SAMPLE STUDY MATERIAL

Mechanical Engineering

ME

Postal Correspondence Course

POWER PLANT

GATE, IES & PSUs

ENGINEERS INSTITUTE OF INDIA
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CONTENT

CHAPTER-1

INTRODUCTION TO POWER PLANT ENGINEERING

1.1 Concept of Power Plant: A power plant is assembly of system to generate electricity *i.e.* power with economy and requirements.

1.2 Classification of Power Plant

Power Plant

- Conventional
  - Gas Turbine Power Plant
  - Diesel Power Plant
  - Hydro-electric Power Plant
  - Nuclear Power Plant
  - Steam Turbine Power Plant
- Non-Conventional
  - Fuel-cell Power Plant
  - Biogas, Biamass
  - Geothermal Energy Plant
  - Ocean thermal Plant
  - Wave and Tidal Wave Plant
  - etc.

Note: The Steam Power Plant, Diesel Power Plant, Nuclear Power Plant, Gas Power Plant are called Thermal Power Plant; because these convert heat into electrical energy.

1.3 Classification of Power Plant Cycle:

(*i*) Vapour Power Cycle: Example. Carnot cycle, Rankine cycle, Reheat cycle, etc.

(*ii*) Gas Power Cycle: Example. Otto cycle, Diesel cycle, Gas turbine cycle etc.

1.4 Economics of power plant engineering: As there as an exponential growth of production of electricity. Then the rate of change of electricity production per year.

$$\therefore \frac{dE}{dt} = Ei \qquad ...(i)$$

Where, E= fractional increases rate in electricity production each year.

And $ln\frac{E}{E_o} = i(t - t_o)$

Or $E = E_o e^{i(t-t_o)} \qquad ..(ii)$

Where E_o=electricity production in the base year t_o

Equation (ii) gives the exponential behavior called doubling time

Or $\frac{E_2}{E_1} = e^{i(t_2-t_1)} \qquad ...(iii)$

If t_d= doubling time =t_2-t_1 then

$$\therefore \frac{E_2}{E_1} \Rightarrow 2$$

Therefore $(l_n)2 = it_d$

Or $t_d = \frac{0.693}{i}$ ...(*iv*)

From (iv), if i=62% then t_d=11.2 year

Note:- The demand of electricity has a linear relation with the gross national product (GNP) of a country. Thus with the increases in economic growth the consumption of electricity also increases

1.5 Power plant planning parameters:

(i) Total power output to be installed (kW_{inst})

(ii) Size of the generating units.

1.6 Determination of the total installed capacity:

(i) First demand (kW_{inst}) estimated

(ii) Growth of demand

(iii) Reserve capacity required.

1.7 Size of the generating units depend on:

(i) Variation of load (load Curve) during 24 hours.

(ii) Total capacity of units connected to the electric grid

(iii) Minimum start up and shut down periods of the units

(iv) Maintenance schedule

(v) Plant efficiency V/s size of unit

(vi) Price and space demand per kW V/s size of unit

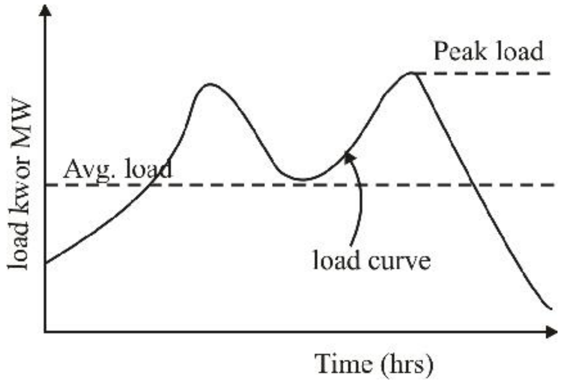
$$\therefore \textbf{Load Factor} = m = \frac{\text{Average load Over a given time interval}}{\text{peak load during the same time inerval}} \quad ...(i)$$

$$\text{Or } m = \frac{\text{kWh(Avg)in a year}}{\text{kW}_{\text{max}} \text{ in a year}}$$

if m<1 then plant capacity remains unutilized for major part of the year and electricity production cost would be high or vice-versa.

Load Curve: the average load is calculated by dividing the area under daily load curve by t he considered time period.

$$\text{Average. load} = \frac{\text{Area under load curve (kwh)}}{\text{24 hours}} \quad ..(ii)$$



- **Capacity factor or plant factor**

$$n=\frac{\text{Average load}}{\text{rated capacity of the plant}}=\frac{\text{kWh generated in a year}}{kW_{inst}\times 24\times 365} \quad ...(iii)$$

If rated capacity=peak load
Then load factor =capacity factor

- **Reserve capacity= load factor –capacity factor** …(iv)

- **Reserve factor** $=r=\frac{k\ W_{inst}}{k\ W_{\max}}$

Or $r=\frac{m}{n}$ ...(v)

- **Connected load:** Each Consumer has a connected load which is the sum of the continuous ratings of all the equipment and output on the consumer's circuits
- **Maximum demand:** It is the maximum load which a consumer uses at any time it is always less than or equal to the connected load.

$\therefore$ **Demand factor** $=\frac{\text{k W}_{\max}\ \text{(Actual)}}{\text{k W}_{\text{conn}}\text{(total)}}$ ...(vi)

- **Diversity factor:** It is the time distribution of maximum demands of similar types of consumers.

$$div=\frac{\text{sum of individual consumer groups}}{\text{Actual peak load of the syatem}} \quad ...(vii)$$

Note: High value of demand factor, load factor capacity factor required for economic operation of the plant and to produce electricity at least cost

$\therefore$ **Plant use factor** $=\text{u}=\frac{\text{kWh}_{\text{gen}}}{\text{kW}_{\text{inst}}\times\text{operting hours}}$.(viii)

If operating hour =1 year =8760 hour Then u=n
As u= 1 then need of additional capacity of the plant. Hence the plant capacity is always designed to be greater

than the peak load to take extra loads coming in future.

- **Load factor × use factor= capacity factor** …(ix)

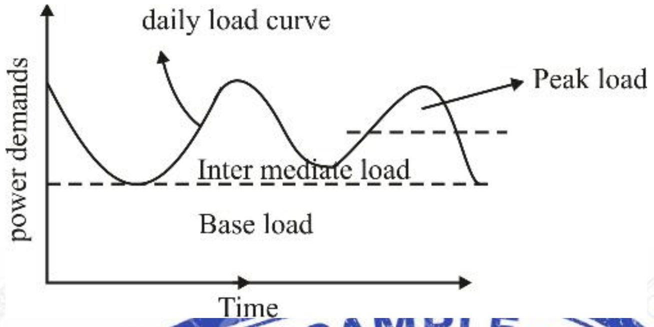
$$\therefore kWh = \int_0^{24} kW\ dt \qquad ..(x)$$

The Area under the annul load duration curve gives the total energy supplied by the utility generating system during the year and it is divided as

(i) **Base load**: it is the load below which the demand never falls and is supplied 100% of the time

(ii) **Peak load:** it occurs about 15% of the time

(iii) **Inter mediate load:** it is the remaining load region.



1.8 **Economics calculations:** A power plant should provide a reliable supply of electricity at minimum cost to the consumer. The cost per kW_{net} is determined by

(i) Fixed costs, interest, depreciation insurance, taxes capital cost.

(ii) Operation and maintenance cost including salaries and wages

(iii) fuel cost

(iv) kWh_{net} sent out per year.

- **Total annual cost**

$$C_t = \frac{I+D+T}{100} \times C_C + W + R + M + C_f \qquad ...(i)$$

Where

I= interest (%)

D= depreciation (%)

T= taxes (%) and insurance (%)

C_C=construction or capital cost

W= wages

R= Repairs or maintenance

M= miscellaneous

C_f= Fuel cost

- kWh_{net} =rated or installed output of generators

L_{Aux} = power consumption by Auxiliaries (%)

n= plant capacity factor

Annual Ratio: A measure of reliability of a power plant

$$= \frac{\text{force outage hours}}{\text{servicehours+forced outagehours}} \quad ....(iii)$$

y **Economy scale of construction cost**

$$C_{C,1} = C_{C,2}\left(\frac{R_2}{R_1}\right)^k \quad ...(iv)$$

Where

$C_{C,1}$ *and* $C_{C,2}$ are for parts with rated output of R_1 and R_2 and k<1.

1.9 Depreciation fund calculation:

(i) **Straight line method:**

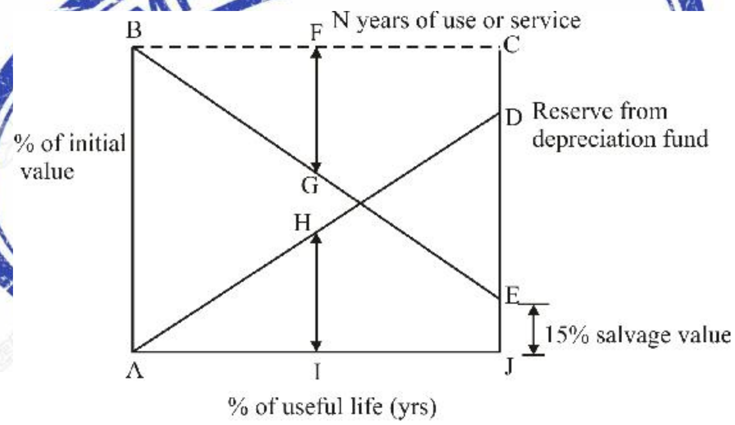
Assumption: the depreciation occurs uniformly every year as per the straight line low and the money saved neglects any interest then

$$\therefore \text{Depreciation change per year } = D = \frac{(A-G)}{N} \quad ...(i)$$

When A= capital cost of equipment

G= salvage value after

N= years of use or service



*(ii)***Sinking found method:** A sum of money is set aside every year for N years and invested to earn compound interest.

Let P= Annul deposit (for 1st year)

I= interest compounded annually when the deposit is invested

After (N-1) years the worth of equipment (compounded annually)

$$\therefore Rs = P(1+i)^{N-1} \quad ...(i)$$

And net worth=$P+P(1+i)+P(1+i)^2+....+P(1+i)^{N-1}$ …(ii)

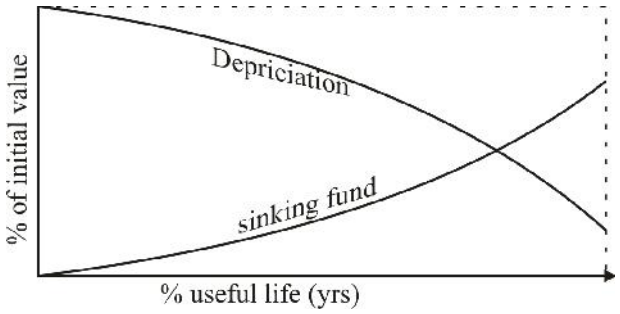
i.e a geometric progression with common ratio=r=(i+i)

$$\therefore Sum,\ S = \frac{P(1+i)^{N-1}}{i} \quad ...(iii)$$

Or S= A(capital cost)-G(salvage cost) ….(iv)

If P=annual payment to sinking found

$$=[(\text{initial value})-(\text{salvage value})] \times \frac{i}{(1+i)^{N-1}} \quad ....(iv)$$



1.10 Incremental heat Rate: the performance of a plant is given by

$$\therefore \text{Plant net heat rate } (P_{NHR}) = = \frac{\text{heat input}}{\text{net kW output}} \; kJ/kWh \quad ...(i)$$

1.11 Economic scheduling principle:

Let I_c= combined input to units 1 and 2

L_c=Combined output of units 1 and 2

When I_c is at a maximum it must hold

$$\frac{dI_c}{dL_1} = 0 .....(i)$$

Since $I_c = I_1 + I_2$

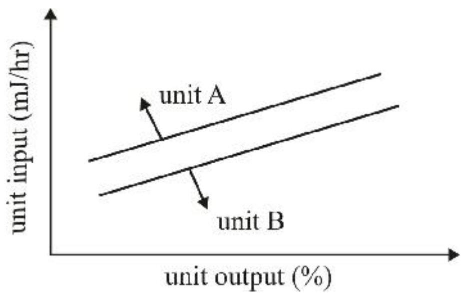
$$\frac{dI_1}{dL_1} + \frac{dI_2}{dL_2} = 0$$

$$\frac{dI_2}{dL_1} = \frac{dI_2}{dL_2} \times \frac{dL_2}{dL_1}$$

Since $L_c = L_1 + L_2$

$$\frac{dL_2}{dL_1} = -1$$

$$\frac{dI_2}{dL_1} = (-)\frac{dI_2}{dL_2} \quad ...(ii)$$



Q.1 A power station supplies the following loads to the consumers:

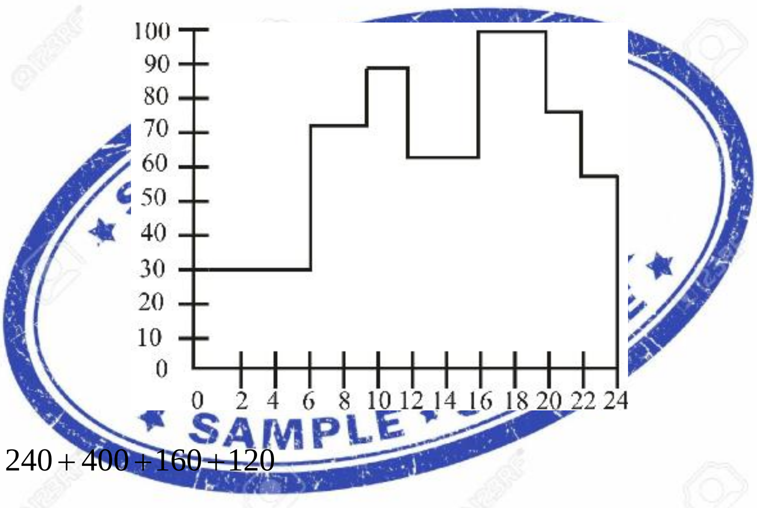
Time in hours	0 – 6	6 – 10	10 – 12	12 – 16	16 – 20	20 – 22	22 – 24
Load in MW	30	70	90	60	100	80	60

(a.) Draw the load curve and estimate the load factor of the plant. (b) What is the load factor of a standby equipment of 30MW capacity if it takes up all loads above 70MW? What is its use factor?

Ans. (a.) The load curve is drawn in figure

Energy generated= area under the load curve

$= 30 \times 6 + 70 \times 4 + 90 \times 2 + 60 \times 4 + 100 \times 4 + 80 \times 2 + 60 \times 2$



$= 180 + 280 + 180 + 240 + 400 + 160 + 120$

$= 1560\ MWh$

Average load $= \dfrac{1560\ MWh}{24h} = 65MW$

Load factor$= \dfrac{\text{average load}}{\text{Peak load}} = \dfrac{65}{100} = 0.65$ *Ans.*

(b) If the load 70 MW is supplied by a standby unit of 30 MW capacity, the energy generated by it

$= 20 \times 2 + 30 \times 4 + 10 \times 2$

$= 40 + 120 + 20 = 180MW\ h$

Time during which the standby unit remains in operation

=2+4+2=8 h

Average load = 180MW h/8h= 22.5 MW

Load factor =22.5/30=0.75 *Ans.*

$$\text{Use factor} = \frac{\text{energy generated}}{\text{plant capacity} \times \text{operating hours}}$$

$$= \frac{180 \times 10^3 kWh}{30 \times 10^3 kW \times 8h} = 0.75 \ Ans.$$

Q.2 The peak load on a power plant is 60MW. The loads having maximum demands of 30MW, 20MW, 10MW and 14MW are connected to the power plant. The capacity of the power plant is 80 MW and the annual load factor is 0.50. Estimate (a) the average load on the power plant, (b) the energy supplied per year, (c) the demand factor, (d) the diversity factor.

Ans:

(a) $$\text{Load factor} = \frac{\text{average load}}{\text{peak load}}$$

$$0.5 = \frac{\text{average load}}{60MW}$$

Average load =30 MW *Ans.*

(b) Energy supplied per year

$$= \text{average load} \times 8760\text{h}$$

$$= 30 \times 8760 MWh = 262.8 \times 10^6 kWh \ Ans.$$

(c) $$\text{Demand factor} = \frac{\text{sum of individual maximum demands}}{\text{simultaneous maximum demands}}$$

$$= \frac{30+20+10+14}{60} = \frac{74}{60}$$

$$= 1.233 \ Ans.$$

Q.3 A thermal power plant of 210MW capacity has the maximum load of 160MW. Its annual load factor is 0.6. The coal consumptions is 1kg per kWh of energy generated and the cost of coal is Rs 450.00 per tonne. Calculate (a) the annual revenue earned if energy is sold at Re 1per kWh and (b) the capacity factor of the plant.

Ans:

Annual load factor = (average load)/(peak load)

Average load= $0.6 \times 160 = 96MW$

Energy generated per year

$$= 96 \times 8760 Mwh = 840.60 \times 10^3 kWh$$

Coal required per year $= 840,960 \times 10^3 kg$

=840,960 tonnes

Cost of coal per year $= 840,960 \times 450 = Rs378.432 \times 10^6$

Cost of energy sold =Rs840,960×10^3

=Rs 840.96×10^6

(a) Revenue earned by the power plant per year

$$= \text{Rs}\,840.96\times10^6 - \text{Rs}\,378.432\times10^6$$

$$= \text{Rs}\,462.528\times10^6 = Rs\,46.25 \text{ crore} \qquad \text{Ans.(a)}$$

(b) Capacity factor $= \dfrac{\text{average load}}{\text{capacity of plant}} = \dfrac{69MW}{210MW}$

$= 0.457 \quad Ans.(b)$