UNIT - 1

Introduction:

The function of a power station is to delivers power to a large number of consumers. The power demands of different consumers vary in accordance to their activities. The demands of consumers form the load on a power station.

Variable load.

The load on a power station varies from time to time due to uncertain demands of the consumers and is known as variable load on the station.

Effects of variable load.

1) Need of additional equipment:-

The variable load on a power station necessitates to have additional equipment. Consider a steam power station. Air, coal and water are the raw materials for this plant. For instance, if the power demand increases, it must be followed by increased flow of coal, air and water to the boiler in order to meet the increased demand. Therefore, additional equipment has to be installed to accomplish this job.

2) Increase in production cost

The variable load on the plant increases the cost of production of electrical energy. If the power demand increases the use of a no. of generating units increases. the initial cost per kW of plant capacity aswell as floor area required increases. This leads to increase in production cost of energy. In practice, alternators with different capacities are installed to generate variable power (if high capacity alternator operates for light loads, it leads to poor efficiency)

Load curves.

The curve showing the variation of load on the power station with respect to time is known as a load curve.

Daily load curve:

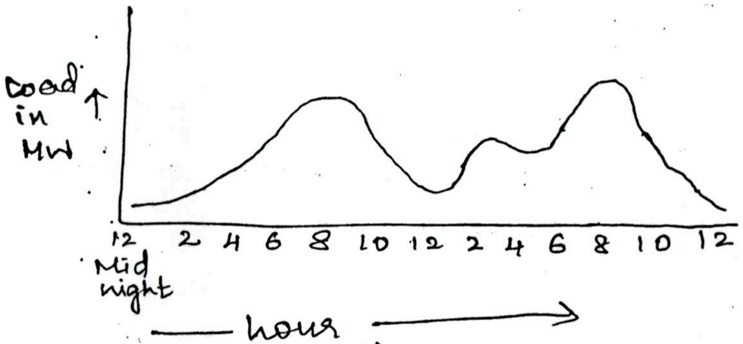
The load variations during the whole day (24 hrs) are recorded half hourly or hourly and are plotted against time on the graph is called Daily load curve

Monthly load curve.

Average values of power over a month at different times of the day are calculated and the plotted on the graph. Thus the monthly load curve can be obtained from the daily load curves of that month. This curve is generally used to fix the rates of energy.

The Yearly load curve is obtained by considering the monthly load curves of that particular year. This curve is generally used to determine the annual load factor.

Load curve (Daily)



* The area (kWh) under the daily load curve gives the no. of units generated in the day.
* The highest point on the daily load curve represents the maximum demand on the station on that day
* The load curve helps in selecting the size and no. of generating units.
* The load curve helps in preparing the operation schedule of the station.

1) Connected load:

It is the sum of continuous ratings of all the equipments connected to supply system.

(The sum of the connected loads of all the consumers is the connected load to the power station)

2) Maximum demand:

It is the greatest demand of load on the power station during a given period.

(Maximum demand is generally less than the connected load)

3) Demand factor:

It is the ratio of maximum demand on the power station to its connected load

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

* Demand factor << 1
* The demand factor helps in determining the capacity of plant equipment.

The average of loads occuring on the power station in a given period (day or month or year) is known as average load or average demand.

Daily average load = $\frac{\text{No. of units (kWh) generated in a day}}{\text{24 hours}}$

Monthly average load = $\frac{\text{No. of units (kWh) generated in a month}}{\text{No. of hours in a month}}$

Yearly average load = $\frac{\text{No. of units (kWh) generated in a year}}{\text{8760 hours}}$.

5) Load factor:

The ratio of average load to the maximum demand during a given period is known as load factor.

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

Load factor = $\frac{\text{Average load} \times T}{\text{Max. demand} \times T}$

= $\frac{\text{Units generated in T hrs}}{\text{Max. demand} \times \text{T hrs}}$

* The load factor may be daily, monthly or annual load factor. if the time period considered is a day or month or year.
* Load factor is always less than 1.
* The load factor helps in determining the overall cost per unit generated.
* Higher the load factor of the power station lesser will be the cost per unit generated.

6) Diversity factor:

The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor.

Diversity factor = $\frac{\text{Sum of individual max. demands}}{\text{Max. demand on power station}}$

* Diversity factor will always be greater than 1
* Greater the diversity factor, lesser is the cost of generation of power.

7) plant capacity factor:-

It is the ratio of actual energy produced to the max. possible energy that could have been produced during a given period.

$$\text{plant capacity factor} = \frac{\text{Actual energy produced}}{\text{Max. energy that could have been produced}}$$

$$= \frac{\text{Average demand} \times T}{\text{Plant capacity} \times T}$$

$$= \frac{\text{Average demand}}{\text{plant capacity}}$$

$$\text{Annual plant capacity factor} = \frac{\text{Annual kwhr o/p}}{\text{Plant capacity} \times 8760}$$

plant capacity factor is the indication of reserve capacity of the plant.

Reserve capacity = plant capacity − Max demand

(or)

Reserve capacity = Load factor − plant capacity factor.

8) plant use factor:-

It is ratio of kwh generated to the product of plant capacity and the no. of hours for which the plant was in operation.

$$\text{Plant use factor} = \frac{\text{Station output in kwh}}{\text{Plant capacity} \times \text{Hours of w.}}$$

9) Units generated per annum.

$$\text{Load factor} = \frac{\text{Average load}}{\text{Max. demand}}$$

Average load = Max. demand × Load factor

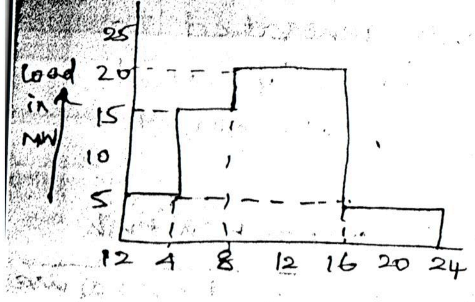
Units generated/annum = Average load (in kW) × Hours in a year

= Max. demand × L.F × 8760

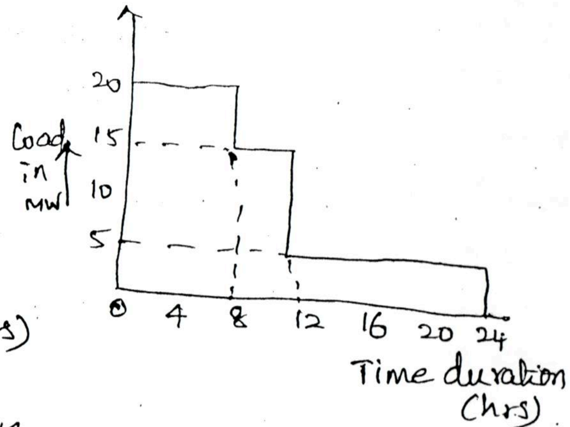
10) Load duration curve:-

When the load elements of a load curve are arranged in the order of descending magnitudes, the curve thus obtained is called Load duration curve

Load curve



Load duration curve.



Load duration curve.

1) It gives data in a more presentable form.
2) The load duration curve can be extended to include any period of time. annual load curve can be drawn by extending x-axis from 0 to 8760 hrs
3) It shows the no. of hours during which the given load has prevailed.

Types of Loads.

A device which taps electrical energy from the power system is called a load on the system.

(i) Domestic load
(ii) Commercial load
(iii) Industrial load
(iv) Municipal load
(v) Irrigation load.
(vi) Traction load.

Problems :-

1) The maximum demand on a power station is 100 MW. if the annual load factor is 40% calculate the total energy generated in a year.

$$\text{Annual Load factor} = \frac{\text{Energy generated/Year}}{\text{Max.demand} \times (24\times365)}$$

Energy generated in a year = Max.demand × L.F × 8760 hrs

$= 100\times10^3 \times 0.4 \times 8760$ KWh

$= \underline{3504\times10^5 \text{ KWh}}$.

2) A generating station has a connected load of 43 MW and a maximum demand of 20 MW; the units generated is 61.5×10^6 KW/an. calculate i) demand factor and load factor.

$$\text{Demand factor} = \frac{\text{Max. demand}}{\text{Connected load}} = \frac{20}{43} = 0.46$$

$$\text{Load factor} = \frac{\text{Units generated/Annum}}{\text{Max.demand} \times 8760}$$

$$\text{Load factor} = \frac{61.5\times10^6}{20\times10^3 \times 8760} = 0.351$$

3) A 100MW power station delivers 100MW for 2hrs, 50MW for 6hrs and is shut-down for the rest of each day. It is also shut down for maintanence for 45 days each year. calculate its annual load factor.

Energy supplied for each working day $= (100\times2)+(50\times6) = 500\,MWh$

Station operates for $365-45 = 320$ days in a year.

Energy supplied/Year $= 500\times320 = 160{,}000\,MWh$

Annual load factor

$= \dfrac{\text{Energy supplied / Year}}{\text{Max. demand} \times \text{working hours in a year}}$

$= \dfrac{160{,}000\ MWh}{(100)\times(320\times24)}$

$= 0.208$

4) A generating ... 25MW, a load factor of 60%, a plant capacity factor of 50% & plant use factor of 72%. find i) reserve capacity of the plant ii) the daily energy produced iii) max. energy that could be produced daily, if the plant while running as per schedule were fully loaded.

Given:-

Max. demand = 25MW

L.F = 60%

PCF = 50%

PUF = 72%

$L.F = \dfrac{\text{Average demand}}{\text{Max. demand}}$

Avg. demand $= 0.6\times25 = 15\,MW$

$PCF = \dfrac{\text{Avg. demand}}{\text{Plant capacity}}$

Plant capacity $= \dfrac{15\,MW}{0.5} = 30\,MW$

(i) Reserve capacity = plant capacity − Max. der

$= 30-25 = 5\,MW$

(ii) Daily energy produced = Avg. demand $\times 24$

$= 15\times24 = 360\,MWh$

(iii) Max energy that could be produced

$$= \frac{\text{Actual energy produced in a day}}{\text{Plant use factor}}$$

$$= \frac{360}{0.72} = 500 \text{ MWh/day}.$$

5) A diesal station supplies the following loads to various consumers.

Industrial consumer = 1500 kW

commercial establishment = 750 kW

Domestic power = 100 kW

Domestic light = 450 kW.

If the max. demand on the station is 2500 kW and no. of kWh generated / year is 45×10^5. determine i) diversity factor (ii) annual load factor.

(i) Diversity factor $= \frac{1500+750+100+450}{2500} = 1.12$

(ii) Avg. demand $= \frac{\text{kWh gen/annum}}{\text{Hrs in a year}} = \frac{45 \times 10^5}{8760}$

$= 513.7$ kW

$\therefore$ L.F $= \frac{\text{Average load}}{\text{Max. demand}} = \frac{513.7}{2500}$

$= 0.205$

$= 20.5\%$.

HW 6) A power station has a max. demand of 15000 kW. The annual load factor is 50%. and plant capacity factor is 40%. Determin the reserve capacity of the plant.

Ans. plant capacity = 18,750 kW

Reserve capacity = 3750 kW

7) A power supply is having the following loads

	Type of load	Max. demand	Diversity of group	Demand factor
1.	Domestic	1500	1.2	0.8
2.	commercial	2000	1.1	0.9
3.	Industrial	10,000	1.25	1

if the overall system diversity factor is 1.35. determine i) Max. demand (ii) connected load of each type.

Soln :-

$$\text{Max. demand} = \frac{\text{Sum of indiv. Max. dem}}{\text{Diversity factor}}$$

Max. demand on system $= \frac{1500+2000+10,000}{1.35} = 10,000$ kW.

connected domestic load $= \frac{\text{Max. demand of diff. domest. con}}{\text{Demand factor.}}$

$= \frac{\text{Max. domestic demand} \times \text{diversity}}{\text{demand factor}}.$

$= \frac{1500 \times 1.2}{0.8} = 2250$ kW.

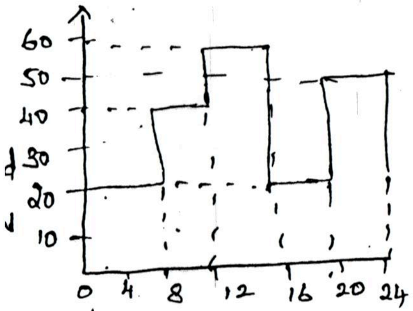
Connected commercial load $= \frac{2000 \times 1.1}{0.9} = 2444$ kW

Connected industrial load $= \frac{10,000 \times 1.25}{1} = 12,500$ kW

8) A power station has the following daily load cycle

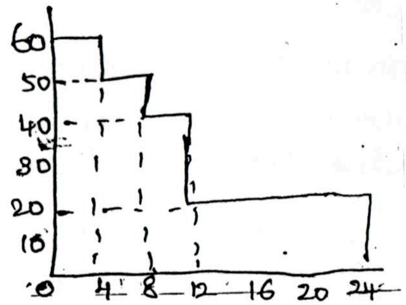
Time in hrs	6-8	8-12	12-16	16-20	20-24	24-6
Load in MW	20	40	60	20	50	20

Plot load curve & load duration curve & calculate the energy generated/day.



Time of day

Load curve



Load duration curve

Units generated/day = Area (in kWh) under daily load curve

$= 10^3((20 \times 8) + (40 \times 4) + (60 \times 4) + (20 \times 4) + (50 \times 4))$

$= 840 \times 10^3$ kWh

9) The annual load duration curve of a power station can be considered as a straight line from 20 MW to 4 MW. To meet this load, three turbine generator units, two rated at 10 MW each & one rated at 5 MW are installed. Determine (i) installed capacity (ii) plant capacity factor (iii) units generated per annum (iv) load factor (v) utilisation factor.

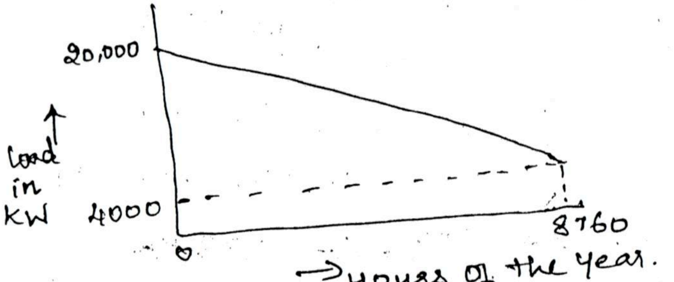
Ans

Installed capacity $= 10 + 10 + 5 = 25$ MW

Average demand $= \frac{20+4}{2} = 12$ MW

Plant factor $= \frac{\text{Average demand}}{\text{Plant capacity}}$

$= \frac{12}{25} = 0.48$



Units generated / Annum = Area in (kWh) under load duration curve

$= \frac{1}{2}(4000 + 20,000) \times 8760$

$= 105.12 \times 10^6$ kWh

Load factor $= \frac{12,000}{20,000} = 0.6$ or 60%

Utilisation factor $= \frac{\text{Max. demand}}{\text{plant cap}} = \frac{20,000}{25,000} = 0.8$

10) A power station has a daily load cycle 260 MW for 6 hrs, 200 MW for 8 hrs, 160 MW for 4 hrs, 100 MW for 6 hrs.
If the power station is equipped with 4 sets of 75 MW each. calculate (i) daily load factor (ii) plant capacity factor (iii) daily requirement if the calorific value of oil used were 10,000 kcal/kg and average heat rate of station were 2860 kcal/kWh.

Sol.

Station capacity $= 75\,MW \times 4 = 300 \times 10^3\,kW$

Max. demand $= 260\,MW$.

Units generated/day $= 10^3[(260\times6)+(200\times8)+(160\times4)+(100\times6)]$

$= 4400 \times 10^3\,kWh$

(i) Daily load factor $= \dfrac{4400\times10^3}{260\times10^3\times24} \times 100 = 70.5\%$.

Plant capacity factor $= \dfrac{\text{Avg. demand}}{\text{Station capacity}}$

Avg. demand $= \dfrac{4400\times10^3}{24} = 1,83,333\,kW$

(ii) $PCF = \dfrac{1,83,333}{300\times10^3} \times 100 = 61.1\%$

(iii) Heat reqd/day = plant heat rate × units/day

$= 2860 \times 4400 \times 10^3\,kcal$

Fuel reqd/day $= \dfrac{2860\times4400\times10^3}{10,000} = 1258.4\times10^3\,kg$

$= 1258.4$ tons

11) A power station has to meet the following demand: (11)

Group A : 200 kW between 8 A.M & 6 P.M
Group B : 100 kW between 6 A.M & 10 A.M
Group C : 50 kW between 6 A.M & 10 A.M
Group D : 100 kW between 10 A.M & 6 P.M & then between 6 P.M & 6 A.M.

plot daily load curve and determine
(i) diversity factor (ii) units gen./day
(iii) load factor.

Ans

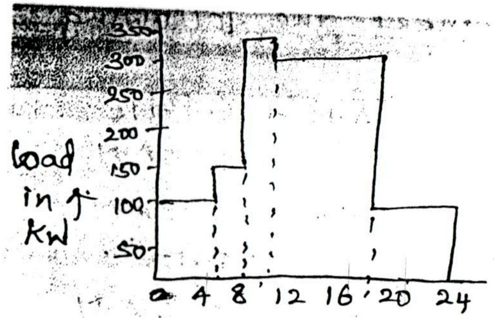
The given load cycle can be tabulated as

Time in hrs	0-6	6-8	8-10	10-18	18-24
Group A	—	—	200 kW	200 kW	—
Group B	—	100 kW	100 kW	—	—
Group C	—	50 kW	50 kW	—	—
Group D	100 kW	—	—	100 kW	100
Total load	100 kW	150 kW	350 kW	300 kW	100

Max. demand = 350 kW.

Sum of individual max. demand of groups $= 200+100+50+100$

$= 450\,kW$



(i) Diversity factor = $\frac{\text{Sum of ind. max. demand}}{\text{Max. demand}}$

$= \frac{450}{350} = 1.286$

(ii) Units generated/day

= Area under Load curve (kWh)

$= (100\times6)+(150\times2)+(350\times2)+(300\times8)+(100\times6)$

$= 4600$ kWh

(iii) Avg. load $= \frac{4600}{24} = 191.7$ kW

Load factor $= \frac{191.7}{350} \times 100 = 54.8\%$

12) A generating station has the following daily load cycle (12)

Time	0-6	6-10	10-12	12-16	16-20	20-24
Load (MW)	40	50	60	50	70	40

Draw load curve & find (i) Max. demand (ii) units gen/day (iii) Average load (iv) load factor.

Ans Units gen/day $= 12\times10^5$ kWh

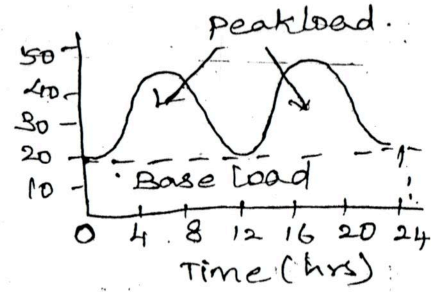
Average load = 50,000 kW

Load factor = 71.4%

Base Load & peak load on power station

The load on the power station varies from time to time.

1) Base load
2) Peak Load



1) Base load :-

The unvarying load which occurs almos the whole day on the station is known as Base load

Peak load :

The various peak demands of load over and above the base load of the station is known as peak load.

The more efficient plant is used to supply base load & less efficient plant is used to supply peak load.

Important points in the selection of units

1. The number and sizes of units should be selected that they approximately fit the annual load curve of the station.
2. The units should be preferably of different capacities to meet the load requirements.
3. The capacity of the plant should be made 15% to 20% more than the max. demand to meet the future load requirements.
4. There should be a spare generating unit so that repairs and overhauling of working units can be carried out.
5. The tendency to select a large no. of units of smaller capacity in order to fit the load curve should be avoided. Because the investment cost per kW of capacity increases as size of unit decreases.

1) A generating station is to supply four regions of load whose peak loads are 10 MW, 5 MW, 8 MW, 7 MW. The diversity factor at the station is 1.5. Avg. annual load factor is 60%. Calculate
(i) Max. demand on the station
(ii) annual energy supplied by the station
(iii) Suggest the installed capacity and no. of units.

Ans
i) Max. demand on station = $\dfrac{\text{Sum of max. demands of the region}}{\text{Diversity factor}}$

$$= \frac{10+5+8+7}{1.5} = 20\text{ MW}$$

ii) Units gen/annum
= Max. demand × L.F × Hrs in a year
$= (20\times10^3)\times(0.6)\times 8760$ kWh
$= 105.12\times10^6$ kWh

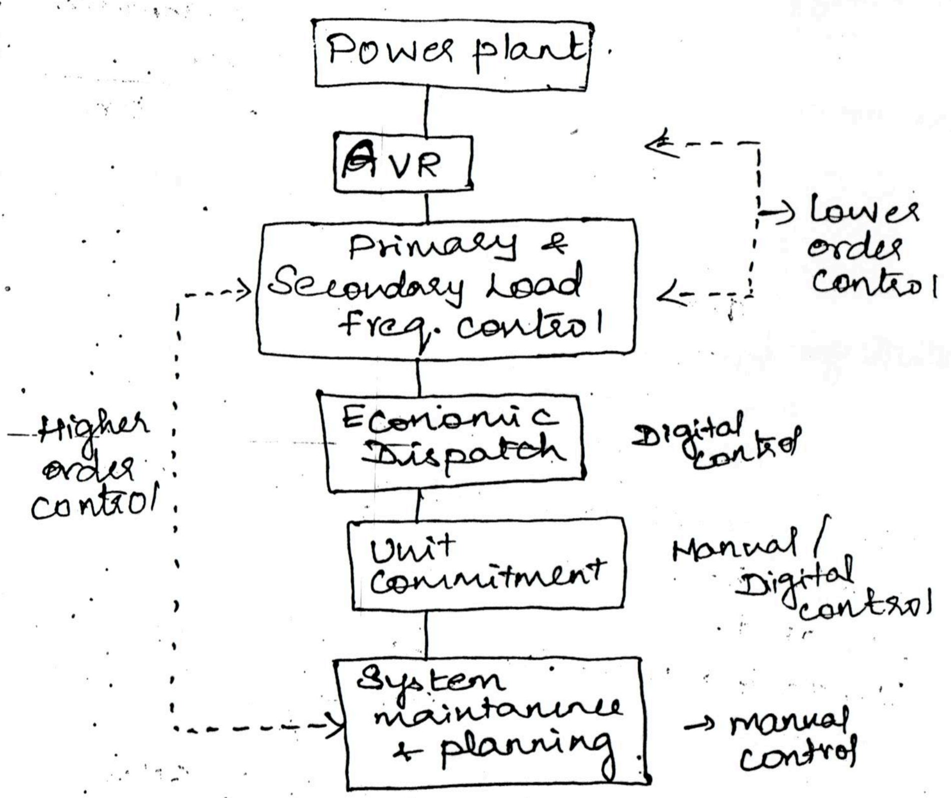
(iii) The installed capacity of the station should be 20% more than the max. demand.
Installed capacity = 1.2 × Max. demand
= 1.2 × 20
= 24 MW

Suitable unit sizes are 4, each of 6 MW capacity.

An overview of power system operation and control.

Power system control is required to maintain demand, while the system frequency, voltage level and security are maintained.

Hierarchial control Structure.



Power system operation is required to ensure the supply of good quality of power to customer. The power delivered to the consumer should be economical and reliable.

(i) AVR loop:- (Exciter control) - plant level control

It is assigned to control the magnitude of terminal voltage (v) of generator, which inturn maintains bus voltage. The terminal voltage is sensed continously and is rectified & compared with a preset dc reference V_{ref}. Then this compared error voltage after amplification is used to control field excitation of alternator.
In this way, terminal voltage of generator is automatically regulated.
AVR loop achieves Q balance by maintaining constant voltage.

(ii) ALFC loop:

It is used to achieve real power balance in the system to maintain constant frequency.

Primary ALFC loop: (Governor control - plant level control)

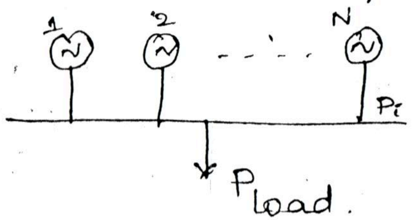
It senses the turbine speed & controls the operation of control valves of turbine. This loop is faster than secondary ALFC loop. It operates in order of secs. It is coarse adjustment of frequency.

Secondary ALFC loop:

It senses the electrical frequency of generator output & maintains proper power interchange with interconnection. This loop is slower and insensitive to rapid load change. It operates in order of mins. It is fine adjustment of frequency.

(iii) Economic dispatch: (power system optimization)

The main objective is to minimize fuel cost rate of unit while satisfying load and losses in transmission lines.



Let us take N thermal generating units connected to a single busbar serving a received electrical load P_{load}.

The I/p to each unit is $F_i \Rightarrow$ Fuel cost rate of unit.

The O/p of each unit is $P_i \rightarrow$ electrical power generated by that units.

Total cost rate of system is sum of costs of each of individual units.

Objective fn:-

Minimize

$$F_T = F_1 + F_2 + \dots + F_N$$
$$= \sum_{i=1}^{N} F_i(P_i)$$

Subject to constraint

without loss: $P_{load} - \sum_{i=1}^{N} P_i = 0.$

with loss $P_{load} + P_{loss} - \sum_{i=1}^{N} P_i = 0$

(iv) Unit commitment (power system operation)

Introduction.

Load on the system varies from time to time. When industrial loads are high load on system will be high. During weekend days load will be less.

Why is this a problem in the operation of electric power system? Why not just commit (turn on) enough units to cover maximum demand & keep them running always! But a great deal of money can be saved by turning off the units when they are not needed.

"Commit the units according to the demand (load). Decommit the units when they are not needed"

Spinning reserve.

If one unit is lost, there must be ample reserve on other units to make up for the loss. The spinning reserve is the term used to describe the total amount of generation available from all the units minus load + losses.

It must be a given % of forecasted demand. It must be spread around the power system.

Load Forecasting.

Load forecasting is a method to estimate the load for a future time point from the available past data.

Load forecasting techniques.

Load curve describes the variation of load with respect to time. Daily load curve can be divided in to 2 parts. constant + variable constant part corresponds to base load while other variable part depends on the nature of customers.

$$d(\sigma) = \underbrace{d_d(\sigma)}_{\text{deterministic part (constant)}} + \overbrace{d_s(\sigma)}^{\text{stochastic part (variable)}}$$

$\sigma \rightarrow$ present time.

$d(\sigma+j) \Rightarrow$ future where $j \rightarrow$ lead time.

Load forecasting may be done by any of the methods

(i) Extrapolation
(ii) correlation
(iii) A combination of both.

There are
short term, Medium term, long term
load forecasting

(i) Method of Extrapolation

The extrapolation technique is based on curve fitting to previous data available. Then with a trend curve obtained from the curve fitted, the load can be forecasted at any future point $(t=\sigma+j)$ by calculating trend curve function at that point $(t=\sigma+j)$. This method is very simple. The errors in data available and errors in curve fitting are not accounted for. ∴ this is called deterministic extrapolation. The method of least squares is generally adopted for curve-fitting. if the accuracy of the forecast available is tested using statistical measures such as mean & variance the basic technique becomes a probabilistic extrapolation.

(ii) Method of correlation

The correlation technique relates the system loads to various demographic and economic factors. This method requires

(i) the interrelationship between nature of load growth and other measurable factors
(ii) forecasting demographic and economic factors.

State estimation :-

The objective of state estimation is to obtain best possible values of bus voltage (magnitude & angle) by using available network data. It estimates true value of state variables. State variables are voltage magnitudes & phase angle at the buses. The inputs to state estimation are imperfect power system measurements. The purpose of state estimation is to design best estimate of state variables though there are errors in the measured quantities & there may be redundant measurements in input. The output data can be used for various real time studies & security analysis.

Control centres.

Nowadays major control centre posses SCADA for system data collection and monitoring.

Functions of control centres.

1) planning :

The most important aspect is
(i) Load forecasting
(ii) generator scheduling
(iii) plant scheduling
(iv) unit commitment
(v) Reactive power scheduling

In plant scheduling, for base load, nuclear plants & steam plants, fossil-fuel fixed units are chosen.

for Intermediate load :- Hydro power plants are most convenient choice where MW output can be controlled by changing waterflow through turbine

for peak load :- Fast responding units are more convenient choice. They are quick start diesel or gas turbine units, pumped storage units.

In reactive power scheduling, during light load system have more reactive power, shunt reactor (inductive) are to be pressed in to service to control voltage. During heavy load, system voltage drops and it needs to inject capacitive reactive power in to system. capacitive reactive compensators are then pressed in to service.

2) Monitoring.

It monitors whether load-generation balance is maintained with respect to Q and real Power, Voltage levels are maintained with in the limits

Control centres should know the following information

1. reactive power, real power
2. frequency
3. Breaker status at substations
4. Exact configuration of power system network

All these information are picked up at regional load dispatch centre & telemetered to central control station and updated. The central control centre receives all these data & checks their validity and displays the information to operator.

[Normally freq variation up to ±0.5% may be tolerated. voltage change of ±3% in transmission sector may be tolerated]

Load varies from time to time. The individual loads may be entirely random in character.

1) At transmission levels, the lumped loads vary in a predictable fashion with time. In general there is considerable variation, not only throughout the hours of the day, but also between weekdays & sundays & holidays.

2) Although the loads are time variant, the variations are relatively slow from minute to minute

3) The typical load always consumes reactive power. Because Motor load is an important ingredient in most cases. Motors are always inductive.

4) The typical load is always symmetric. Since all the motors are always designed for balanced three phase operation.

Types of loads

A. Impedance type Loads
B. Motor loads.

A: Impedance type loads:-

Lighting, heaters, ovens and similar load objects fall in this category.

1) Consider an inductive load. The impedance equals $Z = R+jX$. By how many percent will the real load drop if the voltage is reduced by 1% ?

Inductive load.

$$Z = R+jX$$

$$Y = \frac{1}{R+jX}$$

$$P+jQ = |V|^2 Y^*$$

$$= |V|^2 \frac{1}{R-jX}$$

$$P+jQ = |V|^2 \frac{R+jX}{R^2+X^2}$$

$$\therefore P = |V|^2 \frac{R}{R^2+X^2} \quad — (1)$$

$$Q = |V|^2 \frac{X}{R^2+X^2}$$

the real & reactive loads are proportional to voltage $|V|$.

for a small voltage perturbation $\Delta|V|$

~~$\Delta|V|$~~

(19)

$$\frac{\Delta P}{\Delta|V|} \approx \frac{\partial P}{\partial|V|} = 2|V| \frac{R}{R^2+X^2}$$

$$= 2|V| \cdot \frac{P}{|V|^2} \quad \left[\text{Substituting } \frac{R}{R^2+X^2} = \frac{P}{|V|^2} \text{ from eqn} \right.$$

$$\frac{\Delta P}{\Delta|V|} \approx \frac{2P}{|V|}$$

$$\frac{\Delta P}{P} \approx 2\frac{\Delta|V|}{|V|}$$

The result tells us that a small relative change in voltage results in twice the relative change in megawatts.

[1% drop in voltage causes 2% drop in load]

2) How would a 1% drop in frequency affect the real load. The load is assumed to have a power factor of $\cos\varphi = 0.8$.

We know $P = |V|^2 \frac{R}{R^2+X^2}$ from eqn (1)

where $X = 2\pi f L$.

$$\frac{\Delta P}{\Delta f} = \frac{\partial P}{\partial f} = 0 - |V|^2 \frac{2X \cdot R \cdot 2\pi L}{(R^2+X^2)^2} = \frac{-|V|^2 4\pi f L R X}{f(R^2+X^2)^2}$$

$$= -P\frac{2X^2}{f(R^2+X^2)}$$

$$\frac{\Delta P}{P} \approx -2 \frac{x^2}{R^2+x^2} \frac{\Delta f}{f}$$

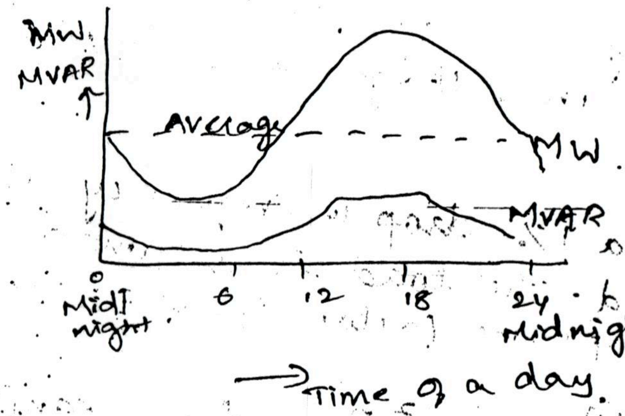
for $\cos\varphi = 0.8$ we have

$$\frac{x^2}{R^2+x^2} = \sin^2\varphi = 0.36$$

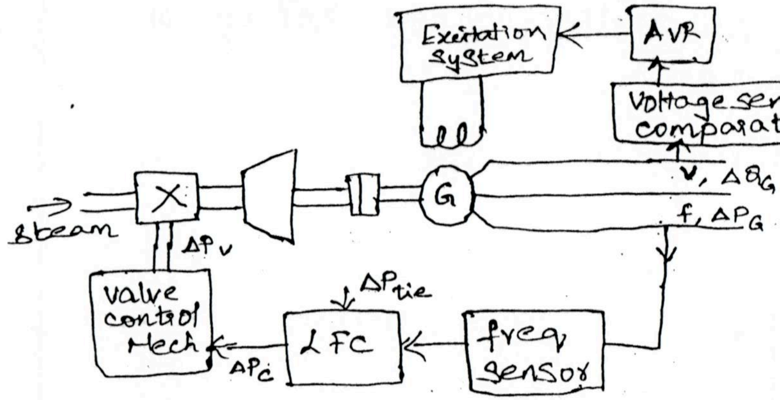
$$\therefore \frac{\Delta P}{P} \approx -0.72 \frac{\Delta f}{f}$$

A one percent freq drop results in 0.72 % load increase.

System load characteristics



Basic P-f and Q-V control loops



P-f loop :-

When load ↑ ~~freq~~ freq ↓, frequency is regulated & maintained by Speed Governor mechanism (primary ALFC) loop. This is done by controlling the control valve. Steam input passing through the control valve can be controlled. Power generated by generating unit can be controlled to maintain frequency.

Q-V loop:- (AVR loop)

When voltage at the generator output ↓, the voltage is sensed & compared with ref. voltage & rectified & is given as i/p to field winding of alternator. $I_f \uparrow, E\uparrow, V\uparrow$

$$\left[\text{Internal EMF } E\uparrow = \frac{\omega\varphi}{\sqrt{2}} = \frac{\omega L I_f\uparrow}{\sqrt{2}}\right]$$

3) Cross coupling between P-f and Q-V loop.

when load ↑ freq ↓, Power generation ↑
~~when~~ Due to the reduction in frequency,

$$\downarrow E = \frac{\omega\phi}{\sqrt{2}} = \frac{2\pi \overset{\downarrow}{f}\phi}{\sqrt{2}}$$

E ↓ V ↓. Before the occurance of this change in voltage is felt by us, AVR is very fast and correct the voltage change. The dynamics in QV loop settles down before the P-f loop reacts.
∴ The coupling between P-f and Q-V loop is negligible.

ii) Coupling between Q-V & P-f loop

Most of the loads are inductive loads (Motor)
It absorbs reactive power.
Q ↓ voltage at that load point ↓.
AVR regulates & maintain this voltage at nominal value.
if the load is voltage sensitive load when volt ↓, power absorbed by load ↓ demand ↑ f ↓.

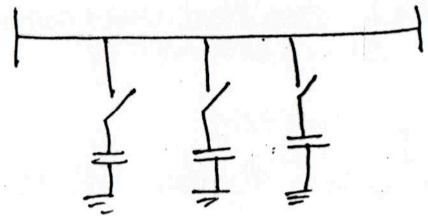
∴ Thus the Q-V control loop affects the frequency of system. There is a coupling between Q-V & P-f loop.

Plant level control :- (local control)

1) Governor control (primary LFC)
2) Primary voltage control (AVR)
3) Tap changing transformer control
4) Shunt capacitor control
5) SVC control.

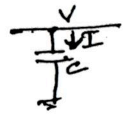
(1,2) AVR & Speed Governor mech. are attatched with each generating unit.

4) Shunt Capacitor control.



When the load ↑, Voltage ↓, reactive power ↓, the voltage is maintained constant by injecting reactive power in the line. This is done by connecting shunt capacitors. The capacitor banks may be permanently connected to the system or can be varied by switch.

Proof :- prove ~~when~~ that capacitor injects reactive power.



$$P+jQ = VI^*$$

$$P+jQ = V.\left[\frac{V}{-jX_c}\right]^* = \frac{V^2}{+jX_c} = -j\frac{V^2}{X_c}$$

where

$$Q = \frac{-V^2}{X_c}$$

I → current drawn by the capacitor

$$Q = -\frac{V^2}{X_c}$$

Q absorbed by the capacitor is -ve so it injects reactive power in to the line to maintain the voltage.

System level control.

1. Secondary LFC
2. Economic dispatch control, Unit commitment
3. Security control State estimation.
4. Secondary voltage control
5. Energy management system (EMS)
6. SCADA.

Secondary LFC & Economic dispatch control called as (AGC) Automatic generation control.

TYPES OF LOADS

1. **Domestic loads:**

It consists of light, fan & other home appliances such as radio, heaters etc. It may be varied due to climate in summer & winter.

2. **Industrial loads:**

It is divided in to small, medium & heavy. for heavy industry, demand factor is 0.5 & for small industry it is 0.8. seasonal variations are less in industrial loads.

Small scale - up to 25 kw, Medium scale - 25-100 kw, large scale - > 50

3. **Commercial loads:**

It consists of lighting, fan & small electrical appliance etc used in shop & restaura

The load is constant from 9 a.m to 8 Am

4) **Traction load:**

It consists of trains & railway statio loads. from midnight (12 pm) to 4 am load is less & afterwards load increas and reaches the peak at 8 am. After 10 A.M it is normal & again rises toward evening.

5) **Municipal loads.**

It consists of load for street lighting water supply and drainage purposes. During nigh street lighting load is consta

6. **Irrigation loads:** It depends only on agriculture load. It is the electric power needed for pumps driven by motors to supply water to fields.

Load forecasting

Load forecasting requires a certain "Lead time" called forecasting intervals.

Nature of forecast	Lead time	Applications.
Very short term	A few secs to several minutes	Generation, distribution schedules for contingency analysis
Short term.	Half an hour to a few hrs	Allocation of spinning reserve, unit commitment, maintanence scheduling.
Medium term	A few days to few weeks	Planning for seasonal peak winter, summer
Long term	A few months to a few years	planning generation growth

Forecasting of Base load - Least square fit

There are many methods for forecast. Extrapolation technique is commonly used.

In this method, future load is predicted from the past historical data available. The max. demand of past years are plotted against time. This points make irregular curve and best fit curve can be obtained from this method. It gives the load for future years.

Analytical functions which are used in this technique are

Straight line $Y = a + bx$

Parabola $y = a + bx + cx^2$

exponential $y = e^{a+bx}$

Let us take

$D \rightarrow$ demand of power in MW

$Y =$ year in which demand is considered.

$Y_0 =$ Base year.

Exponential growth of demand

$$D = e^{a+b(Y-Y_0)}$$

$$Y = y - y_0$$

eqn becomes $D = e^{a+bY}$

Taking ln on both sides

$$\ln D = a + bY$$

Let $a + bY = V$

$$\ln D = V$$

Let $D_1, D_2 \ldots D_n$ be various demands at diff. years.

$$V_1, V_2 \ldots, V_n = \ln D_n$$

Inorder to get correct load, Sum of Squares of error should be minimum.

$$\text{error} = [V - (a + bY)]$$

$$S = \sum_{i=1}^{n} \left[V_i - (a + by_i) \right]^2 \quad [\because y_i = Y - Y_0]$$

for min. value $\frac{dS}{da} = 0$; $\frac{dS}{db} = 0$.

$$\frac{dS}{da} = \sum_{i=1}^{n} 2 \left[[V_i - (a + by_i)](-1) \right] = 0.$$

$$= 0.$$

$$\frac{dS}{da} = \sum_{i=1}^{n} 2V_i - 2 \sum_{i=1}^{n} (a + by_i) = 0$$

$$2 \sum_{i=1}^{n} V_i = 2 \sum_{i=1}^{n} (a + by_i)$$

$$\sum_{i=1}^{n} V_i = na + b \sum_{i=1}^{n} y_i \quad \text{— (1)}$$

$$\frac{dS}{db} \Rightarrow 0.$$

$$\frac{dS}{db} = 2 \sum_{i=1}^{n} \left[V_i - (a + by_i) \right] (-y_i) = 0$$

$$\sum_{i=1}^{n} (V_i)(-y_i) + \sum_{i=1}^{n} (a + by_i)(y_i) = 0.$$

$$\sum_{i=1}^{n} V_i y_i = \sum_{i=1}^{n} (ay_i + by_i^2)$$

$$\sum_{i=1}^{n} V_i y_i = a \sum_{i=1}^{n} y_i + b \sum_{i=1}^{n} y_i^2 \quad \text{— (2)}$$

Substitution $\sum_{i=1}^{n} y_i = 0$ in eq (1) & (2).

eq (1) becomes $\sum_{i=1}^{n} V_i = na$ — (3)

eq (2) becomes $\sum_{i=1}^{n} V_i y_i = b \sum_{i=1}^{n} y_i^2$ — (4)

Solving (3) & (4) we get constants a & b.

$$a = \frac{1}{n} \sum_{i=1}^{n} V_i$$

$$b = \sum_{i=1}^{n} \frac{V_i y_i}{y_i^2}$$

<u>Drawback</u>:

1) Less flexibility.
2) Future load is predicted depending on past trend & It may cause errors.

Problem

1) The yearly demand of a station is tabulated below.

Year	1950	1951	1952	1953	1954	1955	1956	1957	1958
demand	251	287	289	306	337	359	367.5	433	469
Year	1959	1960	1961	1962	1963	1964	1965	1966	
demand	513	637	672	696	780	790	956	1166	

Find out demand in Year 1972

Ans

$Y_i = Y - Y_0$

$Y \rightarrow 1972 \rightarrow$ Year whose demand is to be found.

Y_0 = Base year.

$= \dfrac{\text{total year}}{2} = \dfrac{17}{2} = 8.5 \approx 9^{th}$ Year

Base year = 1958.

from table.

$$a = \frac{1}{n}\sum_{i=1}^{17} V_i = \frac{1}{17} \times 27.124 = 1.595$$

$$b = \sum_{i=1}^{17} \frac{V_i Y_i}{Y_i^2} = \frac{37.489}{408} = 0.091$$

$$\text{Demand} = e^{a+b(Y-Y_0)}$$

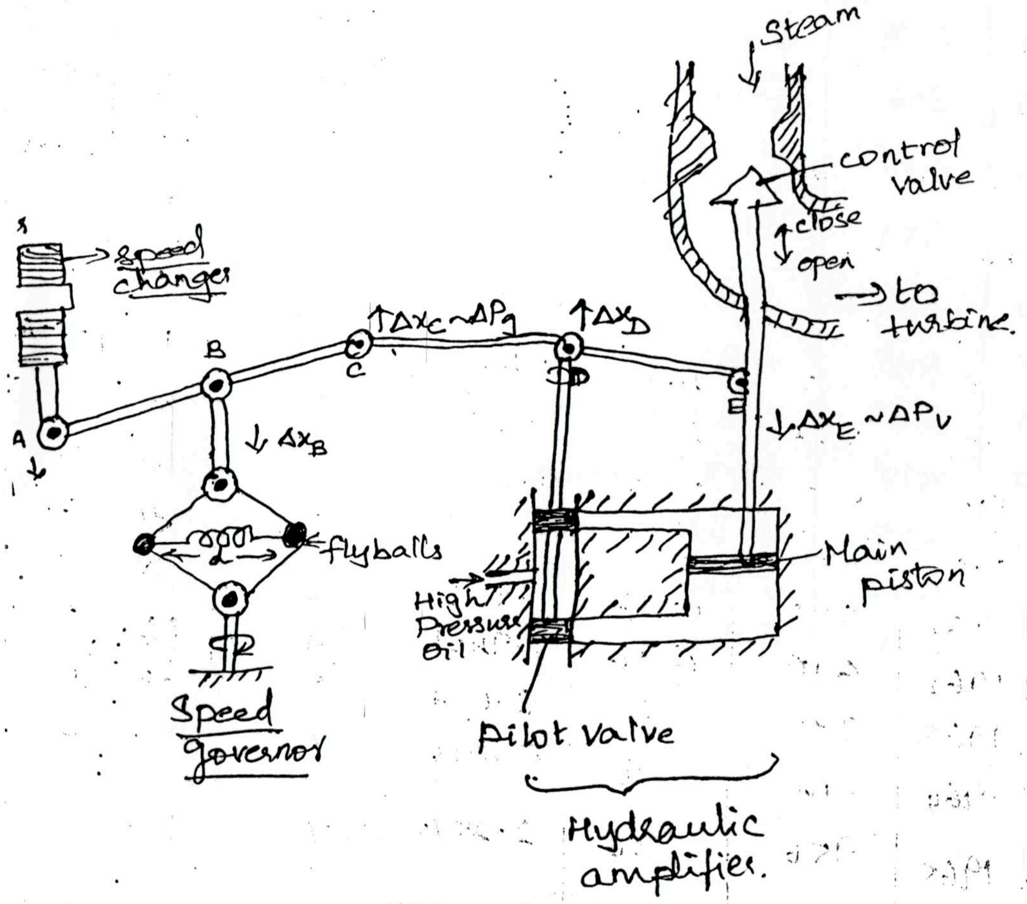
$$= 100e^{1.595+0.091[1972-1958]}$$

$D = 1762\,MW$

Demand in the Year 1972 is 1762 MW

	Year	Max. demand (D)	$D' = \frac{D}{100}$	$V_i = \ln D'$	$Y_i = Y - Y_0$	Y_i^2	$V_i Y_i$
1.	1950	251	2.51	0.9202	-8	64	-7.361
2.	1951	287	2.87	1.0543	-7	49	-7.381
3.	1952	289	2.89	1.06125	-6	36	-6.36
4.	1953	306	3.06	1.11841	-5	25	-5.592
5.	1954	337	3.37	1.2149	-4	16	-4.859
6.	1955	359	3.59	1.2781	-3	9	-3.831
7.	1956	367.5	3.67	1.3015	-2	4	-2.60
8.	1957	433	4.33	1.4655	-1	1	-1.46
9.	1958	469	4.69	1.5454	0	0	0
10.	1959	513	5.13	1.6351	1	1	1.635
11.	1960	637	6.37	1.851	2	4	3.702
12.	1961	672	6.72	1.905	3	9	5.715
13.	1962	696	6.96	1.9401	4	16	7.760
14.	1963	780	7.80	2.054	5	25	10.270
15.	1964	790	7.90	2.0668	6	36	12.400
16.	1965	956	9.56	2.2575	7	49	15.8025
17.	1966	1166	11.66	2.4561	8	64	19.6488
				27.124		408	37.48

1. Basics of speed governing mechanism & Modelling



Operation.

There are five linkage points A, B, C, D, E. ABC is a rigid link pivoted at B and CDE is another link pivoted at D. The movement of A and B are independent of each other. The positional change in A will not affect linkage point B. & viceversa. CDE can be moved either by A or by B or by both.

Speed changer: (setting the reference power ΔP_{ref})

* It is connected at linkage point A. It provides facility to set turbine output at any desired level.
* When we give "raise" command, point A moves downwards, point C moves upwards, pilot valve moves upwards, D moves upwards, pilot valve moves upwards, high pressure oil enters in top of the main piston and pushes down the main piston $\Delta x_E \downarrow$, control valve opens, thereby more steam enters the turbine and turbine power output ↑ & generation is increased.
* When we give "Lower" command, point A moves upwards, $\Delta x_C \downarrow$, $\Delta x_D \downarrow$, pilot valve moves downwards, high pressure oil enters in to bottom of piston & pulls up the main piston, $\Delta x_E \uparrow$, control valve closes, steam i/p to turbine is reduced, turbine power o/p is reduced.

Problems

At the end of a power distribution station, a certain feeder supplies three distribution transformers, each one supplying a group of customers whose connected loads are

	Load	Demand factor	Diversity of groups
Transformer - 1	10 kW	0.65	1.5
Transformer - 2	12 kW	0.6	3.5
Transformer - 3	15 kW	0.7	1.5

if the diversity factor among the transformers is 1.3, find the maximum load on the feeder

Ans

Sum of max. demands of customers on transformer 1 = Connected load × demand factor

$= 10 \times 0.65$

$= 6.5\text{ kW}$

As the diversity factor among consumers connected to transformer 1 is 1.5

∴ Max. demand on transformer 1 is

$$= \frac{\text{Sum of max. demands of customers on trf 1}}{\text{diversity factor on trf 1}}$$

$$= \frac{6.5}{1.5} = 4.33\text{ kW}$$

Similarly

max. demand on transformer 2 is

$$= \frac{12 \times 0.6}{3.5} = 2.057\text{ kW}$$

Maximum demand on transformer 3 is

$$= \frac{15 \times 7}{1.5} = 7\,kW$$

As the diversity factor among transformers is 1.3, Max. demand on the feeder is

$$\frac{4.33 + 2.057 + 7}{1.3} = 10.3\,kW$$

2. It has been desired to instal a diesel power Station to supply power in a Suburban area having the following particulars.

(i) 1000 houses with average connected load of 1.5kW in each house. The demand factor and diversity factor being 0.4 and 2.5.

(ii) 10 factories having overall max. demand of 90kW

(iii) 7 Tubewells of 7kW each and operating together in the morning.

The diversity factor among above three types of consumers is 1.2. What should be the minimum capacity of power station?

Ans

Sum of max demands of houses $= (1.5 \times 0.4) \times 1000$

$= 600\ kW$

Max-demand for domestic load →

$= \dfrac{\text{Sum of max demands}}{\text{diversity factor}}$

$= \dfrac{600}{2.5} = 240\ kW$

Max-demand for factories $= 90\ kW$

Maximum demand for tube wells $= 7 \times 7 = 49\ kW$

The sum of max-demands of three types of loads

$= 240 + 90 + 49 = 379\ kW$.

As the diversity factor among the three types of loads is 1.2

Max. demand on the station $= \dfrac{379}{1.2} = 316\ kW$

Minimum capacity of station required $= 316\ kW$

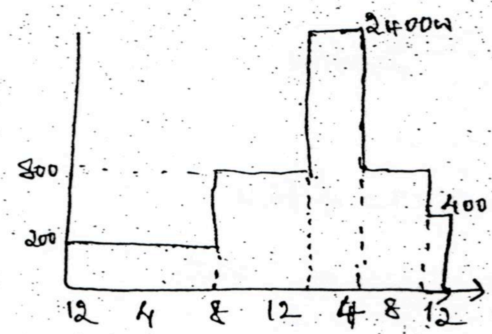
3. The daily demands of three consumers are given below

Time	consumer 1	consumer 2	consumer 3
12 midnight to 8 A.M	No load	200W	No load
8 A.M to 2 P.M	600W	No load	200W
2 P.M. to 4 P.M	200W	1000W	1200W
4 P.M to 10 P.M	800W	No load	No load
10 P.M to midnight	No load	200W	200W

Plot the load curve and find (i) max. demand of individual consumer (ii) load factor of individual consumer (iii) diversity factor (iv) load factor of the station

Ans

Load curve



(i) Max. demand of consumer 1 = 800W
Max. demand of consumer 2 = 1000W
Max. demand of consumer 3 = 1200W

(ii) Load factor of consumer 1

$$= \frac{\text{Energy consumed/day}}{\text{Max. demand} \times \text{Hours in a day}} \times 100$$

$$= \frac{(600 \times 6) + (200 \times 2) + (800 \times 6)}{800 \times 24} \times 100 = 45.8\%$$

Load factor of consumer 2

$$= \frac{(200 \times 8) + (1000 \times 2) + (200 \times 2)}{1000 \times 24} \times 100 = 16.7\%$$

Load factor of consumer 3

$$= \frac{(200 \times 6) + (1200 \times 2) + (200 \times 2)}{1200 \times 24} \times 100$$

$$= 13.8\%$$

ii) The simultaneous maximum demand on the Station is $200 + 1000 + 1200 = 2400\,W$ and occurs from 2 P.M to 4 P.M

$$\therefore \text{Diversity factor} = \frac{800 + 1000 + 1200}{2400} = 1.25$$

3) Station load factor.

$$= \frac{\text{Total energy consumed/day}}{\text{Simultaneous max. demand} \times 24} \times 100$$

$$= \frac{8800 + 4000 + 4000}{2400 \times 24} \times 100$$

$$= 29.1\%$$

A daily load curve which exhibited a 15-minute peak of 3000 kW is drawn to scale of 1 cm = 2 hrs and 1 cm = 1000 kW. The total area under the load curve is measured by planimeter and is found to be 12 cm². Calculate the load factor based on 15-min peak.

$$1\,cm^2 \text{ of load curve} = 1000 \times 2 = 2000\,kWh$$

$$\text{Average demand} = \frac{2000 \times \text{Area of load curve}}{\text{hours in a day}}$$

$$= 2000 \times 12/24$$

$$= 1000\,kW$$

$$\text{Load factor} = \frac{1000}{3000} \times 100 = 33.3\%$$

5. A power station has a daily load cycle as under 260 MW for 6 hrs, 200 MW for 8 hrs, 160 MW for 4 hrs 100 MW for 6 hrs. if the power station is equipped with 4 sets of 75 MW each, calculate (i) daily load factor (ii) capacity factor (iii) daily requirement if the calorific value of oil used were 10,000 kcal/kg and the average heat rate of station were 2860 kcal/kwhr.

Ans

Max. demand on the station is 260×10^3 kW

units supplied/day $= 10^3[260 \times 6 + 200 \times 8 + 160 \times 4 + 100 \times 6]$

$= 4400 \times 10^3$ kwhr.

Daily load factor

$$= \frac{4400 \times 10^3}{260 \times 10^3 \times 24} \times 100 = 70.5\%$$

Average demand/day $= \frac{4400 \times 10^3}{24} = 1,83,333$ kW

Station capacity

$= (75 \times 10^3) \times 4 = 300 \times 10^3$ kW

$\therefore$ capacity factor $= \frac{1,83,333}{300 \times 10^3} \times 100 = 61.1\%$

Heat required/day

= plant heat rate x units/day

$= 2860 \times 4400 \times 10^3$ kcal

$\therefore$ Fuel required/day $= \frac{2860 \times 4400 \times 10^3}{10,000}$

$= 1258.4 \times 10^3$ kg

$= 1258.4$ tons

A base load station having a capacity of 18 MW and a stand by station having a capacity of 20 MW share a common load. Find the annual load factors and capacity factors of two power stations from the following data

Annual Stand by station output = 7.35×10^6 kwh
Annual base load station output = 101.35×10^6 kwh
Peak load on stand by station = 12 MW
Hours of use by stand by station = 2190 hrs / year

Ans

Installed capacity of stand by unit = 20×10^3 KW.
Installed capacity of base load plant
$= 18 \times 10^3$ kW

Stand by station.

Annual load factor = $\frac{\text{Kwh generated/annum}}{\text{Max. demand} \times \text{annual working hrs}} \times 100$

$$= \frac{7.35 \times 10^6}{(12 \times 10^3)(2190)} \times 100 = 28\%$$

Annual capacity factor :-

$$= \frac{\text{Kwh output/annum}}{\text{Installed capacity} \times \text{hrs in a year}} \times 100$$

$$= \frac{7.35 \times 10^6}{(20 \times 10^3) \times 8760} \times 100$$

$= 4.2\%$

Base load station:

Max. demand on the base load station is equal to the installed capacity (18 MW)

Annual load factor $= \frac{101.35 \times 10^6}{(18 \times 10^3) \times 8760} \times 100$

$= 64.2\ \%$

As the base load station has no reserve and it is in continous operation, its capacity factor is also 64.2 %.