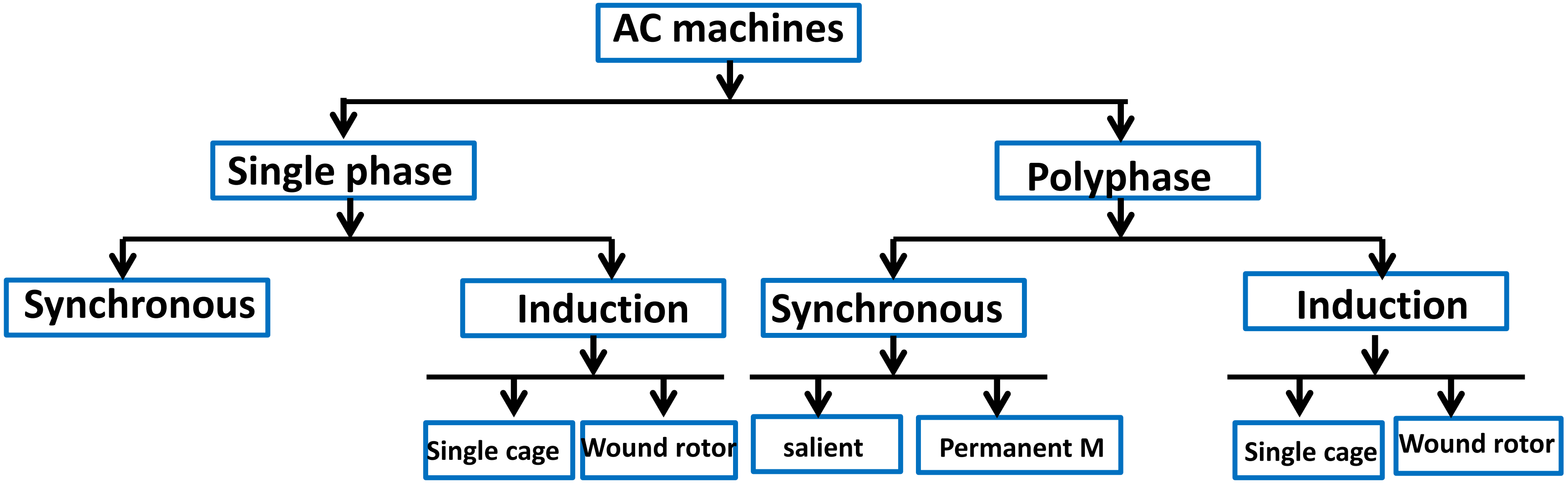
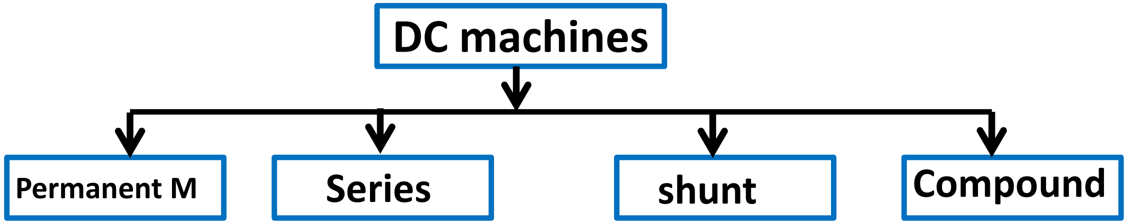
Classification of electrical machines





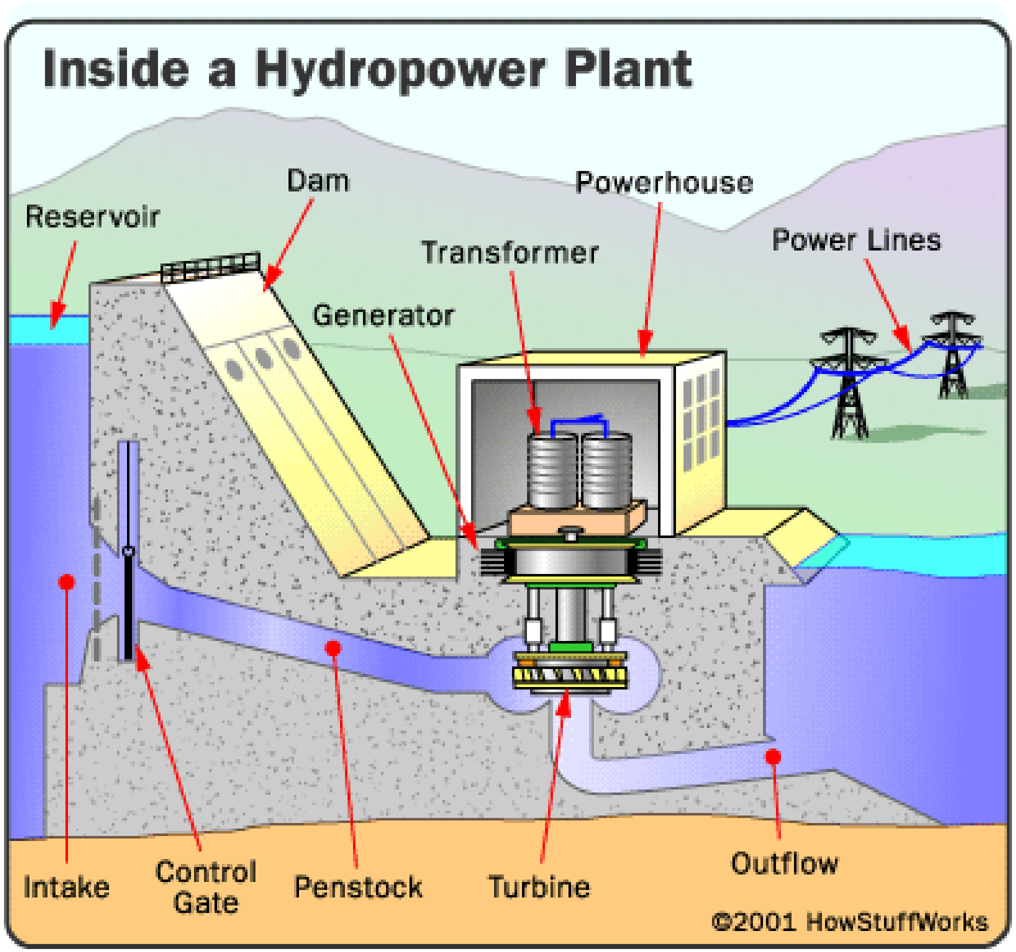
CHAPTER THREE

Synchronous machines

Learning Outcomes:

- Identify different types of synchronous and induction machines
- Explain how synchronous and induction machines works
- Basic calculation on synchronous and induction performance
- Understand areas of application of synchronous and induction machines

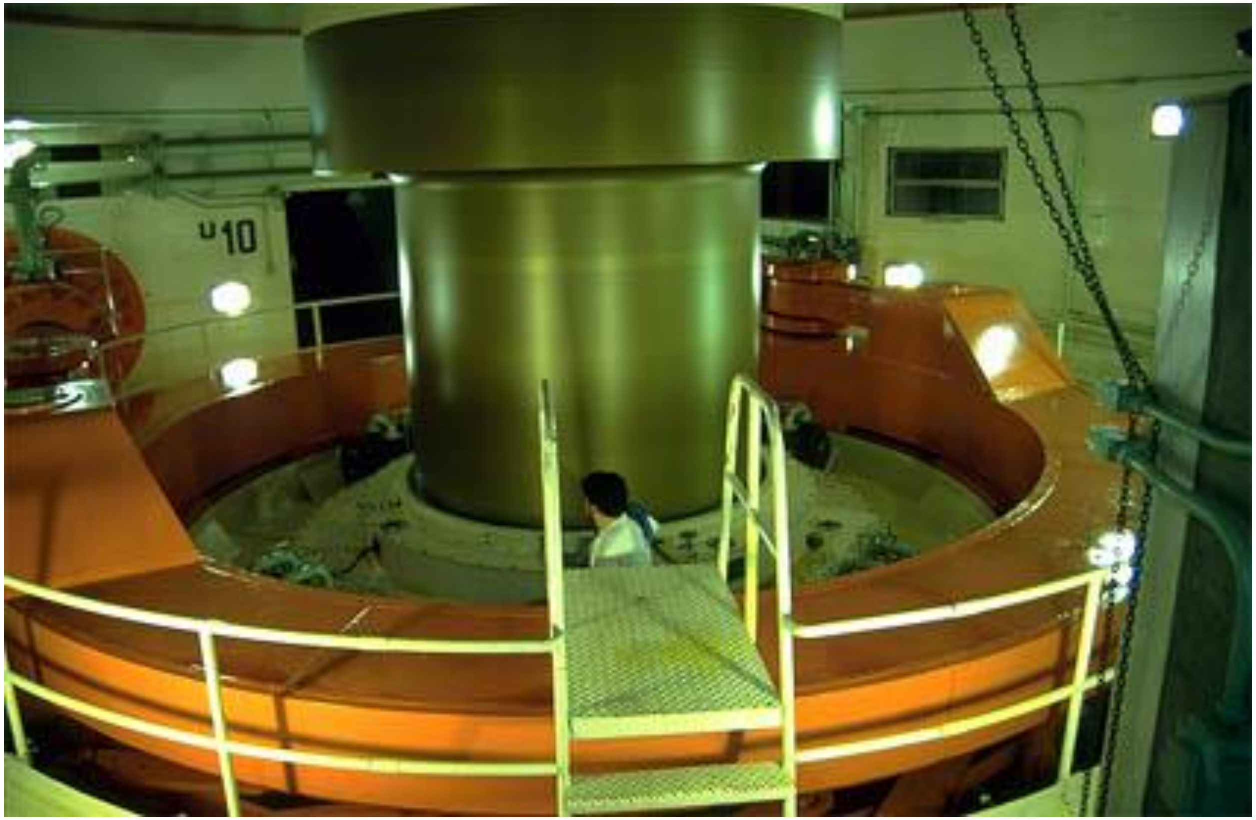
Hydroelectric power plant



715 MW generator

Diameter of rotor: 16 meters

Rotating mass: 2650 ton



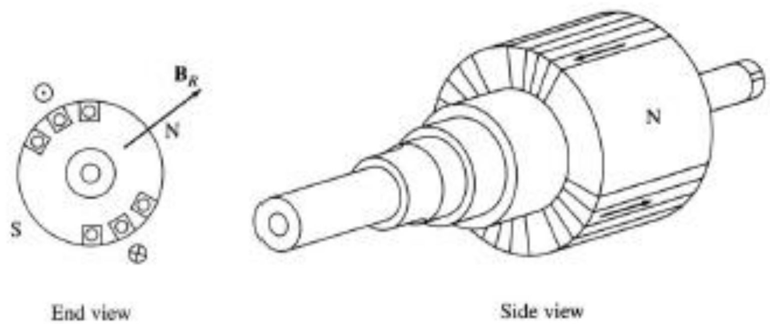
CHAPTER THREE

Synchronous machines

Construction of synchronous machines

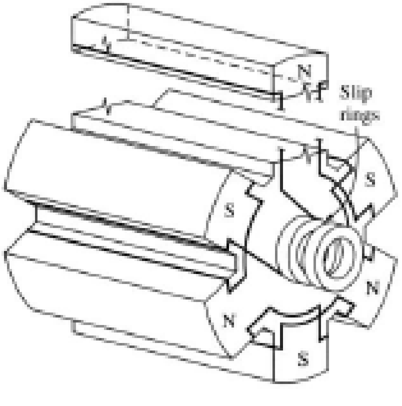
The rotor

The rotor of a synchronous machine is a large electromagnet. The magnetic poles can be either salient (sticking out of rotor surface) or non-salient construction



Non-salient-pole rotor: usually two- and four-pole rotors

Bobines à pôles lisses



Salient-pole rotor: four and more poles

Bobines à pôles saillants

A rotating magnetic field

$$N_{syn} = \frac{60 \times f_{syn}}{p} = \frac{60 \times 50}{p} = \frac{3000}{p}$$

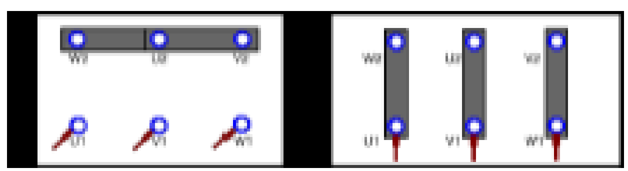
<u>Slip rings</u> **(2 Bagues)**

In a synchronous generator, a DC current is applied to the rotor winding producing a rotor magnetic field. The rotor is then turned by external means producing a rotating magnetic field, which induces a 3-phase voltage within the stator winding.

The stator

- Consisting of a steel frame that supports a hollow, cylindrical core
- Core, constructed from stacked laminations (why?), having a number of evenly spaced slots, providing the space for the stator winding

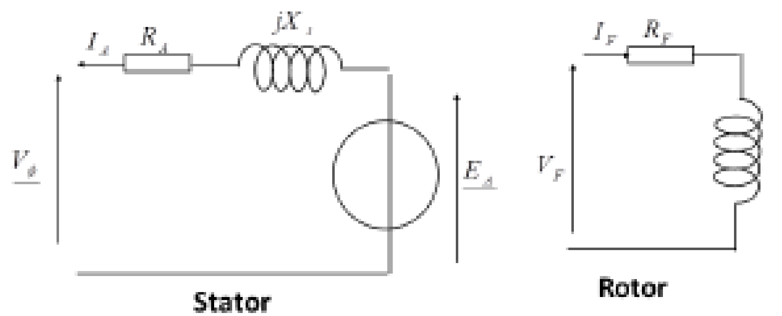
A synchronous machine can be Y- or Δ-connected:



In a synchronous motor, a 3-phase set of stator currents produces a rotating magnetic field causing the rotor magnetic field to align with it. The rotor magnetic field is produced by a DC current applied to the rotor winding.

Field windings are the windings producing the main magnetic field (rotor windings for synchronous machines); armature windings are the windings where the main voltage is induced (stator windings for synchronous machines).

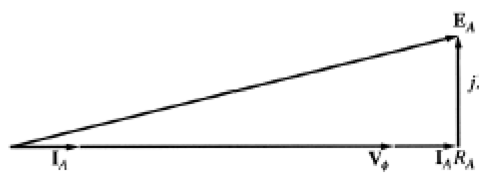
Equivalent circuit of a synchronous generator



The phase voltage is: $V_\phi = E_A - (R + jX_s)I_A$ $\qquad$ $E_A = V_\phi + (R + jX_s)I_A$

Phasor diagram of a synchronous generator

a) A phasor diagram of a synchronous generator with a unity power factor (resistive load)

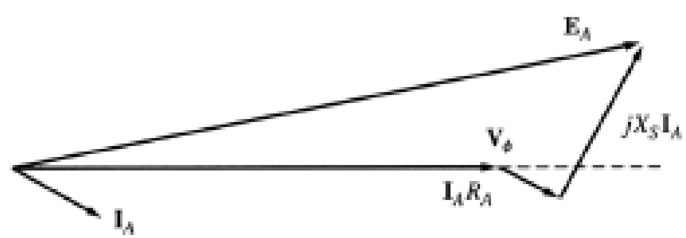


b) Lagging power factor (inductive load): a larger than for leading PF internal generated voltage E_A is needed to form the same phase voltage

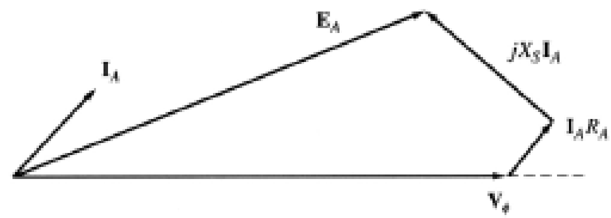
$$E_X = V_T + R_A I_A \cos\varphi + X_s I_A \sin\varphi$$

$$E_y = X_s I_A \cos\varphi - R_A I_A \sin\varphi$$

$$E_A = \sqrt{E_x^2 + E_y^2}$$



c) Leading power factor (capacitive load).

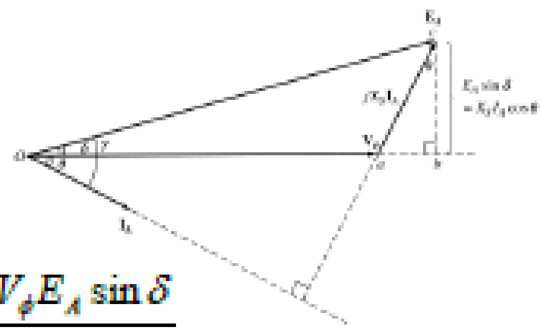


Power and torque in synchronous generators

$$P_{in} = T_{app} \times \Omega_m$$

$$P_{out} = \sqrt{3} \times V_T \times I_L \times \cos\varphi$$

$$Q_{out} = \sqrt{3} \times V_T \times I_L \times \sin\varphi$$



$$I_A \cos\varphi = \frac{E_A \sin\delta}{X_s}$$

$$T_{ind} = \frac{3V_\phi E_A \sin\delta}{\Omega_m X_s}$$

$$P_{out} \cong \frac{3V_\phi E_A \sin\delta}{X_s}$$

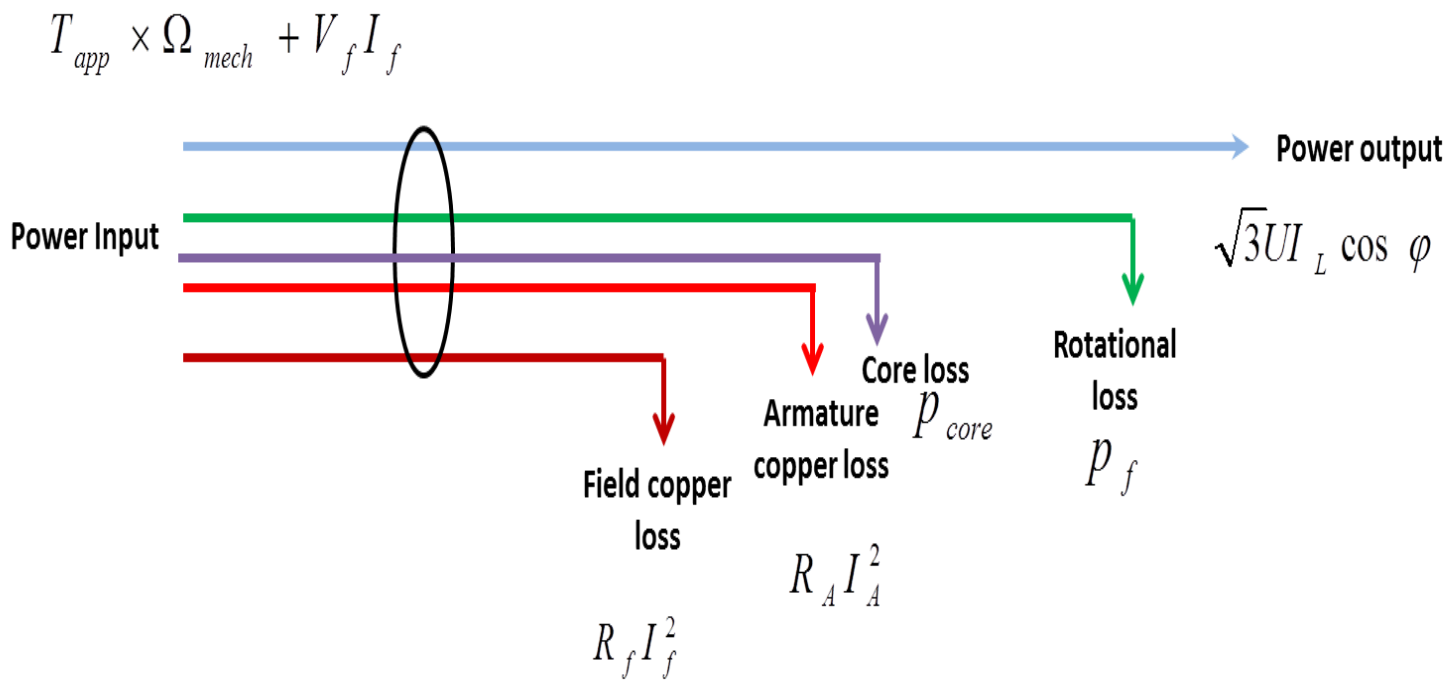
$$P_{max} = \frac{3V_\phi E_A}{X_s}$$

The power flow and losses in synchronous machines

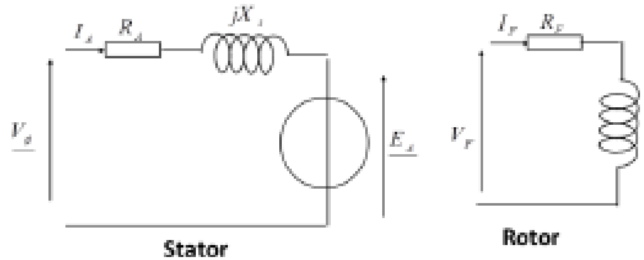
$$P_{out} = P_{in} - \sum losses$$

$\sum losses =$ Copper losses (armature and field) + Core losses (both core) + Mechanical losses

The power-flow diagram of a synchronous generator



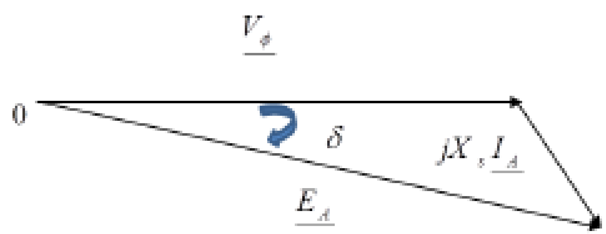
Equivalent circuit of a synchronous motor



The phase voltage is:

$$\underline{V_\phi} = \underline{E_A} + (R + jX_s)I_A$$

Phasor diagram of a synchronous motor



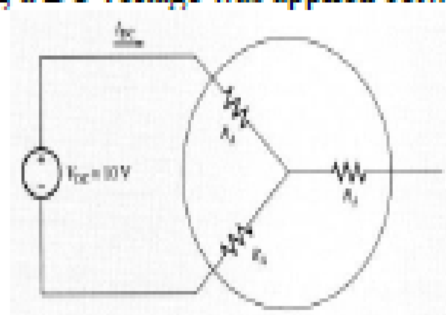
Exercise1: A 200 kVA, 480 V, 50 Hz, Y-connected synchronous generator with a rated field current of 5 A was tested and the following data were obtained:

1. $V_{T,OC}$ = 540 V at the rated I_F.
2. $I_{L,SC}$ = 300 A at the rated I_F.
3. When a DC voltage of 10 V was applied to two of the terminals, a current of 25 A was measured.

Find the generator's model at the rated conditions (i.e., the armature resistance and the approximate synchronous reactance).

Answer:

Since the generator is Y-connected, a DC voltage was applied between its *two* phases. Therefore



Answer:

Since the generator is Y-connected, a DC voltage was applied between its *two* phases. Therefore

$$2R_A = \frac{V_{DC}}{I_{DC}} \rightarrow R_A = \frac{V_{DC}}{2I_{DC}} = \frac{10}{2 \times 25} = 0,2\Omega$$

The internal generated voltage at the rated field current is:

$$E_A = V_{\phi oc} = \frac{V_T}{\sqrt{3}} = \frac{540}{\sqrt{3}} = 311{,}8V$$

The synchronous reactance at the rated field current is precisely:

$$X_s = \sqrt{Z_s^2 - R_A^2} = \sqrt{\frac{E_A^2}{I_{Asc}^2} - R_A^2} = \sqrt{\frac{(311{,}8)^2}{300^2} - 0{,}2^2} = 1{,}02\Omega$$

Exercise2: A 600 kW, 3300V, 50 Hz, Y-connected synchronous generator was tested and were obtained $E_A = 5500V; X_s = 18{,}5\Omega$. Calculate:

1. The torque angle of the machine δ
2. The Lagging power factor $\cos\varphi_{lag}$
3. The armature current I_A

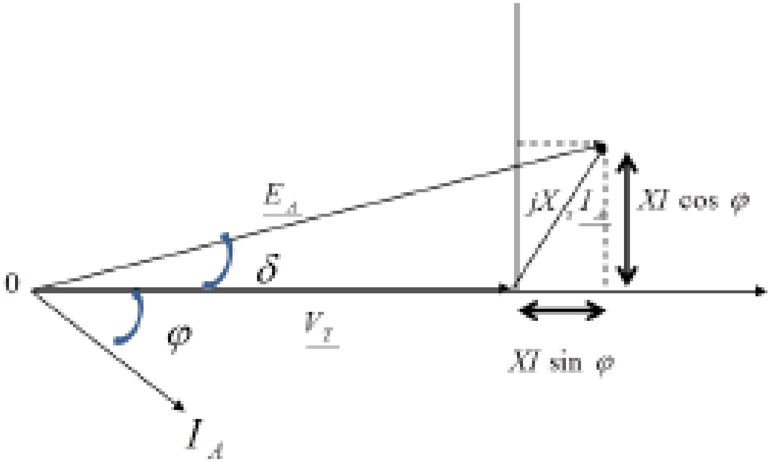
Answer

1. The torque angle of the machine δ

$$E_A \cos\delta = V_T + X_s I_A \sin\varphi \rightarrow (1)$$

$$E_A \sin\delta = X_s I_A \cos\varphi \rightarrow (2)$$

$$P_\phi = V_T I_A \cos\varphi \rightarrow I_A \cos\varphi = \frac{P_\phi}{V_T} \rightarrow (3)$$



(1) & (3):

$$E_{A\phi}\sin\delta = X_s \times \frac{P_\phi}{V_{T\phi}} \rightarrow \sin\delta = X_s \times \frac{P_\phi}{V_{T\phi}E_{A\phi}} = 18,5 \times \frac{200000}{1905 \times 3175,42} = 0,61 \qquad \cos\delta = 0,79 \qquad \delta = 37,8^{\circ}$$

$$V_{T\phi} = \frac{V_T}{\sqrt{3}} = \frac{3300}{\sqrt{3}} = 1905V \qquad E_{A\phi} = \frac{E_{A\phi}}{\sqrt{3}} = \frac{5500}{\sqrt{3}} = 3175,42V \qquad P_\phi = \frac{P_{3\phi}}{3} = \frac{600000}{3} = 200000W$$

2. The Lagging power factor $\cos\varphi_{lag}$

$$I_A \sin\varphi = \frac{E_A \cos\delta - V_{T\phi}}{X_s} = 32,62A$$

$$I_A \cos\varphi = \frac{E_{A\phi}\sin\delta}{X_s} = 104,7A$$

$$\tan\varphi = \frac{I_A \sin\varphi}{I_A \cos\varphi} = 0,31$$

$$\cos\varphi_{lag} = 0,955$$

3. The armature current I_A

$$I_A \cos\varphi_{lag} = 104,7A$$

$$I_A = \frac{104,7}{0,95} = 110A$$

Review

Q1. Magnetic induction occurs when there is relative motion between what two elements?

R1. A conductor and a magnetic field.

Q2. What is the part of an alternator in which the output voltage is generated?

R2. Armature

Q3. What are the two basic types of alternators?

R3. Rotating armature and rotating field

Q4. What is the main advantage of the rotating field alternator?

R4. Output voltage is taken directly from the armature (not through brushes or slip rings).

Q5. Most large alternators have a small dc generator built into them. What is its purpose?

R5. To provide dc current for the rotating field

Q6. How alternators are usually rated?

R6. Kilovolt-amperes (volt amperes).

Q7. What type of prime mover requires a specially designed high-speed alternator?

R7. Steam turbine

Q8. Salient-pole rotors may be used in alternators driven by what types of prime movers?

R8. Internal combustion engines, water force and electric motors

Q9. What does the term single phase indicate?

R9. One voltage (one output).

Q10. In single-phase alternators, in order for the voltages induced in all the armature windings to add together for a single output, how must the windings be connected?

R10. In series


The End