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17/ENG04/057

ELECTRICAL ELECTRONICS ENIGEERING

ELECTRICAL MACHINES (EEE 326) ASSIGNMENT

POWER FACTOR AND HARMONICS

QUESTION:

A 25kVA, 415V, three phase, 4 pole, 60Hz, wye connected synchronous generator has a synchronous reactances of 1.5Ω/phase and negligible stator resistance. The generator is connected to an infinite bus (of constant voltage magnitude and constant frequency) at 415V and 60Hz.

a) Determine the excitation voltage, EA when the machine is delivering rated kVA at 0.8 pf lagging.

b) The field excitation current I_f increased by 20% without changing the power input from the prime mover. Find the stator current I_A, power factor, and reactive power Q supplied by the machine.

c) With the field excitation current I_f as in part (a), the input power from the prime mover is increased very slowly. What is the steady state limit? Determine stator current I_A, power factor, and reactive power Q.

Solution

Parameters Given;

Rated Power, S_{rated} = 25KVA.

Line Voltage, V_L = 415 V

No of poles = 4

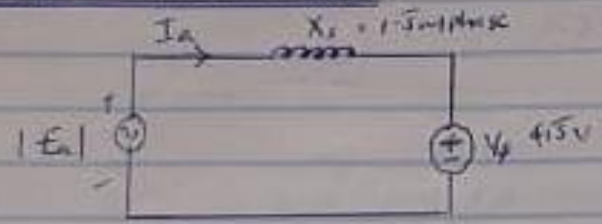
frequency, f = 60Hz

Note: It is a Star Connected Synchronous Generator.

Synchronous reactance, X_s = 1.5Ω/phase

Stator resistance, R_a = 0 (Negligible).

Diagramatic Representation



Question ①.

Determining the excitation voltage, E_a.

Recall that; in a Star Connection,

$$V_{phase} = V_{Line} \div \sqrt{3}$$

$$V_{phase} = 415 \div \sqrt{3}$$

$$V_{phase} = 239.6\text{ V}$$

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∴ Using the formula;

$$I_a = \frac{S_{rated}}{V_L \times \sqrt{3}} = \frac{25000}{718.8}$$

$$\therefore I_a = 34.78\text{ A}.$$

Given that Power factor is 0.8 Lagging

∴ $P.F = \cos\theta$.

$0.8 = \cos\theta$.

$\theta = \cos^{-1} 0.8$

$\theta = 36.9°$ (Lagging)

Using the formula for Excitation Voltage

$$E_a = V_\phi + j * I_a * X_s$$

$$\therefore E_a = \left(\frac{415}{\sqrt{3}} \angle 0^\circ\right) + \left((34.78 \angle -36.9) * (1.5 \angle 90^\circ)\right)$$

$$E_a = 239.60 \angle 0^\circ + 52.17 \angle 53.1^\circ$$

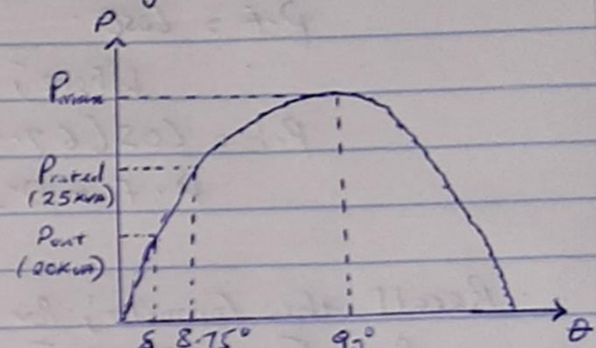
$$E_a = 274.12 \angle 8.75^\circ \, v$$

Question (2).

Recall that;

Real Power of a Synchronous Generator is given as;

$$P_{OUT} = \frac{3 * V_\phi * E_a \sin\delta}{X_s}$$



δ: Torque Angle

$$\therefore P_{out} = \frac{3 * 239.6 * 274.12 * \sin(8.75)}{1.5}$$

$$= 19982.67003$$

$$\simeq 20KVA$$

$\therefore$ The ratio of Rated Power to real Power =

$$\therefore \frac{25}{20} = 1.25$$

$$P_{rated} = 1.25 P_{out}.$$

$$\therefore E_{a_2} = 1.25 * E_{a_1}$$

$$\therefore E_{a_2} = 1.25 * 274.12$$

$$E_{a_2} = 342.65 \, v$$

$\therefore$

Recalling the formula for Induced torque to Calculate Torque Angle (δ)

$$\therefore \frac{3 V_\phi E_{a_1} \sin\delta_1}{X_s} = \frac{3 V_\phi E_{a_2} \sin\delta_2}{X_s}$$

$$E_{a_1} \sin\delta_1 = E_{a_2} \sin\delta_2.$$

$$\sin\delta_2 = \frac{274.12 \sin(8.75)}{342.65}$$

$$\sin\delta_2 = 0.12.$$

$$\delta_2 = \sin^{-1}(0.12)$$

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$\delta_2 = 6.987^\circ$

∴ using the formula below to calculate; I_A Stator Current.

$$I_{A_{Stator}} = \frac{Ea_2 - V_\phi}{X_s}$$

$$= \frac{342.65 \angle 6.987 - 239.6 \angle 0}{1.5 \angle 90^\circ}$$

$I_{A_{Stator}} = 72.5368 \angle -67.4$ A.

∴ Power factor;

$P.f = \cos\theta$

Where; $\theta = 67.4$.

$P.f = \cos(67.4)$

$P.f = 0.384$ Lagging

∴ Recall the formula; for reactive Power Q.

$Q = \sqrt{3} * V_L * I_L * \sin\theta$

$Q = \sqrt{3} * 415 * 72.5368 * \sin(67.4)$

$Q = 48135.75$

$Q = 48$ KVAR.

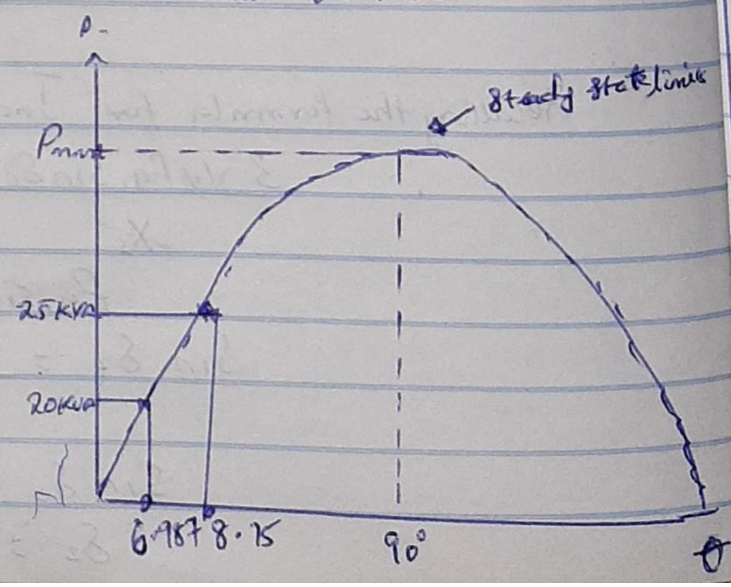
Question (3)

(3). Where; The input Power from the Prime mover is increased slowly;

Steady State limit; This is the maximum Power (P_{max}) transmitted to the receiving end without loss of Synchronism.

It is represented with the formula;

$$P_{max} = \frac{Ea * V_\phi * 3}{X_s}$$



Note; at this point $\theta = 90^\circ$

∴ $\sin 90^\circ = 1$.

④ ∴ The steady state limit

$$\Rightarrow P_{max} = \frac{E_a * V_\phi * 3}{X_s}$$

$$= \frac{3 * 239 * 274.12}{1.5}$$

$$P_{max} = 131029 \text{ KVA}$$

∴ The steady state limit is 131 KVA at 90° (angle) an

⑤ Stator Current; at steady state limit;

$$\bar{I}_{A\,stator_s} = \frac{E_a - V_\phi}{X_s}$$

$$\Rightarrow \frac{274.12\angle 90 - 239\angle 0}{1.5\angle 90}$$

$$= 242.66\angle 41.17°$$

⑦ Power factor;

$$P.F = \cos\theta$$

$$P.F = \cos(41.17)$$

$$PF = 0.752 \text{ (leading)}$$

⑧ Reactive Power;

$$Q = \sqrt{3} * V_L * I_L * \sin\theta$$

$$Q = \sqrt{3} * 415 * 242.66 * \sin(41.17)$$

$$Q = 114822$$

$$Q \cong 115 \text{ KVAR}$$