1

Introduction To Electrical Power Generation, Energy Resources And Power Plants

1.1 Need of Energy

Human civilization has progressed by discovering and harnessing various energy resources, energy conversion processes, energy utilization machines etc. Advanced man has mastered the technologies of power generation transmission control distribution and utilization energy in electrical form. Energy exists in matter ($E = mC^2$), chemicals, moving masses, flowing fluids, electromagnetic fields, gravitational fields, water at high level, sunlight etc. The concepts of energy, work and power as known and understood by us today have been developed over last several centuries. This understanding has been a result of scientific enquiry and continuous technological research and development.

Primitive cave-man used his muscle power for survival. He probably changed his geographical locations for food, water, safety and favourable surroundings. Fire was one of the earliest energy conversion processes used by man. Earlier, the energy displays like fire, sun, lighting were respected as God. Agricultural man developed levers, springs and other simple machines to gain mechanical advantage and enhance the mechanical muscle force.

Horses and bullocks were used by the agricultural man to substitute human muscle power. Solar energy was used naturally without special devices.

The inventive mind and desire to live more comfortably resulted in development of energy conversion processes used in day to day life. Next step was development of *wind mills* and *water wheels* around *13th* century for agriculture.

Steam Engines and Internal Combustion engines (IC Engines) around resulted in rapid growth of industry and well known Industrial Revolution Mobile machines like automobiles, steam-engines and larger *energy conversion machines* were introduced. Electrical energy electro-mechanical machines were invented by the end of 19th century. The various types of electrical machines like a.c. and d.c. generators motors, transformers etc. were developed Electrical supply systems were introduced. The chemical, mechanical, magnetic thermal, photo effects, electromagnetic waves etc. were discovered. *Utilization of electrical energy continued to rise rapidly resulting in ever increasing demand and shortage of electrical power.* Various types of prime-movers were developed for driving 3 phase AC *synchronous generator shafts.* Unit sizes of turbine-generators steadily increased. Larger Hydro-electric power stations, Steam Thermal Power Stations and Nuclear Power Stations with higher unit-sizes are being built in developed and developing countries.

Energy in electrical form has proved to be the most convenient, useful, cleaner reliable, safe, controllable and desired form of secondary energy. Electrical energy and power is used universally since the beginning of 20th century. The electrical energy has become essential for modern civilization.

Electrical energy systems (Electrical utility or Electrical Power Systems) *have been developed for generation, transmission, distribution and utilization of energy* in electrical form. *Electrical Energy Systems* were small and had low MW capacity and coverage during early part of 20th century. The technology advanced, the demand increased, the electrical systems expanded rapidly. The installed generating capacities, rated voltages of transmission, sizes of generators, transformers, etc. increased steadily. Electrical energy was made available to various consumers over large geographical areas.

Today, electrical energy is necessary for industrial, commercial, domestic, agricultural, transport, scientific, social, defence activities, etc. Day-to-day life comes to stand-still with outage of electrical supply.

Energy needs are supplied in the form of petrol, diesel, fire wood and electricity.

1.2. Electrical Energy System (Power System)

Electrical Energy System (power system) comprises the following essential parts : Ref. Fig. 1.1.

— Generating Station (power plants)

[Various conventional and alternative power plants shown in Fig. 1.1]

— Transmission Network (3 Ph. AC)

[L-1, L-2......etc. in Fig. 1.1]

— Distribution Network (3 Ph. AC)

[DD etc. are feeders which feed to distribution substation buses]

— Load centres and loads.

Modern Electrical Energy System converts energy from various non renewable and renewable energy resources to electrical form. *Electrical energy* is generated (produced) in small, medium and large power plants. *Generating Stations* are located near the energy sources or near load points. Generating stations convert energy from primary form to electrical form (secondary form for final consumption) 3 phase AC generators (synchronous generators) of standard frequency (50 Hz, ± 3%) are installed in generating stations. Power is transmitted in electrical form *via* long *Extra High Voltage (EHV) 3 phase AC transmission Network.* The power is distrubuted by 3 phase AC distribution Network. (765 kV AC and 400 kV AC in India): Consumers draw the required power as per their prevailing demand of energy for day-to-day consumptions. Earlier DC, Single phase AC systems, etc. were tried in a limited way. However 3 phase AC systems of constant frequency (50 Hz, ± 3% in India) have been used universally for generation, transmission, distribution. (Except for certain long distance and back to back HVDC schemes). In a 3 phase AC system, the synchronous generator has three identical stator windings spaced at 120° etc. Three windings are connected in star Three phase-terminals and one neutral is brought out. The neutral wire may be provided and or neutral may be earthed. Generators, transformers and individual AC loads like motors also have 3 phase windings connected in star (or delta). Three phase machines are more compact and economical than single phase machines. AC generators, transformers, transmission lines, distribution systems loads etc. operate synchronously (at same frequency, wave form, wave shape, and wave phase) at common prevailing frequency (around 50 Hz) in a natural and automatic way. Demand is fulfilled continuously at all times by matching generation with the load and maintaining frequency within targetted limits (48.5 Hz to 51.5 Hz). In modern electrical energy system the various generating station and transmission networks are interconnected to form a large *Interconnected power system.*

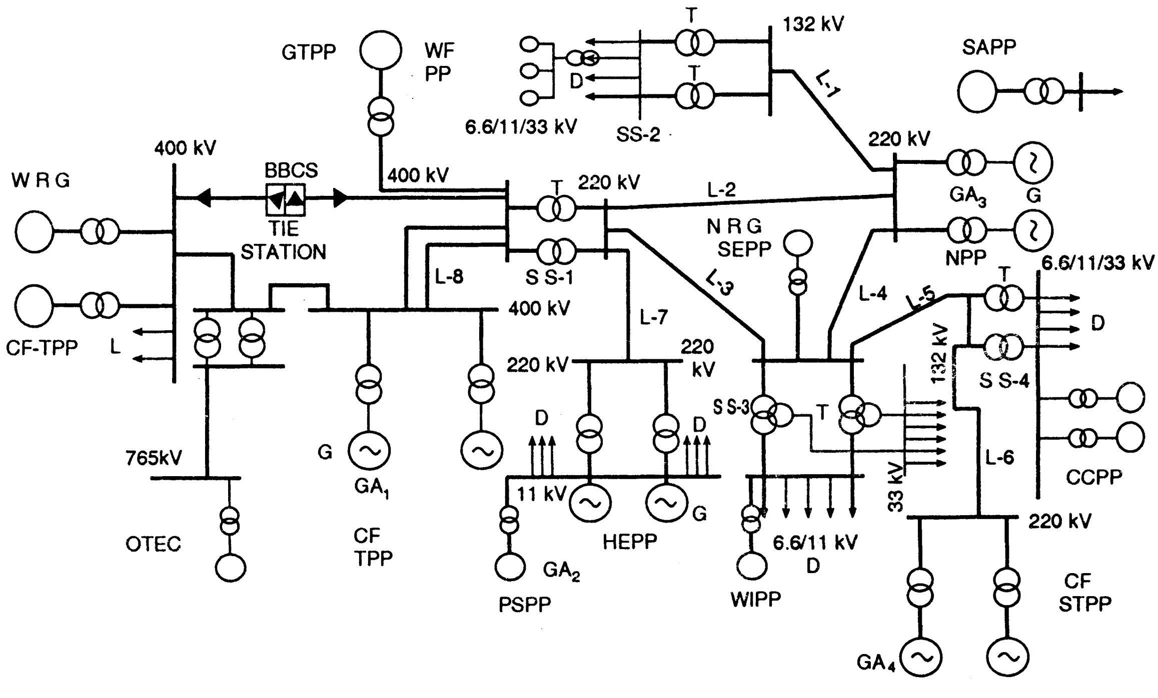


Fig. 1.1. Single Line Diagram of a 3 Ph. A.C. Energy Supply System (Power Systems—Network).

NRG = Northern Regional Grid
WRG = Western Regional Grid
BBCS = Back-to-Back HVDC Coupling Station
NPP = Nuclear-Power Plant
L-1, L-2...3 Ph. AC Transmission Lines
D, D...To Distribution Substations
G, G....Generating-units
SS-1, SS-2...Substations

CF-STPP = Coal Fired Steam-Thermal Power Plant
WIPP = Waste Incinerations Power Plant
HEPP = Hydro-Electric Power Plant
PSPP = Pumped Storage HEPP
GTP = Geo-Thermal Power Plant
WFPP = Wind Farm Power Plant
SAPP = Stand-Alone Power Plant
CCPP = Combined Cycle Power Plant
OTEC = Ocean Thermal Energy Conversion Plant
SEPP = Solar Energy Power Plant

The consumers energy demand varies continuously, hours by hours and each season (summer, winter) to maintain constant frequency of AC supply, the amount of electrical generation is matched with prevailing demand continuously and automatically.

Energy demand on the supply system grows rapidly with industrialization and population growth.

The number of power plants and installed MW capacity of electrical energy system is also increased to meet the growing demand. This calls for optimum use of available primary energy resources.

1.3. Voltage Levels in AC Network

Choice of voltage for transmission of power depends on MW rating and transmission line length. For higher power and/or longer length higher AC voltage gives lesser current and lesser I^2R losses. Entire network is divided into 3 or more hierarchical transmission voltage levels as shown in Fig. 1.2.

For high power long lines EHV-AC level (L-1) is preferred. The voltage class is 400 kV or 765 kV AC, rms, phase to phase.

Such lines feed power to underlying HV-AC network formed by 400 kV and 245 kV back-bone network (L-2).

The 400 kV and 220 kV *AC Transmission lines* feed power to various distribution substations L-3. *Distribution substations* feed power to consumers *via* the distribution lines and service mains.

For transferring energy from remote coal fired steam thermal plants and remote hydro-electric plants, the alternatives available are :

1. Transportation of fuel upto load centre by rail, road, ship transportation.

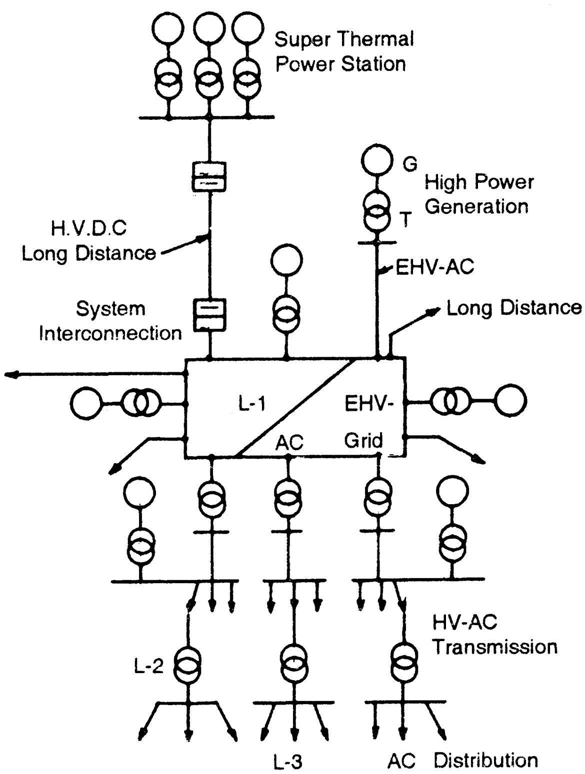


Fig. 1.2. Transmission Voltage Levels in a Energy Supply System (Power System).

L-1 EHV-AC Network (Back-bone Network) of 3 phase, AC, 400 kV lines (in India)

L-2 HV-AC Transmission Network of 3 phase AC, 220 kV lines and 132 kV lines

L-3 Distribution Network, 33 kV, 11 kV, 6.6 kV, 3.3 kV, 3 phase AC lines.

2. Electrical transmission for transmission of high power (1000 MW) to long distances (400 km, 800 km) two alternatives are available.

— EHV-AC Transmission (*e.g.* 400 kV, AC)

— HVDC Transmission (*e.g.* ± 1500 kV, DC).

Following transmission and distribution voltages are used in India.

Table 1.1
Transmission and Distribution Voltage Levels in India

765 kV	400 kV	220 kV	132 kV	110 kV
66 kV	33 kV	22 kV	11 kV	6.6. kV
3.3 kV		400 V a.c. rms. phase to phase		

H.V.D.C. *Transmission
± 500 kV,

Three phase, 50 Hz, AC systems with grounded neutral are used for all the AC voltage levels. Nominal frequency is 50 Hz with permissible variation of ± 3% (Target limits 48.5 Hz to 51.5 Hz).

In USA and part of Canada, Japan, Brazil etc. 60 Hz is a standard frequency. In UK, Europe, USSR etc. 50 Hz is a standard frequency for station auxiliary supplies for battery system, low voltage and medium voltage devices, the following voltages levels are used.

Table 1.2
Voltage Levels for Station Auxiliaries

Auxiliary A.C. Supply :	11 kV, 400 V, 3 ph., phase to phase 230 V a.c. single phase	6.6 kV	3.3 kV
Auxiliary L.V.D.C. :	220 V	110 V	48 V D.C.

Before 1973, cost of primary energy resources (available from nature) was low and no much thought was given to energy resources, energy conservation, environment, long term plan etc. We called the electrical systems as *utilities* or electrical power systems. Recently, the emphasis has shifted to energy resources, energy conservation, renewables, alternatives, environmental impacts of power plants etc. Word Energy is closely related with the word power.

The entire business of electrical power system is to supply adequate electrical energy to all its consumers at lowest possible cost, with high reliability, service continuity and with specified voltages, frequency waveforms, etc, at all times and over vast geographical areas ; without harming ecology and environment.

The emphasis has shifted to 'energy' and 'environment' during recent past.

1.4. Primary Energy Resources and Energy Conversion (Power Plants)

The primary forms of energy resources are those which are available in nature.

Table 1.3
Primary Energy Resources

1. Petrolium Fuels : oil, gas,
2. Various types of coal,
3. Combustible Fuels : wood saw dust, biological materials like rice husk, wheat husk, dried plants bio-gas,
4. Solar energy (from sun),
5. Wind energy (from flowing air),

6. Geothermal energy,
7. Ocean thermal energy,
8. Ocean wave energy,
9. Hydro energy in flowing water,
10. Chemical energy in liquids and gases,
11. *Nuclear Fuels* like uranium (U_{235}), plutomium (Pu_{238}) for nuclear fission.
12. Nuclear fusion fuels under development etc.

Table 1.4
Power Plants and Basic Energy Conversion Processes

	Power Plant	*Main Energy Conversion Processes*
A.	**Conversional Power Plants**	
1.	Steam thermal power plant (STPP)	Coal→Heat→Steam→Mechanical→Electrical
2.	Nuclear Steam Power Plant	Nuclear→Heat→Steam→Mechanical→Electrical Fission
3.	Hydro Power Plant* (HEPP)	Gas→Heat→Mechanical→Electrical
4.	Gas Power Plant	Gas→Heat→Mechanical→Electrical
5.	Combined Cycle Power Plant (Combination of 4 & 1)	Steam→Mechanical→Electrical
B.	**Alternative (Non-conventional Power Plants)**	
1.	Solar Power Plant* (SPP)	Solar→Steam→Mechanical→Electrical
2.	Wind Power Plant* (WPP)	Wind→Mechanical→Electrical
3.	Geothermal Power Plant* (GTPP)	Geothermal Heat→Mechanical→Electrical
4.	Ocean Thermal Power Plant* (OTEC) (EC = Energy Conversion)*	Ocean Heat→Mechanical→Electrical
5.	Ocean Wave Power Plant * (OWPP)	Wave energy→Mechanical→Electrical
6.	Fuel-cell Power Plant* (FCPP)	Fuel oxygen Heat →Mechanical→Electrical
7.	Nuclear Fusion Fuser* Plant	Nuclear fission→Heat→Mechanical→Electrical

*Renewable Energy Resources.

The search for the new types of resources will continue for ever and new names will be added to the above list.

1.5. Energy Conversion Plants

(Power Plants) Generating station convert the energy from primary form (as available in nature) to secondary form (as used by consumers) (*e.g.* electrical energy, heat steam). Electrical power plants are used all over the world for energy conversion from primary to secondary form (electrical form. Ref. Table 1.4.) *Primary energy resources are distributed unevenly in various parts on the earth.* The available quantity varies with time and consumption *e.g.* coal is available in some parts of Bihar, UP, Maharashtra, Tamil Nadu, etc. Petroleum resources are located in Assam and Bombay high. Rapid consumption of fossil fuels† will result in rapid depletion. Energy starvation is likely within a century.

Nuclear fuels (uranium) is located in West Bengal, Tidal Power iş available in usable quantities around certain coastal location in Gujrat, Tamil Nadu. Solar energy is available in entire South and central India during sunny parts of the summer days of summer. Wind energy is available in certain areas away from forests, large cities and at favourable geographical locations on land and off-shore.

†*Fossil Fuels :* Fuels available from earth in the form of coal, oil, petroleum, gas etc. originating from fossils.

Solid fuels like coal, wood, urban, waste, can be transported from the source location to the consumption location in primary form. Alternatively the energy can be converted into electrical forms, transmitted and distributed in electrical form and supplied to user in electrical form. The utilization devices convert electrical energy into required form for ultimate consumption such as heating, melting, lighting, transport driving, crushing entertainment, communication, air-conditioning, electronic equipment etc. We will focus our attention at Energy conversion from primary resources to (secondary) *electrical form*. The plants for conversion of energy from primary forms to electrical form are called *Energy Conversion Plants*, electrical generating plants, generating station, power plants etc. The branch of engineering dealing with energy conversion from primary form to electrical form is often called 'Electrical Generation', 'Electrical Power Plant', Engineering Power Plant, Technology, and recently "Energy Technology".

'Energy has received maximum attention 1973 oil crisis from planners scientists, decision makers, environmentalists, power engineers, nuclear technologist etc. Power generation (Electrical Energy Production) is of interest to a vast cross-section of human civilization.

1.6. Conventional Non-renewable Energy Resources

These include coal, petroleum oils, petroleum gases, nuclear fission fuels (uranium) etc. they are being consumed and are not replenished by nature. Their natural stocks are limited. The non-renewable energy resources will last for limited time of a few decades to a few centuries only. (*Hydro-energy is conventional renewable source*).

1.6.1. Renewable Alternative Energy Resources

These are almost continuously available in nature and their availability is ensured for next several thousands of years. Examples include : wind, solar, geothermal hydro bio-mass, city waste. After 1973 oil crisis higher priority has been given to *Renewable energy resources* (also called non-conventional energy resources).

Though renewables were known in the past, little attention was paid to them due to vast quantities of cheaper fossil fuels (coal, petroleum) wood, muscle power.

Table 1.5
Comparison between Conventional and Renewable

	Convention Power Plants		*Alternative Power Plants*
1.	Suitable for Central Stations	1.	Suitable for small station and isolated loads, rural and remote areas
2.	Presently technologies are well developed	2.	Technologies are under development.
3.	Capital cost of installed generation; low (low Rs/MW) capacity	3.	Capital cost of installed generation capacity is high at present (high Rs/MW).
4.	Energy Resources in large quantities and high concentration supplies ensured for a few more centuries.	4.	Wind, Solar energy density very low, supplies not very regular and continuous.
5.	Large size plants (1000 MW, 2000 MW).	5.	Wind, solar plants are smaller (1 MW, 10 MW).
6.	Environmental hazards NO_x, CO_x, particles deforestation.	6.	Clean Power.
7.	Primary resource cost very high, rising.	7.	Primary Energy cost low, cost reducing.
8.	Will become obsolete when energy resources get depleted.	8.	Will continue to share more and more load.

1.7. Task of Electrical Supply Companies (Utilities)

As electrical energy is essential for everyone, the tasks of Energy Supply Companies (Utilities, Electricity Boards, Power Corporations) have became very important. The important tasks include :

- — Supply of required electrical power to all the consumers in their geographical jurisdiction continuously, at all times.
- — Maximum possible coverage of the supply network over the given geographical boundaries.
- — Maximum security of supply.
- — Shortest possible fault duration.
- — Optimum efficiency of plants and the network.
- — Supply of electrical power within targeted frequency limits (say, between 48.5 Hz and 51.5 Hz).
- — Supply of electrical power within specified voltage limits.
- — Supply of electrical energy to the consumers at the lowest cost.
- — Energy conservation, optimum use of energy resources.
- — Generation Planning.
- — Transmission Planning.
- — Cooperation with neighbouring utilities.
- — Environmental* and ecological** balance.

With growing population and industrialization, the demand for electrical energy increases at a rate of 5 to 10% per year. This increasing demand should be fulfilled by increasing the rating and size of electrical system by 7 to 11% per year. In the developing countries, the gap between energy demand and energy supply is widening every year with power shortage during daily peak load hours.

This results in poor supply frequent outages etc.

The following steps are encouraged :

- — Conservation of non-renewable energy resources.
- — Use of renewable for cooking, heating, mechanical drives, electrical power generation etc.
- — Loss prevention. Reduced electrical, mechanical thermal losses.
- — Encouraging off-peak demand, reducing peak hour demands.
- — Reduction in energy consumptions by simpler life style.
- — Decentralised power stations with more from renewables.

1.8. Types of Generating Stations

Power Plant (Generating Station) is an assamblage of (electrical generators, various electrical equipments, mechanical equipment auxiliaries, associated civil and structural works for delivering electrical energy to high voltage transmission Network or an isolated electrical load. A power plant has usually two or more identical units of generator, prime-mover and associated auxiliaries.

Central Power Station delivers bulk Power (several hundred MW) to the electrical network. Central Power Stations have two or more large generator-turbine units with associated prime-movers (turbines).

Captive Power Plants are medium or small power plants dedicated or supplying power to their respective local loads.

Isolated Power Plants* (Stand-alone Plants) are small or medium power plants of a few kW to a few MW capacity for supplying isolated local loads. They are not connected to the large electrical network. Such plants are also called *stand-alone power plants.*

**Environment* : Nature, plants, vegetation air, water, wind, sunlight, snow, animals, birds, weather, man, heat, dust, ambient.

***Ecology* : Relationship between man, living organisations and environment.

Energy Displacement Plants* are for conversion of renewable energy source power (wind, solar) to electrical power generate electrical energy whenever the renewable resource is actively available the amount of energy produced by energy displacement plants is displaced from conventional energy source consumption to renewable source.

Base Load Station is operated through out the year for supplying electrical power continuously. The base load station is not designed for frequent starts/stops. It is usually operated with high plant load factor example. Steam thermal power plants, Nuclear thermal power plants.

Peaking Load Station is used for supplying peaking power of a few hours duration per day. They are designed for frequent starts/stops. (Example : Gas Turbine Power Plant).

Energy-Storage Power Plants*

During off peak period electrical energy from the network is stored in some form (electrical batteries or compressed air or water at high level). During peak load the stored energy is converted into electrical form and supplied to the Network.

Examples : Pumped Storage Hydro Electric Plant, Lead Acid Battery Power Plant, Compressed Air Power Plant.

1.9. Types of Conventional Power Plants (Based on Energy Resource)

Conventional Power Plants. Power plants are being used traditionally during past several decades (before 1970) these include :

— Coal fired/Fossil fuel fired steam thermal power plants.

— Diesel Electric Power Plants or Internal Combustion Engine Power Plant.

— Hydro-Electric Power Plants.

— Pumped-Hydro Power Plants.

— Nuclear thermal steam power plants.

— Gas Turbine Power Plants* (1950 onwards).

— Combine cycle power plants.* (1970 onwards).

Conventional Power Plants may be with non-renewable Energy Resource (Coal, Petroleum fuel) or

Renewable energy Resources (solar wind). Table 1.6 gives a list of conventional power plants with brief description. Fig. 1.3 illustrates a schematic of electrical and thermal circuits.

1.10. Description of a Typical Power Plant

Fig. 1.3 shows a schematic of essential electrical and thermal equipments. A power plant as a rule has two or more identical turbine-generator units mounted on the same shaft. On electrical side 'B' the generator (10) are connected in parallel *via* the main transformer 11 and main switchgear (12). The *generators* are as a rule 3 phase, 50 Hz, medium voltage, synchronous generators. The rotor of *generator* has DC field winding supplied by DC exciter (not shown). The rotor is driven by the *Turbine* at only synchronous speed

$$N_s = 120 f/p \qquad \dots (1.1)$$

***Renewables (Alternatives)** are generally of these categories. Solar, Wind, Bio, Fuel Cell Power Plants are usually smaller (few kW to a MW), isolated load, for energy displacement, plants for rural areas.

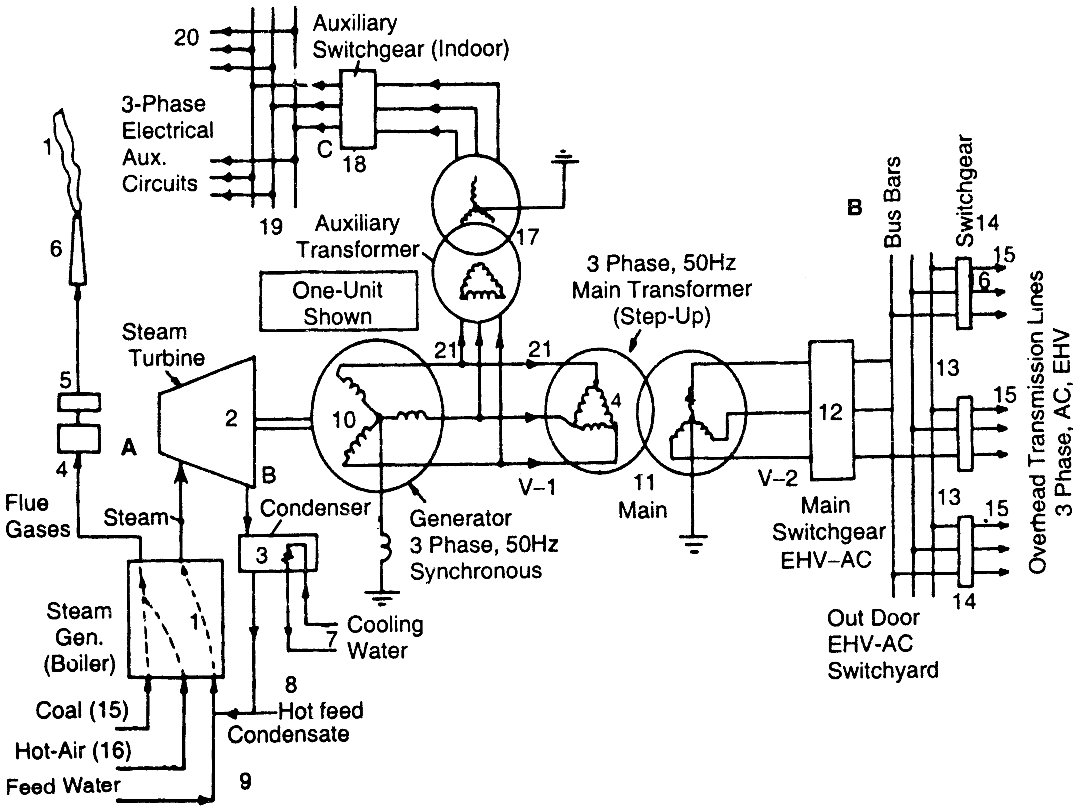


Fig. 1.3. Schematic of One-unit in a Steam-thermal Power Plant.

A. Thermal Subsystem
B. Main Electrical Circuit
C. Auxiliary Electrical Circuit
1. Steam generator (Boiler)
2. Steam Turbine Coupled to 10
3. Condenser
4. Electrostatic Precipitator (ESP)
5. Flue-gas Treatment Units
6. To stack (chimney)
7. To outdoor Cooling-tower
8. Condensate from (3) given to (1), with 9
9. Preheated feed water for (1)
10. Generator
11. Main Transformer
12. Main Switchgear
13. Outdoor Switchyard
14. Switchgear
15. Overhead lines
16. Busbars in 13
17. Unit-auxiliary Transformer
18. Auxiliary Switchgear
19. Indoor Busbars of 18
20. Supplies to Boiler/Turbine/Generator Auxiliaries
21. Metal Enclosed Isolated Phase Busducts

Table 1.6
Conventional Power Plants and their Primary Energy Resources

	Type of Power Plant and Main Equipment	*Energy Resources*	*Usually operated as*
1.	Steam-thermal Power Plat-coal fired – Steam Generator (Boiler) – Steam Turbine – Electrical generator	–Coal (Fossil Fuel, Non-renewable)	– Large (1000 MW) central Power Plant – Base Load – Popularity <
2.	Gas-Turbine Power Plant – Air Compressor – Gas Combustor – Gas Turbine – Electrical Generator	–Natural Gas –Synthetic Gas –Biogas –Petrolium Oils –Gasified Coal – Gas from Fluidised Bed Boiler	–Medium (100 MW) –Peaking load or –Intermediate load –Popularity <
3.	Combined Cycle Power Plant –2 Gas Turbine generator units –Heat Recovery Steam Generator –1 Steam-turbine Generator Unit	– Fuels for Gas Turbine Plant (GTP) –Exhaust heat of GTP is recovered in Heat Recovery Steam Generator –Steam from HRSG drives Steam-turbine Generator	–Base load –Intermediate load –Popularity <
4.	Nuclear Steam-thermal Power Plant –Nuclear Reactor –Steam-Generator –Steam-Turbine –Electrical Generator	–Fissile Nuclear fuels : Uranium U_{225}, U_{238}, PU_2	–Large (1000 MW) –Base load –Near load centres – Popularity <
5.	Hydro Electric Power Plant –Water Storage at higher level –Pipe-line upto Turbine –Hydro-Turbine –Electrical Generator	–Hydro –Flowing water from high level to low level	–Large base load stations (1000 MW) –Medium Intermediate Stations (250 MW) –Small run-off the river stations (20 MW) for local loads or peak loads – Popularity ≤

where N_s = Synchronous speeds

p = number of d.c. poles on rotor of synchronous generator *e.g.* 2, 4, for Steam-turbine Generator 8, 12, 16, 18 for Hydro Turbine Generator.

Corresponding N_s = 3,000, 1500, 750, ... rpm etc.

f = Standard frequency 50 Hz in India, U.K., Europe (6 Hz in USA)

A synchronous generator rotor rotates only at synchronous speed due to magnetic locking between stator field and rotor field. The *Turbine* 2 is called the prime-mover of the generator rotor. In Fig. 1.3, a steam turbine is shown along with Boiler (Steam Generator).

A steam-turbine is used as the prime-mover for the generator in all steam-thermal power plants with conventional and alternative energy resources such as

— Coal-fired steam-thermal Power Plant (STPP)*

— Nuclear STPP*

— Geo-thermal STPP†

*Conventional, Non-renewable Energy P.P.

†Non-conventional, Renewable Energy P.P.

— Solar Central or Distributed heating steam thermal Power Plant
— Ocean Thermal steam power plant*
— Fluidised-bed fired steam thermal power plant
— Waste Incineration (Burning) steam Thermal Power Plant†
— Bio mass combustion steam-thermal Power Plants†

Table 1.7
Synchronous Speeds for 50 Hz Generators

	Steam-turbine driven Generator and Gas Turbine Generator		*Hydro-Turbine driven Generator*		
No. of Poles P	2	4	6	12	24
Synchronous-Speed N_s rpm at 50 Hz	3000	1500	750	375	187.4

The *Steam is generated in a steam-generator* (called boiler in earlier terminologies). The *steam-generator* may be a combination of a furnace and a boiler in coal-fired power plant or a Nuclear Reactor with Heat exchanger in a nuclear power plant, or a heat extracting plant, with a heat exchanger is a geothermal or solar thermal power plant.

Steam-turbine operates on Rankine cycle. Superheated high pressure steam is admitted into the inlet of the steam turbine (*A*). Steam expands in the turbine in several stages as it passes through the fixed 'nozzles' on stator and moving 'buckets' (blades) on the rotor mounted on the turbine shaft. As high pressure and high pressure steam expands through the buckets/blades of the steam turbine, the thermal energy in steam drives the turbine rotor.

The electrical power delivered by the turbine generator unit is of 50 Hz, 3 phase alternating current sinusoidal wave form.

Typical ratings of a steam-turbine generator units used in India are 200 MW, 500 MW at 15 kV to 22 kV, 50 Hz.

The electrical power generated by the units is fed into a large electrical network *via* an outdoor switchyard 13. Long Extra-High Voltage overhead Transmission lines (EHV) feed the power into a super-grid.

Switchgear (14) consists of circuit-breakers or switching the unit on-or-off during normal operation and also during abnormal operating conditions such as faults, over-currents, over-heating etc.

Main-transformer (11) is a 3 phase, 50 Hz, step-up transformer which steps-up the generator voltage V-1 to transmission voltage V-2. The Power Transformer is usually outdoor, OFAF type (oil forced/Air Forced Cooling) with-off circuit tap-switch. A generator/turbine/steam-generator and the power plant have several electrical, mechanical and station service auxiliaries. The electrical auxiliaries receive power at 11 kV/6.6kV/3.3kV/440V through auxiliary switchgear (C).

Part of the generator output (6 to 8%) is supplied to the auxiliaries (20) *via* the auxiliary switchgear (*C*).

Steam-Generator (1) receives fuel (15), hot air (16) and the fuel is burnt in combustion chamber of (1). Flue gases (17) are let-out to atmosphere *via* Electro-static precipitators (4) and Affluent Treatment Plant (5) and the stack (chimney) (6) steam generated in (1) is delivered to the steam Turbine (2) Steam-turbines are condensing type. The exhaust steam is sucked in evacuated condenser (13). Cooling water (7) is circulated through condenser 3 and cooling towers (not shown). Type of Turbine and Auxiliaries differ very widely depending upon primary energy source used. In a *gas Turbine* plant a gas Turbine drives the generator shaft.

In a *hydro-turbine* plant a hydro-turbine drives the generator shaft.

Conventional, Non-renewable Energy P.P.

†Non-conventional, Renewable Energy P.P.

In a *wind-turbine* plant the wind-turbine mounted on a tall tower drives the generator shaft. *Electrical parts 'B' and 'C' are similar in various types of power plants.*

1.11 Types of Non-conventional Energy Resource Power Plants (Alternative Energy Resource Power Plants)

Power Plants which have been recently considered for electrical power generation (after 1973 oil price crisis) as an alternative to conventional power plants are called Non-conventional or Alternative power plants.

Non-conventional (Alternative) power plants are either with Renewable Energy Resources or with non-renewable energy resources. However the priority is for renewable.

Table 1.8
Non-conventional (Alternative) Power Plants

1. **Solar Energy Conversion Power Plants**
   - 1.1. Solar thermal power plant
   - 1.2. Solar PV cell power plant
   - 1.3. Solar-diesel hybrid power plant
   - 1.4. Solar-battery hybrid power plant
   - 1.5. Solar-satellite power plant
2. **Wind-Energy Conversion Power Plants**
   - 2.1. Wind Turbine-battery hybrid power plant
   - 2.2. Wind Turbine diesel hybrid power plant
3. **Geothermal Power Plants**
   - 3.1. Geothermal Steam Power Plant
   - 3.2. Geothermal binary cycle power plant
4. **Ocean-Thermal Energy Conversion Plant (OTEC)**
   - 4.1. Ocean thermal gradient power plant (OTEC power plant)
5. **Ocean Wave Power Plant (OWEC Power Plant)**
6. **Waste-Incineration Power Plant (Bio-Waste Steam Thermal Power Plant)**
7. **Bio-Mass (Fuel) Thermal Power Plant (Biological Fuels from Farms and Forest Burnt to get Steam for Steam turbine)**
8. **Fuel Cell Power Plant**
9. **Nuclear Fusion Power Plant***
10. **Non-conventional Fuel Thermal Power Plant Utilizing Fuels like Magnetic-Hydro Dynamics Generation**
11. **Fuel cell Power Plant Power Plant (MHD)**

*Power Plants for future (After around 2010 AD).

Table 1.9
Renewable Energy Resources

—Solar energy	—Ocean thermal energy (OTE)
—Wind energy	—Hydro (Conventional)
—Geothermal energy	—Nuclear fusion power plant
—Municiple waste fuels	—Gaseous and Liquid chemical fuels (H_2, O_2)
—Bio-fuel power plant	
—Ocean wave energy (OWE)	

1.12. Review of Conventional Power Plants and Energy Resources in India

The electrical utility industry (state electricity Boards, NTPC, NHPC etc.) generate electrical power. ''*Power generation*'' in electrical industry means '*Conversion of energy from primary resource to electrical form*. Electrical utility industry is also called as *Energy Supply Industry* by planners, energy technologists. *The types of electrical power plants* in a particular location depend upon the available natural primary energy resource in the country, capital cost, running cost, size of power plant types of load etc.

Installed capacity of a power plant or an energy supply system is expressed in Mega-Watts (MW). MW is the standard unit of electrical power. *In India, present installed generating capacity of the electrical power system* (Grid) is composed of Steam-thermal, Nuclear thermal, Gas fired and Hydro-electric and combined cycle central power plants and a very few renewable energy power plants.

Table 1.10. Installed Generation Capacity in India

Types of Power Plant	*Primary Energy Resource*	*Installed capacity MW (1990)*	*% Total*
– Coal fired steam thermal	Coal	40,000	
– Gas fired gas Turbine Power Plant	Natural gas	1,300	
– Nuclear thermal	Uranium	8,000	
Hydro electric	Water flow	20,000	
Renewable	Wind, MHD	50	
		69,350	100

The annual growth rate of India's Electrical utility is very high (7 to 10% annual rise).

Coal is the main energy resource during the next few centuries. India has vast coal reserves. Very large coal fired steam. Thermal plants have been built and being built.

Nuclear Power Plant of India is very ambitious. Present installed capacity of 7000 MW will become over 10,000 MW in coming years. India has very high hydro potential 100,000 MW. Present hydro capacity (20,000) is likely to be doubled by year 2015. Planning for renewable power plants is in an initial stage.

1.13. Coal-Fired Steam Thermal Power Plant

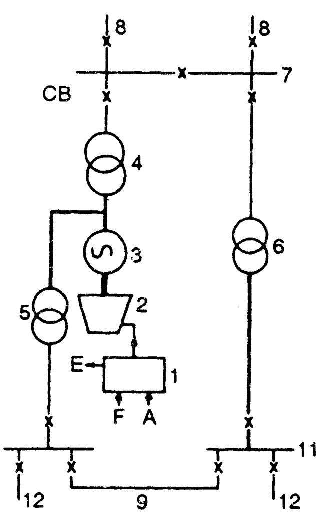


Fig. 1.4. Schematic of a Steam Turbine Generator Unit with Main and Auxiliary Electrical System.

Refer Fig. 1.4 illustrating the main equipment.

1. Steam Generator (Boiler)
2. Steam Turbine for 3
3. 3 phase, AC, Synchronous Generator
4. Main setup, Power Transformer
5. Unit-auxiliary Transformer
6. Station Service Transformer
7. EHV outdoor Busbars (3 phase)
8. Outgoing AC transformer line (3 phase)
9. Inter-connection between 10 and 11
10. Unit auxiliary switchgear
11. Station service switchgear
12. Cables to auxiliary loads.

Coal available in mines is extracted and brought upto the thermal power plant by (1) conveyor belts,

(2) Rail Wagons, (3) Trucks, (4) Ships etc. depending upon transport route.

Coal is crushed and pulverised (powder form). *Chemical energy in coal is converted into thermal and pressure energy of superheated steam.* This energy is converted to electrical form by Turbine-Generator units.

The steam is produced in steam generator (boiler) (1) Steam Turbine (2) is the main prime mover for the electrical generator (3) rotor steam turbine (4) converts thermal and pressure energy of steam into rotational. Kinetic energy and drives the synchronous generator shaft. *Synchronous generator-rotor is driven by the steam Turbine. The generator converts rotating kinetic energy (mechanical) to electrical energy.* The electrical output of the generator is in the form of 3 phase, 50 Hz, AC at medium voltage between (11 kV and 27 kV r.m.s phase to phase) the electrical energy produced by the generator at medium voltage is fed into the electrical transmission lines (8) *via* a main step-up power transformer (4).

The electrical power is transferred to distant load centres by *Extra-High Voltage* (EHV) *AC transmission lines* (8) at 765 kV, or 400 kV, or 220 kV, at 50 Hz. These voltages are phase to phase rms values for sinusoidal voltages at constant-frequency. For long, high power transmission lines and HVDC may be preferred.

Unit Concept. Steam thermal power plants generally have identical units operating is parallel and in synchronism* with each other. Each unit has

1. Boiler (Steam generator)
2. Steam turbine
3. Synchronous Generator
4. Step-up main transformer
5. Auxiliary transformer of unit.

Modern Steam-thermal power plants are built with two or more large size identical steam-turbine-generator. Typical *units ratings* are the following :

11.8 kV	60 MW	In India
13.8 kV	120 MW	In India
15 kV	200 MW	In India
22 kV	500 MW	In India
27 kV	1300 MW	In Europe, USA

1.14. Interconnected Power System

The various types of central power plants (Steam-Thermal, Gas Turbine, Combined Cycle, Nuclear, Hydro) are located in different places. All of them operate in parallel and in synchronism with each other at common *prevailing frequency* between 48.5 Hz and 51.5 Hz. Frequency is maintained within these target limits. Total power generation (MW) of all the generators at a time is adjusted with total electrical load (MW) at that time. This ensures constant prevailing frequency of the total Network (Grid). Increased load tends to reduce frequency. The input to turbines is then increased to bring back the frequency to desired standard value (50 Hz). Thus

Increase Electrical Load → Trend of reduction in frequency → Increased Energy input to Turbine → Increased Electrical output increased frequency

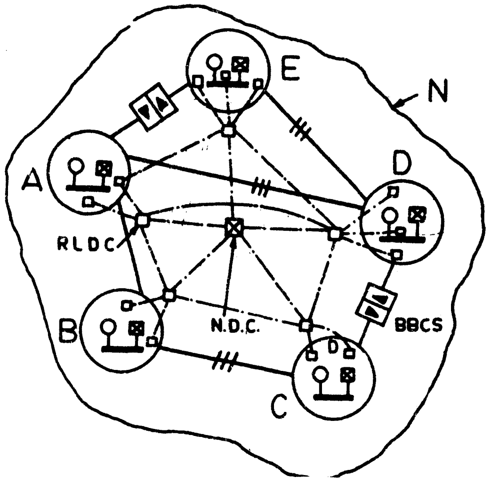
The energy resources in different states are distributed non-uniformly. Hence some states will have more coal fired power plants acting as base load stations some states have predominant hydro-stations acting as intermediate stations. Some states have gas reserves. Nuclear plants can be located suitably near large load centres. Ref. Fig. 1.5. By *interconnecting* the various *Regional (Zonal) Electrical* Grids, (A, B, C, D) a large National Interconnected Grid (*N*) is formed. The advantages of such a grid are

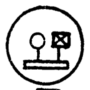
— Each regional grid can *import* power from neighbouring region during *peak loads* and export power during surplus power

— Same total installed capacity can meet higher peak demands

— Better load-frequency control

— Better Hydro/thermal/Nuclear/Renewable coordination and energy conservation.





(Regional grid symbol) —	Regional Grids *A, B, C, D, E* with certain generating capacities each; and connected loads (Σ MW)
⊠ —	National Load Control Centre (NDC)
☐ —	Regional Load Control Centre (RLDC)
—///— —	3 ph. AC Tie Lines
— · — · —	Communication Channels (PLCC)
BBCS —	Back-to-back coupling station
N —	National Grid Coverage

Fig. 1.5. Conceptual Sketch of an Inter- connected Energy Supply System (Power system).

Installed Capacity of Regional Grids and National Grid in India

	Regional Grids	States Covered	*Installed Capacity (1990 Base)*
			MW
1.	Western Region	Maharashtra, Gujrat, MP	21,600
2.	Northern Region	U.P., Haryana, Punjab, J & K, Delhi	20,100
3.	Eastern Region	Bihar, W.B., Orissa	11,100
4.	North Eastern Region	Assam, Arunachal,	2,300
5.	Southern Region	Karnataka, Tamil Nadu, A.P. Kerla, Goa, 1990	18,5,00
	Total		73,600

1.15. National Grid of India

National Grid of India is divided into five regional grids called

—Western Region
—Northern Region
—North Eastern Region
—Southern Region
—Eastern Region

Each Regional grid is responsible for its

—Generation planning
—Transmission planning
—Distribution planning
—Operation and maintenance
—Load-frequency control, etc.

Each *Region Grid* maintains its frequency within targetted limits (48.5 Hz—51.5 Hz in India) by generation of power to match with the prevailing load.

During *deficit generation* the region imports power from neighbouring *Surplus region. National Grid is on higher hierarchical level. The exchange* (import/export) *between the neighbouring Regional Grids* is dictated by the National Load Control Centre located in Delhi.

1.16. Steam Thermal Power Plants in India (Coal Fired)

Coal fired steam power plants constitute about 60% of installed capacity in India (1990). Typical units size are 200 MW and 500 MW each. India has vast coal reserves. Indian coal is with high ash content but low sulphur content.

Environmental Problems by Coal Fired Plants. Coal fired sream-thermal power plants have series environmental risks of a typical coal fired power plant are

—Fly ash (particulate)
—Nitrogen Oxides (NO_X)
—Sulphur Oxide (SO_X)
—Carbon Oxide (CO)
—Heat
—Deforestation

Presently specification of coal fired power plants in India are less stringent than those in developed countries. Earlier steam thermal power plants are without ESPS Electro-Static precipitators (ESP) and other emission controls. Recently built plants have ESPS, but lack stringent controls of SO_x, NO_x, CO, etc.

Prospects of Coal Fired Steam Power Plants in India. India has vast coal reserves and a very large coal industry.

Table 1.12. Major Coal Fields in India

	Name of Coal Fields	*State*
1.	Raniganj	West Bengal
2.	Jharia	Bihar
3.	Bokaro (East and West)	Bihar
4.	Pench-Kanhan Tawa-Valley	Madhya Pradesh
5.	Singrauli, (Shakti Nagar, Vindyachal Corba, Rihand-STPPS)	Uttar Pradesh
6.	Talcher	Orissa
7.	Chandrapur, Wardha	Maharashtra
8.	Godavari Valley	Andhra Pradesh
9.	Neyveli	Tamil Nadu

1.16.1. Indian Coal-Reserves and Future of Coal fired Power Plants

India's estimated coal reserves are 158 billion-tons (1990). The mining rate is 155 million tons per year (1990). Indian coal has poor quality with following fly composition :

—Abrasive fly ash content 25 to 50% —Sulphur < 1%

—Heating value 12 to million J/kg (300 to 9000 kcal/kg)

Coal fired steam thermal power plants will continue to share maximum percentage of installed capacity in India for several decades during the present and next century (> 60%). Short term and mid-term generation planning of India envisages additional 30,000 MW coal fired power during 1990-95 and additional 45000 MW during 1995-2000.

Projected Growth of Coal Fired Steam Thermal Power Plants in India

	Installed Capacity
Present (1990)	40,000 MW
Addition during eight plan (1990-1995)	38,000 MW
Additional during ninth plan (1995-2000)	45,000 MW
The total planned from coal fired P.P. by year 2000	123,000 MW

1.16.2. Thermodynamic Cycle of Steam Turbine Power Plant

Thermodynamic is a science which deals energy conversion from heat to mechanical form. A simple Rankine Cycle is the basis for steam-turbine operation, Fig. 1.6 shows the flow diagram and Fig. 1.7 gives the temperature-entroy diagram of a Rankine Cycle with Superheat and reheating. It has following segments:

$AA' =$ Feed water compressed in pump and admitted in boiler

$A' - B =$ Water heated in boiler to saturated liquid state

$B - C =$ Hot-water converted to saturated steam

$C - C' =$ Steam superheated to C'

$C' =$ Steam enters turbine

$C' - D =$ Steam expands in turbine

$D =$ Steam taken out of turbine and reheated

$D - D' =$ Reheating of steam

$D' - E =$ Steam expands in turbine and gets saturated at E

$E - A =$ Steam condenses is condenser F.

$A - A'$ steam pumped into boiler cycle $A - A' - B - C - C' - D - D' - E - A$ repeats continuously to produce superheated steam and to drive steam-turbine shaft. Typical temperatures and pressures of superheated steam in a conventional steam-turbine plant are 540°C to 570°C and 16.5 MPa.

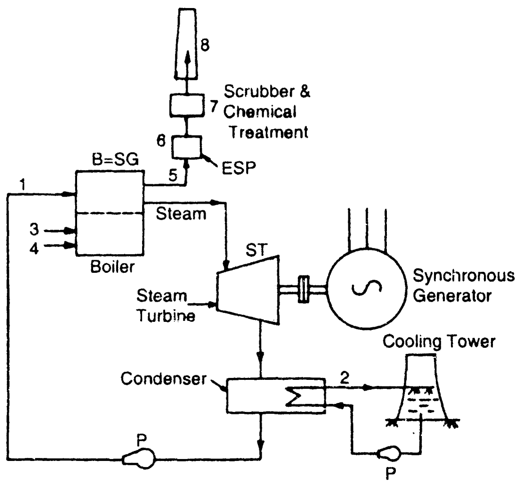


Fig. 1.6. Flow-diagram of a Steam Turbine-Generator Power Plant.
B = SG Boiler, Steam Generator

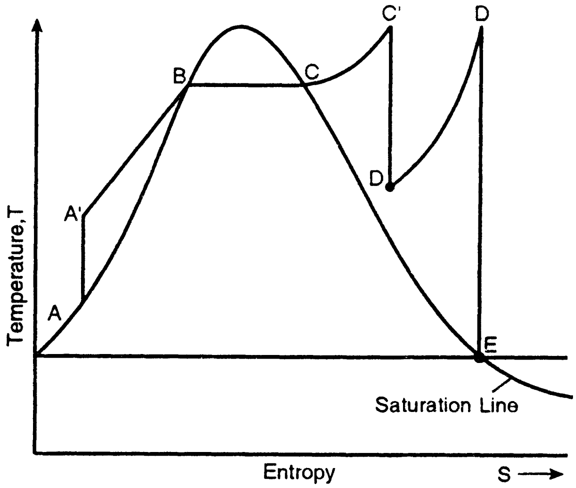


Fig. 1.7. Rankine Cycle on T-S diagram.

Rankine cycle is used for steam-turbine power plants in coal fired stations, nuclear power stations and also non-conventional steam power plants.

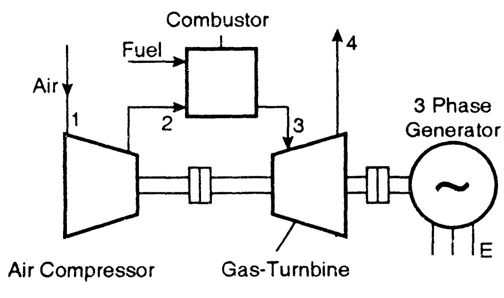


Fig. 1.8. Simple Gas Turbine Flow Diagram.

1.17. Gas Turbine Power Plants

In a gas-turbine power plant, the prime mover is a *gas turbine* (also called combustion turbine in USA). The *gas turbine* converts the fuel (oil/gas) into thermal and pressure energy in high temperature high pressure gas. The fuel is burnt in a *Combustor* to produce gas. The gas turbine converts thermal energy to rotaring mechanical kinetic energy at shaft. The Gas-turbine shaft is coupled to a 3 phase AC, synchronous generator. A single gas-turbine and a single generator from a unit.

A GTTP may have two or more indentical units with the generator operating in paralled electrically. Typical ratings of gas-turbine generator units are in the range of a few MW (10 to 150 MW, recently 250 MW).

Gas-turbine generator units may be of (1) Single shaft design or (2) two single shaft gas Power Plant is shown in Fig. 1.8.

Depending upon the flow path of air combustion-gases, exhaust of gases ; the gas turbine plant has following types of cycle.

1.17.1. Direct Open Cycle Gas Turbine and Plant

— Working Fluid : Air

— Air enters in compressor : at 1

— Compressed air enters combustion chamber : at 2

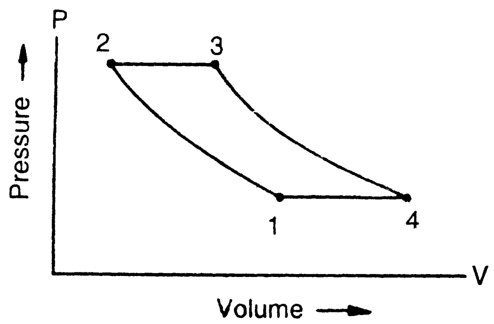
— Compressed high pressure high temperature gases enter gas turbine : at 3

— Gas turbine converts thermal pressure energy in hot high pressure gases to rotational shaft energy

— Generator rotor drives at high speed

— Generator converts mechanical energy into electrical energy and supplies to electrical network at *E*

— Exhaust of gas turbine is let out to atmosphere at 4.



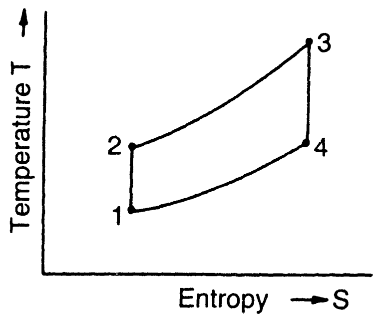


Fig. 1.9. Thermodynamic Cycle "Bryton Cycle" for Gas Turbine Power Plant "Bryton Cycle".

1.17.2. Thermodynamic Cycle for Gas Turbine Power Plant. Fig. 1.9. (*a*) and (*b*) show Bryton Cycle for Gas Turbine Plants on

(*a*) Pressure-Volume diagram and

(*b*) Temperature-Enthropy diagram.

Segments 1-2-3-4 represent distinct thermodynamic processes during energy conversion from fuel to mechanical.

1-2 Air is compressed in the air compressor

2-3 Combustion or heat addition at constant pressure

3-4 Expansion of hot-high pressure gases in Gas-Turbine

4-1 Heat rejection to atmosphere in (simple open cycle).

Due to step (4-1) a large heat is wasted into atmosphere. Hence efficiency is very low (20%). Simple Gas Turbine Power Plants waste precious heat in exhaust gases to atmosphere, thus resulting in low efficiency. This resulted in development of combined cycle power plans.

1.17.3. Combined Cycle Power Plant. It has following :

— two or more gas turbine-generator units

— Exhaust of gas supplied to heat recovery steam-generator (HRGS)

— HRGS produced steam

— Steam drives steam turbine generator
— More economical and efficient than gas turbine plant

1.17.4. Merits of Gas Turbine Power Plants

— Faster installation
— Modular construction
— Quick start
— Quick load pick up
— Quick shut down
— Suitable for peaking plant
— Emergency power supply, Base load plants in gas rich areas, Industrial power plants
— Range includes lower unit ratings (9 to 25 MW) and higher unit ratings 30 to 150 MW
— Low capital cost
— Suitable for combined cycle power plants at higher efficiency
— Least pollution by emission products
— Gas turbine plants can be built for a wide range of fuels
— Wide choice of oils and gases as fuels.

Not suitable for large central power plants of high capacities and for base load stations (except in Gas Rich Areas).

There are growing trends to install gas turbine-generator plants and combined cycle power plants. The primary energy resource is natural gas or gas fired coal.

Fuels for Gas Turbine Power Plants and Combined Cycle Power Plants

Gas turbines are being designed for use with a very wide range of conventional and non-conventional solid, liquid and gases fuels as their primary energy resource input. (Refer Table 1.12). Combined cycle power plants use the same fuels as those for gas turbine units. In a combined cycle plant the gas turbine uses primary fuel and the steam turbine uses the exhaust heat of gas turbine. There is no need of separate primary fuel for steam turbine.

Table 1.13. Fuels for Gas-turbine Power Plants and Combined Cycle Power Plants

Conventional Fuels	*Non Conventional Fuels*
— Natural gases	— Gas with low calorific valve, *e.g.*
— Residual gases	— Gas obtained from oil or coal*
— Blast furnace gases	— Methanol
	— Ethanol
	— By product at coal* Liquefaction
— Extra-light fuel oil	
— Heavy duty fuel oil	— Crude and hydrated shade oil fraction
— Crude oil at virgen origin	

1.17.6. Gas-Turbine Power Plants in India

Five 112 MW (each) gas turbine generating stations have been installed in India (1990). Several medium and small gas turbine power plants (10 MW to 110 MW) are being installed in UP, MP Gujrat etc. The natural gas from Gujrat and Bombay High is used as primary source. The estimated energy resources reserves of crude oil/natural gas in India is as follows.

Table 1.14
Estimated Primary Energy Resource Reserves in India for Gas Power Plants and Combined Cycle Power Plants

— Known recoverable crude-oil reserves (1990)	500 million tons
— Crude oil reserves expected to be depleted by year	2000
— Natural gas reserves (1990)	490 billion-m^3
— Expected to cast upto year	2010
— Estimated capacity growth for gas fired and combined cycle plants	1300 MW

The gas turbine power plants and combined cycle power plants in India may have total installed capacity of only about 1300 MW and life span of 15 to 20 years (1995-2015). However the search for gas and oil is in progress and new reserves are likely to be located any time.

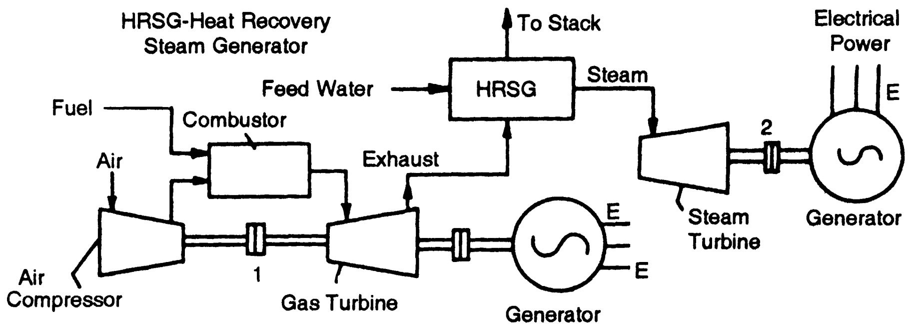


Fig. 1.10. Combined Cycle Power Plant.
E = Electrical energy output.

1. Gas-turbine-generator unit. Only one of two identical units shown.
2. Steam-turbine-generator unit (one).

1.18. Combined Cycle Power Plants

A combined Cycle Power Plant is a combination of following :

— Gas turbine-generator units with electrical output *E*.

— One steam turbine generator unit with electrical output *E*.

Hence the name *Combined Cycle* (Gas Cycle and Steam Cycle). Electrical power is delivered by the two independant types of turbine generator-units (*i.e.* GT and ST).

Fuels (Primary energy resources) are supplied to the *Gas-turbine* units through fuel combustor. The exhaust of gas-turbines is given to *Heat Recovery Steam generator* (HRSG) which recover heat from the exhaust of the gas turbine and produces superheated steam. The steam produced by HRSG is supplied to the *Steam-turbine.* Steam-turbine drives the *generator* rotor coupled to the steam turbine shaft. The energy conversion process in a combined cycle plant is in following principle steps. (Fig. 1.10).

1. Compressed air supplied to combustor.
2. Primary fuels burnt in combustor and supplied to Gas turbine (Exhaust of GT given to HRSG).
3. Gas-turbine Generator produces electrical energy and feads into the electrical network.
4. Heat from exhaust from gas-turbine given to heat recovery steam generator. HRSG recovers heat from exhaust of gas turbine and produces steam. Steam-turbine generator produces electrical energy and feads into the electrical network more and more combined cycle power plants are being installed due to following *merits of combined cycle Gas Turbine Power Plants.*

— *Energy conservation.* Head from GT exhaust is utilized through HRSG.
— Simple gas turbine power plants waste the precious energy in exhaust heat into atmosphere. In combined cycle power plant, this heat is utilized by HRSG and steam-turbine generator. This results in substantial energy conservation.
— *Higher Efficiencies.* Combined cycle power plants have very efficiencies of the order of 48 to 52% (as against low efficiency of simple gas turbine plant 20 to 30%).
— High efficiency over wide load range. Hence suitable for intermediate and peaking power plants as well.
— Power out-put of the plant is usually higher. Two or four gas turbine units with HRSG are combined with one steam-turbine unit resulting in higher total installed capacity.
— *Flexible Operation.* Quick start, quick loading, possibility of part loading and full loading, taking advantage of two or more gas-turbine units.
— *Suitable for base load operation peaking-load operation, cyclic load operation, intermediate load operation* etc.
— Wide variety of oil or gases fuels can be used as primary energy resources (Table 1.13).
— Simple and reliable operation of the power plant.
— Lower capital cost than steam turbine plant of same MW rating.
— Low cooling water requirements than steam power plant of same MW rating.
— Lesser emission of SO_x, NO_x, No emission of particulates (fly-ash).

The first combined cycle power plant in the world was built around 1950 in USA. Now more than 200 plants have been installed in the world (1990) with the total installed capacity of about 20,000 MW.

After 1988 combined cycle power plants have shown remarkable rise. Coal gasification process with combined cycle plant has been successfully developed. Such plants are likely to be preferred.

Table 1.15
Typical Plant Ratings of Combined Cycle Power Plants

Gas-turbine generator units		*Steam-turbine generator unit*		*Total Plant*
Nos.	*Total MW*	*Nos.*	*Total MW*	*MW**
2	31.9	1	19.4	51.3
2	63.7	1	40.7	104.4
2	95.6	1	61.9	157.5
2	127.5	1	83.3	210.8
2	136.8	1	75.5	212.5
2	169.4	1	88.8	258.2
2	254.1	1	131.2	383.3
2	338.8	1	173.7	512.5

Courtesy : ABB
* Multiplied by 2 for plant with 4 Nos. GT units.

Table 1.16
Some Recent Names for Gas Power Plant, Combined Cycle Power Plants

Symbol	*Full Form*	*Description*
CHP	Combined Heat and Power Plant	Delievers — Heat — Power

contd.

Symbol	Full Form	Description
GTCC	Gas Turbine Combined Cycle Power Plant	Gas Turbine Generators and Steam Turbine Generators
IGCC	Integrated Gasification Combined Cycle Plant	Coal is gasified in Coal-gasifier plant. *Gas* from coal gasifier is used for driving gas turbine. Exhaust of Gas Turbine is given to HRSG Steam produced in HRSG drives steam turbine.
IGHAT	Integrated Gas Humid Air Turbine Plant	Reduced Pollution Exhaust of Gas Turbine is saturated in water through several stages.

1.19. Co-generation Plants for Heat and Electrical Power (used in cold countries)

Cogeneration Plants supply electrical power and steam heat to the consumers as secondary energy supply. The primary resource of energy are solid or liquid or gaseous fuels

The energy is converted from primary form to intermediate form in *Fluidised Bed Combustors Boilers (FBCB) for solid fuels in a gas Turbine plant for liquid or gaseous petroleum fuels). Exhaust of gas Turbine is given to the Heat Recovery Steam generator.*

Electrical output of gas turbine generator is fed into electrical network as a secondary source of energy.

Steam output from HRSG is supplied to users as a secondary source of energy. Steam is used by chemical plants, process plants district heating in cold countries etc. as a secondary source of energy. The energy conversion processes of a cogeneration plant are as follows :

— Primary energy source (solid/liquid/gas) supplied to the combustion chamber or Furnace. Air required for combustion is also supplied.

— Combustion for converting energy from chemical form to thermal form in form of hot, high pressure gases.

— Gas-turbine converts this energy and drives electrical generator exhaust is given to HRSG.

Table 1.17. Cogeneration Plant

Electrical Generator	*Heat Recovery Steam generator*
— Supplies electrical energy as plant output (1) to electrical network.	— Supplies steam as plant output (2) through steam pipes.

Cogeneration Plant has following plant outputs (1) Electrical energy (2) Steam (Heat) Energy.

Cogeneration Plants have become popular in colder and industrialised countries after 1985. In cold countries, energy is supplied in secondary form (for consumption by users) in form of :

— Electrical power, and

— Heated water or steam (for industrial plants and district heating).

Such plants are not used so far in India. However, such plants are likely to be installed in chemical plants or process plants as captive power plants requiring electrical power, steam and energy recovery from exhaust waste.

1.20. Total Energy Plant

The title (not very common as yet) implies *on-site energy conversion* from gaseous/liquid/gasified solid fuels or their combination by heat cycles such that almost total energy in the fuel is converted into secondary form (electrical steam). The overall efficiency of total energy plant could reach 80% (as against 20% of simple open cycle gas turbine plant.

1.21. Nuclear Fission Steam-Electric Power Plants

A nuclear power plant uses nuclear fuels (uranium U_{235}) as the primary energy source, and delivers electrical energy as secondary energy output. The *nuclear reactor* converts the nuclear energy into thermal energy, and delivers hot high pressure steam (directly or *via* heat-exchanger). The steam delivered by the nuclear reactor is an input to the steam-turbine. Steam-turbines convert the steam-thermal energy into electrical energy and feeds into electrical network. Nuclear Power Plants generate electrical power. The energy conversion in a nuclear plant is in following steps.

— Nuclear fuels (U_{235}, U_{235}) are primary energy resources

— Nuclear fission and chain reaction in nuclear reactor.

— Nuclear energy converted into thermal energy in form of at steam.

— Steam drives turbine to give mechanical rotary energy at turbine-generator shaft.

— 3 Ph. AC generator coupled to the steam turbine shaft delivers electrical energy.

— Electrical energy is fed into three phase AC network.

— Nuclear power plants are base-load power plants.

1.21.1. Nuclear Fission and Chain Reaction. The process of *Splitting of heavy Nucleus* (U_{235}) into approximately two equal parts is called *Nuclear Fission.* Each nuclear fission is accompanied by release of relatively large amount of atomic energy in the form of heat. Each fission releases one or more Neutrons. Energy in mass 'm' is converted into thermal energy given by Einstein's famous equation $E = mC^2$.

Chain-reaction. A self sustaining continuous process of nuclear fission reactions is called *Chain reaction.* In the chain reaction a fissionable nucleus absorbs a neutron and fissions, releasing additional neutrons. These in turn are absorbed by other fissionable neutrons releasing still more neutrons and heat. *A fission chain reaction is self-sustained when the process of nucleous splitting is continuous. A large amount of thermal energy is released from the nuclear energy in the fuel of very small quantity of fissile materials.*

1.21.2. Nuclear Fuels as Primary Energy Source. (Fissile material) Very few selected materials can give sustained, continuous, controlled fission chain reaction. An element which can be converted into a fissionable element is called *fissible material* primary resources of fissile materials is *uranium* available in some locations on the earth in concentrations of less than 0.3% by weight.

Natural Uranium consists of the following :

U_{238}......29.3% called uranium 238

U_{235}......0.7% called uranium 235

U_{234} traces....called uranium 234

Of the above three elements, only U_{235} is known to give fission chain reaction.

Fertile materials.

Th_{232} called Thorium 232 is also available in nature and can be converted into fissile material by placing along with U-235 Thorium 232, Uranium 238 are called *fertile materials.* Fertile materials themselves are not fissionable. However they can be converted into fissionable materials by irradiation in a nuclear reactor through the following conversion :

Fertile materials	U-238	Th-232
↓	↓	↓
Fissonable materials	U-239	U-233

Uranium Ore is available in west Bengal (India) in some limited quantities. India is not rich in Uranium natural resources.

1.21.3. Nuclear Reactor (Atomic Reactor). Nuclear reactor is a plant in which the nuclear fission chain reaction can be initiated, sustained, maintained controlled, to give energy conversion from nuclear (atomic) to thermal form. The essential features of a nuclear reactor are :

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*Einstein's Equation co-relates mass (m) with Energy (E). $E = MC^2$, C = Velocity of light.

— Reactor core, reflector, shielding
— Fissionable fuel
— Moderator
— Coolant
— Control mechanism.

1.21.4. Nuclear Power Plant (Atomic Power Plant). A nuclear power plant is an assemblage of a nuclear reactor, prime mover (steam turbine) electrical generator, associated electrical, mechanical, chemical, civil subsystems etc. *which together give energy conversion from nuclear form to electrical form.* There are several types of nuclear fission reactors with their identification (name) based on any one or more features such as :

— Type of moderator *e.g.* Heavy Water Reactor, Sodium Graphite Reactor
— Type of cooling system : *e.g.* pressurised water reactor
— Type of heat extraction : *e.g.* Boiling water reactor or sodium graphite reactor.
— Type of nuclear fission process *e.g.* fast breader reactor, thorium cycle reactor.
— Pantented Name : *e.g.* CANDU,

There are several names of nuclear reactors. Following five are most common :

Table 1.18. Types of Nuclear Reactors most widely used

Type of Reactor	*Description*
(1) Boiling water Reactor (BWR) Fig. 1.11.	— Water used as *moderate* and *coolant* — Water is pumped into reactor and absorbs heat is reactor to give steam. Steam turbine drives a.c. generator and gives out electrical power.
(2) Pressurised Water Reactor (PWR) Fig. 1.12.	— Water used as moderator — Similar to BWR with difference that water in reactor in at high pressure steam is produced in adjusaent enclosure — Water used as moderator.
Type of Reactor	*Description*
(3) High Temperature Gas Cooled Reactors (GCR)	— Helium circulated through reactor as coolant and delivers heat to water through heat exchanger. — Heat exchanger produces steam — Helium can be operated at high temperature.
(4) Pressurised Heavy Water Reactor (PHWR)	— Heavy water is used as moderator and coolant instead of ordinary water.
(5) Fast Breeder Reactor	— Reactor core has no moderator — Enriched fluid — Liquid metal cooled — Two liquid-metal coolant circuits. U235 surrounded by U238 — U238 acts as a fertile material. — U238 absorbs excess neutrons and converts to plutonium. — U238 acts as control rods as well.

1.21.5. Nuclear Power Plant in India. Seven pressurised Heavy Water Reactors have been installed in India (1990). In future Thorium cycle reactors are likely to be introduced. India has ambitious nuclear Power programm through Nuclear Power Corporation. Present installed Nuclear Plant Capacity is about 8000 MW. The unit size of earlier turbine-generator units is 210 MW 235 MW and 500 MW more than 500 MW are being installed. Present reactors in India are pressurised Heavy Water Reactor (PHWR).

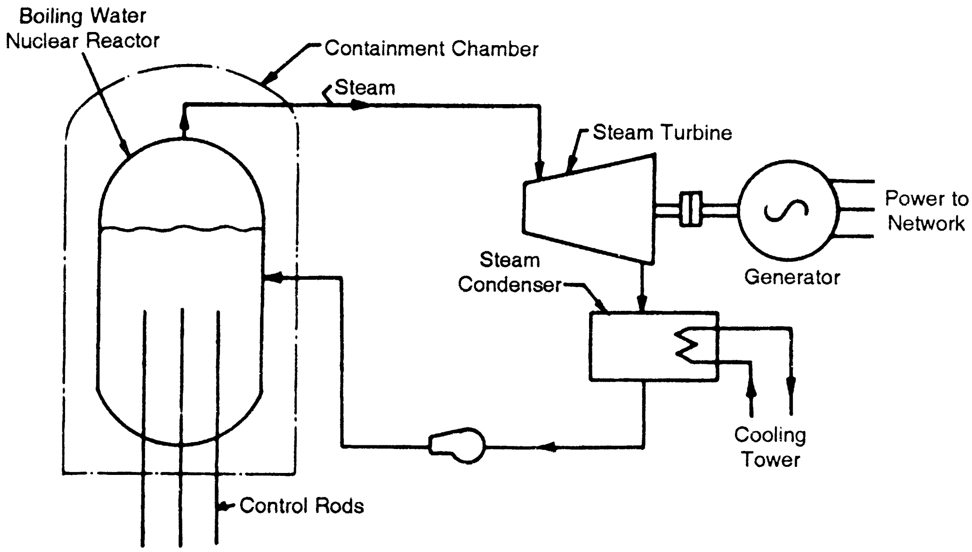


Fig. 1.11 Boiling Water Reactor (BWR) Nuclear Power Plant.

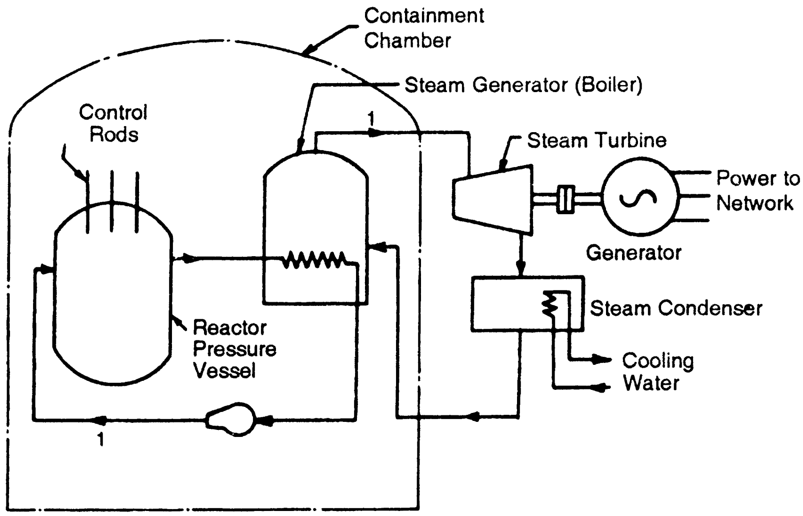


Fig. 1.12. Pressurised Water Reactor (PWR) Nuclear Power Plant.

Projected growth. Nuclear power generation program in India. Present 7000 MW installed capacity will be supplemented by six 500 MW units during 1990-2000, the total nuclear power plant installed capacity is expected to the 10,000 MW by the year 2000.

1.21.6. Historical Review of Nuclear Energy and Nuclear Power Plants

1905 Einstien published famous mass energy equation $E = mC^2$

1938 Nuclear fission discovered in Germany by Otto Hahn and Fritz Strassmann.

1939 Einstein predicted possible Atom bomb and informed President Rooswelt, USA.

1939 Paper by Werner Heisenberg possibility of large thermal energy production through nuclear fission.

1940 Design of nuclear power plant

1942 First nuclear reactor went critical, Chicago, USA, 1954 Nuclear Powered Submarine Nauticus Commissioned.

1954 First nuclear power plant was built in USA, USSR 1956-1990 various types of nuclear reactor power plants were built.

1983 Total 511 Nos. nuclear thermal power plants were is operation in non-communist parts of world with 284 pressurised water reactor (BWR)

132 Boiling Water Reactor (PWR)

53 Gas Cooled Reactor (GCR)

39 Pressurised Heavy Water Reactors (PHWR).

1.21.7. Future of Nuclear Power Plants. Due to depleting fossil fuels, (coal, oil, gas) and uneconomical renewable resources of low power density (solar, wind). Large scale power production by fossil or renewable sources will have limited growth and life span.

Nuclear Power Plants have been given higher priority all over the world including India. The growth has continued since 1970 and Nuclear power plants have bright future.

Advance research for small and medium nuclear plants, Thorium cycle nuclear plants, Nuclear fission power plants, etc. is in progress in advanced countries and in India. India has indigenous nuclear power plant capability.

1.22. Diesel Engine Power Plants (IC Engine Power Plants)

Internal combustion (IC) Engines are used for small and medium power plants. Primary energy resource is diesel (or petrol, petroleum oil). For central stations (Large Power Plants) diesel engines plants are uneconomical and oil diesel electric central plants have become obsolete (The Gas-turbine power plants are becoming popular).

Diesel Engine driven 3 phase AC generators are very widely used today for emergency power supply, standby power supply, uninterrupted power source, small and medium power plants of a few MW capacity. Remote Power Plants away from power network, captive power plant for process industry requiring continuous uninterrupted supply.

In unconventional/renewable energy resources *hybrid power plants* diesel generators are used along with 1. Wind Turbine Generators. 2. Solar-PV Cell Generators etc. to ensure continuous power supply inspite of irregular sunlight or wind.

Primes movers in IC engine power plants are *reciprocating internal combustion engines.* In an I.C. Engine the fuel is burnt in the cylinder resulting in *high pressure* and temperature gas. This energy drives the piston-crank shaft and the engine output shaft gets rotary kinetic energy. *The chemical energy in fuel is converted into rotary mechanical energy in shaft.* The shaft is coupled to a 3 phase AC generator.

The AC generator converts rotary shaft energy into electrical energy. This energy is delivered to electrical load *via* the electrical busbars. Electrical busbars are connected to the 3 phase AC load or 3 phase AC transmission network *via* suitable sub station/conversion package (in case of hybrid substation).

Types of *prime movers* for an IC engine plant are classified as :

— Two stroke engine

— Four stroke engine.

Types of *primary energy resource* used for an IC engine plant are fuels for IC engines include.

(Fuel For IC Engine Power Plants)

— Diesel

— Other oils

— Combination of gas and oil. The petroleum fuels include :

— Crude oil

— Distilate fuel oil

— Petrol

— Gas

— Residual fuel oil

— Gasoline (petrol)

— Petroleum

— Natural Gas

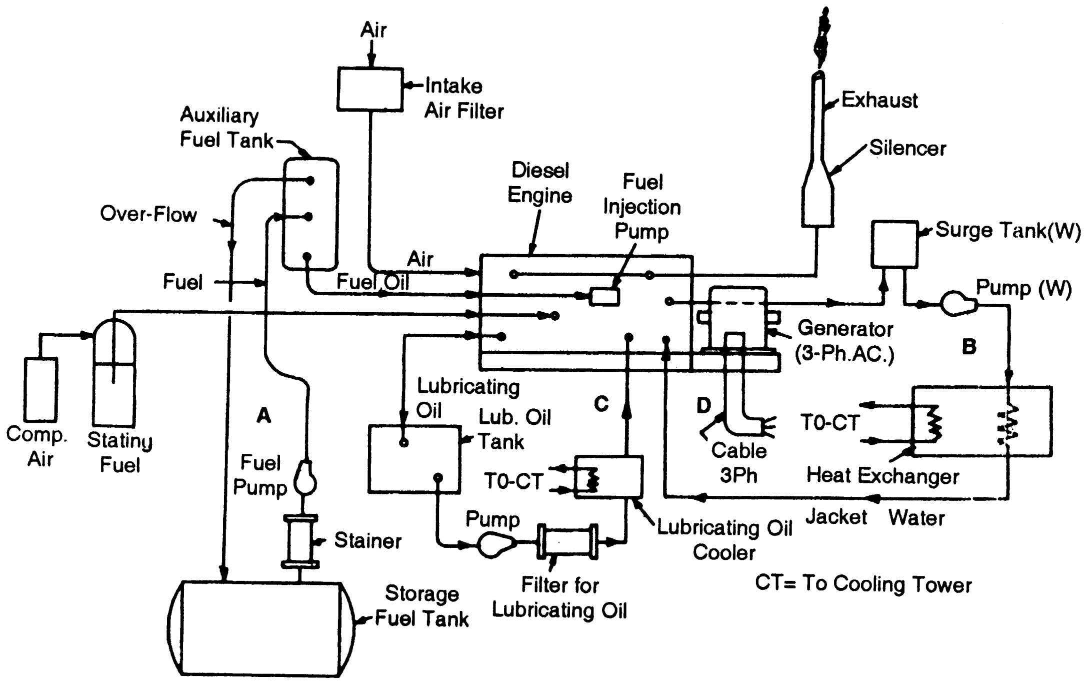


Fig. 1.13. Scheme of Diesel Engine Generator Subsystems.

A Fuel oil system
B Cooling water system
C Lubricating oil system
D Electrical Power Cable (3 core)

— Supply of drinking water
— Flood control
— Irrigation for agriculture
— Agriculture (Fisher)
— Electrical Power generation
— Environment and Ecology.

Engines working on biogas and synthetic gases are likely to be used for alternative power plants.

1.22.1. Functional Requirements of IC Engines. These include the following :

— Fuel supply system
— Air supply system
— Fuel Ignition system
— Cooling system
— Exhaust system
— Lubricating oil system

There are alternative types of each to be covered in a separate section later.

1.22.2. Functional subsystems of an IC Engine Power Plant. These include (*i*) IC engine. (*ii*) Generator driven by (1). (*iii*) Electrical Auxiliaries for (*i*) and (*ii*), (*iv*) Mechanical Auxiliaries for (*i*) and (*ii*). (*v*) Main electric circuit from generator to final load (switchgear). (*vi*) Electrical controls and protection for (*ii*) and (*iii*), (*vii*) Mechanical controls for starting, stoping, braking speed control etc. for IC engines shown in Fig. 1.13 .... a schematic of some of the above subsystems and components.

1.23. Hydro Electric Power Plants

Potential energy in water stored at high level is converted into kinetic energy of water. Hydro-power refers to the primary energy in water. The hydro-electric power plants convert hydro energy in following water into electrical energy.

1.23.1. Types of Hydro-Electric Plants and Energy Conversion Schemes. Hydro-electric power plants are built for wide range of heads, flow rates, sizes, types and capacities of turbines and load services (Peak Load, Intermediate Load, Base Load, Pumped Storage, Standby, etc.).

The hydro-turbines are usually designed for *specific applications and outputs, and service* depending upon how much water is available every year. A good understanding of energy requirements and characteristics of water resources is essential for proper selection of hydro-turbine scheme.

The most common method of classifying the types of Hydro Electric Power Plants is on the basis of *available head of water* between the reservior level and the turbine tail race level. The selection of turbine is based on the head, the flow rate and output rating. The three categories of hydroelectric power plants are.

— High head (more than 150 m)
— Medium head (150 m to 200 m)
— Low head (2 m to 20 m)

Each category requires a different design. Each Hydro Electric Power Plant is tailor-made design.

Energy reserve in the reservoir is proportional to the head (H) of water and quantity (Q) of water in the reservoir. Recently, the small, mini, micro hydro power plants have been given priority by Energy Planners.

The classification is as follows :

— Small Hydro (Less than and upto 15 MW)
— Mini Hydro (upto 1 MW)
— Micro Hydro (upto 100 kW)

The importance of Small, mini, micro hydro projects have been recognised after 1970s and these projects are now covered by *Non-conventional Energy Resource Schemes.*

Hydro-electric stations are of several types depending on the type of hydro-project, available head of water available pondage of water topology of site and whether base load station or peaking load station or medium load station, or pumped storage station.

The types of hydro-electric power plants depending upon the head of the water (level on intake side in meters) the available head dictates the type of turbine (Pelton/Fransic/Kaplan/Bulb) as follows.

Table 1.19. Classification of Hydro Plants

Classification	*Head meters*		*Type of turbine*
High Head	200	1000	Impulse Turbine (Pelton)
Medium Head	20	600	Reaction Turbine (Franus or Derias)
Low Head	4	50	Bulb Turbine
	4	10	Propeller Turbine

A typical hydro-electric power station has the following :

— Catchment area for accumulation
— Reservoir of the accumulated water
— Dam : To create reservoir in catchment area with high-head on reservoir side.

Barrage. To create low head reservoir in the path of a river ;

— Pipeline (penstocks tunnels, surge tanks etc.) for flow of water from the reservoir upto the turbine generator house.
— Power station on the down stream side of the dam/reservoir power station houses the following:
— Hydro turbine driven by flowing water.
— 3 Phase AC generator called hydro-generator coupled directly to the hydro-turbine (with vertical shaft)
— Exciter for generator and control system, protection system for electrical power.
— Electrical auxiliaries.
— Governor for turbine and turbine control
— Mechanical auxiliaries.
— Discharge arrangement and tail race.

1.23.2. Energy Conversion Process in Hydro-Power Plants

Water stored at higher level (head) has potential energy proportional to the head of water when water from higher head flows to lower level, the *Potential energy* is converted into *Kinetic energy* in flowing water into kinetic, mechanical rotory energy of turbine shaft.

Hydro-turbine shaft is directly coupled to the generator shaft. Vertical shafts are favoured though horizontal and inclined shaft designs are also used (with kaplan). *3 Phase, 50 Hz, AC synchronous generator shaft coupled to the turbine shaft* is rotated at relatively low speed (compared with the high speed steam turbine shaft). Number of poles on rotor is large (Ref. Table 1 .... The 3 phase, 50 Hz, AC generator feeds power to the transmission network *via a step-up power transformer and an outdoor substation.*

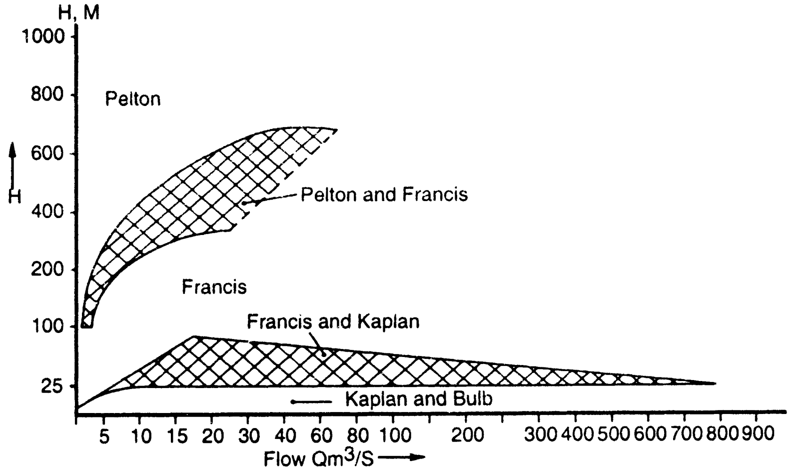


Fig. 1.14. Choice of Hydro-Turbine for different heads (H) and flow rates (Q).

1.23.3. Types of Hydro Turbines. Three types of turbines are used for converting hydro energy in flowing water to rotary energy in generator turbine shaft. The types identified on the basis of arrangement of blades on the hub (conical portion near the tip) are :

1. Impulse turbine (called Pelton wheel) used for high heads 200-1000 m.
2. Reaction turbine (called Francis turbine) used for medium head 20 to 600 m.
3. Propeller turbine (called Kaplan turbine) used for low heads 4 to 50 m.
4. Bulb-Turbine (modified Kaplan) is used for very low heads between 3 m to 10 m the shape of the generator unit is like a bulb the bulb-turbine is mounted in the path.

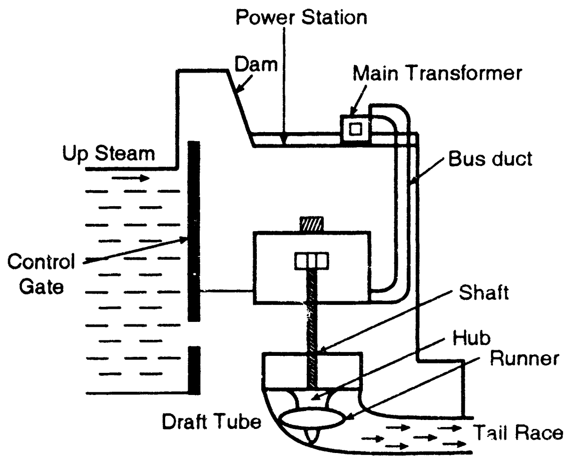


Fig. 1.15. Schematic Cross-section of a hydro-electric power plant with medium head.

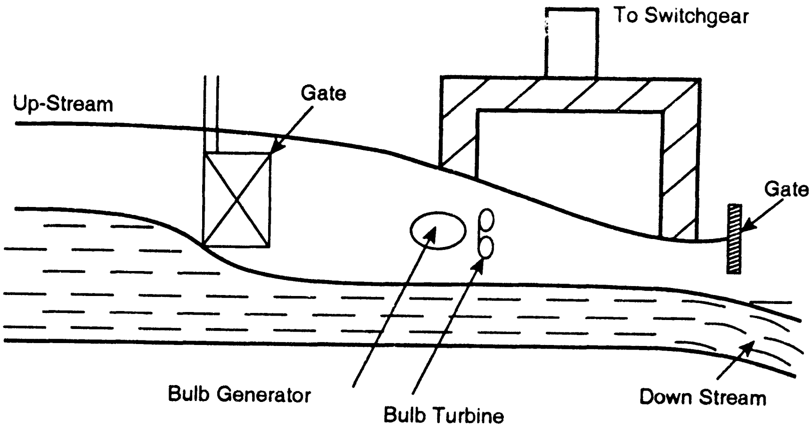


Fig. 1.16. Schematic diagram of a low-head hydro-electric power plant with run-off the river barrage and bulb-turbine.

Table 1.20. Data of Hydro-Turbines for High, Medium, Low Heads

Turbine type	*Impulse Pelton*	*Reaction Francis*	*Propeller*
Application	High Head	Medium Head	Low
Head in storage	200 to 1000	150 to 600	4 to 50 3 to 10 (for Bulb Turbine)
	Large reservoir Large catchment at high level	Medium pondage or storage at medium level	Pondage or run at fiver.
Actual Speed range, rpm	200 to 1000	150 to 600	50 to 250
Specific Speed (kW-m-unit)	300 to 900	60 to 400	40 to 80
Ratio of *Runway Speed*	1.8	1.8 to 2	2 to 2
Normal speed Ratio of runner peripheral speed.	2 to 3	0.7 to 0.9	2 to 3

1.23.4. Application of Hydro-Electric Power Plants. Hydro-electric power plants use renewable energy resource of water derived from Natural rain rivers etc. Energy resource is cheap but cost of civil works is high.

Hydro-electric Power Plants are used as Base load central plants when storage is very large and throughout year.

Medium Load Plants. When storage is available during rainy season.

The generator is in a closed bulb submerged in flowing water. The turbine-generator is mounted within the tunnel used for low heads of 5 to 10 m.

Peaking Power Plants. When storage available is limited and can be conserved for peaking load over the year.

1.23.5. Typical Hydro-Electric Power Plants. Hydro Electric Schemes have a reservoir or a pool on one side of the dam and turbine generator units on the other side at lower level. The Head of water results in the flow. Energy is proportional to total weight of upper level water than can flow through turbine multiplied by the Head of fall.

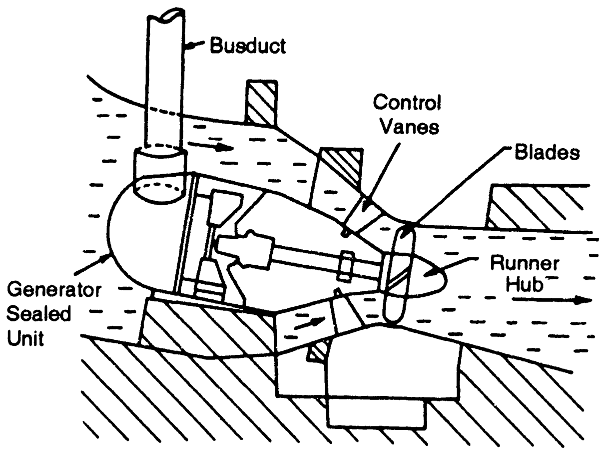


Fig. 1.17. Cross-section of a Bulb-Turbine generator.

The head of water and flow rate have decisive influence on the choice of the turbine. The types of Hydro Plants are :

1. High Head 2. Medium Head 3. Low Head. 4. Underground high head.

High Head Scheme has a large reservoir on higher level and water from high level reservoir flows through pressure pipe to the turbine and is finally discharged into the tail race. The upper reservoir is usually formed by constructing a dam on a river vally at high level. The excess water from the reservoir is discharged through the gates in the dam. The tail race water usually meets the river along the down-stream.

Medium Head Scheme has usually a dam on a river forming the reservoir on the river side and a hydro-electric power plant on the lower level. The tail race water is discharged into the river.

Low Head Scheme is usually with a barrage on a flowing river and turbine-generator units mounted within the nozzle shaped tubular passage through the barrage.

Low Head Schemes are generally Run-of-River schemes with a low high barrage or weir across a river or a canal. The bulb type or tube turbine-generator is installed axially within the passage of water through the draft tube.

The low head schemes are generally small hydro schemes rated upto 15 MW.

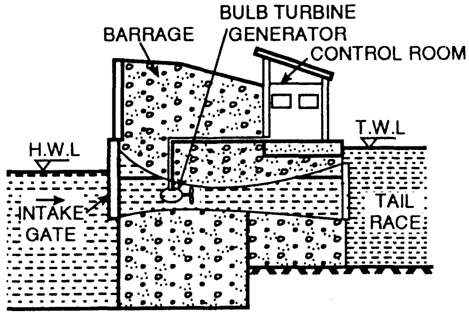


Fig. 1.18. Low-head Run-of-River Scheme (Small Hydro)

Underground Hydro Electric Power Plants are built at lower level and inside a cave. The tail race water is discharged through a tunnel into the downstream path of the river.

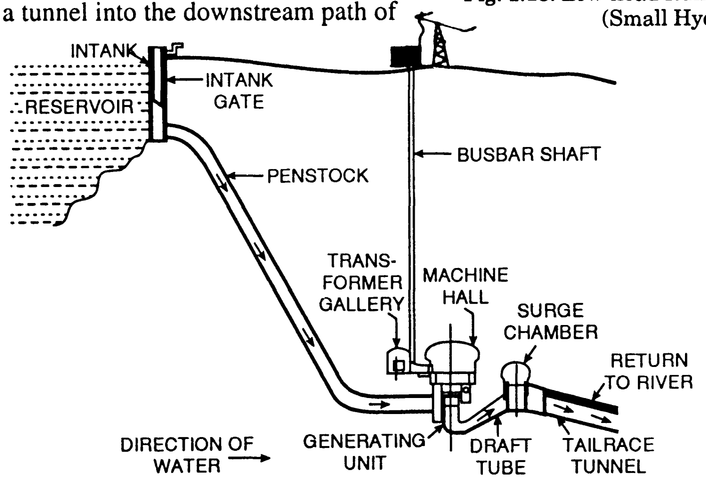


Fig. 1.19. Underground Hydro-Electric Power Plant.

1.23.4. Pumped Storage Hydro-electric Energy Storage Power Plant. The pumped-storage Hydro-electric Turbine generator are reversible type *i.e.* can be operated in two modes :

Table 1.21. Operating Modes of Pumped Hydro

1. Generating mode during peak loads	Water drives Turbine	Generator feeds element power into grid (network)
2. Motoring mode (During off peak periods of the day)	Electrical power taken from the Network electrical machine driven as motor.	Hydro machine acts like a pump. — Water is pumped into reservoir — Reservoir acts as energy storage.

Pumped hydro unit may have

— One electrical machine (generator) during generating mode and motor during motoring mode

— One reversible hydro-machine as turbine or pump alternatively two separate hydro machines (turbine and pump) mounted on the same shape.

During off peak periods, the electrical power from the grid is used for pumping the water to upper reservoir. Energy is stored in the form of water at higher level. During peak loads on electrical network the stored hydro energy is converted into electrical energy. Pumped storage hydro electrical plants are used as energy storage plants. Electrical energy is stored in form of hydro energy.

1.24. Trends in Power Plant Technology (2000-2500 AD)

Fig. 1.20 shows the cost comparison (1990 base) of various types of conventional power plants,for peaking loads, intermediate loads and base loads. With further steep-rise in petroleum prices, the comparison would be need revision on yearly basis. However the trends indicate that :

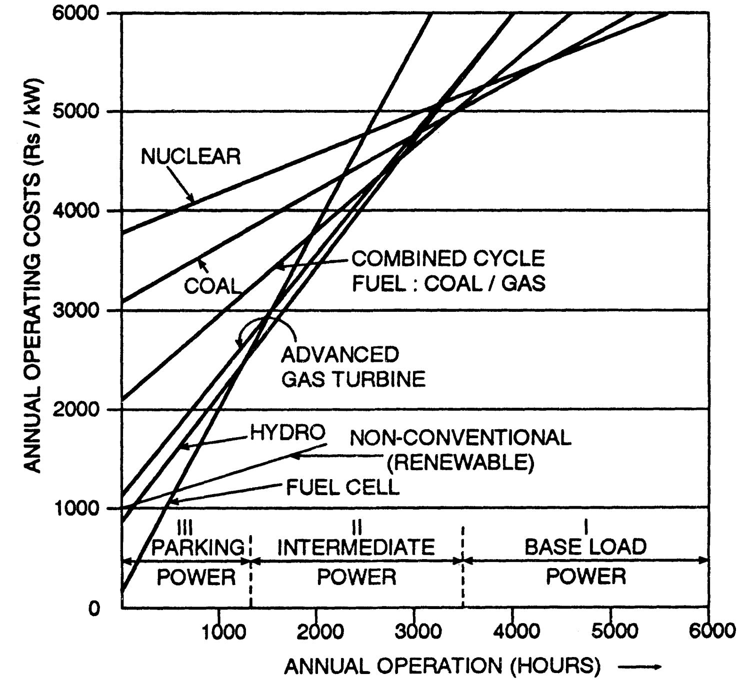


Fig. 1.20. Cost comparison between various types of power plants.

— Nuclear power plants would serve for most economical high capacity base load power stations.

— Coal fired power plants would be equally favoured for large base load plants.

— For intermediate load power plants (below peak load and above base load). Hydro and combined cycle power plants would be a preferred choice.

— For smaller energy-displacement and peaking load power plants, fuel cell plants, hydro plants and renewable energy plants would be ideal choice.

— Renewable, Hydro and nuclear fusion are the resources for 2000 AD.

Table 1.22. Alternative and Renewable Energy Power Plants

	Type	*Remarks*
1.	Solar-Thermal Steam Power Plant	— Boiler installed on tall central tower gets reflected solar irradiation from sun-tracking mirrors on ground level.
	or	— Steam from boilers drives steam turbine-generators.
	Solar Photo-Voltaic Cell Panel Power Plant	— Solar PV cell panels connected in series/parallel. — Direct conversion into electric energy.
2.	Wind-Turbine-Generator Power Plant	— Large wind-turbine with three blades, horizontal axis, installed on nacelle on a tall tower. The wind turbine-gears-rotate generate shaft.

	Type	Remarks
		— Several wind-turbine-generator units (50 kW to 3 MW) installed in one wind-farm.
3.	Geo-thermal-steam Thermal Power Plant or Binary Cycle Power Plant	— Heat inside earth extracted in form of dry steam/wet steam/hot brine through hot deep well (1.5 to 3 km deep) — Heat used for steam turbine or NH_3 turbine/Hydrocarbon Turbine — Turbine drives generator. — Large base load power plants rated 200 MW to 1000 MW.
4.	Ocean Thermal Energy Conversion Power Plant (OTEC)	— Heat in upper layer of water used for driving steam turbine/gas turbine on shore or in floating power plant. — Cold water from bottom of ocean used for condenser.
5.	Ocean wave Energy Power Plant	— Power Plants are located in locations with high waves (2 to 4 m) — Waves drive hydro-turbines in cyclic manner during onward wave or during forward/reverse waves. — Bulb Turbine-generators installed within penstocks located inside long barrages across the ocean-shore.
6.	Ocean Tidal Energy Power Plant	— During high tide, water is accumulated in upper reservoir. During the low tides, the water from upper reservoir flows to lower level and drives the hydro-turbine generators.
7.	Waste incineration Power Plants	— Located in large sites. — Combustible waste from the city (paper, rags, wood chips, wood dust, residence-waste etc.) is used as fuel. — The combustion of fuel gives heat. Steam turbines drive generators Rating 1 to 10 MW. — Flue gases cleaned before letting into atmosphere.
8.	Bio-fuels Power Plants	— Wood, Rice husk, wheat husk, bio-gas, special farms with fuel-crops raised in three months, etc. are burnt and heat used of steam-turbine generators. — Biogas used as fuel for cooking
9.	Fuel Cells Power Plants	— Chemical Liquids, Gases used as fuels and oxidants. Ratings a few kW to a few MW.
10.	Nuclear Fusion Power Plants	— Likely to be introduced by 2010. Presently research and development work is in progress. — Combining (fusion) of some lighter nuclei gives heat. — Likely to serve as major energy resource in future. — Fuel sources practically unlimited
11.	Magneto Hydro Dynamics (MHD) Power Plants	— Hot gases are seeded to form ionized gases. These are passed through strong magnetic field-electrodes held in perpendicular plane collect the current. — Direct conversion from heat to electricity 14 MW plant built in India as prototype. — 100 MW, 200 MW plants built in USSR.
12.	Mini, Micro Hydro	— Small Hydro-electric power plants for villages and farms.

1.25. Definitions and Energy, Work and Power

1. **Energy . The capacity to perform work.** There are several forms of energy including kinetic energy, potential energy, thermal energy, nuclear energy, electro-magnetic energy.
2. **Energy Conversion. Change of energy from one form to other.** *e.g.* Thermal to mechanical, mechanical to electrical, chemical to electrical etc.
3. **Energy Resources.** *Original form of energy available in nature in usable quantities. e.g.* coal ; uranium, solar irradiation, wind, geothermal heat.
4. **Fuel.** Any substance which can be burnt to produce heat. Fuel is a primary energy resource.

5. **Primary Energy Resource.** Energy as available in nature.
   Secondary Energy Resource. Energy as used by man for final consumption *e.g.* electricity.
6. **Coal.** A type of fossil fuel principal types of coal are : Antracite, Bituminous, Sub-bituminous, Lignite.
7. **Pulverised Coal.** Fine powder of coal.
8. **Coal Gasification.** Process of solid coal to gaseous fuels such as Cf, Hygass, CO_2-Acceptor, Bi-gas, Mithanation, Lurgi.
9. **Coal Gas.** Artificial gaseous fuels produced from solid coal by heating coal in absence of oxygen.
10. **Coal Liquefaction.** Conversion of solid coal to liquid hydrocarbon and associated compounds by hydrogenation.
11. **Coal Slurry Pipeline.** Pipe line for transporting pulverised coal suspended in water.
12. **Coke.** Porous solid residue formed by incomplete burning of coal heated in closed chamber.
13. **Combined Cycle Plant.** A plant which uses two thermodynamic cycles for achieving better efficiency, *e.g.*
    — Gas turbine generator → Heat Recovery steam generator → Steam Turbine generator.
14. **Natural Gas.** Gaseous fossil fuel obtained in nature usually along with petroleum oils.
15. **Natural Gas Liquids.** Liquids fuels extracted from natural gas.
16. **Nitrogen Oxides** (NO_x). By product of combustion of natural fossil fuels.
17. **Nuclear Power Plant.** Plant which converts nuclear energy into useful power such as heat, electricity.
18. **Nuclear Reactor.** Plant which can initiate, substation, maintain, control, use the nuclear fission chain reaction.
19. **OPEC.** Organisation of petroleum exporting countries.
20. **Petroleum.** Oily, flammable, bitminous liquid, a complex mixture of hydrocarbons.
21. **Plutonium (Pu).** Heavy radioactive man-made element. Atomic number 94 fissionable Plutonium Pu 239 Plutonium is produced by neutron irradiation of U-238.
22. **Pollution.** Addition of unwanted material in ecosystem.
23. **SO_2.** Sulphur dioxide, SO_x Sulfur oxides. Byproducts of buring fossil fuels : Poisonous.
24. **Steam Electric Plant.** Plant which has steam turbine driven electrical generator.
25. **Thermal Efficiency** of a plant ratio of heat converted into useful energy to heat input.
26. **Thermodynamics.** Science of energy conversion from heat to mechanical energy.
27. **Thorium (Th).** A radio active material available in nature. Atomic number 90, Atomic weight app. 232 Fertile Th 232 isotopes are available in large quantities in nature, can be transferred to fissionable U-233 by neutron irradiation.
28. **EHV.** Extra High Voltage.
29. **UHV.** Ultra High Voltage.
30. **HVDC.** High Voltage Direct Current.
31. **Work.** Work is done when energy is transformed from one form to other.
    Unit = Joule = Symbol (J)
    One Joule = 1 Watt for 1 sec. = Watt. sec.
    Practical Unit = kWhr
    Work is consumption of energy.
32. **Power.** Rate of energy conversion. Rate of performing the work. *Power* is work done in unit time.
    Typical Units. Watts, kW, MW.

33. **Energy and Work.** Practical Units = kWhr, MWhr, 1 kW power used for 1 hr = 1 kWhr, 1 MW power used for 1 hr = 1 MWhr.
34. **Fossil Fuels.** Fuels in nature formed during several centuries by biological plants, animals fishes etc. crushed under earth transformed to fossils with pressure, temperature, chemical actions.
35. **GNP** = Gross National Product.
36. **Per Capita** = Per person in the country.
37. **Installed Capacity.** Total MW capacity of all the power plants installed in the plants or the region.

1.26. Electrical and Thermal Units and Conversion Factors

Power. Unit of Power is watt.

Watts	= Volts × Ampers
1 kW	= 1000 W = 10^3 W
1 MW	= 1000,000 W = 10^6 W
1 horse-power	= 746 W

Energy. Basic Unit Kilo watt hour and symbol kWhr or kWh. A device of 1 kW operated for 1 hr consumes energy of 1 kWhr. kWhr = (kW) × (hr)

Conversion Factors

1 Btu	= 2.93×10^{-4} kWhr
1 Calorie	= 1.2×10^{-6} kWhr
1 British Thermal Unit (Btu)	= 1055 Joules = 0.000293 kWh
1 kWhr	= 3412 Btu
1 Watt-year	= 3.15×10^7 Jouls = 3×10^4 Btu.

1.27. Electrical Energy Supply System (Power System)

Every member of modern civilization depends heavily on the supply of electrical energy at the premises for final utilization of energy in electrical form for various applications. Electrical energy is *indispensable* for domestic, commercial, agricultural, defence, transportation and other vital sectors of economy.

Modern electrical energy supply systems are large interconnected networks formed by interconnection of various regional grids. Each regional grid has several conventional and nonconventional energy conversion stations (power plants, power stations) of various sizes and types.

The energy (MWh) generated by the power plants is supplied to various consumers via the transmission and distribution network of *three phase AC system operating at a common standard frequency (f) of 50 Hz* (in India).

The power drawn by the consumers from the supply system is called the *demand* and is expressed in MW. The load on a particular power plant is also expressed in MW. The MW demanded by the consumer is a load on the supply system. Hence *demand* and *load* are similar terms. The *connected load is the installed load expressed in kW or MW. A residential building may have connected load* of 5 kW. The prevailing load varies from with clock-time according to the needs of the consumers. *The load on the power plants and the regional grid varies continuously.* Modern Electrical Energy Systems have automatic load-frequency control and automatic generation control systems. The total power generation (ΣMW_g) is matched with the total power load (ΣMW_L) to maintain constant supply frequency (*f*). Increase in load should be immediately followed by increase in power generation. The power generation of generating units is increased by increasing the input to turbines. The increase in the energy output requires corresponding increase in energy input.

1.28. Load Curves, Peak Load, Average Load

The demand of electrical power (MW) by various *consumers* acts as a *load* (MW) on the *Power System* and the generating *stations* (Power Plants). Unfortunately, the demand has hourly variation during the day and also seasonal variation. The *connected loads* include residential, commercial, transport, industrial, lighting, agricultural and many others. The individual demand by each of these, have a *characteristic* variation during the day depending upon the daily routine of the their switching-on and switching off. Hence we must recognise two important terms *viz.*, Connected loads and Actual Demand.

Connected Loads. Each power plant (generating station) has certain connected load *e.g.* 4 outgoing transmission line with 200 MW rating each gives total connected load on the power plant as 800 MW. Likewise each group of generating stations in a power system has certain total connecting load given by sum of connected loads on the individual generators.

Connected loads on the power system is the sum of connected loads in its network. It is expressed in MW. It is a fixed quantity during the day of or the month.

Demand (MW) or Actual Load. It is actual power drawn by the connected load in the switched on state. It is expressed in MW. *Actual total demand on a power plant is not the sum of connected loads. Experience has shown that the variation in individual demands of connected load does not occur simultaneously.* The total demand goes on varying from time to time resulting in certain cyclic variation during the day called daily load variation.

Demand Factor. The power plant or power system must satisfy following conditions :

— Supply the energy during maximum demand (peak demand). The *maximum demand* on the power plant is the *peak load* on the power plant.

— Supply total energy requirements during the year (kWhr)

$$\text{Demand Factor} = \frac{\text{Maximum Demand}}{\text{Total Connected Load}}$$

Diversity Factor. There is a diversity in the demand made by the individual connected loads. All of them do not vary simultaneously *e.g.* in a residential load the individual maximum demand of various connected loads (lights, fans, TV, coolers, air-conditioner, washing machine etc.) is different from the actual maximum demand. The actual maximum demand is the maximum meter reading (kWh-maxm.)

$$\text{Diversity Factor of a plant} = \frac{\text{Sum of individual maximum demands}}{\text{Actual maximum demand on the plant}}$$

$$\text{Actual maximum demand of Plant} = \frac{\text{Sum of individual maximum demands}}{\text{Diversity Factor}}$$

Higher Diversity Factor → Reduced Peak Load → Need for lesser installed capacity of Plant

Power supply company encourages higher diversity factor for reducing peak demand. Diversity factor as defined above is always greater than unity.

Variation in Demand, Demand, Curves, Load Curves. The load on a power plant (or a group of power plants) varies during the day and is plotted graphically in the form of load curves. A load curve has chronological time on *X*-axis and actual load (MW) *Y*-axis. Load curves may be :

— Daily Load Curves — Weekly Load Curves — Yearly Load Curves

Load curves is a very valuable tool for generation planning, load scheduling and *daily operational readiness.* A load curve to repeat itself in cyclic form on daily, weekly and yearly basis due to regular pattern of individual, community and natural life styles. (In London peak load occurs during late evening. In Paris, peak load occurs around mid-night). Following load curves are common :

— Daily Load Curves — Weekly Load Curves — Yearly Load Curves

Analysis of a Daily Load Curve :

1. The load curve has peaks and valleys.
2. Line for peak demand or peak load is drawn for point of maximum MW *i.e.* highest peak. This is called peak load or peak demand.
3. Line for *minimum MW i.e.* lowest valley represents minimum demand. This line is called Base Load line.
4. Line for intermediate demand can be drawn at the base of rising peaks. This line represents intermediate demand.

5. Area under a daily load curve has dimensions of (MW × Hours) and therefore represents MWhr supplied during the day *i.e.* $\int_0^{24}$ MW . dhr = MWhr for 24 hrs.
6. Area under the base line of daily curve represents the energy supplied by the base load power plant during the day.
7. Area above the peak load base line represents energy to be supplied by peaking load power plants.

1.29. Load Duration Curves

From chronological daily load curve of (MW × Chronological hrs.) the load duration curves are derived. *A Load Duration Curve* has time duration (hrs.) on *X*-axis and MW load on *Y*-axis. Plotting of load duration curve :

— Draw *X* axis of load curve and *X* axis of load duration curve in same line.

— Draw *Y* axis of load curve and *Y* axis of load duration curve to same scale, with same levels.

— Plot daily load curve.

— Draw horizontal lines parallel to *X*-axis representing various MW loads on load curve and continue them on load duration curve.

— Measure from cumulative hours duration for each MW line from load curve. These are transferred to load duration curve as *cumulative* hours for that MW load.

— Join the points on load duration curve.

— The area under daily load duration curve represents $\int_0^{24}$ MW . dhr ......MWhr

1.30. Energy Conversion Plants for Base Load, Intermediate Load, Peak Load and Energy Displacement

Basic requirements of the generator, turbine, primary energy converter (boiler) differ for Base load/Peak load units. Base Load Stations/Units are :

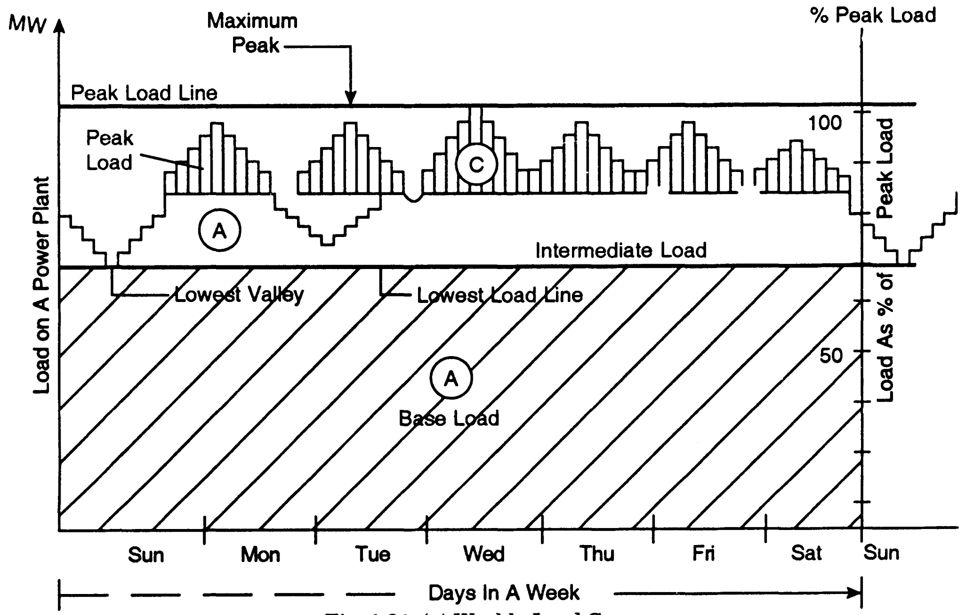
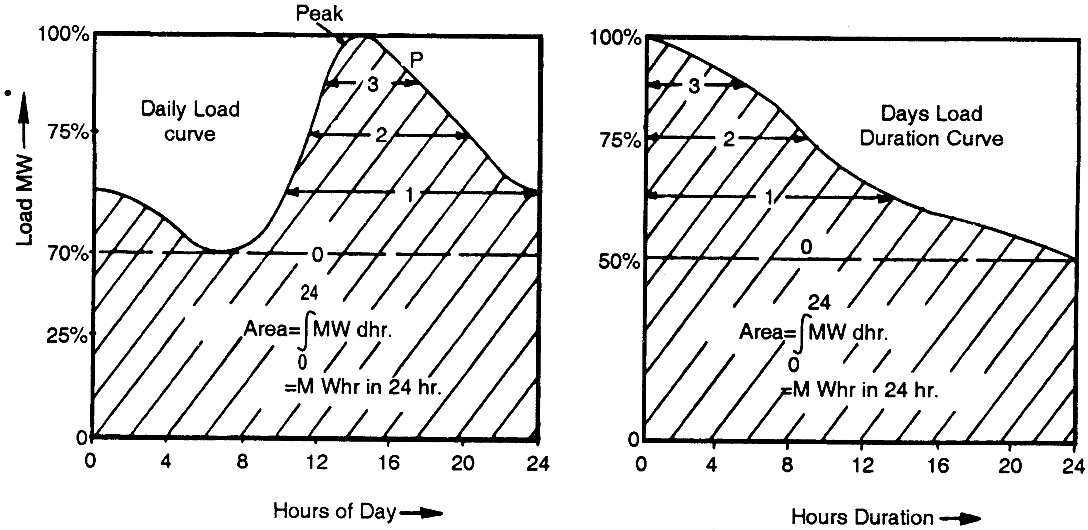


Fig. 1.21. (*a*) Weekly Load Curve.



(*b*) (*c*)

Fig. 1.21. (*b*) Daily Load Curve (*c*) Load Duration Curve.

— Continuous load with high load factor
— No frequent starting, rapid loading, rapid load throw off
— Large reserves of primary energy resource
— High efficiency
— Lowest generation cost (Rs./MWhr)

Intermediate Load Stations/Units are in between the base load and peaking load.

Peak Load Stations/Units are loaded for a few hours in a day. They should be :

— Quick to start, pick-up load, unload, stop
— Relatively lesser MW rating
— Cost of generation Rs./MWhr may be higher but is justified due to lesser MWhr produced by the peaking station/unit.

Table 1.23. Choice of Plant for Base Load, Intermediate and Peak Loads.

Category of Load	*Type of Station*	*Remarks*
Base Load	— Coal Fired Steam Thermal Power Plant — Nuclear Steam Thermal Power Plant — Geothermal Steam Thermal Power Plant — Large Hydro-Electric Power Plant — Combined Cycle Power Plant	— Operated at all times. — Influence overall cost of generation Rs./MWhr.
Intermediate Load	— Combined Cycle Power Plant — Hydro-electrical Power Plant — Less efficient steam thermal units	— Operated at above base load line.
Peaking Load	— Gas Turbine Power Plant — Combined Cycle Power Plant — Hydro-electric Power Plant — Pumped storage Power Plant —Diesel Electric Power Plant	— Operated during peak loads only
Energy Displacement Plants	—Wind power, Solar power, Tidal power	—Whenever Renewable is available
Energy Storage Plants	—Pumped hydro —Compressed Air —Battery	—In storing mode during low loads —In generating mode during peak loads

Energy Conversion Plants suitable for Base Load Supply are called the *Base Load Power Plants.* The Base-Load Energy Conversion Plants operate continuously and should have low operating cost (Rs/MWh). Base Load Energy Plants are Large Grid Connected Power Plants. *Energy Storage Plants* are of several types and applications.

1.31. Plant Operating Factors

Various operating factors for power plants are summarised below :

1. $\text{Load Factor} = \dfrac{\text{MWh Consumed}}{\text{Peak MW} \times \text{Hours}}$

2. $\text{Load Factor} = \dfrac{\text{Average MW, Demand}}{\text{Peak MW Demand}}$

...For same period *e.g.* day

$$= \frac{\text{Energy generated during a day}}{\text{Maximum Demand} \times \text{Hours of the day}} = \frac{\text{MWhr}}{\text{Max. Demand} \times 24}$$

$$\text{Diversity Factor} = \frac{\text{Sum of Individual Maximum Demand}}{\text{Maximum Demand on Installation}}$$

$$\text{Plant Capacity Factor} = \frac{\text{Actual MWh Produced}}{\text{Installed MW Capacity} \times \text{hrs}} = \frac{\text{Average MW load on plant}}{\text{Installed capacity of plant}}$$

...For a given long period

$$\text{Plant use Factor} = \frac{\text{MWh Produced}}{\text{Installed MW capacity} \times \text{Hrs of operation}}$$

Firm Power = Power which should be always available from the plant even during emergency.

Cold Reserves = Generating capacity is reserve but not readity available for loading.

Hot Reserve is the generating capacity ready for sharing the load within a short time at a short notice.

Spinning Reserve. Generating reserve capacity which is in spinning condition and take up the load very quickly against operators instructions.

1.32. Plant Loading from Load Duration Curve

When total demand is to be shared by several power plants, some plants are used as Base Load plants, some as intermediate load stations and some as peaking load stations. The horizontal MW lines on load duration curve are drawn to demarkate the Base Load, Intermediate load and peak load lines and corresponding planned loading of base load plants, intermediate load plants and peak load plants.

1.33. Plant Scheduling

From plant daily load curves the loading of the units of a plant can be determined as follows.

The data of operating costs of the various units in the plant is collected. The units with lowest operating cost (*e.g.* 1 and 2) are used as Base Load Plants (See Fig. 1. 22). The units of more operating cost (2 and 3) are used as intermediate load plants. Units which can be quickly started, loaded, stopped (*e.g.* Gas Turbine Generator) are used for peaking. (Unit 5).

1.34. Suitable Types of Energy Conversion Plants for various Primary Energy Sources

Each energy conversion plant has certain operating characteristics, with reference to starting, stopping, economy of generation, suitable rating etc. The operating characteristics of the conventional power plants and renewable energy power plants differ significantly. Many of the renewables sources are not available during all the 24 hours of a day and the freely available recurring renewable energy cannot be stored in large quantities. Renewable energy plants are presently of much smaller sizes (kW to a few MW) to make an impact on the large energy supply systems (several thousand MW). The choice of plant for base load and peak load is based on :

1. *Starting, stopping and running time :* Slow starting for Base Load Plant, fast for Peaking Plant.
2. *Economy of generation :* Low cost of generation for Base Load Plant. May be higher for Peaking Plant.

3. *Size of plant* : Large for Base Load Plant, Small for Peaking Plant.

Types of energy conversion plants suitable for Base Load, Peak Load and Intermediate Loads differ. Hence primary energy consumption requirements for these three categories are different.

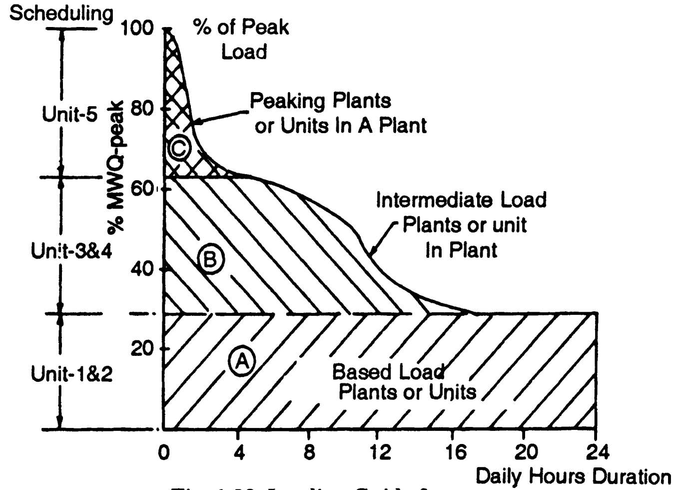


Fig. 1.22. Loading Guide for

(*A*) Base load plants (*B*) Intermediate Load Plants (*C*) Peak Load Plants.

Table 1.24. Types of Energy Conversion Plants in Electrical Energy Systems

Conventional Electrical Energy Supply Systems	*Non-conventional Electrical Energy Supply Systems*
1. Fossil Fuel Power Plants — Coal Fired (thermal) (B) — Gas Turbine (P/B) — Combined Cycle (B) — Diesel-Electric (P/B)	— Integrated Coal Gasification — Combined Cycle (ICGCC) — Fludised Bed Combustion (FBC) — Magneto Hydro Dynamic (MHD)(B)
2. Hydro-Electric Power Plants (B/I) — Large Hydro — Pumped Hydro (ES)	— Mini, Micro Hydro — Underground Pumped Hydro (ES)
3. Nuclear Power Plant (B) — Nuclear Fission Chain Reaction Power Plants	— Nuclear Fusion Power Plants
4. Ocean Energy Power Plants (ED)	— Ocean Thermal — Ocean Tidal — Ocean Wave — Ocean Biomass — Ocean Salinity Gradient Plants
5. Solar Energy Plants (ED)	— Solar Thermal Steam Cycle Plants — Solar Thermal Binary Cycle Plants — Solar Chemical Energy Plants
6. Wind Energy Plants (ED)	— Grid Connected — Isolated with Hybrid Solution
7. Biomass Energy Plants (IL/ED)	— Forest, Urban, Agricultural, Marine
8. Geothermal Power Plants (B)	— Steam Cycle Geothermal Plant — Binary Cycle Geothermal Plant
9. Energy Storage Plants — Pumped Hydro — Lead acid battery	— Thermal, Compressed Air — Superconducting Magnet, Hydrogen Gas, Flywheel Chemical Reactants

(*B*) = Base Load Plants (*P*) = Peaking Load Plants

(*IL*) = Intermediate Load Plants (*ED*) = Energy Displacement Plants

1-B

Alternative and Renewable Energy Power Plants and Energy Storage Plants

PART — A Renewable Energy Power Plants

Definitions

Energy Resource. Energy form as available for further conversion or direct use.

Primary Energy Resource. Energy resource as available in nature *e.g.* wind.

Secondary Energy Form. Energy form as made available for consumption *e.g.* electrical.

Renewable. Which gets renewed, replenished by nature and their future supplies are ensured.

Non-conventional. Non-traditional, which were not considered earlier for power generation or consumption.

Alternative. Alternative to conventional energy resources.

1.35. Importance and Necessity of Renewables

—Presently the conventional, energy resources (Hydro, Nuclear, Coal/Oil/Gas) are supplying bulk of the energy needs in India for generation of electrical power. Conventional primary energy resources are presently available in nature in high density, large acceptable quality and cheap rate so that large central power stations are being built and open.

—*Fossil Fuels* (Petroleum oils, Natural Gas, Coal) have a limited stock in nature and will get *depleted* within a few decades or a few centuries. *Fossil Age* will cover only about 1000 years of human civilization. (Fig. 1.30).

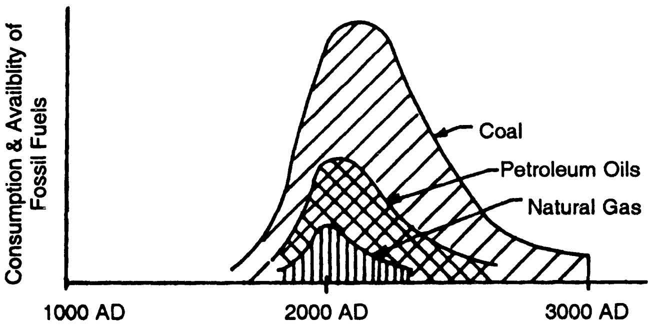


Fig. 1.30. Fossil-Fuel Age for Electrical Power Plants and Transport.
Fossil Fuels : Coal, Petroleum Oils, Natural Gas Reserves will be completely depleted by 3000 AD.

After around 2050 petroleum products will not be available at economical rates, Coal of good quality may not be available after around 2200. *Fossil fuel power will therefore become obsolete.*

— *Coal fired* power plants give emission products like ash, NO_x, CO, SO_x, Heat, coal dust which creates *worst pollution.*

— *Hydro-resources* for generation of electric power will continue as *renewables.* Hydro resources are cheap (inexpensive) and need harnessing for multipurpose (irrigation, flood-control, drinking water, cooling water, agricultural, forestation, fisheries and electrical power generation). However deforestation, earthquake prone areas ; up-rooting of human settlements are the *basic objections* for large hydro electric power plants. *Environmentalists* and Environmental Ministries usually oppose Hydro Projects on these grounds.

— Hydro-electric power plants need large catchment areas for reservoirs.

- Hydro-electric power plants depend on renewable 'rains'. A dry season results in poor water level and reduced power generation.
- Many states do not have hydro potential. Present hydro-reserves (North-East states) are very large 1000,000 MW but for away from load centres and in earthquake prone areas. Capital cost would be very high.
- Hydro-projects require large areas, high capital cost, long period for *civil construction.*
- The maximum possible installed capacity of viable hydro schemes may cover 20 to 30% energy needs only.
- *Stocks of Nuclear fission* fuels (Fissile Uranium) may last for another 1000 years in the world and 100 years in India. Hence for the 21st century Nuclear energy continue as most important primary resource.
- Demand for electrical energy is rising at a rate of 7 to 10% annually in developing countries. With rise in population, industrialisation, increased transportation etc. *The rate of rise of demand* is also increasing.

$$\frac{dD}{dt} < \frac{dS}{dt}$$

$\frac{dD}{dt}$ = Rate of rise of demand for electrical energy; $\frac{dS}{dt}$ = Rate of rise of supply of electrical energy

$D =$ Demand MW

$S =$ Supply (Generation) MW

$\Delta =$ Deficit $= D - S$

With annual increase in demand rising at a rate of 7%, in demand rises as follows. The demand will double in *ten* years.

- Renewable energy resources are *vast* and must be *tapped* for increasing the electrical power generation.
- Before 1973, fossil fuels were available in large quantities at low cost.

After 1973 oil crisis, petroleum products prices increased and have continued to increase this resulted in increased cost of transportation and other energy resources.

- Cost of basic *renewable resource* like solar/wind is low.
- Renewables last for several centuries to come.
- *The renewable resources are becoming attractive for power generation* with following developments during recent past (1970-1990).
- Technologies have developed on commercial basis.
- Geological and geographical curves have been made.
- Priority has been given to renewables. Renewables (Alternatives) are subsidised and funded by Governments and International Monetary Institutions.
- Renewables (Alternative) power plants will act as energy displacement plants during next few decades and as main power plants by the turn of 21st century to 22nd century.
- Renewables may become man-stay during 22nd century.
- Progress of the Nations, Civilizations will depend on growth of electrical generating capacity.
- Developed countries have made a break-through by installing very *large* geothermal power plants; *medium* solar thermal power plants, and wind power plants, small fuel cell, battery power plants etc. *Cost of renewables in developed countries is* reducing rapidly.
- In *India renewable energy* is being tapped at village level and remote agricultural purposes.

Plans for Renewable Energy Power Plants are in Initial Stage of Execution. A few wind, farm electrical projects, an MHD project, a few thousands of solar PV power packs of smaller ratings etc. have been installed.

Renewable energy power plants will have a low share of total generation upto about year 2010. Thereafter a steep rise is expected.

1.36. Planning of Renewable Energy Resources in India

The various NRSE (New Renewable Sources of Energy) Schemes are being promoted by the Indian Renewable Energy Development Agency (IREDA).

Table 1.21

Projected Growth of Non-conventional Energy Conversion Power Plants by 2000 AD

	Type of Source	*Planned Installed Capacity 1990-2000 AD (MW)*
1.	Bio-gas	6000
2.	Agricultural Waste	2000
3.	Solar Power	5000
4.	Wind Power	500
5.	Ocean thermal Plants	1000
6.	Tidal Power	400
7.	Others	100
	Total by 2000 AD	15000 MW

1.36. 1. Comparison : Renewable and Conventional

The use of renewable energy resource like wind ; solar ; ocean wave, ocean-thermal is quite different from the conventional non-renewable energy resources in following respects.

Table 1.22

		Renewable	*Conventional*
1.	*Concentration* of Energy Resource	Weak	String
2.	Availability	Non-continuous seasonal, daily variation	Continuous supply possible
3.	Stocks	Naturally replenished	Get exhausted by consumption
4.	Type of power Plants	— Energy displacement* — Hybrid with battery and Diesel† — Small, Medium, Large units	— Central, Large units economical synchronised into network
5.	Suitable for	— Isolated Stand Alone Power Plants or Synchronise with Network	
6.	Suitability	For remote areas	For Network
7.	Technology Absorption in Developing countries	Being established in	Established
8.	Environmental and Ecological Balance	Not serious	Serious
9.	Future Scope	Will supersede	Will become absolute

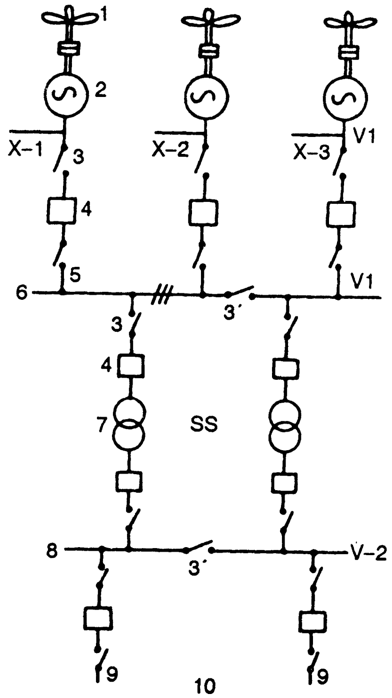
*Renewable Energy Power Plants based on Solar, Winds, Ocean Thermal, Ocean Tidal generate during favourable periods only. Thus they *displace* the energy consumption of non-renewable energy resources by amount of MWhr during favourable periods.

†Energy is stored by changing storage battery-banks favourable periods. During non-favourable periods diesel generators operate.

1.37. Wind Energy Electrical Power Plants

Energy in Wind is converted into electrical form in a Wind-Turbine Generator Unit. Wind is air flowing naturally. Wind speeds of 4 m/s to 14 m/s are used for wind-turbine-generators.

A typical *windfarm* has several identical Wind-Turbine generator units located in windy-area away from cities, forests. The generators are connected in paralled and operate synchronously or asynchronously. The electrical power delivered by the wind farm power plants is either supplied to isolated farm load or into the 3 phase AC Network.



1. Wind Turbine
2. AC Generator
3. Isolator
4. Circuit breaker
5. Isolator
6. Busbar at V-1
7. Power Transformer
8. Busbar at V-2
9. Distribution feeder
10. Distribution system

Fig. 1.31. Wind-Farm Electrical Power Plant-Schematic of Main Power Circuit Single line representation of 3 phase systems.

X_1, X_2.....Control cables to control and protection panels

Ratings : Individual Wind-Turbine generator units rated 15 kW, 20 kW, 50 kW, 100 kW, 200 kW, 250 kW are being manufactured and have been installed in India, with 10 to 50 units in a single wind farm.

Large individual Wind-Turbine generator units rated 1 MW, 2 MW, 3 MW, 4 MW are being manufactured and installed on commercial basis in developed countries. A typical wind farm may have 10 to 50 such units with total wind-farm output of 10 MW to 200 MW at medium distribution voltage (up to 33 kV).

Wind Turbines. Several designs of wind-turbines have been evolved and used for prototypes. These include :

1. *Vertical shaft Derrius Turbine.* An oval blade in vertical plane is placed on vertical axis-bearings. The upper support is held in position by means of guy-wire ropes Generator is installed at the base of Derrius Axis High unit ratings (1 MW to 15 MW) are expected.

2. *Horizontal shaft Giant Wheel.* (Multi-Bladed Wind Turbine). The horizontal shaft fabricated rotor has several blades.

3. Horizontal shaft with one or two or three blades on hub. This design is most successful and has been used for commercial wind-turbine generators. Three-blade designs upto 3 MW unit size have been installed in developed countries and units rated 50 kW to 250 kW have been installed in developing countries like India.

Description of a Wind Turbine Generators. Wind Turbine (1.1) is installed on a tall tower made of steel pipe/RCC/fabricated galvanised steel structure. It has 1, 2 or 3 blades mounted on a hub with *horizontal axis*. The blades are designed aerodynamically for typical wind speeds in the range of 4 m/s to 14 m/s. *Three-blade design is most popular* due to lower vibration level and better balanced rotor. The generator is either 3 phase AC Synchronous Generator or 3 Ph AC Asynchronous Generator. (Induction Generator).

Table 1.23. Typical Ratings of Wind-Turbine Generator Units

Rated Power of each Unit	*330 kW*	*750 kW*	*2000 kW*	*3000 kW*
Type	Synchronous or Induction	Induction	Induction	Synchronous
Frequency	50 Hz	50 Hz	50 Hz	50/60 Hz
Rated Voltage	460 V	3.6 kV	7.2 kV	12 kV
Phases	3	3	3	3
Rated Speed*	1500 rpm	1500 rpm	1500 rpm	1500 rpm
Axis	H	H	H	H

* 60 Hz in USA with speed 1600 rpm.
H = Horizontal.

Wind Farm. Refer Fig. 1.32. The generators feed the power to distribution system (10) *via* common substation (SS) having busbars (6) at generator voltage level V-1, busbars (8) at distribution voltage level V-2. Total power of the Wind farm is supplied to the distribution Network (10) *via* the substation.

Wind-Turbine-Generator Unit. Fig. 1.32 gives a cross-section and Table 1.32 gives of a typical 300 kW, and 750 kW units.

Controls. Wind-turbine generator unit has following controls

— Blade-pitch control for reducing or increasing turbine speed.
— Braking and stopping
— Nacelle direction control
— Protection monitoring of generator output
— Synchronising individual unit with the busbars.

A microprocessor based control is located in the basement of the tower. Another microprocessor is located in control room of the wind farm.

Wind Energy Resource. The wind data is collected and a geographical wind-map of the country indicating high wind speed regions favourable for wind farms are indicated. Speed and direction of wind are recorded on hourly and daily basis over a few years at various heights from ground level (between 50 m and 150 m). Wind farms are located away from cities and forests in high velocity wind areas. With average wind speed of 7 m/s for most part of the year. Two types of installation are

1. on land installation
2. off-shore installation on sea or lake.

Wind Power. Power density (W/unit area) of wind is given by the equation

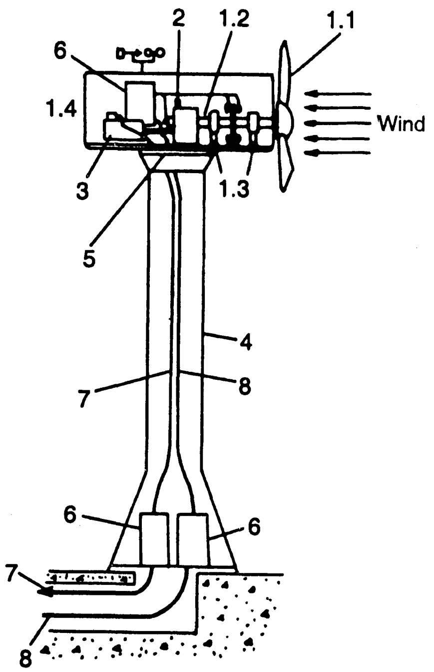


Fig. 1.32. Cross section of a Typical Wind-Turbine Generator Unit. (Refer Table 1.33 for item description).

1.1. Wind Turbine

1.2. Turbine Shaft

1.3. Bearings

1.4. Nacelle

2. Gear Box

3. Generator

4. Tower

5. Control Unit in (1.4)

6. Control Unit on ground base

7. Switchgear on Ground

8. Power Cable

9. Control Panels in Base Control Room.

Table 1.24. Description and Data of the Wind Turbine Generator Unit

	Item in Fig. 1.32	*Description*
1.	Wind-Turbine	— 3 blade design is most widely used. 1 — blade and 2 blade also designs used for 1 MW rating.
	1.1 Blades	— Horizontal shaft 1.2 most widely used.
	1.2 Shaft	— Mounted on *Nacelle* 1.4
	1.3 Bearings	— Nacelle gets automatically oriented in the direction of wind.
	1.4 Shaft	— Blade TIPS have pitch control for adjusting power output and speed. — Blades are designed aerodynamically
2.	Gear Item No. 2	Converts wind turbine speed to generator shaft speed.
3.	Generator	— 3 Phase AC at 50 Hz or 60 Hz with syn. speed 1500 rpm or 1600 rpm — Synchronous or Asynchronous (induction) — Driven by geat (2)
4.	Tower	— Tall structure 20 to 30 m height supports nacelle on hub. — RCC/Fabricated/Steel pipe towers have been installed
5.	Control System (in 1.4) for speed control power control	— Controls power output and speed of turbine generator
6.	Main switchgear	— Power flow from generators (3) to substation bus is *via* main switchgear through power cable.

(Contd.)

	Item in Fig. 1.32	*Description*
7.	Power cable	— 3 Phase AC, 50 Hz power cable with 3 cores — Connected between the generator terminals (3) and out-door substation bus.
8.	Control cables	Controls signals, protection signals auxiliary power etc. takes through them
9.	Wind-direction senser	— Senses wind direction and gives signal to control system *via* (5) — Axis of nacelle (1.4) gets automatically adjusted such that axis of 1.1 is in paralled with wind.
10.	Control panel at ground level	— Control cables between wind-generator unit control (5) and substation control panels are taken *via* (10) — Operator of wind mill monitors the performance of in-dividual wind generator unit from 10

$$P_w = KV^3 \ldots \text{Watts/m}^3$$

$$V = \text{Wind speed, m/s}$$

$$P_w = \text{Watts/m}^2$$

$$K = 0.64$$

$$m^2 = \text{Area normal to wind direction.}$$

Typical wind speeds are in the range of 4 m/s to 14 m/s. Average speed for calculations is 7 m/s 8 lock-out speed is 4 m/s and 7 m/s.

Application of Wind-turbine Generator Units. These can be identified in following four broad categories

— For generation of electrical energy on continuous basis on large scale (1 MW units 10 to 50 per Wind-farm). Such wind farms are connected to electrical network and act as energy-displacement plants. (Consumption of energy resources like coal/petroleum/gas is displaced)

— Isolated (stand-alone) system for farms loads remote from distribution network, island etc.

— Small non-critical rural applications

— Hybrid systems (Wind-diesel battery).

Hybrid Wind-diesel Power Plants. Fig. 1.33 shows a schematic of hybrid power plant utilizing.

1. Wind turbine generator-unit ; 2. Diesel-generator unit
3. Load (L).

The *Diesel Generator Unit* feeds the load. During non-wind period, during good-wind period the wind turbine generator feeds the load (3) of supply network (7).

Prospects for Wind-Power Plants in India. Estimated Wind-Power potential in India is 20,000 MW. This will require several thousand of wind farms there is a vast scope for design, production. Some of the wind farms would be on land and some could be on off-shore shallow-waters.

Estimated Wind-Electric Potential in India :

Number of wind farms	1500
No. of units per farms	50
Total no. of wind-turbine generator units	75,000
Average Rating of unit	- 0.25 MW
Total Potential	18,000 MW
Present Planning (1990)	10,000 units, 200 kW each

1. Wind Turbine Generator Units of Wind Forms

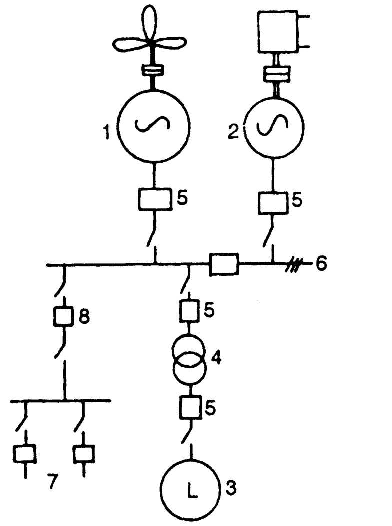


Fig. 1.33. Concept of Hybrid-Wind-Diesel, Wind-Battery Power Plant.

2. Diesel Generator Unit
3. Load 3 ph. AC, 50 Hz
4. Transformer
5. Circuit breakers
6. Busbars 3 Ph
7. AC Supply Network 3 phase AC, 50 Hz
8. Synchronising Breaker

1.38. Solar Energv Electrical Power Plants

There are two distinct principles of conversion of solar energy to electrical energy.

1. Direct energy conversion from solar to electrical by Photo-voltaic cells (PV cells) (solar cells).
2. Solar Energy to steam. Thermal or gas-thermal and then to drive turbine generators or electrical power.

The configurations of energy collectors energy convertors and power plant equipment and their sizes in above categories are quite different.

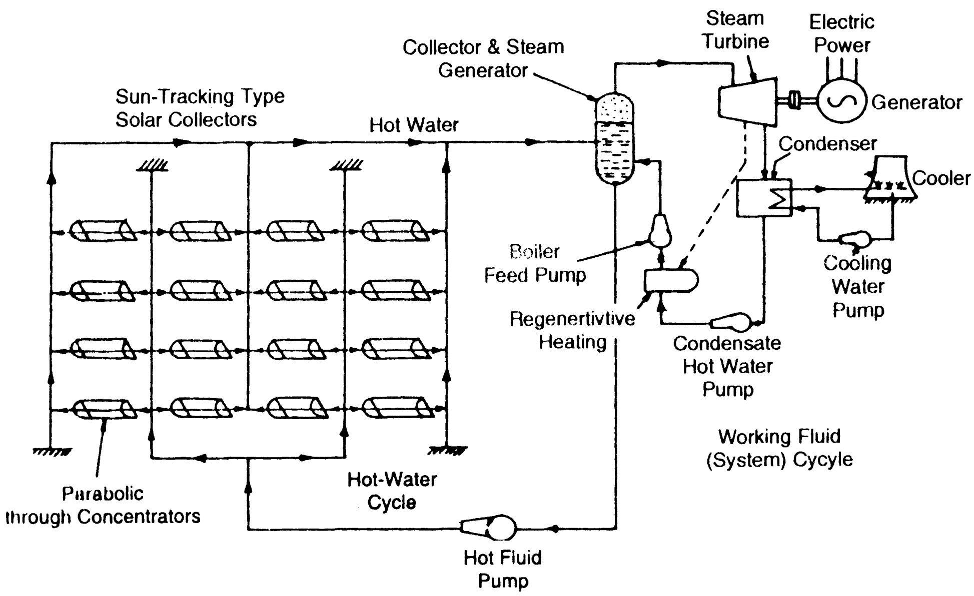
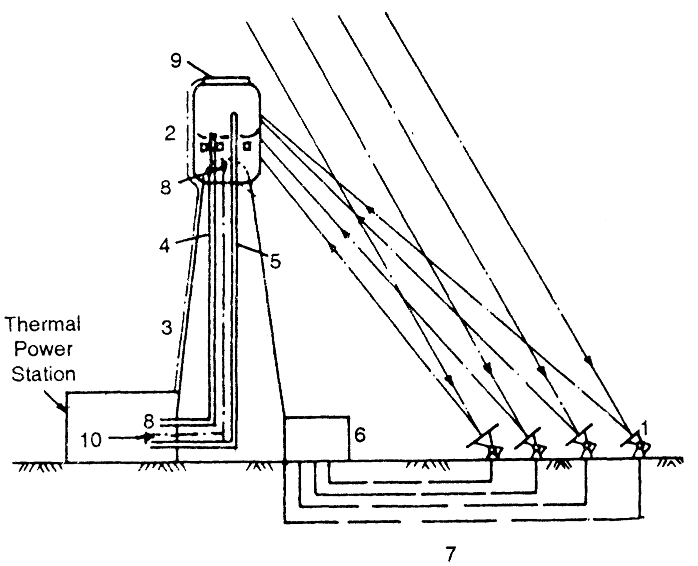


Fig. 1.34. Schematic diagram of a Solar thermal power plant with distributed collectors.

1.38.1. Solar Thermal Power Plants and Solar Energy. The various types of configurations include: A, B, C, D as described below :

(*A*) *Distributed collector type solar steam thermal plant* (Fig. 1.34). Distributed collectors are connected in series, parallel to collect heat to heat-up the circulating water. The collectors are either fixed type or sun tracking type. *The water receives solar heat to produce steam.* Steam is given to steam turbine. Steam turbine drives 3 phase AC generator. Electrical power output of generator is supplied to the load/the network/or battery charger.

(*B*) *Concentrating Sun-Tracking reflectors with central steam-Boiler* (Fig. 1.35). Several flat reflecting mirrors are arranged at ground level around a large central boiler installed on a tall tower. The mirrors are *sun-tracking type* with automatic positioning control system for reflection, is positioned on the control tank. The water in the central tank boils and steam is used for driving steam turbine unit in the thermal power plant on ground. In Fig. 1.35 the boiler 2 has additional fuel burners (8).



1. Flat sun-tracking reflectors (Heliostats)
2. Boiler + Furnace
3. Tower
4. Cold water inlet pipe
5. Hot steam outlet pipe
6. Control for positioning of 1
7. Control cables and power cables for 1
8. Burner
9. PV Panels on 2
10. Fuel for 8

Fig. 1.35. Geothermal Power Plant with Concentrating Sun-Tracking Reflectors.

(*C*) *Concentrating paraboloid Reflector with central boiler* (Fig. 1.36). A large reflector concentrates reflected rays on a central boiler installed on a tall tower. Solar heat boils the water-steam produced in the boiler drives steam turbine generator units located in the power plant.

(*D*) *Binary cycle solar thermal power plant* (Fig. 1.37). Steam from solar collector is transferred to the liquid ammonia (NH_3). Ammonia vapour drives gas turbine generator. NH_3 is condensed and recirculated. The plant has (1) Hot Water cycle and (2) Ammonia cycle. Solar thermal plants are built in large sizes the surface area of reflectors should be very large (---) to generate electrical power of the order of a few MW.

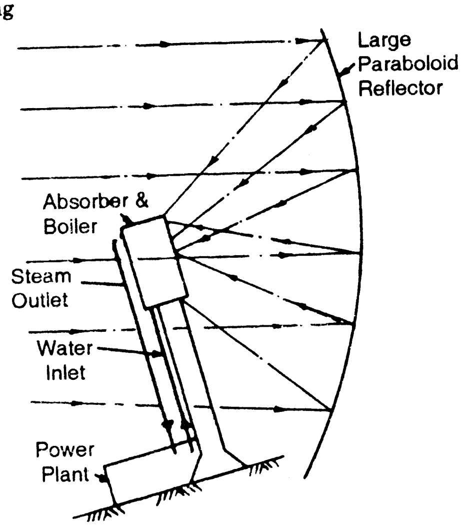


Fig. 1.36. Solar Power Plant with Concentrating Paraboloid Reflector with Central Boiler (Such a plant has been built in France).

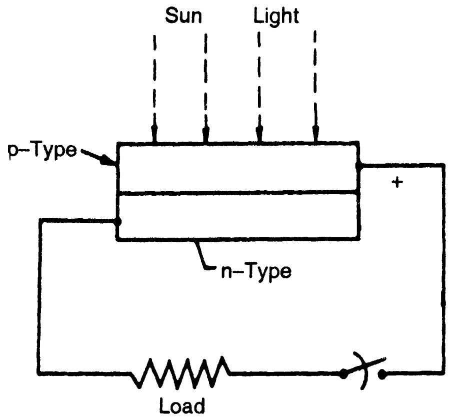


Fig. 1.37. Principle of a PV Cell Solar Cell.

1.38.2. Solar PV cell power plant. The energy conversion is achieved by using photo voltaic cells (PV-cells). PV cells are also called solar cells.

Photo-voltaic cel (PV-cell) converts solar energy radiation directly to electrical energy. Basically a PV cell is a semiconductor *p-n* junction fabricated with silicone with gallium arsenoid or cadmium sulphite etc. When light strikes the *p*-type surface, and the pond *n* terminals are connected to external electric circuit, current flows and electrical energy is generated.

A single P-V cell (solar cell) exposed to solar irrandiance of 1 kW/m^2 has open circuit voltage of about 0.5 V, short circuit current of about 0.004 A/cm^2. Several solar cells are connected in series to get desired output DC voltage. Several solar cells are connected in paralled to get desired output current. A *solar PV panel* has several PV cells connected in series/paralled. The output of a typical panel is about 160 W/m^2. In USA very large solar PV panel are connected in series/paralled for medium size power plant *Applications.*

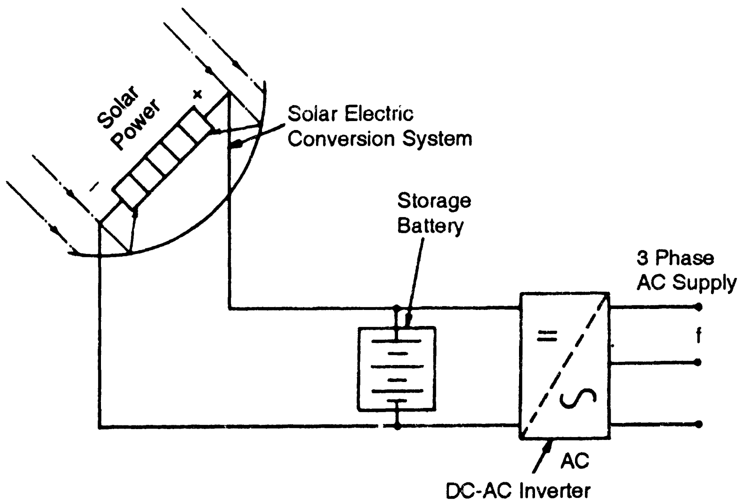


Fig. 1.38. Solar Power Pack with PV Panel, Battery and Inverter. During Off-solar Period Battery Supplies Power. During Good Solar Period Batteries Get Charged Again.

Solar PV panel power packs with storage batteries are used for small and medium power applications like

— Street lighting

— Remote isolated loads communication, military locations

— Small loads like residential farm, communication sets.

— Portable, battery charger sets.

Solar-Battery Diesel Hybrid. Fig 1.39 shows a solar, battery, Diesel hybrid. During the day the lead acid battery cells get charged. The DC-AC Inverter gives AC power to load. Typical ratings are 5 kW, 10 kW, 50 kW.

1.38.3. Solar Power in India. A 50 kWe solar thermal power plant has been installed in Gawalpahri, Haryana (1989) 30 MWe solar thermal power plants with parabolic through collectors and steam-turbine generators have been planned by NRSE (Non Conventional Renewable Source of Energy) schemes under ministry of Department of non conventional energy.

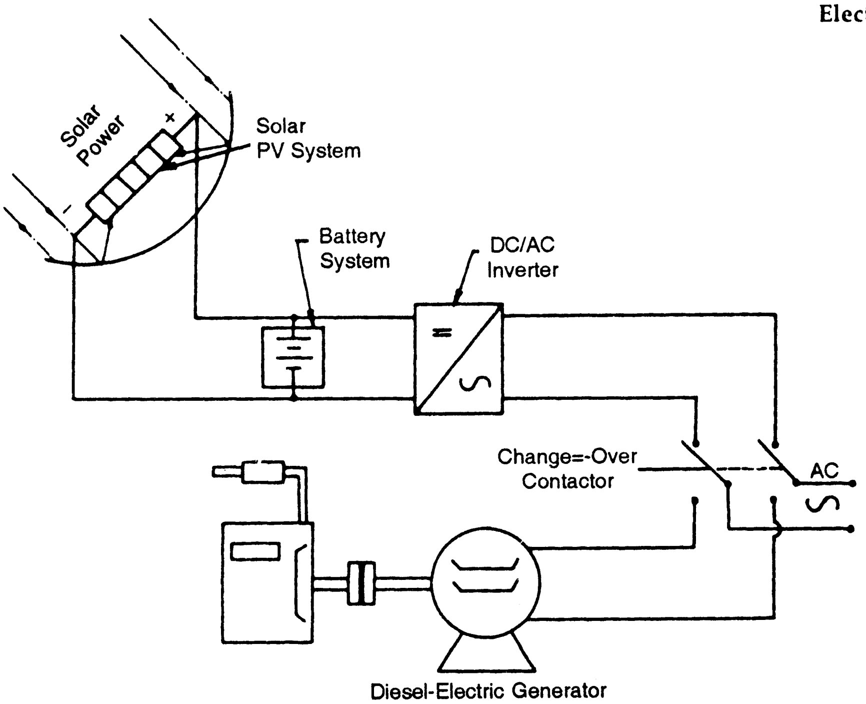


Fig. 1.39. Solar Power Pack = Hybrid of Solar, Battery, Diesel Generator. [During off-solar periods Battery supplies power. When battery is discharged, Diesel Generator supplies power].

1.38.4. Solar Energy Constants. Power density (Watts/unit area) of solar energy *outside* earths atmosphere is called *solar constant* and is estimated to be

$$P_{se} = 1355 \text{ W/m}^2$$

The solar power received on earth's surface varies with (1) Geographical location, (2) Season of the year, (3) Hour of the day (4) Condition of clouds, smoke, and dust etc.

Thus

$$P_{se} = K\, P_{se}$$

where P_s = Solar radiation on earth's surface

K = Constant governed by local conditions

P_{se} = Solar Power constant outside atmosphere around earth.

K varies widely between 0.3 to 0.74 with available power density on earth's surface at noon equal to

$$P_{se} = 0.3 \times 1355 = 406 \text{ W/m}^2$$

$$P_{se} = 0.74 \times 1355 = 1000 \text{ W/m}^2$$

Assuming conversion efficiency of 10%. For 1 MW power plant are of collectors

$$\frac{1000{,}000}{1000 \times \eta} = \frac{100}{0.1} = 10{,}000 \text{ m}^2$$

1.39. Geothermal Power Plants

Very large quantity of thermal energy is available in the planet earth. This energy is in the form of hot liquid, (malma) hot gases and steam. In some geographical locations springs as of hot water and steam-spring out naturally from earth. *Geothermal power plants* use one of the following as *primary energy resources* obtained from the hot-wells.

1. Hot dry steam
2. Hot wet steam
3. Geothermal brine (hot liquid)
4. Hot water.

Fig. 1.40 shows a typical schematic of a Geothermal Power Plant. The plant is located in sites where geothermal source is at relatively lesser depth (less than 3 km). In some locations geothermal source is very near the earth surface. Such locations are selected for Geothermal Plant sites.

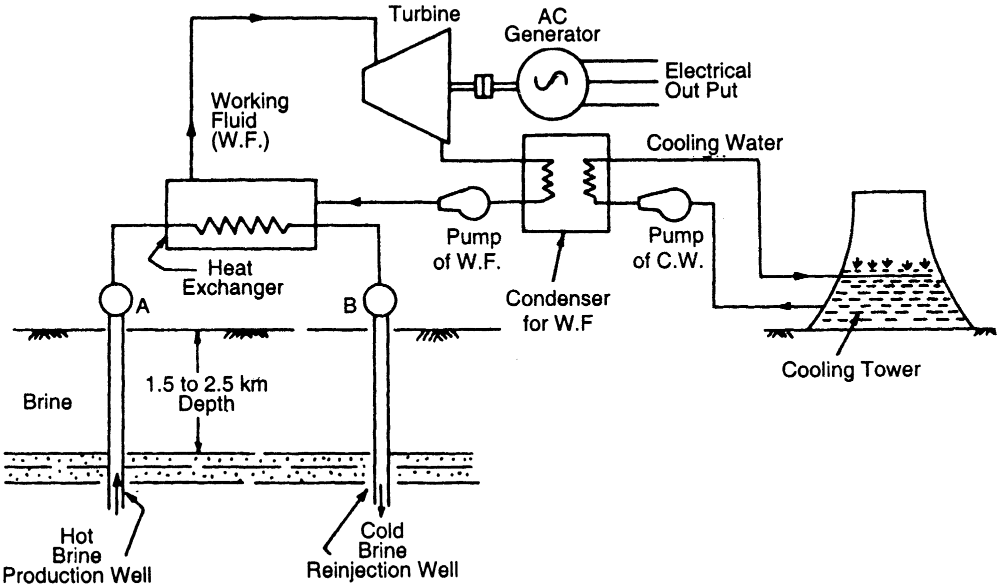


Fig. 1.40. Schematic of a Geothermal Power Plant with Steam Cycle.

Usually two deep bore wells are made *Hot Well* is used for extracting hot brine/hot water/dry steam/wet steam from the geothermal source. Reinjection well (cold well) reinjects the brine/condensate of steam back to the resource. This ensures continuous intake of hot energy resource through hot well.

The hot-brine is pumped up to ground level. The heat from the resource is extracted in the heat exchangers. The heat is given to the working fluid *e.g.* (Freon, Ammonia or steam).

Steam Cycle or Binary Cycle. In steam turbine geothermal plant, the condensate water is heated in the heat-exchanger (steam generator). The steam is used for driving steam turbine generator. The steam discharged from the steam turbine is condensed in a condenser and reheated in the heat exchanger. The geothermal energy is used for producing steam in heat exchanger (boiler).

In some geothermal fields hot dry steam comes up naturally through the hot wells. Such steam is used directly as intake in special steam turbines.

In some plants, hot brine is used for special radial in flow turbines compiled to AC generator shaft. In some geothermal sites, the hot well gives wet-steam. This may be used for evaporating the working fluid (*e.g.* NH_3 or Freon) the gaseous NH_3 or Freon drives gas-turbine generator and is condensed and recirculated.

Hot-Rock Geothermal Power Plant. A disc-shaped vertical fracture is made in deep or rock (at a depth of 2 to 3 km) by special geothermal blasting techniques. Deep wells are drilled for hot and cold brine. (Fig. 1.41). Cold brine is *injected* into the hot-rock fracture. The hot brine pumped-up from not well is used for heating working fluid (steam or NH_3) in the heat exchanger. The turbines drive electric generators.

Ratings of Geothermal Power Plants. Large geothermal power plants with rated installed capacity of 100 MW, 200 MW, 500 MW, 1000 MW have been built in USA, Iceland, Italy etc. Examples are :

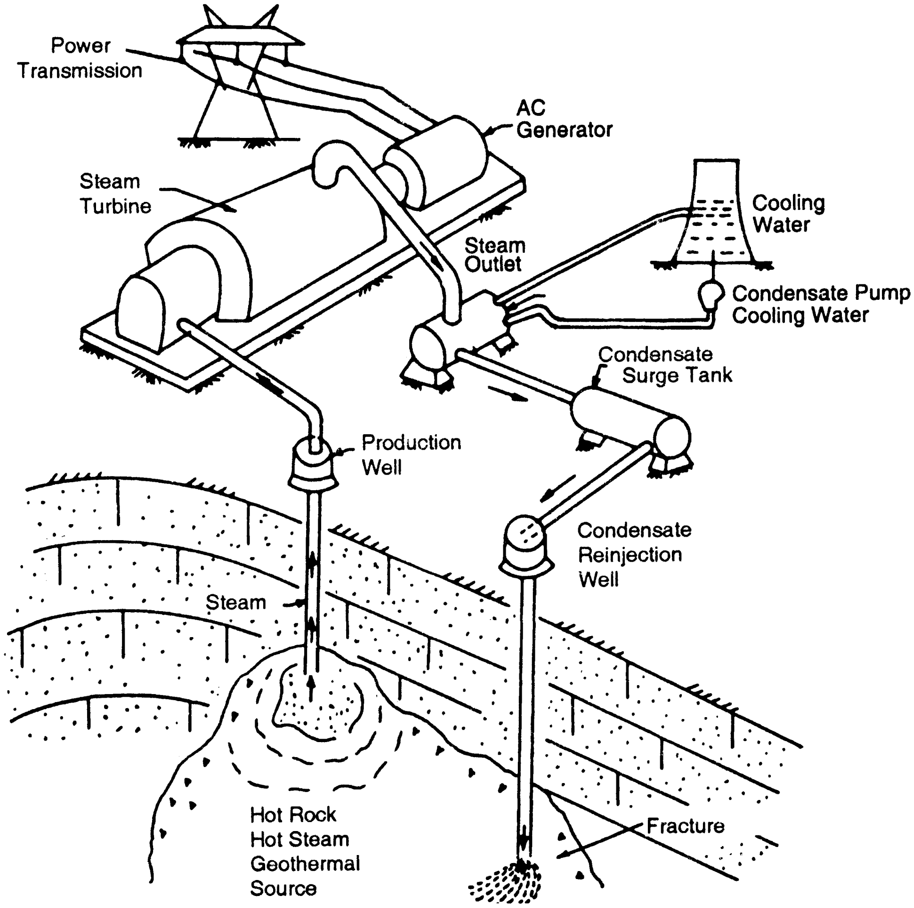


Fig. 1.41. Hot Rock Geothermal Power Plant Conceptual Diagram.

Geothermal Electrical Power Plants (1990)

New Zealand	40% Generation by GT
Italy	6% Generation by GT
USA	322 MW Plant, Gaysers 1972
USSR	5 MW, 25 MW GT plants at Kamachatka, Kurlis
Indonasia	2.5 MW Experimental GT plant at Lahendong 1991

Geothermal Power Plants in India. Deep-drilling technology high temperature material technology for hot well equipment is not available in India. Geothermal power has not been considered on priority so-far (1992).

1.40. Ocean Thermal Energy Conversion Power Plants (OTEC)

Refer Fig. 1.42. During the day, solar radiation energy is absorbed by the ocean water and temperature in the upper layers rises (app 26°C). The lower layers of water remain cold. (app. 6°C). Ocean thermal energy conversion plants utilize the heat in the upper layers of the tropical-ocean water for producing NH_3 vapour. The NH_3 vapour drives gas turbine generator. The outlet NH_3 vapour is taken into a condensor (6). The condensate NH_3 liquid returns to the heat exchange (2). Cooling water (8) for condenser (6) is taken from the deep-ocean (8). The highest difference in the upper layers of sea water and lower layers of ocean water is app. (26 – 6 = 20°C). This temperature difference is very small. Hence a very large quantity of warm water and cold water must be continuously circulated through the binary cycle energy conversion plant.

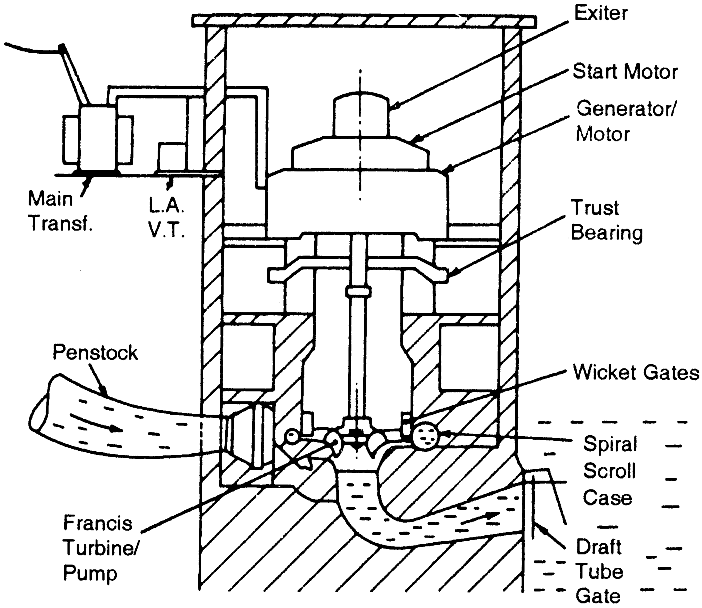


Fig. 1.42. Schematic of a Binary Cycle. Ocean Thermal Energy Conversion Power Plant (OTEC).
[Warm water from upper layers of ocean is used for producing NH_3 vapour in 2 cold water from lower depths of ocean is used for condensing NH_3 in (6). Gas turbine (4) drives generator (5)].

OTEC Plant with Binary Cycle. Hot water from upper layers of sea is pumped through heat exchanger and then discharged to sea surface. The heat-exchanger give heat to the working fluid (*e.g.* NH_3). The working fluid gets evaporated in the heat exchanger. The vapours of the gas (NH_3) are used for driving gas turbine generator unit. Generator gives electrical energy output. Discharge vapour of working fluid gas from gas-turbine is condensed in surface condenser ( ). The cooling water for condenser is taken from deep-sea. This the OTEC with gas turbine generators has following cycles.

— Warm water from upper sea circulated through heat exchanger and returned to sea (open cycle)

— Working fluid (NH_3) circulated through heat exchanger, gas turbine surface condenser and back to heat exchanger (closed cycle)

— Cold water from deep sea circulated through the condenser and then returned to the sea (open cycle).

Floating OTEC Power Plants. The principle is same, the entire power plants is installed on an off shore floating platform. Such plants have been conceptually designed in USA Japan for power supply to large on the sea coast.

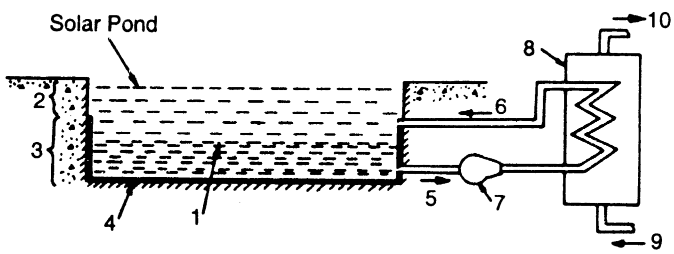


Fig. 1.43. Solar Pond for Hot Water Supply.

1. Solar pond water
2. Upper layer of lower salt concentration
3. Lower layer of higher salt concentration
4. Black-painted bottom
5. Hot water
6. Cold water
7. Pump
8. Heat exchanger
9. Fresh cold water
10. Hot water (fresh)

Typical Plant Ratings. OTEC are with steam cycle have unit steam turbine generator size of 50 kW to 1 MW (present) (upto 10 MW in future plant size = upto 100 MW).

OTEC Plants Planned in India (1990). Ocean Thermal Energy conversion plants have been planned by Tamil Nadu Electricity Board, and Ocean Energy Cell of India. Institute of Technology (Madras) with know how for design and construction from Sea Solar Power Inc (SSP) USA. Six OTEC plants of 100 MW each are likely to be constructed on the Tamil Nadu coast, India, the first one will be at Kulsekara-Patanam, Tamil Nadu.

1.41. Solar Pond for Hot Water Supply

Such ponds have been installed in Israel for obtaining hot water for desalination plants, district heating etc. A large-surface shallow pond is constructed with bricks, cement etc. to store water (1). The surface of tank (4) is painted black for absorbing solar heat.

The pond water (1) is mixed with common salt to have lower layers (3) of higher salt concentration and higher density.

The upper layers (2) are of lower salt concentration and lower density.

Natural Convection is prevented to retain the layers of (2) and (3) despite heating of water by solar heat.

Lower layer (3) receive heat from black-tank surface and get heated up quickly. Upper layers (2) acts transparent thermal insulation without convection currents.

Warm water (3) is pumped through heat exchanger and returned to the pond. Heat exchanger (8) gives the heat to fresh water circulated through (9-10), this heat received by the pond water (1) is imparted to the fresh water. The warm fresh water is used as a secondary energy resource.

1.42. Ocean Wave Energy Conversion Power Plants

The hydro-energy in the ocean waves is converted to electrical energy by specially designed wave machines (wave power machine) (wave power turbine) installed in ocean wave energy conversion power plant (OWEC). The OWEC is installed in coastal areas having regular high waves (1.5 m to 0.2 m) for 4 to 10 sec. Floating type OWEC plants are envisaged in future. These will be mounted on large platform floating in deep sea.

Several patents have been awarded for different design principles of OWEC machines (wave machines).

Wave Power. Amount of Power (P) of a wave depends on length L, Amplitude A and wave period t. From measurement prototype floating wave machines in USA, the following empirical equation has been derived for wave power.

$$P/L = 1.75\, A^2 t \text{........kW/m.}$$

where P = *wave power per meter length perpendicular to direction of propagation of wave, kW/m*

A = Amplitude of wave (m)
(Range 1.0 to 3 m)
(Half of height or wave)

t = Wave period, seconds.

L = Length

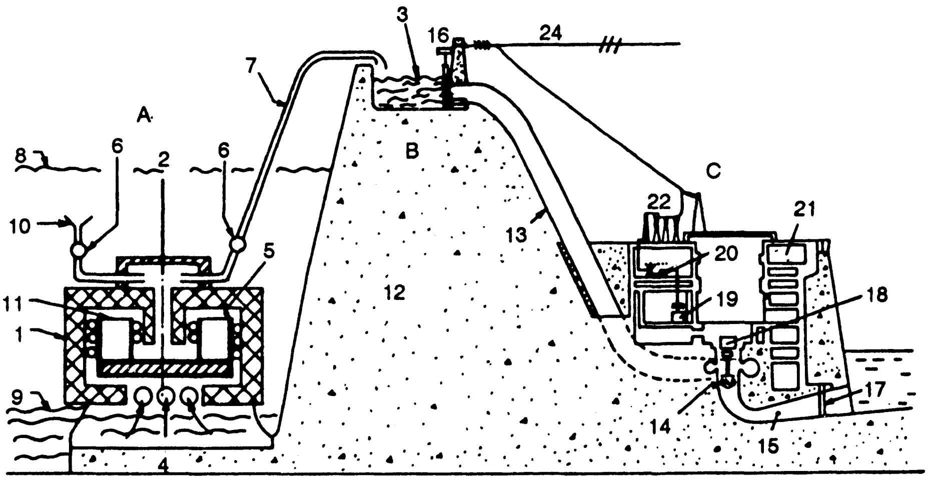
Example 1. Given wave height 2 m wave period 6 seconds calculated power of wave per unit length ppd. to direction of wave

$$P/L = 1.75\, A^2\, t \text{ kW/m}$$
$$= 1.75 \times (2/2) \times 6$$
$$= 10 \text{ kW/M.} \quad \textbf{Ans.}$$

High Level Reservoir Type Wave-Energy Machine. Fig. 1.45 represents a schematic of high level reservoir storage type ocean wave Energy conversion plant. Section A is the pumping plant, section B is high level reservoir and section C is power plant.

The function of the wave-turbine (1) is to pump ocean water from chamber (2) to high level reservoir (3) *via* pipe 7 during every high amplitude of ocean wave, thus section A pumps ocean wave energy to hydro-potential energy of section B. The wave machine (1) acts on the principle of hydraulic pressure magnification. During the high wave water enters through inlets (4) at the bottom and acts on piston (5) Piston (5) is pushed-up. Piston (5) compresses air cushion (11) on upper half of the piston. The water in pumping zone (2) in the upper zone of (1) gets compressed. As the area at bottom of piston (5) is many times the area A_2.

Pressure in upper passage increases in the proportion $P_2/P_1 = A_1/A_2$. High Pressure water in chamber (2) is pumped into upper reservoir (3) *via* pipe 7 during every wave. The water enters the chamber (2) *via* inlet (10). During low wave level (9), the compressed air in zone 11 pushes back the piston (5) to bottom position.



1.44. Ocean-Wave Hydro Electric Power Plant.

	A. Wave-Turbine	B. Reservoir	C. Power Plant
1	Wave Turbine enclosure	12	Dam across ocean length
2	Pumping zone of 1	13	Penstocks
3	High level reservoir	14	Hydro-turbine
4	Inlet water in lower side of 1	15	Tail-race discharging to ocean
5	Piston of 1	16	Gate at entry of 13
6	Check valve for inlet water in upper chamber	17	Gate at outlet of 15
6′	Check valve is outlet path of 2 to 7	18	Generator, 3 ph, AC
7	Pipe between 2 and 3	19	Power Transformer
8	Wave with high amplitude	20	Switchgear
9	Wave during low amplitude	21	Central room
10	Inlet of after to zone 2.	22	Busdust (SF_6 Filled)
11	Air cushion in upper half of (1)	23	Outdoor Switchyard
11′	Sliding seals for 11	24	Transmission Line

The water pumped in storage reservoir (3) gains potential energy.

Section C is a hydro-electric power plant. Water from (3) flows through penstocks (13) to turbine (14) and back to the ocean *via* tail race (15). *Generator* (18) generates electrical power and feeds it to network *via* switchgear (23) and transmission line (24).

1.43. Fuel Cell Power Plants

Fuel cell is an electrochemical device which converts continuously. The chemical energy in the fuel plus the oxidant into electrical energy.

The *fuel cells* are different from primary cells and secondary cells that they supply electrical energy continuously. The fuel and oxidants are supplied to the fuel cell continuously.

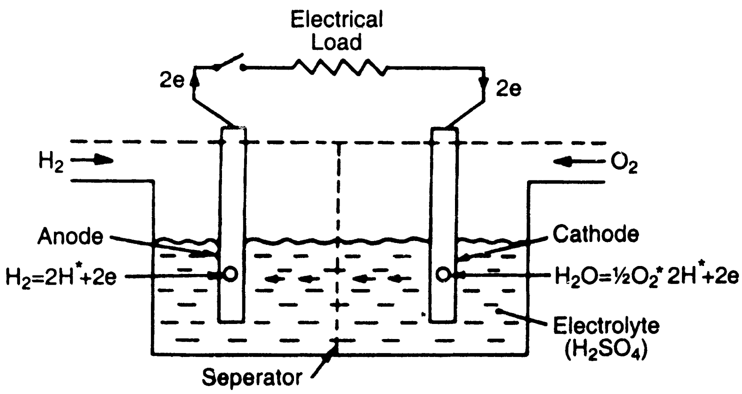
Types of Fuel Cells

The fuel cells are classified according to the (1) Fuel (2) Oxidant (3) Electrolyte and (4) Operating temperature.

Table 1.25
Classification of Fuel Cells

	Fuel 1	*Oxydant* 2	*Electrolyte* 3	*Temperature* 4*	*Application* 5
1.	Hydrogen	Oxygen (Liquid)	Alkaline Solid Polymer	*L, I* *L*	Remote "
2.	Coal Gas " "	Air "	Phosphoric Acid Sodium Oxide	*I* *H*	Central power plant "
3.	Hydrocarbon Methanol Ethanol	Air	Phosphoric Acid Molten Carbonate	*I* *H*	Power packs for commercial use
4.	Hybride	Air	Alkaline	*L*	Low power <100 W and High Power >500 W Power Packs
5.	Hydrogen	Air	Phosphoric Acid	*I*	Vehicles

*L = Low, I = Intermediate, H = High



[Energy is fuel H_2 and oxydent O_2 is converted to electrical form and supplied to electrical load. A fuel cell plants has several cells connected electrically in series parallel to get high electrical power output]

Fig. 1.45. A Schematic of an H_2–O_2 Fuel Cell.

Description of a Typical H_2–O_2 Fuel Cell

Fig. 1.45 illustrates a schematic of an Hydrogen-Oxygen fuel cell. Two calatalyzed carbon electrodes are immersed in the electrolyte (H_2SO_4). A gas barrier is placed between the two electrodes. Fuel (H_2) and oxidant (O_2) are supplied. Electrodes are connected to external load.

Following electrolytic reactors occur in the fuel cell with Acidic Electrolyte when load is switched on and fuel, oxidant are supplied.

$$H_2 \rightarrow 2H + 2e \text{ at Anode}$$

$$\frac{1}{2} O_2 + 2H^+ + 2e \rightarrow H_2O \text{ at Cathode}$$

$$H_2 + \frac{1}{2} O_2 \rightarrow H_2O \text{ Overall}$$

The electrical energy is generated and supplied to the load.

A fuel cell has following essential components

— Anode — Fuel supply
— Cathode — Oxidant supply
— Electrolyte — Heat supply.

Fuel Cell Power Plants

A typical fuel cell power plant has following block :

— Fuel processing block — Fuel cell power block
— Power conditioning block

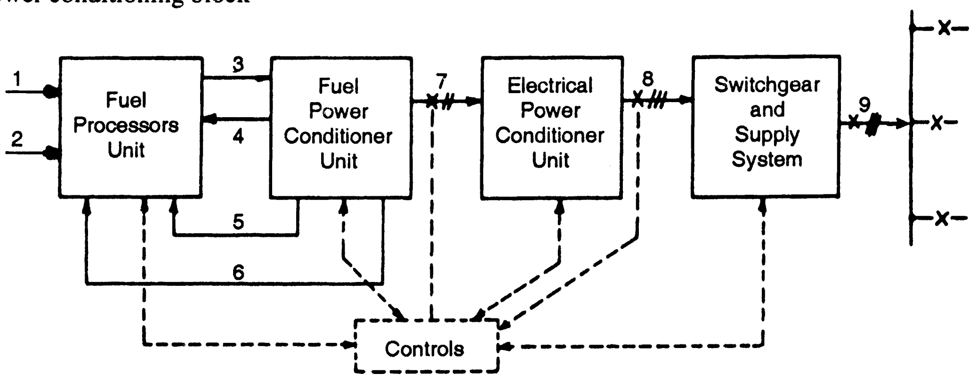


Fig. 1.46. Block Diagram of a Fuel Cell Power Plant.

1. H_2 Gas supply ; 2. Fuel : Natural Gas/Low Sulphur Distilate/Neptha Methyl Fuel ;
3. Processed Fuel 3 Water ; 7. DC power output ;
8. AC Power Output 3 ph. 50 Hz ; 9. AC Substation

The categories of fuel cell power plants are given in Table 1.26.

Fig. 1.46 shows the subsystem blocks and flow diagram of a Fuel-cell power plant.

The fuel cellls power pack consists of several fuel cells connected in series/parallel. The processed fuel, oxygen, heat, water etc. The DC output is converted into 3 ph. 50 Hz AC by and fed to AC Network via switchyard.

Application and Range of Fuel Cell Power Plants

Applications	*Plant Capacity Range*	*Fuel*	*Electrolyte*
Small Remote	50—500 kW	Gas through Pipeline	Phosphoric Acid
Medium Power Stations	5—25 kW	Petroleum or coal derived liquid or gas	Phosphoric Acid
Large Power Stations	100—500 kW	Coal	Molten carbonate or Phosphoric acid

Table 1.26
Categories of Fuel Cell Power Plants

Type	*Size*	*Particulars*
1. Central Power Plant	100 to 500 MW	*Fuel* : Coal, *Electrolyte* : Molten Carbonate or Phosphoric Acid.
2. Medium Power Plant	1 to 25 MW	*Fuel* : Coal gas or Petroleum gas *Electrolyte* : Phosphoric Acid
3. Gaseous Fuel Power Plant	10 to 500 kW	*Fuel* : Pipeline Gas *Electrolyte* : Phosphoric Acid

1.44. Nuclear Fusion Power Plants

Research and development work is in progress in advanced countries. The basic fuel is *Deuterium* which is present in hydrogen in proportion of Deuterium 1 atom in 50 atoms of Hydrogen. Thus the nuclear fusion fuel would be available in *unexhaustible* quantities for future electric power generation. Nuclear fusion reaction is expected to be developed by 2000 AD.

Reaction

When nuclear (ions) of two elements of low atomic number are brought together in a plasma at sufficiently high temperature, and velocity, the nuclei colloids each other and *fuse* together. (Combine) The fusion converts part of their mass into kinetic energy.

Deuterium, Tritium, Lithium Cycle (D-T-Li) cycle is being considered for Nuclear Fusion Power Plants.

The nuclear fusion reaction in D-T-Li cycle involves following two reactions.

First Reaction

Deuterium + Tritium = Helium + Neutron of High Energy

$$D + T = {}^4He + n$$

This reaction gives 4 helium particles with energy of 3.5 MeV and a neutron with energy of 14.1 MeV.

Second Reaction

Lithium + Neutron of High Energy = Tritium + Helium

$$ {}^6Li + n = T + {}^4He, \text{ and}$$
$$ {}^7Li + n = T + {}^4He + n$$

The T generated in the second reaction is reused in the first reaction.

For above reactions kinetic temperature of plasma required is about 15 keV.

Power Generation through Nuclear Fusion

This involves following two steps :

(*A*) about 80% of the energy released through above reactions of ($D + T$) cycle is carried by the high energy neutrons (n). The neutrons are chargeless. Hence they can not be deflected by magnetic of electric fields. Hence they cannot produce electric power.

The kinetic energy in high energy neutrons (n) is converted into heat. This heat is extracted from Lithium-blanket by heat transfer.

The heat is converted into electrical energy by Steam-cycle or potassium cycle.

(*B*) Remaining 20% of energy released by nuclear fission reaction involves the charged particles (${}^4He$). The charged particles can be deflected suitably by magnetic/electric fields in Magneto Hydro dynamic generators (MHD generators) to obtain direct conversion of thermal energy into electrical energy.

Ref. Fig. 1.47 giving a conceptual diagram of a ($D + T$) Fusion Reactor power plant.

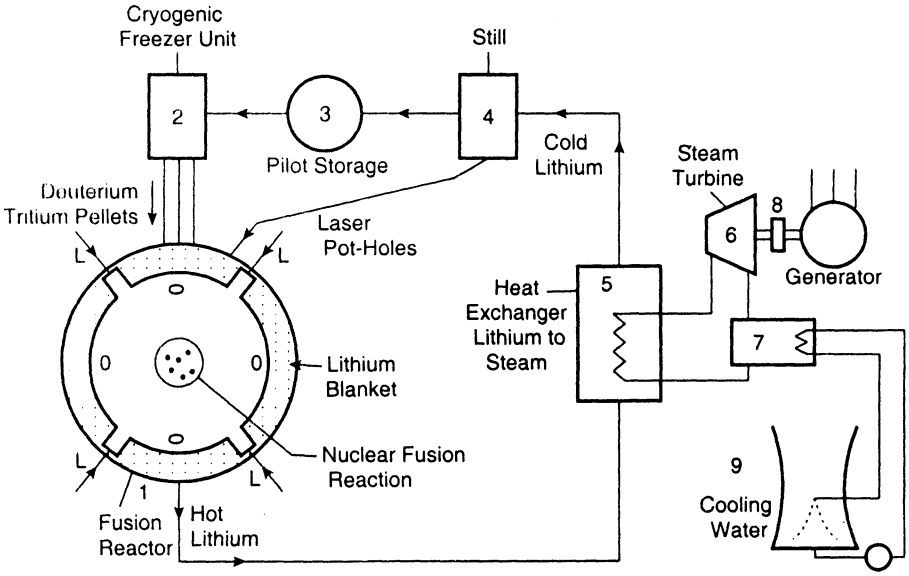


Fig. 1.47. Conceptual Drawing of Nuclear Reactor Power Plant on ($D + T$) Principle the demand of the city. Hence less transmission losses.

The heat generated by the *nuclear fusion* in the fusion reactor is transferred to circulating Lithium. The hot lithium exchanges heat with circulating water in heat exchanger (5). Heat exchanger (5) generates steam to Steam Turbine (6) drives generator (7) Generator (7) feeds power to electrical grid.

Condenser (7) condenses the out-let steam of steam turbine (6) and the condensate is pumped back in closed circulation (5) through cooling tower (9) provides circulating cooling water to the condenser.

1.45. Waste Incineration Power Plants

In large cities the urban waste (municipal waste) and certain combustible waste from agricultural products and Forest Products are used as the 'fuel' for waste Incineration (Burning) Electric Power Plants located in the cities. The advantages are :

— Waste is used as energy source

— Transportation and dumping problems are minimised. In normal course the waste is transported for away from the large cities (transportation distance 100 to 300 km). The land required for dumping is scarce and dumping of waste creates pollution and environmental hazard.

— Electrical Power generated is utilized to meet the demand of the city. Hence less transmission losses

— Plant can supply electricity, heat, steam.

— Cost of fuel is negligible since the waste is utilized.

Fuels which can be burnt

Fuel. Municipal garbage is segragated in combustible portion and non-combustible portion (metals). The combustible portion includes cloth rags, waste paper, kitchen waste, word chips, wood dust, tree-leaves etc.

Typical Plant Capacity

Incineration Capacity 8 t/hr

Fuel heating value 6600—15400 kJ/kg

Generator 6.3 MVA

Transformer 5 MVA

Schematic Diagram of a Waste Incineration Plant

Fig. 1.48 gives a schematic.

Firing System : The main items include :

— Waste (Refuse) charging

— Dosing System (Charge control)

— Combustion grate

— Driving assembly

— Automatic Combustion Control.

Combustion Air Supply. Air required for combustion is supplied by forced draft (5) through three places into the furnace (1) undergrate (2) secondary air (3) side wall cooling air.

Seam-Boiler Plant

A twin-flue natural circulation boiler placed over the grate converts useful heat to steam. The boiler has a vertical combustion chamber (8) and horizontal second flue containing secondary convection heating surfaces.

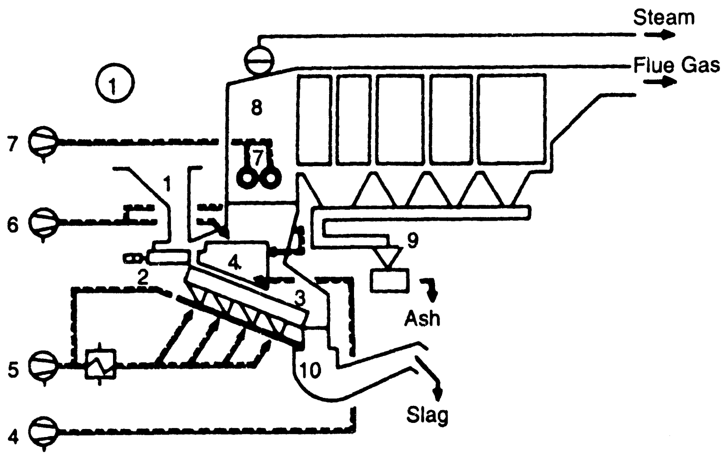


Fig. 1.48. Schematic Diagram of a Waste Incineration Furnace and Boiler Plant. [Steam is supplied to Steam Turbine Power Plant]

1. Waste (Municipal Refuse) feed hopper
2. Ram feeder
3. Combustion grate
4. Slag preventing system
5. Forced draft combustion air system
6. Secondary air system
7. Ignition and Auxiliary Firing
8. Boiler plant
9. Ash Conveyor
10. Slag discharge

Exhaust Gas Purification System

The exhaust gases are purified before passing out to atmosphere through stack. The purification plant serves following functions :

1. Separation of poisonous and noxions gases such as HCL, HF, HCL, SO_2
2. Particulate removal (Dust and ash removal)
3. Removal of vaporised salts such as NaCl
4. Utilization of waste heat of heat-up water
5. Effluent free operation

Slag and Ash Removal

Residual slag, ash originating from combustion process is collected in silos through (9) and (10).

Steam Turbine Generator

Steam from boiler is given to inlet of steam turbine. Steam turbine generator delivers electrial power to the network at 3 ph. 50 Hz

Electrical Substation

Generator voltage (11 kV, 3 ph, 50 Hz) is stepped up to distribution voltage (*e.g.* 33 kV 3 ph) by power transformer. The substation of waste Incineration power plant is connected to feed into the distribution system of the city.

Co-generation

The plant supplies (1) steam for District Heating (2) Hot water (3) Electrical Power.

Table 1.27
Technical Data of a Waste Incineration Power Plant

Furnace	
Capacity	8 t/h
Fuel heating value	6600-15400 kJ/kg
Boiler	
Steam outlet temperature	420°C
Steam outlet pressure	42 bar
Steam Turbine	
Steam inlet	40 bar at 400°C
Nominal output	5.3 MW
Generator	
3 Ph. AC, 50 Hz	6.3 MVA, 11 kV 1500 RPM
Transformer	
Nominal power	5000 MVA
Voltage Ratio	11 kV/33 kV
Vector group	Y_y NO
Tap changer	ON LOAD
Cooling system	ONAN

MV Switchgear

11 kV, 630 A, 350 MVA

1.46. Tidal Power Plants

The principles of Ocean Wave Power Plant and Tidal Power Plant are different.

Ocean tides occur due to lunar cycle. During high tide, the water level of ocean rises and during the low tide the level drops. Tidal schedule has regular 24 hour cycle. Moon rotates around earth in 24 hr. 50 min. During this rotation tide rises and falls twice resulting in a *tidal cycle* of 12 hr 25 min. a lunar month of 29.5 days the daily tides undergo a marked variation in amplitude with period of 12 hr 25 m.

Tidal range (height, power, energy) varies with coastal profile, slope of shore, water depth, direction of wind etc. When these are favorable high tides occur. A very few locations around the coast-line has high-range tides (10 m to 20 m) and are suitable sites for tidal power plants. There are two types of Tidal Power Plants called (L) Single Pool Tidal Power Plant and (2) Double Pool Tidal Power Plant.

Both use hydro-turbine-generators for energy conversion.

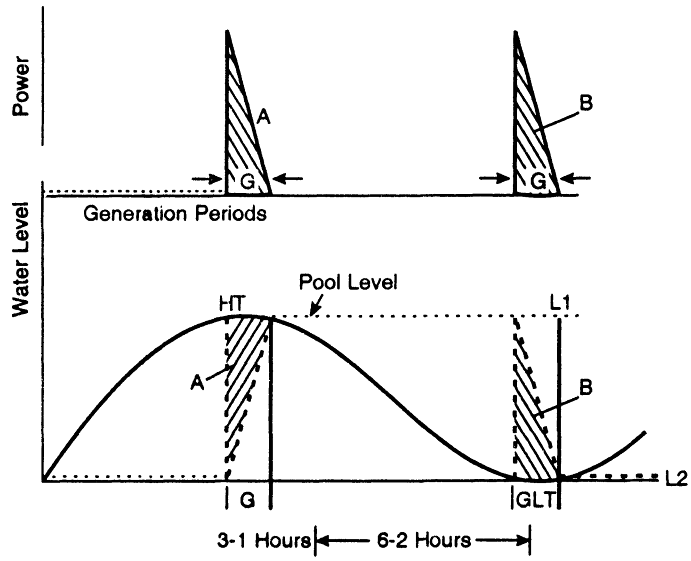


Fig. 1.49. (*a*) Power generation periods of a simple single pool Tidal Power Plant.

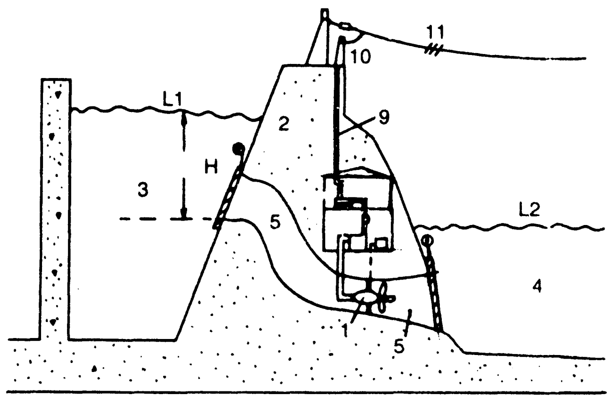


Fig. 1.49. (*b*) Schematic of a single pool tidal power plant.

L_1 = High Tide Maximum Level H = Head Difference L_2 = Low Tide Level

1. Bulb-Turbine Generator
2. Dam across ocean
3. High Level Reservoir on shore side
4. Low level ocean side
5. Penstock in 2
6. Busduct at Medium Voltage
7. Transformer
8. Substation and control
9. HV Gas Insulated Busduct
10, Busting
11. Transmission line

Single Pool Tidal Power Plant

Fig. 1.49 (*a*) and 1.49 (*b*) illustrate the principle. During high tide (*HT*) water flows through the penstock (5) in dam (2) in direction (*A*). The level in the pool 3 rises to L_1. During low tide (LT) the stored water in the pool (3) flows to lower level (L_2) through penstock (5).

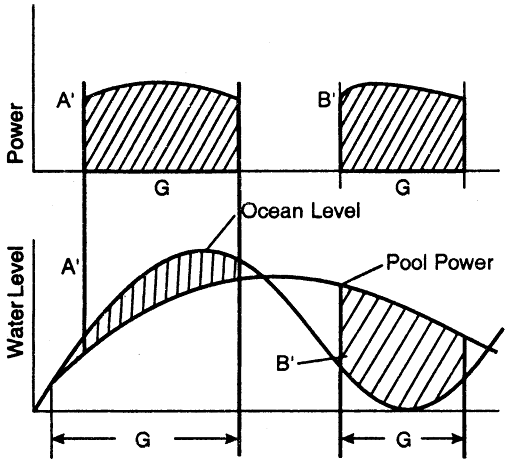


Fig. 1.50. Generating periods (G) in Modified Single Pool Reversible Turbine Plant.

A bulb-turbine-generator (1) is installed within the penstock.

The Kaplan Turbine of the bulb-turbine drives the generator shaft. The generator is bulb shaped and is totally sealed unit.

Busduct (6) are provided between bulb-turbine generator and the power-transformer (7) substation 8 is connected between the power transformer and external transmission lines.

There are two types of Turbine Generators.

— *Single Flow Turbine Generator Plants.*

Earliest plants were of this type. The hydro power is converted into electrical power during flow in one direction only.

One set of turbines are driven during high tide flow (direction A) and generate power during hatched area *A*. Other set of turbines are driven during flow B and generate power during hatched area B. Power is generated intermittently during short spells of time as shown by hatched areas *A* and *B*. During rest of the time the plant does not generate. Hence such plants give low MWh of output energy and are uneconomical.

— Reversible Modified Turbine Plants

Turbines are reversible. Power is generated by each turbine generator unit during high tide flow (*A*) and low tide flow (*B*).

Turbines are designed for variable head from shorter heads to longer heads. Thus duration of power generation is increased to *A′* and *B′* as shown in Fig. 1.50.

Commercial Tidal Power Plants

France (1996)	24 Nos. 10 MW
River Rance	Reversible Turbines
St. Malo	Peak Power 240 MW
Brittany, France	Adverge Power 160 MW
USSR (1970)	2 MW Prototype unit

Due to high civil construction cost and low output Tidal Power Plants have not succeeded commercially. However in future such plants will be undertaken due to importance of renewables section B source of energy.

SECTION B
ENERGY STORAGE ELECTRICAL PLANTS

1.47. Need For Storage of Electrical Power and Difficulties

The demand for electrical power varies according to load daily load curves with peaks and valleys. During peak loads lasting for a few minutes to a fraction of hour, the installed capacity of all the generating plants put together should be more than total MW load. This needs high capital investment (Rs/MW). During *off-peak loads* the installed generating capacity is not utilized fully. The *load factors* are generally poor.

The problem due to poor load factor and high peak loads is two-fold.

1.47.1. The Problem of Electrical Energy Storage

1. It is difficult to meet peak load demands and installed capacity is generally inadequate to meet peak load demand. Some load scheduling is carried out to maintain frequency.

2. Increasing installed capacity for meeting peak demand of short duration is often very uneconomical.
3. Electrical energy cannot be economically stored in large quantities (several hundred MW)

1.47.2. The Solutions

1. *Inter connection* between neighbouring grid having different peak demand hour. (This is covered in Chapter)
2. *Energy storage* in large quantities (several hundred MW) Energy is stored during *off peak period* in some suitable form (*e.g.* hydro, pneumatic, thermal, chemical). During peak demand periods the energy stored in some other form is reconverted into electrical form and is supplied back to the network.

1.47.3. Types of Energy Storage Plants and Range

Type of Plant	*Plant Capacity*
1. *Storage Battery Cells Plant*	Up to 10 MW
2. *Pumped Hydro Electric Plants*	Up to 400 MW

3. *Flywheels* (Advanced Vaccum Flywheels with Magnetic Bearings)
4. *Magnetic Storage.* Super conducting magnetic energy storage (SMES) 5000 MWh
5. *Thermal Storage*
6. *Hydrogen Storage*
7. *Compressed Air or Nitrogen* Energy storage (CAES) 25, 50, 200 MW.

1.48. Comparison of Energy Storage Systems on Economic Basis

Type	*Conversion Cost Rs/MW*	*Storage Cost Rs/MWh*
1. Storage Battery	Low	High
2. Pumped Hydro	Low	Very High
3. Magnetic Storage (SMES)	Low	Very High
4. Flywheel	Medium	Very High
5. Compressed Air (CAES)	Medium	Low

1.49. Storage Battery Energy Storage

Following types of secondary cells are used

— Lead Acid Batteries

— Nickel cadmium batteries

— Advanced Batteries

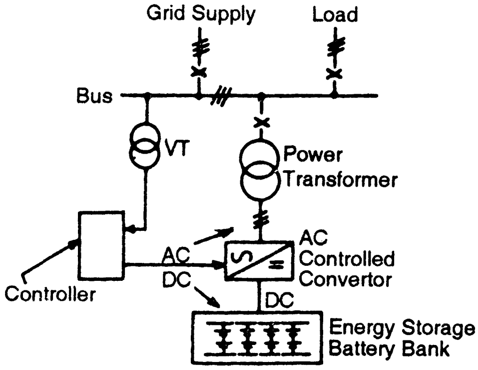


Fig. 1.51. Energy storage Battery Bank.

Cells are connected in series parallel branches to form a Battery-Bank. During off-peak periods, the circuit-breaker is switched on and the Thyristor Convertor is operated in *rectifier mode* (by controlling phase angle α) to less than 90°) Batteries get charged.

During peak loads on the grid, the thyristor convertor is operated in inverter mode (DC to AC) by increasing delay angle and beyond 90°.

The batteries supply stored energy to the network. Plants of capacity 1 MW, 5 MW, 10 MW have been installed in USA, West Germany (1990).

1.50. Pumped Hydro Energy Storage

The plant stores energy in pumped hydro form. The plant operates in following two district modes.

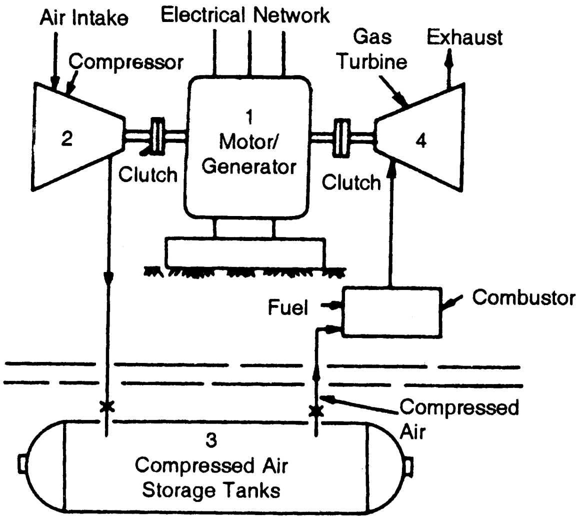


Fig. 1.52. Schematic of a Compressed Air Energy Storage Plant (CAES).

During of load :

(1) Motor and

(2) Compressor. During peak load :

(4) Gas Turbine and

(1) Generator Energy is stored in

(3) Inform of Compressed Air or Compressed Nitrogen

1. Motoring/Pumping Mode during off peak periods. Energy storage.
2. Generating/Turbine mode during peak load period. Energy Discharge.

Details in Chapter 1.

1.51. Compressed Air Energy Storage Plant (CAES)

Fig. 1.52 shows a schematic. During off peak period, the electrical machine (1) acts as an motor, taking power from Electrical Network and drives Air-Compressor (2). Energy is stored in the form of compressed air in Air storage Tanks (3). During peak loads on the electrical network. The energy in compressed air is used for driving Gas-turbine (4). The electrical machine (1) is operated in generating mode. The stored energy in (3) is supplied to the electrical network.

1.52. Super-conducting Magnet Energy Plant

This is form of electromagnetic energy storage used for obtaining very high power for short durations for damping power system oscillations or to supply energy to improve transient stability of the power system.

Fig. 1.53 illustrates the principle.

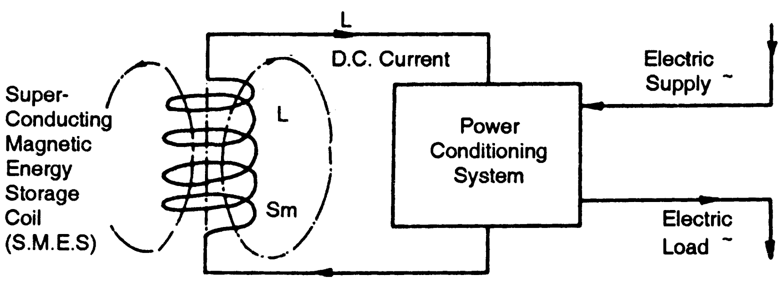


Fig. 1.53. Principle of SMES (Super-conducting Magnetic Energy Storage).

An inductance of L Henry carrying d.c. current I amp has energy.

$$S = 1/2\ L\ I^2 \text{ Joules}$$

To obtain large inductance of several henries and to obtain high current I of several kA (*e.g.* 75 kA), a very large magnetic core with super-conducting winding is necessary. The super-conducting coil is connected in the circuit on DC side of the power conditioning system. During the normal state, the energy is stored in the coil ($S = 1/2\ LI^2$). During transient instability the energy is released through the power conditioning unit.

Description

Rating 10 MW 3 sec.

Application : Damping of Sub-synchronous resonance

Presently : Experimental

Future : Commercial Versions (2000 AD)

1.53. Flywheels

Large flywheels balanced an magnetic bearings and housed in evacuated enclosure is kept rotating at high speed (30,000 rpm). The energy is stored in rotary kinetic form to absorb and dissipate mechanical energy and to smoothen the rotation of rotating machines.

1.54. Thermal Storage

This is used in colder countries (Europe/Canada) for heating residential buildings, offices etc. During off peak periods the electricity is used for heating the thermal-energy absorvers in residential buildings. During peak load on electrical network the heater supply is switched off and stored energy is dissipated through circulating water for room heating.

1.55. Hydrogen/Oxygen/chemicals

During off peak periods the electrical energy is used by chemical plant for producing Hydrogen, Oxygen and other chemical fuels/oxidants. Energy is stored in form of H_2, O_2 etc. During peak load fuel cell plant uses the fuel and oxidant to generate electricity. Such systems have not been commercialised yet.

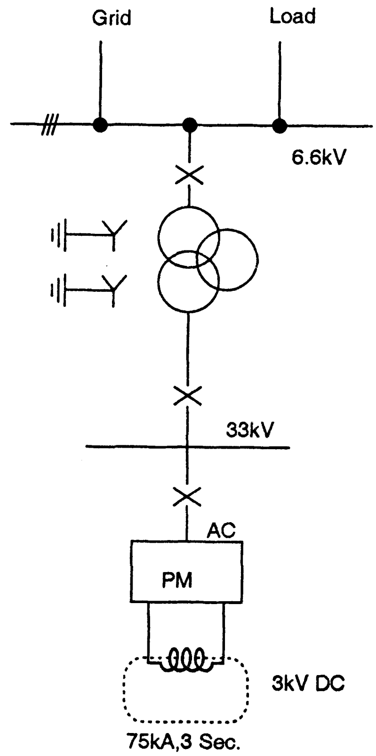


Fig. 1.54. Electrical Scheme for SMES.

Summary

Power generation from renewable energy resources includes following power plants (P.P.) :

— Wind-electric p.p.
— Solar Electric P.P.
— Geothermal Electric p.p.
— Hydro-Electric P.P.
— Ocean Wave p.p.
— Ocean Thermal p.p. (OTEC)
— Waste Incineration p.p.
— Nuclear Fusion P.P.
— Hybrid Solar/diesel p.p.
— Hybrid wind/diesel p.p.

Research efforts are directed towards newer energy resources, energy conversion and power generation. Presently, the power generation in developing countries is mostly by conventionals (Nuclear Fission, Hydro, Fossil Fuel) covered in chapter 1 A.

In future power generation form renewables is expected to have more and more share of total generated power.

Energy storage methods include :

— Hydro Pumped Storage

— Compressed Air Energy Storage (CAES)

— Super-conducting Magnet Energy Storage

— Storage batteries

— Thermal Storage — Flywheels

— H_2, O_2, Chemical Fuels for fuel cells

In these, methods, during off-peak periods, electrical energy is taken from grid an is converted and stored in suitable form. During peak load on the grid, the *stored energy* is converted back to electrical energy at 50 Hz and supplied to the network as a generated power. Thus Energy storage plants

— Help in meeting peaking demand

— Help in loading the power system during off peak periods

— Improve load Factor

— Improve energy balance

— Improve utilization of renewable energy sources (Hydro, Chemical H_2/O_2).

Energy storage Plants are of high installation cost and high conversion cost. *Interconnection* is a more successful alternative to meet peak demand.

QUESTIONS

1. Distinguish between 'Renewable' and 'Non Renewable' sources of energy and give examples of each.
2. Describe a typical Wind Farm and a Wind turbine generator unit stating the main components.
3. State the *two* methods of converting Solar energy to electrical energy.
4. What is the difference between Nuclear Fusion and Nuclear Fission ? Describe Nuclear Fusion Reactor Plant.
5. Describe a typical Geothermal Power Plant.
6. What is the difference between ocean wave and Tidal Power Plant ?
7. Describe with the help of a simple schematic "Waste Incineration Power Plant". What is a 'Co-generation Plant' ?
8. Explain the need of Energy Storage Plants with an electrical Power System. State the various types.
9. Describe the principle of a compressed air energy storage plant.
10. Illustrate the principle of superconducting Magnetic Energy Storage Plant and state its typical ratings and applications.