EEE363

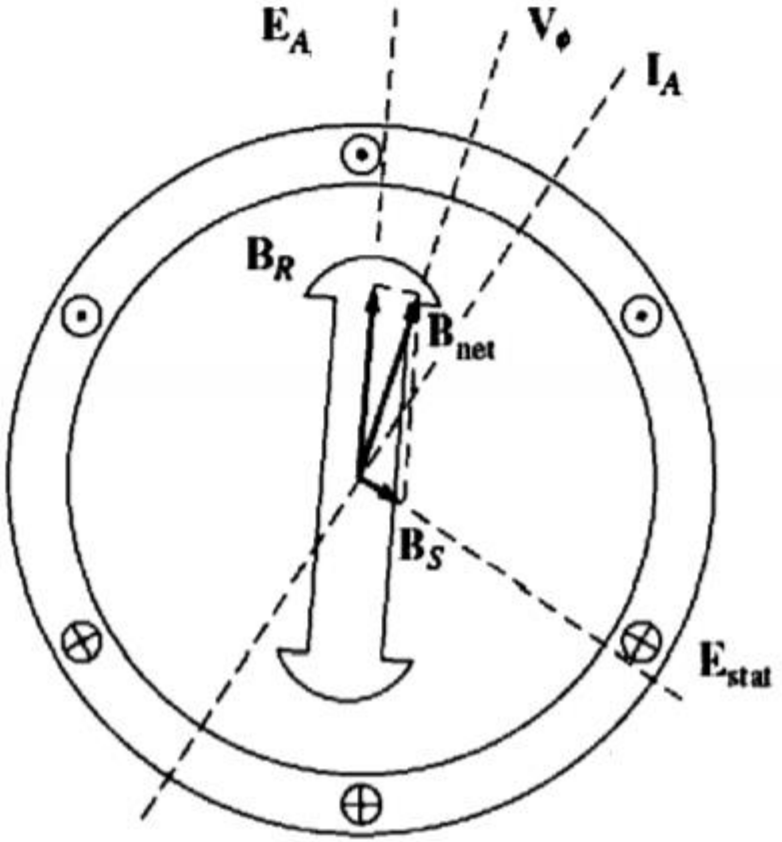
Electrical Machines

Lecture # 16

Dr Atiqur Rahman

Armature Reaction

- Rotor magnetic field B_R produces an internal generated voltage E_A.
- A current I_A flows in the stator due to a load connected to it.
- This stator current I_A produces its own magnetic field B_S.
- B_S produces its own voltage E_{stat} in the stator.



$$\boxed{\boldsymbol{V_\varphi = E_A + E_{stat}}}$$

$$\boxed{\boldsymbol{B_{net} = B_R + B_S}}$$

E_{stat} → Armature reaction voltage

Equivalent circuit formulation

$$V_\varphi = E_A - j\,XI_A$$

In addition to the effects of armature reaction, the stator coils have a self inductance and a resistance.

If the stator self-inductance is called L_A (and its corresponding reactance is called X_A) while the stator resistance is called R_A , then the total difference between E_A and V_φ is given by

$$V_\varphi = E_A - j\,XI_A - jX_AI_A - R_AI_A$$

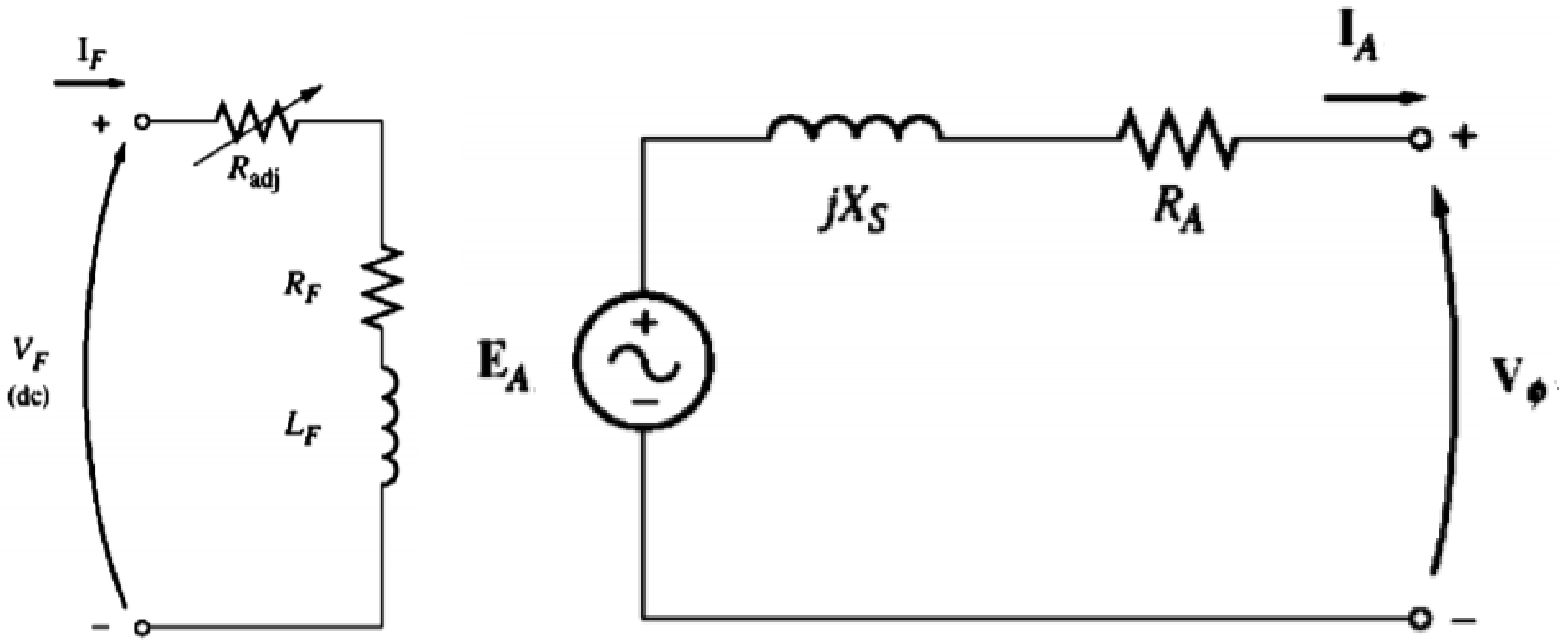
$$= \; E_A - j\,X_SI_A - R_AI_A$$

where $X_S = X + X_A$

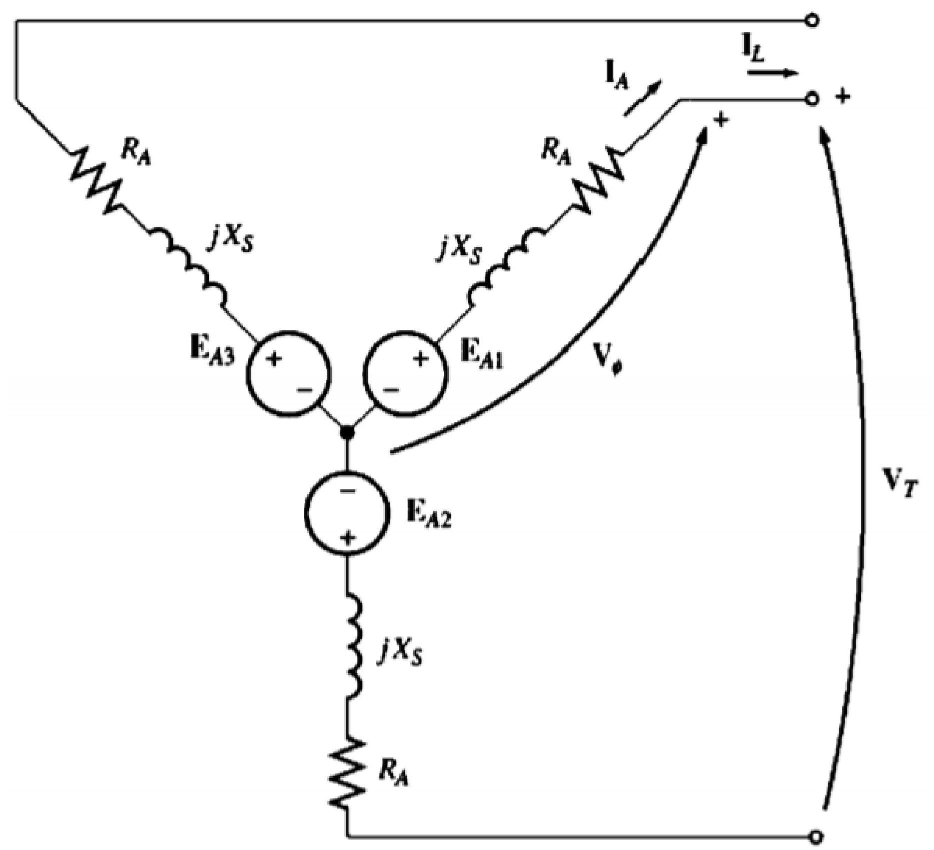
$X_S \longrightarrow$ Synchronous reactance

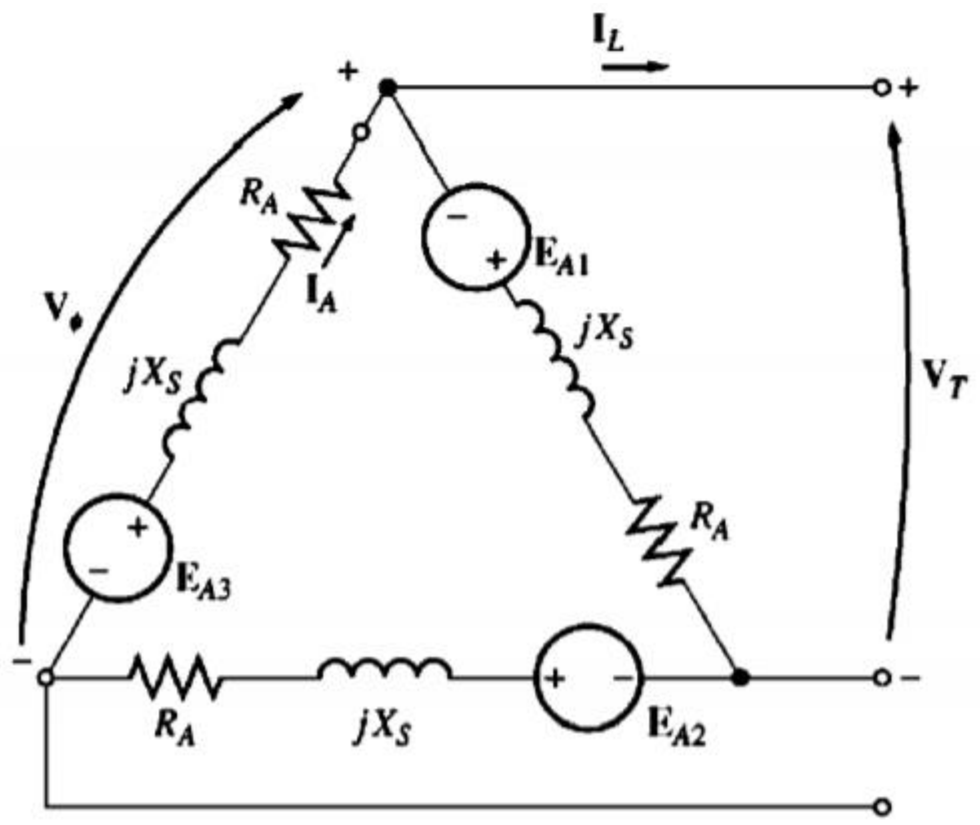
Alternator equivalent circuit

$$V_\varphi = E_A - j\,X_S I_A - R_A I_A$$



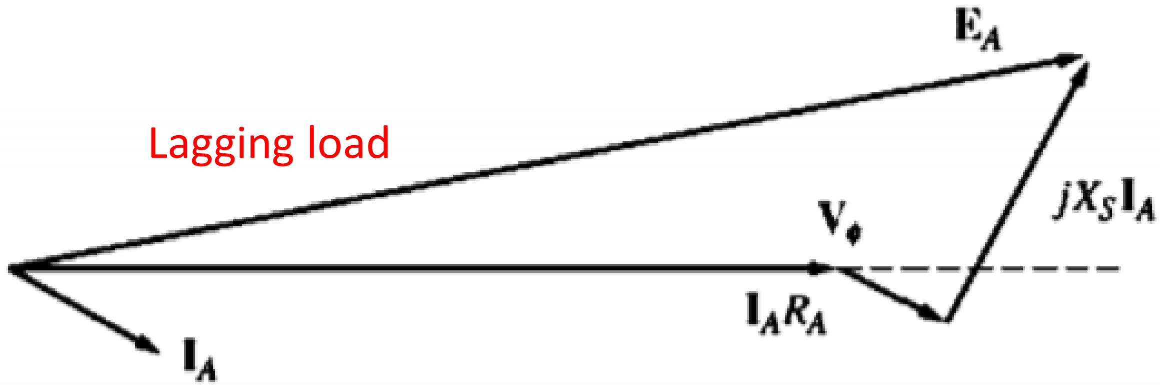
3-ϕ Alternator

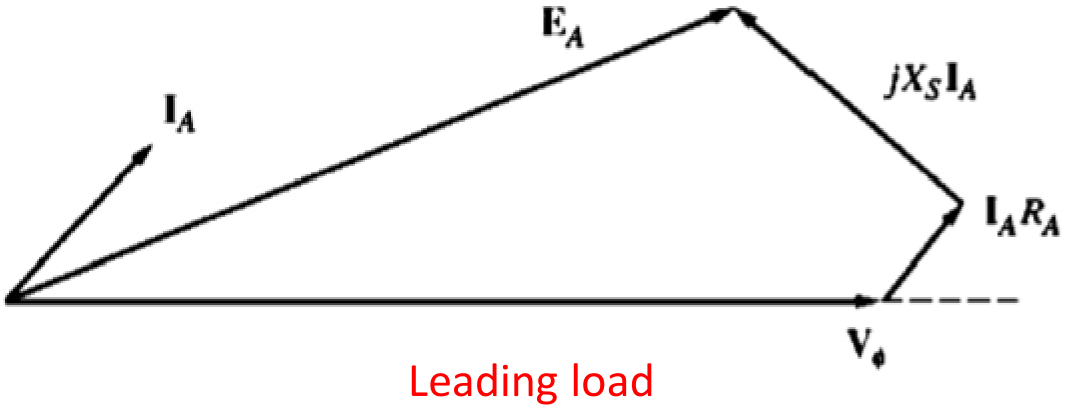


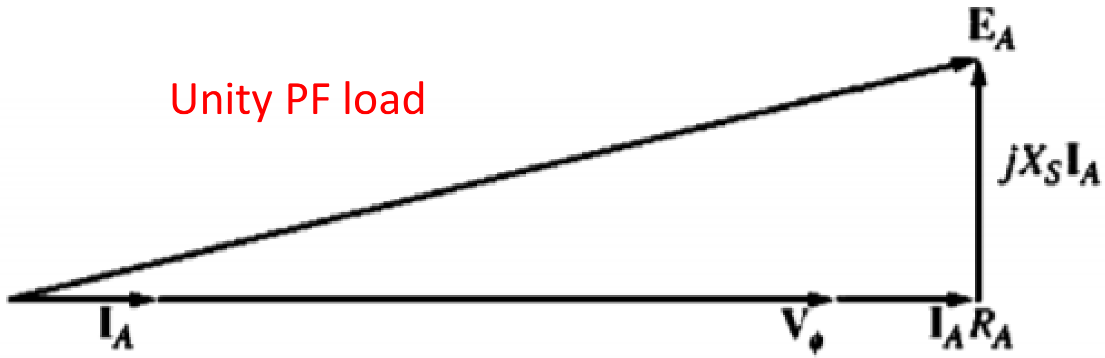


Phasor diagram of alternator

$$V_\varphi = E_A - j\,X_S I_A - R_A I_A$$

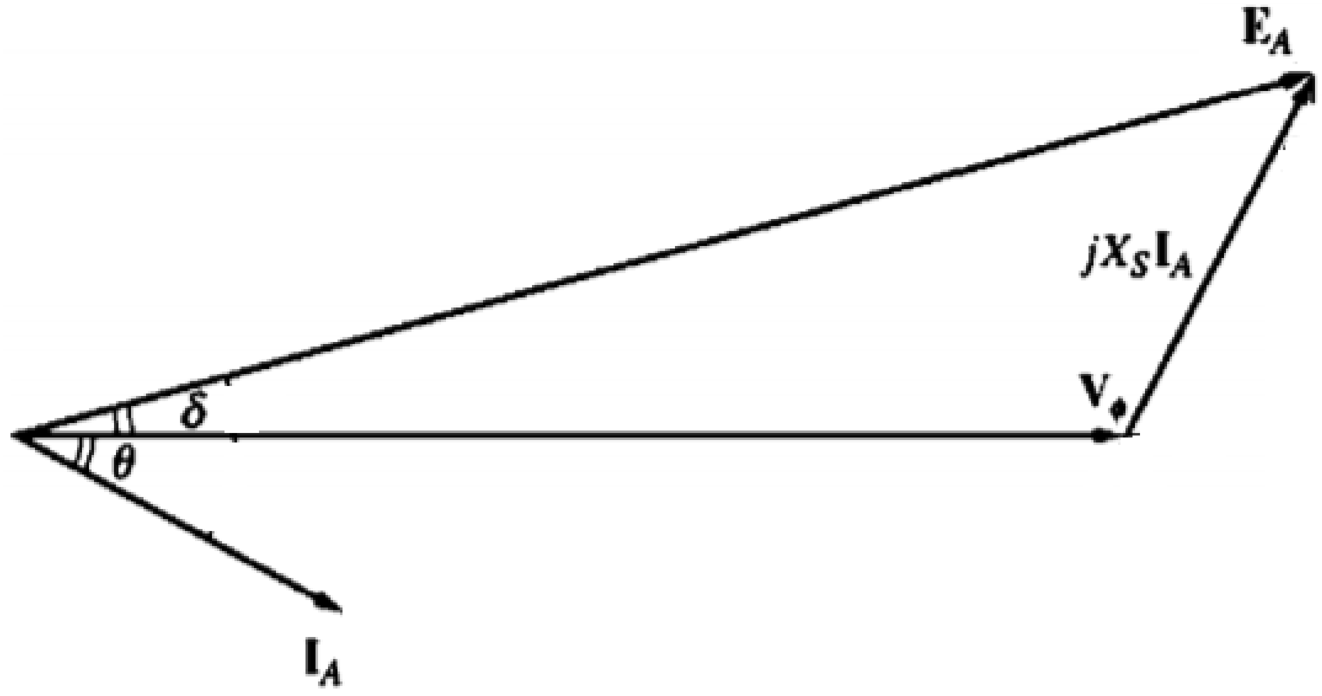




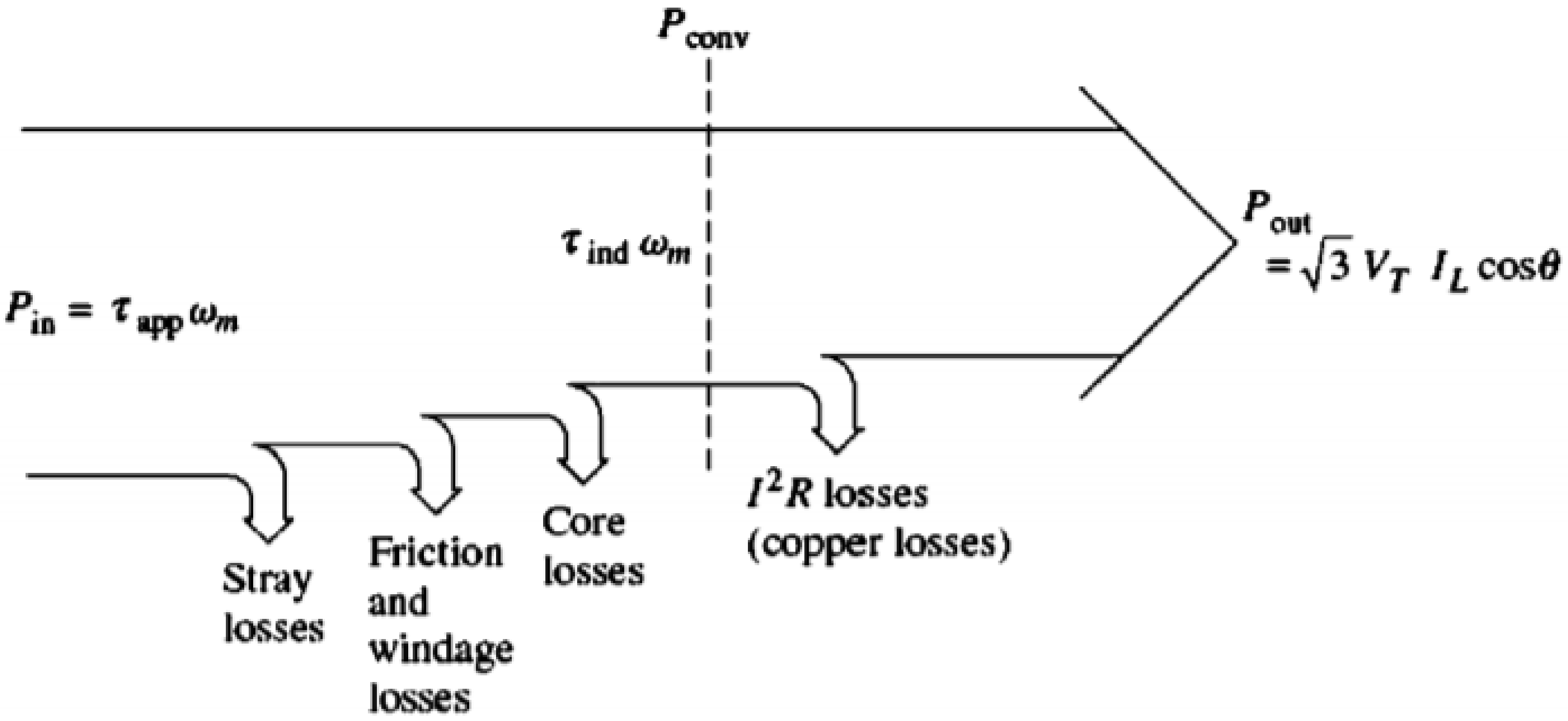


Simplified Phasor diagram

✓ Since $R_A \ll X_S$ for a practical alternator, $R_A I_A$ is ignored in the simplified Phasor diagram.



Power flow diagram



Power and Torque of alternator

$$P_{out} = 3V_\varphi I_A \cos\theta$$

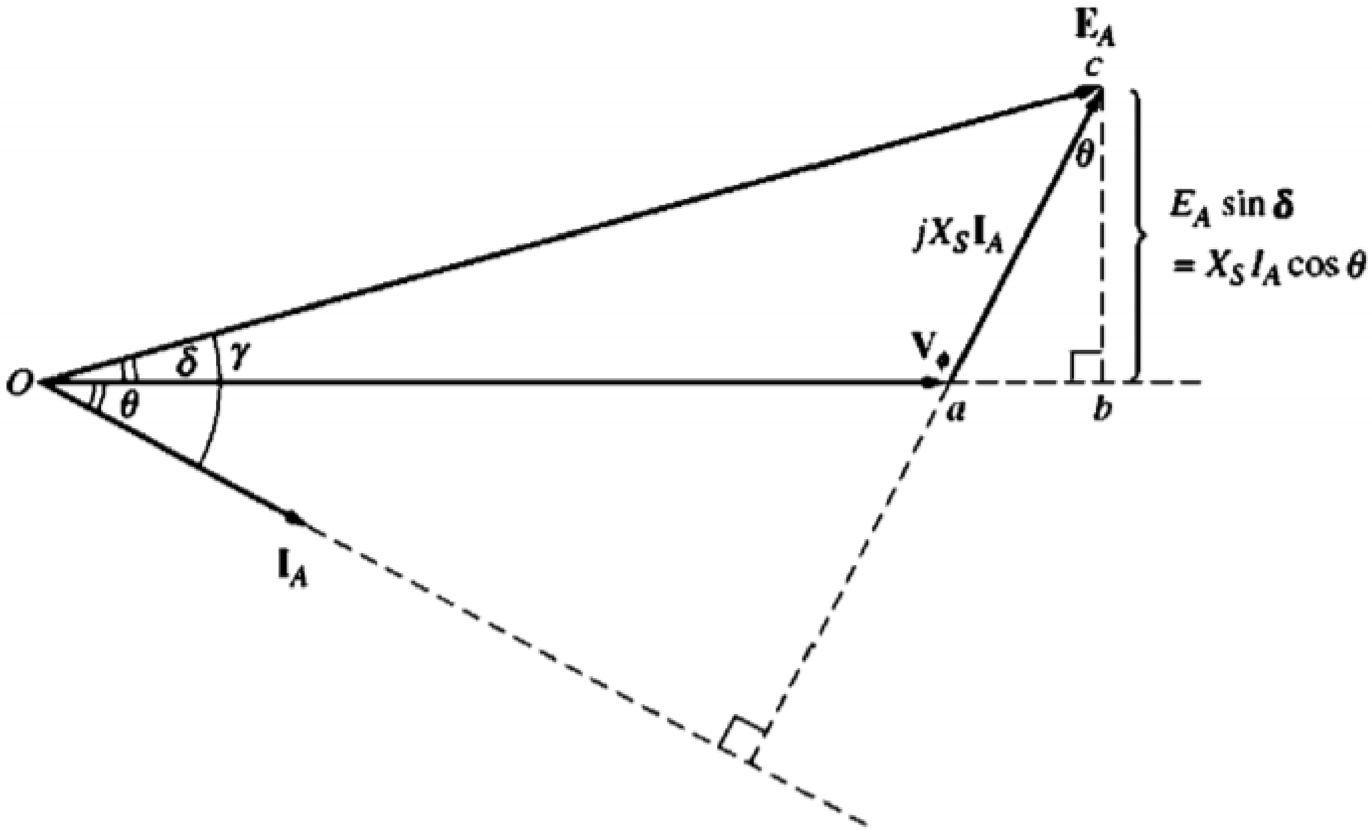
From the diagram

$$E_A \sin\delta = X_S I_A \cos\theta$$

$$I_A \cos\theta = \frac{E_A \sin\delta}{X_S}$$

Thus $$P_{out} = \frac{3V_\varphi E_A \sin\delta}{X_S}$$

$$P_{max} = \frac{3V_\varphi E_A}{X_S} \longrightarrow \textit{Static stability limit}$$



$$P_{conv} = \tau_{ind}\, \omega_m = 3E_A I_A \cos\gamma$$

Induced torque

General formula for induced torque $\boldsymbol{\tau_{ind}} = k\ \mathbf{B_{loop}} \text{ x } \mathbf{B_s}$

$\boldsymbol{\tau_{ind}} = k\ \mathbf{B}_{\boldsymbol{R}} \text{ x } \mathbf{B_s}$ → *Customised for alternator*

$$\boldsymbol{\tau_{ind}} = k\ \mathbf{B}_{\boldsymbol{R}} \text{ x } (\mathbf{B}_{\boldsymbol{net}} - \boldsymbol{B_R})$$

$$= k\ \mathbf{B}_{\boldsymbol{R}} \text{ x } \mathbf{B}_{\boldsymbol{net}}$$

Induced torque in a generator is a counter torque opposing the rotation caused by the external applied torque

Thus the magnitude of the induced torque can be written as

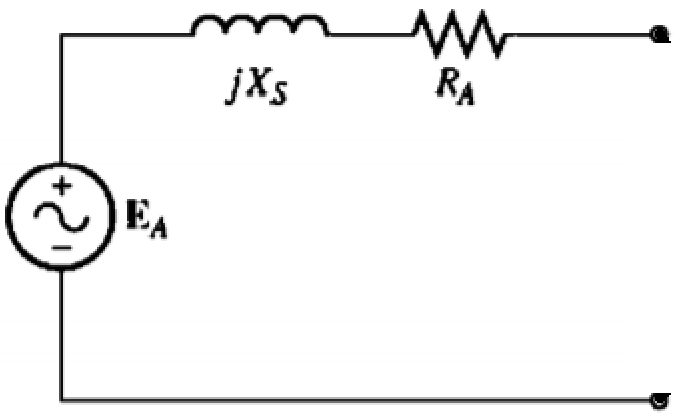
$$\tau_{ind} = kB_R B_{net} \sin\delta$$

$$\tau_{ind} = \frac{3V_\varphi E_A \sin\delta}{\omega_m X_S}$$

← *Another useful equation for torque*

Equivalent circuit parameters

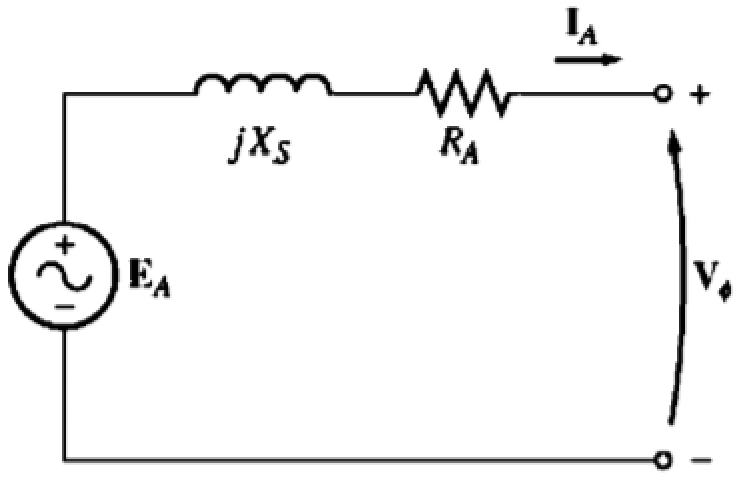
1. Open circuit test
2. Short circuit test
3. DC test

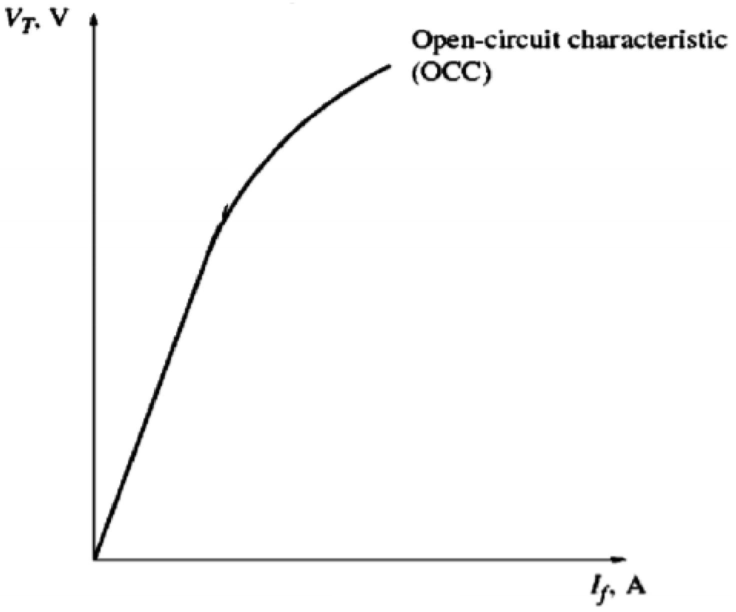


Open circuit test

Just need to record open circuit terminal voltage for different values of field current.

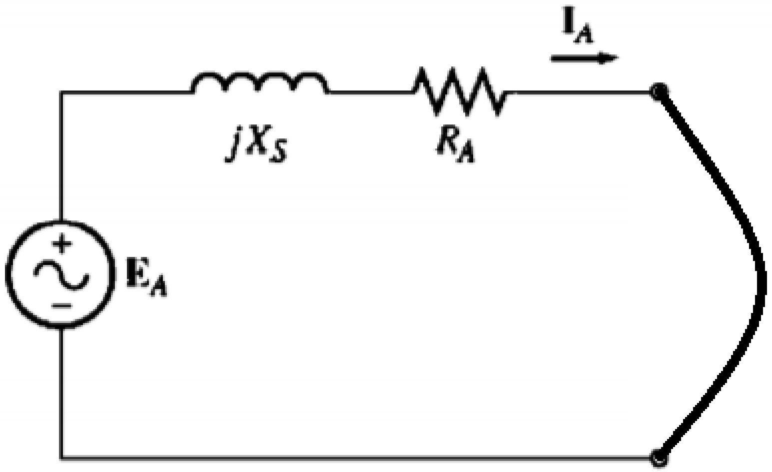
V_T							
I_f							





Short circuit test

- ✓ Initially field current is set to zero.
- ✓ Then the armature current I_A or the line current I_L is measured as the field current is increased.

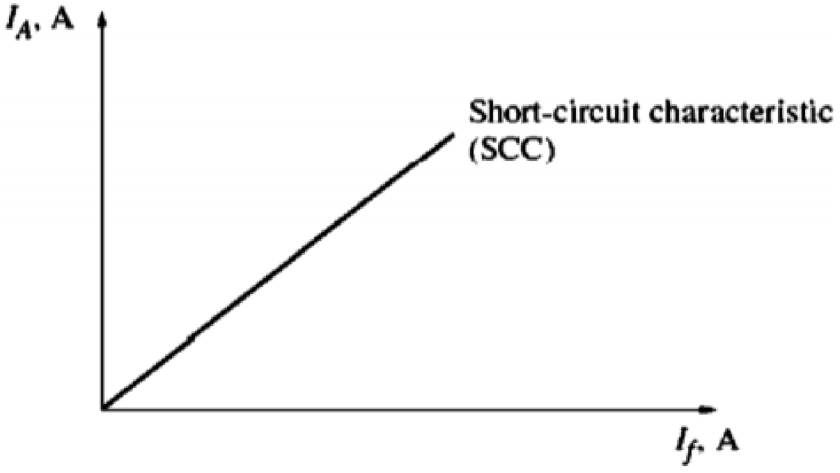


- When the terminals are short-circuited, the armature current I_A is given by

$$\mathbf{I_A} = \frac{\mathbf{E_A}}{\mathbf{R_A} + \mathbf{jX_S}}$$

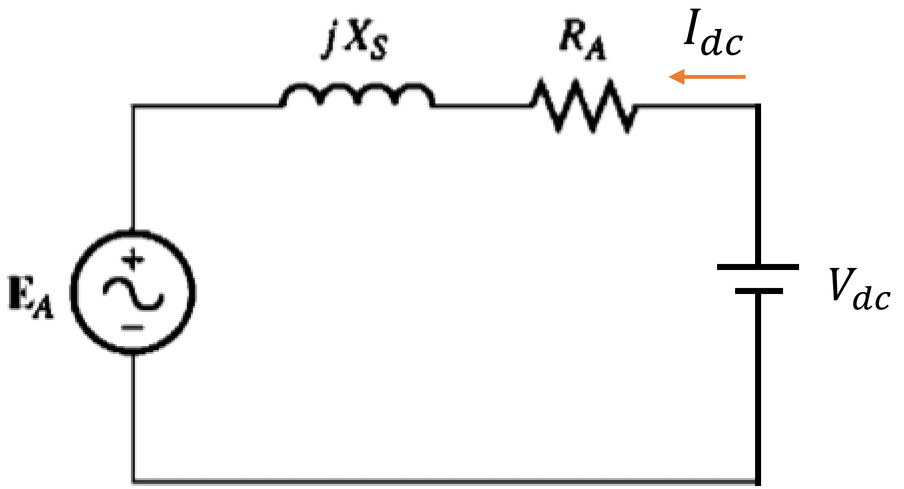
Magnitude of $\mathbf{I_A}$ ⟶ $$|I_A| = \frac{E_A}{\sqrt{(R_A^2 + X_S^2)}}$$

$$X_S = \frac{E_A}{|I_A|}$$ [Assuming $R_A \ll X_S$]



DC test

- ✓ This test is done when the generator is in off mode.
- ✓ A DC voltage is then applied at the generator terminal and the current I_{dc} is measured.
- ✓ Note that under this condition $E_A = 0$



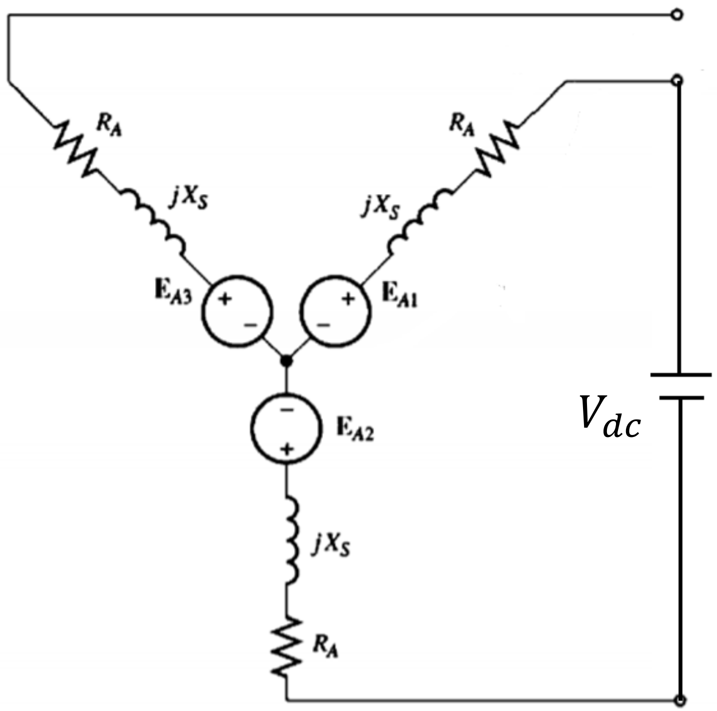
Thus $$R_A = \frac{V_{dc}}{I_{dc}}$$

Problem # 1

Example 5–1. 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 taken:

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

$$2R_A = \frac{V_{DC}}{I_{DC}} \quad \Rightarrow \quad R_A = \frac{V_{DC}}{2I_{DC}} = \frac{10\text{ V}}{(2)(25\text{ A})} = 0.2\ \Omega$$



Internal generated voltage at rated field current is

$$E_A = V_{\phi,OC} = \frac{V_T}{\sqrt{3}} = \frac{540\text{ V}}{\sqrt{3}} = 311.8\text{ V}$$

Generator is Y – connected, thus $I_{L.SC} = I_{A.SC} = 300\text{ A}$

Problem # 1 contd...

$$\sqrt{R_A^2 + X_S^2} = \frac{E_A}{I_A}$$

$$\sqrt{(0.2\ \Omega)^2 + X_S^2} = \frac{311.8\ \text{V}}{300\ \text{A}}$$

$$\sqrt{(0.2\ \Omega)^2 + X_S^2} = 1.039\ \Omega$$

$$0.04 + X_S^2 = 1.08$$

$$X_S = 1.02\ \Omega$$