56

Renewable and Conventional Energy and Power Plants

56.1. ENERGY RESOURCES AND FORMS OF ENERGY

Primary energy resources are those available in nature in raw form. (Coal, Petroleum-Oil, Natural Gas, Fire-wood, wind, water and high level, solar-irradiation, Geothermal, Ocean-waves, Ocean thermal, Ocean tides nuclear fuels etc.)

Secondary energy sources are those supplied to the user for consumption (electrical energy); steam, hot water, gas in cylinders or pipe-lines, petroleum Oils, fire-wood etc.).

Fossil Fuels (Coal, Petroleum, Natural Gas are organic matters formed from plant/animal fossils under temperature, pressure by biological and chemical decomposition over past several centuries.

Non-renewable energy resources are those which do not get replenished after their consumption, *e.g.* coal once burnt is consumed without replacement, of the same (Fossil fuels, Nuclear fission fuels).

Renewables are those which are renewed by the natural again and again and their supply is not affected by rate of consumption. (Wind energy ; solar-energy, Geothermal energy , Ocean wave ; Hydro-energy etc.).

Alternative energy sources are those which are non-traditional. They are *alternatives* to the conventional energy resources.

Table 56.1. Conventional and Renewable Resources for Electrical Power Generation

Conventional	*Alternative, Renewable*
Coal	Wind power
Petroleum oils	Solar power
Natural Gas	Geothermal
Hydro	Ocean waves
Nuclear fission fuels	Oean tide
Chemical cells	— Bio-mass fuels — Waste-fuels — Bio-gas — Synthetic gases — Nuclear fusion fuels — Fuel cells — Fire-wood.

Conventional energy resources are those which have been used traditionally for several decades before 1970s. After the oil energy crisis in 1973, the non-conventional energy resources have received high priority all over the world. Cost of various energy resources is increasing steeply. This has affected the overall national economy, the standard of living and the progress of various developing and developed nations.

*For further reading : "Energy Technology-Renewable and Conventional" —S. Rao and B.B. Purulekar, Khanna Tech. Publications, Delhi, 1995.

Electrical Energy is most widely accepted form of energy all over the world. Electrical Energy is supplied by the utilities (Electrical Supply Companies) to the consumers at all times. The consumers convert the *electrical energy* to several other forms such as mechanical (drives), heat (furnaces, ovens), light (lighting), high frequency waves etc. Energy supply and electrical powers supply are intimately related.

56.2. UNITS OF ELECTRICAL ENERGY

Joule = Watts × Seconds   kWh = Kilo-watt × Hours

MWh = Mega-watt × Hours

Units of Electrical Power : Watts, kW, MW, MWe represents electrical MW rating to distinguish from thermal rating.

56.3. ELECTRICAL LOAD AND DEMAND

Customers 'demand' certain MW and this 'demand' acts as a 'load' on the power plants. Hence 'load' and 'demand' are similar terms.

The *connected load* is the MW rating of the installed load. A residential building may have a connected load of 2.5 kW.

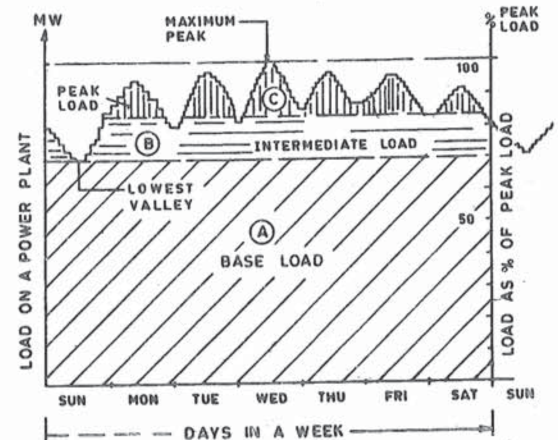
Actual demand (load) is the MW or kW power drawn by the particular user at prevailing time (say at 9 AM) *e.g.* the residential building mentioned above may have prevailing demand of 1 kW at 9 A.M. The prevailing *demand* of individual consumer, group of consumers, a locality, a city and a group of cities goes on varying during the day and during the week, during the seasons etc. This *demand* is a *load* on a power station or a group of power stations.

The *greatest problem for a power supply company is varying load.* The generation should be matched with the load constantly.

56.4. LOAD CURVES AND PEAK LOAD

Cronological time is plotted on X-axis and load in MW on a particular plant or a group of plants if plotted on Y-axis. A *load curve* is drawn for (*i*) 24 hours of a day (Daily Load Curve), (*ii*) 7 days of a week (weekly load curve) or (*iii*) 12 months of an year (Yearly Load Curves).

Fig. 56.1 shows a weekly load curve. The daily variation has a certain repetitive cyclic depending upon life-style, business hours, industrial hours etc. The load line touching the highest peak



A = Base Load stations operation period
B = Intermediate stations operation period
C = Peaking station operation period.

Fig. 56.1. Weekly Load Curve.

gives *Peak Load.* The total installed capacity of a plant (or a group of plants) should be more than the peak load with adequate surplus margin for steady state stability limits of generators, planned outages, single or twin contingency due to forced outages etc.

Instead of increasing installed capacity for peak load ; the region may import power through *interconnected line* as per scheduled exchange. Peak loads in two regions are generally displaced in time.

56.5. BASE LOAD, INTERMEDIATE LOAD AND PEAK LOAD

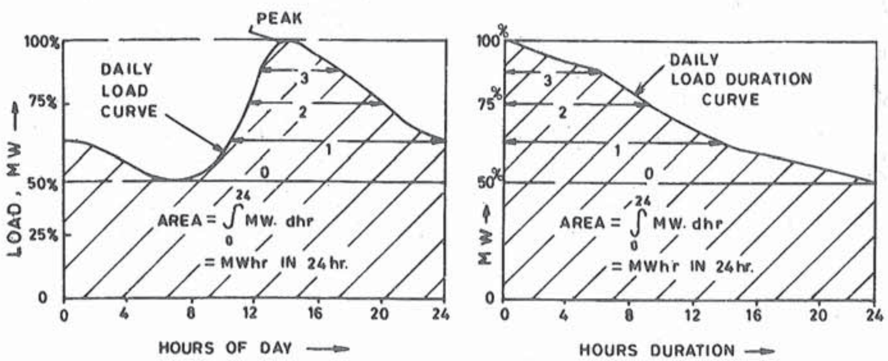
Lowest line parallel to X-axis and touching the minimum load is called the *Base Load Line.* This load is present at all the time.

The line parallel to X-axis at the base of the rising peaks is called Intermediate Load Line. In Fig. 56.1. (*A*), (*B*), (*C*) show the demarkation.

Note. During peak loads all the three categories (*A, B , C*) generate power. There should be some spare capacity for contingency.

56.6. LOAD DURATION CURVE

From daily load curve, corresponding daily load duration curve is plotted as shown in Fig. 56.2 (*a*), (*b*). The *Y*-axis is of MW load and *X*-axis is number of hours for which the load prevailed (Duration of MW).



(*a*) (*b*)

Fig. 56.2 (*a*) Daily load curve (*b*) Corresponding load duration curve.

Fig. 56.3 shows the load duration curve with markings for base load, intermediate load and peak load. **Note.** Area under the curve gives MWhr supplied.

Area under the daily load curve and corresponding daily load duration curve is given by

$$\text{Area} = \int_0^{24} \text{MW} \cdot \text{dhr} = \text{MWhr}$$

Thus area under these curves represents *electrical energy* supplied during 24 hours.

From the well known law of conservation of energy.

Total MWhr Energy Generated = Total MWhr Energy Consumed + Total MWhr Losses
Also Total MW being Generated = Total MW Prevailing + Total MW Losses

Some generating units may have lesser efficiency and higher generating cost (Rs./MWh). Such units are used for intermediate loads (*B*) Efficient units with lower generating cost are used for Base Load (*A*). Units with quick start/loading/stop are used for peaking (*C*) even though their fuel costs may be higher.

The scheduling of 5 units in a station or 5 stations in a regional grid is indicated on the left side of Fig. 56.3.

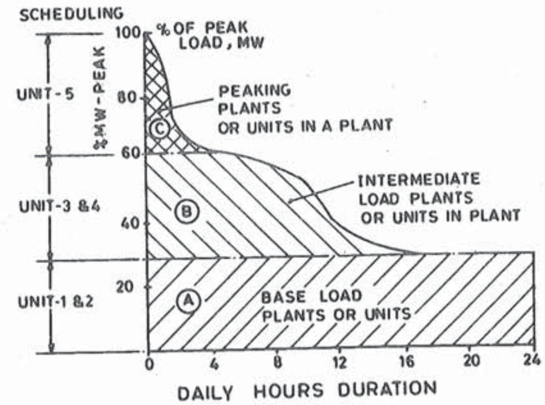


Fig. 56.3. Daily load duration curve with demarkation
(*A*) Base load (*B*) Intermediate load (*C*) Peak load.

56.7. TYPES OF GENERATING UNITS FOR BASE LOAD, INTERMEDIATE LOAD AND PEAKING LOAD

Basic requirements of the generator, turbine, primary energy convertor (boiler) differ for Base load/Intermediate load/Peak load units.

Base Load Stations/Units are with :

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

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

Peak Load Station / 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 56.2. Types of Power Plants for Base Load, Peaking Load

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

Energy Displacement Power Plants. Solar power plants and wind power plants generate electrical energy only during favourable natural conditions of sun-light and wind. During favourable conditions, they are allowed to generate full power and the other intermediate power plants are relieved of equal power generation. The energy consumption of non-renewable is displaced by corresponding amount of MWhr.

Hybrid of Renewable and Storage Plants. Energy displacement plants may operate in liaison with a conventional diesel electric plant and battery-energy storage to form Hybrid solution. Hybrid power plants introduced commercially are :

— Solar-Battery-Diesel — Wind-Battery-Diesel.

During favourable conditions of sun/wind, the storage batteries are charged. During unfavourable natural conditions the battery-back supplies energy *via* a suitable power conditioning unit (DC to AC).

When stored energy in battery-bank reduces, diesel-generator sets are started to supply the power.

Table 56.3
Operation of Renewable — Battery-Diesel Hybrid Power Plants

During favourable solar/wind Hours	→	Primary energy from renewable source converted to electrical
During unfavourable solar/wind hours — with batteries fully charged	→	Battery-pack supplies electrical energy *via*. conditioner.
— with battery charge exhausted	→	Diesel-Generator gives power.

56.8. PLANT FACTORS AND RESERVES

For economic operation of power plants and the energy supply system; load factor should be high, Diversity, Factor should be high. From the regular pattern of the daily load curves, advance preparations of the various 'reserves' are maintained.

Boilers, steam turbines, combustion processes, gas turbines etc. have different starting and loading characteristics.

Load Factor $= \dfrac{\text{MWh generated in a given period}}{\text{Maximum Demand} \times \text{Hours of operation in given period}}$

$= \dfrac{\text{Average Demand}}{\text{Maximum Demand}}$

Diversity Factor $= \dfrac{\text{Sum of individual consumers Maximum demands}}{\text{Maximum load on the station}}$

Plant Capacity Factor $= \dfrac{\text{MWhr produced}}{\text{MW capacity} \times \text{Total hours}}$

$= \dfrac{\text{MWhr. Produce}}{\text{MWhr. could be produced}}$

Plant Use Factor $= \dfrac{\text{MWhr. produced}}{\text{MW capacity} \times \text{Hours of operation}}$

Firm Power = Power which should always be readily available even during emergency state.

Cold Reserves = Reserve generating capacity available but not in operation

Hot Reserves = Reserve capacity available with thermal process in operational readyness.

Spinning Reserves = Operating capacity connected to bus and ready for taking load.

56.9. POWER PLANTS WITH CONVENTIONAL ENERGY RESOURCES

Fig. 56.4 shows the present alternatives on cost basis. The type of generating plants in a country or a region will mainly depend upon :

— natural (primary) energy resources available locally and their present and future supplies.
— Energy resources which could be transported by sea, rail, road upto the plant sites.
— Technology available/imported.
— Relative costs
— Ecological and Environmental clearances.

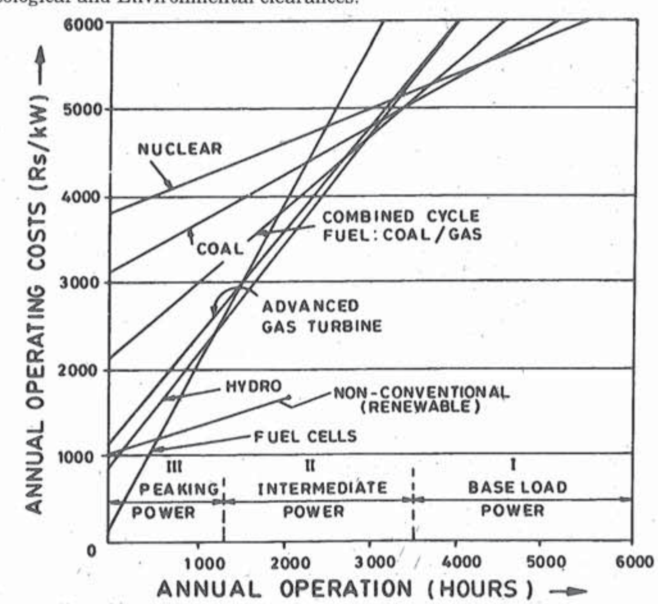


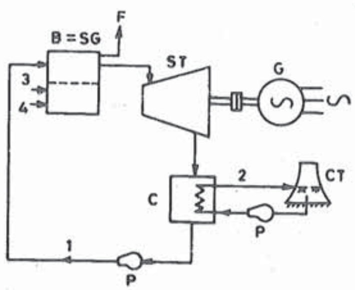
Fig. 56.4. Comparison of Generation Cost for Power Plants with different energy resources.

Conventional Power Plants of importance are :

1. Coal Fired Steam Turbine Power Plants
2. Hydro-Turbine Power Plants
3. Nuclear Reactor Power Plants
4. Gas-turbine and Combined Cycle-Power Plants. (Gas Turbines plus Steam Turbines)
5. Diesel-Engine driven Gernerator Plants

56.10. COAL FIRED STEAM-TURBINE POWER PLANTS

Refer Fig. 56.5. Pulverised Coal (powered coal) (3) and preheated air (4) are supplied to the Boiler — steam generator. Chemical energy in coal is converted into heat by *combustion*. The flue



1 = Feed water
2 = Cooling water
3 = Pulverised coal
4 = Preheated Air
B = SG Boiler Steam Generator
C = Condenser
ST = Steam-Turbine
G = Generator
CT = Cooling Tower
P = Pump
F = Flue gases

Fig. 56.5. Schematic of a Boiler — Steam Turbine Generator Unit.

gases (*F*) are sent out through stack (Chimney) after removal of fly-ash, SOx, NOx, CO etc.

Superheated high pressure steam is admitted into *steam-turbine inlet. Steam-turbine* is the prime-mover of generator-rotor. A steam turbine has series of nozzles on stator and series of buckets (Blades) on rotor. Steam *expands* from high pressure to low pressure and drives rotor blades. Steam is condensed in the condenser (*C*) at vacuum level. The condensate is recirculated as feed water (*I*).

Turbine-generator-exciter are mounted on a single shaft. The *Generator* is as a rule of 3 phase. AC, 50 Hz. Synchronous generator operating in parallel with other generators, and in synchronism with busbar/system frequency $f = N_s P/120$).

The generator units for steam turbine plants must be of higher MW rating for economical generation. Hence steam turbine generator units are generally of unit rating of 200 MW, 300 MW, 400 MW, 500 MW, 600 MW ... upto 1300 MW.

In India following unit ratings have been standardised for steam-turbine generator units :

Rated voltages	:	12 kV to 22 kV rms, ph to ph
Rated frequency	:	50 Hz ± 1%
Rated MW	:	200 MW, 237 MW (Nuclear)
		500 MW (Coal fired and Nuclear)
		800 MW (Next likely size).

Synchronous generators operate in synchronism with the other synchronous generators in the station and the network.

Coal Fired Power Plants in India. About 66% of installed MW capacity in India is by coal-fired steam turbine power plants. This percentage will be retained for about a century. India has vast reserves of coal. Estimated reserves are around 160 billion-tons with present mining rate of about 160 million-tons. India will have coal age for next hundred years (2000-2100). The coal in Indian mines is of high ash content, low heat value and low sulphur content.

Table 56.4. Indian Coal Composition Range

Ash content	25 to 50%
Sulphur content	< 1%
Heat value	12 to 16 million J/kg. 3000 to 4000 kcal/kg

India's coal reserves are in Bihar, UP, Maharashtra, Madhya Pradesh, Orissa, Andhra Pradesh, Tamil Nadu.

Present coal fired power plants are with unit sizes of 200 MW and 500 MW. The average national load factor is 58%.

Flue gases from coal fired power plants create environmental pollution by emitting fly ash (particulates). SOx, NOx, CO etc. Most of the earlier coal fired plants in India are without any Electro Static Precipitators (ESP) for controlling fly ash ; or SOx scrubbers, NOx treatment plants. Hence India's coal technology and power plant technology needs revision (1990).

56.10.1. Fluidised Bed Combustion Chamber Boilers

Coal pieces or some (other solid fuel pieces like wood chips, rice husk, wheat husk, sugar cane skins, etc.) are introduced in the furnace having a bed of ash and calcium carbonate. High velocity air through nozzles is swirlded in the furnace bed. The particles get heated by collusion and fuel burns at relatively low temperature. Water is boiled and used for steam turbines. Flue gases are cleaned and let into atmosphere or Heat Recovery Steam Generator.

Fluidised Bed Boilers are manufactured in smaller capacities (10 MW to 50 MW). They can be designed to accept a variety of solid fuels.

56.11. INTEGRATED COAL GASIFICATION COMBINED CYCLE POWER PLANTS (ICGCC)

Coal is Gasified in coal gasifier. Gasified coal is used as the primary fuel for a gas turbine of combined cycle power plant having (*i*) Gas Turbine (*ii*) Heat Recovery Steam Generator (*iii*) Steam Turbine.

ICGCPP have been recently introduced in Europe ; USA.

The main purpose is *reduction* of emission products like fly ash, SOx, NOx from combustion of the gasified coal as compared with burning of pulverised coal.

56.12. HYDRO ELECTRIC POWER PLANTS

The *potential energy* is stored water in the reservoir with high head is converted into kinetic energy is the flowing *water*.

The flowing water converts the energy into mechanical rotary energy in the hydro turbine. Hydro-turbine drives the rotor of hydro-electric generator.

The hydro-electric power plants are located near dams or river-barrages generally away from load centres. The types of hydro-turbines and power plants are classified as high head, medium head and low head power plants. The choice of turbine depends on head H and flow rate Q. There are three types of turbines (Table 56.5).

Table 56.5. Types of Hydro-Turbines

Type	*Head* H, m	*Flow rate* Q, m^3/s
Impulse (Pelton)	High 100 to 1000	2 to 100
Reaction (Francis)	Medium 5 to 30	5 to 500
Kaplan	Low 2 to 100	5 to 100

India's hydro-electric potential is about 100,000 MW mostly located in northern, Himalayan region. Present installed capacity of hydro plants is 15000 MW and is likely to be doubled to 30,000 MW by the year 2000.

Environmental problems include earthquakes, deforestation, submergence of villages/agricultural lands etc.

Financial problems include high civil-works cost, long construction periods, long transmission lines etc.

Considering the continuing supply of hydro-energy as a *primary renewable*, hydro electric power will have 20 to 30% share of the total installed capacities in India during 1990 to 2050.

Pumped Hydro Plants. During off-peak, the electrical machine operates as a motor and hydraulic machine operates as a pump. Water from lower head is pumped to higher head reservoir for *storage of energy*.

During peak loads, the higher head water flows down and drives the hydraulic machine operating in turbine mode and the electrical machine in generating mode.

There may be one or two separate hydro-machine and one electrical machine on same shaft.

Two pumped hydro plants have been commissioned in India.

56.13. NUCLEAR FISSION REACTOR POWER PLANTS

Some heavy uranium isotopes U235, U238, PU 233 etc. are used as primary fuels in a *nuclear reactor*.

Nuclear Fission is the process of splitting of a nucleus into two almost equal fragments accompanies by heat.

Fission Chain Reaction is a self-sustained continuing sequence of nuclear fission in a controlled manner.

Nuclear Reactor is a plant which initiates, sustains, controls, maintains, nuclear chain reaction and provides shielding against the radio active radiation.

Fissile Materials are materials which can give nuclear fission *e.g.* U 235.

Fertile materials are these which by certain processes get converted into fissile material (*e.g.* U238 gets converted to U235).

Nuclear Power Plant has a nuclear reactor, heat exchanger and steam turbine generators along with other auxiliaries.

There are several types of nuclear reactor power plants with names based on (*i*) Fuels (*ii*) Moderators (*iii*) Method of Heat removal (4) Patented Process etc.

India's nuclear uranium fuel resources are located in West Bengal.

Nuclear power generation is being perused regoriously in India with self dependence in engineering and technology. Presently, India has seven Pressurised Heavy Water Reactor Plant (PHWR) with 210 MW and 235 MW size steam-turbine generator units. Six 500 MW units are being installed (1990-2000). Present installed capacity of Nuclear Power Plants is 7000 MW (1991). This would grow to 10000 MW by the year 2000 AD. Thorium Cycle Plants will be introduced after 2000 AD.

Research projects for smaller nuclear fission power plants are in progress. Success has been reported in 1996.

56.14. GAS TURBINE POWER PLANTS

Fuels. Natural gas; Petroleum oils of various grades ; gases from blast furnace ; Synthetic gases ; gasified coal etc. are used as primary fuels for both (*i*) Gas Power Plant and (*ii*) Combined Cycle Power Plant.

The Gas Power Plant has the following (Ref. Fig. 56.6).

1. Air compressor
2. Fuel Combustor
3. Gas Turbine
4. Synchronous generator driven by Gas Turbine.

Gas-turbine generator units are produced in standard sizes in the range of 10 MW to 150 MW (recently 250 MW). *In simple open cycle gas-turbine power plant. The exhaust is let into atmosphere. Therefore, heat in exhaust is wasted and thermal efficiency is very poor (20%).*

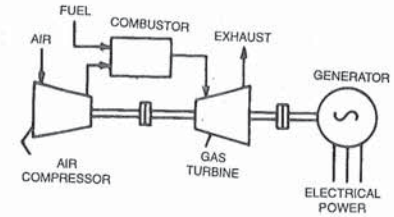


Fig. 56.6. Simple, open cycle Gas Turbine Power Plant.

Gas turbine power plants are easy to install ; have low capital cost ; quick to start ; quick to load ; quick to stop, with modular construction, with least pollution hazards etc. They are ideally suited for (*i*) peaking power plants, (*ii*) Emergency power plants (*iii*) Standby power plants (*iv*) *Supply of auxiliary power during peak loads etc.*

Due to increasing fuel costs and importance of energy conservation simple open cycle gas power plants are not favoured. The combined cycle power plants are preferred.

56.15. COMBINED CYCLE POWER PLANTS

Fig. 56.7 shows the schematic with one unit of gas turbine generator and one unit of steam-turbine generator. In practice there are two or four gas turbine generators and one steam turbine generator. *Combine Cycle Plant has a combination of (i) Gas Turbine Generators and (ii) A Steam Turbine Generator. Hence the name 'combined cycle'.*

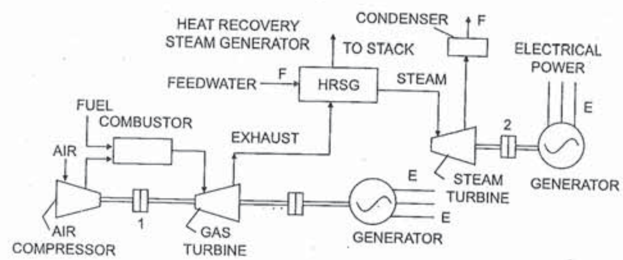


Fig. 56.7. Schematic of a Combined Cycle Power Plant Combination of 1. Gas-turbine Generator 2. Steam-turbine Generator.

Main equipment include :

1. Gas Turbine Units
   — Air Compressor — Combustor
   — Gas Turbine — Synchronous Generator
2. *Heat Recovery Steam Generator* (HRSG)
3. *Steam-Turbine Generator Unit*
   — Steam Turbine — Synchronous Generator

The flue gases from HRSG have low heat and low emission products.

56.15.1. Integrated Coal Gasification Combined Cycle Plants

Coal is gasified and used as an input fuel in the gas plant of the combined cycle plant.

India's known recoverable sources are as follows :

Crude-oil reserves	500 million-ton
Natural Gas	490 billion m^3.

Oil reserves are insufficient even for transportation sector and India is an importer of oil.

Ten 112 MW Gas Power Plant have been commissioned with total installed capacity of 896 MW (1996). Estimated potential is 1300 MW by year 2000. The gas reserves are expected to last upto 2015.

56.16. DIESEL ELECTRIC POWER PLANTS

The diesel (a petroleum oil) is primary fuel. Its energy is converted into mechanical rotary energy in a diesel engine generator units. The ratings range between a few kW to a few MW.

Diesel Engine Plants can be started quickly (a few seconds) and are preferred for

1. Peaking power plants
2. Remote, stand-alone power plants of smaller ratings where steam power plants or gas turbine power plants are not economical.
3. Hybrid of solar battery diesel.
4. Hybrid of wind-battery diesel.
5. Captive power plants for continuous process industry with uninterrupted power plants.

56.17. AGE OF RENEWABLE AND ALTERNATIVES

Fossil Fuel age is expected to span only 1000 years of human civilization (1700 AD to 2700 AD) with ever increasing population and fuel consumption rates ; and increase in petroleum product, prices ; the energy starvation is felt by every developing and developed country.

After 1973 petroleum price rice, the attention of planners, decision makers, engineers and technologists has been focussed on alternative, renewable energy resources and power plants. The alternative energy power plants have been built on commercial basis in several advanced countries developing countries have also initiated ambitious projects for harnessing the renewables. Table 56.7 gives the summary.

Present installed capacities of renewable energy plants (except hydro) in India are negligible. By the year 2000, about 250 MW installed capacity of renewables is expected in India. Present emphasis is to consume available fossil fuels. The renewable technology is under the development. It is costly and requires very high capital cost for a relatively small capacity power plants.

Table 56.7. Alternative and Renewable Energy Power Plants

Type	*Remarks*
1. Solar-Thermal Steam Power Plant or Solar Photo-Voltaic Cell Panel Power Plant	— Boiler installed on tall central tower gets reflected solar irradiation from sun-tracking mirrors on ground level. — Steam from boilers drives steam turbine-generators — Solar PV cell panels connected in series/parallel
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. — Several wind-turbine-generator units. (50 kW to 300 kW) installed in one wind-farm.
3. Geo thermal-steam Themral 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. — 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-turbine 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 rated a few MW — Flue gases cleaned before letting into atmosphere.
8. Bio-Fuels Power Plants	— Wood, Rice husk, wheet husk, special farms with fuel-crops raised in three months, etc. are burnt and heat used for steam-turbine generators.
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 nuclei gives heat.* — *Likely to serve as major energy resource in future.*
11. *Magneto Hydro Dynamics (MHD) Power Project*	— *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.*

Wind Energy. India's wind energy potential is of 20,000 MW. Wind farms would be located in sea-shores, shallow sea water, windy areas.

Wind-farms with unit rating of 50 kW to 200 kW have been installed in Gujarat, Tamil Nadu. Total installed capacity is 120 MW and projects of 200 MW capacities are under installation.

Solar Energy is being used for heating water. 50 kWe solar thermal electric plant has been installed in Gwalpheri, Haryana. Solar power plants rated 30 MWe with parabolic through collectors, steam turbine generators are being planned. First station will be built in Jodhpur.

Ocean Tidal Potential in Gujarat and West Bengal states is about 10,000 MW Kutch in Gujrat and Sunderban in West Bengal are selected as locations for ocean tidal power plants.

Ocean-thermal Power Plants rates 100 MW each are envisaged in Kulasekarpatnam, Marakkanam, Pondicherry, Cuddalore. (Tamil Nadu). Totally 6 plants of 100 MW each are being considered.

New and Renewable Sources of Energy (NRSE). Schemes under Ministry of Non-conventional Energy. India has planned following by 2000 AD.

Biomass	6000 MW
Agricultural waste	2000 MW
Solar systems	5000 MW

The share of installed capacity would be increasing rapidly after 2000 AD due to depleting fossile fuels, increasing cost of fossile fuels, established infra-structurer for alternative energy power plants. Fig. 56.8 illustrates the likely trends.

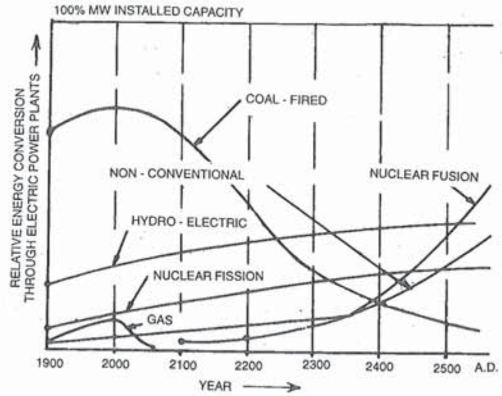


Fig. 56.8. Trends in energy resources for power generation.

56.18. ENERGY STORAGE PLANTS

It is uneconomical to increase installed capacity for meeting peak demand of few minutes or an hour or so. Energy storage plants are designed to store energy during off-peak periods and supply it during peak load periods. Following types of plants have been built in advanced countries.

— Pumped hydro (2 plants in India)
— Compressed Air (or Nitrogen) Energy Storage
— Thermal Energy Storage
— Superconducting Magnet Energy Storage (1/2 Li^2 in superconducting coal)
— Secondary cell energy storage
— Fuel-cell Energy storage (in form of fuels and oxidants derived during off-peak periods)
— Ocean tidal power plants.

56.19. POWER QUALITY

With use of digital devices, microprocessors, digital computers, plants management systems, EDP etc. the quality of electric supply has received more attention. New terms are being defined and standardised. Agreements between users and utilities with legal and political implications are envisaged particularly in advanced countries.

Power Quality is defined in terms of parameters of supply voltage and includes specified values and permissible tolerances for voltage, waveform, frequency, balance in three phase, continuity and disturbances. The *load parameters* affecting power quality include power factor ; starting currents, starting duration, load fluctuations, load unbalance, load power-factors (reactive power drawn), maximum kVA demand etc. While some terms have been defined and specified the others are not.

Table 56.8. Parameters of Power Supply Quality and Load Quality

Parameters	*Range or Limit*
1. Supply AC Voltage	Nominal, Highest, Lowest Voltages Specified
2. Voltage Disturbance — Transient overvoltages — Momentary under-voltages — Temporary under-voltages	 < 0.2 ms + 150% to 200% 4 to 20 ms with – 100% < 0.5 sec – 25% to – 30%
3. Voltage harmonic Distortion	3% to 5%
4. Electrical Noise	Not defined
5. Supply Frequency	India 50 Hz ± 3% USA 60 Hz ± 1%
6. Rate of change of frequency	1 Hz/sec.
7. 3 phase voltage unbalance in supply	2.5% to 5%
8. Load 3 phase unbalance	5% to 20% for any one phase
9. Load Power Factor	0.8 to 0.9
10. Peak Load demand	0.75 to 0.85 of connected load

Categories of Disturbances in Power Quality. These could be in terms of duration and magnitude of disturbance. Table 56.9 gives and example.

Table 56.9. Categories of Disturbances in Voltages

	Disturbance	*Duration*	*Range of Magnitude*
1.	Harmonic Distortion	Steady State to few seconds	Upto 1 percent
2.	Power Supply outage	Hours to millisecond	0 power
3.	Voltage Dips of short duration	0.5 to 50 cycles	1 to 0.5 pu
4.	Temporary overvoltages	0.5 to 50 cycles	1 to 1.75 pu
5.	Fast voltage transients (Noise, Notches, spikes in waveform	< 10 ms	up to 6 kV

The power quality encompasses several topics related with switchgear and protection. Assuring good power quality is the aim of electric power supply company and require understanding and cooperation between supply companies , users, system designers, system analysts and operating staff.

56.20. INTERCONNECTED POWER SYSTEM

Fig. 56.9 is a conceptual diagram of a National Grid (N) knowing five regional grids (*A, B, C, D, E*). Each regional grid covers the consumers in certain geographical area. Each regional grid has certain installed generating capacity (MW) of conventional/renewables and certain connected loads (Σ MW). Some interconnections are EHV-AC and some are Back-to-back HVDC coupling substations for quick, accurate power exchange and damping of system disturbances automatically.

Fig. 56.10 shows a regional grid having a variety of conventional and non-conventional power plants and the transmission and distribution networks.

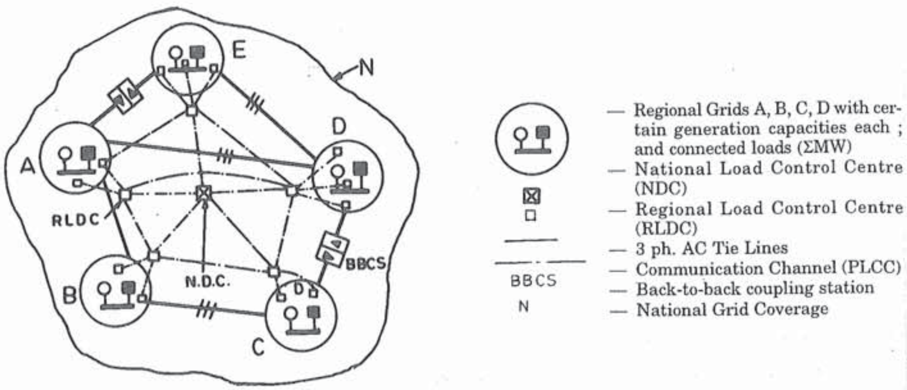
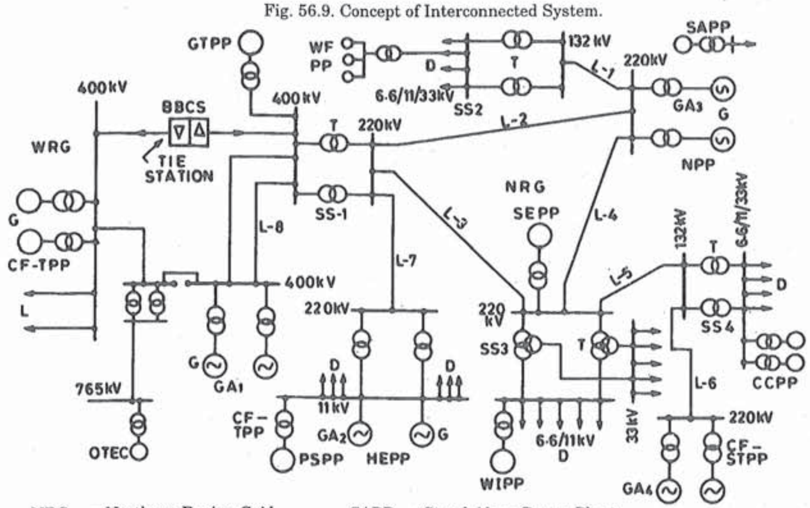


Fig. 56.9. Concept of Interconnected System.



NRG = Northern Region Grid
WRG = Western Region Grid
BBCS = Back-to-back HVC Coupling Station
PSPP = Pumped Storage PP
WIPP = Waste Incineration PP
WFPP = Wind Farms PP
G = Generator
L = Transmission Line
SAPP = Stand Alone Power Plant
SEPP = Solar Energy PP
CCPP = Combined Cycle Power Plant
CFTPP = Coal Fired Steam Thermal PP
GTPP = Geo Thermal Power Plant
HEPP = Hydro Electric Power Plant
NPP = Nuclear Power Plant

Fig. 56.10. Conceptual single line diagram of a Regional Grid.

56.21. PROJECTED GROWTH OF ENERGY SUPPLY SYSTEM INDIA

Present installed capacity is app-85,000 MW. The National Grid of Indian envisages additional 50,000 MW installed capacity during ninth plan (1996-2000). The total capacity would be about 135,000 MW by 2000 AD.

The *generation* responsibility is with National Thermal Power Corporation. (NTPC); National Hydro Power Corporation, (NHPC); State Power Corporation, State Electricity Boards etc.

With present population of 85 crores the per capita installed capacity is about 100 watts.

The EHV-AC and HVDC transmission responsibility is of newly formed Power Grid Corporation Limited (PGCL) and State Electricity Boards. The "National Power Transmission Plan 1990-2000" envisages additional 50,000 ckt km of 400 kV AC lines, 500 ckt km of 765 kV AC lines, 4000 Ckt km of HVDC lines, Five Back-to-back HVDC coupling substations between adjacent Regional Grids. Several Renewable and Conventional Power Plants would be added to achieve the target.

56.22. SIGNIFICANCE OF SWITCHGEAR PROTECTION AND POWER SYSTEM AUTOMATION

Electrical form of energy is an important link between the primary energy resources and energy forms for ultimate utilization.

Energy and power science and technology has developed to ensure continuous supply of electrical energy of good power quality without disturbing ecology and environment. The growth, prosperity, advancement of civilization is influenced by the capability of handling the energy from resources to final consumption. Per-capita installed capacity and power capita energy consumption have become accepted measures for economic progress. Modern Energy Supply Sytems are dependant on switchgear protection and power system automation for supplying quality power to all the consumers at all times in present and future.