DETAILS EXPLANATIONS

EE : Paper-1 (Paper-4) [Full Syllabus]

[PART : A]

1. For fixed values of V_S, V_R and X, the reactive power is proportional to the magnitude of voltage drop in the line *(i.e.*. $V_S - V_R$).

2. The voltage employed for primary distribution system depends upon the amount of power to be supplied and distances of the substations required to be supplied.

3. Advantages of adopting of EHV/UHV for transmission of AC electric power are reduced line losses, high transmission efficiency, improved voltage regulation, reduced conductor material requirement, flexibility for future system growth, increase in transmission capacity of the line, increase of SIL.

4. The faults giving rise to unsymmetrical currents *i.e.,* currents differing in magnitude and phases in the three phases of the power system are known as unsymmetrical faults. Unsymmetrical faults may also be defined as the faults involving one or two phases (not involving 3 phases) such as L-G, L-L, L-L-G faults.

5. ***Linear and Non-Linear :***

A linear element is an electrical element with a linear relationship between current and voltage. Resistors are the most common example of a linear element. Other examples include capacitors and inductors. Whereas a nonlinear element or nonlinear device is an element which does not have a linear relationship between current and voltage. A diode is a simple example. The current through a diode is a non-linear function of the voltage over its terminals.

6. ***Peak Value :***

The maximum value attained by an alternating quantity during one cycle is called its peak value. This is also called maximum value or crest value or amplitude. A sinusoidal alternating quantity obtains its maximum value at 90°. The peak value of an alternating voltage and current is denoted as V_m and I_m.

7. It is that set of elements or branches of graph that separates two main parts of a network. If any branch of the cut-set is not removed, the network remains connected. The term cut-set is derived from the property designated by the way by which the network can be divided into two parts.

8. It can be reversed by interchanging many two supply lines feeding the 3-ϕ induction motor with this, the direction of rotating field gets reversed and like wise direction of rotor rotation is reversed.

9. (i) The effect is to increases the starting torque; maximum torque, however, remains constant.

In case rotor circuit resistance is quit larger, starting torque may get reduced, under such a case maximum torque may occur at a slip more than one.

(ii) The effect is also to alter the motor operating speed.

10. When excitation voltage E_f is less than the terminal voltage V_t, the alternator voltage regulation would be negative. This can happen when alternator is delivering a capacitive load.

11. These materials when placed in a magnetic field acquire weak magnetization in a direction opposite to that of applied magnetic field called as diamagnetic materials.

The value of magnetic susceptiability for these materials is negative and very small

Example: Diamond, silicon, Ge.

12. Magnetising flux $\phi_m = \frac{N_1 I_m}{\xi}$

$$\xi = \text{Reluctance}$$

We know that $\sqrt{2}\pi f N_1 \phi_m = V_1$

$$\Rightarrow \qquad \phi_m = \frac{1}{\sqrt{2}\pi N_1}\frac{V}{f} \propto \frac{V}{f}$$

with the airgap the ξ in the path of ϕ_m increases.

$$I_m = \frac{\phi_m \xi}{N_1}$$

$$\phi_m = \text{constant,}$$

I_m increases with increass in ξ.

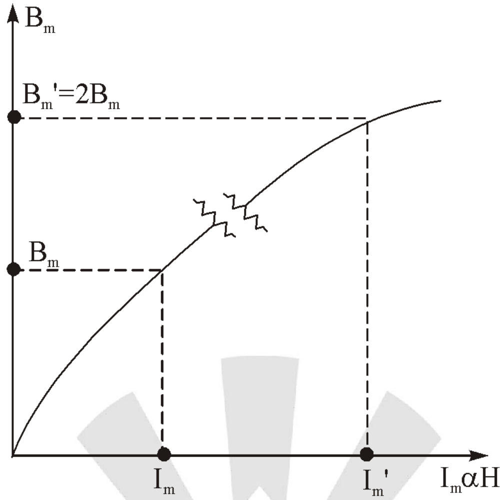
13. ***In core type transformer :*** For a particular voltage rating more number of turns are required, less iron required and more Cu (Conductor materials) so for HV rating core type is preferred.

In shell type : more iron required and less Cu so for LV rating shell type is preferred.

14. $V_1 \ \alpha \ f\phi_m \ ; \ V_1' \ \alpha \ f'\phi_m'$

$$\phi_m' = 2\phi_m$$

$$\beta_m' = 2\beta_m \text{ (Peak flux density)}$$



$$I_m' = 100 I_m$$

Due to saturation mode if the flux density is doubled, the magnetising current required of normal magnetising current.

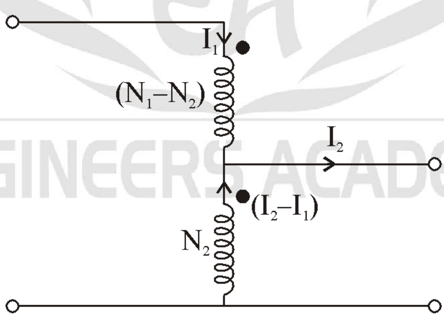
$$I_m = 0.05 \text{ If } l$$

$$I_m' = 100\ I_m = 5\ \text{If}l$$

15.

$$\frac{G_{Auto}}{G_{T.w}} = \frac{(N_1 - N_2)I_1 + N_2(I_2 - I_1)}{N_1I_1 + N_2I_2}$$

$$\frac{G_{Auto}}{G_{T.w}} = \frac{(N_1I_1 + N_2I_2) - 2N_2I_1}{N_1I_1 + N_2I_2} = \frac{2N_1I_1 - 2N_2I_1}{2N_1I_1}$$



$$\frac{G_{Auto}}{G_{T.w}} = \frac{N_1 - N_2}{N_1} = 1 - \frac{N_2}{N_1} = 1 - \frac{1}{a} = \frac{a-1}{a}$$

$$G_{Auto} = \left(\frac{a-1}{a}\right) G_{Tw}$$

$$G_{Auto} < G_{Tw}$$

There is significant save of copper only if $a < 2$.

16. Copper bismuth, copper lead, copper tellurium, copper thallium, silver bismuth, silver lead and silver tellurium are some of alloys employed as contact materials in vacuum circuit breakers.

17. Relay setting means actual value of the energizing or characteristic quantity at which the relay is designed to operate under given conditions.

18. Unit system of protection is one in which the protection responds to faults in the protected zone alone and it does not respond to through faults (faults beyond the protected zone). Non unit systems do not have exact zone boundary.

19. A surge diverter is a device that is connected between line and earth, *i.e.,* in parallel with the equipment under protection at the substation. It limits the duration and amplitude of the follow current.

20. Ferromegnetic materials are spontaneously magnetized even in the absence of external magnetic field. All ferromagnetic materials becomes paramagnetic above certain temperature called as curie temperature.

The value of magnetic susceptibility for these materials is positive and very high.

Example: Soft Iron, Carbon, Steel.

[PART : B]

21. Earthing screen consists of a network of copper conductors, earthed at least on two points, over all the electrical equipment in the substation. An electrostatic shield against external field is presented by such a screen and so protects the system. Earthing screen protects the system from direct lightning strokes, reduces the voltages induced electrostatically or electromagnetically but does not provide any protection against voltage waves which may still reach the terminal equipment. Substations, interconnectors and powerhouses are protected from direct strokes by earthing screen.

22. Distance relay is superior to overcurrent protection for the protection of transmission lines. The reasons are faster protection, simpler coordination, simpler application permanent setting without need for readjustments, less effect of amount of generation and fault levels, fault current magnitude, permits the high line loading.

23. When the feeder ring main is energized from two or more than two generating stations or substations it is called the *interconnected network system.* Because of interconnected feeders, power can be supplied to all the distribution transformers even though a part of network may be out of service. Such a system provides better reliability and flexibility and is employed in large metropolitan cities where continuity of supply is the most important.

24. The impedance Z of the given circuit is given as

$$Z = j4 + \frac{4 \times j4}{4 + j4} - \frac{j}{\omega C} = -\frac{j}{\omega C} + j4 + \frac{j16(4 - j4)}{32}$$

$$= -\frac{j}{\omega C} + j4 + j2 + 2 = -\frac{j}{\omega C} + j6 + 2$$

The power factor will be unity (i.e., the phase angle between the input voltage and current will be zero) only if the reactive part of the impedance is zero.

i.e., if $\frac{1}{\omega C} = 6$

or, $C = \frac{1}{6\omega} = \frac{1}{6 \times 314} = 796\ \mu F$

[$\because$ $\omega = 2\pi f$ and f = 50 Hz (assumed)]

Thus, the required capacitance would be 796 μF only.

25. Application of KVL in loop-1, yields ($t = 0^+$)

$$R_1(i_1 + i_2) + L_1 \frac{di_1}{dt} = 0 \qquad ...(1)$$

Application of KVL involving loop-1 and loop-2 yields or,

$$R_1(i_1 + i_2) + R_2 i_2 + L_2 \frac{di_2}{dt} = 0 \qquad ...(2)$$

From equation (2),

$$i_1 = -\frac{L_2}{R_1} \cdot \frac{di_2}{dt} - \frac{R_1 + R_2}{R_1} i_2 \qquad ...(3)$$

Substituting of (3) in (1), simplification yields

$$\frac{d^2 i_2}{dt^2} + \left(\frac{R_1 + R_2}{L_2} + \frac{R_1}{L_1}\right)\frac{di_2}{dt} + \frac{R_1 R_2}{L_1 L_2} i_2 = 0$$

26. Steam supply cut off means prime mover failure, for ∞-Bus V, f = constant

Speed of stator field $N_S = \dfrac{120f}{p}$ = constant

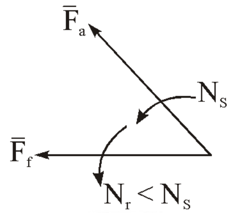


Figure : $\bar{F}_f$ leads $\bar{F}_a$ in case of generator

When pm fails the rotor primeover decrease below N_S but the speed of stator field will remain constant as frequency is cconstant So after some time $\bar{F}_a$ will be leading $\bar{F}_f$. $\bar{F}_a$ will be leading $\bar{F}_f$ it means it beings to act as motor and it start taking current from supply, the direction of supply current get reversed but phase sequence will remain same so direction of rotation of stoator field will be same.

Now in the motoring mode operation there will be locking between opposite poles of rotor and stator so rotor will again pick up synchronous speed so it continious to rotate at rated speed in same direction.

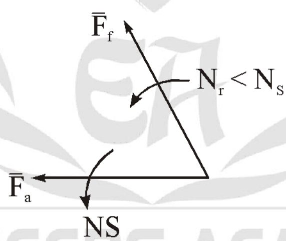


Figure : abc $\rightarrow$ Phase sequence

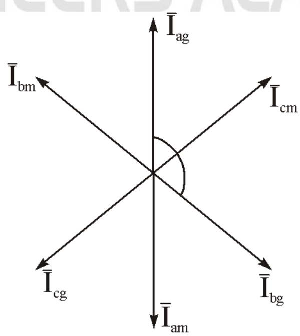


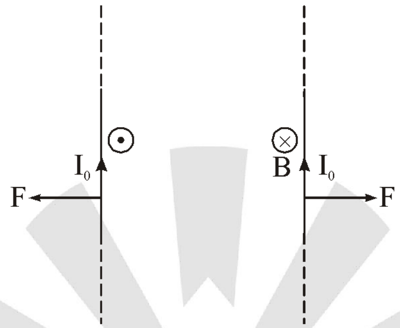
Figure : abc $\rightarrow$ Phase sequence will be same

27.

$$B = \frac{I_0}{2\pi d}$$

$$F = I_0 BL\sin 90^{\circ}$$

$$\frac{F}{L} = \frac{I_0^2}{2\pi d} \text{ N/m.}$$



Both the force will be repulsive type.

28. The interpoles are narrow poles placed exactly midway between the main poles. The interpoles are fitted to the yoke and also known as commutating poles or compoles for a generator, the polarity of the interpole must be the same as that of the main pole ahead of it, in the direction of rotation, for a motor, the polarity of the interpole must be the same as that of the main pole behind it.

The interpoles of appropriate polarity are strengthened so that in interpolar zone; the armature cross flux is neutralized and in addition some flux is produced there. This additional flux in the interpolar zone induces rotational emf in the commutated coil in such a direction as to oppose the reactance voltage. If this rotational emf due to the additional inter polar flux is equal and opposite to the reactance emf, then the resultant emf in the commutated coil would be zero and therefore zero current in that coil would amount to sparkless commutation. This is the reason why interpoles are designed to provide more mmf than the armature mmf in the commutating zone.

29. Speed of rotating mmf wave $= \frac{2f}{P}$ rps

But in one revolutation a peripheral distance of π D meter is traversed.

Speed of travelling mmf wave

$$= \frac{2f}{p}(\pi D) \text{ m/sec} = 2f\left(\frac{\pi D}{P}\right) \text{ m/sec}$$

$$= 2f(\text{Pole pitch}) = f(\lambda) \text{ m/sec}$$

Heve λ is the wavelength of the travelling mmf wave and is equal to two-ople ritches.

For diameter D = 1.2 m, the speed of travelling mmf wave.

$$= 2f\left(\frac{\pi \times 1.2}{6}\right) = 100\left(\frac{\pi \times 1.2}{6}\right) = 62.82 \text{ m/sec}$$

30. In a concentrated winding, the emf induced in various coils gets added up arithmetically. For example, assume two concentrated coils, If rms value of emf generated in coil 1 is E_1 then total generated emf in both the coils of the concentrated winding would be $2E_1$.

Now assume these two coils to be distributed in two adjacents slots. Let the angle between the slots be r° if rms value of emf generated in coil 1 is E_1, then rms value of generated emf in coil2 would also be E_1 but this emf would resultant emf is $[(E_1 + E_1 \cos r)^2 + (E_1 \sin r)^2]^{1/2}$. But this emf is less than $2E_1$.

This shows that emf induced in a distributed AC winding.

31. Impedance of line,

$$Z = (30 + j110)\Omega$$

Base kVA,

$$kVA_B = 100 \text{ MVA or } 100000 \text{ kVA}$$

Base kV, $kV_B = 132$ kV

Per unit impedance,

$$Z_{pu} = \frac{Z \times kVA_B}{(kV_B)^2 \times 1{,}000} = \frac{(30 + j110) \times 100000}{(132)^2 \times 1000}$$

$$= (0.172 + j0.631) \text{ pu}$$

32. Conductor radius,

$$r = \sqrt{\frac{a}{\pi}} = \sqrt{\frac{10}{\pi}} = 1.784 \text{ cm} \qquad (\because a = \pi r^2)$$

Spacing of conductors, d = 5 m

Geometric mean radius (GMR) of conductor,

$$r' = 0.7788\, r = 0.7788 \times 1.784 = 1.39 \text{ cm}$$

Loop inductance of 500 m long single phase line,

$$L = 0.4 \log_e \frac{d}{r'} \times l = 0.4 \log_e \frac{500}{1.39} \times \frac{1}{2} = 1.177 \text{ mH}$$

[PART : C]

33. Fault current, $I_f = 5{,}000$ A

CT ratio = 500 : 1

Relay current,

$$I_R = \frac{I_f}{\text{CT ratio}} = \frac{5000}{500} = 10\text{A}$$

Pick-up value of relay = Current setting × Rated secondary current of CT = $\frac{125}{100}\times 1 = 1.25$ A

Plug setting multiplier of the relay,

$$\text{PSM} = \frac{\text{Fault current in relay coil } I_R}{\text{Pick-up value of relay}} = \frac{10}{1.25} = 8$$

Time corresponding to the PSM of 8 from the given data is 3.2 seconds

So actual operating time = 3.2 × Time setting multiplier

= 3.2 × 0.3 = 0.96 second

34. $$\tan\phi = \frac{\omega L}{R}$$

or $\tan 63.5^\circ = \frac{0.02\omega}{R}$ [$\because \phi = 63.5^\circ$; L = 20 mH]

or $2R = 0.02\,\omega$

i.e., $R = 0.01\,\omega$ ...(1)

But $Z = \sqrt{R^2 + (\omega L)^2} = \sqrt{(0.01\omega)^2 + (0.02\omega)^2}$

[$\because$ in (1) we have obtained R = 0.01 ω and L = 0.02 H]

$\therefore$ Z = 0.0224 ω or 17.85 = 0.0224 ω

$\therefore$ ω = 796.875 rad/sec

and R = 0.01 ω = 7.98 ω ≃ 8 Ω

Thus we have obtained,

R = 8 Ω; ω = 796.875 rad/sec

35. There are three method of obtaining sparkless commutation :

- ***Resistance Commutation***

This method of improving commutation consist of using carbon brushes. This makes the contact resistance between commutator segments and brushes high. This high contact resistance has the tendency to force the current in the short-circuited coil to change according to the commutation requirements, namely, to reverses and then build up in the reverse direction.

- ***Voltage Commutation***

  In this method, arrangement is made to induce a voltage in the coil undergoing commutation, which will neutralize the reactance voltage. This injected voltage is in opposition to the reactance voltage. If the value of the injected voltage is made equal to the reactance voltage, quick reversal of current in the short-circuited coil will take place and there will be sparkless commutation two methods may be used to produce the injected voltage in opposition to reactance voltage:

  (i) Brush Shift : The effect of armature reaction is the shift the magnetic neutral axis MNA in the direction of rotation for the generator and against the direction of rotation for the motor. Armature reaction establishes a flux on the neutral zone. A small voltage is induced in the commutating coil since it is cutting the flux.

  (ii) Commutating Poles or Interpoles : Are narrow poles attached to the stator yoke and placed exactly midway between the main poles. The interpole winding are connected in series with the armature because the interpoles must produce fluxes that are directly proportional to the armature current I_a. The armature and interpole mmfs are affected simultaneously by the same I_a the interpoles must induce a voltage in the conductors undergoing commutation that is opposite to the voltage cause by the neutral-plane shift and reactance voltage for a generator, the neutral plane shift in the direction of rotation and in case of motor shift in the opposite direction of rotation.

  For a generator, the polarity of the interpole must be the same as that of the next main pole further ahead in the direction of rotation for a motor the polarity of an interpole in opposite to that of the next main pole in the direction of rotation.

- ***Compensating Windings***

  Are placed in slots provided in pole faces parallel to the rotor (armature) conductors. These winding are connected in series with the armature windings. The direction of current in the compensating winding must be opposite to that in the armature winding just below the pole faces. Thus compensative winding produces an mmf that is equal and opposite to the armature mmf in the effect the compensating winding demagnetizes or neutralizes the armature flux produced by the armature conductors lying just under the pole face. The flux per pole is then undisturbed by the armature flux regardess of the load conditions.

36. The Scott connection is the most common method of connecting two single phase transformers to per-form the 2-phase to 3-phase conversing and vice-versa. The two transformers are connected electrically but not magnetically. One transformer is called main transformer and the other is known as auxiliary transformer.

The main transformer is centre-tapped at D and is connected across the lines B and C of the 3-phase side.

Frquently identical interchangeable transformer are used for the Scott connection, in which each transformer has a primary winding of T_p turns and is provided with tappings at 0.289 T_p, 0.5 T_p and 0.866 T_p.

Phasor Diagram :

The line voltage of the 3-phase system V_{AB}, V_{BC} and V_{CA}. Which are balanced are shown in figure. The same voltages are shown as a close equilateral triangle in figure.

$$|V_{AB}| = |B_{BC}| = |V_{CA}| = V_L \text{ (say)}$$

Let V_{BC} be taken as reference voltage so that

$$V_{BC} = V_L\angle 0^\circ$$
$$V_{CA} = V_L\angle -120^\circ$$
$$V_{AB} = V_L\angle +120^\circ$$

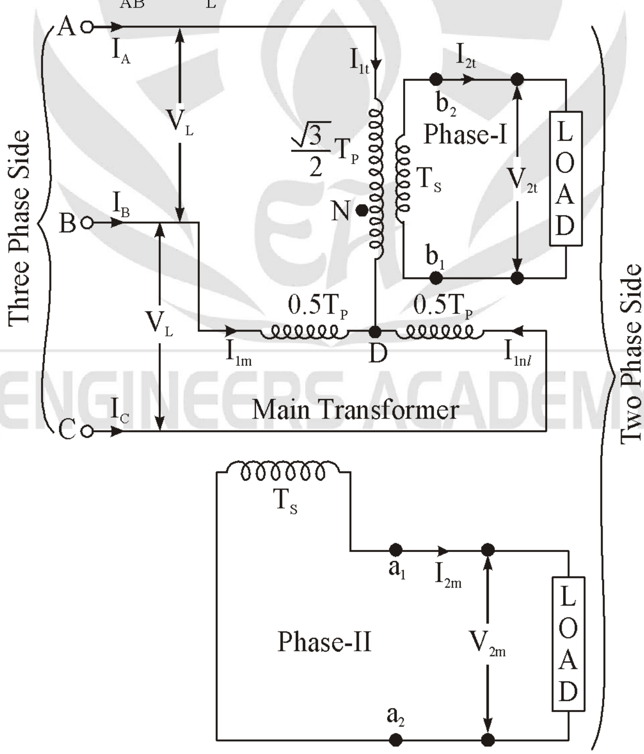


Figure : Scott Connection of Transformers

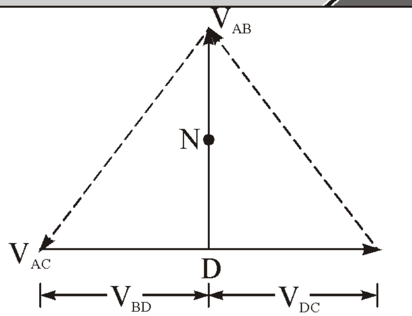


Figure : Voltage on Transformer Primary Winding

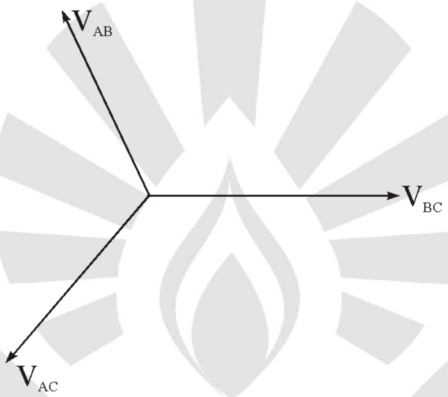


Figure : 3-Phase input Voltages

D divides the primary BC of the main transformer in two equal halves, number of turns in portion BD = Number of turns in portion

$$DC = \frac{T_P}{2}.$$

The voltages V_{BD} and V_{DC} are equal they are in phase with V_{BC}.

$$\therefore \quad V_{BC} = V_{DC} = \frac{1}{2}V_{BC} = \frac{1}{2}V_L\angle 0^\circ$$

The voltage between A and D is

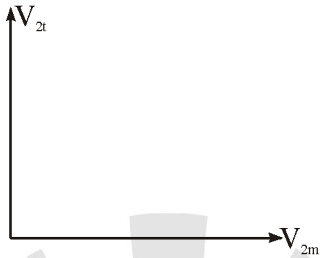
$$V_{AD} = V_{AB} + V_{BD}$$

$$V_{AD} = V_L\angle 120^\circ + \frac{1}{2}V_L\angle 0^\circ = V_L\left(-\frac{1}{2} + j\frac{\sqrt{3}}{2}\right) + \frac{1}{2}V_L$$

$$= \frac{j\sqrt{3}}{2}V_L = 0.866V_L\angle 90^\circ$$

The auxilary transformer has a primary voltage rating that is 0.866 of voltage rating of the main transformer.

Voltage V_{AD} is applied to the primary of the teaser transformer and therefore, the secondary voltage V_{2t} of the teaser transformer will lead the secondary terminal voltage V_{2m} of the main transformer by 90° as shown in figure.

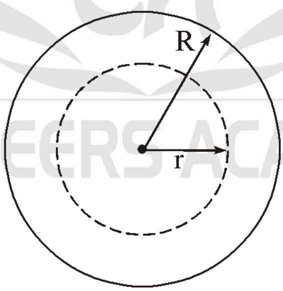


For the same flux in each transformer, the voltage perturn should be the same. In order to keep voltage per turn same in the primary of the main transformer and primary of the auxilary (teaser) transformer. The number of turns in the primary of the teaser transformer, that is, in portion AD, should be equation to $\frac{\sqrt{3}}{2}T_p$.

Then $\frac{V_{S1}}{V_{AD}} = \frac{T_S}{T_{AD}}$.

$$V_{2t} = \frac{T_S}{T_{AD}}V_{AD} = \frac{T_S}{(\sqrt{3}/2)T_p} \times \frac{\sqrt{3}V_L}{2} = \frac{T_S}{T_P}V_L = V_{2m}.$$

37. Consider a sphere of radius R and volume charge density ρ_0.



$$W_E = \frac{1}{2}\int_v \epsilon_0 E^2 dv \quad \ldots(1)$$

$$\oint \bar{D}.\bar{ds} = \rho_0 \times \frac{4}{3}\pi r^3$$

$$\epsilon_0 E \times 4\pi r^2 = \rho_0 \times \frac{4}{3}\pi r^3$$

$$E(r) = \frac{\rho_0 r}{3\in_0} \text{ but in (1)}$$

$$W = \frac{1}{2}\frac{\rho_0^2}{9\in_0^2}\times\in_0\int_v r^2\, dv = \frac{\rho_0^2}{18\in_0}\int r^4 dr\int \sin\theta d\theta\int d\phi$$

$$W = \frac{\rho_0^2}{18\in_0}\int_0^R r^4 dr\int_0^\pi \sin\theta\, d\theta\int_0^{2\pi} d\phi = \frac{\rho_0^2 R^5}{90\in_0}\times 4\pi$$

$$W = \frac{2\pi\rho_0^2.R^5}{45\in_0}\ \text{J.}$$

38. The power factor(p.f.) of a synchrnonous motor can be controlled by variation of field current I_f. It has also been observed that the armature current I_a changes with the changes in I_f. Let us assume that the motor is operating at no load. If the field current is increased from this small value, the armature current I_a decreases untill the I_a becomes minimum, at this minimum I_a the motor is operating at unity p.f. upto this point the motor was operating at a lagging p.f. if the I_f is increased further, the I_a increases again at the motor starts to operate at a leading p.f. if a graph is plotted between I_a and I_f at no load the lowest curve in figure, is obtained. If this procedure is repeated for various increased loads, a family of curves is obtained as shown in figure.

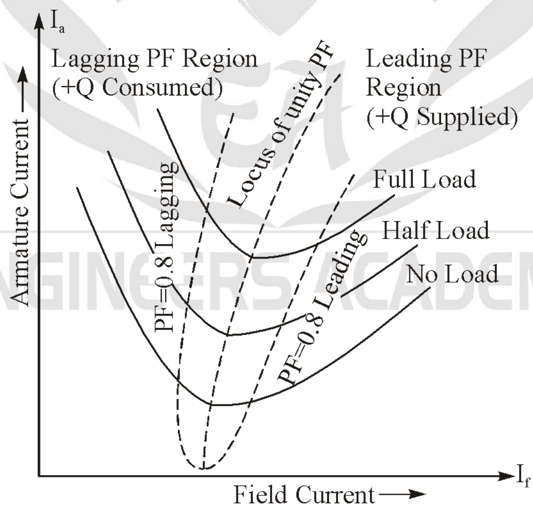


Figure : V-Curves of a Synchrnonous Motor.

V-curve are plots of stator current versus I_f for different constant loads. The point at which unity p.f. occurs is at the point where armature current I_a is minimum the curve connecting the lowest points of all V curves for various power levels is called the unity p.f. compounding curve. Similarly, compounding curve for 0.8 p.f lag and 0.8 p.f. lead are shown by dotted curves in figure. The compounding curves for other p.f. can be drawn. Thus, the loci of constant p.f. Bints on the V curves are called compounding curve the compounding curves the compounding curves show the manner in which the I_f should be varied in order to maintain constant p.f. under changing loads. Point to the right of the unity p.f. compounding curve corresponding underexcitation and lagging current input.

The V curves are useful in adjusting the I_f. increasing the I_f beyond the level for minimum I_a results in leading p.f. similarly, decreasing the I_f below that for minimum I_a result in lagging p.f. therefore, by controlling the I_f of a synchronous motor, the reactive power supplied to or consumed from the power system can be controlled.

A family of curves is obtained by plotting the p.f versus I_f. These are inverted V curves as shown in figure the highest point on each of these cuves indicates unity p.f. it is so be noted that the field current I_f for unity p.f. at full load is more than the I_f for unity p.f. at no load. figure also shows that if the synchronous motor at full load is operating at unity pf then removel of the shaft load causes the motor to operate at a leading power factor.

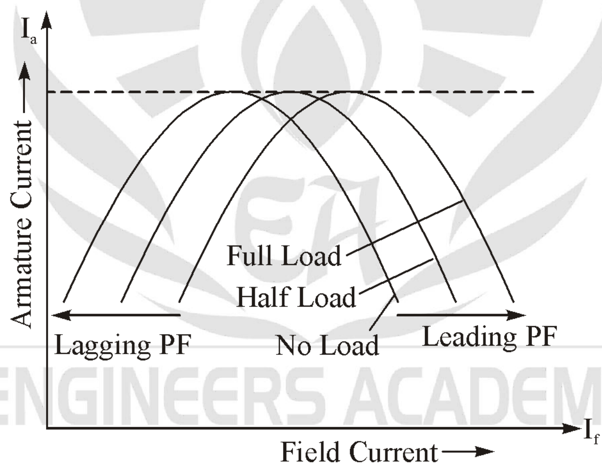


Figure: Power Factor Versus field Current at different loads.

39. Conductor radius,

$$r = 0.5 \text{ cm}$$

Spacing of conductors,

$$d = 1 \text{ metre} = 100 \text{ cm}$$

(i) Loop inductance per km of line with copper conductor

$$= \left(1 + 4\log_e \frac{d}{r}\right) \times 10^{-7} \times 1{,}000 \text{ H}$$

$$= \left(0.1 + 0.4\log_e \frac{100}{0.5}\right) \times 10^{-3} \text{ H}$$

= 2.22 mH

(ii) Loop inductance per km of line with steel conductor

$$= \left(\mu + 4\log_e \frac{d}{r}\right) \times 10^{-7} \times 1000\text{H}$$

$$= \left(50 + 4\log_e \frac{100}{0.5}\right) \times 10^{-4}\text{H}$$

= 7.12 mH

❍❍❍