Line Supports.

Line supports are poles and main requirements for such supports are -

1. Must be mechanically strong
2. Must be light in weight without the loss of strength.
3. Must have least no. of parts.
4. Economical
5. Must have min. maintenance cost
6. Longer life
7. Must be easily accessible for erection of line conductors.

Different types of poles are -

1. Wooden poles - use of such poles is limited to low voltages & generally used for distribution purposes. These are cheap and provide an insulating property.
   Main disadvantage is that they are elastic and tend to rot, hence life is short. The portion of the pole which is buried in the ground must be treated with preservative like oil.

2. Steel tubular poles - Wooden poles may be substituted by steel tubular poles. These are stronger than wood, so with these poles longer spans are possible. To increase the life of

of poles, they must be galvanized or painted regularly. For safety purposes they must be earthed.

3. Reinforced concrete poles.— In modern days, the reinforced concrete poles have almost replaced the wooden & steel tubular poles; as they are more attractive to look at. These poles are quite heavy, so transportation cost increases, but maintenance cost is quite low. They are mechanically strong & have longer life.

4. Steel tower.— The poles are used for distribution purposes, but the towers are useful for transmission lines. It is not hard & fast rule; even wooden poles may also be sometimes used for transmission purposes depending upon need and circumstances. Generally broad base lattice-steel towers are used, which are mechanically very strong & have longer life. Due to robust construction, long spans can be used & are much useful for crossing fields, valleys, railway lines, rivers etc.

Disposition of conductors.

The disposition of conductors in transmission or distribution of electrical energy has much bearing on the performance of the line. The line can either be a single circuit or a double circuit.

	Single ckt:	Double ckt
1.	Subjected to less wind pressure so it requires less weight of steel tower & lesser foundation	subjected to more wind pressure, structure is heavier & height of tower is more.
2.	less danger at the time of repair	Danger from other alive ckt
3.	Design is not reliable as regards continuity of supply	Design is quite reliable.
4.	Greater spacing of conductors is reqd.	Less conductor spacing
5.	Due to more spacing, higher reactance.	Due to less spacing, low reactance.

Methods of conductors arrangements Over the line supports.

1. Single phase circuits. - Single ph. transmission lines can either be single ckt or double ckt.
2. Three phase circuit - Conductors are arranged at corners of equilateral Δ $\xrightarrow{}$ equal distance or at ~~cor~~ corners of right angled Δ so that

dist. betn them is unequal.

Spacing betn the conductors.

The most suitable spacing betn the conductors can be arrived at by mathematical calculations.

Generally following formulae are used -

$$\text{Spacing} = \left(0.75\sqrt{D} + \frac{V_{kV}^2}{20000}\right) \text{ meters.}$$

V_{kV} - vltg. in kV

D = sag in m.

Length of the span

For the purpose of economy the T.L. is reqd. to be constructed at lowest possible cost and to achieve this, the span of the line must be optimum. This will reduce the no. of poles and other fixtures thereby reducing the overall cost. There is no definite mathematical expression which directly gives the length of economical span. While deciding the length various factors such as voltage, max. tension on poles during any part of the year, public safety & rules of government must be kept in mind.

* Sag should be so adjusted that tension in the conductors is within safe limits. It is a std. practice to keep condr tension less than 50% of its ultimate tensile strength.

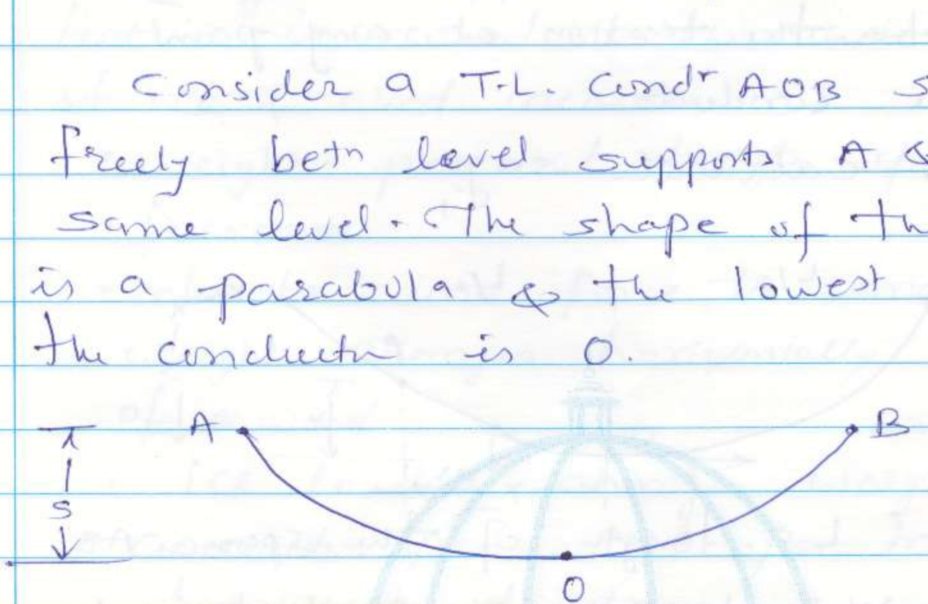
Usual spans are.
wooden poles - 50 m.
steel tubular - 50-80 m.
RCC poles - 80-100 m
steel towers 100-300 m.

Sag tension calculation.

In a T-L., sag is defined as the vertical difference in level between points of support and the lowest point of the conductor. The calculation of sag & tension in a T.L. depends on the span of the overhead conductor.

- Sag having equal level supports is called level span.
- Sag with unequal levels of supports is known as unequal level span.

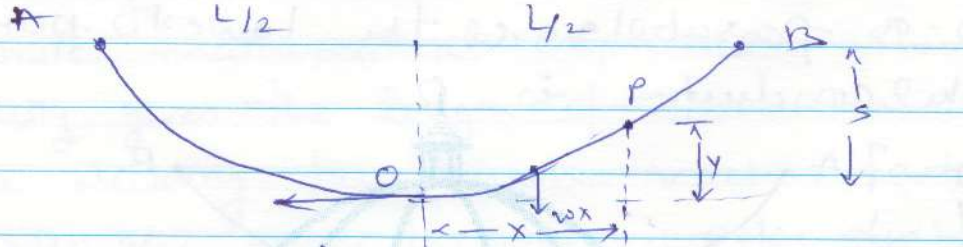
Consider a T.L. condr AOB suspended freely betn level supports A & B at the same level. The shape of the conductor is a parabola & the lowest point of the conductor is O.



Sag is mandatory in T.L conductor suspension. This is because it protects the conductor from excessive tension. If the conductor is stretched fully during installation, wind exerts pressure on the conductor, hence there are chances of conductor to be broken or detatched from its end support. Hence it is allowed to have some sag.

- Imp. points.
- the sag span curve is parabolic
- the tension in each point of the conductor acts always tangentially
- The horizontal compo. of the tension of the conductor is constant throughout conductor length
- The tension at supports is nearly equal to the tension at any point in the conductor

To calculate sag,



Let L = length of the span = AB

w is the weight per unit length of cond^r

T is the tension in the condr
Let P is any point on the condr
The distance of point P from the lowest point O is x
y is the height from point O to point P

Equating two moments of two forces about point O from above fig.,

$$Ty = wx \times \frac{x}{2}$$

$$y = \frac{wx^2}{2T} \quad \text{when } y = S \text{ \& } x = L/2$$

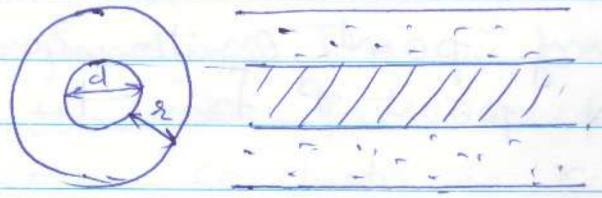
Thus $S = \frac{wL^2}{8T}$ — the eqn of Parabola.

** → Continued.

Effect of ice covering and wind over the line
above formulae for sag are true only in still air & at normal temp. when condr is acted by its weight only.

Under the severest conditions of ice covering and wind, the stress over the line is increased to the maximum. The effects of ice & wind include.-

- weight per unit length of conductor increases
- due to wind force, the conductor self-weight changes horizontally in the direction of ~~a~~ wind
- ice loading changes weight of conductor per unit length in the vertical downward direction.



Let, c.s. area of conductor $= \frac{\pi}{4} d^2$

overall c.s. area when covered with ice,

$$= \frac{\pi}{4}(d+2r)^2$$

∴ Sectional area of ice,

$$= \frac{\pi}{4}(d+2r)^2 - \frac{\pi}{4} d^2$$

$$= \frac{\pi}{4}\left[d^2 + 4dr + 4r^2 - \cancel{\pi} d^2\right]$$

$$= \pi r(d+r)$$

Density of ice $= 0.915$ g/cm³

∴ Weight of ice per metre length

$$= \pi r(d+r) \times 100 \times 0.915 \times 10^{-3} \text{ kg}$$

$$= 0.287\, \pi(d+r) \text{ kg}$$

- sag in vertical plane

$$= D_i + \frac{(w+w_i)}{W_i}$$

$D_i \rightarrow$ deflection in inclined plane

$w =$ dead weight

$w_i =$ weight of ice load per m.

$W_i =$ Resultant pressure

Sag in horizontal plane,

$$= D_i \times \frac{P_w}{W_i}$$

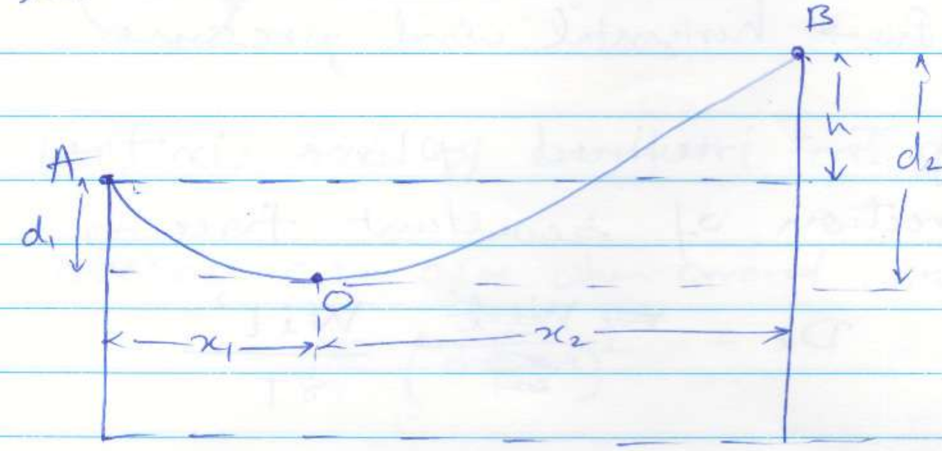
$P_w \rightarrow$ horizontal wind pressure

- Sag in inclined plane in the direction of resultant force is,

$$D_i = \cancel{\frac{W_i l^2}{8T}} \; \frac{W_i L^2}{8T}$$

** continued.

2. Sag & tension with supports at unequal levels.



Where,

$$d_1 = \frac{w x_1^2}{2T} \quad \text{and}$$

$$d_2 = \frac{w x_2^2}{2T}$$

where,

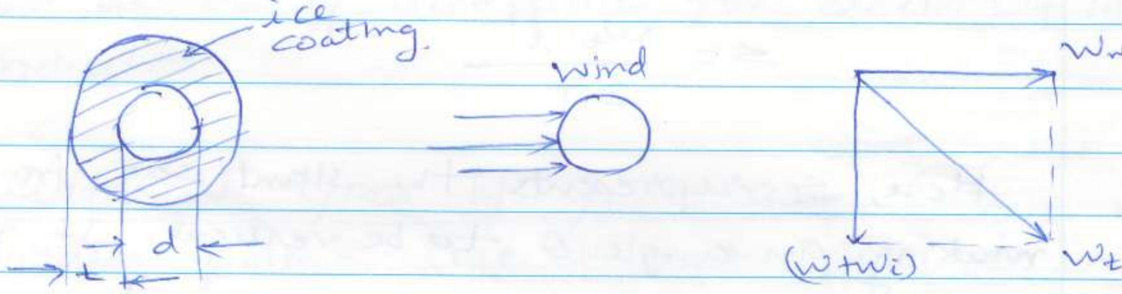
$$x_1 = l - \frac{hT}{2wl} \quad \text{and}$$

$$x_2 = l + \frac{hT}{2wl}$$

In some cases, x_1 may be -ve which mean that there may be no horizontal point (like O) in the span. Such a thing is very likely to happen when line runs up a steep mountain side.

* Effect of wind & ice loading.

In actual practice, a cond^r may have ice coating & simultaneously subjected to wind pressure. The weight of ice acts vertically downwards & force due to wind is assumed to act horizontally, i.e. at right angle to the projected surface of the cond^r. Hence the total force on cond^r is the vector sum of horizontal & vertical forces.



Total weight of cond^r p.u. length is,

$$w_t = \sqrt{(w+w_i)^2 + (w_w)}$$

where, w = weight of cond^r p.u. length.
= cond^r material density x volume p.u. length

w_i = weight of ice p.u. length
= density of ice x volume of ice p.u. length
= density of ice x $\frac{\pi}{4}\left[(d+2t)^2 - d^2\right] \times 1$
= density of ice x $\pi t\,(d+t)$

W_w = wind force per unit length.
= wind pressure p.u. area × projected area p.u. length
= wind pressure × $[(d+2t) \times 1]$

When the cond^r has wind & ice loading also,

i) The cond^r sets itself in a plane at an angle θ to the ~~ver~~ vertical ~~plane~~ where,

$$\tan\theta = \frac{w_w}{w+w_i}$$

ii) The sag in the cond^r is given by,

$$s = \frac{w_t \cdot l^2}{2T}$$

Here, s represents the slant sag in a direction making an angle θ to be vertical. If no specific mention is made in the problem, then slant sag is calculated by using above formula.

iii) The vertical sag = $s\cos\theta$.

Line Insulators.

In order to prevent the flow of current to the earth from support, the transmission lines or distribution lines are all secured to the supporting towers or poles with the help of insulators. Insulators play an imp. role in successful operation of lines. The main requirement of insulators are-

1) mechanically strong
2) High dielectric strength.
3) provide high insulation resistance to the leakage currents.
4) must be free from internal impurities
5) should not be porous.
6) should not be affected with change in temp.
7) should have high ratio of puncture strength of flash over voltage.

Material of insulators

Most commonly used insulator ~~is~~ materia porcelain. Other materials are glass and steatite.

Porcelain insulators - The porcelain is manufactured from china clay which ~~app~~ is found in ~~also~~ nature in the form of aluminium silicate. Porcelain is manufactured by adding some other material & chemical processes.

The insulator so formed is hard, smooth, glazed and free from porosity. Due to the glaze, the surface will be free from traces of water. The porosity of the material decreas its dielectric strength, as some amount of water will be present there. Also impurity reduces the dielectric strength.

A mechanically sound porcelain insulator has a dielectric strength of about ~~6000~~ 60000 V per cm. of thickness.

Glass Insulators - Many times glass is also used as insulating material. The advantages of glass insulators are -

1) very high dielectric strength of order of 140 kV per cm of thickness
2) when properly annealed, they have high resistivity
3) Low coeff. of thermal expansion
4) due to higher dielectric strength, glass insulators have simple design and even one piece designs can be used.
5) Higher compressive strength than porcelain.
6) they are transperant, so any impurity or air bubble can be easily detected.
7) cheaper than porcelain

Disadvantages are -

1) Moisture easily condenses over glass surface, hence dirt / dust can deposit on it & it will help the leakage current

Steatite Insulators - Steatite is a magnesium silicate found in various proportions of magnesium oxide and silica in many parts of the world. It has very high & tensile strength as compared to porcelain. Hence it is used in places where insulator has to be in tension, example, when transmission lines take sharp turns.

Types of insulators used in T.L.

1] Pin type insulators - It is one of the earliest designs used for supporting line ~~insulators~~ conductors. For lower voltages generally one piece type of insulator is used. The leakage path is shown by the dotted line. Pin insulator is a device that isolates a wire from a physical support. It is normally made up of porcelain or glass. The wire is usually attached to the insulator by wrapping around it or fixed into grooves on the insulator itself.

Electrical breakdown of insulator can occur either by flashover or puncture. In flashover arc occurs betn conductor & pin.
In puncture, discharge is ~~for~~ from cond' to pin through body of insulator

When the insulator is wet, its outer surface becomes conductive making the insulator less effective. Hence to protect the lower part of it, one, two or three ~~&~~ rain shades are made. These rain shades are so designed that when these insulators are wet, even then sufficient dry space is provided by the inner shades.

The pin insulators are screwed on & firmly attached on the supports on the poles.

For higher voltages, the thickness of the material required for insulation purpose is more. But from practical point of view, a quite thick single piece insulator cannot be manufactured. In ~~such~~ such ~~as~~ cases, a pin type insulator made up by no. of shells fixing together by portland cement is used.

These insulators are available for upto 50kV and they are never used for vltgs. beyond 80kV. Modern practice is, these are not used for ~~&~~ vltgs. beyond 33kV.

2. Suspension type insulators - As line vltg. increases, the pin insulators become heavy & construction also becomes complicated, also cost increases. Also replacement of damaged insulators cost more.

Hence for higher vltgs, suspension type insulators are used. Generally, it is made up of porcelain and includes single or a string of insulating discs hanged over a tower. It operates at above 33kV and overcomes ~~almost~~ limitations of pin type insulators. A number of such discs are connected in series to form a chain and the line conductor is carried by the bottom most insulator.

Each suspension insulator is designed for 11kV, so by connecting a no. of such insulators, can be used for required voltage.

If any one of the insulator in the string fails, it can be replaced easily. When string of the insulators is used in conjunction with the steel tower, the line conductors are less affected by lightening, since line conductors are at lower level than the cross arm which is earthed and acts as a lightning arrester.

greater flexibility as in hanging position

3) Strain insulators - When there is a dead end of the line or there is corner or a sharp curve or the line crosses river, etc, the line is to withstand great strain. For low voltage lines Shackle insulators can be used, but for high vltg T.L, strain insulators are used. Strain insulators consists of an assembly of suspension insulators as shown in diag. If the pull on the string of the suspension insulators is high as in case of long spans across the river, under such cases two, three or four strings of insulators are used in series.

4) Shackle insulators:- low vltg distribution lines. Such insulators can either be used in a horizontal or in vertical position. The conductors are fixed in the groove.
In early days they were used as strain insulators.
They can be directly fixed to the pole with a bolt or to the cross arm

Prob.

A 132 kV T.L. has following data,
weight of condr = 680 kg/km
Length of span = 260 m
ultimate strength = 3100 kg
Safety factor = 2
Calculate height above ground at which the conductor should be supported. Ground clearance reqd. is 10m.

Soln.

Weight of condr/m, $w = 680/1000 = 0.68$ kg.

Working tension $T = \frac{\text{Ultimate strength}}{\text{safety factor}} = \frac{3100}{2}$

$= 1550$ kg.

Span, $l = 260$ m.

$$\therefore \text{sag} = \frac{wl^2}{8T} = \frac{0.68 \times (260)^2}{8 \times 1550}$$

$= 3.7$ m.

∴ Condr should be supported at a height of $10 + 3.7$ m. $= 13.7$ m.

Factors associated with generation syste

Electricity, unlike water & gas cannot be stored economically (except in very small quantities in batteries) and the electric utility have little control over the load (power demand) at any time. Therefore, the power system must be capable of matching the output from the generator to the demand at any time at a specified voltage & frequency.

The load variations over a day comprises three components - 1) a steady component known a base load.

2). a varying component whose daily pattern depends upon time of day, weat season, festive time, etc.

3) a purely randomly varying compo. of relatively small amplitude.

Different definitions. -

1. Connected load. - is defined as sum of ratings of all equipment that is connected to a power system. Connected load considers all the equipment despite its condition - running or not.

It can be mathematically calculated by ~~sm~~ simply adding all the ratings of equipment.

Eg. - a domestic consumer has 3 lamps each having 30 W, 2 fans of 70 W & water heater of ~~1000 kw.~~ 1 kW.

$\therefore$ Connected load $= (3\times30) + (2\times70) + 1000$

$= 1230$ W.

2. Maximum Demand - Maximum demand is the highest level of electrical demand monitored in a particular period usually for a month period. If all the devices are used simultaneously to the full extent, the max. demand of the consumer would be equal to his connected load.

But actually, consumers do not use all the devices at full load simultaneously. Hence, max. demand of each consumer is less than his connected load.

The max. demand & connected load are related by,

3. $$\text{Demand factor} = \frac{\text{Max. demand}}{\text{Connected load.}}$$

Problem:

A residential consumer has following connected load: 8 bulbs of 100 W each, 2 fans of 60 W each, and 2 light plug points of 100 W each. His use of electricity during a day is as given -

12 midnight to 5 am - 1 fan
5 am to 7 am - 2 fans & one light point
7 am to 9 am - NIL.
9 am to 6 pm - 2 fans
6 pm to midnight - 2 fans & 4 bulbs.

Find. - (a) connected load (b) max. demand (c) demand factor (d) energy consumed in 24 hrs. (e) energy consumed in 24 hrs. if all devices are used all the day.

Sol^n.

(a) Connected load = ~~8a~~(8 × 100) + (2 × 60) + (2 × 100).
= 1120 w.

(b) Total wattage at diff. times -
12 midnight to 5 am = 60 w.
5 am to 7 am = ~~20~~(2 × 60) + (1 × 100) = 220 w.
7 am to 9 am = 0
9 am to 6 pm = (2 × 60) = 120 w
6 pm to midnight = (2 × 60) + (4 × 100) = 520 w

∴ max. demand is 520 w.

(c) Demand factor = $\frac{520}{1120}$ = 0.464

(d) Energy consumed,
= (60 w × 5 hrs) + (220 × 2) + (120 × 9) + (520 × 6)
= 4940 wh = 4.94 kwh.

(e) If all devices are used ~~all~~ throughout the day, the energy consumed is,
= 1120 × 24 = 26880 wh
= 26.88 kwh.

4 Average load.- Average load or average demand is defined as the total energy delivered in a certain period divided by the time interval. It is possible to calculate a daily, weekly, monthly & yearly average load.

5. Load factor - ~~it is a ratio~~ Load factor for a plant or a system is the ratio of average load to the peak load, for a certain period of time.

L.F. varies with type of load, being poor for lighting load (about 12%) & high for industrial load (80-90%)

$$\therefore \text{Load factor} = \frac{\text{Average load}}{\text{Peak Load}} = \frac{\text{Energy generated in given period}}{\text{max. demand} \times \text{hours of operation in given period}}$$

A high load factor helps in drawing more energy from a given installation.

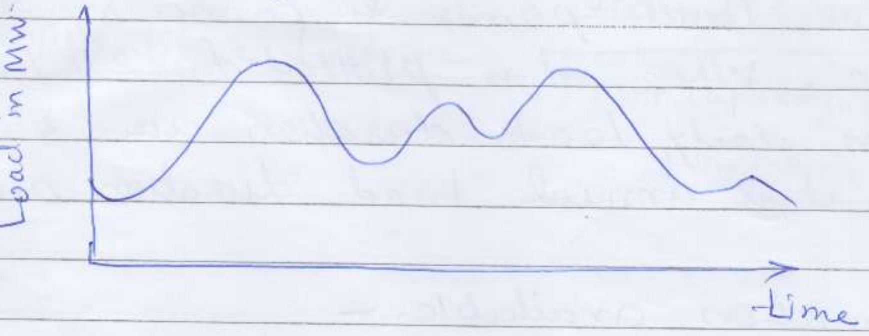
6. <u>Diversity factor</u> - It is defined as sum of maximum demands of the consumers divided by max. load (demand) on the system.
This factor gives the time diversification of the load and is used to decide the installation of sufficient generating and transmission plant. * see next pages.

7. <u>Capacity factor</u> - Plant capacity factor (also known as plant factor) is the ratio of the average annual load to the power plant capacity.

$$\text{Capacity factor} = \frac{\text{Average annual load}}{\text{Rated plant capacity}}$$

8. <u>Load curve</u> - Load curve is a graphical representation of load (in kW or MW) in proper time sequence and the time in hours. It shows the variation of load on the power station.
When load curve is plotted for 24 hrs then it is called daily load curve. If it is drawn for one year, then it is called annual load curve.
The load curve of the power system is not same all the day. It

differs from day to day and season to season.

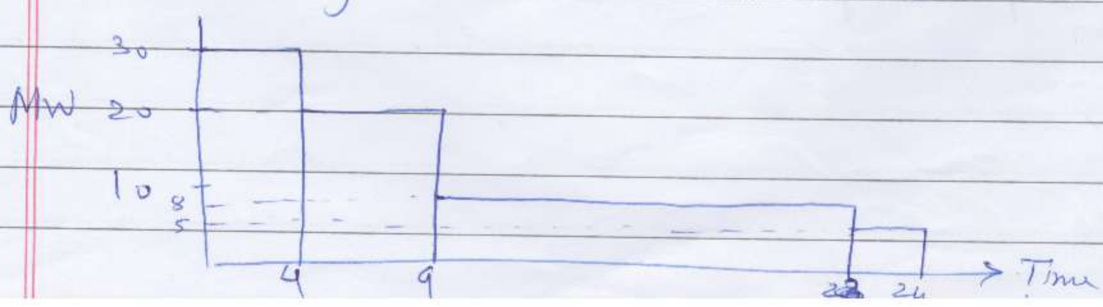


Information obtained from load curve.

1) it determines the load variation during different hours of the day
2) It indicates peak load which determines the max. demand on the power station.
3) Area under the curve gives the total energy generated in the period under consideration.
4) Area under the curve divided by total no. of hrs, gives the average load.
5) Ratio of area under the load curve and the total area of the rectangle in which it is contained gives the load factor.

9. <u>Load duration curve</u> –

The load duration curve ~~o~~ is defined as the curve between the load & time in which the ordinates representing load, ~~pto~~ are plotted in the order of decreasing magnitude, ie, with the greatest load at the left, lesser loads towards right & lowest loads at extreme right.



Load duration curve is constructed by selecting the maximum load points & connecting them by a curve. When it is plotted for 24 hrs, it is called as daily load duration curve & when for a year, it is annual load duration curve.

Information available. –

i) it gives minimum load present throughout the specified period.

ii) it helps in selection of base load & peak load plants.

iii) it gives total duration in hrs. for the corresponding load.

iv) average demand can be obtained

v) area under the curve represents the energy associated with the load duration curve.

10. Reserve Capacity – It is the extra generation capacity that is installed to meet the need of scheduled downtimes for preventive maintenance. ~~The~~ This reserve capacity also takes care of forced equipment outages and the possibility of the actual load exceeding the forecast.

The amount of reserve capacity to be provided is a subjective judgement related to past ~~exper~~ experience.

11. Plant use factor :-

$$\text{Plant use factor} = \frac{\text{Actual energy produced}}{\text{Plant capacity} \times \text{Time (hrs) the Plant has been operated.}}$$

* Diversity factor continued.

$$D.F = \frac{\sum \text{individual max. demand of consumers}}{\text{Max. load on the system.}}$$

This factor is more than unity. It is high for domestic loads. It can be made high by adjustment of timing & ~~ea~~ operation in each shift in industry by providing incentives.

classmate
Date
Page

1. A generating station supplies the following loads to various consumers.

Industrial consumer - 750 MW.
Commercial -u- 350 MW.
Domestic power 10 MW.
Domestic light 50 MW.

If the max. demand on the station is 1000 MW and no. of MWh generated per year is 50×10^5, determine,

i) diversity factor.
ii) annual load factor.

i) Diversity factor $= \dfrac{750+350+10+50}{1000}$

$= 1.16$

ii) Average demand $= \dfrac{\text{MWh generated in a yr.}}{\text{Hours in a yr.}}$

$= \dfrac{50 \times 10^5}{8760}$

$= 570.78$ MW.

$\therefore$ Load factor $= \dfrac{\text{Avg. load (demand) in a yr.}}{\text{Max. demand}}$

$= \dfrac{570.78}{1000}$

$= 0.57078$

$= 57\%$

classmate
Date
Page

2. A generating station supplied the following loads: 150 MW, 120 MW, 85 MW, 60 MW & 5 MW. The station has a max. demand of 220 MW. The annual load factor of ~~sta~~ the station is 48%. Calculate:

i) no. of units supplied annual
ii) diversity factor
iii) demand factor.

$$\text{Load factor} = \frac{\text{No. of units supplied annually}}{\text{Max. demand} \times 8760}$$

$$0.48 = \frac{\text{No. of units supplied annually}}{220 \times 8760}$$

$$\therefore \text{No. of units supplied annually} = 0.48 \times 220 \times 8760$$

$$= 9.25 \times 10^5 \text{ units.}$$

ii) $$\text{Diversity factor} = \frac{\text{Sum of max. demands of each consumer}}{\text{Station max. demand}}$$

$$= \frac{150+120+85+60+5}{220}$$

$$= 1.909$$

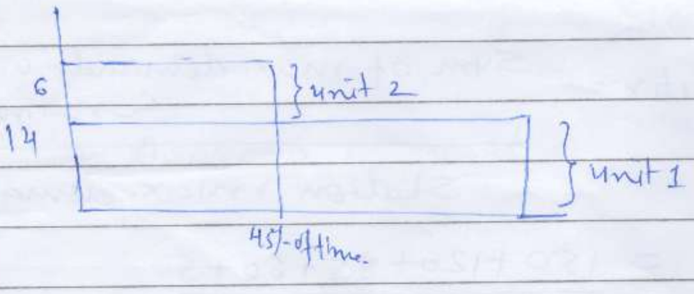
iii) $$\text{Demand factor} = \frac{\text{Max. demand}}{\text{Connected load}} = \frac{220}{420}$$

$$= 0.524$$
$$= 52.4\%$$

3. From a load duration curve, following data is Obtained: Max. demand on the system is 20 MW. The load supplied by the two units is 14 MW & 10 MW. Unit 1 works for 100% of time & Unit 2 (peak load unit) works only for 45% of the time. Energy generated by unit 1 is 1×10^8 units and that by unit 2 is 7.5×10^6 unit. Find the load factor, plant capacity factor & plant use factor of each unit & load factor of total plant.

$$\text{Annual load factor for unit 1} = \frac{1 \times 10^8 \ (\text{units in kwh})}{14 \times 1000 \times 8760 \ (\text{Max. demand in kW})} \times 100$$

$$= 81.54\%$$



∴ Max. demand on ~~unit~~ unit 2 is 6 MW

$$\therefore \text{Annual load factor for unit 2} = \frac{7.5 \times 10^6}{6 \times 1000 \times 8760} \times 100$$

$$= 14.27\%$$

$$\text{Load factor for unit 2 For the time it takes load} = \frac{7.5 \times 10^6}{6 \times 1000 \times 0.45 \times 8760} \times 100$$

$$= 31.71\%$$

Since no reserve is available at unit 1, its capacity factor is same as load factor ie, 81.54%.

Also unit 1 is running throughout the year, the plant use factor equals the plant capacity factor ie 81.54%

$$\text{Annual plant capacity factor of unit 2} = \frac{7.5 \times 10^6}{10 \times 1000 \times 8760} \times 100$$

$$= 8.56\%$$

$$\text{Plant use factor of unit 2} = \frac{7.5 \times 10^6}{10 \times 1000 \times 0.45 \times 8760} \times 100$$

$$= 19.02\%$$

$$\text{Annual load factor of total plant} = \frac{1.075 \times 10^8}{20000 \times 8760} \times 100$$

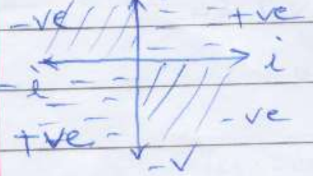
$$= \cancel{8}\, 61.35\%$$

Concept of Power in A.C. Transmission System.

Power in an electric circuit is the rate of flow of energy through a given point of a circuit.

In a simple A.C. circuit, consisting of a source & a linear load, both the voltage & current are sinusoidal. If the load is purely resistive, the two quantities are in phase with each other. At every instant, the product of voltage & current is positive or zero, the result being that, the direction of energy flow does not reverse. In this case only active power is transferred.

If the load is purely ~~reactive~~ inductive, then the voltage & current are 90° out of phase. For two quarters of each cycle the product of voltage & current is positive but for the other two quarters, the product is negative, indicating that on average there is no net energy flow over each half cycle. In this case only reactive power flows: ie, there is no net transfer of energy to the load, however, electrical power does flow along the wires & returns by flowing in reverse direction along same wires.



Same is for ~~Cap~~ purely capacitive ckt. also.

The current required for this reactive power flow dissipates energy in the line resistances, even if the ideal load device (inductor/capacitor) consumes no energy itself. Practical loads have ~~both~~ resistance as well as inductance or capacitance, so both active & reactive power will flow to the normal loads.

Apparent power is the product of the rms values of voltage & current. Apparent power is taken into account when designing & operating power systems, because although the current associated with reactive power does no work at the load, it still must be supplied by power source. Conductors, transformers & generators must be capable of carrying the total current, not just the current that does useful work.

Failure to provide for the supply of sufficient reactive power in electrical grids can ~~too~~ lead to lowered voltage levels & under certain operating conditions to the complete collapse of the network or blackout.

Conventionally, the total power flow in a single phase AC system is termed as "Complex power" or "apparent power" and is represented by kVA or MVA and frequently the rating of the power apparatus is expressed in terms of kVA or MVA.

~~Com~~ Complex power" is "the complex sum of real & reactive powers". In rectangular form, $S = P + jQ$ & in polar form,

$$S = \sqrt{P^2 + Q^2} \angle \tan^{-1}\left(\frac{Q}{P}\right)$$

Where, ~~P~~ real power $P = V.I.\cos\phi$ &
reactive power $Q = V.I.\sin\phi$
Real power is produced by linear compo. &
reactive power is produced by non-linear compo.
The complex ~~for~~ power for transmission lines is, $S = V.I^*$ where
I^* is complex conjugate of current.

For a single phase AC circuit, the voltage & current phasors are written as,
$V = |V| \angle \theta_v$ &
$I = |I| \angle \theta_i$
Actually complex power is defined as,
$S = V.I$
so we get, $S = |V||I| (\angle\theta_v + \angle\theta_i)$
But in terms of power, we want the phase difference betn these two parameters, ie,
$\theta = \theta_v - \theta_i$
But in the above eqn we get addition of angles.
Hence, to get the difference instead of sum, the conjugate of I ie, I^* is taken.

When you find the conjugate, the magnitude stays the same but the angle has opposite sign. So when you multiply the complex voltage and ~~complex~~ current, you are subtracting θ_v & θ_i.

$\therefore I^* = |I| \angle -\theta_i$

$\therefore \boxed{S = V.I^*}$
$= |V||I| (\angle\theta_v - \angle\theta_i)$
$= |V||I| \angle\phi$

Where angle $\phi = \theta_v - \theta_i$ reprents the angle betn the vltg. & current.

∴ Equation is,

$$S = |V||I|\cos\phi + j|V||I|\sin\phi$$

$$S = P + jQ$$

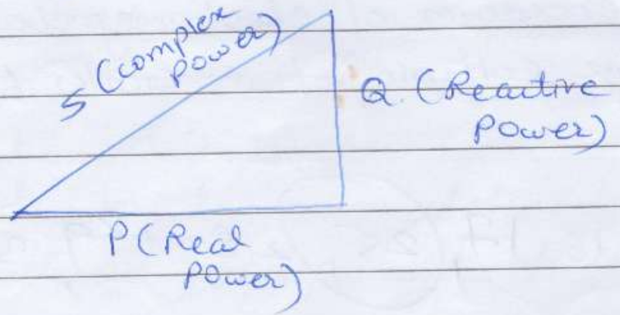
where, $P = V \cdot I \cdot \cos\phi$

$Q = V \cdot I \cdot \sin\phi$

Alternative expressions for complex power may be obtained using the basic relationships betn ~~V~~ V & I as,

$V = ZI$	$I = YV$
$S = VI^*$	$S = V \cdot I^*$
$= IZI^*$	$= V \cdot Y^* \cdot V^*$
$\boxed{S = Z\|I\|^2}$	$\boxed{S = Y^*\|V\|^2}$

In power system analysis, expression of complex power 'S' may be expressed in any of the forms represented above.



Real power accomplishes useful work like ~~While reactive power~~ lighting lamps, rotating motors, etc.

AC power supply systems produce & consume two types of powers — active (Real) & reactive power.

Reactive power is also equally important in power system for following reasons —

i) <u>voltage control</u> — P.S. equipments are designed to operate within ± 5% of the nominal voltage. Fluctuations in voltage leads to malfunctioning of various appliances. Hight vltg. damages the insulation of windings, whereas low vltg. causes poor performance of equipments like low illumination of bulbs, Overheating of induction motors, etc.

If the power demand is more than that supplied by the transmission lines, current drawn from the supply lines increases, which causes voltage to fall drastically at the receiving end side. If this low voltage is decreased further, it leads to tripping of generator units, overheating of motors & other equipment failure.

To overcome this, reactive power should be supplied to the load by putting reactive inductors in transmission lines.

If power demand is less, the load voltage ~~level~~ rises to higher level which leads to automatic tripping of transmission equipment, low p.f., insulation failure

If the reactive power is too low, inductive loads such as transformers will be unable to maintain voltages necessary for the generation of electromagnetic fields, leading to a "voltage collapse" that creates blackouts.

9, 10, 14, 16, 17, 25, 28, 29, 33,

Real power accomplishes useful work while reactive power supports the voltage that must be controlled for system reliability. Reactive power has a profound effect on the security of power systems because it affects voltages throughout the system.

Reactive power is a byproduct of A.C. system and produced from inductive & capacitive loads. It exists when there is phase displacement betn voltage & current.

Since the reactive power is simply moving back & forth in the line, it acts as an additional load. Hence it is considered for deciding the ratings of all cables, transformers, switchgears & other equipment. This means that all these P.S. installations need to be designed for apparent power which considers both active & reactive powers.

If the reactive power exists in excess amount it will ~~greatly~~ greatly reduce the sys. p.f. & hence lowers the system efficiency. This causes undesirable voltage drops, greater losses, excess heating & higher operational costs.

In order to overcome these limitations, reactive power compensation techniques are generally employed in electrical transmission sys. to improve efficiency & p.f.

Reactive power plays an important role in power sys. for various functions. Some are discussed below -

Date / /
Page

1. Voltage control –

In general, all electrical equipment are designed to operate satisfactorily within specified limits of rated voltage ($\pm 5\%$) at the consumer side. The voltage variations are mainly caused due to variation in load.

If the load on the p.s. increases, the voltage drop in the p.s. components increases, thereby voltage at consumer side decreases and vice versa. These voltage changes on the supply system ~~a~~ are undesirable as it deviates the actual performance of the equipment such as lamps, ~~mot~~ motors, etc.

A power system, therefore, must be designed so as to maintain those voltage variations by providing voltage control equipment at suitable places.

The most common method of maintaining the voltage level is through injecting & absorbing reactive power. In general, increasing reactive power causes the system voltage to rise while decreasing reactive power causes voltage to fall.

Reactive power is supplied to the load by putting reactive inductors or reactors in transmission lines. If the power demand is less than reactive power supplied, the load voltage rises to a higher level which leads to tripping of equipment, low p.f. etc.

To overcome this, additional reactive

power available on the system must be compensated. Various compensation equipments like shunt capacitors, series capacitors, synchronous condensers, etc. used. These devices ~~and~~ inject the capacitive reactive power to compensate inductive reactive power in the system.

2. To satisfy reactive power demand. –

Some loads such as transformers & HVDC converters need reactive power for their proper functioning. When the loads have large reactive power demand, the voltage drop takes place.

As the voltage drops, more current is taken from the supply to maintain the power. This causes the lines to consume more reactive power & hence voltage drops further. If the voltage drops too low, it causes voltage collapse. This vltg. collapse causes tripping of generators, ~~or~~ & other equipment.

This voltage collapse is due to the fact that the p.s. is unable to supply reactive power demand of load which is not met due to shortage of reactive power generation & transmission.

In order to overcome this, reactive power sources like series ~~capaci~~ capacitors are connected to the loads locally where reactive power is required.

However, utility companies charge consumers as a penalty for reactive power demand if the loads draw excess reactive power than allowed.

3. To reduce electrical blackouts –

As discussed earlier, insufficient quantity of reactive power causes voltage collapse that ultimately leads to the shutdown of generating stations & various equipments.

Some of these blackouts include at Tokyo in July 23, 1987, London in Aug. 28, 2003.