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Improvement Test

Sub:	Transformers and Generators							Code:	15EE33
Date:	20/11/2017	Duration:	90 mins	Max Marks:	50	Sem:	3rd	Branch:	EEE

Note: **Answer any 5 questions**. Explain your notations explicitly and clearly. Sketch figures wherever necessary. Good luck!

		Marks	OBE CO	OBE RBT
1	Two 100 V, 1-Φ furnaces take loads of 600 kW and 900 kW respectively at a power factor of 0.707 lagging and are supplied from 6600V ,3-phase supply through a Scott connected transformer. Calculate the line currents in the 3-phase side.	[10]	C303.4	L3

Sol:-

$V_{2T} = V_{2m} = 100V$

$P_{2T} = 600 kW$

$P_{2m} = 900 kW$

$\cos\phi_2 = 0.707$ lag.

$V_{1L} = 6,600V$

$a = \frac{6600}{100} = 66$

$I_{2T} = \frac{P_{2T}}{V_{2T}\cos\phi_{2T}} = \frac{600k}{100(0.707)}$

$I_{2T} = 8,486.56 A$

$I_{2m} = \frac{P_{2m}}{V_{2m}\cos\phi_{2m}} = \frac{900k}{100(0.707)}$

$I_{2m} = 12,729.84 A$

$I_A = I_{1T} = \frac{2}{\sqrt{3}} \frac{I_{2T}}{a} = \frac{2}{\sqrt{3}} \frac{848656}{66} = 148.47 A$

$I_B = I_C = \sqrt{\left(\frac{I_{2m}}{a}\right)^2 + \left(\frac{1}{2} I_{1T}\right)^2}$

$= \sqrt{\left(\frac{12,729.84}{66}\right)^2 + \left(\frac{148.47}{2}\right)^2} = 206.67 A$

2 A 400 kVA 3-ϕ load at 0.7 pf lagging is supplied by three 1-Φ transformers connected in Δ/Δ. Each of the Δ/Δ transformers is rated at 200 kVA, 2300/230 V. if one defective transformer is removed from service, calculate for the V/V connection [10] C303.4 L4

i) The kVA load carried by each transformer.
ii) Percent rated load carried by each transformer.
iii) Total kVA ratings of the transformer bank in V/V.
iv)Ratio of V/V bank to Δ/Δ bank transformer ratings
v) Percent increase in load on each transformer when one transformer is removed.

(d) $\frac{\text{V-V bank rating}}{\Delta\text{-}\Delta \text{ bank rating}} = \frac{346.4}{3\times200} = 0.577$ pu $= 57.7\%$

(e) Original load kVA per T/f in ΔΔ

$= \frac{1}{3}\times$ total load kVA

$= \frac{1}{3}\times 400 = 133.3$ kVA

increase in load kVA per T/f in V-V.

= VA load per T/f in V-V − VA load per T/f in Δ-Δ

$= 230.9 - 133.3 = 97.6$

% increase of load on each T/f $= \frac{\text{Increase in load per T/f in V}}{\text{load per T/f in } \Delta\text{-}\Delta}$

$= \frac{97.6}{133.3}\times100 = 73.2\ \%$

3 Two single phase transformers, rated at 250KVA each are operated in parallel on both sides. Impedances of transformers are (1+j6)Ω and (1.2+i4.8)Ω respectively. Find the load shared by each when the load is 500kVA at 0.8 pf lagging. [10] C303.4 L4

$S_{rA} = S_{rB} = 250$ kVA

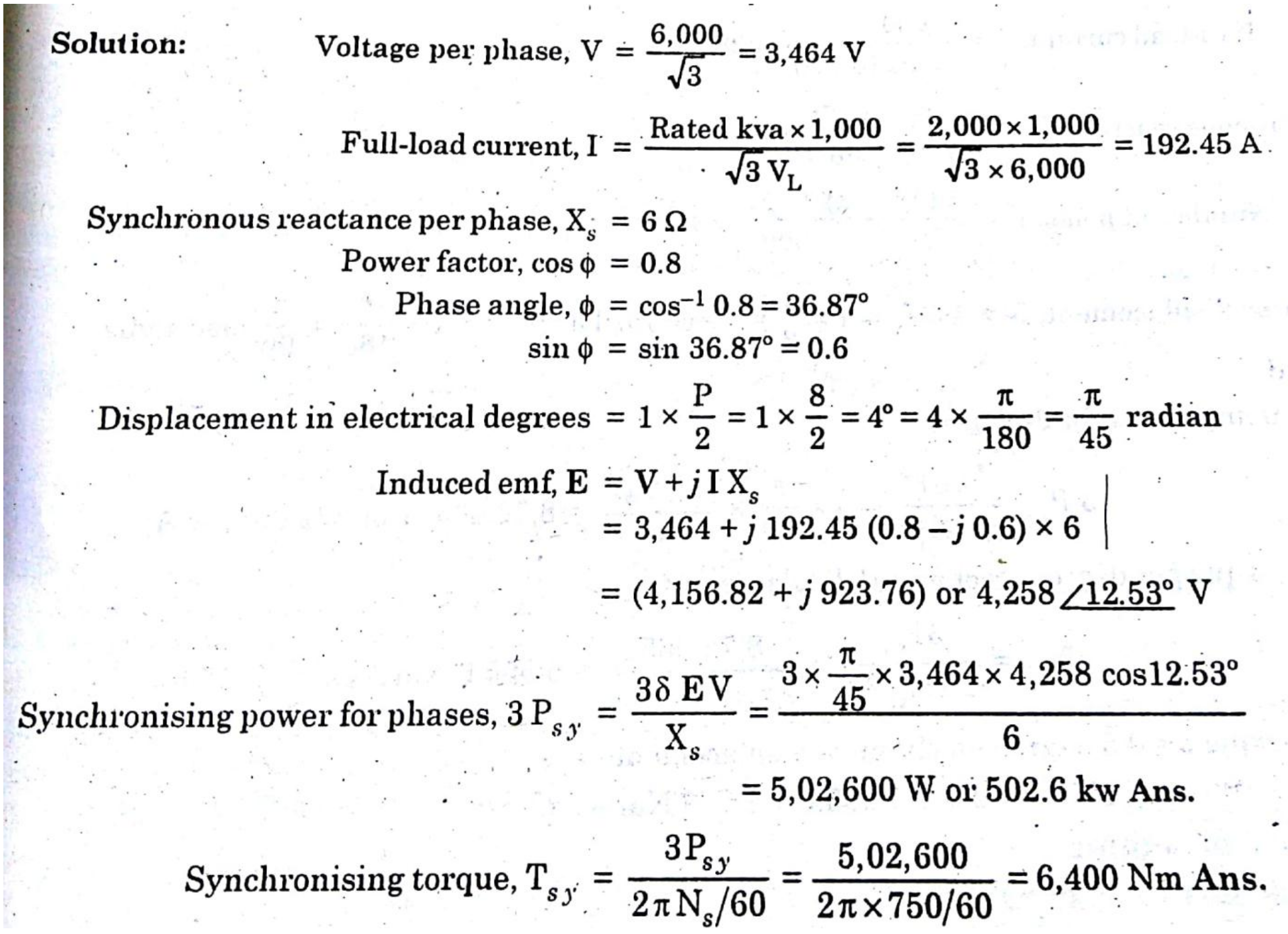
$Z_A = 1 + j6\ \Omega$
$Z_B = 1.2 + j4.8\ \Omega$ $\Big\}$ $Z_A + Z_B = 2.2 + j10.8\ \Omega$

$S_L = 500$ kVA, 0.8 pf lag. = total load
$= 500\angle 36.86°$ kVA

load shared by T/f A $= S_A = S_L \dfrac{Z_B}{Z_A + Z_B} = 224.45\angle -39.38°$ kVA
$= 22.445$ kVA at 0.773 lag.

load shared by T/f B $= S_B = S_L \dfrac{Z_A}{Z_A + Z_B} = 27.59\angle -34.8°$ kVA
$= 27559$ kVA at 0.8211 lag.

4	A 2,000kVA, 3-phase, 8-pole alternator runs at 750 rpm in parallel with other machines on 6,000V bus-bars. Find synchronizing power on full load 0.8 pf lagging per mechanical degree of displacement and the corresponding synchronizing torque. The synchronous reactance is 6Ω/ph.	[10]	C303.4	L3



Solution: Voltage per phase, $V = \dfrac{6{,}000}{\sqrt{3}} = 3{,}464$ V

Full-load current, $I = \dfrac{\text{Rated kva} \times 1{,}000}{\sqrt{3}\, V_L} = \dfrac{2{,}000 \times 1{,}000}{\sqrt{3} \times 6{,}000} = 192.45$ A

Synchronous reactance per phase, $X_s = 6\ \Omega$

Power factor, $\cos\phi = 0.8$

Phase angle, $\phi = \cos^{-1} 0.8 = 36.87°$

$\sin\phi = \sin 36.87° = 0.6$

Displacement in electrical degrees $= 1 \times \dfrac{P}{2} = 1 \times \dfrac{8}{2} = 4° = 4 \times \dfrac{\pi}{180} = \dfrac{\pi}{45}$ radian

$$\text{Induced emf, } E = V + jIX_s$$
$$= 3{,}464 + j\,192.45\,(0.8 - j\,0.6) \times 6$$
$$= (4{,}156.82 + j\,923.76) \text{ or } 4{,}258\angle 12.53° \text{ V}$$

$$\text{Synchronising power for phases, } 3P_{sy} = \frac{3\delta EV}{X_s} = \frac{3 \times \frac{\pi}{45} \times 3{,}464 \times 4{,}258 \cos 12.53°}{6}$$

$= 5{,}02{,}600$ W or 502.6 kw **Ans.**

$$\text{Synchronising torque, } T_{sy} = \frac{3P_{sy}}{2\pi N_s/60} = \frac{5{,}02{,}600}{2\pi \times 750/60} = 6{,}400 \text{ Nm}$$ **Ans.**

5 With neat diagrams, explain the Potier reactance method of calculating the voltage regulation. [10] C303.5 L2

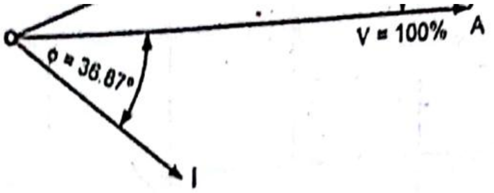


Fig. 3.44

3.18. ZERO POWER FACTOR OR POTIER METHOD OF DETERMINATION OF VOLTAGE REGULATION OF AN ALTERNATOR

The regulation obtained by mmf and emf methods is based on the total synchronous reactance (the sum of reactance due to armature leakage flux and due to armature reaction effect). This method is based on the separation of reactances due to leakage flux and that due to armature reaction flux, therefore, it is more accurate.

For determination of voltage regulation by this method, the data required are (*i*) effective resistance of armature winding (*ii*) open-circuit characteristic (*iii*) field current to circulate full-load current in the stator, and (*iv*) zero-power factor full-load voltage characteristic—*a curve between terminal voltage and excitation while the machine is being run on synchronous speed and delivering full-load current at zero power factor.*

The first three have already been discussed in Art 3.15. The zero power factor characteristic curve can be obtained as follows.

The machine is run at rated synchronous speed by a prime-mover. A purely inductive load (variable load reactors) is connected across the armature terminals and the excitation or field current is raised so as to cause flow of full-load armature current. The value of the reactance is then increased step by step in such a way that the excitation current is adjusted to a value that causes full-load rated armature current to flow. The armature terminal voltages are varied from 125 % to 25 % of the rated voltage in steps, maintaining the speed and rated armature current constant throughout the test. The armature terminal voltages and excitation currents are noted at each step. The curve drawn between terminal voltage and excitation current, as shown in fig 3.45, gives the *zero power factor (lagging) characteristic.*

When the zero power factor (lagging) characteristic is to be used only for obtaining the Potier reactance, it is sufficient to determine the point representing rated armature current and rated voltage. This is indicated by point B in fig 3.45.

The alternator can be loaded alternatively by an under-excited synchronous motor.

There is a definite relationship between the zero power factor (lagging) characteristic and an open-circuit characteristic of an alternator. The zero power factor characteristic curve is of exactly the same shape, as the OCC but it is shifted vertically downward by leakage reactance drop IX_L and horizontally by the armature reaction mmf.

Zero power factor full-load voltage-excitation characteristic can be drawn by knowing two points A and B. Point A is obtained from a short-circuit test with full-load armature

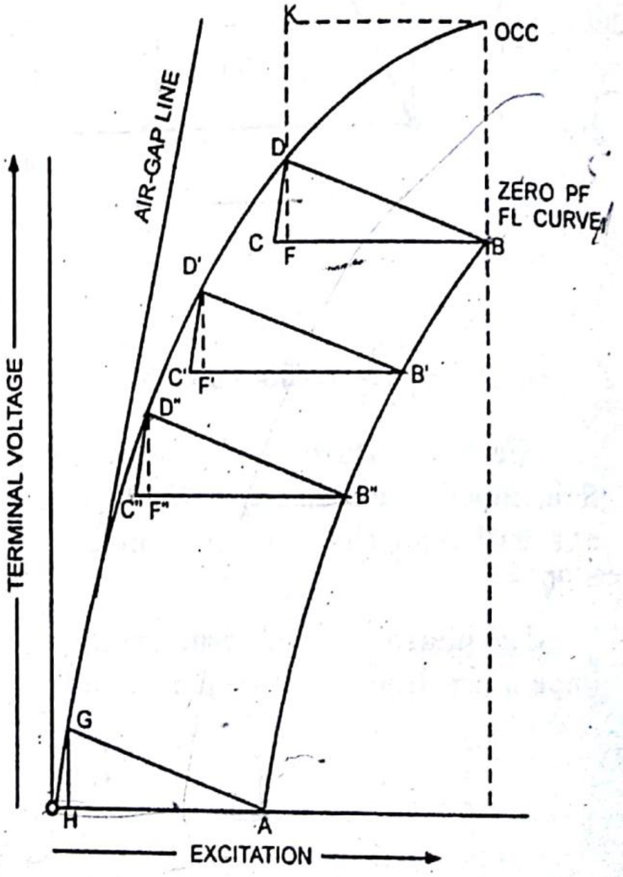


Fig. 3.45

current. Hence OA represents excitation (field current) required to overcome demagnetising effect of armature reaction and to balance leakage reactance drop at full load. Point B is obtained when full load current flows through the armature and wattmeter reads zero, as discussed above.

From B, line BC is drawn equal and parallel to AO. Then a line is drawn through C parallel to initial straight part of OCC (parallel to OG), intersecting the OCC at D. BD is joined and a perpendicular DF is dropped on BC. The triangle BFD is imposed at various points OCC to obtain corresponding points on the zero factor curve.

In Δ BDF the length BF represents armature reaction excitation and the length DF represents leakage reactance drop ($I X_L$)*. This is known as Potier reactance voltage drop and the triangle is known as *Potier triangle*. The potier reactance is given as

$$X_p = \frac{\text{DF (voltage drop per phase)}}{\text{Zero power factor current per phase}}$$

In case of cylindrical rotor machines, Potier reactance is nearly equal to armature leakage reactance. In case of salient pole machines, the magnetising circuit is more saturated and the armature leakage reactance is smaller than the Potier reactance.

Potier Regulation Diagram : Potier regulation diagram is drawn as follows.

OV is drawn horizontally to represent terminal voltage, V on full load and OI is drawn to represent full load current at a given power factor. VE is drawn perpendicular to phasor OI and equal to reactance drop (IX_L), neglecting resistance drop. Now phasor OE represents generated emf E. From OCC field excitation I_1 corresponding to generated emf E is determined, OI_1 is drawn perpendicular to phasor OE to represent excitation required to induce emf OE on open circuit. $I_1 I_2$ is drawn parallel to load current phasor OI to represent excitation equivalent to full-load armature reaction. OI_2 gives total excitation required. If the load is thrown off, then terminal voltage will be equal to generated emf corresponding to field excitation OI_2. Hence emf E_0 may be determined from OCC corresponding to field excitation OI_2. Phasor OE_0 will lag behind phasor OI_2 by 90°. EE_0 represents voltage drop due to armature reaction. Now regulation can be obtained from the relation

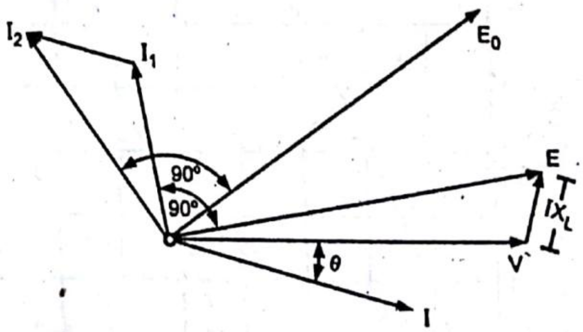


Fig. 3.46

$$\%\ \text{Regulation} = \frac{E_0 - V}{V} \times 100$$

6 (a) Write a short note on all day efficiency. [05] C303.5 L2

All-day (or Energy) Efficiency :-

The primary of distribution transformer is connected to line for 24 hrs a day ∴ core losses occur for the whole 24hrs. But cu loss occur only when T/f is on load.
∴ the performance of distribution T/f is more appropriately represented by all-day efficiency

Energy efficiency of a transformer is defined as the ratio of total energy output for a certain period to the total energy i/p for the same period.

If the energy efficiency is calculated for a day of 24hrs it is called all-day efficiency.

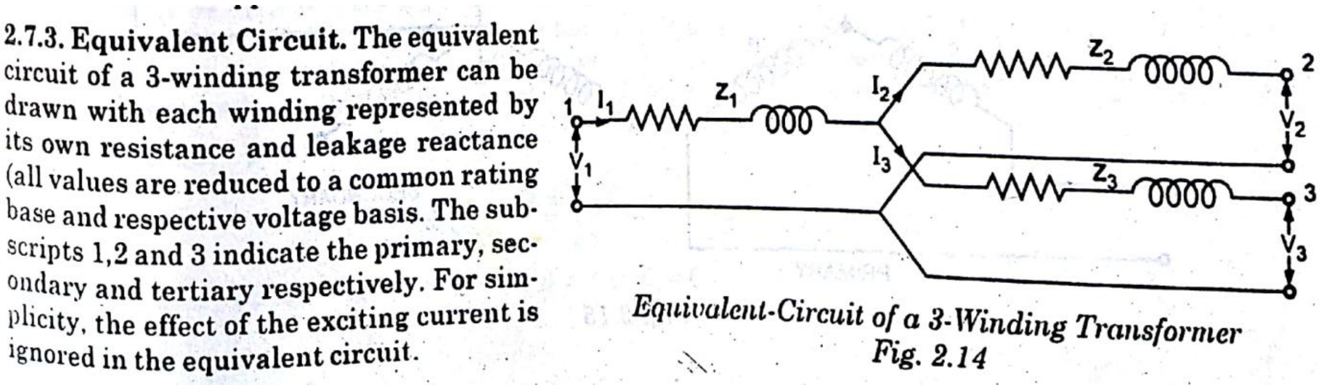
All-day efficiency is defined as the ratio of energy o/p to the energy i/p taken over a 24-hour period.

$$\eta_{AD} = \frac{\text{energy o/p over 24 hours}}{\text{energy i/p over 24 hours}}$$

$$= \frac{\text{energy o/p over 24 hr}}{\text{energy o/p over 24 hours + energy losses over 24 hours.}}$$

If the load cycle of the transformer is known, all-day efficiency

(b) Draw the equivalent circuit of tertiary winding transformer. [05] C303.1 L1



2.7.3. Equivalent Circuit. The equivalent circuit of a 3-winding transformer can be drawn with each winding represented by its own resistance and leakage reactance (all values are reduced to a common rating base and respective voltage basis. The subscripts 1,2 and 3 indicate the primary, secondary and tertiary respectively. For simplicity, the effect of the exciting current is ignored in the equivalent circuit.

Equivalent-Circuit of a 3-Winding Transformer
Fig. 2.14

It may be noted that the load division between the secondary and tertiary circuits is completely arbitrary. Three external circuits are connected between terminals 1,2 and 3 respectively and the common terminal labelled O. Neglecting exciting current I_0 we have $I_1 + I_2 + I_3 = 0$.

The impedances for such an equivalent circuit can be readily determined from the data of three short-circuit tests as follows. For circuit shown in fig 2.14.

SC impedance of windings 1land 2 with winding 3 open (impedance of equivalent circuit when the terminals of circuit 2 are short-circuited and the terminals of circuit 3 are open),

$$Z_{12} = Z_1 + Z_2 \quad \text{... (2.10)}$$

SC impedance of windings 1 and 3 with winding 2 open

$$Z_{13} = Z_1 + Z_3 \quad \text{... (2.11)}$$

and SC impedance of windings 2 and 3 with winding 1 open,

$$Z_{23} = Z_2 + Z_3 \quad \text{... (2.12)}$$

All the impedances are referred to a common base.

Solving equations (2.10), (2.11) and (2.12) we have

$$Z_1 = \frac{1}{2}(Z_{12} + Z_{13} - Z_{23}) \quad \text{... (2.13)}$$

$$Z_2 = \frac{1}{2}(Z_{23} + Z_{12} - Z_{13}) \quad \text{...(2.14)}$$

$$\text{and } Z_3 = \frac{1}{2}(Z_{13} + Z_{23} - Z_{12}) \quad \text{... (2.15)}$$

7 (a)	A 4-pole, 3-phase, 50Hz star connected alternator has 60 slots with 2 conductors/slot. Coils are short pitched in such a way that if one coil side lies in slot number 1, the other lies in slot number 13. Determine the useful flux per pole requires to generate a line voltage of 6000V.	[05]	C303.4	L3

$$\text{Slot angle } \beta = \frac{180^\circ \times \text{poles}}{\text{slots}} = \frac{180 \times 4}{60} = 12^\circ$$

$$\text{Coil span } = 12\,\beta = 12 \times 12 = 144^\circ$$

$$\alpha = 180^\circ - 144^\circ = 36^\circ$$

$$k_c = \cos\frac{\alpha}{2} = \cos\frac{36^\circ}{2} = 0.951$$

$$m = \frac{\text{slots}}{\text{poles} \times \text{phase}} = \frac{60}{4 \times 3} = 5$$

$$k_d = \frac{\sin\frac{m\beta}{2}}{m\sin\frac{\beta}{2}} = \frac{\sin\frac{5 \times 12^\circ}{2}}{5\sin\frac{12^\circ}{2}} = 0.9567$$

$$Z_p = \frac{60 \times 2}{3} = 40$$

$$E_p = 2.22\, k_c k_d f \Phi Z_p$$

$$\frac{6000}{\sqrt{3}} = 2.22 \times 0.951 \times 0.9567 \times 50 \times \Phi \times 40$$

$$\Phi = 0.8576 \text{ Wb}$$

(b) Explain the use of inter poles or commutating poles of improving commutation. [05] C303.1 L4

3. By Use of Interpoles or Commutating Poles. In practice, carbon brushes are generally used and there is an appreciable resistance at the brush contacts. The effect of this resistance is to aid commutation but is not sufficient to constitute a solution of the problem.

What is really required, therefore, is to produce in some way in that coil, during the time that it is short-circuited an emf of proper magnitude and direction to overcome the emf of self induction and so cause complete reversal of the current in the time available (commutating period). This is accomplished in practice by placing a narrow pole, called an *interpole* or a *commutating pole*, over the short-circuited coil, as shown in fig. 3.13. When the brushes are located at the mechanical neutral, the sides of a coil are located midway between the main poles at the instant the commutation of the coil take place. Therefore, the location of the commutating poles must be midway between the main poles. The direction of commutation flux must be such that when the coil cuts across the commutating flux, a voltage will be induced in the coil which will be in the same direction as that of the current through the coil after the coil has passed through the commutating period. Therefore, in case of a generator, the polarity of the commutating pole will be the same as that of the main pole just ahead in the direction of rotation, as shown in fig. 3.13. For motor operation, the polarity of the commutating pole will be of the main pole just behind.

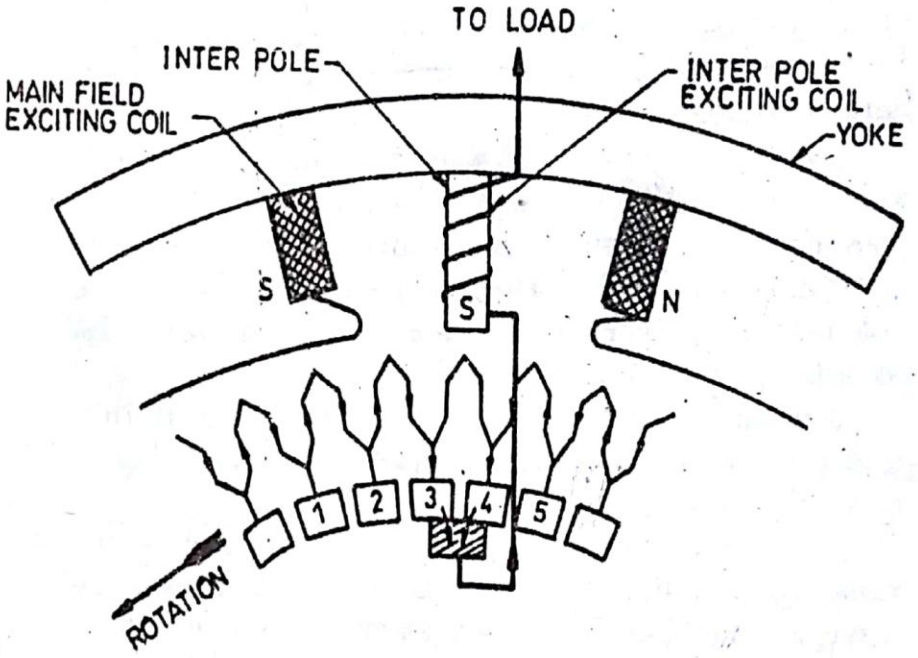


Fig. 3.13

Since the amount of emf of self induction present in the armature coil varies with the amount of armature current flowing, the amount of commutating flux must also, therefore, vary. To make the commutating flux produced by the interpoles proportional to the armature current, interpole windings are connected in series with the armature circuit. The output current is passed around a few turns of heavy copper conductor placed on the interpole and care is taken to see that there is enough iron in it so that it will not become saturated at any armature current that the generator can be expected to carry. The strength of interpole is then directly proportional to the load current. The series connection must be made so that the commutating poles will have the correct polarity, as mentioned in the foregoing para, with respect to the main poles, otherwise they will develop the emf in a coil undergoing commutation, which will oppose the reversal of current instead of aid it. This would result in violent sparking.

The ampere-turns required on the commutating poles must be sufficient enough (*i*) to neutralize the effect of armature reaction and (*ii*) to produce enough field in the interpolar gap to overcome the reactance voltage due to commutation. It may be added that field developed by a commutating pole

8 (a) Why do transformers make humming noise? How can it be minimized? [05] C303.1 L4

2.8. TRANSFORMER NOISE

Under no-load conditions, the "hum" caused by energized power transformers originates in the core, where the laminations tend to vibrate by magnetic forces. The noise is transmitted through the oil to the tank side and thence to the surroundings. The essential factors for noise production in transformers are (*i*) magnetostriction;* (*ii*) the mechanical vibrations caused by the laminations, depending upon the tightness of clamping, size, gauge, associated structural parts, etc; (*iii*) the mechanical vibration of tank walls, and (*iv*) the damping.

In general, the total noise emission may be reduced by (*i*) preventing vibration of core-plate, which needs the use of a lower flux density and attention to constructional features such as clamping bolts, proportions, and dimensions of the "steps" in plate width, tightness of clamping and uniformity of plates; (*ii*) sound insulating the transformer from the tank by cushhions, padding, or oil-barriers; (*iii*) preventing tank wall vibration by suitable design of tank and stiffeners; and (*iv*) sound insulating the tank from the ground or surrounding air. There is no complete solution to the noise problem.

(b) Write a short note on SCR (short-circuit-ratio) of a 3-phase alternator. [05] C303.4 L2

3.16. SHORT-CIRCUIT RATIO (SCR)

The short-circuit ratio (SCR) of a synchronous machine is defined as the ratio of field current to produce rated voltage on open-circuit to field current required to circulate rated current on short-circuit while the machine is mechanically driven at synchronous speed.

From OCC and SCC shown in fig 3.34, according to definition

$$\text{Short-circuit ratio, SCR} = \frac{I_{f_1}}{I_{f_2}} = \frac{OA}{OD} = \frac{AB}{DE} = \frac{AB}{AC} = \frac{1}{AC/AB}$$

$$\because \frac{AC}{AB} = \frac{\text{PU voltage on open-circuit}}{\text{Corresponding PU current on short-circuit}} = X_s$$

$$\text{So SCR} = \frac{1}{X_s} \qquad \text{...(3.14)}$$

Thus SCR is reciprocal of per unit synchronous reactance X_s,. The value of synchronous reactance depends upon saturated conditions of the machine but SCR is specific and defined at rated voltage.

A small value of SCR indicates a smaller value of current under short-circuit conditions owing to large value of synchronous reactance. The SCR of a high speed turbo-alternator usually lies between 0.5 and 0.75 while that of low speed salient pole generators lies between 1.0 and 1.5.

With high value of SCR, stability limit increased, voltage regulation improved and machines with a low value of SCR have difficulty during parallel operation owing to small value of synchronising power.