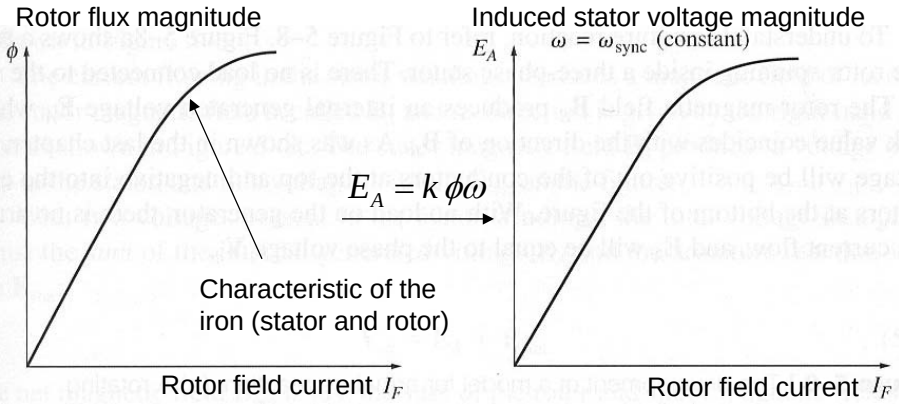
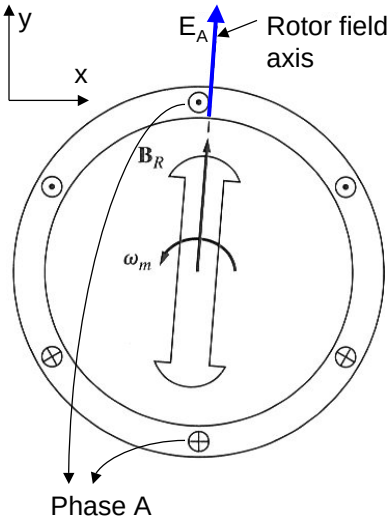
SM No-Load Characteristic



Effect of saturation: for large field currents the no-load armature voltage magnitude scales sub-proportionally with I_F and the voltage waveform becomes non sinusoidal (distorted).

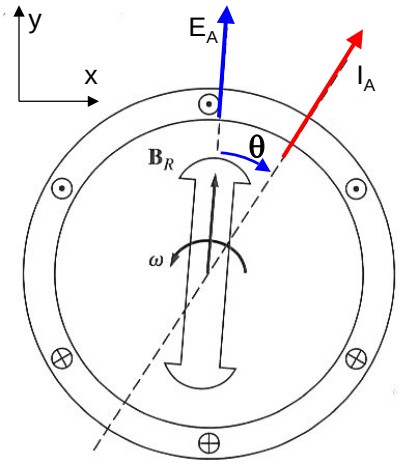
SM Armature Reaction I

- **Unloaded generator at arbitrary rotor position**
- **Phase-A induced voltage can be represented by a space vector E_A which aligns with rotor field vector B_R**
  - The time evolution of phase-A voltage and current is the projection of the respective space vector onto the y-axis



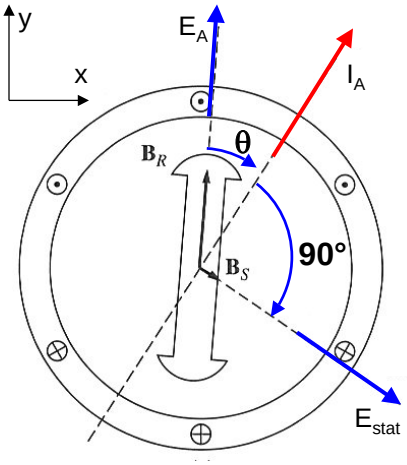
SM Armature Reaction II

- **Generator with lagging load current (balanced)**
- **Phase-A current space vector I_A is rotated (in space) out of the rotor B_R axis by the load phase angle θ**
  - It will require the time θ/ω for the I_A space vector to reach the rotor axis
  - The phase-A current produces a magnetic excitation in the x-axis only



SM Armature Reaction II

- **The balanced 3-phase stator current system generates a rotating magnetic field B_S which is another 90° "behind" the phase-A current space vector**
  - Reasoning: B_S points in x-direction when when $i_A(t)$ is at its peak, i.e. when I_A reaches the y-direction
- **B_S itself induces voltages E_{stat} in the stator**



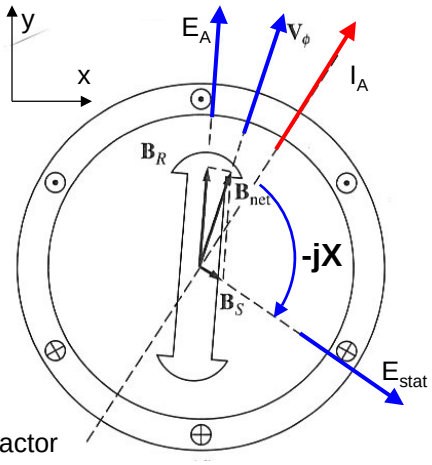
SM Armature Reaction II

- **The resulting terminal voltage of the machine is**

$$\vec{V}_\phi = \vec{E}_A + \vec{E}_{stat}$$

- **Which aligns with the resulting (net) magnetic field** $\vec{B}_{net} = \vec{B}_R + \vec{B}_S$

- **Since E_{stat} is proportional to I_A the relationship in phasor quantities becomes**



$$V_\phi = E_A - jXI_A$$

X is a factor

-j accounts for the -90° rotation

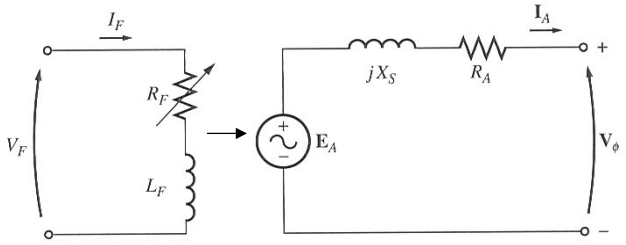
SM Single-Phase Equivalent Circuit Model

Armature reaction — Armature (self) reactance

$$V_\phi = E_A - \left(jX + jX_A + R_A \right) I_A$$

$$V_\phi = E_A - \left(jX_S + R_A \right) I_A$$

Synchronous reactance — Armature resistance

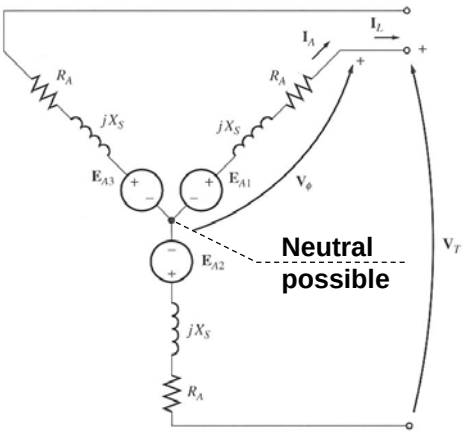


$$E_A = kI_F$$

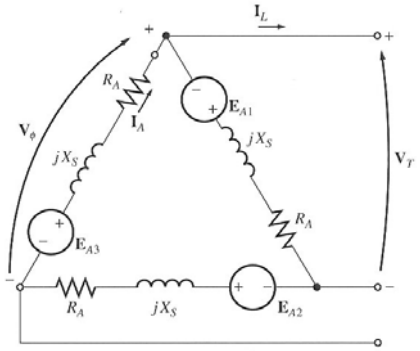
(below saturation)

SM 3-Phase Equivalent Circuit Model

Y-connection



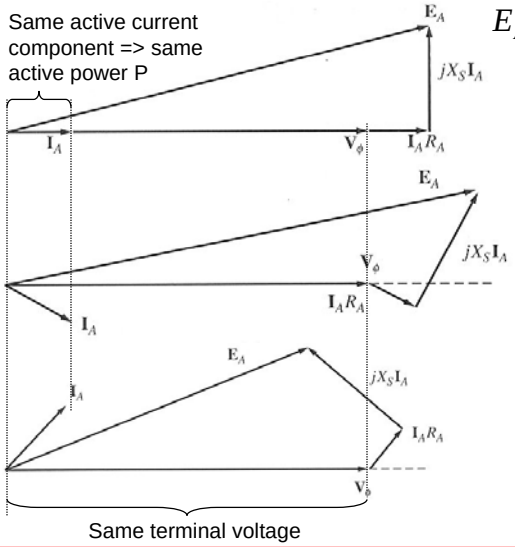
Δ-connection



V_T terminal (line-line) voltage
I_L line current

SM Phasor Diagrams (incl. R_A), Generator

Same active current component => same active power P



$$E_A = V_\phi + \left(jX_S + R_A \right) I_A$$

Unity PF

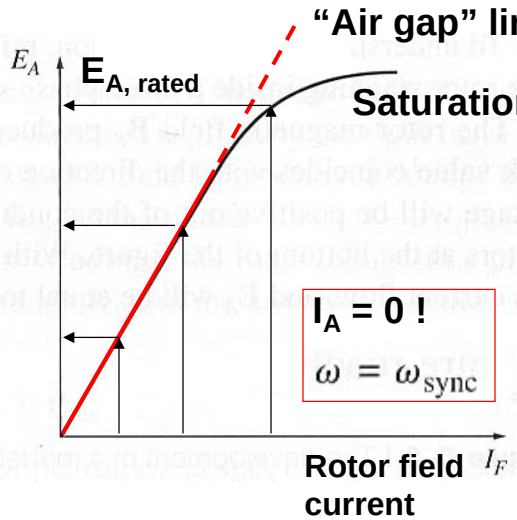
Lagging

Leading

Measuring Machine Parameters

- **Parameters required for machine model**
  - $E_A = f(I_F)$
  - X_S
  - R_A
  - Losses (other than I^2R_A)

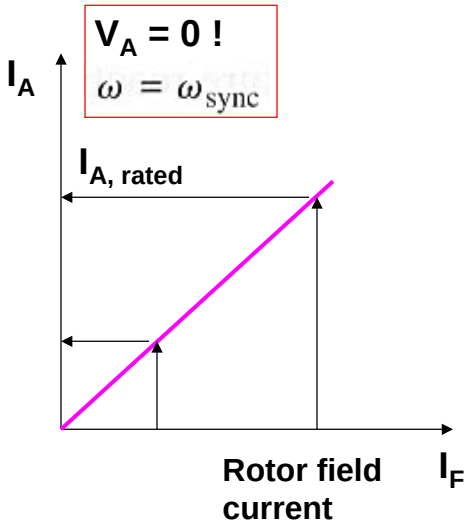
Open Circuit Test



Results:

- $E_A = k_{F,OC} I_F$ (only in linear region)
- No-load losses (windage, core & bearing)

Short Circuit Test



Results:

- $I_A = k_{F,SC} I_F$
- Load losses (windage, **copper** & bearing)

$$\frac{E_A(I_F)}{I_A(I_F)} = jX_S + R_A$$

$$X_S \gg R_A$$

$$X_S \cong \frac{E_A}{I_A}$$