3-5 Synchronous Condenser:

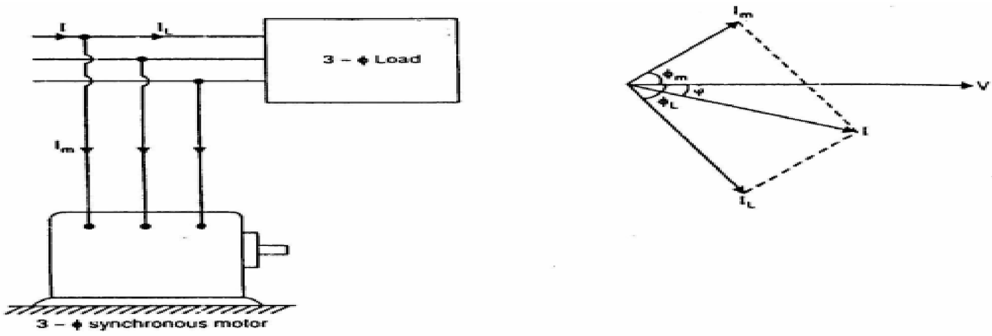
A synchronous motor takes a leading current when over-excited and, therefore, behaves as a capacitor. An over-excited synchronous motor running on no-load in known as synchronous condenser. When such a machine is connected in parallel with induction motors or other devices that operate at low lagging power factor, the leading kVAR supplied by the synchronous condenser partly neutralizes the lagging reactive kVAR of the loads. Consequently, the power factor of the system is improved. Fig. (11.14) shows the power factor improvement by synchronous condenser method. The 3 - Øload takes current I_L at low lagging power factor cos$Ø_L$. The synchronous condenser takes a current I_m which leads the voltage by an angle $Ø_m$. The resultant current I is the vector sum of I_m and I_L and lags behind the voltage by an angle Ø. It is clear that Ø is less than $Ø_L$ so that cos Ø is greater than cos $Ø_L$. Thus the power factor is increased from cos $Ø_L$ to cos Ø. Synchronous condensers are generally used at major bulk supply substations for power factor improvement.

Advantages

(i) By varying the field excitation, the magnitude of current drawn by the motor can be changed by any amount. This helps in achieving stepless control of power factor.

(ii) The motor windings have high thermal stability to short circuit currents.

(iii) The faults can be removed easily



(i) (ii)

Disadvantages

(i) There are considerable losses in the motor.
(ii) The maintenance cost is high.
(iii) It produces noise.

(iv) Except in sizes above 500 KVA, the cost is greater than that of static capacitors of the same rating.

(v) As a synchronous motor has no self-starting torque, then-fore, an auxiliary equipment has to be provided for this purpose.

Applications of Synchronous Motors

(i) Synchronous motors are particularly attractive for low speeds (< 300 r.p.m.) because the power factor can always be adjusted to unity and efficiency is high.
(ii) Overexcited synchronous motors can be used to improve the power factor of a plant while carrying their rated loads.
(iii) They are used to improve the voltage regulation of transmission lines.

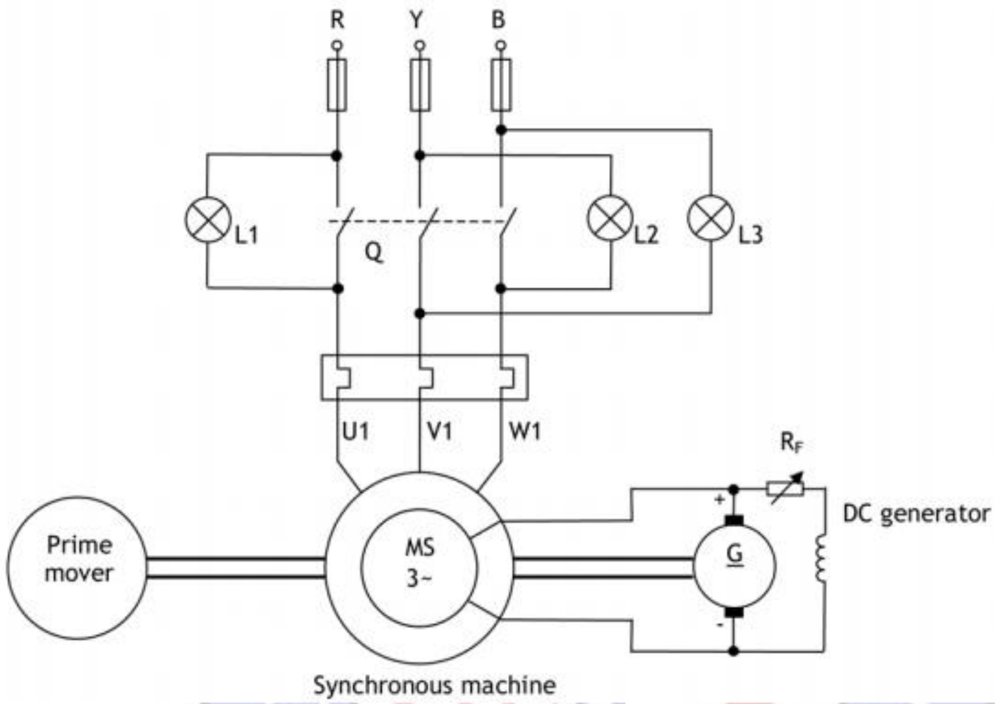
(iv) High-power electronic converters generating very low frequencies enable us to run synchronous motors at ultra-low speeds. Thus huge motors in the 10 MW range drive crushers, rotary kilns and variable-speed ball mills.

3-6 Methods of Starting:

1-Auxiliary drive: Driven unloaded by an auxiliary motor exc. voltage is applied while armature windings still open, motor operating as generator $P_{aux} = 10 - 20\% P_r$

2-Variable frequency starting $f = 0 \rightarrow f_r$

3-Induction start: Using squiral- cage winding called damper or starting winding. The circuit connection is shown. Reduce voltage starting method can be used E_x. winding should not be left open or shorted. When open a high emf is induced. When shorted a pulsating field producing positive torque T_1 and negative torque T_2 .When summing with the induction torque T_α given the resultant torque T_r. The pull-in torque(when applying dc voltage to the excitation winding) is not 95% n_s.



3-7 Stopping of Synchronous Motor:

Owing to the inertia rotor and its load, a large Syn. motor may take several hours to stop after being disconnect from the line to reduce the time we use the following braking methods:

1-Maintain full dc excitation with the armature in short circuit.

2-Maintain full dc excitation with the armature connect to three external resistors.

3-Apply mechanical braking.

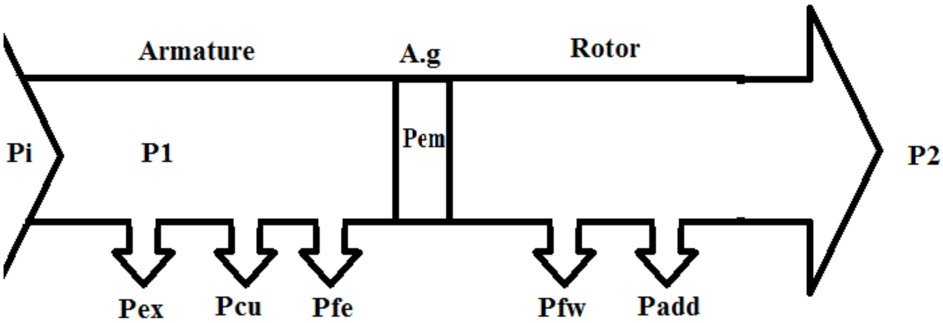
3-8 Motor Power:

$P_1 = \mathrm{P_i} - \mathrm{P_{ex}}$

$\mathrm{P_{em}} = \mathrm{P_1} - (P_{cu1} + P_{fe})$

$= \mathrm{P_{em}} - (\boldsymbol{P_{fw}} + \boldsymbol{P_{add}})$

$T = \frac{P_2}{W_s}$, $T_m = \frac{V\,E_o}{W_s\,X_s}$, $P = \frac{3VE_o}{X_s} \times \sin\delta$



Example1:

A 208 V, 45 KVA, 0.8 pf leading Δ connect 60 Hz syn. motor has a syn. reactance of 2.5Ω and negligible arm. resistance. Its core friction and winding losses are 2.5 Kw. The shaft initially supplying a 15-hp. load and the motor power factor is 0.8 leading. Find $\mathrm{I_a}$, $\mathrm{I_2}$,E_o , assume that the load increase to 30 hp, and find the pf.

Solution

$\mathrm{P_2} = 15 \times 746 = 11190\, W$

$\mathrm{P_1} = \mathrm{P_2} + \mathrm{P_{losses}} = 11190 + 2500 = 13690\ \mathrm{W}$

$$\mathrm{I_L} = \frac{P_1}{\sqrt{3}\ V\cos\theta} = \frac{13690}{\sqrt{3} \times 208 \times 0.8} = 47.5\ A$$

$I_a = \frac{I_L}{\sqrt{3}} = \frac{47.5}{\sqrt{3}} = 27.4 \angle 36.87° \mathrm{A}$

$E_o = V - j\,I_a X_s$=$208\angle° - j(27.4 \angle 36.87 \times (2.5)$

$= 249.1 - j54.8 = 255\angle - 12.4°\ \ voltage$

After the load change:

$P_1 = \mathrm{P_2} + \mathrm{P_{losses}} = 30 \times 764 + 2500 = 24880\,W$

$\delta = \sin^{-1}\frac{\mathrm{X_s\,P}}{3\,\mathrm{V\,E_o}} = \sin^{-1}\left[\frac{2.5\times 24880}{2\times 208\times 255}\right] = 28°$

$\mathrm{I_a} = \frac{V-E_o}{\mathrm{jX_s}} = \frac{208\llcorner° - 255\llcorner -23°}{\mathrm{j\ 2.5}} = 41.2\llcorner 15°$

$\mathrm{I_L} = \sqrt{3}\,\mathrm{I_a} = \sqrt{3} \times 41.2 = 71.4\ \mathrm{A}$ $\qquad \cos\varphi = \cos 15 = 0.966\ \ Leading$

Example 2:

Tow identical, 3-phase SG operating in parallel to supply load of 1MVA and 11kV, 0.8 lagging power factor. If the resistance and reactance of each generator are 5 and 50Ω respectively. If when varying the excitation of the first generator its current become 40A lag. Find: a) cosφ1 and cosφ2 b) I2.

Solution:

The load current is $I = \frac{P}{\sqrt{3}\,V\ \cos\varphi} = \frac{1X\ 10^6}{\sqrt{3}\ X 11 X 10^3 X\ 0.8} = 66A$

With active component of: $I_a = I\cos\varphi = 66x0.8 = 52.8$

And reactive component of: $I_a = I\sin\varphi = 66x0.6 = 39.6A$

$I_{a1}=I_{a2}=I_a/2 = 52.8/2 = 26.4A$,

$I_{r1}=I_{r2}= I_r/2= 39.6/2=19.8A$

$I_1=I_2=I/2=66/2=33A$

When changing the excitation only reactive component is changing

$I_{r1}=\sqrt{I_1^2 - I_{a1}^2} = \sqrt{40^2 - 26.4^2} = 30A$

$I_{r2} = I_r - I_{r1} = 39.6-30=9.6A$

I2= $\sqrt{I_{a2}^2 + I_{r2}^2} = \sqrt{26.4^2 + 9.6^2} = 28A$

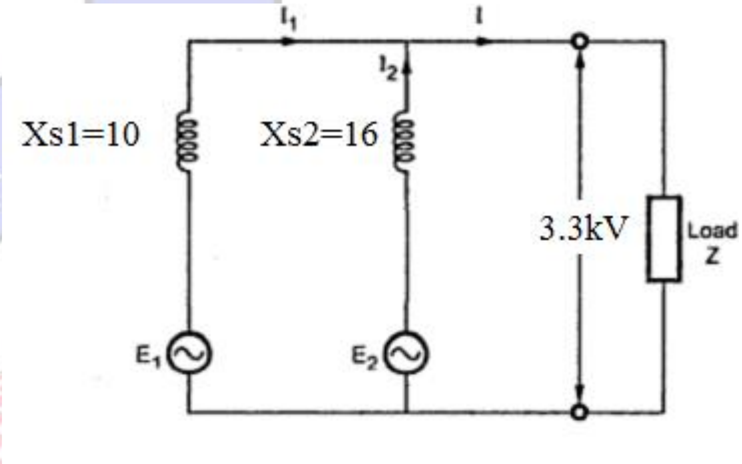
$$\cos\varphi 1 = \frac{I_{a1}}{I_1} = \frac{26.4}{40} = 0.66$$

$$\cos\varphi 2 = \frac{I_{a2}}{I_2} = \frac{26.4}{28} = 0.94$$

Example 3:

Two 3-phase, 3.3 kV, star connected alternators are connected in parallel to supply a load of 800kW at 0.8 power factor lagging. The prime movers are set that one machine delivers twice as much power as the other. The more heavily loaded machine has a synchronous reactance of 10Ω per phase and excitation is so adjusted that it operates at 0.75 lagging power factor. The synchronous reactance of the other machine is 16Ω per phase. Calculate the current, emf, power factor and load angle of each machine. The resistances may be neglected.

Solution:



The load apparent power:
S=P/cosφ

S= 800/0.8= 1000kVA

The load current is:

$I=\frac{S}{\sqrt{3}V}\ (\cos\varphi - J\sin\varphi)$

= 139.96-J104.97A

The current of first generator:

P_1=P 2/3= 800x2/3 = 533.33kW

$I_1=\frac{P_1}{\sqrt{3}V\ \cos\varphi} = \frac{533.33X10^3}{\sqrt{3}X\ 3.3X10^3X\ 0.75} = 124.4 < -14.4°$

Or I_1= 39.3-j82.3A

Then I_2= I-I_1 = 46.7-j22.7A

$E_1=V+jI_1X_{s1}=\frac{33..}{\sqrt{3}} + j10(39.3 - j82.3) = 2728 + j933$

$= 2888 < 18°V$

$E_2=V+jI_2X_{s2}=\frac{33..}{\sqrt{3}} + j16(46.7 - j22.7) = 2268 + j747$

$= 2388 < 18.2°V$

cosφ1=0.75 cosφ2= 0.899 load angle: δ1= 18º, δ =18.2º

Example 4:

A 3-phase, 3.3kV, Δ-connected, SG with 0.5Ω/phase effective resistance, supplying a 5.94MVA, Δ-connected 0.8 power factor load. If VR% is -5% find the alternator Xs,

Solution:

$$\frac{Eo - Vr}{Vr} = -0.05 \;\; then\; Eo = 0.95Vr = 3.135kV$$

$$I_r = \frac{MVA}{3Vr} = \frac{5.94\times10^6}{3\times3.3\times10^3} = 600A$$

IxR= 600x0.5 = 300V , IxX_s= 600X_s

Eo= $[(V\cos\varphi + IxR)^2 + (V \sin\varphi - IX_s)^2]^{1/2}$

$3.135^2 = (3.3x0.8+0.3)^2 + (3.3x0.6 + 0.6X_s)^2$

X_s= 1.5Ω