MODULE-2

CHARACTERISTICS OF SYNCHRONOUS GENERATOR & PARALLEL OPERATION

VOLTAGE REGULATION

With change in load, there is a change in terminal voltage of an alternator. The magnitude of this change depends on the load and the load power factor.
The voltage regulation of an alternator is defined as **"the rise in voltage when full-load is removed (field excitation and speed remaining the same) divided by the rated terminal voltage."**

∴ % regulation 'up' ={ (E0-V)÷V} x 100

(i) E0 − V is the arithmetical difference ,not the vectorial one.
(ii) In the case of leading load p.f., terminal voltage will fall on removing the full-load. Hence, regulation is negative.
(iii) The rise in voltage when full-load is thrown off is not the same as the fall in voltage when full-load is applied.

DETERMINATION OF VOLTAGE REGULATION

1.**Synchronous Impedance or E.M.F. Method.** (Behn Eschenberg)

2. **The Ampere-turn or M.M.F. Method**. (Rothert)

3. **Zero Power Factor or Potier Method.** (Potier)

All these methods require —
1.**Armature (or stator) resistance Ra**
- Armature resistance Ra per phase measured by voltmeter and ammeter method, under working conditions the effective value of Ra due to 'skin effect is 1.6 times the d.c. value.

2.**Open-circuit / No-load characteristics**
- As in d.c. machines, this is plotted by the values of induced voltage and field excitation current on no load.
- The O.C.C is a plot of the armature terminal voltage as a function of field current with a symmetrical three phase short-circuit applied across the armature terminals with the machine running at rated speed.

- At any value of field current, if E is the open circuit voltage and isc is the short circuit current then for this value of excitation
- Zs=E/Isc
- At higher values of field current, saturation increases and the synchronous impedance decreases.
- The value of Zs calculated for the unsaturated region.
- The O.C.C is called the unsaturated value of the synchronous impedance.

3.**Short-circuit characteristics** (but zero power factor lagging characteristic for Potier method).

- The S.C.C is a plot of short-circuit armature current versus the field current.
- The current range of the instrument should be about 25-50% more than the full load current of the alternator.
- Starting with zero field current, increase the field current gradually and cautiously till rated current flows in the armature.
- The speed of the set in this test maintained at the rated speed of the alternator.

PROBLEMS

- A 60-KVA, 220 V, 50-Hz,1ϕ alternator has effective armature resistance of 0.016 ohm and an armature leakage reactance of 0.07 ohm. Compute the voltage induced in the armature when the alternator is delivering rated current at a load power factor of (a) unity (b) 0.7 lagging and (c) 0.7 leading.

Sol.

Full load rated current I = 60,000/220 = 272.2 A

IRa = 272.2 × 0.016 = 4.3 V ;

$IX_L = 272.2 \times 0.07 = 19$ V

(a) UPF

$E^2 = ((V + IRa)^2 + (IX_L)^2)$

$= ((220 + 4.3)^2 + (19)^2)$

ie, E = 225 V

(b) 0.7 LAG

$E^2 = [V \cos\phi + IRa)^2 + (V \sin\phi + IX_L)^{2]}]$

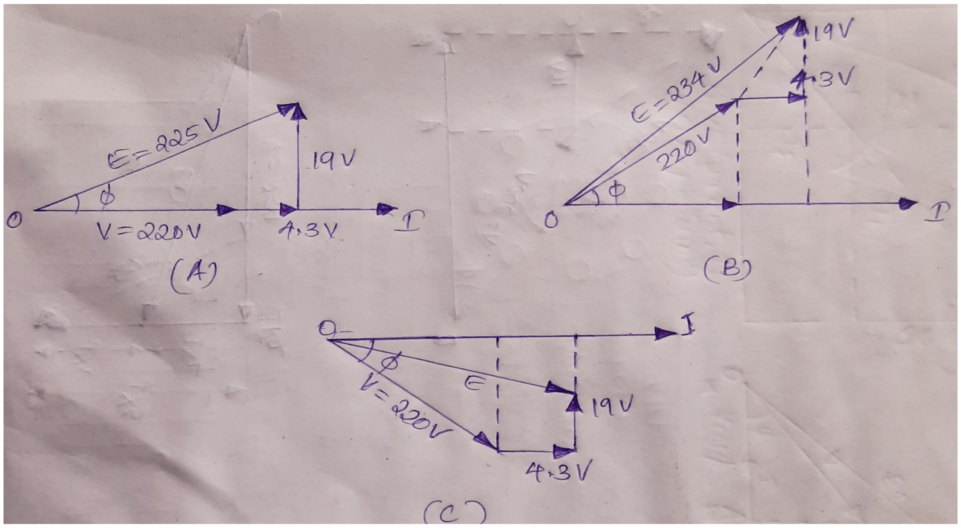
$=((220x0.7 + 4.3)^2 + (220x0.7 + 19)^2)$

ie, E = 234 V

(c) 0.7 LEAD

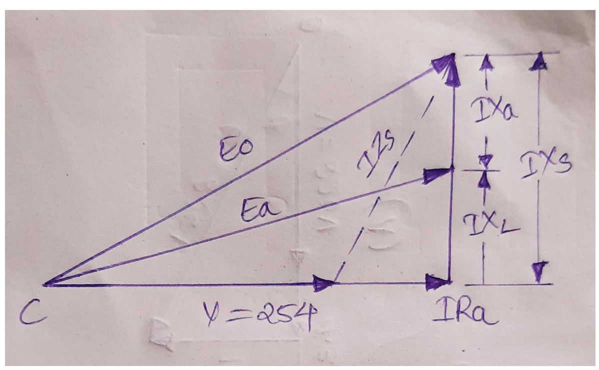
$E^2 = [(V \cos\phi + IRa)^2 + (V \sin\phi - IX_L)^2]$

ie,E = 208 V



- In a 50-kVA, star-connected, 440-V, 3-phase, 50-Hz alternator, the effective armature resistance is 0.25 ohm per phase. The synchronous reactance is 3.2 ohm per phase and leakage reactance is 0.5 ohm per phase. Determine at rated load and unity power factor :a) Internal e.m.f. Ea
  b) no-load e.m.f. E0
  (c) percentage regulation on full-load
  (d) value of synchronous reactance which replaces armature reaction

Sol.



V = 440 / 1.73 = 254 V

(a) F.L. output current at u.p.f. = 50,000/ 1.73 × 440 = 65.6 A
Resistive drop = 65.6 × 0.25 = 16.4 V
Leakage reactance drop IX_L = 65.6 × 0.5 = 32.8 V

∴ $Ea^2 = (V + IRa)^2 + (IXL)^2 = (254 + 16.4)^2 + 32.82^2$
Ea = 272 volt
Line value = 1.73 × 272 = 471 volt.

(b) The no-load e.m.f. E0 is the vector sum of (i) V (ii) IRa and (iii) IXs or is the vector sum of V and IZs

$\therefore$ $E0^2 = (V + IRa)^2 + (IXs)^2 = (254 + 16.4)^2 + (65.6 \times 3.2)^2$

E0 = 342 v

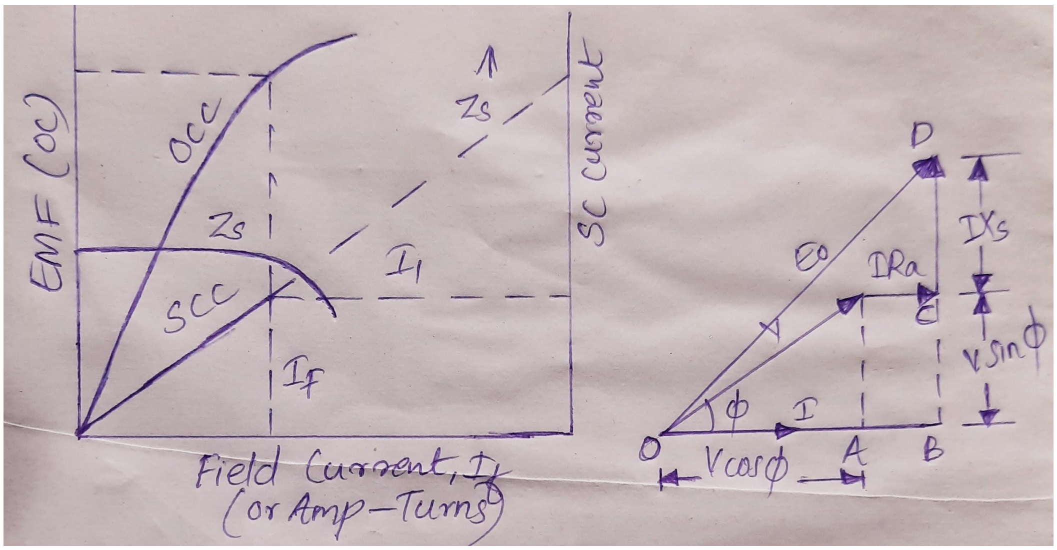
Line value = 1.73 × 342 = 592 volt

(c) % age regulation ‘up’ = (E0 − V)÷ V

={ (342 − 254)÷254 } x100 = 34.65 %

(d) $Xa = Xs - X_L = 3.2 - 0.5 = 2.7\ \Omega$

SYNCHRONOUS IMPEDANCE METHOD / EMF METHOD



procedural steps

1. O.C.C is plotted from the given data
2. S.C.C. is drawn from the data of the short-circuit test.

   It is a straight line passing through the origin. Both these curves are drawn on a common field-current base.

   Consider a field current If. The O.C. voltage corresponding to this field current is E1. When winding is short-circuited, the terminal voltage is zero, the whole of this voltage E1 is being used to circulate the armature short-circuit current I1 against the synchronous impedance ZS.

   $\therefore$ $E1 = I_1Zs$= E1 (open-circuit voltage) ÷ I_1(short circuit current)

3.Since Ra can be found

   $X_s^2 = (Zs^2 - Ra^2)$

4.Knowing Ra and XS, vector diagram as shown in Fig (b) can be drawn for any load and any power factor.

   Here $OD = E_0$

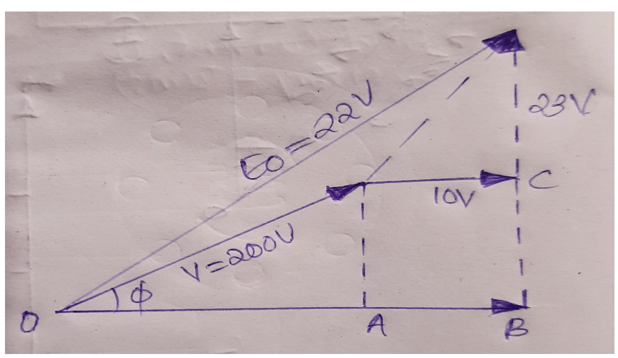
$\therefore E_0^2 = OB^2 + BD^2$
Or $E_0^2 = (V \cos\phi + IRa)^2 + (V \sin\phi + IXs)^2$
$\therefore$ % regn. 'up' $= \{ (E_0 - V) \div V \} \times 100$

NOTE
(i) Value of regulation for unity power factor or leading p.f. can also be found in a similar way.
(ii) This method is not accurate because the value of ZS more than normal voltage conditions and saturation and the value of regulation is more than an actual test. ie- it is called a pessimistic method. The value of ZS is not constant but varies with saturation. At low saturation, its value is larger because then the effect of a given armature ampere-turns is much more than at high saturation.
Now, under short-circuit conditions, saturation is very low, because armature m.m.f. is directly demagnetising. Different values of ZS corresponding to different values of field current are also plotted in Fig (a).
(iii) The value of ZS usually taken is that obtained from full-load current in the short-circuit test.
(iv) Here, armature reactance Xa has not been treated separately but along with leakage reactance XL.

PROBLEMS

- Find the synchronous impedance and reactance of an alternator in which a given field current produces an armature current of 200 A on short-circuit and a generated e.m.f. of 50 V on open-circuit. The armature resistance is 0.1 ohm. To what induced voltage must the alternator be excited if it is to deliver a load of 100 A at a p.f. of 0.8 lagging, with a terminal voltage of 200V.

Solution.



It will be assumed that alternator is a single phase one. Now, for same field current,
Now, Zs = O.C. volts / S.C current = $50 \div 200 = 0.25\ \Omega$
$Xs^2 = Zs^2 - Ra^2$
$= (0.25^2 - 0.1^2)$
$Xs = 0.23\ \Omega$
$IRa = 100 \times 0.1 = 10$ V, $IXs = 100 \times 0.23 = 23$ V
$\cos\phi = 0.8$, $\sin\phi = 0.6$

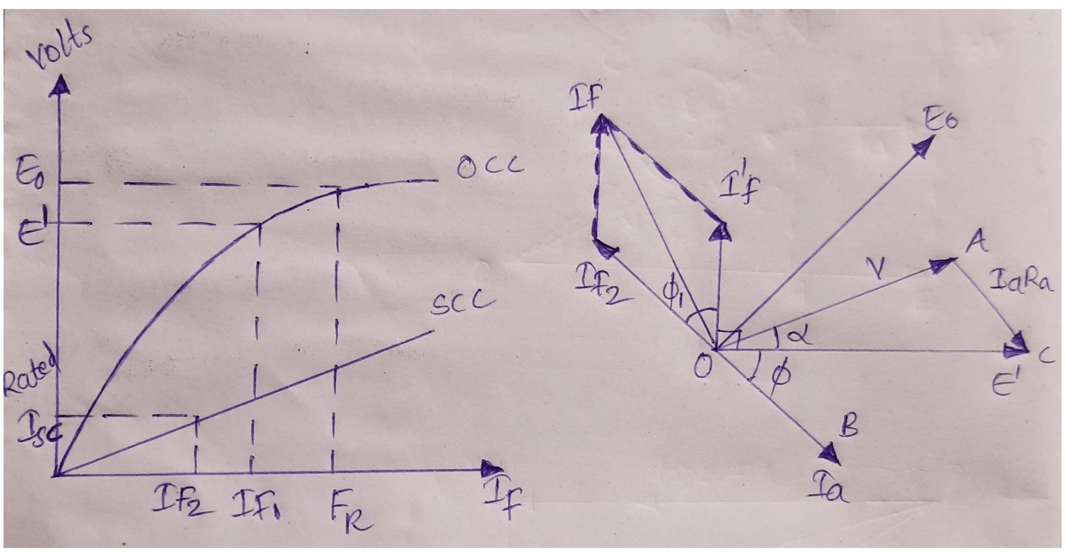
$E_0^2 = (V \cos \phi + IRa)^2 + (V \sin \phi + Ixs)^2$

$E_0^2 = (200 \times 0.8 + 10)^2 + (200 \times 0.6 + 23)^2$
$E_0 = 222$ V

AMPERE-TURN METHOD / MMF METHOD

- The synchronous impedance method is based on the concept of replacing the effect of matraction by an imaginary resistance the Magnets motive force (MMF)
- The MMF method replaces the effect of armature leakage reactance by an equivalent additional I armature reaction MMF so that this MMF may be combined with the armature reaction MMF
- To calculate the voltage regulation by MMF Method the following information is required They are as follows

1. The resistance of the stator winding per phase
2. Open circuit characteristics at synchronous speed
3. Short-circuit characteristics



STEPS TO DRAW PHASOR DIAGRAM OF MMF METHOD

- The armature terminal voltage per phase (V) is taken the reference phasor along OA
- The armature current phasor Ia is drawn lagging the phasor voltage for lagging power factor angle for which the regulation is to be calculated
- The armature resistance drop phasor IaRa is drawn in phase with the Ia along the line AC. Join O and C. OC represents the E'
- Considering the OC Characteristic shown above the field current I'f corresponding to the voltage E' is calculated
- Draw the field current I'f leading the voltage E' by 90 degrees. It is assumed that on short circuit all the excitation is opposed by the MMF of armature action

- From the Short Circuit characteristics (SCC) shown above determine the field current If2 required to circulate the rated current on a short circuit. This is the field current required to overcome the synchronous reactance drop IaXa.
- Draw the field current If2 in phase in opposition to the current armature current Ia.
- Determine the phasor sum of the field current I'f and If2
- This gives the resultant field current if which would generate a voltage Eo under no load conditions of the attemater. The open circuit EMF Eo corresponding to the field current if is found from the open circuit characteristics
- The regulation of the alternator is found from the relation shown below.

Regulation = { (Eo-V) ÷V }× 100 %

General Case:- Now consider that the load power factor is cos ϕ in such case, the resultant mmf is to be determined by vector addition of Fo And $F_{AR.}$

cos ϕ, lagging pf :-
$(F_R)^2=(Fo+F_{AR}Sin\phi)^2+(F_{AR}\cos\phi)^2$

cos ϕ,leading pf
$(F_R)^2=(Fo-F_{AR}Sin\phi)^2+(F_{AR}\cos\phi)^2$

Using Cosine rule to triangle

$$(F_R)^2=(Fo)^2+(F_{AR})^2-2FoF_{AR}\cos(Fo\wedge F_{AR})$$

$Fo\wedge F_{AR}=90+\phi$ if ϕ is lagging
$=90-\phi$ if ϕ is leading

PROBLEMS

A 3.5-MVA, Y-connected alternator rated at 4160 volts at 50-Hz has the open-circuit characteristic given by the following data :

Field Current (Amps)	50	100	150	200	250	300	350	400	450
EMF (Volts)	1620	3150	4160	4750	5130	5370	5550	5650	5750

A field current of 200 A is found necessary to circulate full-load current on short-circuit of the alternator.

Calculate by (i) synchronous impedance method and (ii) ampere-turn method the full-load voltage regulation at 0.8 p.f. lagging. Neglect resistance.

Solution:

(i) As seen from the given data, a field current of 200 A produces O.C. voltage of 4750 (line value) and full-load current on short-circuit which is

ZS = O.C. volt/phase ÷ S.C. current/phase

= 4750/ 1.73 ÷ 486

= 2740/486 = 5.64 Ω / phase

Ra = 0, Xs = Zs

∴ IRa = 0, IXs = IZs = 486 × 5.64 = 2740 V

F.L. Voltage/phase = 4160/ 1.73

=2400 V

cos ϕ = 0.8,sin ϕ = 0.6

$Eo^2 = (V \cos\phi + IRa)^2 + (V \sin\phi + I, Xs)^2$

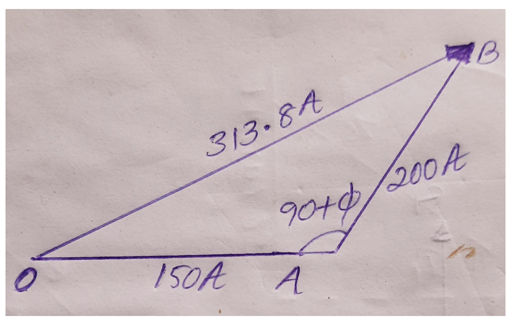
$= (2400 \times 0.8 + 0)^2 + (2400 \times 0.6 + 2740)^2$

Eo= 4600 V

% Voltage regulation up = { (4600-2400)÷2400 }× 100

=92.5%

(ii) It is seen from the given data that for normal voltage of 4160 V, field current needed is 150 A. Field current necessary to circulate F.L. Current on short-circuit is 200 A.



In Fig. OA represents 150 A. The vector AB which represents 200 A is vectorially added to OA at (90° + ϕ) = (90°+36°52′) = 126°52′.

Vector OB represents excitation necessary to produce a terminal p.d. of 4160 V at 0.8 p.f. lagging at full-load.

OB = [1502 + 2002 + 2 × 150 × 200 × cos(180°− 126°52′)]1/2

= 313.8 A

The generated phase e.m.f. E0, corresponding to this excitation as found from OCC (if drawn) is 3140 V.

Line value is 3140 × 1.73 = 5440 V.

% regulation = { (5440-4160)÷4160 } × 100

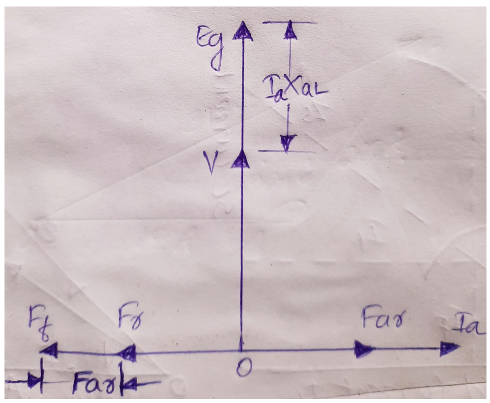
=30.7%

ZERO POWER FACTOR / POTIER TRIANGLE METHOD

- The Potier triangle determines the voltage regulation of the machines
- This method depends on the separation of the leakage reactance of the armature and their effects.

Assumptions for Potier Triangle

1. The armature resistance Ra. is neglected.
2. The OCC taken on no load accurately represents the relation between MMF and Voltage on load
3. The leakage reactance voltage IaXL is independent of excitation.
4. The armature reaction MMF is constant.



What are the requirements for plotting the graph to calculate the values of leakage reactance drop and armature reaction drop ?

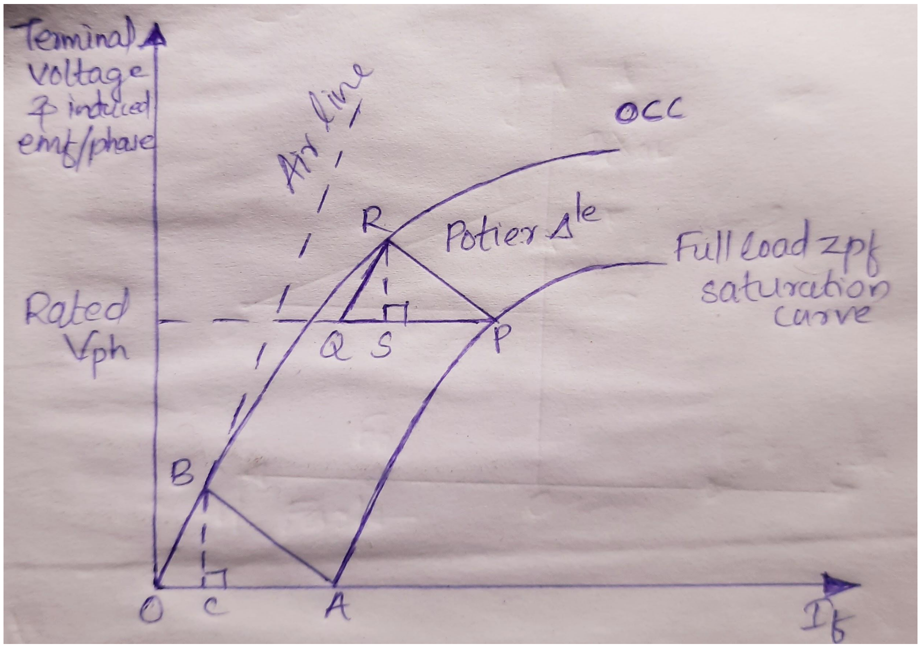
1. Firstly we need to draw the open circuit characteristics of a synchronous machine curve. This can be obtained by plotting the graph between open circuit voltage against field current whose values are obtained by conducting an open circuit test on a synchronous machine.

2. To obtain zero power curve we require two points they are::-

a) At short circuit condition field current required to give full load short circuit armature current.

b) Field current required to give rated terminal voltage while delivering rated full load armature current

Graph for calculating the values of leakage reactance drop and armature reaction drop:



Steps for drawing the graph to calculate the value of leakage reactance drop and armature reaction drop:

1.Draw the open circuit characteristics curve. For different values of field current, plot its corresponding values of open circuit voltage whose values are already tabulated by conducting the open circuit test on alternator.

2. Now plot the full load zero power factor curve by using two values.

a) Field current at short circuit full load zero power factor armature current which is denoted by A

b) Field current required to give rated terminal voltage while delivering rated full load armature current which is denoted by P.

3. To the open circuit characteristics curve draw a tangent through the origin. This is called air gap line it is shown in the graph by dotted line OB
4. Now draw a line PQ which is parallel and equal to OA as seen in the graph.
5. Now draw a line parallel to air gap line from Q such that it intersects the open circuit characteristics curve at R.
6. Now join RQ and RP
7. The triangle obtained is called the potier triangle.
8. Now from point R draw a perpendicular on to QP. It touches QP at point S.
9. The potier triangle obtained is constant for a given armature current
10. Now draw a line parallel to PR through point A such that it meets the open

circuit characteristics curve at B

11. Now draw a perpendicular to OA from B which intersects OA at point C
12. Now triangles OAB and PQR are similar triangles.
13. The length of the perpendicular RS gives the voltage drop due to armature leakage reactance i.e. XLph
14. The length of PS gives field current required to overcome demagnetizing effect of armature reaction at full load.
15. Length SQ represents field current required to induce an e.m.f for balancing leakage reactance drop RS.

PARALLEL OPERATION OF ALTERNATORS

The operation of connecting an alternator in parallel with another alternator or with common bus-bars is known as synchronizing. Ie,the alternator is connected to infinite bus-bars.

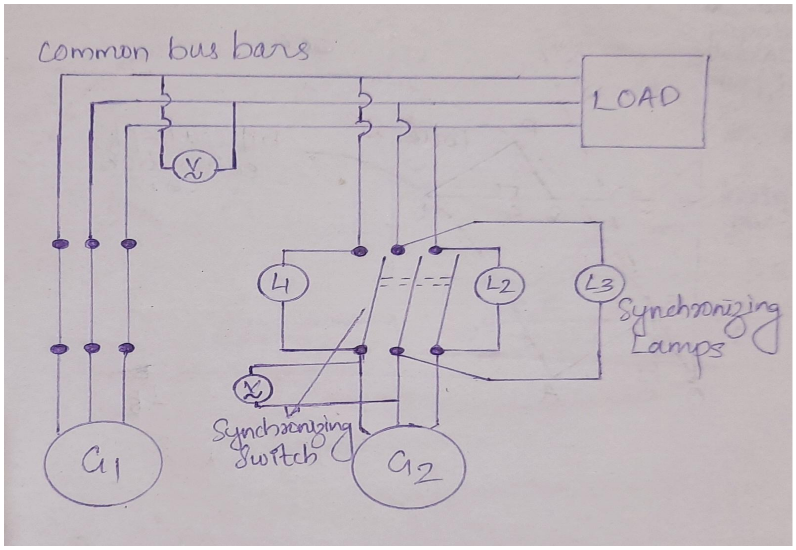
For proper synchronization of alternators, the following three conditions must be satisfied :

1. Equal voltage: The terminal voltage of the incoming alternator must be equal to the bus-bar voltage.
2. Similar frequency: The frequency of generated voltage must be equal to the frequency of the bus-bar voltage.
3. Phase sequence: The phase sequence of the three phases of alternator must be similar to that of the grid or bus-bars.
4. Phase angle: The phase angle between the generated voltage and the voltage of the grid must be zero.

There are different techniques being available for the synchronization of alternators. The common methods used for synchronizing the alternators are given below.

- **Three dark lamp method**
- **Two bright,one dark method**
- **Synchroscope method**

THREE DARK LAMP METHOD



Procedure:

1. Consider alternator-1 is supplying power to load at rated voltage and rated frequency which Means alternator-1 is already in synchronism with bus-bar,
2. Now we need to connect alternator-2 in parallel with alternator-Across the 3 switches of alternator-2 three lamps are connected as shown in the figure.

3.. To match the frequency of alternator-2 with the bus-bar frequency we need to run the prime mover of alternator-2 at nearly synchronous speed which is decided by the frequency of bus-bar and number poles present in alternator-2

4.To match the terminal voltage of alternator-2 with bus-bar voltage we need to adjust the field current of alternator-2 until terminal voltage of alternator-2 matches with the bus-bar voltage. The required value of voltage can be seen in the voltmeter connected to the bus-bar.

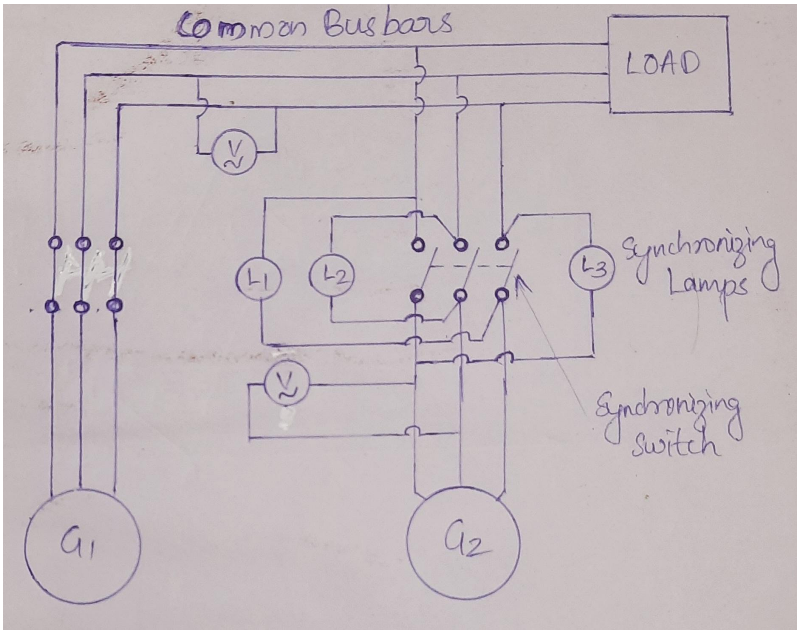
5.To know whether the phase sequence of alternator 2 matches with the bus-bar phase sequence we have a condition. If all the three bulbs ON and OFF concurrently then we say the phase sequence of alternator-2 matches with the phase sequence of bus-bar. If the bulbs ON and OFF one after the other then the phase sequence is mismatching.

6. To change the connections of any two leads during the mismatch of phase sequence first off the alternator and change the connections.

7.. ON and OFF rate of bulbs depends upon frequency difference of alternator-2 voltage and bus-bar voltage. Rate of flickering of bulbs is reduced when we match the frequency of alternator-2 with bus-bar voltage by adjusting the speed of prime mover of alternator2

8. If all the conditions required for synchronization are satisfied then the lamps will become dark.
9. Now close the switches of alternator-2 to synchronize with alternator-1.
10.Now the alternators are in synchronism

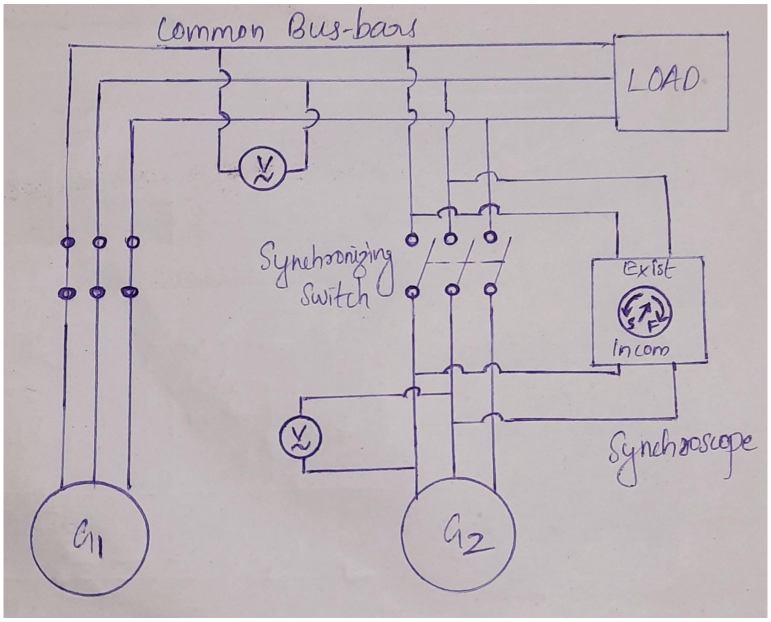
TWO BRIGHT, ONE DARK METHOD



Procedure:

1. Consider alternator-1 is supplying power to load at rated voltage and rated frequency which means alternator 1 is already in synchronism with the bus-bar.
2. Now we need to connect alternator-2 in parallel with alternator-1.
3. Here lamp L-2 is connected similar to the three dark lamp methods.
4. Lamps L-1 and L-3 are connected in different ways. One end of lamp L-1 is connected to one of the phases other than the phase to which lamp L-2 is connected and the other end of lamp L-1 is connected to the phase to which lamp L-3 is connected.
5.Similarly one end of lamp L-3 is connected to a phase other than the phase to which lamp L-2 is connected and other end of lamp L-3 is connected to the phase to which lamp L-1 is connected as shown in the following circuit.
6. To match the terminal voltage of alternator-2 with bus-bar voltage we need to adjust the field current of alternator-2 until terminal voltage of alternator 2 matches with the bus- bar voltage. The required value of voltage can be seen in the voltmeter connected to the bus-bar.
7. Depending upon the sequence of lamps L1,L2, L3 becoming dark and bright we can decide whether the alternator-2 frequency of voltage is higher or lower than bus-bar frequency.
8. If the sequence of bright and dark lamps is L1-L2-L3 then the frequency of alternator-2 is higher than the bus-bar voltage. Now until the flickering reduces to a low value decreases the speed of prime mover of alternator-2.
9. If the sequence of bright and dark lamps is L1-L3-L2 then the frequency of alternator-2 is less than the bus-bar voltage. Now until the flickering reduces to a low value increase the speed of prime mover of alternator-2.
10. When the L1 and L3 are equally bright and lamp L2 is dark then close the switches.
11.Now the alternators are in synchronism.

SYNCHROSCOPE METHOD

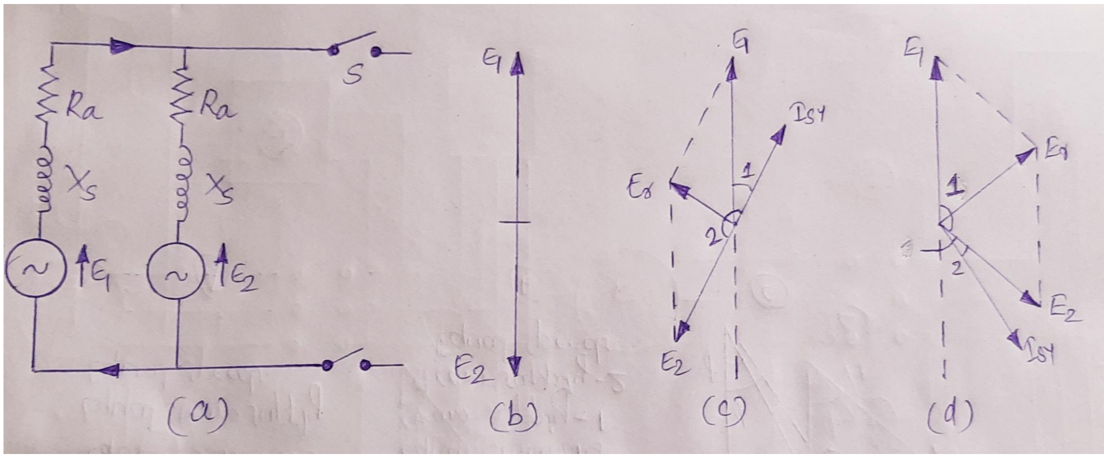


Procedure:

1. A synchroscope is used to achieve synchronization accurately.
2. It is similar to two bright and one dark lamp method and tells whether the frequency of incoming alternator is whether higher or lower than busbar frequency,
3. This contains two terminals; they are a) existing terminal b) incoming terminal.
4. Existing terminals are to be connected to bus-bar or existing alternator here in the diagram it is alternator-1 and incoming terminals are connected to incoming alternator which is alternator2 according to the diagram which we have considered
5. Synchroscope has a circular dial inside which a pointer is present and it can move both in clockwise and anti clockwise direction.
6. To match the terminal voltage of alternator-2 with bus-bar voltage we need to adjust the field current alternator-2 until terminal voltage of alternator-2 matches with the bus-bar voltage The the required value of voltage can be seen in the voltmeter connected to the bus-bar.
7. Depending upon the rate at which the pointer is rotating the difference of frequency of voltage between the incoming alternator and the bus-bar can be known.
8. And also if the pointer moves anti clockwise then the incoming alternator is running slower and has frequency less than the bus bar or existing alternator frequency and if the pointer moves clockwise then the incoming alternator is running faster and has frequency greater than bus-bar or existing alternator frequency.
9. Now both the alternators are in synchronism.

SYNCHRONIZING CURRENT

Once synchronized properly, two alternators continue to run in synchronism. Any tendency on the part of one to drop out of synchronism is immediately counteracted by the production of a synchronizing torque,which brings it back to synchronism.When in exact synchronism, the two alternators have equal terminal p.d.'s and are in exact phase opposition, so far as the local circuit (consisting of their armatures) is concerned. Hence, there is no current circulating round the local circuit.



As shown in Fig. (b) e.m.f. E1 of machine No. 1 is in exact phase opposition to the e.m.f. of machine No. 2 i.e. E2. ie, the two e.m.f.s. are in opposition, so far as their local circuit is concerned but are in the same direction with respect to the external circuit. Hence, there is no resultant voltage (assuming E1 =E2 in magnitude) round the local circuit.

But now suppose that due to change in the speed of the governor of the second machine, E2 falls back by a phase angle of á electrical degrees, as shown in Fig. (c) (though still E1 = E2). Now, they have a resultant voltage Er, which when acting on the local circuit, circulates a current known as synchronizing current. The value of this current is given by I_{SY}= Er /ZS where ZS is the synchronous impedance of the phase windings of both the machines (or of one machine only if it is connected to infinite bus-bars).

The current I_{SY} lags behind Er by an angle θ given by tan θ = XS /Ra where XS is the combined synchronous reactance of the two machines and Ra their armature resistance. Since Ra is negligibly small, θ is almost 90 degrees. So I_{SY} lags Er by 90° and is almost in phase with E1. It is seen that I_{SY} is generating current with respect to machine No.1 and motoring current with respect to machine No. 2

This current I_{SY} sets up a synchronising torque, which tends to retard the generating machine (i.e. No. 1) and accelerate the motoring machine (i.e. No. 2).Similarly, if E2 tends to advance in phase [Fig.(d)], then I_{SY}, being generating current for machine No. 2, tends to retard it and motor current for machine No. 1 tends to accelerate it. Hence, any departure from synchronism results in the production of a synchronizing current I_{SY} which sets up synchronizing torque. This re-establishes synchronism between the two machines by retarding the leading machineand by accelerating the lagging one. This current I_{SY}, it should be noted, is superimposed on the load currents in case the machines are loaded.

SYNCHRONIZING POWER

Consider Fig.(c) above where machine No. 1 is generating and supplying the synchronizing power= $E1 \times I_{SY}$ cos φ1 which is approximately equal to $E1 \times I_{SY}$ (φ1 is small). Since φ1 = (90° − θ), synchronizing power =$E1 \times I_{SY}$ cos φ1 =$E1 \times I_{SY}$ cos (90°− θ) = $E1 \times I_{SY}$, sin θ ≅ $E1 \times I_{SY}$ because θ ≅ 90° so that sin θ ≅ 1. This power output from machine No. 1 goes to supply (a) power input to machine No. 2 (which is motoring) and (b) the Cu losses in the local armature circuit of the two machines. Power input to machine No. 2 is E2 I_{SY}cos φ2 which is approximately equal to $E2.I_{SY}$

$\therefore E1 \times I_{SY} = E2 \times I_{SY}$ + Cu losses
Now, let E1 = E2 = E (say)
Then, Er = 2 E cos [(180° − α)/2] = 2E cos [90° − (α/2)]
= 2 E sin α/2 = 2 E × α/2 = αE ($\because$ α is small)
Here, the angle α is in electrical radians.

Now, I_{SY} = Er/Zs = Er/2Xs= αE /2Xs —if Ra of both machines is negligible

Here, Xs represents synchronous reactance of one machine and not Synchronizing power (supplied by machine No. 1) is

$$P_{XY} = E1 \times I_{SY} \cos \varphi1 = E \times I_{SY} \cos (90° - \theta) = E \times I_{SY} \sin \theta \cong E \times I_{SY}$$

Substituting the value of I_{SY} from above,

$$P_{XY} = E.\alpha E/2\ Zs = \alpha E^2/2Zs \cong E^2\ \alpha/2Xs$$

(more accurately, $P_{XY} = \alpha\ E^2 \sin \theta/2Xs$)
Total synchronizing power for three phases
$= 3\ P_{XY} = 3\ \alpha E^2/2Xs$ (or $3\ \alpha E^2 \sin \theta/2Xs$)
This is the value of the synchronizing power when two alternators are connected in parallel and are on no-load.

ALTERNATORS CONNECTED TO INFINITE BUS-BARS

The expression for synchronizing power

$E_r = \alpha E$

$I_{SY} = E_r/Z_s \cong E_r/X_s = \alpha E/X_s$ – if Ra is negligible

Synch. power $P_{XY} = E I_{XY} = E. \alpha E/Z_s = \alpha E^2/Z_s \cong \alpha E^2/X_s$ – per phase

Now, $E/Z_s \cong E/X_s$ = S.C. current I_{SC}

Total synchronizing power for three phases = $3 P_{XY}$

SYNCHRONIZING TORQUE

Let T_{SY} be the synchronizing torque per phase in newton-metre Nm

(a) When there are two alternators in parallel

$T_{SY} \times (2\pi \times Ns/60) = P_{SY}$

Therefore, $T_{SY} = P_{SY} / (2\pi \times Ns/60)$

$= \alpha E^2 / 2X_s \div (2\pi \times Ns/60)$

Total torque due to three phases $= 3P_{SY} / (2\pi \times Ns/60)$

$= 3\alpha E^2 / 2X_s \div (2\pi \times Ns/60)$ N-m

(b) Alternator connected to infinite bus-bars

$T_{SY} \times (2\pi \times Ns/60) = P_{SY}$

Therefore, $T_{SY} = P_{SY} / (2\pi \times Ns/60) = \alpha E^2 / X_s \div (2\pi \times Ns/60)$ N-m

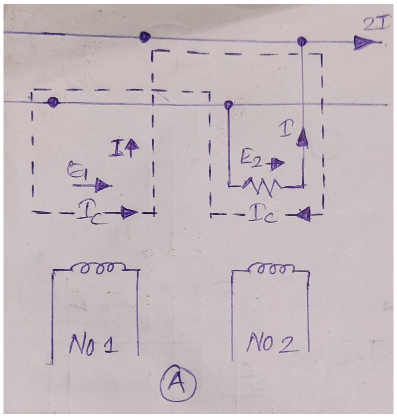
Torque due to three phase $= 3P_{SY} / (2\pi \times Ns/60) = 3\alpha E^2 / X_s \div (2\pi \times Ns/60)$ N-m

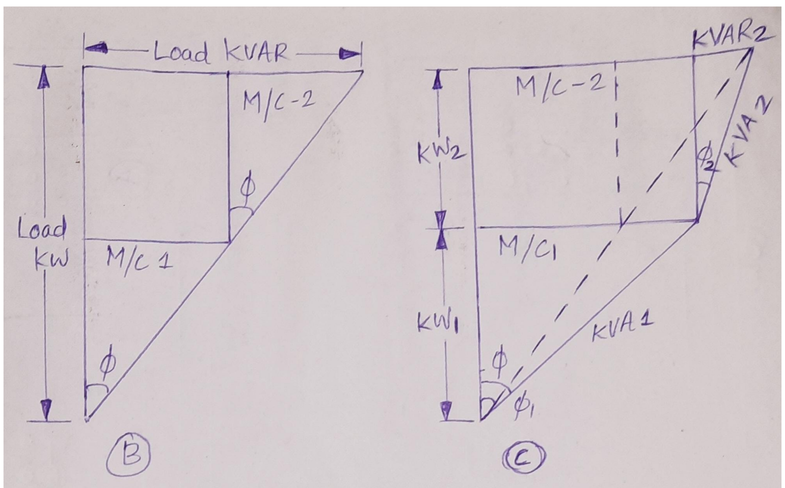
Where Ns=sync speed in rpm =120f/P

DISTRIBUTION OF LOAD

The amount of load taken by an alternator running, in parallel with other machines, is determined by its driving torque or the power input to its prime mover (steam, in steam drive m/c). Any alteration in its excitation merely changes its kVA output, but not its kW output. ie, it changes the power factor at which the load is delivered.

(A) EFFECT OF CHANGE IN EXCITATION





Two parallel identical alternators. Each supplies one half of the active load (kW) and one-half of the reactive load (kVAR), the operating power factors thus being equal to the load p.f. In other words, both active and reactive powers are divided equally thereby giving equal apparent power triangles for the two machines as shown in Fig.(b)

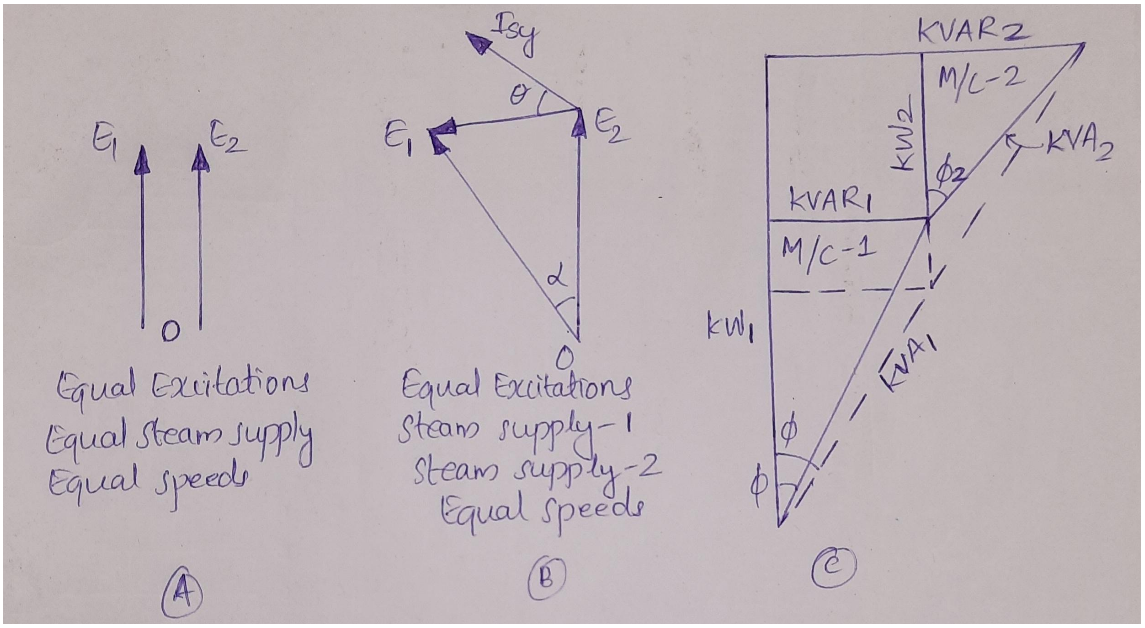
.In Fig.(a), each alternator supplies a load current I so that total output current is 2 I.Now, let excitation of alternator No. 1 be increased, so that E1 becomes greater than E2

The difference between the two e.m.fs. sets up a circulating currentIC = ISY = (E1 − E2)/2Zs

This current is superimposed on the original current distribution and IC is vectorially added to the load current of alternator No. 1 and subtracted from that of No. 2. The two machines now deliver load currents I1 and I2 at respective power factors of cos ϕ 1 and cos ϕ 2. These changes in load currents lead to changes in power factors, such that cos ϕ 1 is reduced, whereas cos ϕ 2 is increased.

The effect on the kW loading of the two alternators is negligible, but kVAR1 supplied by alternator No. 1 is increased,whereas kVAR2 supplied by alternator No. 2 is correspondingly decreased, as shown by the kVA triangles of Fig.(c).

(B) EFFECT OF CHANGE IN STEAM SUPPLY



If the excitations of the two alternators are kept the same but steam supply to alternator No. 1 is increased i.e. power input to its prime mover is increased. The speeds of the two machines are tied together by their synchronous bond, machine No.1 cannot overrun machine No 2. Alternatively, it utilizes its increased power input for carrying more load than No. 2. This can be made possible only when rotor No. 1 advances its angular position with respect to No. 2 as shown in Fig.(b) where E1 is shown advanced ahead of E2 by an angle α.

Resultant voltage Er (or Esy) is produced which, acting on the local circuit, sets up a current Isy which lags by almost 90° behind Er but is almost in phase with E1.

The power per phase of No. 1 is increased by an amount = E1Isy whereas that of No. 2 is decreased by the same amount (assuming total load power demand to remain unchanged).

Since Isy has no appreciable reactive (or quadrature) component, the increase in steam supply does not disturb the division of reactive powers, but it increases the active power output of alternator No. 1 and decreases that of No. 2. Load division, when steam supply to alternator No. 1 is increased, is shown in Fig.(c).So, it is found that by increasing the input to its prime mover, an alternator can be made to take a greater share of the load, though at a different power factor.

NOTE

1.The load taken up by an alternator directly depends upon its driving torque or in other words,upon the angular advance of its rotor.
2. The excitation merely changes the p.f. at which the load is delivered without affecting the load so long as steam supply remains unchanged.
3. If input to the prime mover of an alternator is kept constant, but its excitation is changed, then the kVA component of its output is changed, not kW.

IMPORTANT QUESTIONS

1.Explain synchronous impedance method for finding voltage regulation(6 marks)

2.Explain the condition for proper synchronization of alternator (6marks)

3.Why terminal voltage alternator is lower than generated emf (8marks)

4.List the methods for finding voltage regulation (3marks)

5.Explain the method to find voltage regulation by EMF method (6marks)

6.Explain the method to find voltage regulation by Ampere Turn method(mmf method) (8marks)

7.Explain the procedure steps to determine the voltage regulation by ZPF methods (8marks)

8.Explain bright lamp method alternator with infinite busbar (8marks)

9. What Are The Advantage Of Parallel Operation Of Alternator(7marks)

10. Explain oc and sc test with connection diagram and characteristics(7marks)