DETAILS EXPLANATIONS

Electrical Machine
[PART : A]

1. Open circuit test is to determine iron loss, As iron loss depends upon the applied voltage. So it is performed at rated voltage hence it is performed on L.V. side.

Short circuit test is performed to determine cu loss. As cu loss depends upon load current so short circuit test is performed at rated current to flow the rated current in short circuit condition reduced voltage upto 5% of rated voltage is required. So short circuit test is performed at H.V. side or Low current side.

2.
$$\eta = \frac{P_0}{P_{in}} = \frac{P_0}{P_0 + P_L}$$

$$\eta = \frac{xS_0 \cos\phi}{xS_0 \cos\phi + P_i + x^2 P_{CF}}$$

$$P_0 = xS_0 \cos\phi$$

$$P_{in} = \text{Power output + Losses}$$

Where S_0 = Transformer capacity (VA)

x = Percentage load (P.U.)

P_i = Iron losses

P_{CF} = Full load cu losses.

3. The voltage regulation of a transformer is the arithmetical difference in the secondary terminal voltage between no load and full load at a given power factor with the same value of primary voltage for both no load and full load.

$$\text{V.R.} = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100$$

$$\text{V.R.} = x[R_{pu} \cos\phi + x_{pu} \sin\phi]$$

Where V_{nl} = Voltage at no load

V_{fl} = Full load voltage

x = Per unit load

R_{pu} = Resistance in p.u.

X_{pu} = Reactance in p.u.

4. (i) Loss i.e. iron loss = 0, cu loss = 0

i.e. R_1 and $R_2' = 0$, $P_i = \dfrac{E_1^2}{R_i} = 0$

$\Rightarrow \quad R_i = \infty$

(ii)No leakage flux i.e. leakage reactance are zero.

(iii) $\phi_m \neq 0$ but $I_m = 0$ i.e. $X_m = \infty$ or $L_m = \infty$

$$\phi_m = \frac{\text{mmf}}{\text{Reluctance}} = \frac{N_1 I_m}{\xi}$$

$$\text{Reluctance } (\xi) = \frac{l}{\mu_0 \mu_r A}$$

$$\mu_r = \infty$$

5. Magnetising flux $\phi_m = \dfrac{N_1 I_m}{\xi}$

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

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

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

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.

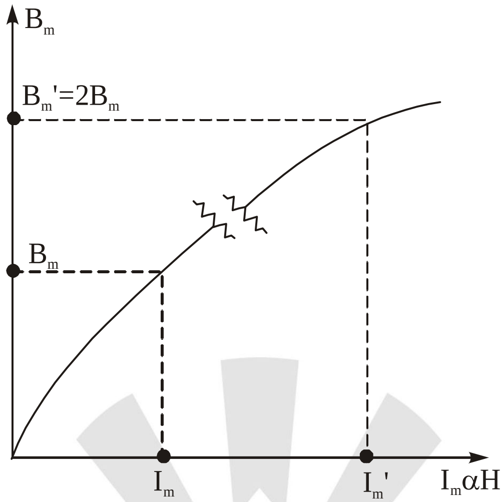
6. ***In core type transformer :*** For a particular voltage rating more number of turns are required, less iron required and more Cu (Conductor materials) so for HV vating core type is preferred.

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

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

$$\phi_m' = 2\phi_m$$

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



$I_m' = 100 I_m$

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

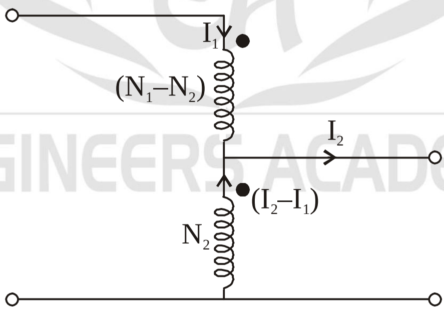
$$I_m = 0.05 \text{ If } l$$

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

8.

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

$$\frac{G_{Auto}}{G_{T.w}} = \frac{(N_1 I_1 + N_2 I_2) - 2N_2 I_1}{N_1 I_1 + N_2 I_2} = \frac{2N_1 I_1 - 2N_2 I_1}{2N_1 I_1}$$



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

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

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

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

9.
- The harmonic induced emf gets reduced significantly without much reduction in fundamental. So induced emf wave form is improved i.e. closer to sinusoidal.
- Slot depth is reduced hence there is reduction in slot harmonics.

10. Winding factor (k_w)

$$k_w = k_p.k_d$$

where, k_p = Pitch factor

k_d = distribution factor.

$$k_d = \frac{\sin\frac{Qr}{2}}{Q\sin\frac{r}{2}}$$

$$k_p = \cos\left(\frac{p}{2}\right)$$

where, $r = \dfrac{\pi}{(\text{slot / pole})}$

Q = Slot/pole/phase = $\dfrac{S}{MP}$

$Qr = \Psi =$ Phase spread or phase belt

p = Angle of short pitching or angle of cording

11. n^{th} harmonic pitch factor

$$k_{p_n} = \cos\frac{n\rho}{2}$$

To eliminate n^{th} harmonic

$$k_{p_n} = 0$$

$$\cos\frac{n\rho}{2} = 0$$

So, $$\frac{n\rho}{2} = \frac{\pi}{2}$$

$$S = \frac{\pi}{n} = \frac{1}{n} \times \text{full pitch}$$

$$\text{Coil Span} = \pi - \rho = \pi - \frac{\pi}{n}$$

$$= \frac{n-1}{n} \times \pi = \frac{n-1}{n} \times \text{full pitch.}$$

12. Following method to minimize slot harmonics.

- By increasing the air gap length.
- Using less slot opening.
- Using distributed and short pitch winding.
- Using fractional slot windings.
- Using skewed slot by one slot pitch.

13. Following method to minimize armature reaction.

- Using interpoles.
- To reduce the armature flux ϕ_a, reluctance in the path of ϕ_a is increased using liminated pole shoe.
- By using non-uniform airgap i.e. minimum at centre and progressively increasing towards corners.
- Using compensating winding.

14. Reason of failure of voltage building up

- Residual flux is absent.
- Field terminals are wrong/connection wrong.
- Direction of ratation is wrong as E is reverse, If is reversed so that ϕ_{res} will be destroyed.
- Field resistance is more than critical field registance R_{fc}.
- Speed is less then critical speed i.e., $N < N_C$.

15. Transformer core loss P_c consist of two components, hysteresis less P_h and eddy current loss P_e i.e.,

$$P_c = P_n + P_e$$
$$= k_h f B_m^x + k_e f^2 B_m^2$$

where, x = Steinmetz's constant varies from 1.5 to 2.5 depending upon the magnetic properties of core material.

k_h = Depend upon volume and quality of the core material.

k_e = Depend upon the volume and resistivity of core material.

16. The exciting (or non-load) current of a transformer has two components; normely magnetizing current I_m and core-loss current I_c.

The function of magnetizing current I_m is to produce the necessary mmf to create the required mutual flux in the core. The function of core-loss current is to provide for the core loss in the transformer.

17. For low value of load p.f. primary and secondary winding currents become more ($\because$ current α load/pf), therefore, ohmic loss increases as the load pf is lowered.

Core loss, however, remains unaffected because B_m, f are not altered by load pf.

18. Electrical angle is a measure of one cycle of emf wave or current wave. In electrical engineering, one cycle = 360^o electrical.

In a P-pole machine, $\frac{P}{2}$ cycles (or $P/2 \times 360^o$ electrical) are generated in one revolution (= 360^o mech). So we can get $\frac{P}{2}\times 360^o$ electrical from 360^o mech. by multiplying 360^o mech by $\frac{P}{2}$.

$$\therefore \qquad Q_{elec} = \frac{P}{2} Q_{mech}$$

19. Amplitude of square wave = $\frac{Ni}{2}$

Peak value of fundamental mmf wave

$$= \frac{4}{\pi}\frac{NI}{2} AT_s$$

20. If the flux produced by one phase of a 3-ϕ induction motor has peak value ϕ_m, then maximum value of the revolning flux is $\frac{3}{2}\phi_m$.

[PART : B]

21. $(\varepsilon_r \cos\theta_2 + \varepsilon_x \sin\theta_2 = VR_{pu})$

Equation shows that VR varies with load power factor. If load factor is varies with constant value of load current and secondary emf, then zero voltage regualtion will occur when

$\varepsilon_r \cos\theta_2 + \varepsilon_x \sin\theta_2 = 0$

$$\tan\frac{\theta}{2} = -\frac{\varepsilon_r}{\varepsilon_x} = -\frac{\frac{I_2 I_{e2}}{E_2}}{\frac{I_2 x_{e2}}{E_2}} = -\frac{r_{e2}}{x_{e2}}$$

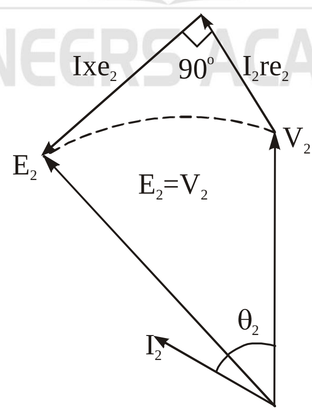


Figure : Phas or Diagram for 1-ϕ transformer for zero V.R.

$\therefore$ Magnituse of load p.f., $\cos\theta_2 = \frac{x_{e2}}{z_{e2}}$

The negative value of $\tan\theta_2$ indicates a leading pf therefore, zero voltage regulation occurs when load pf is $\frac{x_{e2}}{z_{e2}}$ leading for leading pfs greater than $\frac{x_{e2}}{z_{e2}}$, the voltage regulation will be negative, i.e., the voltage will rise from its no load value as the transformer load is increases.

22. For a constant load current, the ohmic losses P_{sc} are constant. Core loss P_c is already fined quantity. There fore, total transformer losses are constant for a constant load current.

Now η is

$$\eta = \frac{V_2 I_2 \cos\theta_2}{V_2 I_2 \cos\theta_2 + \text{constant losses (c)}}$$

pf at which maximum η occurs can be obtained by equation

$$\frac{d\eta}{d\theta_2} = 0$$

$$\frac{d\eta}{d\theta_2} = \frac{[V_2 I_2 \cos\theta_2 + C] V_2 I_2(-\sin\theta_2) - (V_2 I_2 \cos\theta_2) V_2 I_2(-\sin\theta_2)}{[V_2 I_2 \cos\theta_2 + C]^2} = 0$$

or $\sin\theta_2 = 0$

or $\text{pf} = \cos\theta_2 = 1$

Thus the maximum η for a constant load current, occurs at unity pf.

23. Following disadvantage of Auto transormer :

(i) If the ratio of transformation k differs for fram unity, the economic advantages of auto-transformer over two winding transformer decreases.

(ii) The main disadvantage of an outo-transformer is due to the direct electrical connection between the low-tension and high tension side. If primary is supplied at high voltage, then an open circuit in the common winding, would result in the appearance of dangerously high voltage on the low voltage (LV) side this high voltage may be deterimental to the load and the persons working there, thus a suitable protection must be provided against such an occurrence.

(iii) The short circuit current in an auto-transformer is higher than that in a corresponding two-winding transformer.

24. **1.** The first cause of hum, and therefore the noise, is the magnetostriction.

2. The details of core construction, size and gauge of liminations and the degree of tightness of damping the core by unts and bolts do influence the frequency of meachnical vibrations and therefore the noise in transformers.

3. Joints in the core are also responsible for noise production through to a lesser degree. Most of the noise emission from a transformer may be reduced.

- By using low value of flux density in the core.
- By proper tightening of the core by clamps, bolts etc.
- By sound-insulating the transformer core from the tabnk wall in case of large transformers or by sound-insulating the transformer core from where it is installed in case of small transformers.

25. For detect correct place for brush following procedure may be adopted.

- Run the machine at rated speed as a DC generator, first in one direction and then in the opposite direction. for the same field and armature currents. If the terminal voltage for both the direction of rotation are the same, then the brushes are placed correctly along the quadrature axis.
- Alternatively, run the machine as a DC motor, first in one direction and then in opposite direction, for the same field and armature currents, if the rotor speed turns out to be the same for both directions of ratation. Then the brushes are placed correctly along the quadrature axis.
- If the brushes get shifted inadvertently from the quadrature axis, then the terminal voltage in case of generator or speed in case of motor, for both the direction of rotation, would not be equal.

26. The effect of brush shift can be examines from the developed view of the armature conductor and field poles, for this purpose, let the brushes be shifted in the forward direction for a generator or brackward direction for a motor. The peak of the triangular armature mmf wave is also shifted by the same angle, because armature mmf axis must cincide with the brush axis.

The flux per pate is reduced if the brushes are given a forward shift in case of generator or back ward shift in case of a motor. This reduction in fluse cause a decrease in the generator terminal voltage or an increase in the motor speed.

If the brushes are given a backward shift in a generator or foward shift in a motor, the flux per pole becomes more and as a result of it, the generator terminal voltage rises and the motor speed falls.

27. 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 porarity 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 strength ened 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.

28. The operating voltage

$$V_1 = \sqrt{2}\pi f_1 B_{m1} A_i N$$

$$V_2 = \sqrt{2}\pi f_2 B_{m2} A_i N$$

$$\frac{V_1}{V_2} = \frac{f_1 B_{m1}}{f_2 B_{m2}}$$

or $$\frac{220}{230} = \left(\frac{60}{50}\right)\left(\frac{B_{m1}}{B_{m2}}\right)$$

$$\Rightarrow B_{m2} = \frac{60(230)}{50(220)}$$

$$B_{m1} = 1.255\ B_{m1}$$

We know that

$$P_n = k_n f\, B_m^x$$

$$\therefore \quad \frac{P_{n2}}{P_{n1}} = \frac{f_2 B_{m2}^x}{f_1 B_{m1}^x} = \frac{50}{60}(1.255)^{1.6}$$

$$P_{n2} = 340\left(\frac{5}{6}\right)(1.255)^{1.6} = 408\ W$$

We know that

$$P_e = k_e f^2 B_m^2$$

$$\therefore \quad \frac{P_{e2}}{P_{e1}} = \left(\frac{f_2}{f_1}\right)^2 \left(\frac{B_{m2}}{B_{m1}}\right)$$

$$= \left(\frac{50}{60}\right)^2 (1.255)^2$$

$$P_{e2} = (120)\left(\frac{5}{6}\right)^2 (1.255)^2 = 131.3 \text{ W}$$

Total core loss

$$P_{c2} = P_{n2} + P_{e2}$$
$$= 408 + 131.3 = 539.3 \text{ W}$$

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. The field winding loss $V_f I_f$ and no-load rotational losses w_o remain approximately constant. The maximum efficiency as before, occurs when variable losses $I_a^2 r_a$ are equal to the Constant losses $V_f I_f + W_o$ this can be proved as follows:

We know that generator efficiency

$$\eta_g = \frac{V_t I_L}{V_t I_L + I_a^2 r_a + V_f I_f + w_o}$$

In shunt or compound machines, assume that the field current If is negligible as compared with the line current I_L with this assumption, $I_L = I_a$ and generator efficiency becomes.

$$\eta_g = \frac{V_t I_L}{V_t I_L + I_L^2 r_a + V_f I_f + w_o}$$

For a given value of V_t, the maximum efficiency occurs, when

$$\frac{d\eta_g}{dI_L} = \frac{\left[V_t I_L + I_L^2 r_a + V_f I_f + W_0\right] V_t - V_t V_L \left[V_t - 2 I_L r_a\right]}{\left[\text{Denominator}\right]^2} = 0$$

or $\left[V_t I_L + I_L^2 r_a + V_f I_f + W_0\right] V_t = V_t V_L \left[V_t + 2 I_L r_a\right]$

or $I_L^2 r_a = V_f I_f + W_0$

Variable armature circuit loss = Constant loss.

31. 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 resultan 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.

32. The shunt field current

$$I_f = \frac{220}{110} = 2A$$

At no load, armature current

$$I_{a1} = 5 - 2 = 3 \text{ A}$$

Counter emf

$$E_{a1} = 220 - 3 \times 0.2$$

$$= 219.4 \text{ Watts}$$

$\therefore$ Rotational Losses $= E_{a1}I_{a1}$

$= 219.4 \times 3 = 658.2$ Watts

At full load, armature current

$$I_{a2} = I_L - I_f = 52 - 2 = 50A$$

$\therefore$ Counter emf $E_{a2} = 220 - 50 \times 0.2 = 210$ V

Here ϕ_1(No load flux) = ϕ_2(full load flux)

Because the field current is constant at 2A and effect of AR is neglected.

$$\therefore \quad \frac{E_{a1}}{E_{a1}} = \frac{n_1\phi_1}{n_2\phi_2}$$

$$\text{or} \quad n_2 = \frac{n_1\phi_1}{\phi_1} \times \frac{E_{a2}}{E_{a1}} = \frac{1500 \times 210}{219.4} = 1435 \text{ rpm}$$

Shaft power

$$P_{sh} = \text{Electromagentic power} - \text{Roational losses}$$

$$= 210 \times 50 - 658.2 = 9841.8 \text{ Watts}$$

$$\therefore \text{ Shaft torque} = \frac{P_{sh}}{W_m} = \frac{9841.8 \times 60}{2\pi \times 1435} = 65.4 \text{ Nm}$$

[PART : C]

33. Open circuit and short circuit test are performed to determine the circuit constant, efficiency and regulation without actually loading the transformer.

Open Circuit Test :

Figure shows the cannection diagram for the open circuit test. The high voltage (H.V.) side is left open.

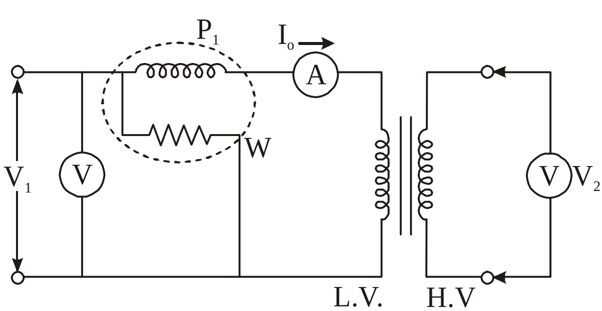


Figure : Open-Circuit Test on Transformer

There secondary is open-circuited, a very small current I_0, called the no-load current, flow in the primary. the ammeter A reads the no-load current I_0. The power loss in the transformer is due to core loss and a very small I^2R loss in the primary. There is no I^2R loss in the secondary since it is open and $I_2 = 0$ since the I_0 is very small (usually 2 to 5% of the full load primary current) the I^2R loss ln the primary winding can be neglected. The core loss depend upon the flux. Since the rated voltage V_1 is applied, the flux setup by it will have normal value so that normal core losses will occur. This core loss is the same at all loads. The no-load equivalent circuit can be determined

$$p_1 = V_1 I_0 \cos \phi_0$$

No load p.f.

$$\cos \phi_0 = \frac{P_i}{V_1 I_0}$$

$$I_w = I_0 \cos \phi_0$$

$$I_\mu = I_0 \sin \phi_0$$

$$R_0 = \frac{V_1}{I_w}$$

$$X_0 = \frac{V_1}{I_\mu}$$

Short Circuit Test :

Usually the LV side is short circuited by a thick conductor an ammeter, a voltmeter and a watt metter are connected on the H.V. side. The reasons for short circuiting the L.V. side and Taking measurement on the H.V. side are as follows:

- The rate current on H.V. side is lower than that on LV side this current can be safely measured with the available ammeter.
- Since the applied voltage is less than 5% of the rated voltage of the winding, greater accuracy in the reading of the voltmeter is possible when the H.V. side is used as the primary. The H.V. winding is supplied at the reduced voltage from a variable voltage supply. The supply voltage is gradually increased untill full-load primary current flows. When the rated full-load current flow in the primary winding rated full-load current will flow in the secondary winding by transformer action.

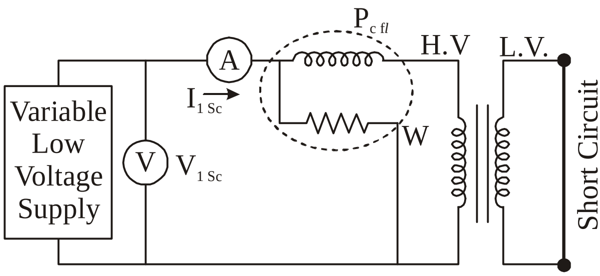


Figure : Short Circuit Test on a Transformer

Thus the wattmeter gives the full load copper losses p_{cfl}. The reading of the instrument on short-circuit test, the following calculations can be made :

Equivalent resistance of the transformer referred to primary

$$R_{e1} = \frac{P_{cfl}}{I_{1Sc}^2}$$

and equivalent inpedance refered to primary

$$Z_{C1} = \frac{V_{1Sc}}{I_{1Sc}}$$

Equation reactance referred to primary

$$X_{e1} = \sqrt{Z_{e1}^2 - R_{e1}^2}$$

$$\cos\ \phi_{Sc} = \frac{R_{e1}}{Z_{e1}}$$

The full load p.f.

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

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

$$V_{BC} = V_L\angle 0^o$$
$$V_{CA} = V_L\angle -20^o$$
$$V_{AB} = V_L\angle +120^o$$

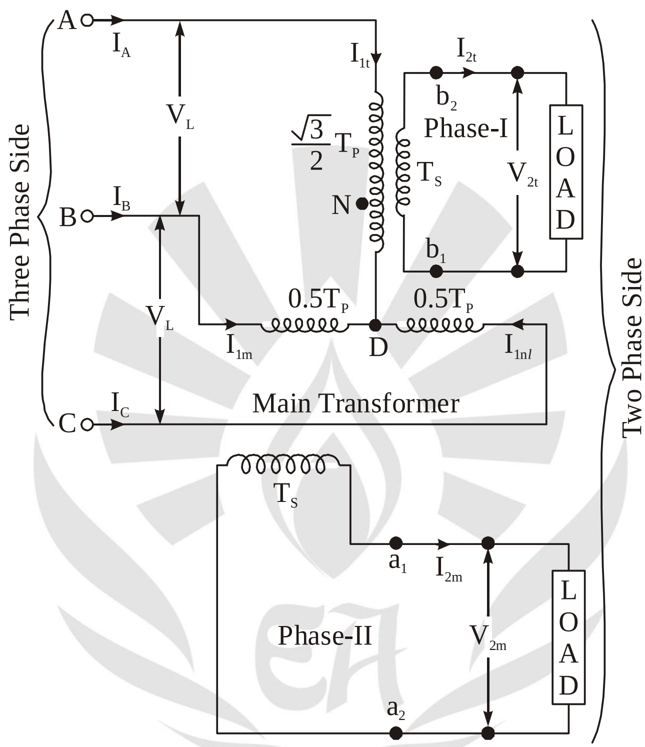


Figure : Scott Connection of Transformers

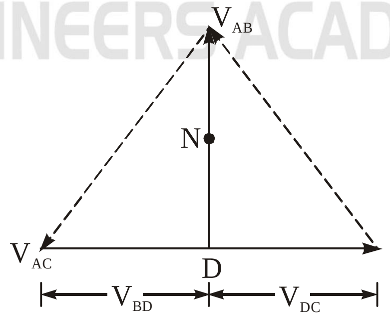


Figure : Voltage on Transformer Primary Winding

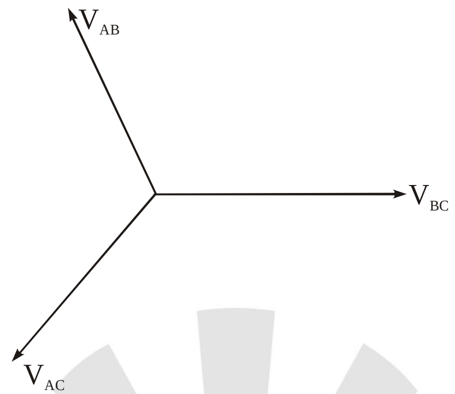


Figure : 3-Phase input Voltages

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}.

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

The voltage between A and D is

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

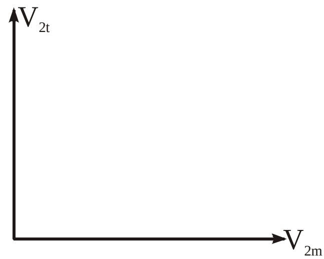
$$V_{AD} = V_L\angle 120^o + \frac{1}{2}V_L\angle 0^o$$

$$= V_L\left(-\frac{1}{2} + j\frac{\sqrt{3}}{2}\right) + \frac{1}{2}V_L$$

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

The auxilary transormer has a primary voltage ratting 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 termainl voltage V_{2m} of the main transformer by 90^o 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 $\frac{V_{S1}}{V_{AD}} = \frac{T_S}{T_{AD}}$.

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

35. When a transformer is initially energized, there is a sudden inrugh of primary current. The maximum value attained by the flux is over twice the normal flux. The core is driven for into saturation with the result that the magnetizing current has a very high peak value. Let a sinsusoldal voltage

$$V_1 = V_{1m} \sin (wt + \alpha) \qquad ...(1)$$

Be applied to the primary of a transformer, the secondary of which is an open circuit here α the angle of the voltage sinusoid at t = 0.

Suppose for the moment we neglect core losses and primary resistance, then

$$V_1 = T_1\frac{d\phi}{dt} \qquad ...(2)$$

Where, T_1 = Primary transformer

ϕ = Flux in core

In the steady state

$$V_{1m} = w\phi_m T_1 \qquad ...(3)$$

From equation (1) and (2)

$$T_1 \frac{d\phi}{dt} = V_{1m} \sin(wt + \alpha)$$

$$\frac{d\phi}{dt} = \frac{V_{1m}}{T_1} \sin(wt + \alpha) \quad ...(4)$$

From equation (3) and (4)

$$\frac{d\phi}{dt} = w\phi_m \sin(wt + \alpha) \quad ...(5)$$

INtegration of equation (5) gives

$$\phi = -\phi_m \cos(wt + \alpha) + \phi_C \ ...(6)$$

Where, ϕ_C is the constant of integration to be found from initial conditions at t = 0. Assume that when the transformer was last disconnected from the supply line, a small residual flux ϕ_r remained in the core. Thus at t = 0, $\phi = \phi_r$ substituting these value in equation (6)

$$\phi_r = -\phi_m \cos \alpha + \phi_C$$

$$\therefore \quad \phi_C = \phi_r + \phi_m \cos \alpha \quad ...(7)$$

equation (6) then becomes

$$\phi = \phi_m \cos(wt+\alpha)+\phi_r+\phi_m \cos\alpha ...(8)$$

($\phi_m \cos(wt + \alpha) \rightarrow$ Steady-state component of fluxe ϕ_{ss})

($\phi_r+\phi_m \cos\alpha \rightarrow$Transient component of flux ϕ_C.)

If the transformer is switched on at $\alpha = 0$, then $\cos \alpha = 1$.

$$\phi_C = \phi_r + \phi_m$$

Under this condition

$$\phi = \phi_m \cos wt + \phi_r + \phi_m \quad ...(9)$$

At $\quad wt = \pi$

$$\phi = \phi_m \cos \pi + \phi_r + \phi_m = 2\phi_m + \phi_r$$

Thus, the core flux attaing the maximum value of flux equal to ($2\phi_m + \phi_r$), which is over twice the normal flux. This is known as doubling effect. Consequently, the core goes into deep saturation. The magnetizing current required for producing such a large flux in the core may be as large as 10 times the normal magnetizing current. Same times the rms value of magnetizing current may be larger than the primary rated current of the transformer. This inrugh current may produce electromagnetic force about 25 times the normal value. Therefore the winding of large transformers are strongly braced, due to this inrugh current may large humming due to magnet ostriction of the core.

If the transformer is connected to the supply line near a possitive or negative voltage maximum, the current inrugh will be minimized, it is usually impractical to attempt to connect a transformer at predetermined time in the voltage cycle.

For tunately, inrugh current do not occur as might be thought the magnitude of inrugh current is also less than the value calculated by purely theoretical considerations.

36. An induction motor with two rotor windings or cages is used for obtaining high starting torque at low starting current. In the doublecage rotor there are two layers of bar as shown in figure.

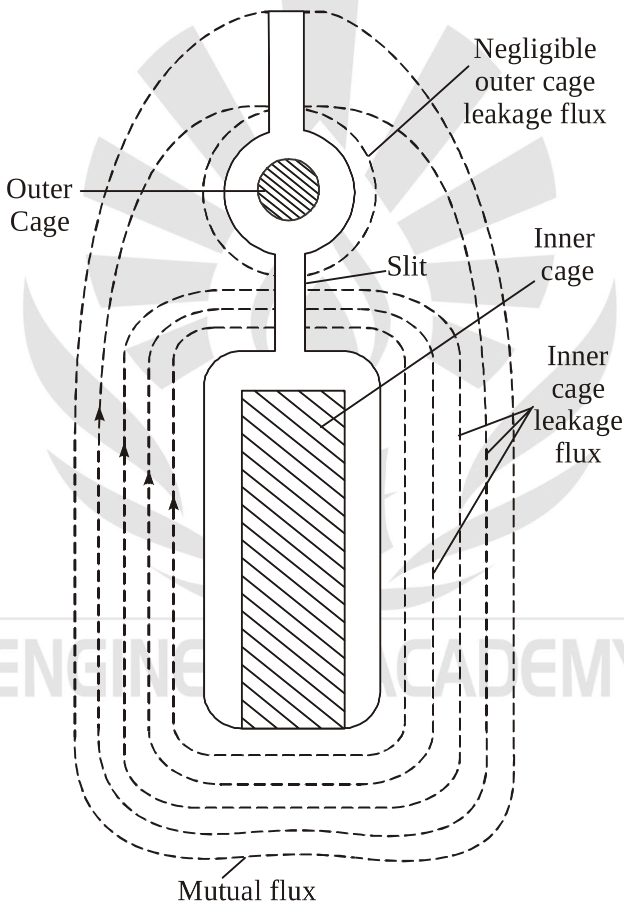


Figure : Double-Cage Rotor Slot

Each layer is short circuited by end rings the outercage bars have a smaller cross-sectional area than the inner bars are made of high resistivity materials like brass, aluminium, bronze etc. the inner-cage bars are made of low resistance of the inner-cage. There is a slit between the top and bottom slats. The slit increases permeance for leakage flux around the inner-cage bars. Thus, the leakage flux linking the inner-cage winding is much larger than that of the outer-cage winding, and the inner winding, therefore, has a greater self inductance.

At starting, the voltage induced in the rotor is same as the supply frequency ($f_2 = f_1$). Hence, the leakage reactance of the inner-cage winding (= $2\pi fL$) is much larger than that of the outer-cage winding. Therefore most of the starting current is flowing in the outer-cage winding which offers low-impedance to the flow of current. The high resistance outer-cage winding, therefore, develops a high starting torque.

As the rotor speed increases, the frequency of the rotor emf (f_r = sf) decreases, at normal operating speed, the leakage reactance (= $2\pi sfL$) of both the windings become negligible small. The rotor current division between the two cages is governed mainly by their resistances. Since the resistance of the outer cage is about 5 to 6 times that the inner cage, most of the rotor current flow through inner cage. Hence under normal operating speed, torque is developed mainly by the low-resistance inner cage.

Equivalent circuit of double-cage induction motor :

It is assume that the main flux completely links both the cages, the impedance of the two cages can be considered in parallel.

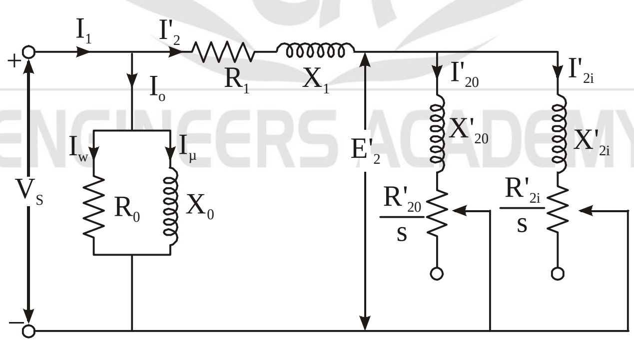


Figure : Equivalent Circuit of Double Cage Induction Motor.

The equivalent circuit of the double-cage induction motor at slip s is shown in figure. If the shunt branches containing R_0 and X_0 are neglected, the equivalent circuit is simplified to that shown in figure.

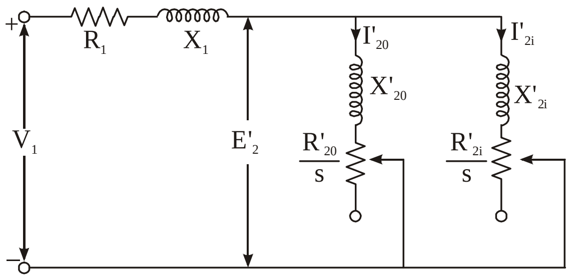


Figure: Approximate Equivalent Circuit of Double Cage Induction Motor with Magnetising Current Neglected.

As slip s, the outer cage impedance, $Z'_{20} = \frac{R'_{20}}{s} + jX'_{20}$

At slip s, the inner cage impedance $Z'_{2i} = \frac{R'_{2i}}{s} + jX'_{2i}$

37. The power factor(p.f.) of a synchrnonous motor can be contralled by variation of field current I_f. It has also been observed that the armature current I_q changes with the changes in I_f. Let us assume that the motor is operating at no load. If the field current in 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.

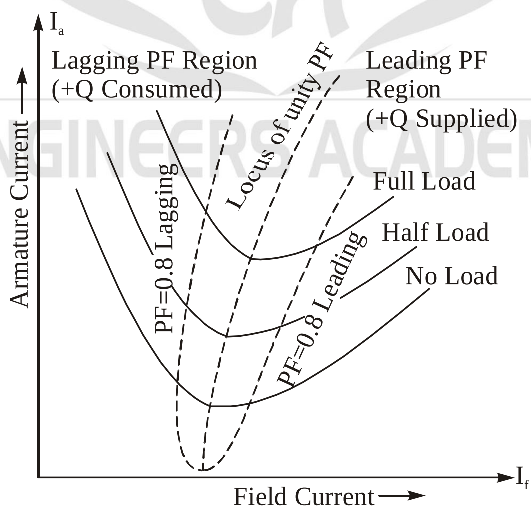


Figure : V-Curves of a Synchrnonous Motor.

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 colled 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 ereactive 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 synchrnous 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.

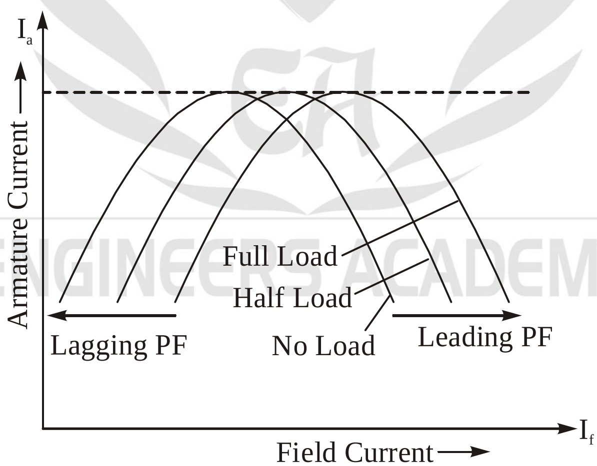


Figure: Power Factor Versus field Current at different loads.

38. Shows in the figure connections of a capcitor-start motor. It has a cage rator and its stator has two windings namely. The main winding and the auxilary winding (starting winding) the two winding are displaced 90° in space a capcitor C_s is connected in series with the starting windings A centrifugal switch S_c is also connected as show in figure.

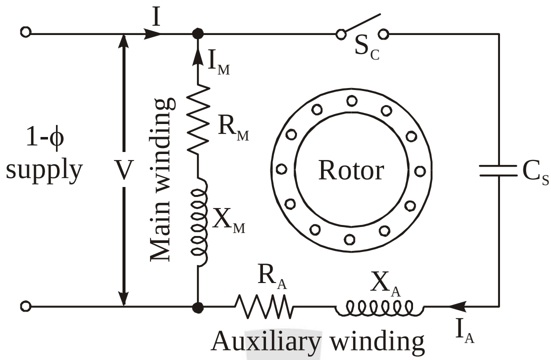


Figure (a) : Circuit Diagram

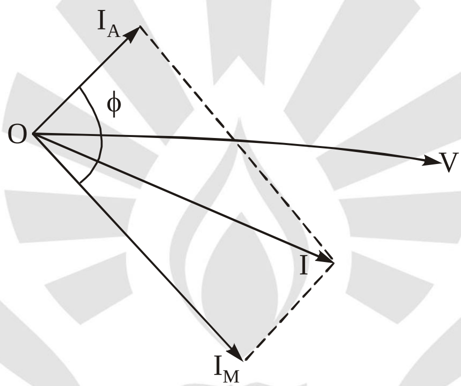


Figure (b) : Phasor Diagram

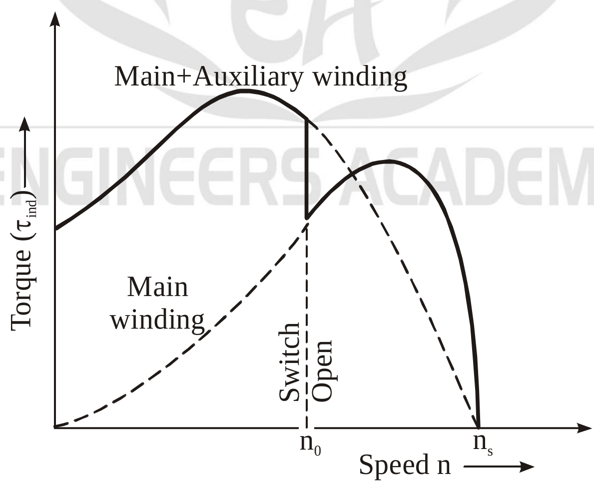


Figure (c) : Torque-Speed Characteristic

Figure : Capacitor Start Motor

Thus the windings are displaced 90° electrical and their mmf's are equal in magnitude but 90° apart in time phase.

Therefore the motor acts like a balanced two-phase motor As the motor approaches its rated speed, the auxipary winding and the starting capcitor C_s are disconnected automatically by the centrifugal switch S_C mounted on the shaft. The motor is so named because it uses the capcitor only for the purpose of starting.

Motor Characteristics :

The capcitor-start motor develops a much higher starting torque(3.0 to 4.5 times the full load torque) than does an equally rated resistance-start motor the value of the starting capacitor must be large and the starting-winding resistance low to obtain a high starting torque.

Because of high VAR rating of the capcitor required, electrolytic capacitors of the order of 250 μF are used. The capacitor C_s is short time rated. The torque-speed characteristic of the motor is shown in figure(c), which also shows that the starting torque is high.

Capcitor start motors because of the additional cost of the capcitor.

39. Drawbacks of 3-point Starter.

The three-Point starter suffers from a serious draw back for motors with large variation of speed by adjustment of the field rheostat to increase the speed of the motor the field resistance should be increased therefore the current through the shunt field is reduced. The field current may may become very low because of the addition of high resistance to obtain a high speed. A very low field current will make the holding electromagnet too weak to overcome the force exerted by the spring. The holding magnet mayrelease the arm of the starter during the normal operation of the motor and thus disconnected the motor from the line this is not desirable. A four point starter is used to overcome this difficulty.

Four Point Starter :

The schematic connection diagrma of four point starter is shown in figure.

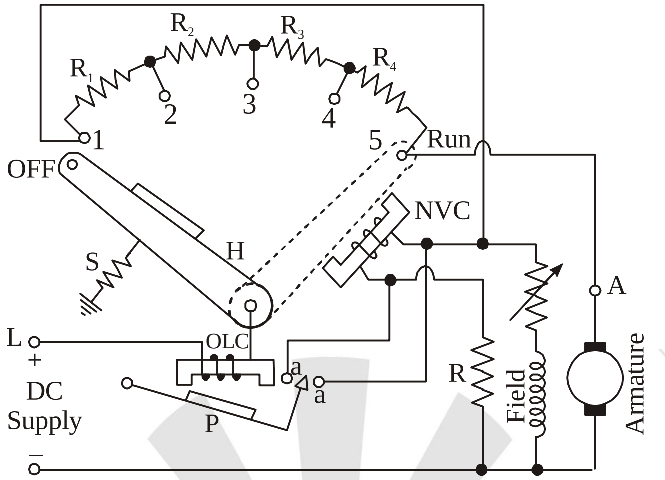


Figure : 4-Point DC Shunt Motor Starter

The basic difference in the circuit of a 4-point starter as compared to a 3-point starter is that, the holding coil is removed from the shunt field circuit and is connected directly across the line with a current limiting resistance R in series. Such an arrangement from three parallel circuits:

- Armature, starting resistance and overband release.
- A variable resistance and shunt field winding.
- Holding coil and current limiting resistance.

With this arrangement, a change in field current for variation of speed for the motor, does not affect the current through the holding coil, because the two circuits are independent of each other.

Now a days automatic push button starters are also used in such starter the ON push button is pressed to connected the current limiting starting resistor in series with the armature circuit. These resistor are gradually disconnected by an automatic ocontrolling arrangement untial full line voltage is available to the armature circuit wit pressing the off button. The circuit is disconnected Automatic starter circuits have been developed using electromagnetic contactors and time delay relays. The automatic starters enable even an inexperienced operator to start and stop the motor without any difficulty.

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