CMR INSTITUTE OF TECHNOLOGY

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Internal Assesment Test - II

Sub:	Transformers and Generators							Code:	17EE33
Date:	17/10/2018	Duration:	90 mins	Max Marks:	50	Sem:	3-A	Branch:	EEE
Answer Any FIVE FULL Questions									

		Marks	OBE CO	OBE RBT
1.a	List the conditions to be satisfied for satisfactory parallel operation of both single phase and three phase transformers.	[5]	CO1	L2
1.b	Two transformers having equivalent impedances referred to secondary of (0.3 + j3) ohm and (0.2 +j02) ohm are sharing a common load of impedance (8 + j6)ohm. Determine the current delivered by each transformer if the open circuit emf are 6600 V and 6400 V	[5]	CO1	L3
2.	Explain the operation of Scott connection for balanced and unbalanced load with the help of neat figures and phasor diagrams.	[10]	CO1	L3
3.a	Derive the expression for distribution factor Kd and pitch factor K_p.	[6]	CO1	L2
3.b	A 3-phase, 8-pole; 750 rpm star connected alternator has 72 slots on armature. Each slot has 12 conductors and winding is short chortled by 2 slots. Find the induced emf between lines, given the flux per pole is 0.06 Wb.	[4]	CO1	L3
4.a	List out the advantages of short pitched winding and distributed winding and explain how harmonics in the alternators can be reduced in reference to that.	[6]	CO1	L3
5.a	Develop the phasor diagram of alternators on load for (i) lagging pf load, (ii) leading pf load and (iii) unity pf load and explain.	[5]	CO1	L1
5.b	Describe armature reaction in alternators with the help of neat figures.	[5]	CO2	L3
6	What is voltage regulation? 'Discuss synchronous the impedance method of calculating voltage regulation	[10]	CO2	L2
7.a	A 2300 V, 50 Hz, 3 phase star connected alternator has an effective armature resistance of 0.2 ohm. A field current of 35 A produces a current of 150 A on short circuit and an open circuit emf 780 V (line value). Calculate the voltage regulation at (i) 0.8 pf lagging, (ii) 0.6 pf leading, and (iii) unity pf. The full load current is 25 A.	[10]	CO1	L1

Course Outcomes		PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1:	Describe the construction, operation and performance of single phase and three phase transformers	**3**	**2**	**2**	**2**	-	-	-	-	-	-	-	-

CO2:	Explain the need of operating transformers in parallel and the procedure to do it.	**3**	**3**	**2**	**2**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
CO3:	Illustrate the concept of auto transformer; tap changing transformer and tertiary winding.	**3**	**2**	**2**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
CO4:	Analyze armature reaction and commutation and their effects in a dc machine.	**3**	**3**	**2**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
CO5:	Describe the construction, operation, characteristics and applications of synchronous generators	**3**	**2**	**2**	**2**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
CO6:	Perform the analysis of synchronous machines by using different methods	**3**	**3**	**2**	**2**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Cognitive level	KEYWORDS
L1	List, define, tell, describe, identify, show, label, collect, examine, tabulate, quote, name, who, when, where, etc.
L2	summarize, describe, interpret, contrast, predict, associate, distinguish, estimate, differentiate, discuss, extend
L3	Apply, demonstrate, calculate, complete, illustrate, show, solve, examine, modify, relate, change, classify, experiment, discover.
L4	Analyze, separate, order, explain, connect, classify, arrange, divide, compare, select, explain, infer.
L5	Assess, decide, rank, grade, test, measure, recommend, convince, select, judge, explain, discriminate, support, conclude, compare, summarize.

PO1 **-** *Engineering knowledge*; PO2 **-** *Problem analysis*; PO3 **-** *Design/development of solutions*; PO4 **-** *Conduct investigations of complex problems*; PO5 **-** *Modern tool usage*; PO6 **-** *The Engineer and society*; PO7- *Environment and sustainability*; PO8 – *Ethics*; PO9 **-** *Individual and team work*; PO10 **-** *Communication*; PO11 **-** *Project management and finance*; PO12 **-** *Life-long learning*

SOLUTION

1. a.)

Conditions for Parallel Operation

When two or more transformers are to be operated in parallel, then certain conditions have to be met for proper operation. These conditions are -

- **Voltage ratio of all connected transformers must be same.**
  If the voltage ratio is not same, then the secondaries will not show equal voltage even if the primaries are connected to same busbar. This results in a circulating current in secondaries, and hence there will be reflected circulating current on the primary side also. In this case, considerable amount of current is drawn by the transformers even without load.
- **The per unit (pu) impedance of each transformer on its own base must be same.**
  Sometimes, transformers of different ratings may be required to operate in parallel. For, proper load sharing, voltage drop across each machine must be same. That is, larger transformer has to draw equivalent large current. That is why per unit impedance of the connected transformers must be same.
- **The polarity of all connected transformers must be same** in order to avoid circulating currents in transformers. Polarity of a transformer means the instantaneous direction of induced emf in secondary. If polarity is opposite to each other, huge circulating current flows.
- **The phase sequence must be identical of all parallel transformers.**
  This condition is relevant to poly-phase transformers only. If the phase sequences are not same, then transformers cannot be connected in parallel.
- **The ratio of their winding resistances to reactances should be equal for both the transformers.**
  This condition ensures that both transformers operate at the same power factor, thus sharing their active power and reactive volt-amperes according to their ratings.

Parallel Operation of 3-phase Transformers

All the conditions which apply to the parallel operation of single-phase transformers also apply to the parallel running of 3-phase transformers but with the following additions :

1. The voltage ratio must refer to the terminal *voltage of primary and secondary*. It is obvious that this ratio may not be equal to the ratio of the number of turns per phase.

2. The phase displacement between primary and secondary voltages must be the same for all transformers which are to be connected for parallel operation.

3. The phase sequence must be the same.

4. All three transformers in the 3-phase transformer bank will be of the same construction either core or shell.

b)

1.b) $E_A = 6600V$ $\quad E_B = 6400V$

$Z_A = 0.3+j3 \quad Z_B = 0.2+j2 \quad Z_L = 8+j6$

$$I_A = \frac{E_A Z_B + (E_A - E_B) Z_L}{Z_A Z_B + (Z_A + Z_B) Z_L} = \frac{6600(0.2+j2) - (6600-6400)(8+6j)}{((0.2+j2)(0.3+j3)) + (0.2+j2+0.3+j3)(8+j6)}$$

$$I_B = \frac{E_B Z_A - (E_A - E_B) Z_L}{Z_A Z_B + (Z_A + Z_B) Z_L} = \frac{6400(0.3+j3) - (6600-6400)(8+j6)}{(0.2+j2)(0.3+j3) + (0.2+j2+0.3+j3)(8+j6)}$$

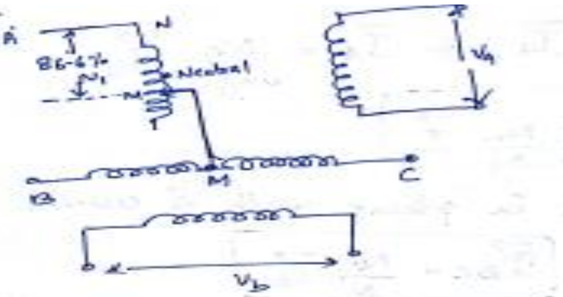
$I_A = 269.44\angle -47.37° \; A$

$182.67 - 198.06j \; A$

$I_B = 264.09922 - 198.08437i \; A$

$= 330.13\angle -36.87° \; A$

2.

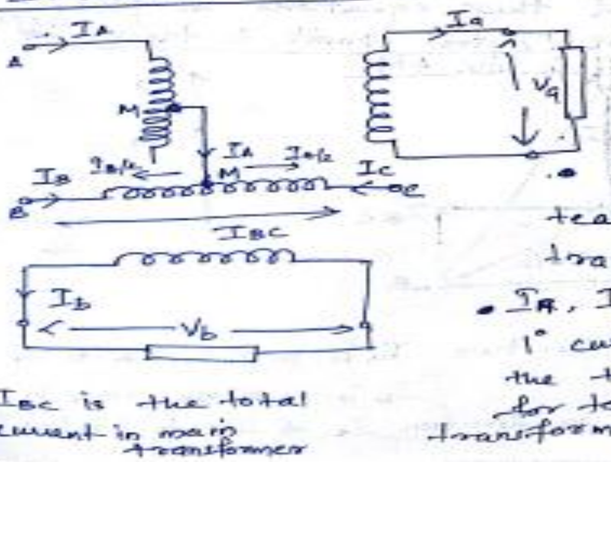


So to make $|\vec{V_a}| = |\vec{V_b}|$

- Teaser transformer turns ratio must be $\sqrt{3}/2 \; N_1 / N_2$
- Main transformer turns ratio is N_1/N_2

Load Conditions

Balanced load. (Resistive load)



when a balanced resistive load is connected across the secondaries,

- I_a, I_b is the teaser and main transformer 2° current
- I_A, I_B, I_C is the 1° currents input to the terminals A, B, C for teaser and main transformer.

- I_{BC} is the total 1° current in main transformer

Then from the fig:-

$$\vec{I}_A = \frac{N_2}{N}\vec{I}_a \Rightarrow \vec{I}_A = \frac{N_2}{\sqrt{3}/2 N_1}\vec{I}_a$$

or $$\boxed{\vec{I}_A = \frac{2}{\sqrt{3}}\frac{N_2}{N_1}\vec{I}_a}$$

ie :- $\vec{I}_A$ is in phase with 2° current $\vec{I}_a$.

Similarly, $$\boxed{\vec{I}_{BC} = \frac{N_2}{N_1}\vec{I}_b}$$

ie :- $\vec{I}_{BC}$ is in phase with 2° current $\vec{I}_b$.

Also $$\boxed{\vec{I}_B = \vec{I}_{BC} - \vec{I}_A/2}$$

[As M is the midpoint I_A divides equally at point M]

$$\boxed{\vec{I}_C = -\vec{I}_{BC} - \vec{I}_A/2}$$

To represent these equations in phasor diagram, Neutral point is taken at a point with ratio 2:1 in line AM.

- As load is resistive I_a is in phase with V_a
  I_b is in phase with V_b

Draw I_A in direction I_a & I_{BC} in direction I_b

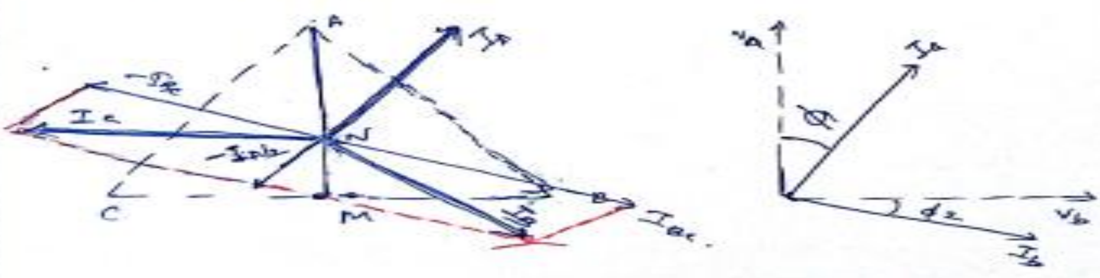
Balanced inductive load

For balanced inductive load

I_a and I_b lags V_a and V_b by some angle ϕ corresponding to load. Then the Phasor diagram will be as follows.

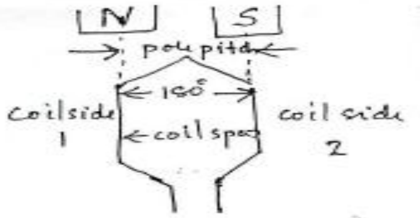
Unbalanced Load

For unbalanced load. I_a lags V_a by angle ϕ_1 and I_b lag V_b by angle ϕ_2 and $\phi_1 \neq \phi_2$.



3. a.

Full pitched wdg



Here coilspan = pole pitch = 180°

E_{c1} → emf in coilside 1

E_{c2} → emf in coilside 2

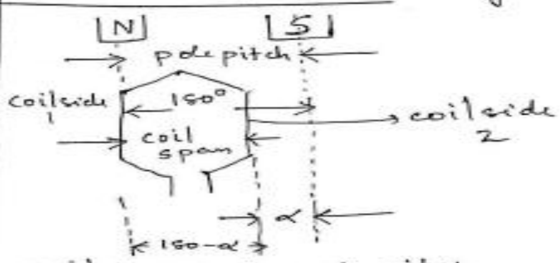
E_{c1} & E_{c2} are in phase with each other for full pitched winding.

Resultant emf

if $|E_{c1}| = |E_{c2}| = E$

$$E_c = 2E$$

Short pitched wdg.



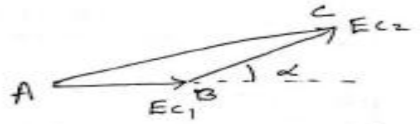
coil span < pole pitch

coil span ≠ 180°

α → short pitched angle

coilspan = $180 - \alpha$

E_{c1} & E_{c2} are not in phase. E_{c2} is displaced by 'α'



Resultant emf is AC

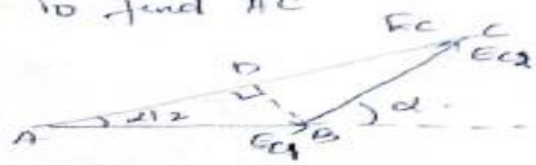
If short pitched coils are used, there exists coil span factor or Pitch factor K_c.

$$K_c = \frac{\text{emf induced with short pitched wdg.}}{\text{emf induced with full pitched wdg.}}$$

$$= \frac{\text{Phasor sum of emf in coils}}{\text{Arithmetic sum of emf in coils}}$$

$$= \frac{AC}{2E}$$

To find AC



From Δ ADB

∠ DAB = α/2 (External angle is sum of internal angles)

∴ $AD = AB \cos \alpha/2$

$AD = E_{c1} \cos \alpha/2$ $\qquad |E_{c1}| = |E_{c2}| = E$

$AC = AD + DC = 2AD = 2E \cos \alpha/2$

Coil span factor / Pitch factor $= K_c = \frac{AC}{2E} = \frac{2E \cos \alpha/2}{2E}$

$K_c = \cos \alpha/2$ where α is the short pitch angle.

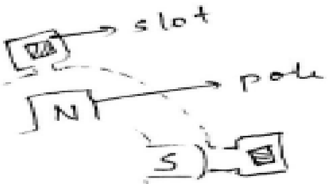
Concentrated and Distributed winding.

a) concentrated winding

In this type,

No. of Poles = No. of slots = no. of coilsides

ie; slots / pole = 1



One coilside is inside one slot under one pole and the other coilside is inside other slot under next pole.

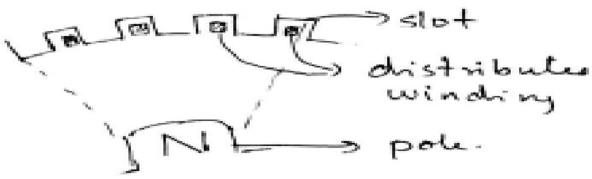
emf induced in all coilsides ($E_{c1}, E_{c2} \ldots$) are in phase.

b) Distributed winding

In this type

No. of slots > no. of poles.

Conductors are placed in several slots under one pole



Advantages of distributed wi

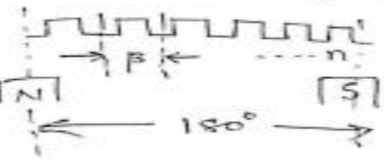
1. Gives sinusoidal emf
2. Reduces harmonics & nois
3. Reduces armature reaction
4. Cooling is effective and easy.

emf induced in one (E_{c1}) coilside is shifted from other by β (slot angle)

slot angle (β)

Let no. of slots / pole = n

slot angle $\beta = \frac{180°}{n} = \frac{180°}{\text{slots/pole}}$



Electrical degree corresponds to one slot is the slot angle.

Distribution factor or Breadth factor Kd

Let no of slots / pole / phase = m

slot angle $\beta = \frac{180}{\text{slots / pole}}$

Let AB, BC, CD, EF ...... are the coilsides in each slot, (total No = m)

For distributed winding, emf induced in all slots has a phasor difference of β.

Length OA = r (radius of the sector)

N is the midpoint of AB

Consider ΔOAN $\angle AON = \beta/2$

$AN = r \sin \beta/2$.

$AB = 2AN = 2r \sin \beta/2$

For m no. of slots

Algebraic sum of coil emfs

$= 2mr \sin \beta/2$ ——— (1)

Draw the resultant vector AF.

Let 'P' is the mid point of AF

Then

$\angle AOP = \frac{m\beta}{2}$

In ΔAOP

$AP = OA \sin\left(\frac{m\beta}{2}\right) = r \sin\left(\frac{m\beta}{2}\right)$

$\therefore AF = 2AP = 2r \sin \frac{m\beta}{2}$

$\therefore$ Distribution factor

$$k_d = \frac{\text{Vector sum of coil emfs}}{\text{Algebraic sum of coil emfs}} = \frac{2r \sin\left(\frac{m\beta}{2}\right)}{2mr \sin(\beta/2)} = \frac{\sin\left(\frac{m\beta}{2}\right)}{m \sin(\beta/2)}$$

b)

3b) $E_{ph} = 2.22 f \phi Z_{ph} k_c k_d$ Volts.

$f = \frac{PN}{120} = \frac{8 \times 750}{120} = 50 Hz$

$\phi = 0.06$ Wb

$Z_{ph} = \frac{72 \times 12}{3} = 288$

pole pitch = no. of slots/pole = 72/8 = 9

$\alpha = \frac{2}{9} \times 180 = 40$

$k_c = \cos(\alpha/2) = \cos 20 = 0.9397$

m = no. of slots/pole/phase = 72/9 ~~13~~ 8 = 2.67 ≈ 2.7 ~~2.3~~

$\beta = \frac{180}{\text{Pole pitch}} = \frac{180}{9} = 20$

$$k_d = \frac{\sin\left(\frac{2.7 \times 20}{2}\right)}{2.7 \sin\left(\frac{20}{2}\right)} = \frac{0.5056}{0.5267} = 0.9597$$

0.9492

$E_{ph} = 1729.96$ V   1710.85 ✓

$E_L = 2996.38$ V   2963.27 ✓

4. a)

Advantages of chorded pitch/short pitched winding

- It saves copper of end connections
- Reduction in resistance and inductance of the winding due to the lesser length of the coil ends
- The wave form of the induced emf is improved
- The distorting harmonics can be reduced
- Due to elimination of high frequency harmonics eddy current and hysteresis losses are reduced , thereby increasing the efficiency
- Mechanical strength of coil is increased

Advantages of distribution Winding

- Harmonics are reduced
- Induced voltage approached sinusoidal wave form
- Armature reaction effect is reduced
- Losses are reduced
- Efficiency is improved
- Provide better cooling

Harmonics Minimization from induced voltages:

To eliminate or **minimize the harmonics** from the voltage waveform, the windings must be properly designed. The different ways to **eliminate the harmonics** from generated voltage are,

1) Distribution of armature windings :

Instead of having concentrated type of windings, they should be distributed in different slots. The distribution factor for **harmonics** is comparatively less than that of the fundamental and hence magnitude of harmonic e.m.f. is small.

2) Chording :

The e.m.f. generated in the winding is proportional to cos (x /2) where a is angle of chording and x is order of harmonic. If proper value of angle of chording is selected then **harmonic** e..m.f.s can be reduced significantly.

b)

Alternator on load

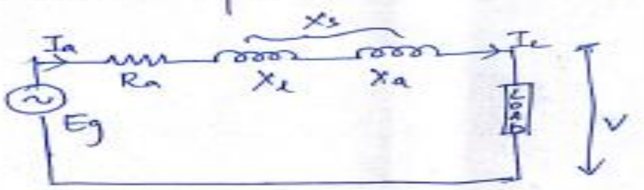
When load is connected across the armature terminal a current flows through armature winding towards the load. A decrease in terminal voltage with respect to generated emf is experienced due to following factors

(i) Armature winding resistance (R_a) drop – $I_a R_a$.

(ii) Leakage reactance (X_L) drop – $I_a X_L$

(iii) Armature reactance (X_a) drop – $I_a X_a$.

The resultant equivalent circuit of armature is



From figure

$$X_L + X_a = X_s \longrightarrow \text{Synchronous reactance}$$

$$R_a + jX_s = Z_s \longrightarrow \text{Synchronous [illegible] impedance}$$

Then, the generated emf,

$$E_g = V + I_a R_a + j I_a X_L + j I_a X_a$$

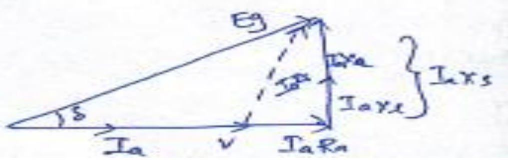
$$= V + I_a R_a + j I_a (X_L + X_a)$$

$$= V + I_a R_a + j I_a X_s$$

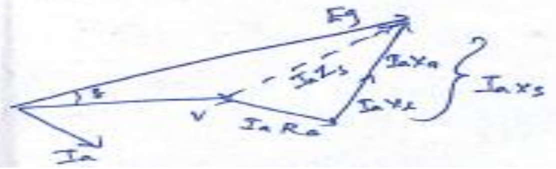
$$= V + I_a (R_a + j X_s) = V + I_a Z_s.$$

Phasor Diagrams of alternator at different loads

upf load



Lagging pf load



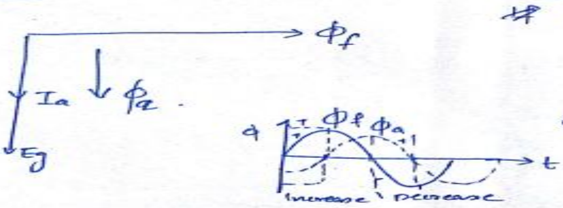
At leading pf load

5. ,

* ARMATURE REACTION IN ALTERNATORS

when load is connected to the alternator terminal a current flows in the armature winding which produces armature flux. This flux interacts with the field flux and give different effects on the induced emf. This effect of armature flux on main flux is known as armature reaction. Armature reaction varies for loads at different power factors.

(i). At upf load (Pure Resistive load)

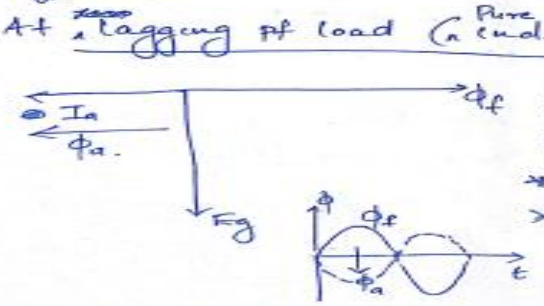


* Let ϕ_f = main field flux
E_g = Generated emf
I_a = Armature current
ϕ_a = Armature flux.

* The generated emf E_g lags the main field flux by $90°$
* As the connected load is resistive E_g and I_a are in phase.
* Armature flux ϕ_a will therefore be in phase with I_a and lags ϕ_f by $90°$.

So the resultant flux $\phi_r = \sqrt{\phi_f^2 + \phi_a^2}$ will vary non-uniformly. ie; at some portions ϕ_r will increase and at some other times it will decrease. ie., resultant flux has a distorted nature. This effect on armature flux on main flux is called cross magnetizing effect.

At lagging pf load (Pure inductively load)



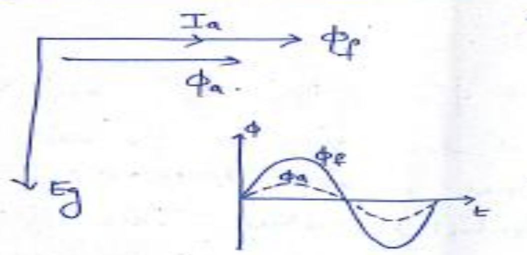
* when inductively load is connected armature current will lag voltage by $90°$

* So armature flux ϕ_a is in phase with I_a will lag ϕ_f by $180°$

* ∴ ϕ_a will be direct phase opposition with ϕ_f. so resultant flux will the difference of these two fluxes..

* Net flux ϕ_r has lower magnitude. So this effect is called 'demagnetizing effect'.

iii) Leading pf load (a Pure Capacitive load)



* For capacitive load, the armature current will lead the voltage by 90°.
* So Ia will be in phase with ϕ_f and so is ϕ_a.

* ∴ ϕ_f and ϕ_a are in phase & they has additive nature and net flux ϕ_r has higher magnitude. So this effect is called 'Magnetizing effect'.

In practical cases as loads are partially resistive, inductive or capacitive in natures, that these effects of armature reaction varies. Usually net effect of armature reaction is considered as a voltage drop. So to represent this, the armature reaction is represented as a reactance called armature reactance (Xa) and reduction of voltage is represented as voltage drop across it ($I_a X_a$)

6. .,

Voltage Regulation in Alternators

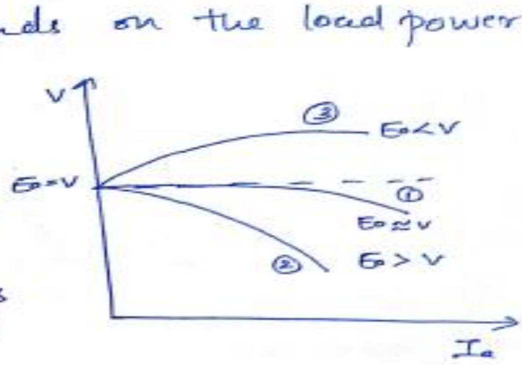
Voltage regulation is the change of alternator voltage from no load to full load.

$R = E_0 - V$

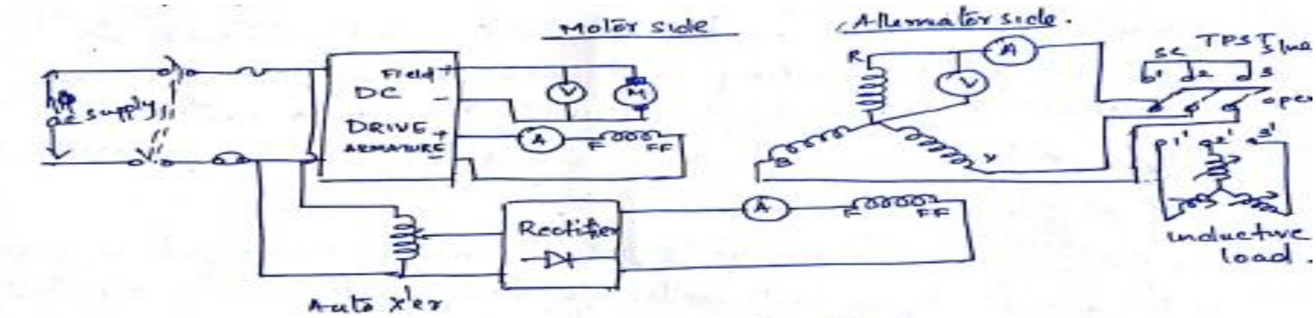
Regulation is always represented as percentage.

$\therefore \; \% R = \frac{E_0 - V}{V} \times 100$.

The value of regulation depends on the load power factor.



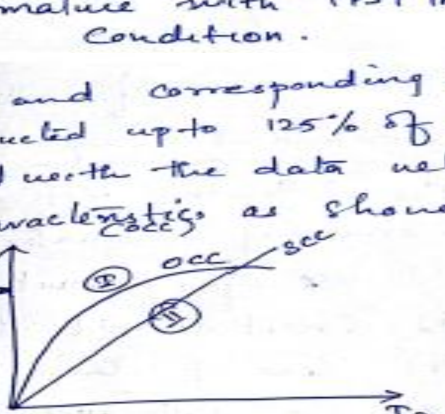
* For resistive load,
  $E_0 \approx V$ So $\% R = 0$ or '+ive' (Low value)
* For inductive load
  $E_0 > V$ So $\% R =$ +ve always (Demagnetizing)
* For Capacitive load,
  $E_0 < V$ So $\% R =$ '-ve' always. (magnetizing).



* Connections are made as per circuit diagram.
* TPST s/w is in open or no-contact position
* Turn on the supply and set rated speed to the dc motor by adjusting dc drive.
* OC test

Vary the alternator field supply and note different voltage values across alternator armature with TPST in open condition.

Tabulate the no load voltages and corresponding field current. The test can be conducted upto 125% of rated voltage. A graph can be plotted with the data which is known as open circuit characteristics (OCC) as shown as (I)



SC test
with field minimum in alternator, Close the TPST to position 1-2-3, the armature winding is now short circuited.
Now adjust the field and set rated current (Ia) in the armature winding and note corresponding field current. A graph is plotted with this data as shown in (II) which is known as Short circuit characteristics (SCC)

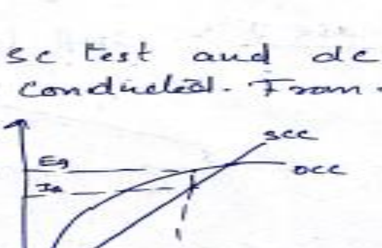
(i) Synchronous impedance method

This method is also known as Emf method. Here the magnetic circuit is assumed to be unsaturated. In this method Mmfs (fluxes) produced by rotor and stator are replaced by their equivalent emf and hence called emf method. Regulation calculated by this method has high value compared to actual value of regulation and so this method is also called pessimistic method.

To calculate regulation oc test, sc test and dc resistance test of alternator is conducted. From the occ and scc

Sychronous impedance,

$$Z_s = \frac{\text{OC voltage}}{\text{SC current}} \Big| \text{ At same } I_f$$



$$R_a = 1.6 \times R_{dc}$$

∴ Synchronous reactance

$$X_s = \sqrt{Z_s^2 - R_a^2}.$$

Regulation is to be calculated for different loads

Case 1 Lagging pf load (inductive load)

Let V_{ph} = Terminal voltage / phase

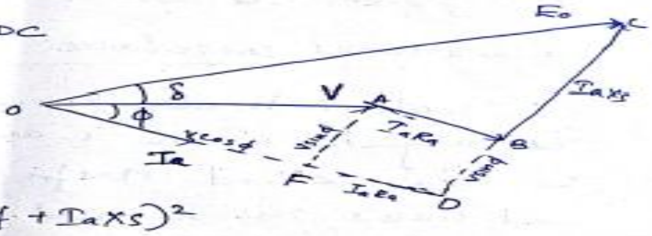
I_a = Armature current

ϕ = angle current lags with voltage

The phasor diagram is shown.

To calculate E_0 form ΔODC

Such that



$$OC^2 = OD^2 + DC^2$$

$$= (OF + FD)^2 + (DB + BC)^2$$

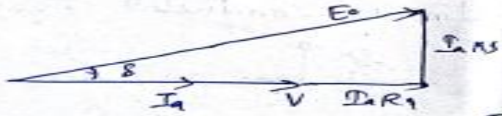
$$= (V\cos\phi + I_aR_a)^2 + (V\sin\phi + I_aX_s)^2$$

$$\therefore E_0 = \sqrt{(V\cos\phi + I_aR_a)^2 + (V\sin\phi + I_aX_s)^2} \quad \text{------ (1)}$$

$$\therefore \%R = \frac{E_0 - V}{V} \times 100$$

where E_0 = no load voltage/phase

Case 2 :- Upf load (resistive load)



For this load $\phi = 0$

$\therefore \cos\phi = 1 \quad \sin\phi = 0$

From eqn (1)

$$E_0 = \sqrt{(V + I_aR_a)^2 + (I_aX_s)^2}$$

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

Case 3 Leading pf load (Capacitive load)

For leading pf load X_s = '-ve'

$$\therefore E_0 = \sqrt{(V\cos\phi + I_aR_a)^2 + (V\sin\phi - I_aX_s)^2}$$

$$\%R = \frac{E_0 - V}{V} \times 100.$$

7\.

7)

$R_a = 0.2\ \Omega$

$Z_s = \frac{780/\sqrt{3}}{150} = 3.00\ \Omega$

$X_s = \sqrt{3.00^2 + 0.2^2} = \underline{3\ \Omega}$

$V = 2300/\sqrt{3}$

$= \underline{1327.9\ V}$

$I_a = 25\ A\ (I_L)$

At lagging pf 0.8

$$E_0 = \sqrt{(V\cos\phi + I_aR_a)^2 + (V\sin\phi + I_aX_s)^2}.$$

$$= \sqrt{(1327.9 \times 0.8 + 25 \times 0.2)^2 + (1327.9 \times 0.6 + 25 \times 3)^2}$$

$= \underline{1378.08\ V}$ $\quad \%R = \underline{3.78\ \%}$

At leading pf (0.6)

$$E_0 = \sqrt{(V\cos\phi + I_aR_a)^2 + (V\sin\phi - I_aX_s)^2}$$

$$= \sqrt{(1327.9 \times 0.6 + 25 \times 0.2)^2 + (1327.9 \times 0.8 - 25 \times 3)^2}$$

$= 1271.28\ V$

$\%R = \underline{-4.26\ \%}$

At upf

$$E_0 = \sqrt{(V + I_aR_a)^2 + (I_aX_s)^2}$$

$$= \sqrt{(1327.9 + 25 \times 0.2)^2 + (25 \times 3)^2}$$

$= \underline{1335.\ V}$

$\%R = \underline{0.535\ \%}$