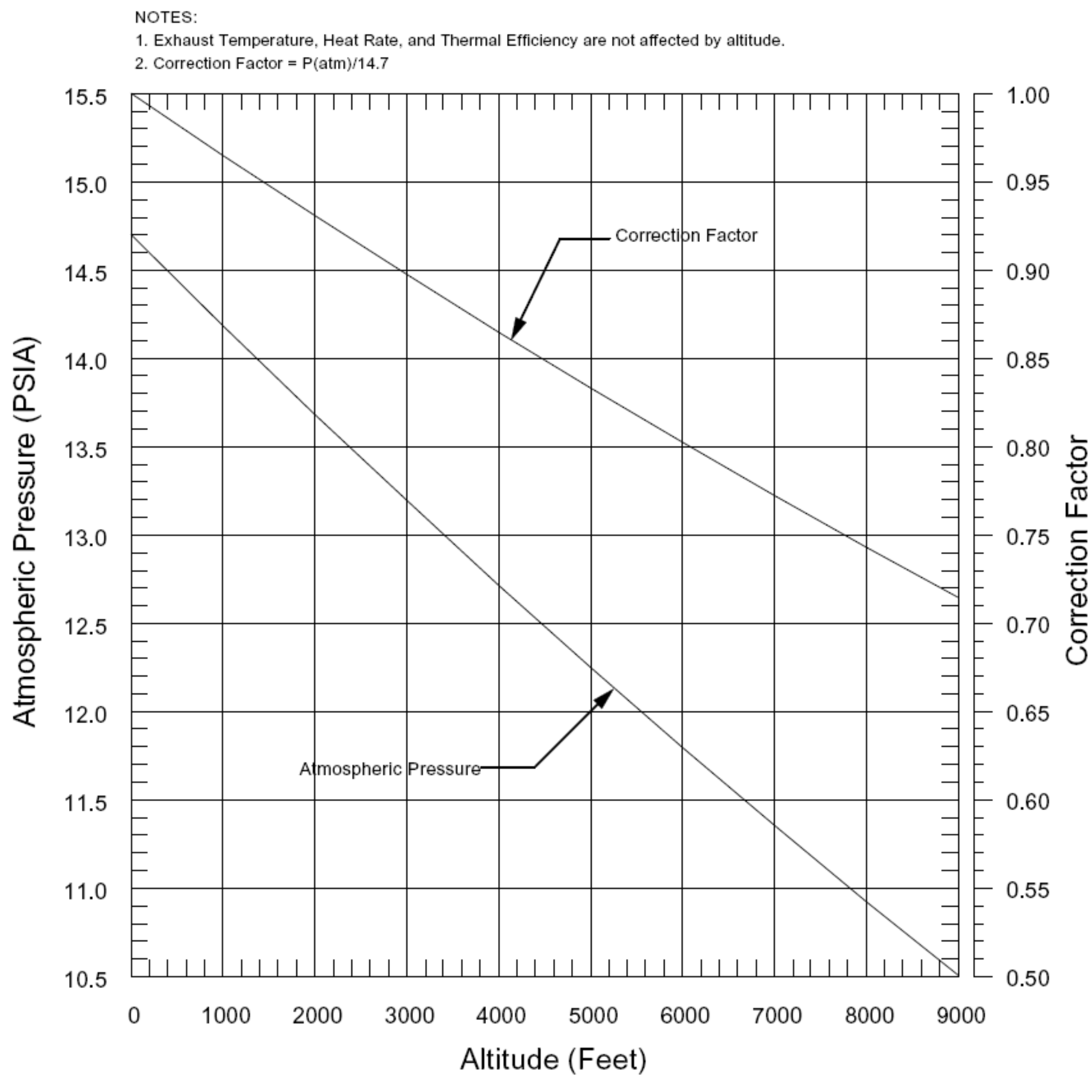
*Gross LHV basis

Gas Turbine Generator Performance

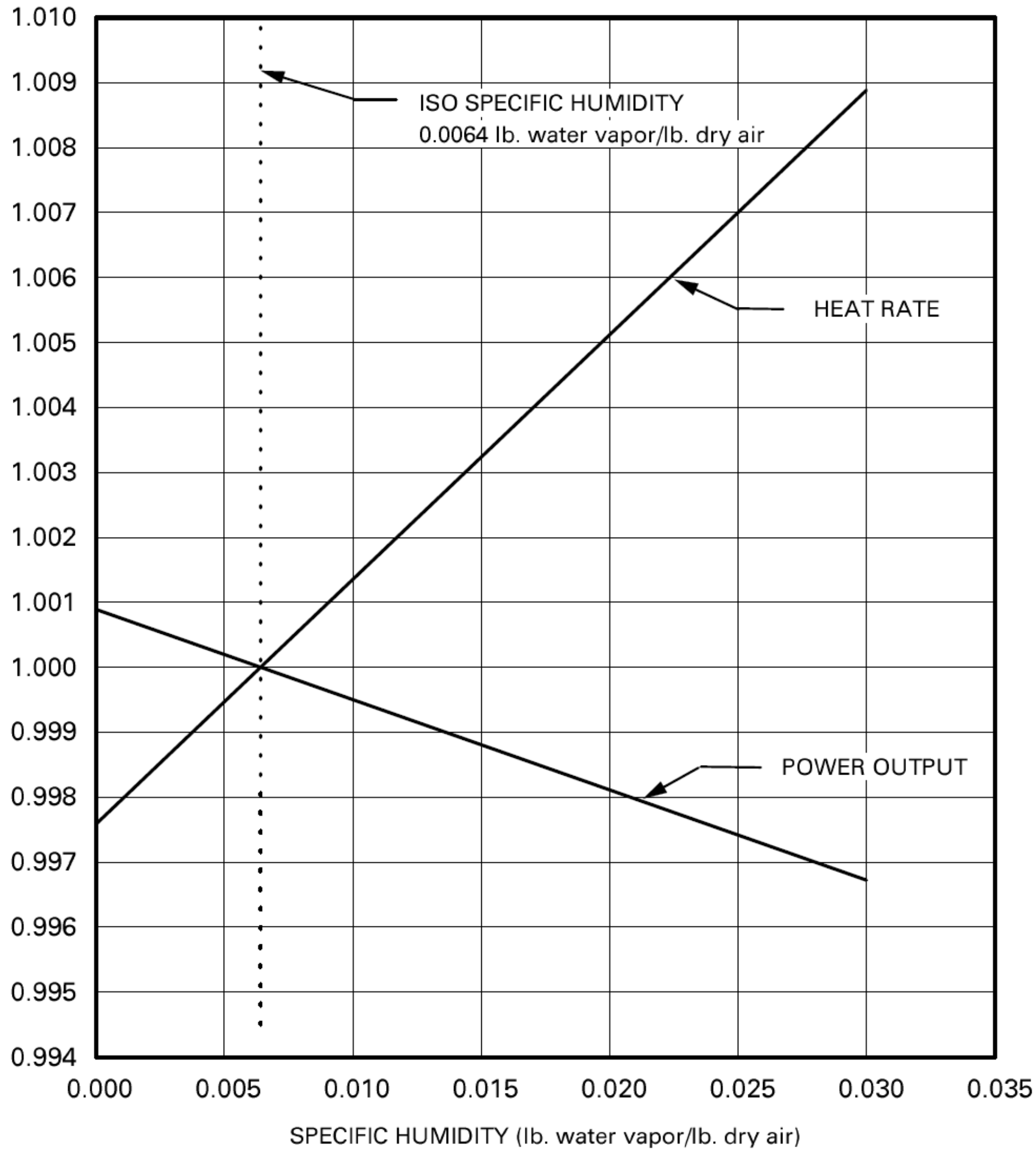
Factors that Influence Performance

- Fuel Type, Composition, and Heating Value
- Load (Base, Peak, or Part)
- Compressor Inlet Temperature
- Atmospheric Pressure
- Inlet Pressure Drop
  - Varies significantly with types of air cleaning/cooling
- Exhaust Pressure Drop
  - Affected by addition of HRSG, SCR, CO catalysts
- Steam or Water Injection Rate
  - Used for either power augmentation or NO_x control
- Relative Humidity

Altitude Correction



Humiditv Correction



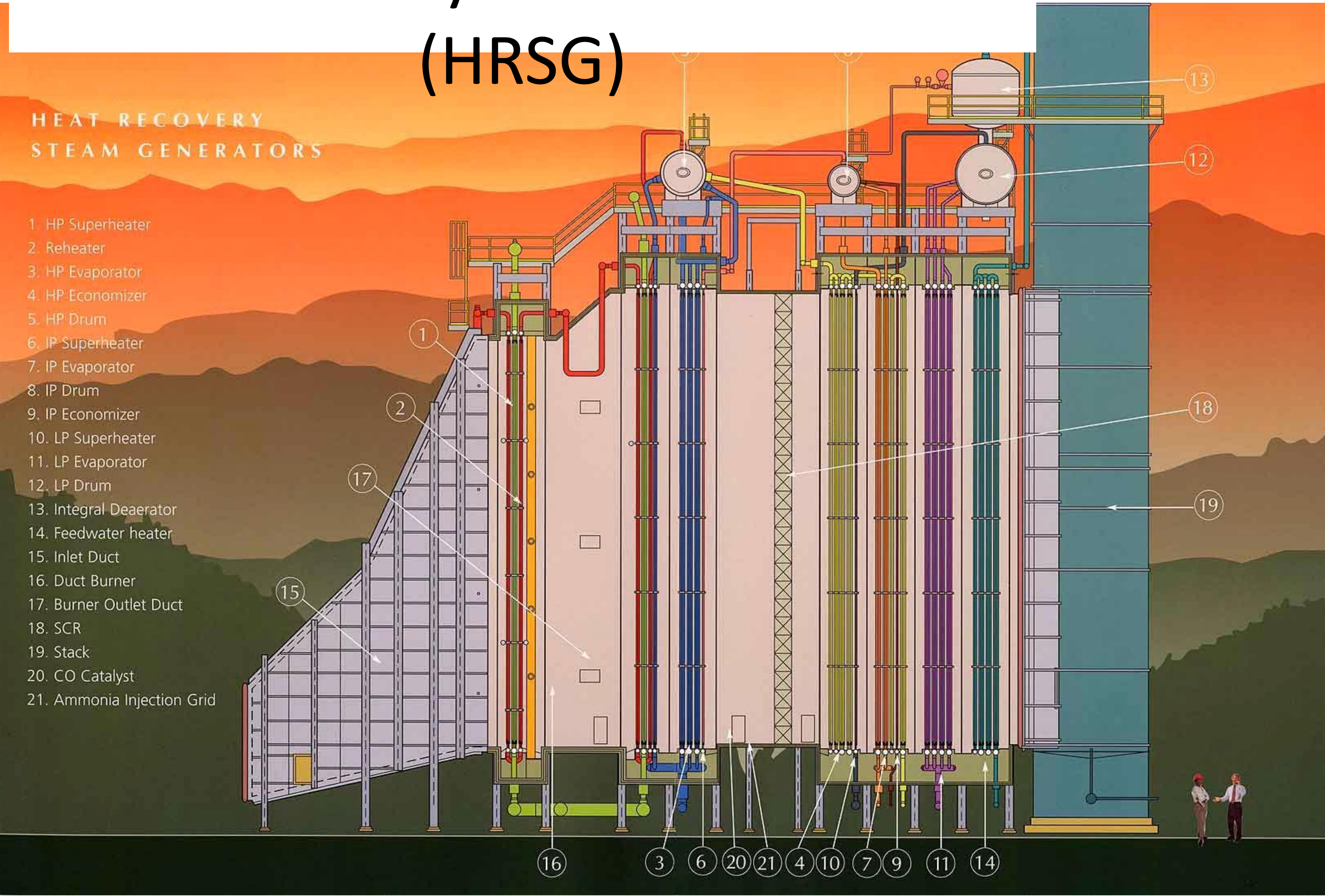
Cogeneration Plant

- A Cogeneration Plant
  - Power generation facility that also provides thermal energy (steam) to a thermal host.
- Typical thermal hosts
  - paper mills,
  - chemical plants,
  - refineries, etc…
  - potentially any user that uses large quantities of steam on a continuous basis.
- Good applications for combined cycle plants
  - Require both steam and electrical power

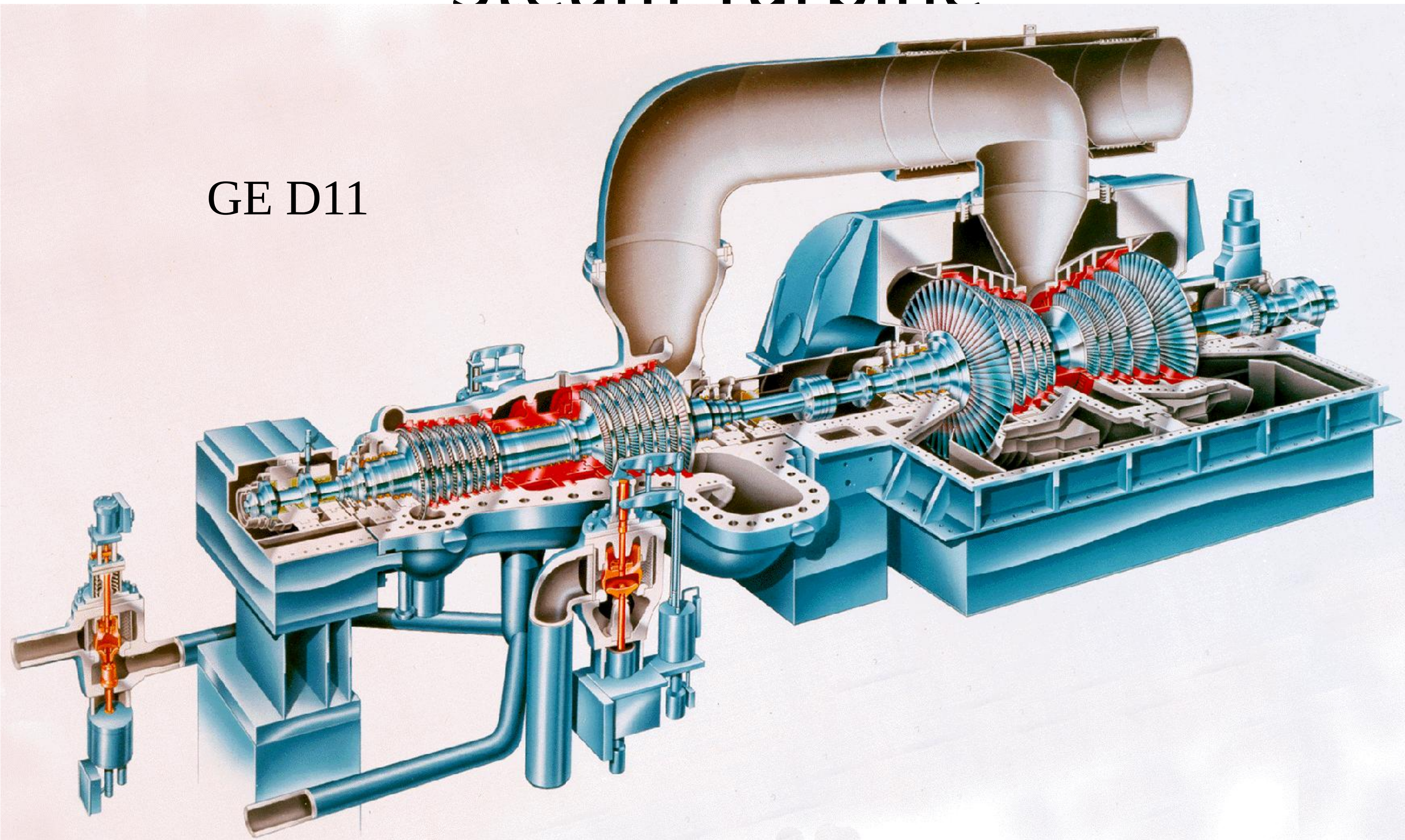
Major Combined Cycle Plant Equipment

- Combustion Turbine (CT/CTG)
- Steam Generator (Boiler/HRSG)
- Steam Turbine (ST/STG)
- Heat Rejection Equipment
- Air Quality Control System (AQCS) Equipment
- Electrical Equipment

Heat Recovery Steam Generator (HRSG)

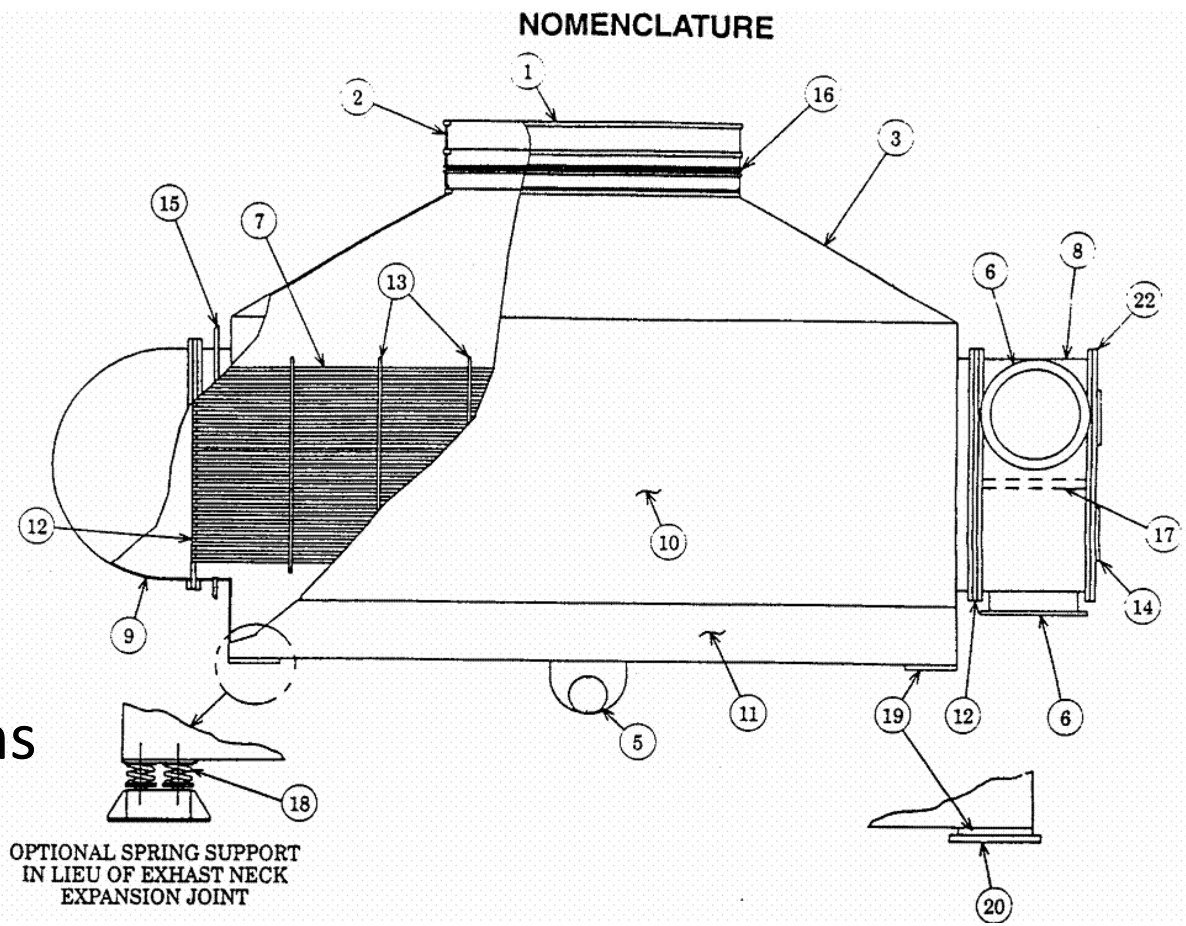


Steam Turbine



Heat Rejection Equipment - Condenser

- Same Function as discussed earlier in Session 9
  - Usually utilizes a cooling tower to reject heat to the atmosphere
  - Rarely uses once through cooling (retrofit applications or ocean)



Alternating Current, Power Distribution, and Voltage Systems

Electricity for Refrigeration, Heating and Air Conditioning 7th Edition

Alternating Current, Power Distribution, and Voltage Systems

Upon completion of this chapter the student will be able to:

- Explain the basic differences between direct and alternating current.
- Briefly explain how alternating current is produced.
- Explain the difference between single-phase and three-phase, power distribution systems.
- Explain inductance, reactance, and impedance.
- Explain a basic power distribution system.
- Explain the common voltage systems.
- Identify the common voltage systems.

Key Terms

- Alternator
- Capacitive Reactance
- Delta System
- Effective Voltage
- Frequency
- Impedance
- Inductance
- Inductive Reactance
- Peak Voltage
- Phase
- Power Factor
- Reactance
- Sine Wave
- Single Phase
- Three Phase
- Wye System

Power Distribution

- Direct Current was used in the beginning to supply consumers with their electrical needs.
- However this has many disadvantages.
  - Transmission for a long distance is impossible without using generators to boost the power.
  - Its inability to raise and lower it's voltages.
  - The use of large transmission equipment

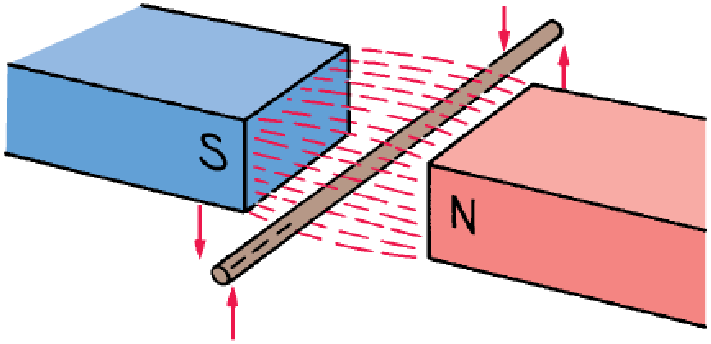
Direct Current

- Electrons flowing in an electric circuit is called current.
- Current flow can be obtained in an electric circuit by a bolt of lighting, by static electricity, or by electron flow from a generator.
- There are two types of electric current: direct current and alternating current.
- Direct current flows in one direction only.
- Typically produced by dry cell batteries.

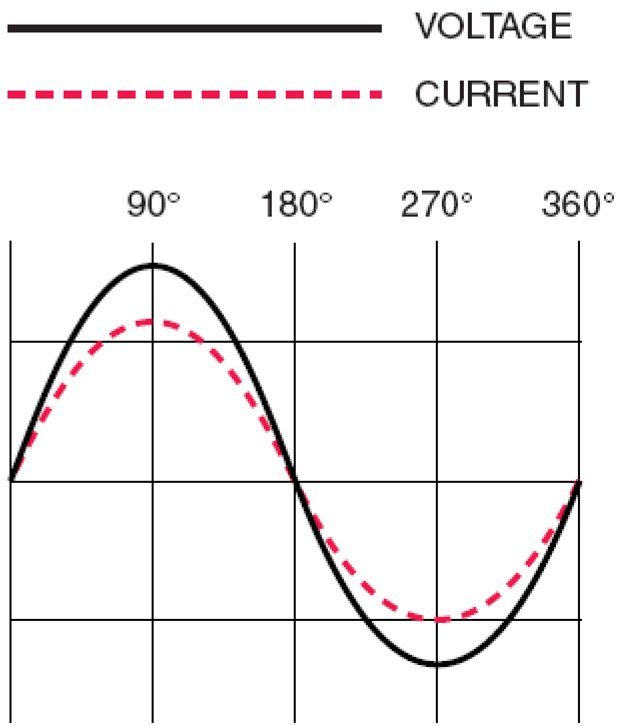
Alternating Current

Basic concepts of alternating current

- Alternating current is an electron flow that alternates, flowing in one direction and then in the opposite direction at regular intervals.
- Alternating current is produced by cutting a magnetic field with a conductor.
- Alternating current is graphically represented by using the sine wave.



Sine Waves



Cycles and Frequency

- When a conductor rotates through on complete revolution, it has generated two alternations, or flow reversals.
- Two alternations (changes in direction) equal one cycle.
- One cycle occurs when the rotor, or conductor, cuts the magnetic field of a north pole and south pole.

Frequency

- The frequency of alternating current is the number of complete cycles that occur in a second.
- The frequency in known as hertz (Hz), but many times it is referred to as cycles.
- In the United States the common frequency is 60 Hz.

Effective Voltage

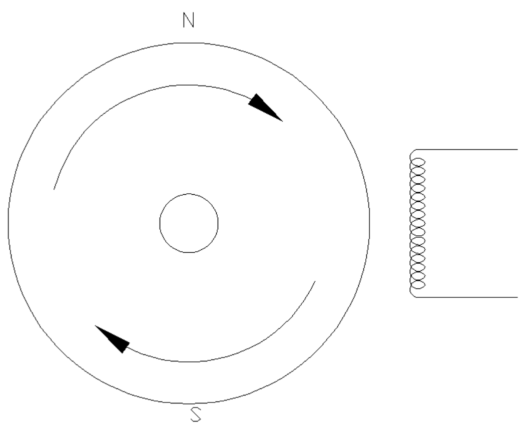
- Because alternating current starts at 0, reaches a peak, and then returns to 0, there is always a variation in voltage and an effective value has to be determined.
- Alternating current reaches a peak at 90 electrical degrees, also known as the peak voltage.
- The effective voltage of an alternating current circuit is 0.707 times its peak voltage.

Phase

- The phase of an AC circuit is the number of currents alternating at different time intervals in the circuit.

Single-Phase

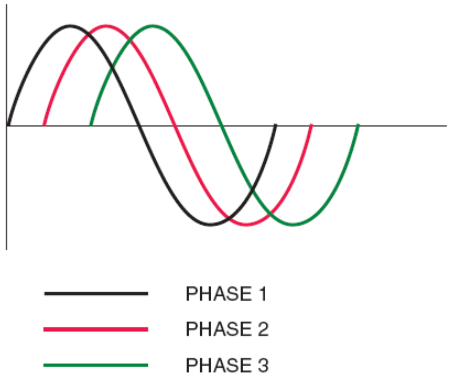
- Single-Phase current would allow only a single current

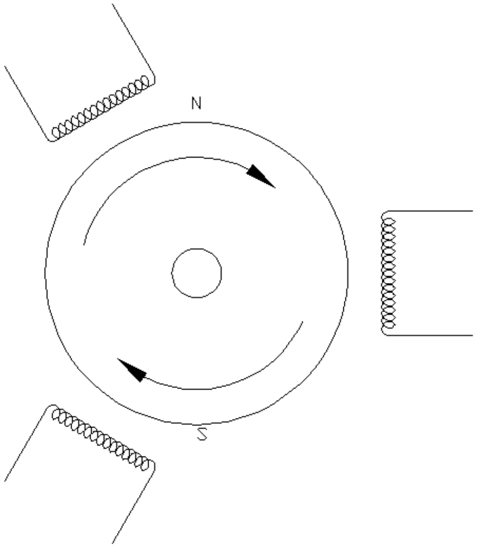


Winding arrangement of a single-phase alternator

Three-Phase

- Three-Phase current has three separate currents.





Alternator

- Alternating current is produced by an alternator.
- The alternator is made up of a winding or set of windings called the stator and a rotating magnet called the rotor.
- The number of windings used depends on the desired phase characteristics of the current.

Inductance and Reactance

- The fluctuation of the magnetic strengths in an AC circuit, and in conductors cutting through more than one magnetic field, induces (causes) a voltage that counteracts the original voltage.
- This effect is called inductance.
- AC circuits are affected by resistance, but they are also affected by reactance.
- Reactance is the resistance that alternating current encounters when it changes flow.
- There are two types of reactance in Alternating current; inductive reactance and capacitive reactance.

Inductive Reactance

- Is the opposition to the change in flow of alternating current, which produces an out-of-phase condition between voltage and amperage

Capacitive Reactance

- Is caused in AC circuits by using capacitors.
- When a capacitor is pit in an AC circuit, it resist the change in voltage, causing the amperage to lead the voltage.

Power

- The ratio between the true power and the apparent power is called the power factor and is usually express as a percentage.
- PF = true power/Apparent power

Inductive Reactance

- Is the opposition to the change in flow of alternating current, which produces an out-of-phase condition between voltage and amperage

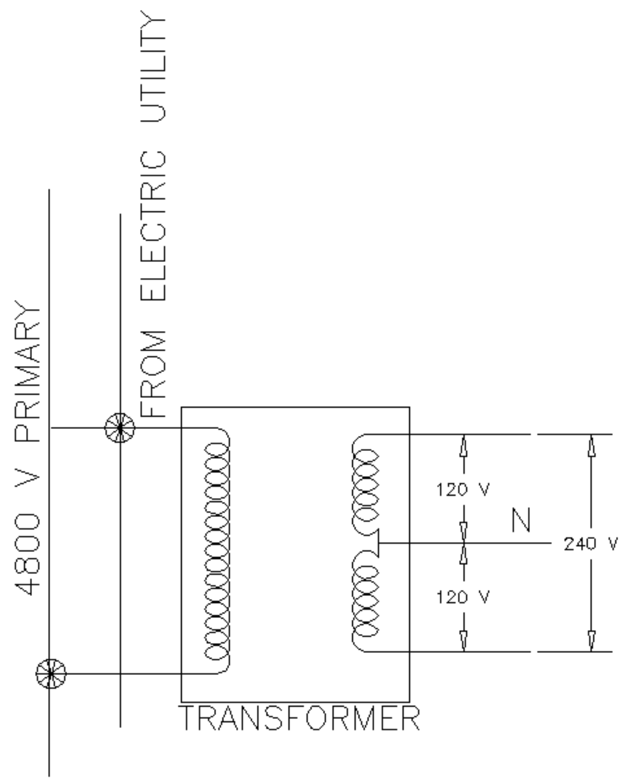
Production and Transmission of AC

1. When AC is produced from a generator it typically is boosted to approximately 220,000 volts for transmission.
2. This is typically transmitted to a substation where it is reduced to 4800 volts.
3. It is then supplied to a transformer where it is reduced to a usable voltage.

240 Volt-Single-Phase-60 Hertz Systems

- Single phase alternating current exist in most residences.
- Any domestic appliance that operates on 120 volts is considered single-phase equipment.
- In some older structures it is still possible to find a single-phase, two wire system.
- The most common voltage systems found today is the 240 V Single Phase 60 Hz systems.

240 Volt-Single Phase 60 Herz System



Three Phase Voltage Systems

- Three-phase alternating current is common in most commercial and industrial applications.
- Three-phase electrical services supply three hot leg of power with one ground to the distribution equipment and then on to the equipment.
- Three-phase are more versatile than single-phase supplies.
- Most residences do not use enough electric energy to warrant a three-phase power supply.

Advantages of Three-phase Power

- Three-phase electric motors do not require special starting apparatus.
- Three-phase power offer better starting and running characteristics for motors.

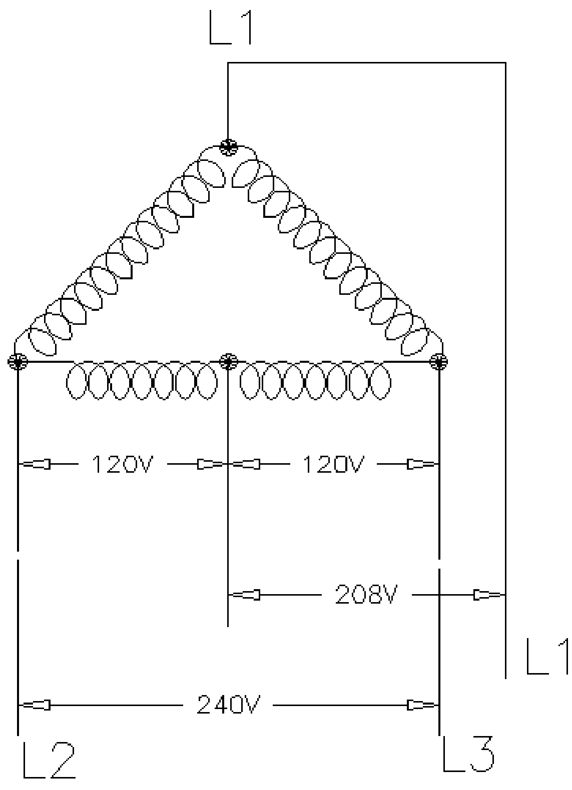
Disadvantages of Three-phase Power

- Three-phase systems have a higher cost associated with the electric panels and distribution equipment.

240 Volt-Three-Phase-60 Hertz Delta System

- Is used in structures that require a large supply to motors and other three-phase equipment.
- The delta system is usually supplied to a structure with four wires. Three hot and a neutral wire.

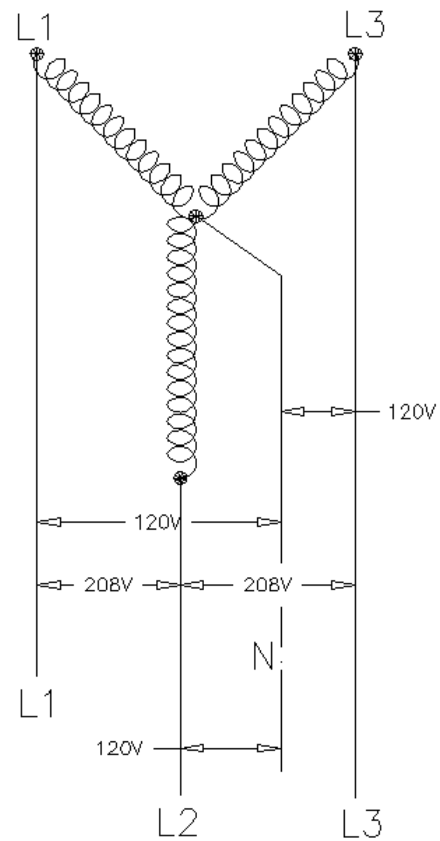
Delta System



208 Volt-Three-Phase-60 Hertz Wye System

- This system is common in structures that require a large number of 120-volt circuits, such as schools, hospitals and office buildings.
- It offers the versatility of using three-phase alternating current and the possibility of supplying many 120-volt circuits.

208 Volt-Three-Phase, 60 Hertz Wye System



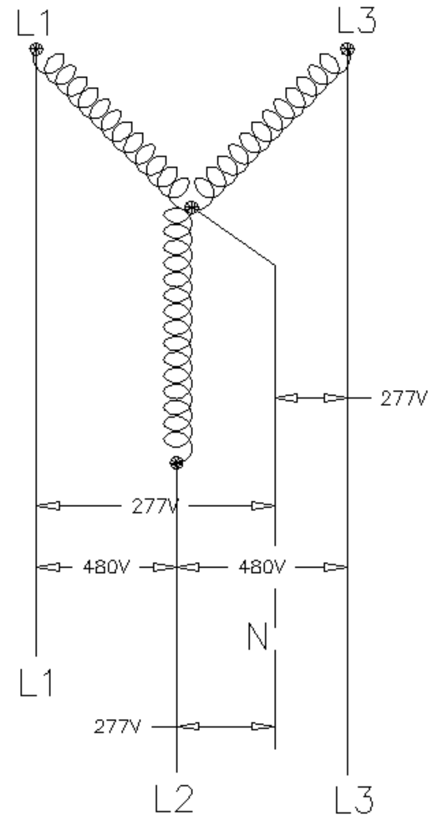
Higher Voltage System

- Higher-voltage systems are becoming increasingly popular because many advantages.
- The higher-voltage systems are used mostly in industrial structures, but in some cases they are used in commercial.
- Several high-voltage systems are available.
- 240/480 volt-single phase system
- 240/416 volt-three phase systems
- 277/480-volt single phase system

Advantages

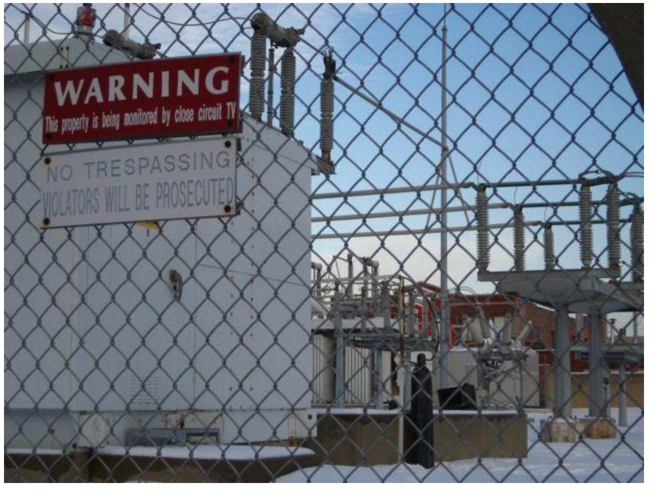
- There is little difference in the switches, relays and other electric panels used in 208-volt and 480-volt systems.
- The service equipment and wiring may be smaller for 480-volt systems than for 208-volt systems.

277/480-Volt System



What is a **SUBSTATION** ?

Please push your ENTER key to advance thru this slide show!



What is a substation?

… what does it do?

… how does it work?

These are excellent questions!

Let’s deal with them one at a time.

What is a substation?

An electrical substation takes electricity from a very high voltage and lowers it to the voltage we use in our homes & businesses

The electrical substation in the 1800 block of Allen Street is similar to this one.

What is a substation?

Water comes from the water plant in very big pipes (taller than a *niño*), yet it comes out in your *cocina* or *baño* in much smaller pipes.

The electrical substation in the 1800 block of Allen Street is similar to this one.

What does a substation do?

Electricity is made at a very high, powerful voltage. A substation safely changes the electricity from very high voltage to lower voltage we can use.

The electrical substation in the 1800 block of Allen Street is similar to this one.

How does a substation work?

Transformers ‘step down’ the electricity from the high voltage needed to economically transmit the electricity.

The electrical substation in the 1800 block of Allen Street is similar to this one.

How does a substation work?

There are also complex circuit breakers, switches, relays, and capacitors.

The electrical substation in the 1800 block of Allen Street is similar to this one.

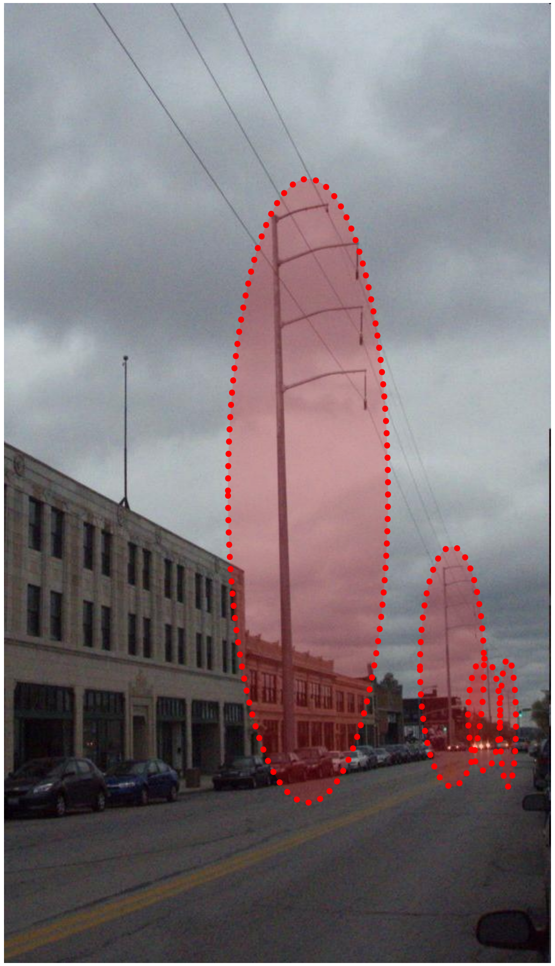
How does a substation work?

Substations have HUGE power poles to bring in the high voltage electricity. These would be more than 200 feet tall on the WestSide

The electrical substation in the 1800 block of Allen Street is similar to this one.

These are the power lines on Troost.

How does a substation work?



The electrical substation in the 1800 block of Allen Street is similar to this one.

How does a substation work?

Substations operate without any workers on-site.

Substations are monitored by remote control.

The electrical substation in the 1800 block of Allen Street is similar to this one.

How does a substation work?

Because these are very dangerous activities and no workers are present, they have automated emergency gear.

The electrical substation in the 1800 block of Allen Street is similar to this one.

How does a substation work?

There are detectors for fire and line breaks.

There is automatic fire suppression.

The electrical substation in the 1800 block of Allen Street is similar to this one.

How does a substation work?

KCP&L workers will come occasionally to do maintenance work on the substation.

The electrical substation in the 1800 block of Allen Street is similar to this one.

Can a substation harm me?

The short answer is YES!

That's why there are fences around them. They can electrocute people.

The electrical substation in the 1800 block of Allen Street is similar to this one.

Can a substation harm me?

Poisonous and corrosive chemicals are inside the substation.

The electrical substation in the 1800 block of Allen Street is similar to this one.

Can a substation harm me?

All substations emit invisible electrical waves. Some scientists believe these waves harm us.

[Not all scientists agree about this, including those at KCP&L.]

The electrical substation in the 1800 block of Allen Street is similar to this one.

Can a substation harm me?

That buzz you hear at the start of these slides is similar to the constant buzz from a substation. This can cause to headaches.

The electrical substation in the 1800 block of Allen Street is similar to this one.

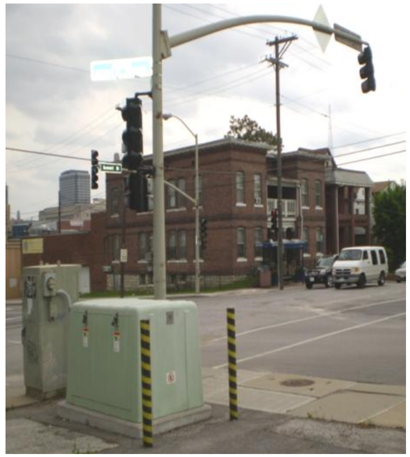
So why do we have substations?

We need them to cheaply transfer electricity.

Substations are a part of what we call **essential infrastructure**.

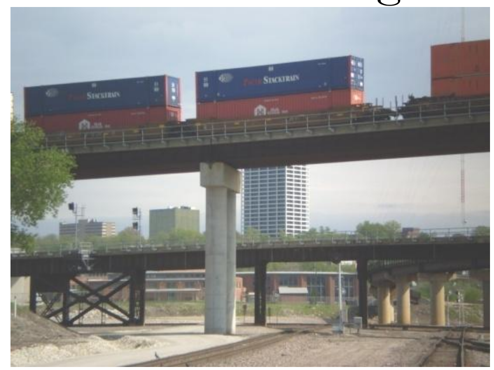
Essential Infrastructure on the Westside

Radio, cell phone & microwave towers



Streets & highways

Railroads & bridges



Pipelines for natural gas :& other chemicals

Water & wastewater treatment plants

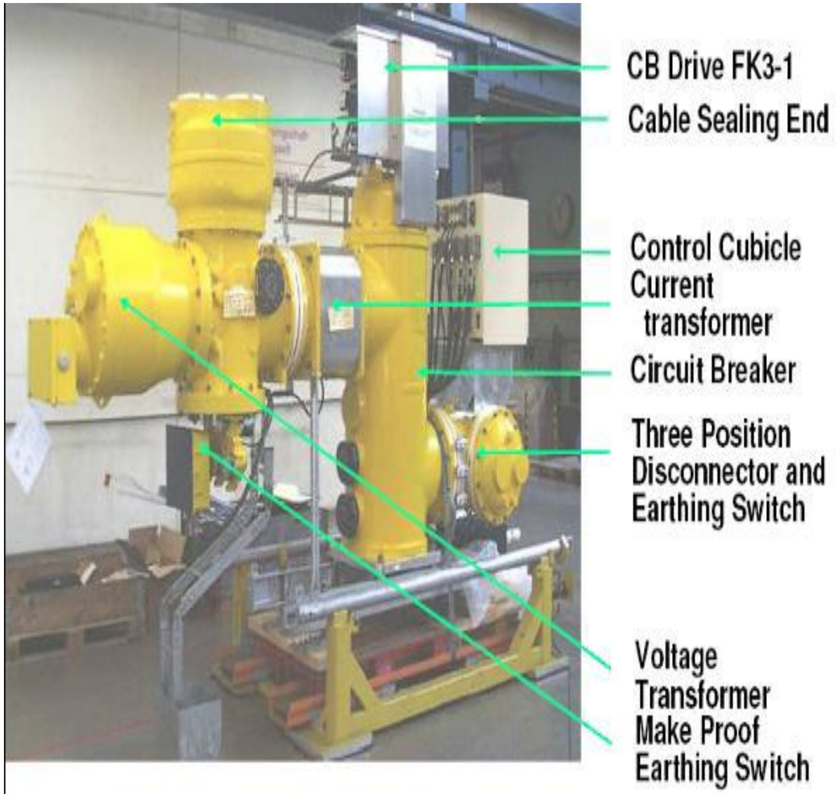
GAS INSULATED SUBSTATIONS

INTRODUCTION

- Conventional substations requires, small installation size, protection against atmospheric pollution and moisture, noiseless operation, nonexplosive and flame resistant, reduced maintenance, minimal radio interference, but totally enclosed substations using SF6 gas as insulation that are also known as GIS is now in widespread use in the electrical power industry

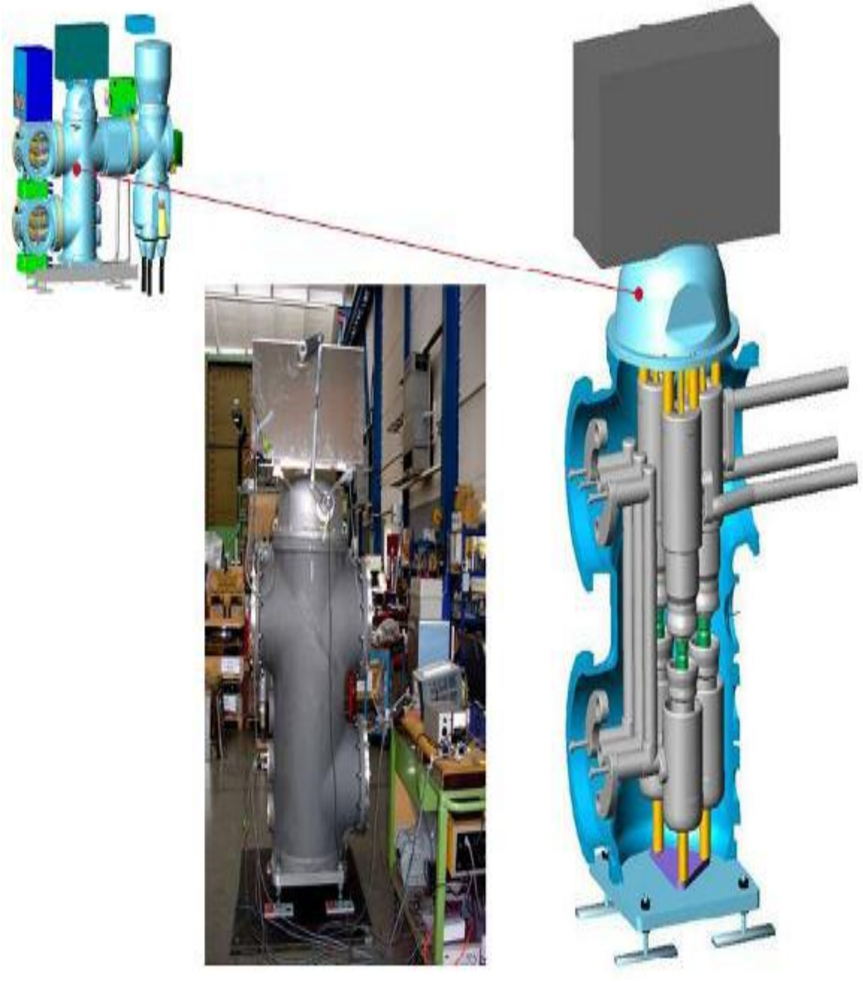
IT CONSISTS OF

- Bus bars
- Circuit breakers
- Disconnecting switches
- Earthing switches
- Current transformers
- Voltage transformers
- Densimeter
- Cable and boxes
- Gas supply and gas monitoring equipment
- Local control



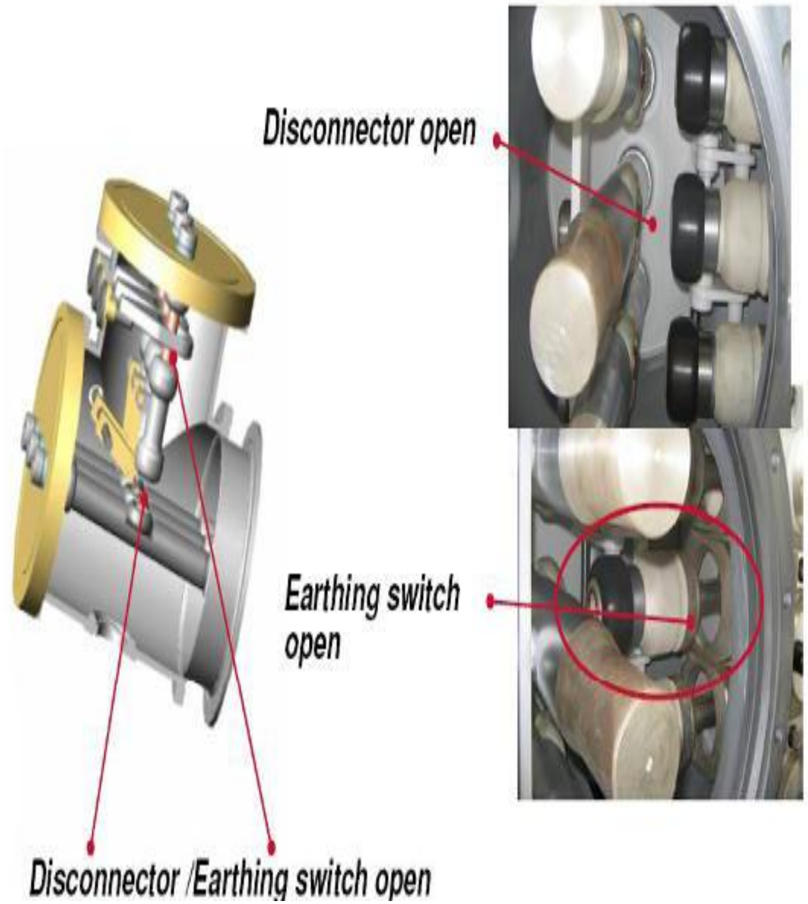
Circuit Breaker

- Under short circuit conditions, however, the current may reach tens of thousands of amperes at a power factor as low as 0.1. It is duty of a circuit breaker to interrupt such currents as soon as possible to avoid equipment damage.



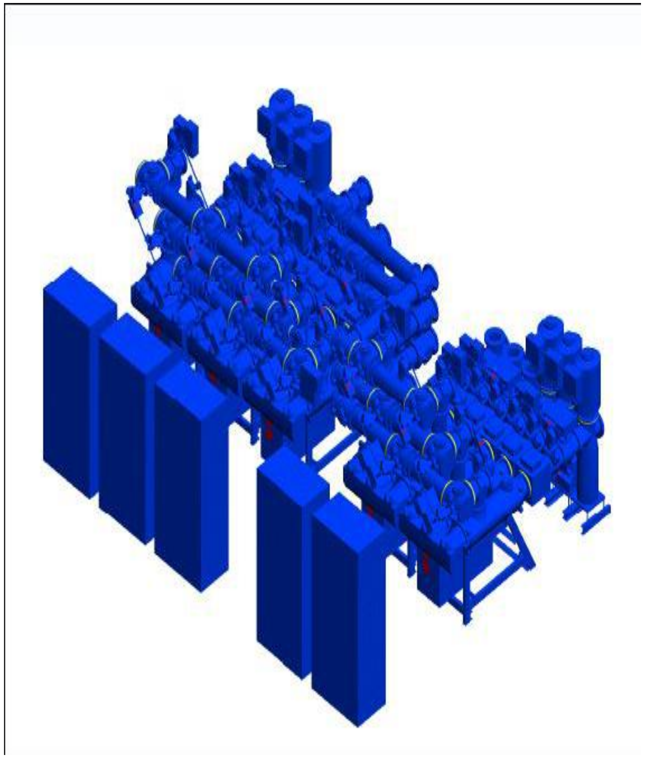
Disconnectors

- Disconnectors or isolators are used for electrical isolation of circuit parts
- They are slow acting and operating at off load
- Disconnectors must be carefully designed and tested to be able to break small charging current without generating too-high over voltage,



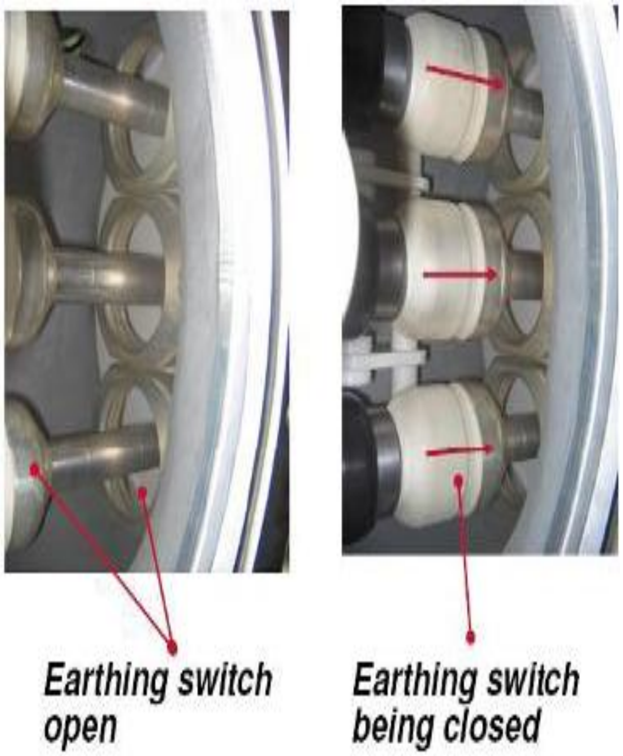
Local Control Cubicles "LCC"

- LCC is the interface cubicles to all secondary systems of a substation which are represent a station control and protection.
- LCC includes control and alarm functions as well as the correct distribution of auxiliary power supply for the relevant GIS bay.



Earthing Switch

- Slow-operating earthing switch are used for protection purpose when work is being done in the substation, but are operated only when it is certain that the high-voltage system is not energized. The fast-closing earthing switch can close against full voltage and short circuit power. The high speed earthing switch is achieved by means of a spring-closing device.



Voltage Transformer

- Variable location on feeder and busbars.
- Integrated disconnecting facility for GIS and power cable testing without dismantling and gas handling.
- Flexible gas compartment allocation for optimal service oriented gas supervision.

Current Transformer

- In the single phase enclosed Core of CT is located outside the enclosure$inside for three phase
- Gas compartment to reduce access of moisture and to suppress gas-tight bushings for secondary connections.

Cables Compartment

- Optimized solution for plug-in type power cable connection.
- Adjustable support structures for minimum requirements for the GIS floor.
- Fixation to the GIS floor by cemented anchor bolts, no need for special foundation (steel beams….etc)

PROPERTIES OF SF6

- SF6 does not harm to the ozone layer.
- Sf6 gas is chemically stable
- Non poisonous
- Colourless&heavier than air
- Almost water insoluble
- Non inflammable
- Its dielectric strength is three times more than air

ADVANTAGES

- Gis have no risks for fire&explosion due to leakage of oil
- They generate no noise&have no radio interference
- Located closure to load centers there by reducing transmission&distribution s\ms
- It offer solutions including

-In industrial areas where space&pollution problems

-Mountain areas where ice&snow are major problems

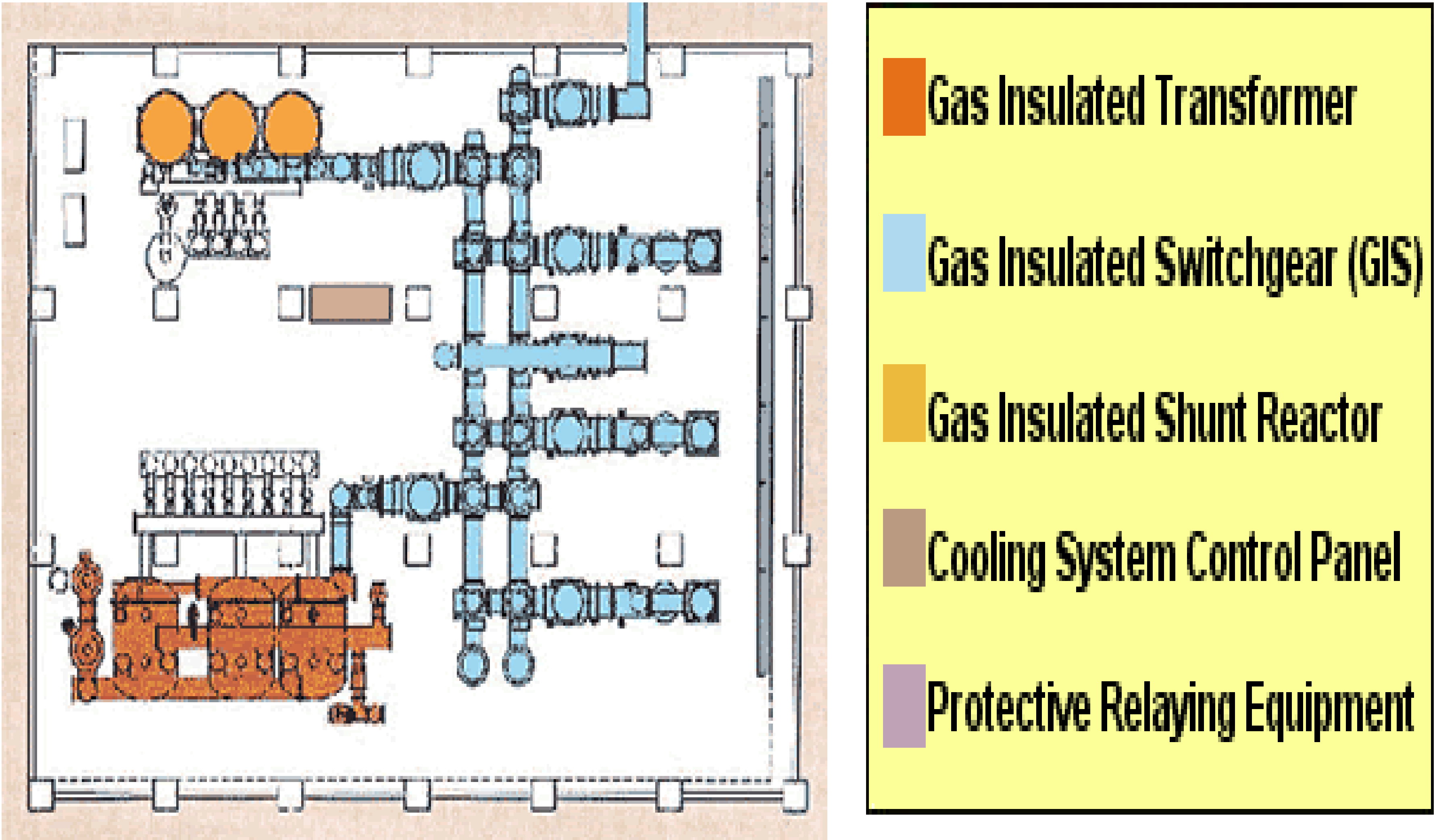
DISADVANTAGES

- GIS installations tend to be much more expensive that air-insulated installations with the same rating.
- VFTO during switching operations or earth faults and transient enclosure voltages and particle contamination

APPLICATIONS

- High voltage installations (above 115kv)
- Urban installations
- Indoor installations

LAY OUT OF GIS



GAS INSULATED TRANSFORMER

- Use SF_6 Gas as the insulating and cooling medium instead of insulating oil.
- First units produced in 1967.
- Transformer applications: Distribution class units up to 400 MVA, 345 kV.
- Primarily used in substations located in urban areas (including inside buildings, underground) due to safety benefits.

GAS INSULATED SWITCH GEAR

- The space occupied by switch gear is greatly reduced
- Totally unaffected by atmospheric conditions
- Provides high degree of operational reliability
- Easier to install in difficult site conditions

GAS INSULATED SHUNT REACTOR

Features

- Suitable for installation
- Excellent history of reliability and safety
- Fine radial core
- Circular yoke and circular tank
- Low loss
- Easy maintenance

Manufacturing Range

- Voltage-13.8 ~ 138kV
- Frequency-50 or 60Hz
- Capacity-5 ~ 60Mvar

FUTURE TRENDS IN GAS INSULATED SUBSTATIONS

- Compact design of switch gear by using three phase modules
- Use of vacuum circuit breaker cells in the medium high voltage GIS and fewer brakes per pole in high voltage circuit breakers
- Optimization of GIS design to allow easier maintenance

CONCLUSION

- GIS are necessary for EHV&UHV and some important areas to be studied include more conservative designs better particle control&improved gas handling&decomposition product management techniques
- Achieving&maintaining high levels of availability requires a more integrated approach to quality control by both users and manufactures
- It occupies very less space (1/10th) compared to ordinary substations. Hence these Gas Insulated Substations (GIS) are most preferred where area for substation is small (eg: Cities)

THE POWER TRIANGLE

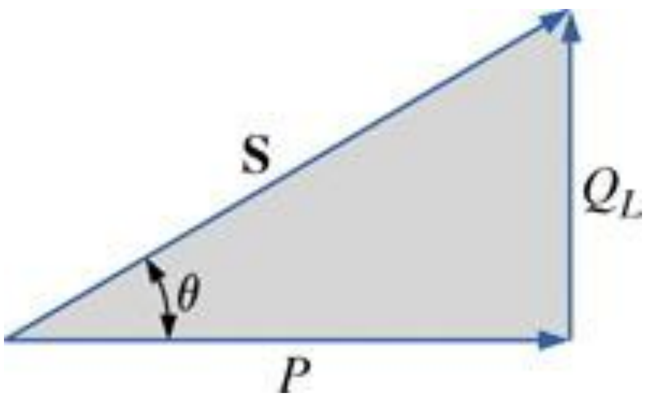


FIG. 19.14 *Power diagram for inductive loads.*

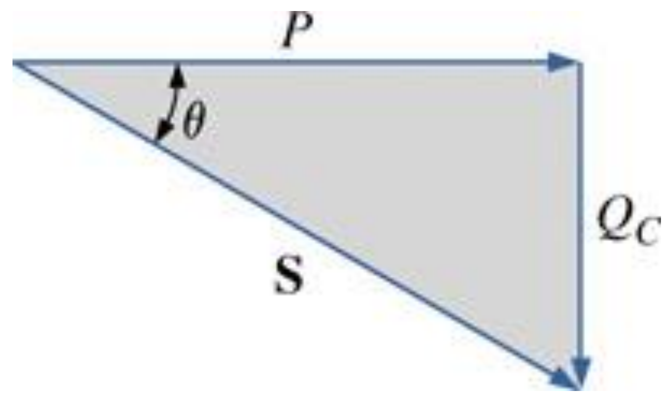


FIG. 19.15 *Power diagram for capacitive loads.*

THE POWER TRIANGLE

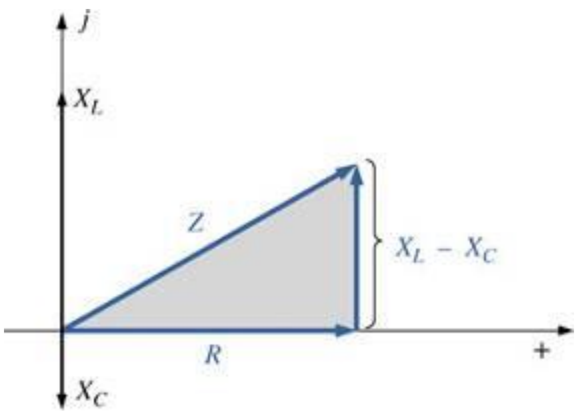


FIG. 19.17 *Impedance diagram for a series R-L-C circuit.*

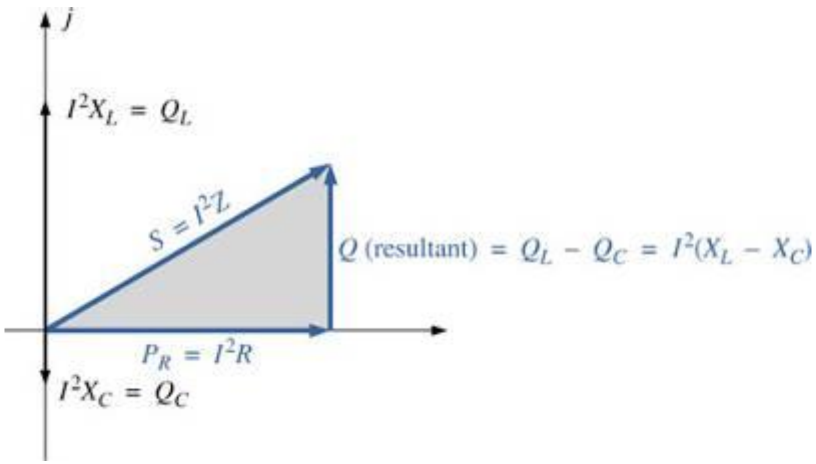


FIG. 19.18 *The result of multiplying each vector in Fig. 19.17 by I^2 for a series R-L-C circuit.*

THE POWER TRIANGLE

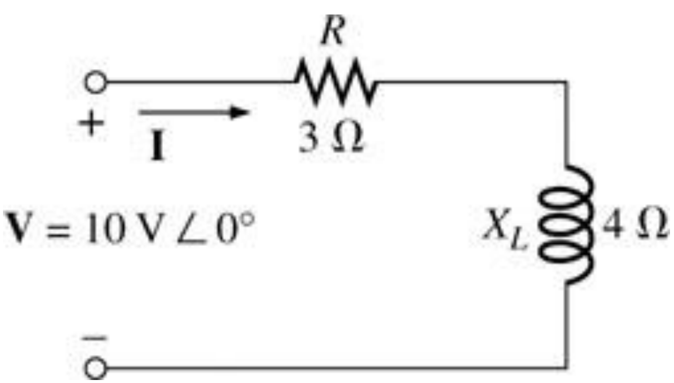


FIG. 19.19 *Demonstrating the validity of Eq. (19.29).*

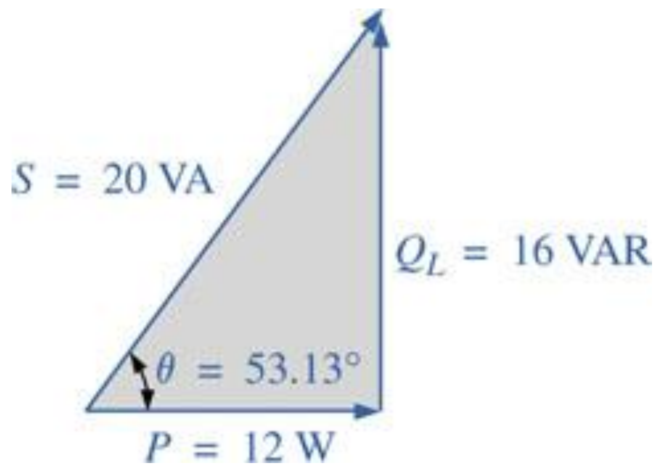


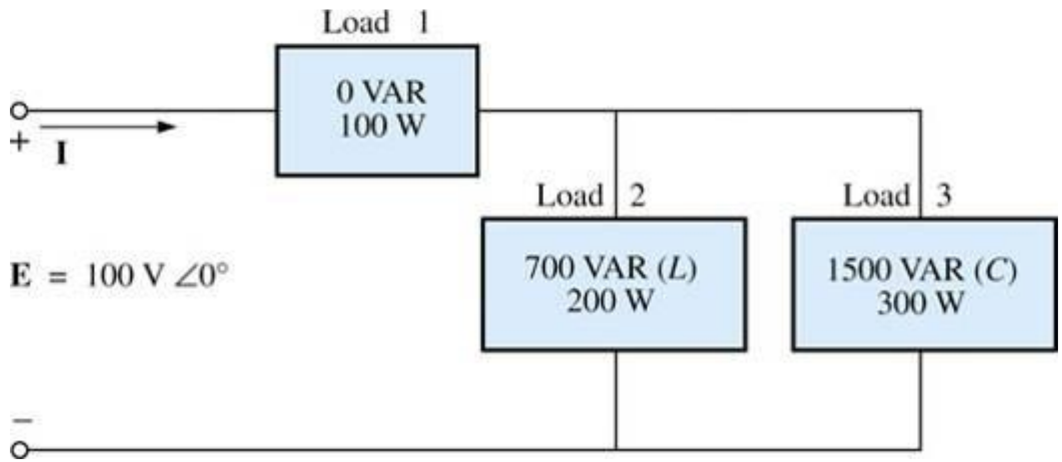
FIG. 19.20 *The power triangle for the circuit in Fig. 19.19.*

THE TOTAL P, Q, AND S

- The total number of watts, volt-amperes reactive, and volt-amperes, and the power factor of any system can be found using the following procedure:

1. *Find the real power and reactive power for each branch of the circuit.*
2. *The total real power of the system (P_T) is then the sum of the average power delivered to each branch.*
3. *The total reactive power (Q_T) is the difference between the reactive power of the inductive loads and that of the capacitive loads.*
4. *The total apparent power is $S_T = \sqrt{P_T^2 + Q_T^2}$.*
5. *The total power factor is P_T/S_T.*

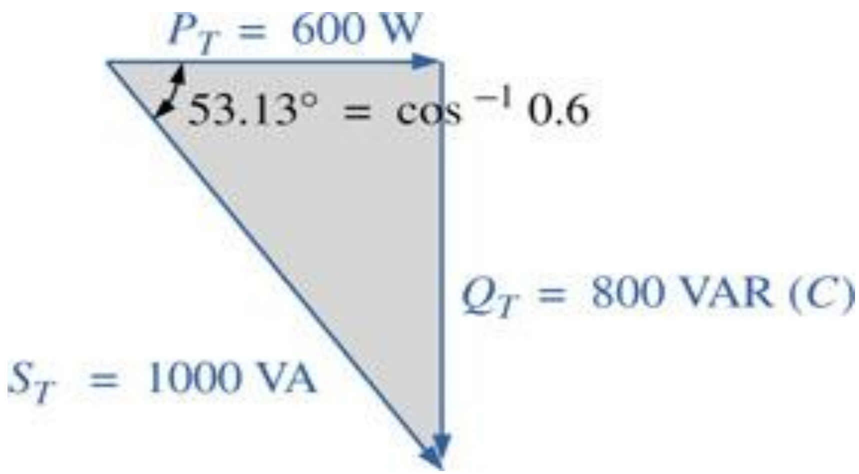
THE TOTAL P, Q, AND S



THE TOTAL P, Q, AND S

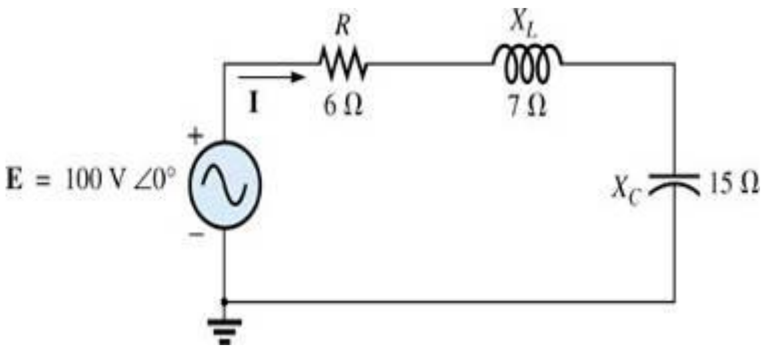
Load	W	VAR	VA
1	100	0	100
2	200	700 (L)	$\sqrt{(200)^2 + (700)^2} = 728.0$
3	300	1500 (C)	$\sqrt{(300)^2 + (1500)^2} = 1529.71$
	$P_T = \mathbf{600}$ Total power dissipated	$Q_T = \mathbf{800}(C)$ Resultant reactive power of network	$S_T = \sqrt{(600)^2 + (800)^2} = \mathbf{1000}$ (Note that $S_T \neq$ sum of each branch: $1000 \neq 100 + 728 + 1529.71$)

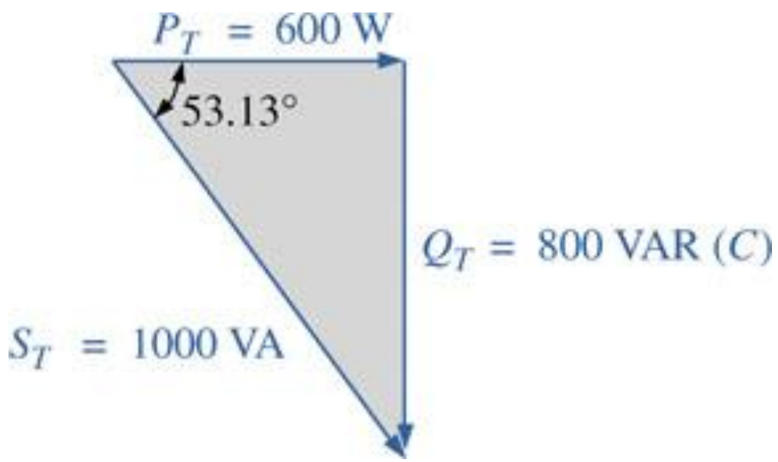
THE TOTAL P, Q, AND S



Power triangle .

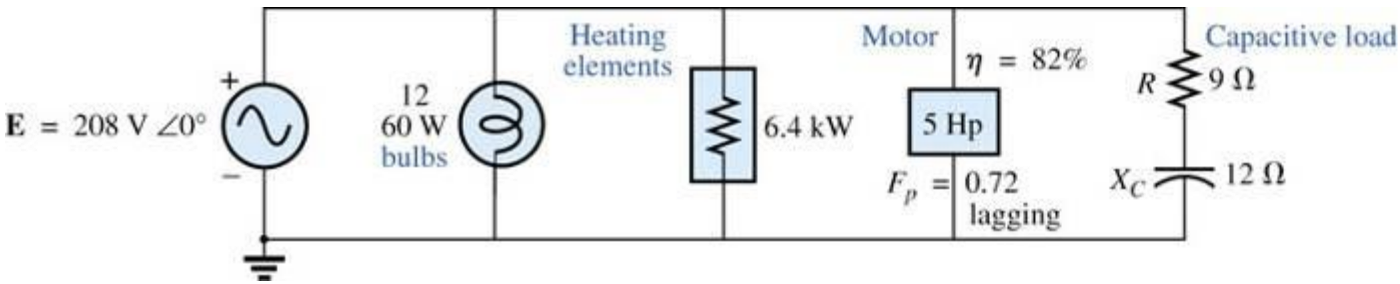
THE TOTAL P, Q, AND S



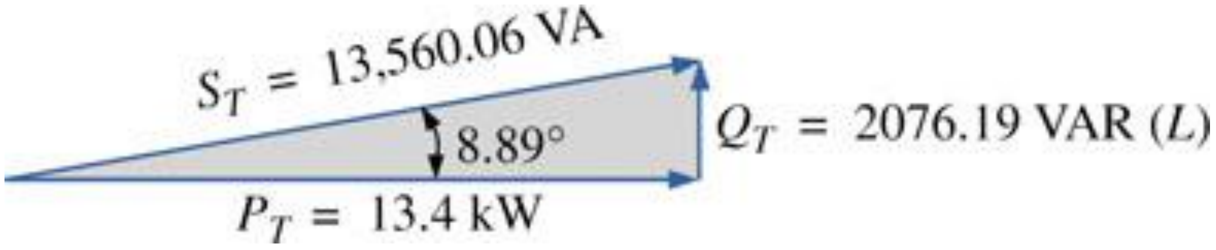


Power triangle f

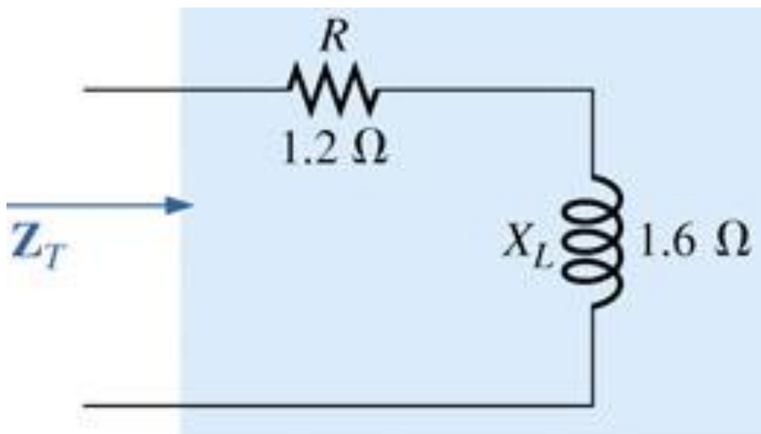
THE TOTAL P, Q, AND S



THE TOTAL P, Q, AND S



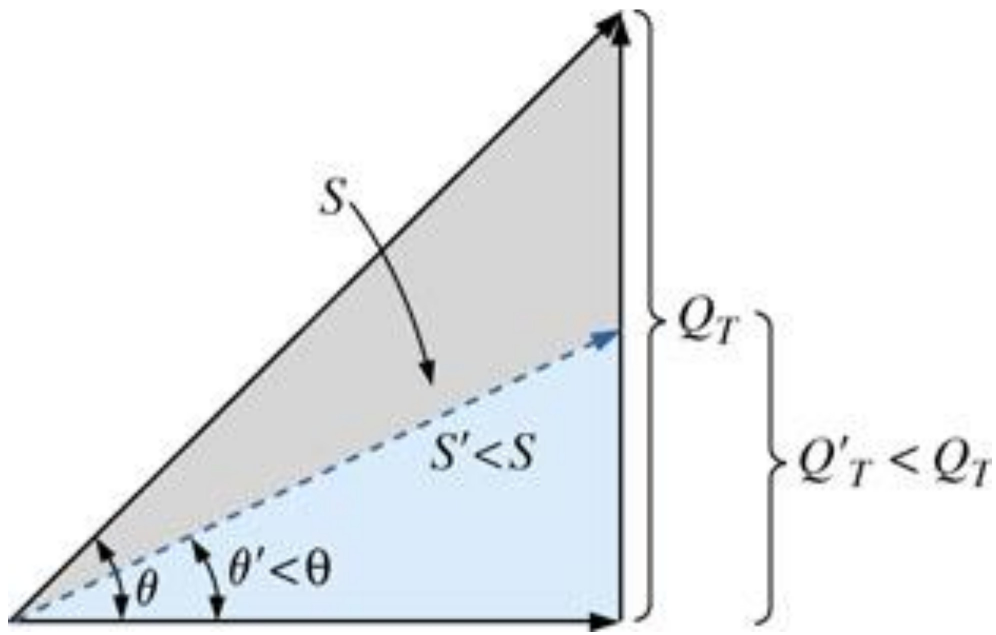
THE TOTAL P, Q, AND S



POWER-FACTOR CORRECTION

- The design of any power transmission system is very sensitive to the magnitude of the current in the lines as determined by the applied loads.
- Increased currents result in increased power losses (by a squared factor since $P = I^2R$) in the transmission lines due to the resistance of the lines.

POWER-FACTOR CORRECTION

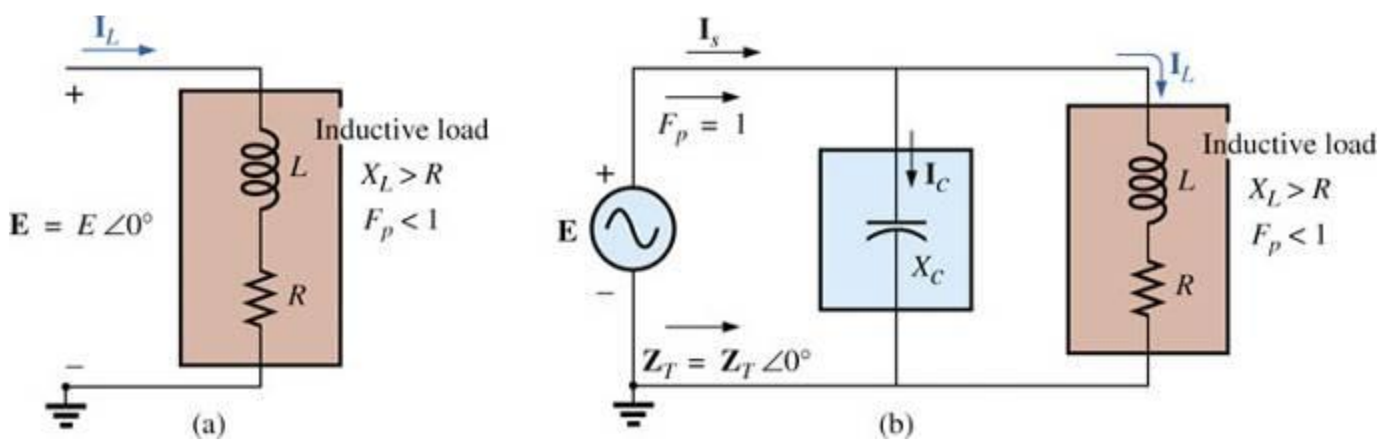


Demonstrating the impact of power-factor correction on the power triangle of a network.

POWER-FACTOR CORRECTION

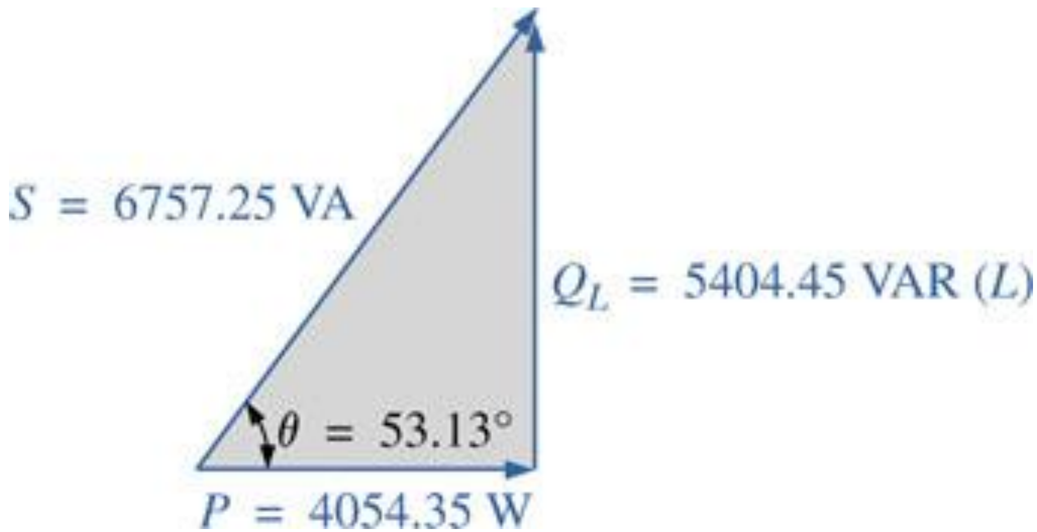
- The process of introducing reactive elements to bring the power factor closer to unity is called power-factor correction.
- Since most loads are inductive, the process normally involves introducing elements with capacitive terminal characteristics having the sole purpose of improving the power factor.

POWER-FACTOR CORRECTION



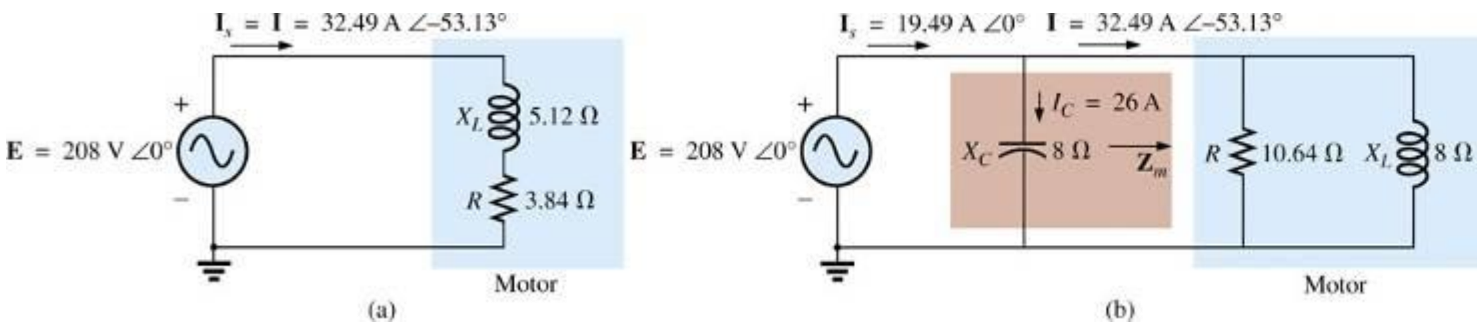
Demonstrating the impact of a capacitive element on the power factor of a network.

POWER-FACTOR CORRECTION



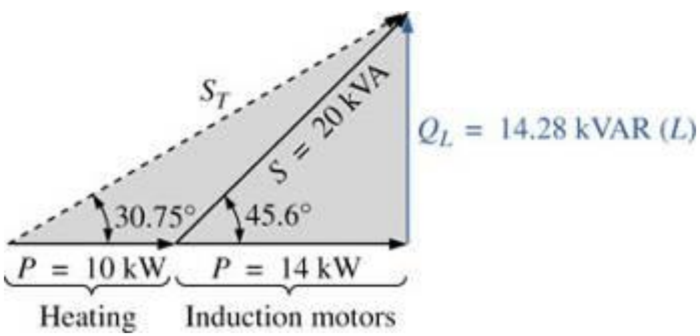
Initial power triangle for the load in Example 19.7.

POWER-FACTOR CORRECTION

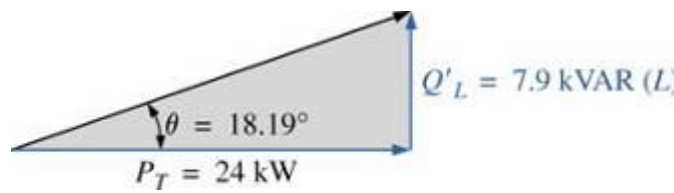


Demonstrating the impact of power-factor corrections on the source current.

POWER-FACTOR CORRECTION



Initial power triangle for the load in Example 19.8.



Power triangle for the load in Example 19.8 after raising the power factor to 0.95.

CONTROL OF REACTIVE POWER AND VOLTAGE

Reactive Power and Voltage Control

Control objectives contributing to efficient and reliable operation of power system:

- Voltage at terminals of all equipment are within acceptable limits
  - both utility and customer equipment designed to operate at certain voltage rating
  - prolonged operation outside allowable range could cause them damage
- System stability is satisfactory
  - voltage levels and reactive power control have significant impact on stability
- The reactive power flow is minimized so as to reduce I^2R and I^2X losses to a practical minimum
  - ensures transmission system operates efficiently

Production and Absorption of Reactive Power (Q)

- Synchronous Generators
  - can generate or absorb Q depending on excitation
  - capability limited by field current, armature current, and end-region heating limits
  - automatic voltage regulator continuously adjusts excitation to control armature voltage
  - primary source of voltage support!
- Overhead lines
  - at loads below natural or surge impedance load (SIL), produce Q
  - at loads above SIL, absorb Q
- Underground cables
  - have high SIL due to high capacitance
  - always loaded below SIL, and hence generate Q

cont'd

Production and Absorption of Q cont'd)

- Transformers
  - absorb Q due to shunt magnetizing reactance and series leakage inductance
- Loads
  - a typical "load bus" is composed of a large number of devices
  - composite characteristics are normally such that a load bus absorbs Q
  - industrial loads usually have shunt capacitors to improve power factor
- As power flow conditions vary, reactive power requirements of transmission network vary
- Since Q cannot be transmitted over long distances, voltage control has to be effected using special devices dispersed throughout the system

Methods of Voltage Control

- Control of voltage levels is accomplished by controlling the production, absorption, and flow of reactive power at all levels in the system
- Generating units provide the basic means of voltage control
- Additional means are usually required to control voltage throughout the system:
  - sources or sinks of reactive power, such as shunt capacitors, shunt reactors, synchronous condensers, and static var compensators (SVCs)
  - line reactance compensators, such as series capacitors
  - regulating transformers, such as tap-changing transformers and boosters

cont'd

Methods of Voltage Control (cont'd)

- Shunt capacitors and reactors, and series capacitors provide passive compensation
  - are either permanently connected to the transmission and distribution system, or switched
  - contribute to voltage control by modifying the network characteristics
- Synchronous condensers and SVCs provide active compensation; the reactive power absorbed/ supplied by them are automatically adjusted so as to maintain voltages of the buses to which they are connected
  - together with the generating units, they establish voltages at specific points in the system
  - voltages at other locations in the system are determined by active and reactive power flows through various circuit elements, including the passive compensating devices

Objectives of Reactive Power Compensation

- To control voltage and/or improve maximum power transfer capability
- Achieved by modifying effective line parameters:
  - characteristic impedance, $Z_C = \sqrt{\frac{L}{C}}$
  - electrical length, $\theta = \beta l$
- The voltage profile is determined by Z_C
- The maximum power that can be transmitted depends on Z_C as well as β

Shunt Reactors

- Used to compensate the undesirable voltage effects associated with line capacitance
  - limit voltage rise on open circuit or light load
- Shunt compensation with reactors:
  - increases effective Z_C
  - reduces the effective natural load , i.e., voltage at which flat voltage profile is achieved
- They are connected either:
  - directly to the lines at the ends, or
  - to transformer tertiary windings; conveniently switched as var requirements vary
- Line reactors assist in limiting switching surges
- In very long lines, at least some reactors are required to be connected to lines

Shunt Capacitors

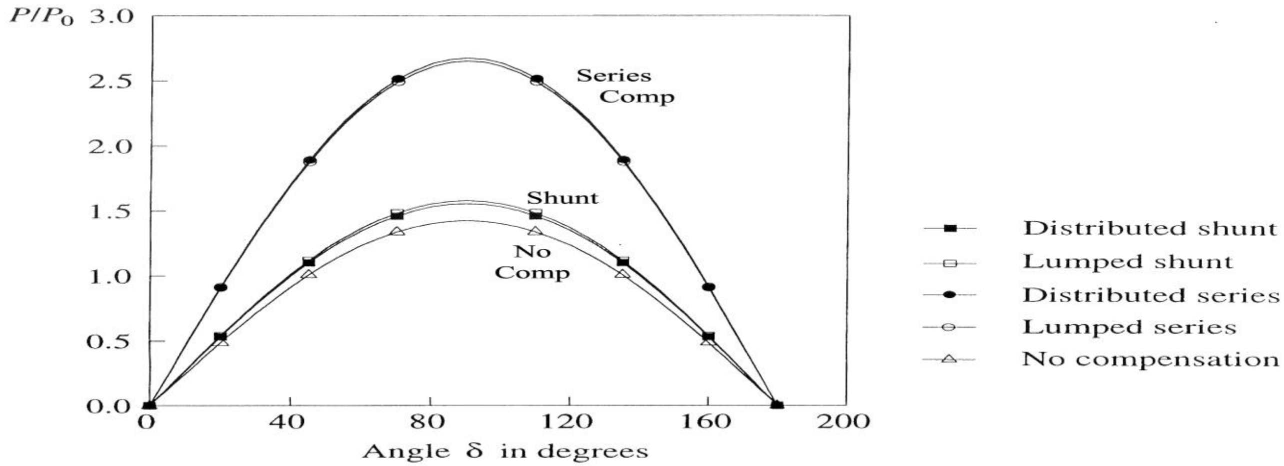
- Used in transmission systems to compensate for I^2X losses
- Connected either directly to H.V. bus or to tertiary winding of transformers
- Normally distributed throughout the system so as to minimize losses and voltage drops
- Usually switched: a convenient means of controlling voltage
- Shunt capacitor compensation of transmission lines in effect
  - decreases Z_C
  - increases θ, i.e., electrical length
- Advantages: low cost and flexibility of installation and operating
- Disadvantages: Q output is proportional to square of the voltage; hence Q output reduced at low voltages

- Shunt capacitors are used extensively in distribution systems for power factor correction and feeder voltage control

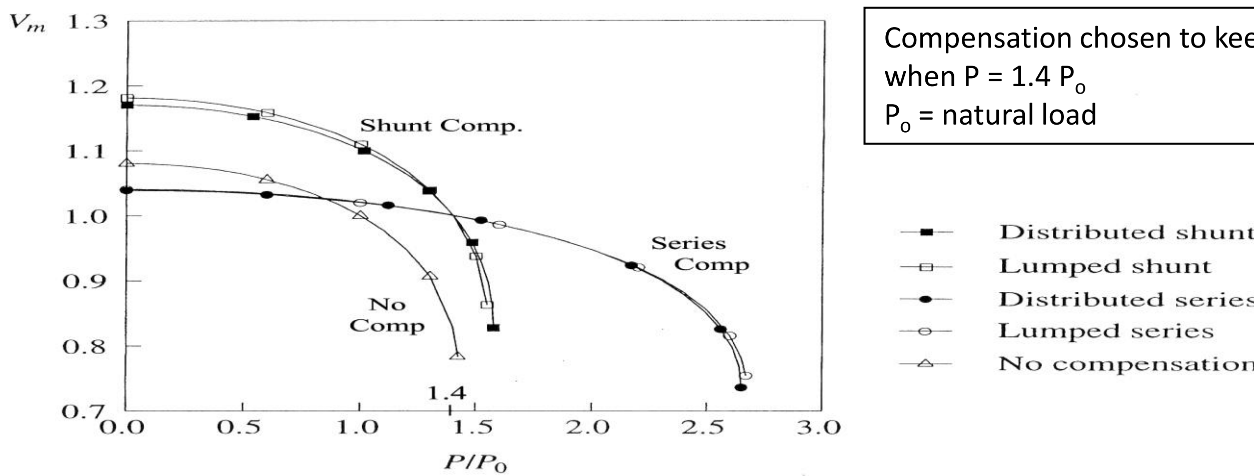
Series Capacitors

- Connected in series with the line
- Used to reduce effective inductive reactance of line
  - increases maximum power
  - reduces I^2X loss
- Series capacitive compensation in effect reduces <u>both</u>:
  - characteristic impedance Z_C, and
  - electrical length θ
- Reactive power produced increases with increasing power transfer
  - Self regulating !
- Typical applications
  - improve power transfer compatibility
  - alter load division among parallel lines
  - voltage regulation

Relative Performance of Shunt and Series Caps



(a) Power transfer as a function of transmission angle δ



Compensation chosen to keep V_m at 1.0 pu when $P = 1.4\ P_o$
P_o = natural load

(b) Midpoint voltage as a function of power transfer

Figure 11.56 Performance of 600 km line with and without passive compensation

Conclusions from Results Presented in Fig. 11.56

- With shunt capacitor compensation (chosen to keep midpoint voltage at 1.0 pu when $P = 1.4\ P_o$)
  - maximum power transfer capability increased to 1.58 pu of natural power (SIL); represents an increase of 0.16 pu over the uncompensated case
  - voltage regulation is poor, i.e., the voltage magnitude is very sensitive to variations in power transfer
- With series capacitor compensation (chosen to keep mid point voltage at 1.0 pu when $P = 1.4\ P_o$)
  - maximum power transfer capability increased to 2.65 pu
  - voltage regulation significantly improved

Compensation Requirements

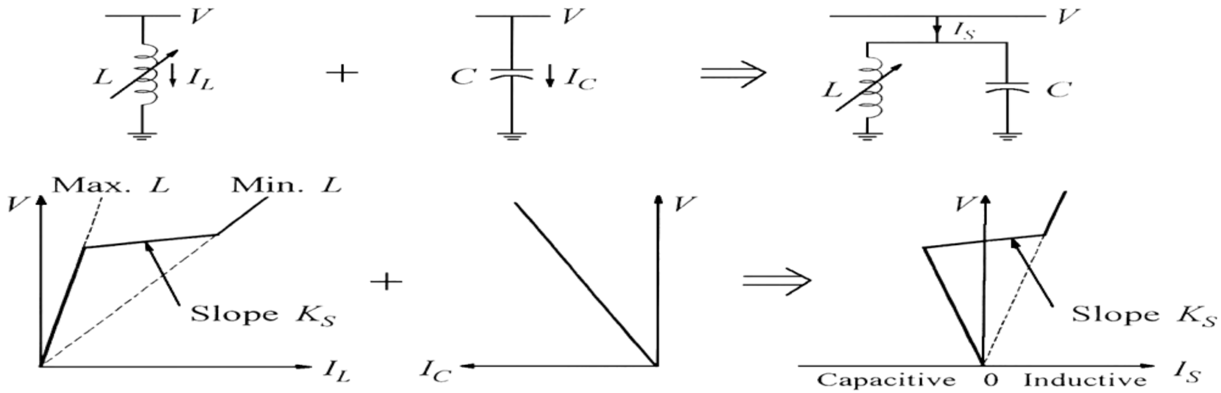
- In all cases it is not required to satisfy both the objectives of:
  - increasing the power level at which the voltage profile is flat; and
  - decreasing electrical length θ in order to improve power transfer level
- Short lines may require voltage support, i.e., increase natural load
  - This may be achieved by shunt capacitors, provided θ does not become excessive as a result
- Lines longer than 500 km cannot be loaded up to natural load because of excessive θ
  - In such cases, reduction of θ is the first priority

Synchronous Condenser

- A synchronous machine running without a prime mover or a mechanical load
- Depending on field excitation, it can either absorb or generate vars
- With a voltage regulator, it can automatically adjust vars to maintain constant voltage
- Started as an induction motor and then synchronized
- Normally connected to tertiary windings of transformers
- Unlike a SVC, a synchronous condenser has an <u>internal voltage</u>
- Speed of response not as fast as that of an SVC

Static VAR Compensators (SVC)

- Shunt connected static var generators and/or absorbers whose outputs are varied so as to control specific power system quantities
- The term static is used to denote that there are no moving or rotating components
- Basic types of SVCs:
  - thyristor-controlled reactor
  - thyristor-switched capacitor
  - saturated reactor
- A static var system (SVS) is an aggregation of SVCs and mechanically switched capacitors or reactors whose outputs are coordinated
- When operating at its capacitive limit, an SVC behaves like a simple capacitor



(a) Controllable reactor

(b) Fixed capacitor

(c) SVS

Figure 11.41 Composite characteristics of an SVS

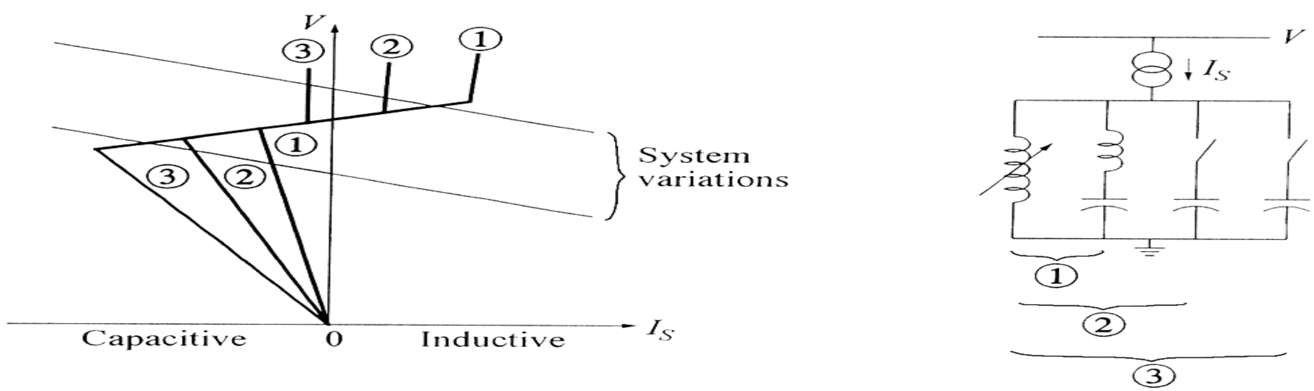


Figure 11.44 Use of switched capacitors to extend continuous control range

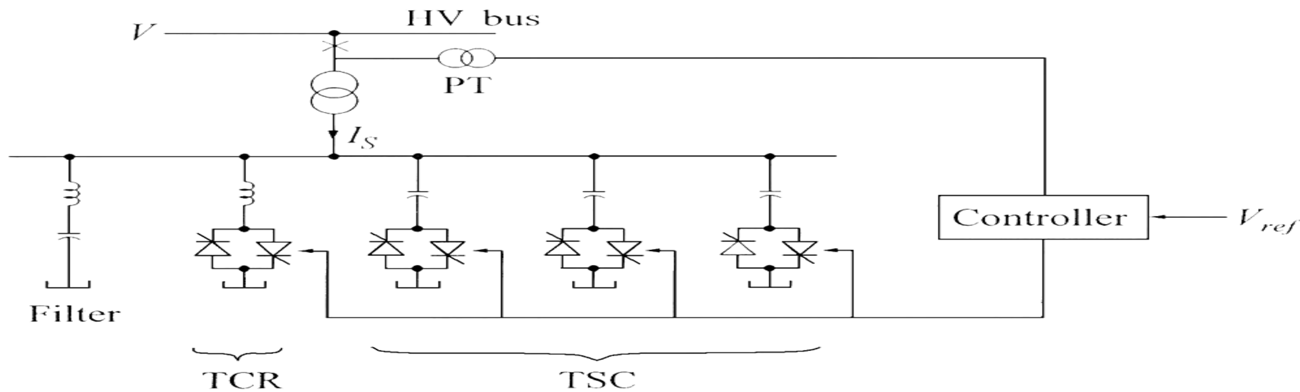
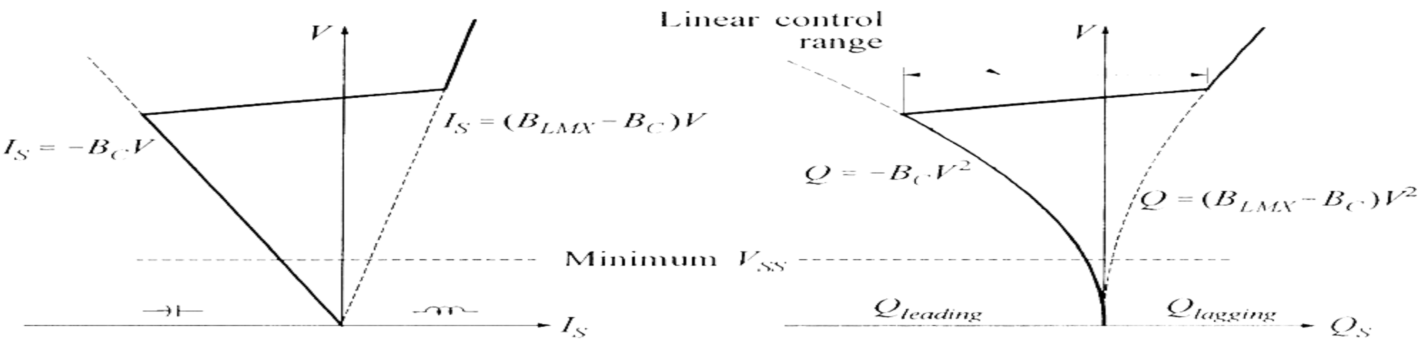


Figure 11.52 A typical static var system



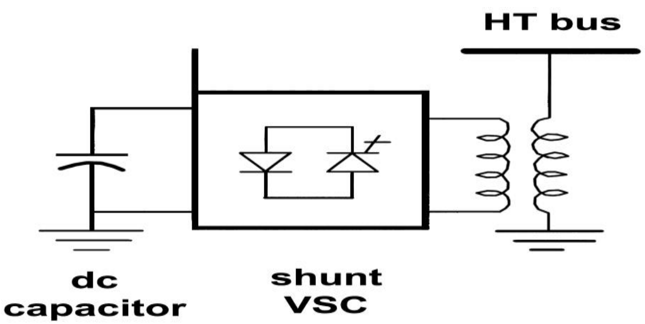
(a) Voltage-current characteristic

(b) Voltage-reactive power characteristic

Figure 11.53 SVS steady-state characteristics

Static Synchronous Compensator (STATCOM)

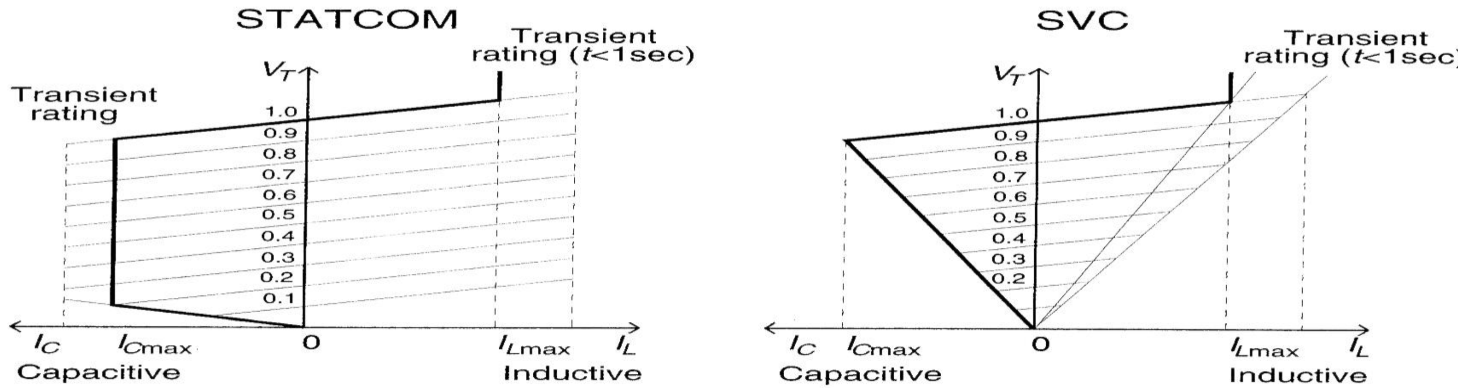
- Can be based on a voltage-sourced or current-sourced converter
- Figure below shows one with voltage-sourced converter
  - driven by a dc voltage source: capacitor



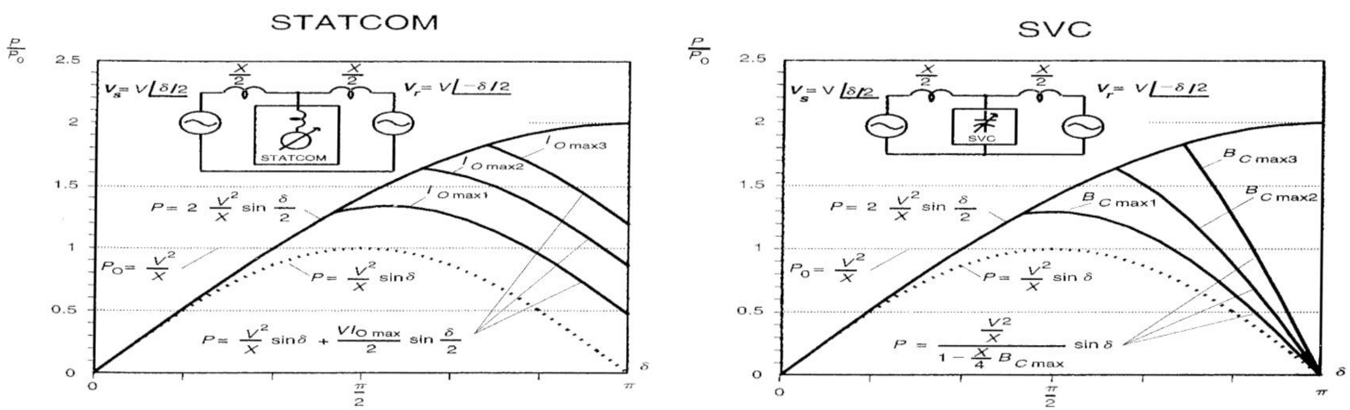
- Effectively an alternating voltage source behind a coupling reactance
  - controllable in magnitude
- Can be operated over its full output current range even at very low (typically 0.2 pu) system voltage levels
- Requires fewer harmonic filters and capacitors than an SVC, and no reactors
  - significantly more compact

Comparison of STATCOM and SVC Characteristics

(a) V-I characteristics:



(b) P-



Source: N.G. Hingorani and L. Gyugi, "Understanding FACTS", IEEE Press, 1999

Comparative Summary of Alternative Forms of Compensation

- Switched shunt capacitor compensation generally provides the most economical reactive power source for voltage control
  - ideally suited for compensation transmission lines if reduction of Z_C, rather than reduction of line length θ is the primary consideration
  - however, heavy use of shunt capacitor compensation could result in poor voltage regulation and may have an adverse effect on system stability
- Series capacitor is self-regulating, i.e., its reactive power output increases with line loading
  - ideally suited for applications where reduction of line length (θ) is the primary consideration
  - improves voltage regulation and system stability
- A combination of series and shunt capacitors may provide the ideal form of compensation in some cases

Comparative Summary (cont'd)

- A static var compensator (SVC) is ideally suited for applications requiring direct and rapid control of voltage
  - has advantage over series capacitors where compensation is required to prevent voltage sag at a bus involving multiple lines; total cost may be less than that for series compensation of each of the lines
- When an SVC is used to permit a high power transfer over a long distance, the possibility of instability when the SVC is pushed to its reactive limit must be recognized
  - when operating at its capacitive limit, the SVC becomes a simple <u>capacitor</u>
- An SVC has limited overload capability and has higher losses than series capacitor compensation
- STATCOM overcomes some of the limitations of an SVC

Tap-Changing Transformers

- Transformer with tap-changing facilities constitute an important means of controlling voltages throughout the power system
- Control of a single transformer will cause changes in voltages at its terminals
  - in turn this influences reactive power flow
  - resulting effect on the voltages at other buses will depend on network configuration and load/generation distribution
- Coordinated control of the tap changers of all transformers interconnecting the subsystems required to achieve overall desired effect
- During high system load conditions, network voltages are kept at highest practical level to
  - minimize reactive power requirements
  - increase effectiveness of shunt capacitors and line charging

cont'd

Tap-Changing Transformers (cont'd)

- The highest allowable operating voltage of the transmission network is governed by
  - requirement that insulation levels of equipment not be exceeded
  - need to take into consideration possible switching operations and outage conditions
- During light load conditions, it is usually required to lower network voltages
  - reduce line charging
  - avoid underexcited operation of generators
- Transformers with under-load tap-changers (ULTC) are used to take care of daily, hourly, and minute-by-minute variations in system conditions
- Off-load tap-changing transformers used to take care of long-term variations due to system expansion, load growth, or seasonal changes

Modelling of Transformer ULTC Control Systems

- Functional block diagram of ULTC control system shown in Fig. 11.79 and block diagram suitable for system studies
- Line drop compensator regulates voltage at a remote point along the line or feeder
- Measuring element consists of adjustable dead band relay with hysteresis. The output of the measuring element is Vm; which takes a value of 0, 1, or -1, depending on input V_{err}
- Time delay element prevents unnecessary tap changes

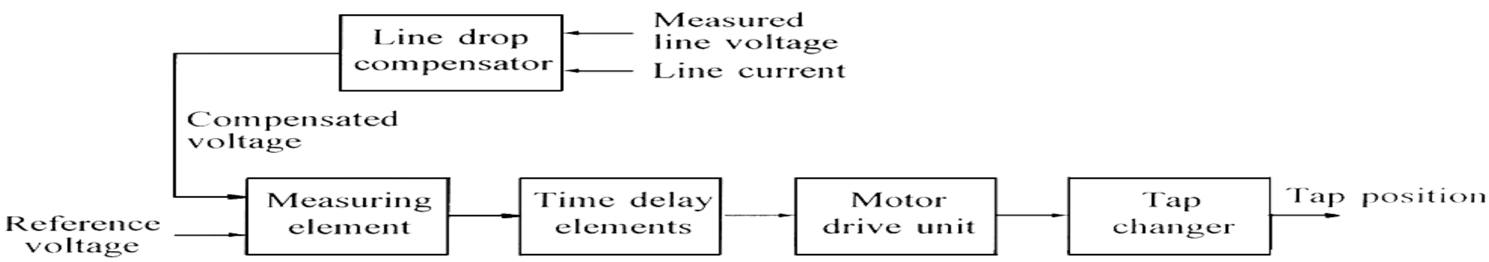
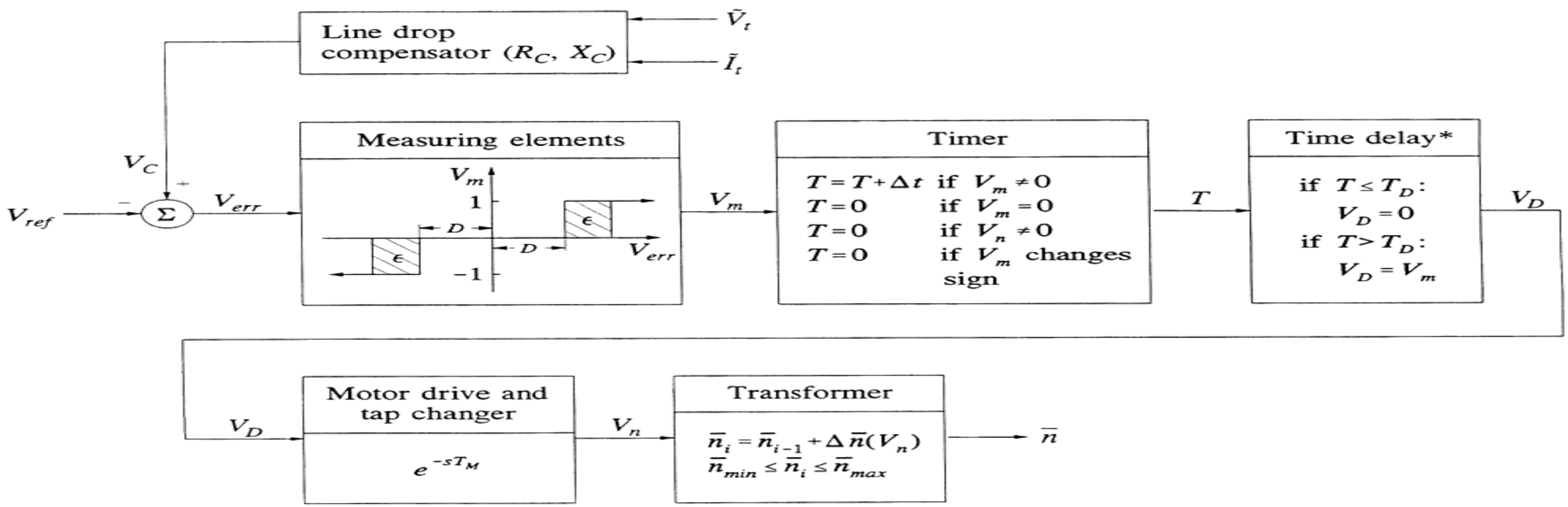


Figure 11.79 Functional block diagram of control system for automatic changing of transformer taps



* T_D = T_{D0} for first tap change
= T_{D1} for subsequent tap change

Distribution System Voltage Regulation

- Substation bus regulation
  - substation transformer equipped with ULTC facilities to control secondary voltage
  - alternatively, substation may have a separate voltage regulator
- Feeder regulation
  - feeder regulators control the voltage of each feeder
  - older units are the induction type - provide accurate and continuous control; however, they are costly and have been superseded by step type regulator
  - step voltage regulator (SVR) is basically an autotransformer with taps or steps in the series winding; however, it is purely a voltage control device and not used for voltage transformation

cont'd

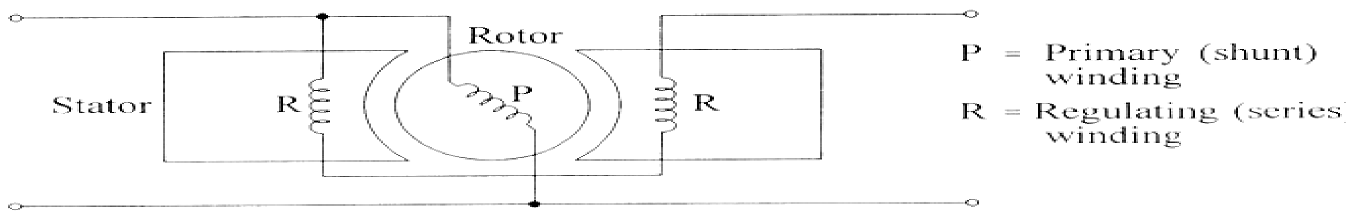


Figure 11.75 Schematic of an induction regulator

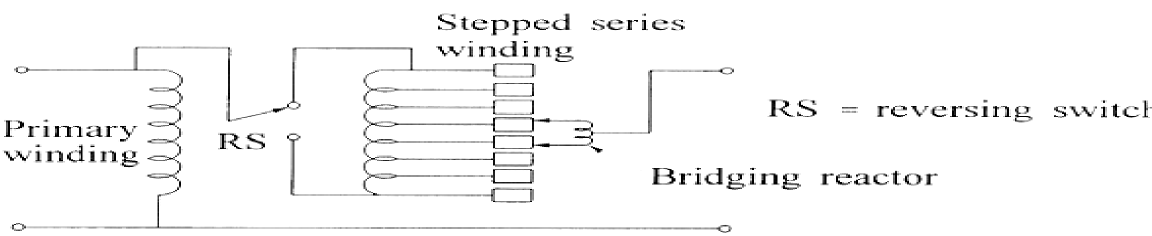


Figure 11.76 Schematic of a step voltage regulator

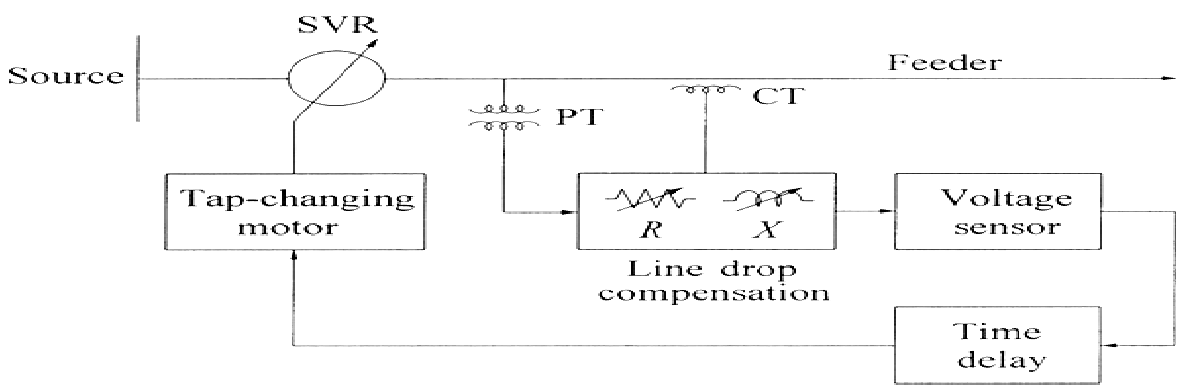


Figure SVR control mechanism

Distribution System Voltage Regulation

(cont'd)

- Application of voltage regulators and capacitors for control of voltage profile along a feeder is illustrated in Fig. 11.78
  - curve 1 shows voltage with distributed loads along the line, without any regulation
  - the addition of voltage regulator R_1, capacitor C and voltage regulator R_2, brings the voltage profile along the entire feeder (from the first consumer to the last) to within max and min limits

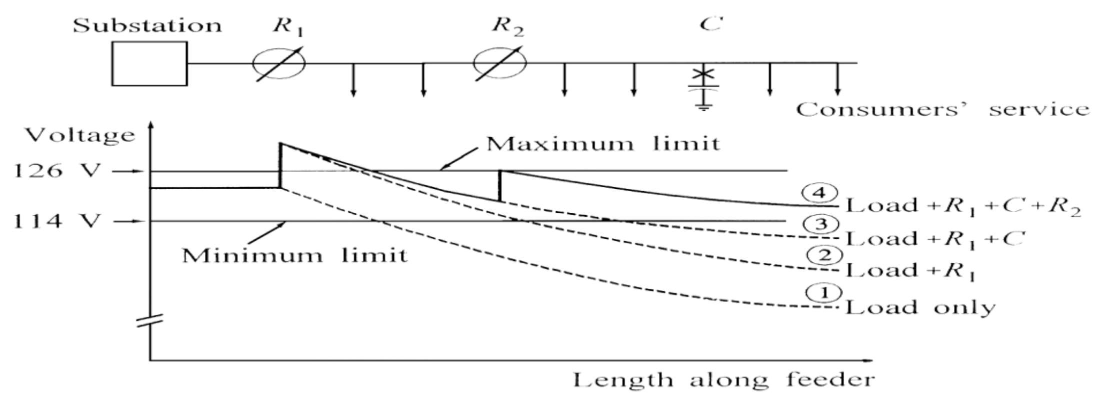


Figure Voltage profile of a feeder with a station regulation (R_1), supplementary regulator (R_2) and a shunt capacitor bank (C)

Implementation of Overall Reactive Power Control

- Effect of reactive power control is felt mostly locally:
  - equipment for supplying Q at appropriate points throughout the system necessary

- Coordination of the overall scheme a complex task:
  - approach is still largely based on operator experience and off-line load flow studies
  - implementation of automated schemes with optimum dispatch is feasible and practical methods are being pursued

- EDF and ENEL have used secondary and tertiary voltage control schemes to provide coordinated voltage control in HV networks
  - CIGRE TF 38.02.23 set up to assess the potential and provide guidelines

Appendix to Section on
Control of Reactive Power and Voltage

1. Copy of Section 11.2.9 from the book "Power System Stability and Control"
- - Provides information on Modeling of Reactive Compensating Devices

ENERGY

Energy

- In electrical industry it is generally expressed as kilowatt hour (kWh). It is the amount of energy in spend in one hour. If one kilowatt electrical heater (which consumes one kilo-Joules per second) is turned for one hour it will consume one kWh.
- In electrical industry it is commonly called unit.
- Mechanical work done over a period of time is also a form of energy like heat.

ENERGY

Work done

- It is applied force times distance covered (N x m). Its unit is N.m. The thermal energy is also a form of work done. It's unit is Joules after the famous scientist Joule, who discovered that energy and work are equivalent. It is also at times expressed in the heat unit of calorie.
- 1 calorie = 4.186 Joules
- Electrical work is the product of voltage difference and the current that flows .

Volt x Amp = watt = Joule/sec

Power plant terms

Installed capacity

- It is the designed power generation capacity of a plant. It is expressed in terms of energy generated per unit time.

  Megawatt electric (MW or MWe) is the most commonly used term for electricity generating plants. In case of process steam plant it is either expressed in amount of steam generated per unit time (t/h or kg/s) or in Megawatt thermal (MWth).

Power plant terms

Power

- It is the rate of work or work done per unit time. In the power industry it is generally expressed as Megajoules per second or MW. The basic unit is watt (Joules per second).

Base load Plant

- It is a type of plant which caters to a constant load demand. Such plants run 100% of the time. Nuclear and Coal fired plants are suitable for this

Peak Load Plant

- These plants helps tide over short term (15%) demand peak. Gas turbine, hydro plant can be used.

Efficiency

Heat rate:

- It is the amount of energy (kJ) that the fuel must supply to produce unit amount of electrical energy (kWh). It is expressed as kJ/kWh or kCal./ KWh or BTU/kWh. This represents the overall efficiency of a power plant.

  HR = (KJ fuel burnt/kWh electricity produced)

- <u>Turbine Heat rate:</u>

  It is the amount of heat steam (kJ or BTU) must deliver to produce unit of heat (kWh).

  It gives the thermodynamic efficiency of the steam cycle, but it does not include the boiler efficiency.

Efficiency

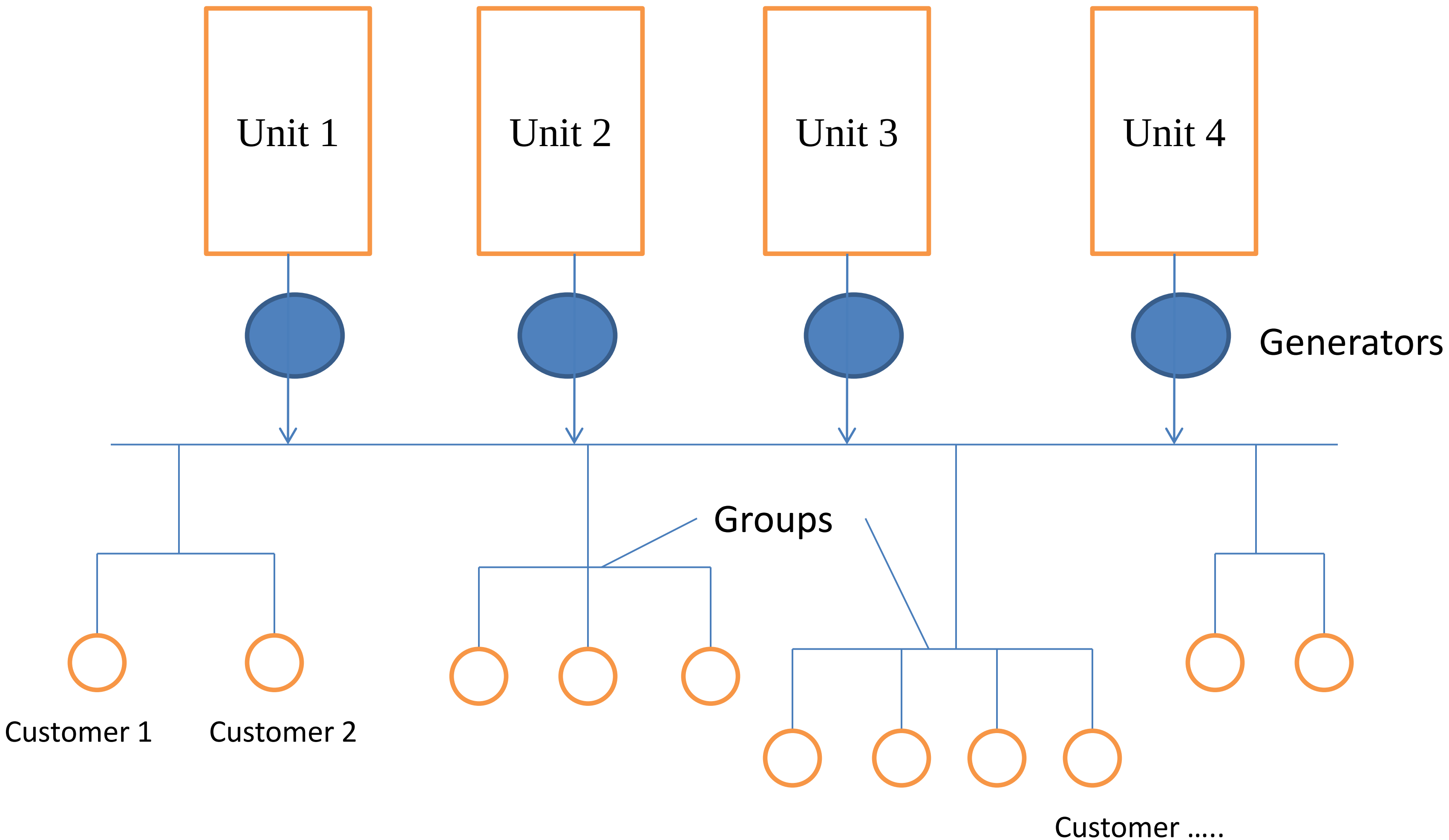
- **Thermal efficiency**

  It is the amount of heat carried by the steam per unit amount of heat delivered through the fuel.

- **Combustion efficiency**

  It is the ratio of the amount of energy or heat released by the fuel and the energy contained in the fuel burnt

Load Distribution



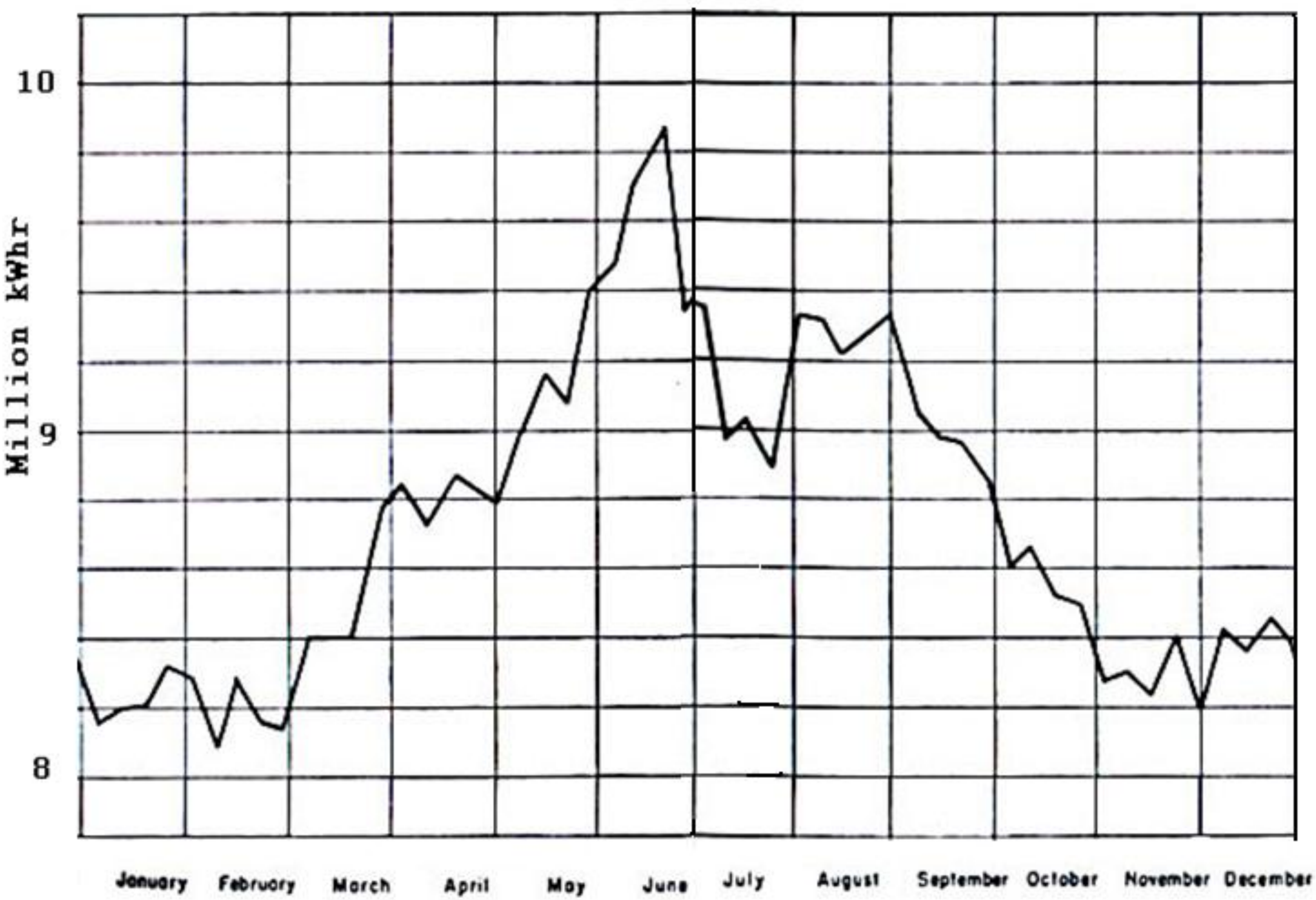
Load Distribution

- *Demand Factor (d)*= $\frac{Maximum\ Demand}{Connected\ Load}$ *< 1.0*

- *Group Capacity Factor (D)*= $\frac{\Sigma\ Indivedual\ \text{max load}}{Actual\ max.\ demand}$ *>1.0*

- *Peak Diversity Factor (r)*= $\frac{Max.demand\ of\ group}{Demand\ of\ a\ group\ at\ load\ peak}$ *>1.0*

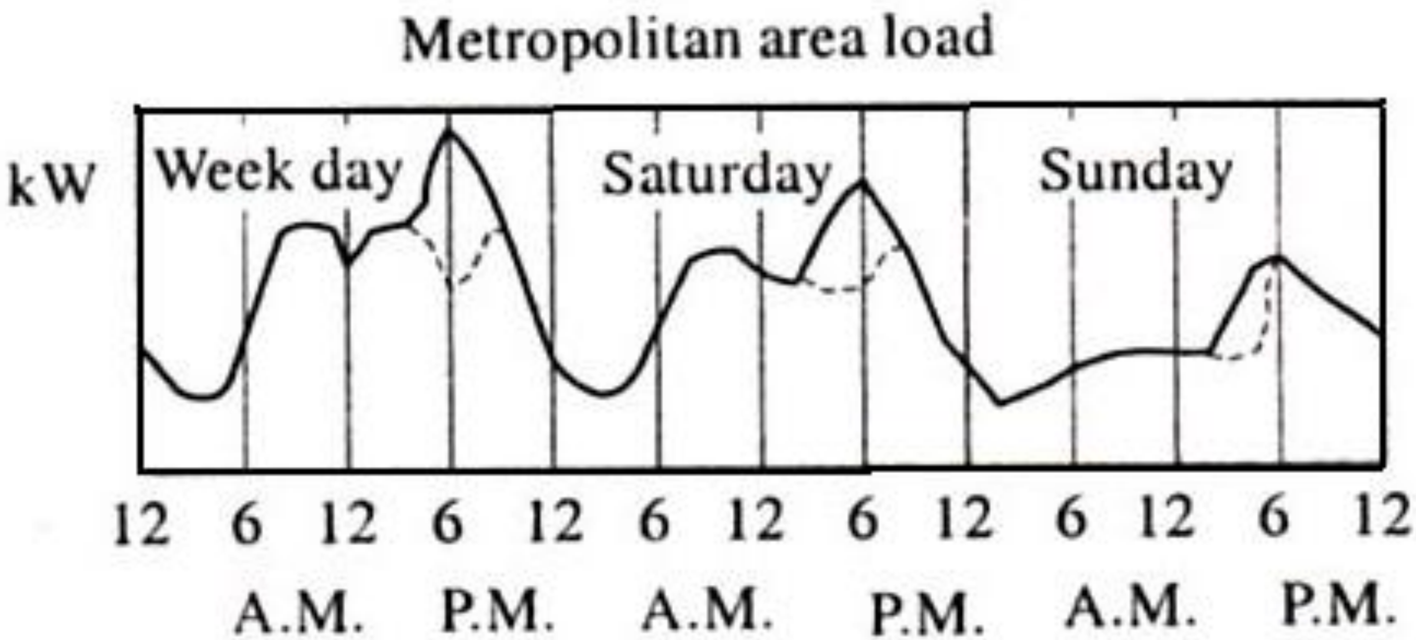
Yearly Load curve (Chronological Curve)



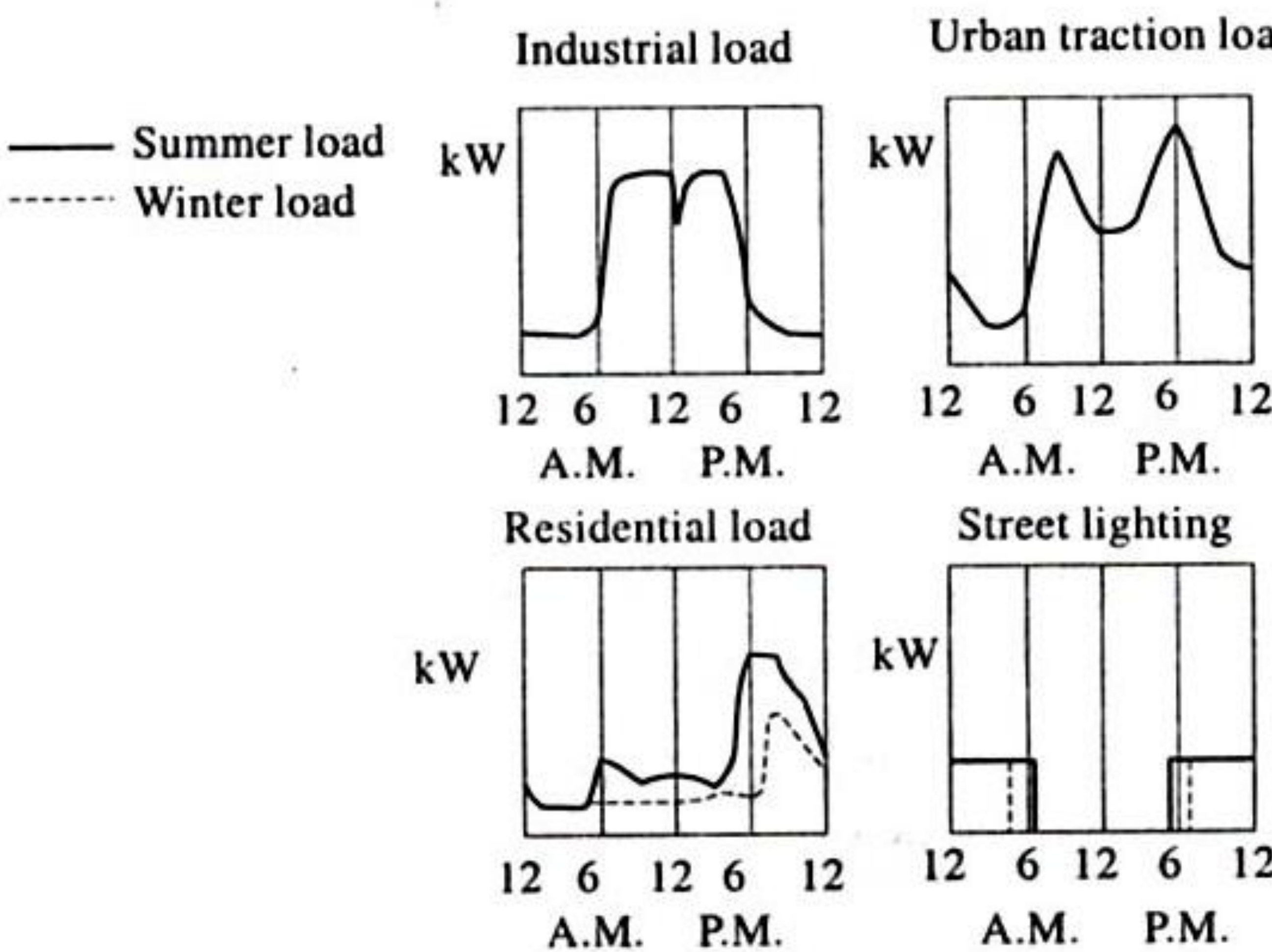
Information obtained from load curves:

- Area under load curve = Units generated
- Highest point of the curve = MD
- (Area under curve) ÷ (by total hours) = Average load
- (Area under load curve) ÷ (Area of rectangle containing load curve) = LF
- Helps to select size & number of generating units.
- Helps to create operating schedule of the power plant.

Weekly load in Metro



Load variation by sector



Example

a)1000 apartments- connected load/apt= 4 kW

For residential take: d= 0.45, D= 3.5, r=1.4

b) Other services

Load	Conn. Load kW	d	Max. demand
Laundry	20	0.68	13.6
Mosque	20	0.58	11.6
Restaurant	60	0.52	31.2
Stores	4x12	0.75	36
Theater	100	0/49	439

For commercial take D=1.5, r = 1.1

Example (cont.)

- For apts.

  Max. load= 1000 x 4 x 0.45 =1800 kW

  Required load = 1800/(3.5 x 1.4) = 367 kW

- For Commercial

  Required load = 141.4/(1.5 x 1.1) = 85.7 kW

  Total Load = 367 + 85.7= 452.7 kW

PLANT CAPACITY

Availability

It is the fraction of **the time a plant is available for generation.**

Sometimes a plant may be partially available due to lack of operation of some components of the plant. It is called partial availability. This term, however, is not very commonly used.

Outage

It is another term for shut down of the plant either for planned maintenance (Planned outage) or due to unforeseen break down (forced outage).

PLANT CAPACITY

Utilization factor

It is the ratio of present maximum generation of the plant and the installed or the original design capacity of the plant.

Utilization factor =(Maximum load)/(rated capacity of plant)

-

Capacity factor

It is the ratio of total generation of the plant for a given period and that the plant is capable of delivering over the same period.

Capacity Factor = (Average load)/(rated capacity of plant)

-

Average Load

Average load = (Area under load curve)/(duration of the load curve)

Load Factor

- Load factor *(Lavg/Lmax)* = $\frac{\text{Average load over a period}}{\text{Peak load in that period}}$

- Capacity factor *(Lavg/Cap)*= (Average load)/(rated capacity of plant)

  = $\frac{\text{Total energy output in a period}}{\text{Rated capacity of the plant x period}}$

Load Factor

$$\text{Utilization factor } (L_{max}/Cap) = \frac{\text{Peak output in a period}}{\text{Output if the plant operated in full rated capacity over the period}}$$

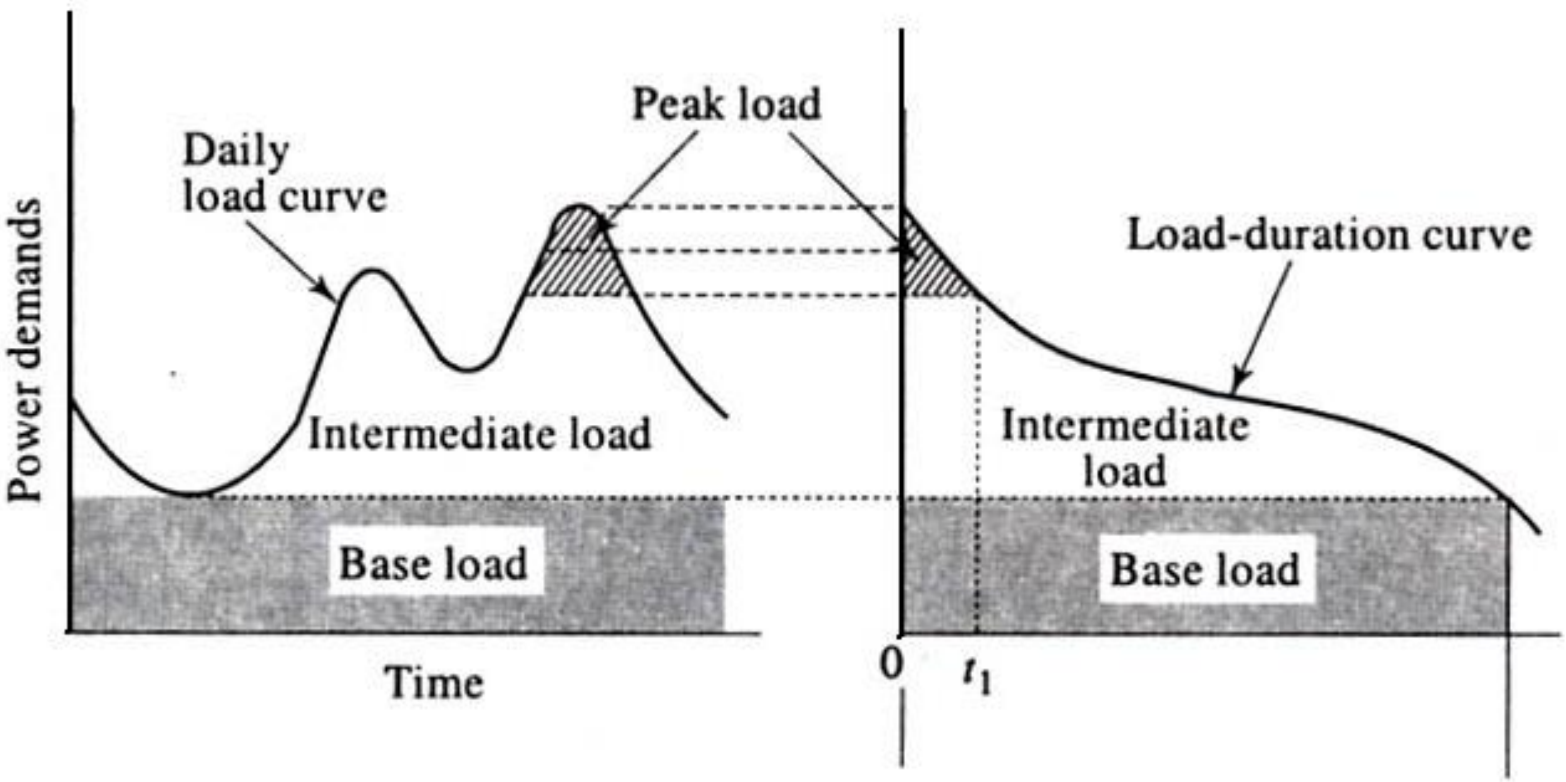
Also known as Plant load factor (PLF) or Use factor

Reserve factor = Load factor/
Capacity factor

Load Duration Curve

- Is a set of time series data such as hour-to-hour electric usage, sorted in a way so you can easily see how frequently values are very high or very low. A relatively flat duration curve means the values tend to fall within a small range.

Base Load vs Peak Load



INTRODUCTION

The electrical energy produced at the generating station is delivered to a large number of consumers. The rate at which energy is sold to the consumers (called tariff) is fixed by the supplying company .While fixing the tariff, the supply companies are to ensure that they should not only recover the total cost of producing the **energy** but also earn some profit. However, the profit should be minimum possible so that electrical energy can be sold at reasonable rates and the consumers insured to use more electricity.

IMPORTANT TERMS RELATED TO ECONOMICS OF GENERATION

Before studying about tariff an engineer must have the knowledge of the following important terms

Connected load : The sum of the continuous ratings of all the equipments connected to the power system is called **connected load**.

Maximum Demand : The load on the power station is not constant, it varies from time to time

The greatest of all the demands (loads) which occur during a given period is called **maximum demands**.

DEMAND FACTOR

The ratio of maximum demand on the system to the rated connected load to the system is called **demand factor**.

Mathematically ,

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

The actual maximum demand is always less than the rated load connected to the system , therefore, demand factor is always less than unity.

AVERAGE LOAD

The average of all the loads occurring at the various instants on the generating station is called **average load**. Or

The total electrical energy (in WH or KWH) delivered in a given period divided by the time (in hours) is that period , called **average load**.

$$\text{Daily average load} = \frac{\text{kWh energy supplied in day}}{24}$$

$$\text{Monthly average load} = \frac{\text{kWh energy supplied in month}}{24 \times 30}$$

LOAD FACTOR

The ratio of average load to the maximum load is called **load factor**.

$$\text{Load factor} = \frac{\text{Average load}}{\text{Maximum load}}$$

Since the average load is always less than maximum load , therefore, load factor is always less than one. Load factor is generally used for determining the average load or energy delivered by the generating station in a given period.

DIVERSITY FACTOR

Various types of consumers are connected to the power station and usually their maximum demands do not occur at the same instant,

therefore, the sum of individual maximum demands of all the consumers is always more than the actual maximum demand occurring on the generation stating

The ratio of sum of individual maximum demands of all the consumers connected to the generating station to the maximum demand on the power station is called **diversity factor**.

DIVERSITY FACTOR

$$\text{Diversity factor} = \frac{\text{Sum of individual maximum demands}}{\text{Maximum demand on the power station}}$$

Diversity factor is always more than one. It is generally used for determining the maximum demand on the generating station to meet with the individual maximum demands of all the consumers connected to the station and thus to calculate the capital investment for the erection of generating station

TARIFF

The rate of electrical energy at which it is sold to the consumers is called **tariff** .

The supply companies invest money to generate, transmit and distribution of electrical energy, a tariff is fixed .

The cost of generation depends upon the magnitude of energy consumed by the consumers and his load conditions. Therefore, due consideration is given to different types of consumers (e.g. domestic, commercial and industrial) while fixing a tariff .

OBJECTIVES OF TARIFF

The main objective of the tariff is to ensure the recovery of the total cost of generation and distribution .Tariff should include the following items:

(1) Recovery of cost of electrical energy generated at the generating system.

(2) Recovery of cost on the capital investment in transmission and distribution system.

(3) Recovery of cost of operation, supplies and maintenance of equipment.

OBJECTIVES OF TARIFF

(4) Recovery of cost of metering equipment, billing and miscellaneous services .

(5) A marginal return (Profit) on the capital investment .

MAIN FACTORS INVOLVED IN FIXING A TARIFF

The following are the principal factor involved in fixing a tariff:

(1) The tariff should ensure the recovery of the total cost of generation, transmission, and distribution etc.

(2) The tariff should be simple, cheap and capable of easy explanation to consumers.

(3) The tariff should be attractive so that consumers are encouraged to make more extended use of electrical energy.

MAIN FACTORS INVOLVED IN FIXING A TARIFF

(4) The tariff should be such that it would earn a reasonable profit.

(5) The tariff must be fair and the consumers should be charged according to what the energy costs.

TYPES OF TARIFF

There are various types of consumers (domestic, commercial and industrial etc.) and their energy requirements are also different. Accordingly, several types of tariffs have been designed so far, out of which the most commonly applied are described below:

TYPES OF TARIFF

SIMPLE TARIFF

FLAT RATE TARRIF

BLOCK RATE TARIFF

TWO-PART TARIFF

MAXIMUM DEMAND TARIFF

POWER FACTOR TARIFF

SIMPLE TARIFF

Simple Tariff: The tariff in which the rate per unit of energy is fixed, is called **simple tariff**.

This is a simplest possible tariff. The rate per unit of energy consumed by the consumer is fixed irrespective to the quantity of energy consumed by a consumer. This energy consumed is measured by installing an energy meter .

ADVANTAGES

The following are the advantages :

1. It is in simplest form and easily understood by the consumers.
2. Consumer is to pay as per his consumption.

DISADVANTAGES

1. Consumer is to pay the same rate per unit of energy consumed irrespective of the number of units consumed by him. Hence, consumers are not encourage to consume more energy.
2. The cost of energy per unit delivered is high.
3. The supplier do not get any return for the connection given to the consumer if consumer does not consume any energy in a particular month.

APPLICATION OF SIMPLE TARIFF

Since it is very simple form of tariff, it is generally applied to tube wells which are operated for irrigation purposes

FLAT RATE TARIFF

The tariff in which different types of consumers are charged at different per unit rates is called **flat rate tariff**.

This type of tariff is similar to simple tariff. Only difference is that consumers are grouped into different classes and each class of consumer is charged at a different per unit rate. For example flat rate for fan and light loads is slightly higher than that for power loads.

ADVANTAGES

(1) It is more fair to different types of consumers.

(2) It is quite simple in calculations.

DISADVANTAGES

(1) Consumers are not encouraged to consume more energy because same rate per unit of energy consumed is charged irrespective of the quantity of energy consumed.

(2) Separate meters are required to measured energy consumed for light loads and power loads.

(3) The suppliers does not get any return for the connection given to the consumer if he does not consume any energy in a particular period or month.

APPLICATION OF FLAT RATE TARIFF

Since it is simple and easy for explanation to consumers, therefore this tariff is generally applied to domestic consumers.

BLOCK RATE TARIFF

The tariff in which first block of energy is charged at a given rate and the succeeding blocks of energy are charged at progressively reduced rates is called block rate tariff

BLOCK RATE TARIFF

In this type of tariff, the energy units are divided into numbers of blocks and the rate per unit of energy is fixed for each block. The rate per unit of energy for the first block is the highest and reduces progressively with the succeeding blocks. For example, the first 100 units may be charged at the rate of Rs. 3.00 per unit; the next 100 units may be charged at the rate of Rs.2.50 per unit and the remaining additional units may charged at the rate of Rs. 2.00 per unit.

ADVANTAGES

(1) By giving an incentive, the consumers are encouraged to consume more energy. This increases the load factor of the power system and hence reduces per unit cost of generation.

(2) Only one energy meter is required to measure the energy .

DISADVANTAGES

(1) The supplier does not get any return for the connection given to the consumer if consumer does not consume any energy in a particular period.

APPLICATION OF BLOCK RATE TARIFF

This type of tariff is mostly applied to domestic and small commercial consumers.

TWO – PART TARIFF

The tariff in which electrical energy is charged on the basis of maximum demand of the consumer and the units consumed by him is called **two-part tariff**.

TWO- PART TARIFF

In this tariff, the total charges to be made from the consumer are split into two components namely fixed charges and running charges. The fixed charges are independent of energy consumed by the consumer but depend upon the maximum demand, whereas the running charges depend upon the energy consumed by the consumer. The maximum demand of the consumer is assessed on the basis of the kW capacity of all the electrical devices owned by a particular consumer or on the connected load.

TWO-PART TARIFF

Thus, the consumer is charged at a certain amount per kW of energy is consumed i.e.

Total charges= Rs. (a X kW + b X kWh)

where, Rs. a= charges per kW of maximum demand

Rs. b= charges per kWh of energy consumed

TWO- PART TARIFF

In this tariff basically, the charges made on maximum demand recovers the fixed charges of generation such as interest and depreciation on the capital cost of building and equipment, taxes and a part of operating cost which is independent of energy generated. Whereas, the charges made on energy consumed, recovers operating cost which varies with variation in generated (or supplied) energy.

ADVANTAGES

(1) It is easily understood by the consumers.

(2) The supplier gets the return in the form of fixed charges for the connection given to the consumer even if he does not consume any energy in a particular period.

DISADVANTAGES

(1) If a consumer does not consume any energy in a month even then he has to pay the fixed charges .

(2) Since the maximum demand of consumer is not measured, therefore, there is always conflict between consumer and the supplier to assess the maximum demand.

MAXIMUM DEMAND TARIFF

The tariff in which electrical energy is charged on the basis of maximum demand of the consumer and the units consumed by him is called maximum demand.

This tariff is actually similar to two-part tariff with only difference that the maximum demand is actually measured by installing a maximum demand indicator meter. Thus the draw-back of two-part tariff is removed.

APPLICATION OF MAXIMUM DEMAND TARIFF

This tariff is mostly applied to bulk supplies

and large industrial consumers.

POWER FACTOR TARIFF

The tariff in which power factor of the consumer's load is also taken into consideration while fixing it, is called power factor tariff.

Power factor plays an important roll in a.c. system.

A low power factor increases the rating of power plant equipment and gives higher losses. Therefore, consumers are advised to operate their loads at higher power factor.

KVA MAXIMUM DEMAND TARIFF

In this case the fixed charges are made on the basis of maximum demand in KVA instead of KW. Therefore, a consumer having low power factor has to pay more fixed charges.

Thus the consumers are encouraged to operate their loads at higher power factor.

So in these day suppliers ask consumer to use shunt capacitors to improve power factor.

KWH & KVARH TARIFF

In this tariff, the consumers are charged for KWH and KVARH separately. Therefore, a consumer having low power factor shall have to pay more charges.

SLIDING SCALE TARIFF

In this case, an average power factor , say 0.8 lagging, is taken as reference. If the power factor of the consumer is below the reference, an additional amount is charged from the consumer as a penalty. On the other hand, if the power factor is above the reference, a discount is allowed to the consumer as a gift.

APPLICATION OF SLIDING SCALE TARIFF

The power factor tariff is mostly applied to large industrial consumers.

BLOCK RATE TARIFF WITH MINIMUM FIXED CHARGES

Tariff in which number of blocks (usually three blocks) of energy are formed which are charged at different rates. However if the energy consumed by the consumer is low, he is being charged on the basis of minimum charges made per KW of his maximum demand.

RULES

In this tariff, the energy units are divided into number of blocks and the rate per unit of energy is fixed for each block. In our state, the rate per unit of energy for the first block is minimum and increases progressively with the succeeding blocks.

This method is adopted to help the low income group for the utilization of electrical energy.

ADVANTAGES

(1) It helps the consumers of low income group to use electrical energy at low rates.

(2) The consumers uses electrical energy as per requirement and wastage of energy causes more bills.

(3) Only one meter is required to measure energy.

(4) It is quite easy to understand.

DISADVANTAGES

(1) The consumers using more energy are charged at higher rate than normal rates.

(2) The consumers are to pay the fixed charges unnecessarily even when they do not consume energy at all in a month.

APPLICATION OF BLOCK RATE TARIFF

This tariff is very popular in the country like INDIA.

FIXING A TARIFF IN INDIA

In India, supply of electrical energy is a State affair. Therefore, the States are empowered to fix up the tariff. Most of States impose

Education Tax

Sale Tax

Development Tax

This increases the rate of energy.

FIXING A TARIFF IN INDIA

Most of states deliver energy to the weaker section at low rates and increase the rates for middle and upper class consumers. Sometimes, State like Punjab deliver energy to a particular section free of cost for rapid development of that section or to fulfill some political motives.

Example : the yearly consumption of a factory is 50,00,000 units with a maximum demand of 15,000 KW. Calculate the annual cost of energy if the energy is charged at (1) Rs. 1000 per KW demand plus 40 paisa per unit and (2) at a flat rate of Rs.3.00 per unit.

maximum demand = 15,000 KW

Energy consumed/ year = 5×10^6 KWh

(1) As per two-part tariff,

fixed charges = Rs. $1000 \times 15,000 = 150 \times 10^5$

Running charges= Rs. $40/100\ (5 \times 10^{5)} = 20 \times 10^5$

Annual cost = Rs. $(150 + 20) \times 10^6 = 170 \times 10^5$

(2) As per flat rate tariff :

annual bill = Rs. $3.00 \times 5 \times 10^{6} =$ Rs. 150×10^5

A consumer takes a steady load of 200 KW at power factor of 0.8 lagging for 16 hours per day and 300 days per annum. Estimate his annual payment if charged at 40 paisa per KWh plus Rs. 800 per KVA per annum.

Average load = Maximum load = 200 KW

Maximum load in KVA = max. load in KW/p.f.

= 200/ 0.8 = 250 KVA

Energy consumed /year = Av. Load X No. of hrs/year

= 200 X 16 X 300 = 960 000 KWh

As per tariff, Annual payment

= 40/100 X 960 000 + 800 X 250

= Rs. 5 84 000

A factory has a maximum load of 300 KW at 0.72 p.f. with annual consumption of 4×10^4 units. The tariff is Rs. 300 per KVA of max. demand plus 20 paisa per unit. Find out the average price per unit.

Max. demand of factory = 300 KW

Power factor = 0.72

no. of unit consumed = 40 000

Maximum demand in KVA = 300/ 0.72 = 416.67

Annual bill = 300 X 416.67 + 0.2 X 40 000

= Rs. 1 33 000

Average price per unit = 1 33 000/ 40000 = 3.32 Rs.

TARIFF DS/ NRS AS PER 01.04.2011

TYPE	TARIFF RATE	PER MONTH PER UNIT	MINIMUM CHARGE	ELECTRICITY TAX	OCTROI
D S	FIRST 100 UNITS	348 PAISA	41 Rs/ kw	13 % of expenditure	10 paisa / unit
	NEXT 200 UNITS	488 PAISA	41 Rs/ kw	13 % of expenditure	10 paisa / unit
	REMAINING UNITS	515 PAISA	41 Rs/ kw	13 % of expenditure	10 paisa / unit
NRS	ALL UNITS	556 PAISA	148 Rs./ KW		

SERVICE CHARGES PER MONTH

	CATEGORY	DS	NRS	DS	NRS
1	DS & NRS SUPPLY	Old rates		New rates	
	SINGLE PHASE	1.50	1.50	5.00	5.00
	THREE PHASE UPTO 20 KW	3.00	8.00	10.00	25.00
	INDUSTRIAL / BULK SUPPLY				
	UPTO 20 KW	6.00		20.00	
	BETWEEN 100 TO 500 KW	50.00		150.00	
	ABOVE 500 KW	150.00		450.00	

RATE OF METER RENTALS

	PARTICULAR	RATE
1	SINGLE PHASE LT METER	11.00
	THREE PHASE LT METER	25.00
	THREE PHASE METER WITH 50/5 AMP CT	57.00
	THREE PHASE METER WITH 100/5 AMP CT	42.00
	POLY PHASE MOTOR	1.6 PAISA PER
		RUPEE COST OF METER/
		METERING EQUIPMENT

RATE OF ELECTRICITY DUTY PER UNIT

S.N	CATEGORY	RATE PAISA PER UNIT
1	DOMESTIC SUPPLY	9
2	NON RESIDENTIAL SUPPLY	11
3	INDUSTRIAL BULK SUPPLY PUBLIC LIGHTING	11
4	AGRICULTURAL SUPPLY	NIL
5 (A)	MARRIAGE OR OTHER FUNCTION ILLUMINATION	100
5 (B)	FOR OTHER THAN ILLUMINATION	NORMAL RATE
6	GOVERNMENT OFFICES	EXEMPTED FROM DUTY

A domestic consumer who has a sanctioned load of 9.6 KW having 3 phase meter, consumed 410 units per month. The tariff charges imposed by Electricity Board is as per 16-08-2000. Calculate monthly Electricity bill.

Amount for first 100 units = Rs. 150/100 X 100 = Rs. 150

Amount for next 200 units = Rs. 260/100 X 200 = Rs. 520

Remaining units = 410 – 300 = 110

Amount for remain. 110 units=Rs. 290/100 X 110 = Rs.319

Service charges = Rs. 10

Meter Charges = Rs. 25

Electricity duty = Rs. 9/100 X 410 = Rs. 36.90

Total amount = Rs. 150 + 520 + 319 + 10 + 25 + 36.90

= Rs. 1060.90 Monthly Electricity Bill

A Jewellery shop has a sanctioned load of 11.5 KW consumes 850 units in a month. The tariff for NRS are as per 16-08-2000. Calculate monthly bill.

Amount of energy consumed = Rs.350/100 X 850 =Rs.2975

Service charges = Rs. 25

Meter Rent = Rs. 25

Duty on electricity consumed = Rs. 11/100 X 850 = Rs.93.50

Electricity bill is = Rs. 2975 + 25 + 25 + 93.50 = Rs. 3118.50

THANKS