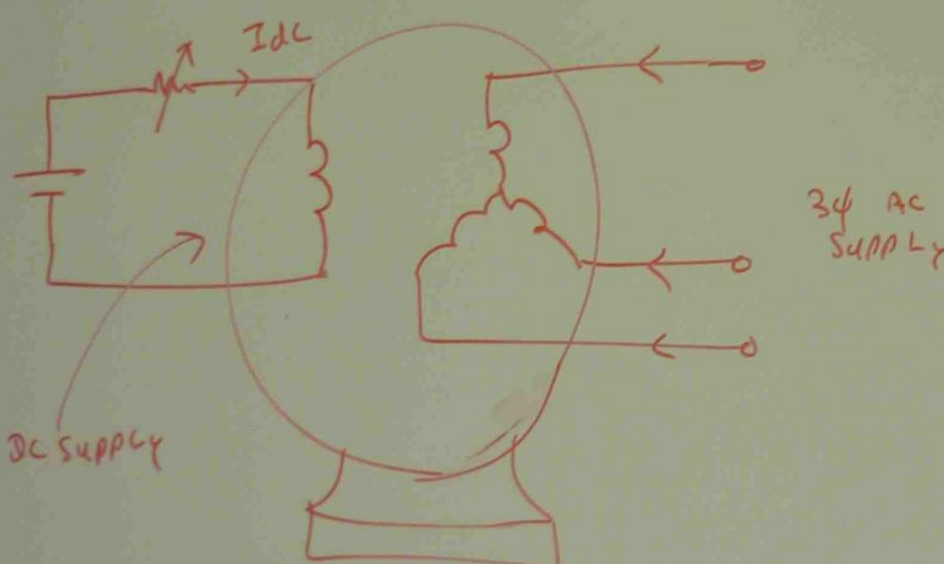
EFFECT OF FIELD EXCITATION ON POWER FACTOR OF SYNCHRONOUS MOTOR

INDUCTION MOTOR — CONSTANT LAGGING POWER FACTOR

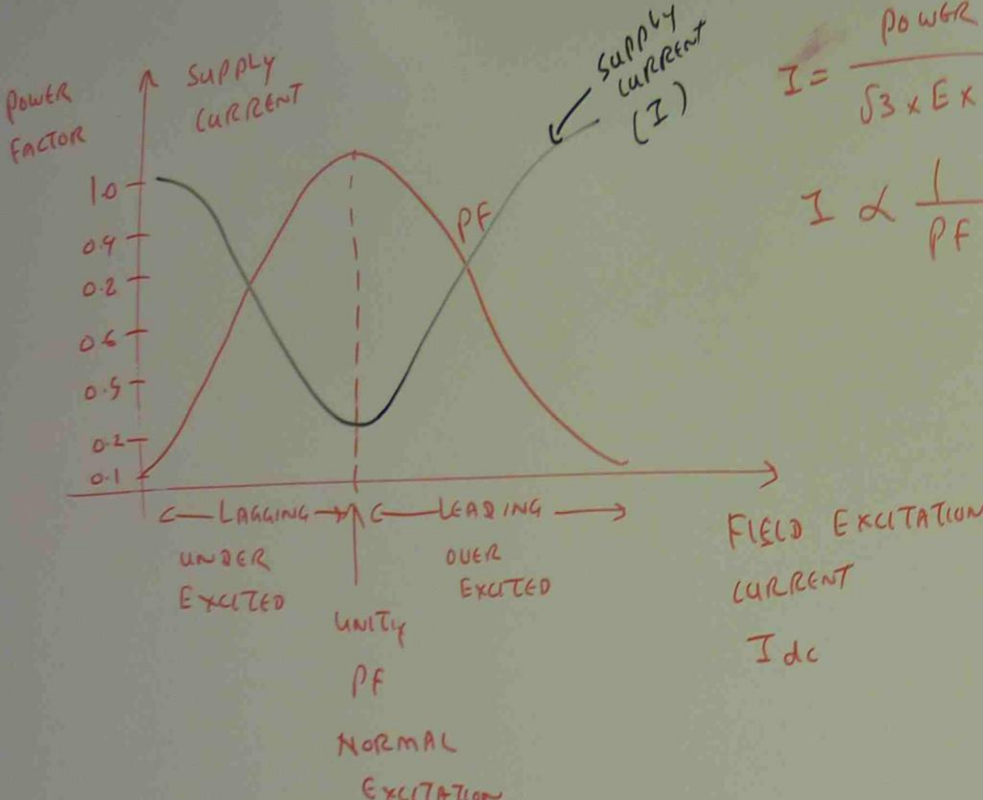
SYNCHRONOUS MOTOR - VARIABLE POWER FACTOR DEPENDING ON FIELD EXCITATION



HIGH FIELD EXCITATION CURRENT — OVER EXCITED → LEADING POWER FACTOR

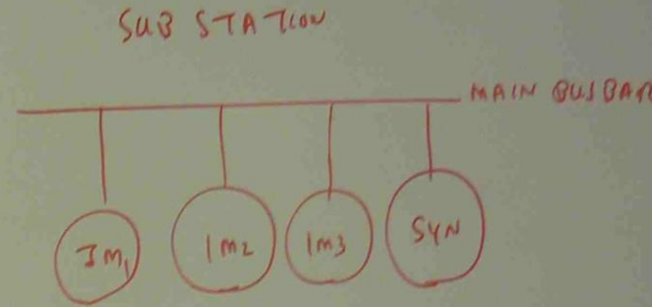
LESS FIELD EXCITATION CURRENT — UNDER EXCITED — LAGGING POWER FACTOR

NORMAL EXCITATION — NORMAL EXCITED — UNITY POWER FACTOR



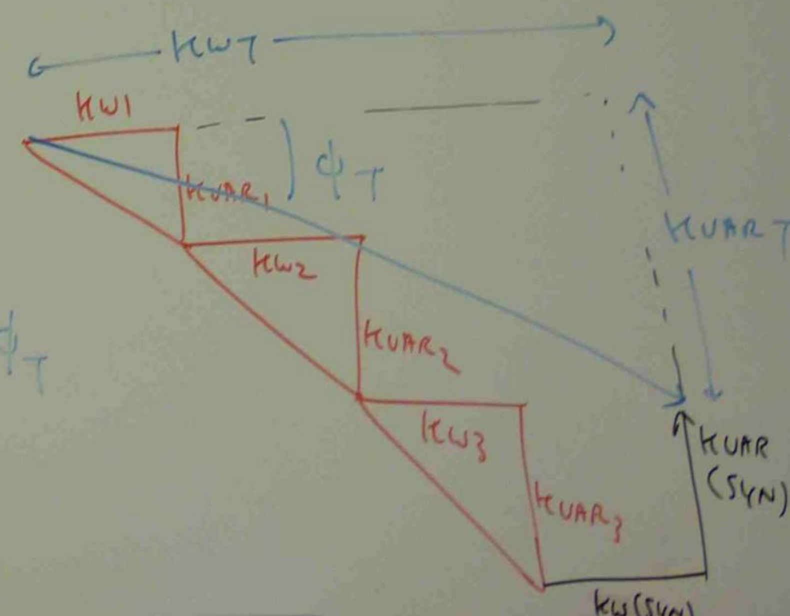
$$I = \frac{POWER}{\sqrt{3} \times E \times P.F}$$

$$I \propto \frac{1}{PF}$$



SYN - SYNCHRONOUS MOTOR

Im - INDUCTION MOTOR



TOTAL PF = $\cos \phi_T$

CHARACTERISTICS OF SYNCHRONOUS MOTOR

TEST (1)

Pb/ A 3 PHASE STAR CONNECTED ALTERNATOR HAS A RESISTANCE OF 0.5 Ω AND A SYNCHRONOUS REACTANCE OF 5 Ω PER PHASE. IT IS EXCITED TO GIVE 6600 V (LINE) ON OPEN CIRCUIT. DETERMINE THE TERMINAL VOLTAGE AND PER UNIT VOLTAGE REGULATION ON FULL LOAD CURRENT OF 130 Amp WHEN THE LOAD POWER FACTOR IS (a) 0.8 LAGGING (b) 0.6 LEADING.

$$E_f = V + I Z_s$$

$$E_f \angle \delta = V \angle 0 + I \angle \phi \, (R + j X_s)$$

$$E_f \angle \delta = E_{ph} = \frac{E_{LINE}}{\sqrt{3}} = \frac{6600}{1.7321} = 3810 \text{ V}$$

(a) 0.8 PF LAGGING

$$\phi = \cos^{-1} 0.8 = 36.8$$

$$3810 \angle \delta = V \angle 0 + 130 \angle -36.8 \, (0.5 + j5)$$

$$3810(\cos\delta + j\sin\delta) = V + 130 \angle -36.8 \left(\sqrt{0.5^2 + 5^2} \; \angle \tan^{-1} \frac{5}{0.5} \right)$$

$$3810\cos\delta + j\,3810\sin\delta = V + 130\angle{-36.8} \times 5.02\angle{84.3}$$

$$3810\cos\delta + j\,3810\sin\delta = V + 653\angle{84.3-36.8}$$

$$3810\cos\delta + j\,3810\sin\delta = V + 653\angle{47.4}$$

$$3810\cos\delta + j\,3810\sin\delta = V + 653\,(\cos 47.4 + j\sin 47.4)$$

$$3810\cos\delta + j\,3810\sin\delta = V + 441 + j\,450.6$$

EQUATE LHS & RHS REAL AND IMAGINARY TERMS

$$3810\cos\delta = V + 441 \quad \text{——— } (1)$$

$$3810\sin\delta = 450.6 \quad \text{——— } (2)$$

$$\sin\delta = \frac{450.6}{3810} = 0.126$$

$$\delta = \sin^{-1} 0.126 = 7.24^\circ$$

$$3810\cos 7.24 = V + 441$$

$$3810 \times 0.992 = V + 441$$

$$V = 3810 \times 0.992 - 441$$

$$= 3338\,V$$

$$\%\text{ VOLTAGE REGULATION} = \frac{E_f - V}{V} \times 100$$

$$= \frac{3810 - 3338}{3338} \times 100$$

$$= 14.17\%$$

(b) 0.6 PF LEADING

$\phi = \cos^{-1} 0.6 = 53.2$

$3810 \angle \delta = V\angle 0 + 130 \angle +53.2 \times 5.02 \angle 84.3$

$3810 \angle \delta = V + 653 \angle 137.5$

$3810 \cos\delta + j\, 3810 \sin\delta = V + 653 \cos 137.5 + j\, 653 \sin 137.5$

$3810 \cos\delta + j\, 3810 \sin\delta = V - 476.69 + j\, 440$

EQUATE REAL AND IMAGINARY

$3810 \cos\delta = V - 476.69$ —— (1)

$3810 \sin\delta = 440$ —— (2)

$\sin\delta = \frac{440}{3810} = 0.115$

$\delta = \sin^{-1} 0.115 = 6.64$

$3810 \cos 6.64 = V - 476.69$

$V = 4261.08$

$\%\ \text{VOLTAGE REGULATION} = \frac{E_f - V}{V} \times 100$

$= \frac{3810 - 4261.08}{4261.08} \times 100$

$= -10.5\%$

TEST (1)

Pb A 4000 HP (3000 kW) 6600 V, 60 Hz 200 RPM SYNCHRONOUS MOTOR OPERATES AT FULL LOAD AT A LEADING POWER FACTOR OF 0.8. IF THE SYNCHRONOUS REACTANCE IS 11 Ω, CALCULATE THE FOLLOWINGS.

(a) THE APPARENT POWER OF THE MOTOR PER PHASE

(b) THE AC LINE CURRENT

(c) THE VALUE AND PHASE OF E_F

(d) DETERMINE THE TORQUE ANGLE δ.

(a) $$\text{ACTIVE POWER}/\text{PHASE} = \frac{3\phi \text{ ACTIVE POWER}}{3} = \frac{3000\,\text{kW}}{3} = 1000\,\text{kW}$$

$$\text{APPARENT POWER}/\text{PHASE} = \frac{1\phi \text{ ACTIVE POWER}}{\text{POWER FACTOR}} = \frac{1000\,\text{kW}}{0.8} = 1250\,\text{kVA}$$

(b) $$\text{AC LINE CURRENT} = \frac{1\phi \text{ ACTIVE}}{\text{PHASE VOLTAGE}} = \frac{1000 \times 10^3}{6600/\sqrt{3}} = \frac{1000,000}{3810}$$

$$= 328 \text{ Amp}$$

$\theta = \cos^{-1} PF = \cos^{-1} 0.8 = 36.8^\circ$

(c) $V = E_f + I Z_s$

$3810\angle 0 = E_f \angle\delta + 328\angle{+36.8}\,(0 + j11)$

$3810\angle 0 = E_f \angle\delta + 328\angle 36.8 \times 11\angle 90$

$3810\angle 0 = E_f \angle\delta + 3608\angle 126.8$

$3810 = E_f \angle\delta + 3608\,(\cos 126.8 + j \sin 126.8)$

$E_f \angle\delta = 3810 - 3608\,(\cos 126.8 + j \sin 126.8)$

$E_f \angle\delta = 3810 - (-2166 + j2889)$

$E_f \angle\delta = 5977 - j2885$

$E_f \angle\delta = \sqrt{5977^2 + 2885^2}\,\angle -\tan^{-1}\frac{2885}{5977}$

$E_f \angle\delta = 6637\angle -26$

$E_{f\,ph} = 6637\,V$

(d) $\delta = -26^\circ$

TEST 1

Pb A SYNCHRONOUS CAPACITOR IS RATED AT 160 MVAR 16 KV, 1200 RPM, 60 HZ. IT HAS A SYNCHRONOUS REACTANCE OF 0.8 PU AND IS CONNECTED TO A 16 KV LINE.

CALCULATE THE VALUE OF E_F SO THAT THE MACHINE

(a) ABSORB 160 MVAR (b) DELIVER 120 MVAR.

$$Z_S(\Omega) = Z_S(pu) \times \frac{(E_{LINE})^2}{MVA}$$

$$Z_S(\Omega) = 0.8 \times \frac{(16 \times 10^3)^2}{160 \times 10^6} = 1.28\,\Omega$$

$$Z_S = R + jX_S = 0 + j1.28 = 1.28 \angle 90^\circ\,\Omega$$

TO ABSORB 160 MVAR

CURRENT LAGS BEHIND VOLTAGE

$$I = \frac{MVA}{\sqrt{3}\,E}$$

$$= \frac{160 \times 10^6}{1.7321 \times 16 \times 10^3}$$

$$= 5780$$

ABSORB MVAR

$$I = 5780 \angle -90^\circ$$

LAGGING P.F.

$$E_F = V - I Z_S$$

$$E_F = \frac{16000}{\sqrt{3}} - 5780 \angle -90 \times 1.28 \angle 90$$

$$= 9250 - 5780 \times 1.28$$

$$= 4850\,V$$

TO DELIVER 120 MVAR

$$I = \frac{MVA}{\sqrt{3}E} = \frac{120 \times 10^6}{1.7321 \times 16 \times 10^3}$$

$$= 4335 \text{ Amp}$$

DELIVER – CURRENT LEADS VOLTAGE

$$4335 \angle +90^\circ \text{ Amp.}$$

$$E_f = V - I Z_s$$

$$= \frac{16000}{\sqrt{3}} - 4335 \angle 90 \times 1.28 \angle 90$$

$$= 9250 - 5550 \angle 180$$

$$= 9250 - 5550 (\cos 180 + j \sin 180)$$

$$E_f = 9250 - 5550 \times (-1)$$

$$= 9250 + 5550$$

$$= 11480 \text{ V}$$