Electric Machinery III

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Some slides at the end of this powerpoint were borrowed from Dr. Hani Raouf Sheybani, a lecturer at Ghochan University, and I made some changes to them. I would like to thank Dr. Raouf for his valuable contributions.

References for Electric Machinery III

Text: A. E. Fitzgerald, Charles Kingsley, Jr And Stephen D. Umans, *Electric Machinery*. Mc Graw Hill, 7th Edition

Reference 1: P.C. Sen, *Principles of Electric Machines and Power Electronics*. Wiley, 3rd Edition

Reference 2: P.S. Bimbhra, *Electrical Machinery* . Khanna Publication

Electrical Machine III Syllabus

1. Introduction

………

2. Introduction to Rotating Machines

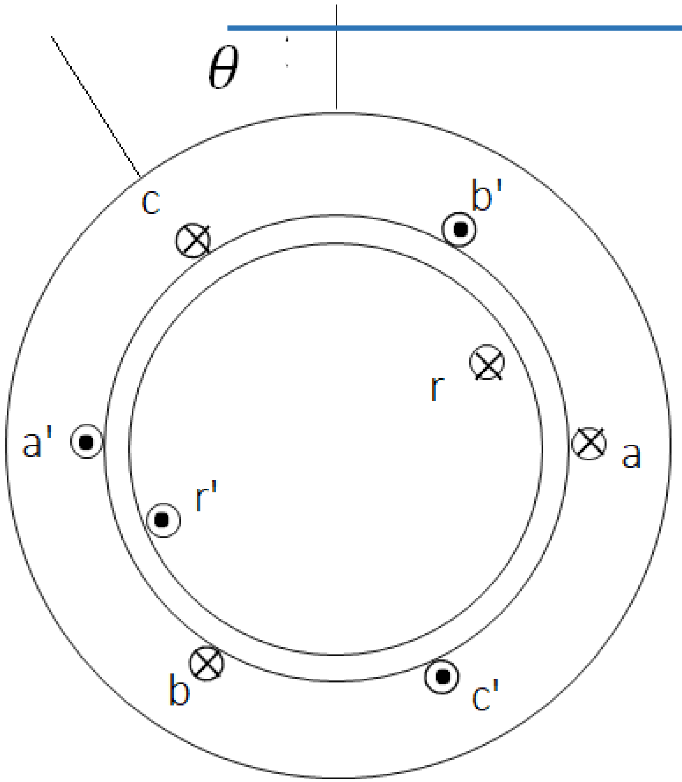
…….

3. Generation of Sinusoidal Voltage in a Synchronous Generator

……

4. Synchronous-Machine Analyses
   - Synchronous-Machine Inductances; Equivalent Circuits
   - Steady-State Power-Angle Characteristic
   - Steady-State Operating Characteristic
   - Open- and Short-Circuit Characteristics
   - Effects of Salient Poles; Introduction to Direct and Quadrature-Axis Theory
   - Steady-State Power-Angle Characteristic of Salient-Pole Machines
   - Permanent Magnet Synchronous Machine
   - Transient Behavior of Synchronous Machine.

Synchronous-Machine Inductances; Equivalent Circuits



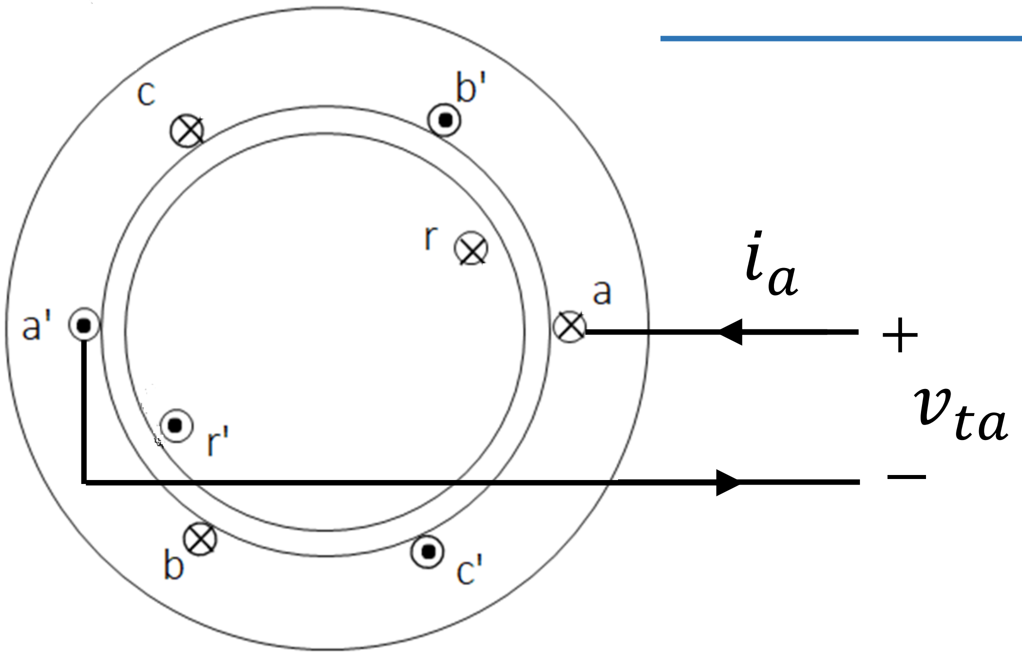
$$\begin{bmatrix}\lambda_a\\\lambda_b\\\lambda_c\\\lambda_r\end{bmatrix}=\begin{bmatrix}L_{aa} & L_{ab} & L_{ac} & L_{ar}\\L_{ba} & L_{bb} & L_{bc} & L_{br}\\L_{ca} & L_{cb} & L_{cc} & L_{cr}\\L_{ra} & L_{rb} & L_{rc} & L_{rr}\end{bmatrix}\begin{bmatrix}i_a\\i_b\\i_c\\i_r\end{bmatrix}$$

$L_{aa} = ?$ $\quad L_{aa} = L_{bb} = L_{cc} = L_{aa0} + l_{al}$ $\quad L_{rr} = L_{rr0} + l_{rl}$

$L_{ab} = ?$ $\quad L_{ab} = L_{ba} = L_{ac} = L_{ca} = L_{bc} = L_{cb} = -\frac{1}{2}L_{aa0}$

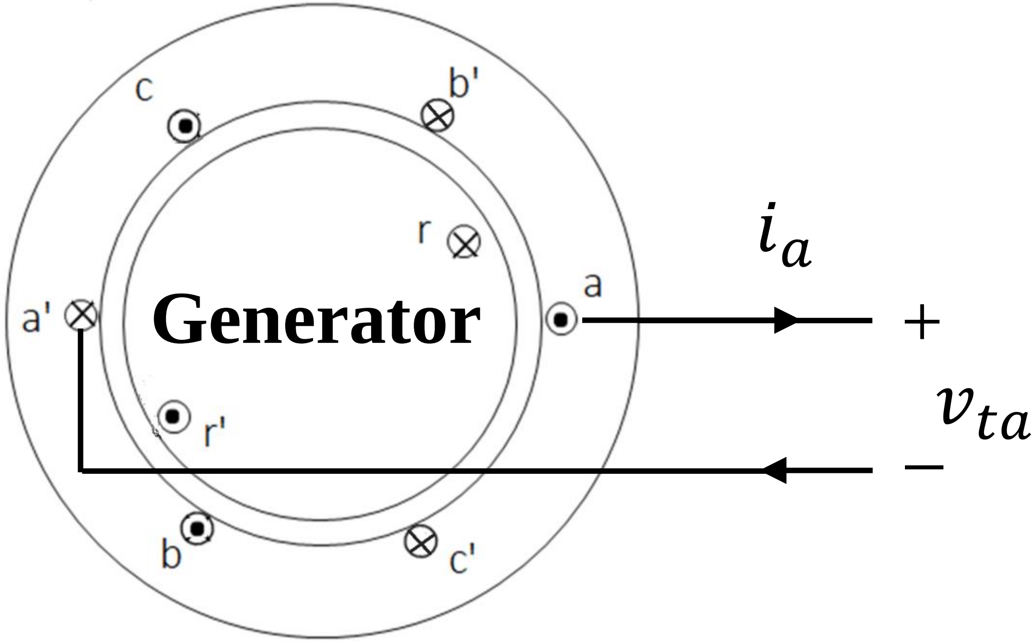
$L_{ra} = ?$ $\quad L_{ra} = L_{ar} = M\cos\theta$ $\quad L_{rb} = L_{br} = M\cos(\theta + 120)$ $\quad L_{rc} = L_{cr} = M\cos(\theta - 120)$

Synchronous-Machine Inductances; Equivalent Circuits



Motor Configuration:

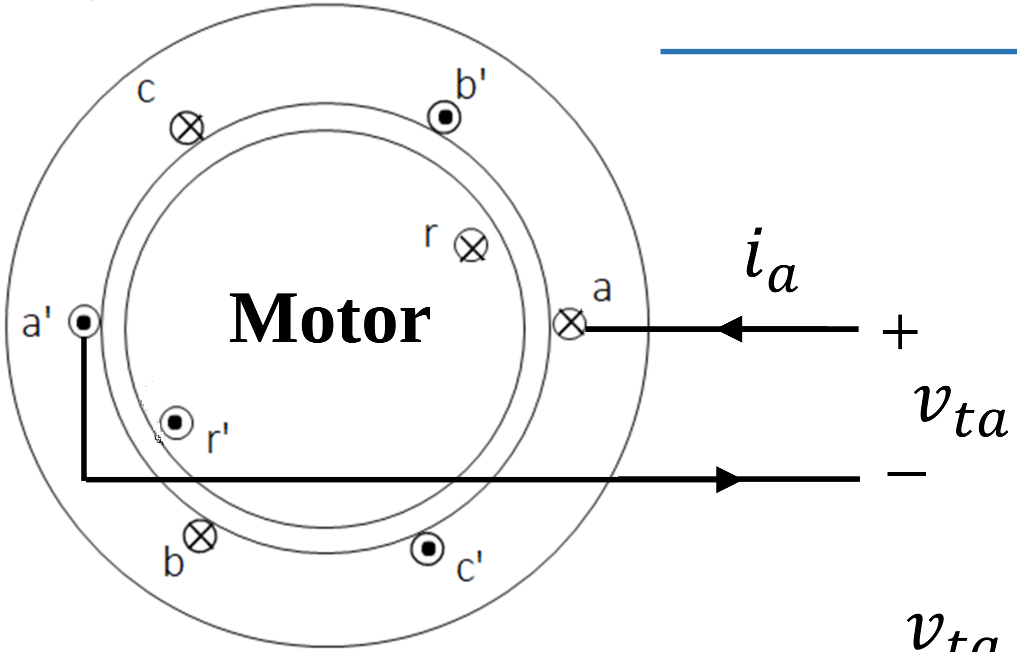
$$v_{ta} = R_a i_a + \frac{d\lambda_a}{dt}$$



Generator Configuration:

$$v_{ta} = -R_a i_a + \frac{d\lambda_a}{dt}$$

Synchronous-Machine Inductances; Equivalent Circuits



Motor Configuration:

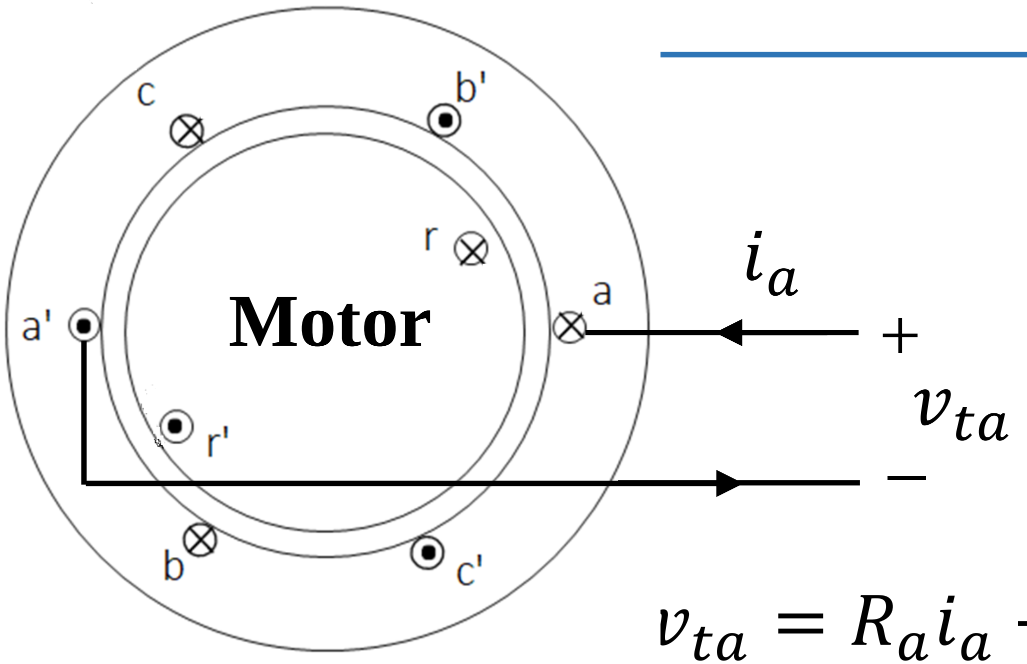
$$v_{ta} = R_a i_a + \frac{d\lambda_a}{dt}$$

$$v_{ta} = R_a i_a + \frac{d}{dt}(L_{aa} i_a + L_{ab} i_b + L_{ac} i_c + L_{ar} i_r)$$

$$v_{ta} = R_a i_a + \frac{d}{dt}\left((L_{aa0}+l_{al}) i_a - \frac{1}{2} L_{aa0} i_b - \frac{1}{2} L_{aa0} i_c + M cos\theta i_r\right)$$

$$v_{ta} = R_a i_a + (l_{al} + \frac{3}{2} L_{aa0}) \frac{di_a}{dt} + \frac{d}{dt}(M cos(\omega t + \delta) I_r\ )$$

Synchronous-Machine Inductances; Equivalent Circuits



Motor Configuration:

$$v_t = R_a i_a + \frac{d\lambda_a}{dt}$$

$$v_{ta} = R_a i_a + (l_{al} + \frac{3}{2}L_{aa0})\frac{di_a}{dt} + \frac{d}{dt}(M\cos(\omega t + \delta)I_r\ )$$

Steady state condition

(phasor notation)

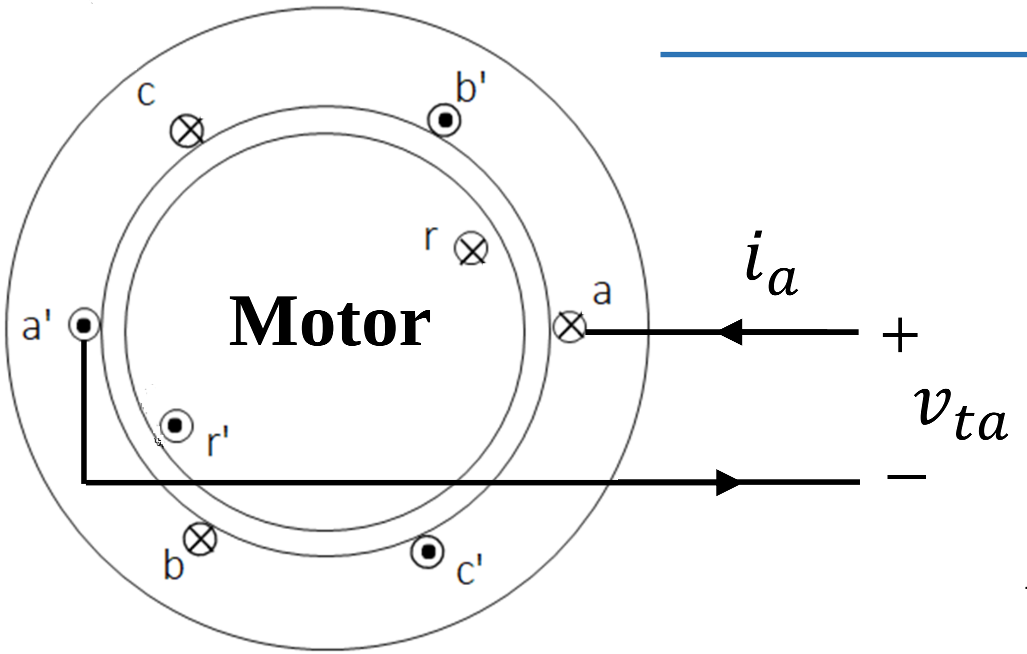
$$V_a = R_a I_a + (l_{al}\omega j + \frac{3}{2}L_{aa0}\omega j)I_a + E_{af}$$

$$V_a = R_a I_a + (jx_{al} + jx_{ar})I_a + E_{af}$$

$$V_a = R_a I_a + jx_s I_a + E_{af}$$

$$|E_{af}| = \frac{M\omega I_r}{\sqrt{2}}$$

Synchronous-Machine Inductances; Equivalent Circuits



Motor Configuration:

$$v_t = R_a i_a + \frac{d\lambda_a}{dt}$$

$$V_a = R_a I_a + (l_{al}\omega j + \frac{3}{2}L_{aa0}\omega j)I_a + E_{af}$$

$$V_a = R_a I_a + (jx_{al} + jx_{ar})I_a + E_{af}$$

$$V_a = R_a I_a + jx_s I_a + E_{af}$$

E_{af} = Generated Voltage

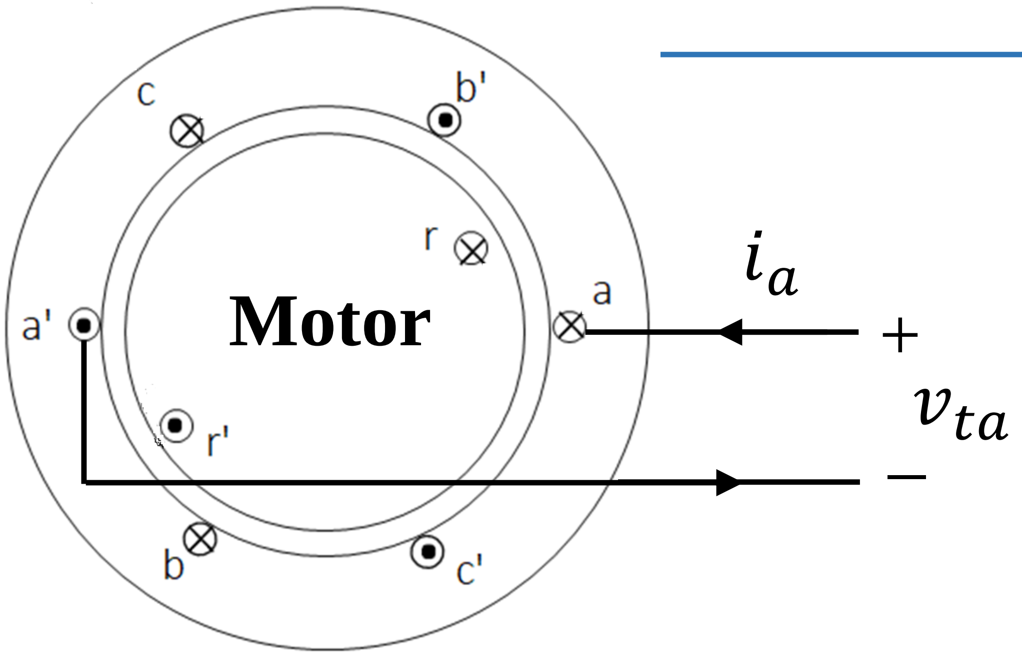
R_a = Armature Resistance

x_{al} = Armature Leakage Reactance

x_{ar} = Armature Reaction Reactance

x_s = Synchronous Reactance

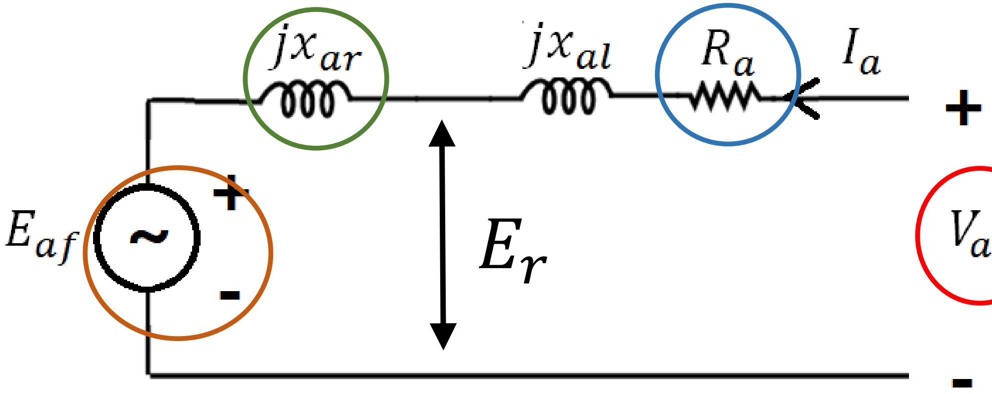
Synchronous-Machine Inductances; Equivalent Circuits

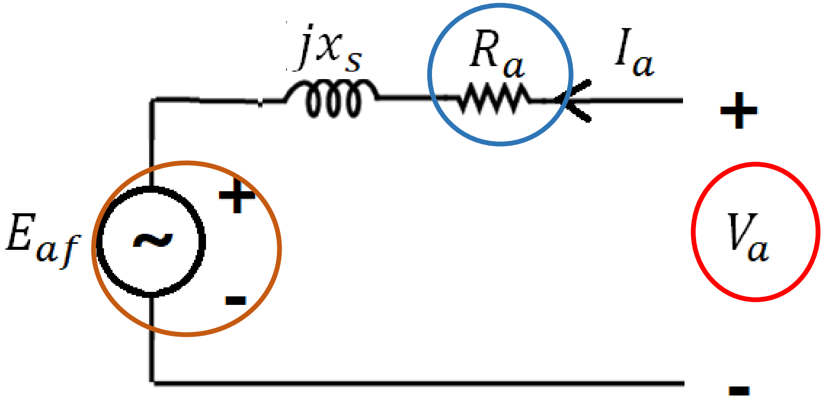


Motor Configuration:

$$V_a = R_a I_a + (jx_{al} + jx_{ar}) I_a + E_{af}$$

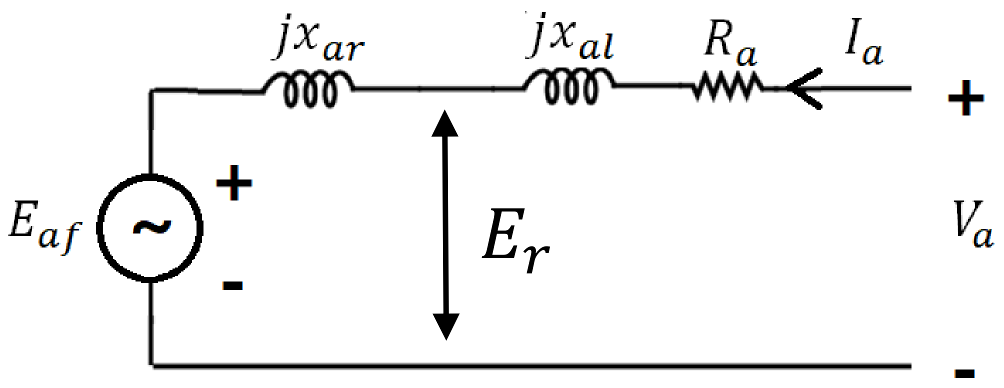
$$V_a = R_a I_a + jx_s I_a + E_{af}$$





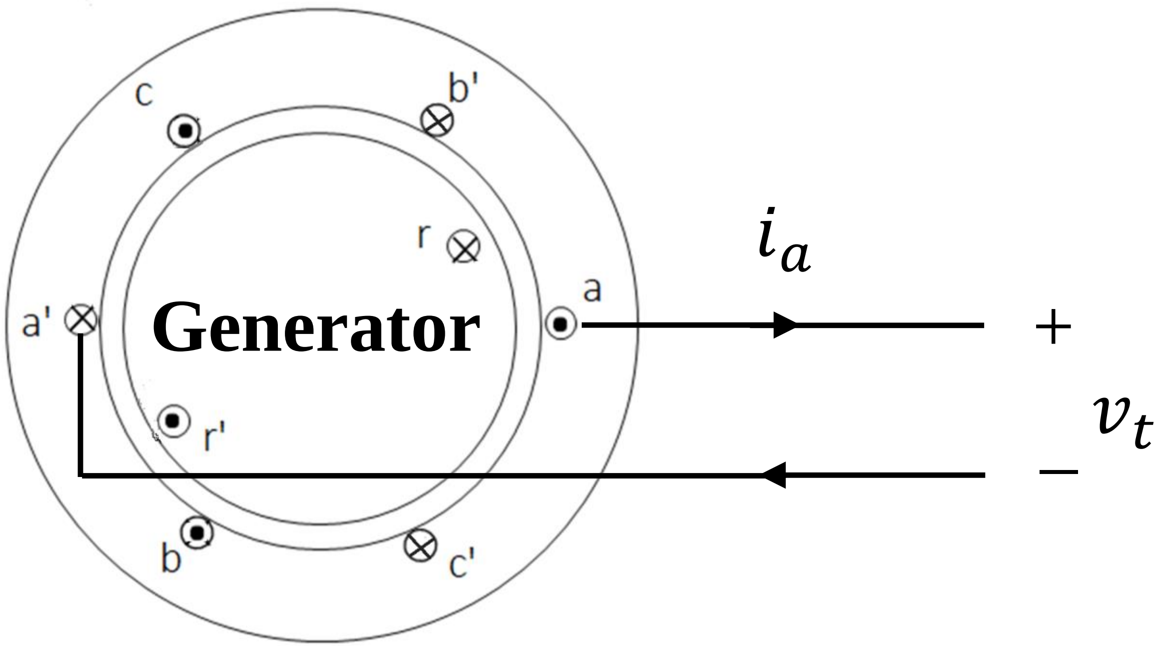
With same procedure $V_r = R_r I_r$

Synchronous-Machine Inductances; Equivalent Circuits



Motor Configuration:

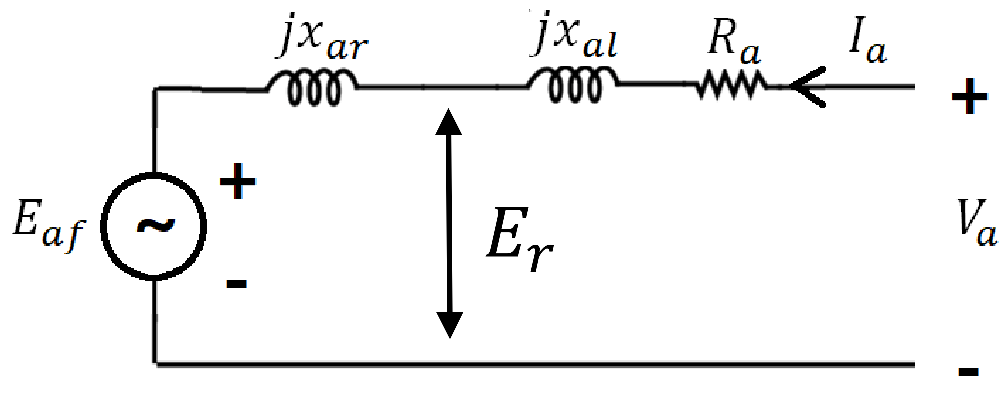
$$V_a = R_a I_a + (jx_{al} + jx_{ar})I_a + E_{af}$$



Generator Configuration:

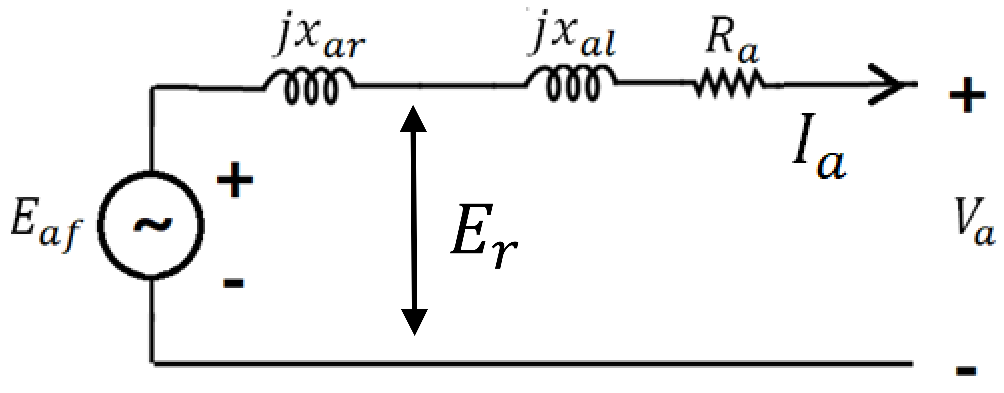
$$v_t = -R_a i_a + \frac{d\lambda_a}{dt}$$

Synchronous-Machine Inductances; Equivalent Circuits



Motor Configuration:

$$V_a = R_a I_a + (jx_{al} + jx_{ar}) I_a + E_{af}$$



Generator Configuration:

$$V_a = -R_a I_a - (jx_{al} + jx_{ar}) I_a + E_{af}$$

$$E_{af} = R_a I_a + (jx_{al} + jx_{ar}) I_a + V_a$$

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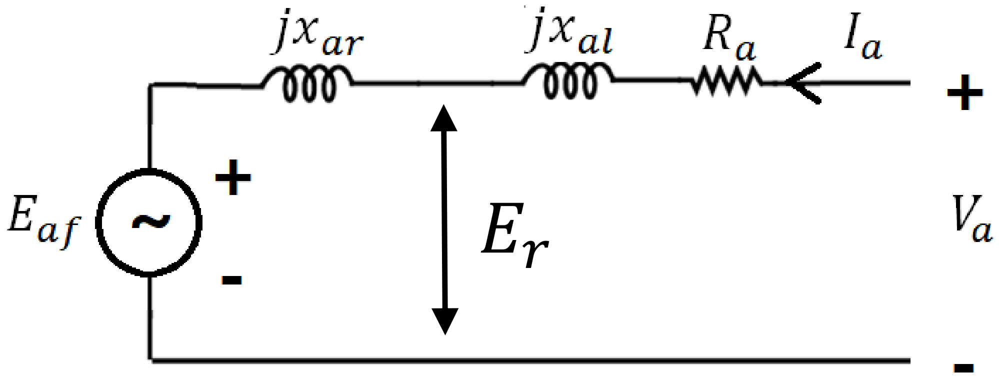
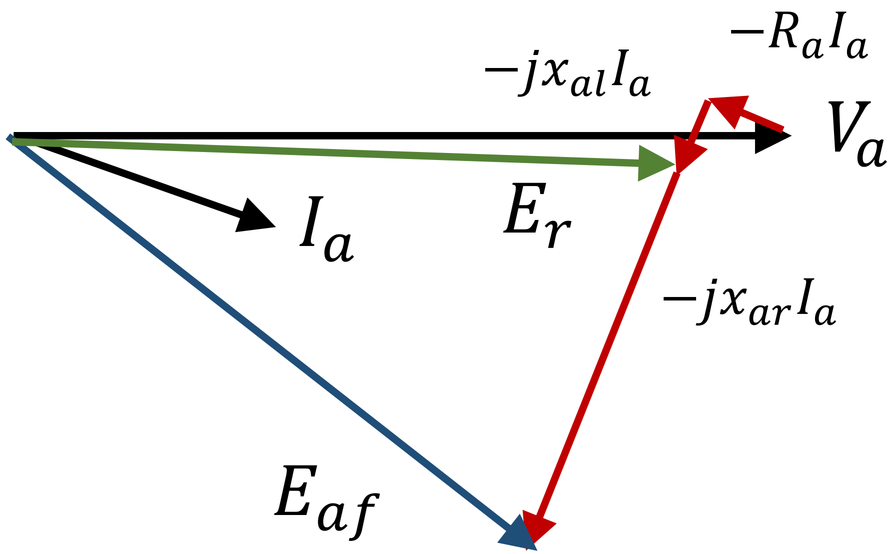
Steady-State Power-Angle Characteristic



$$V_a = R_a I_a + (jx_{al} + jx_{ar}) I_a + E_{af}$$

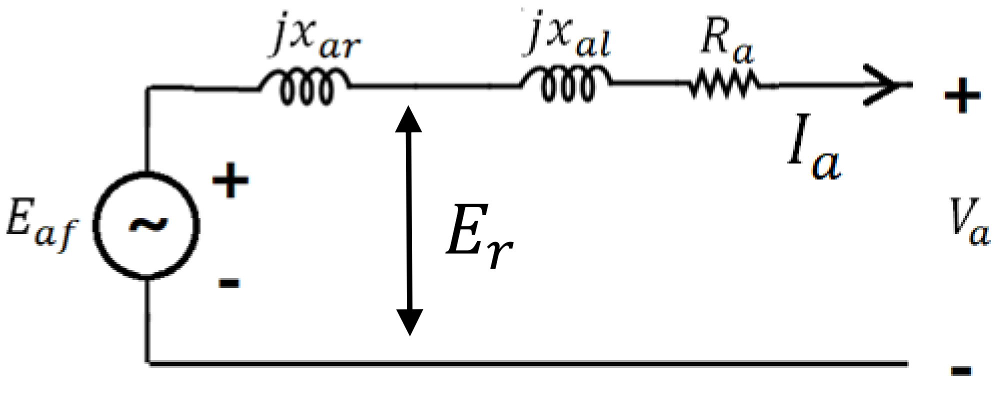


Remark 1: Size of diagram?

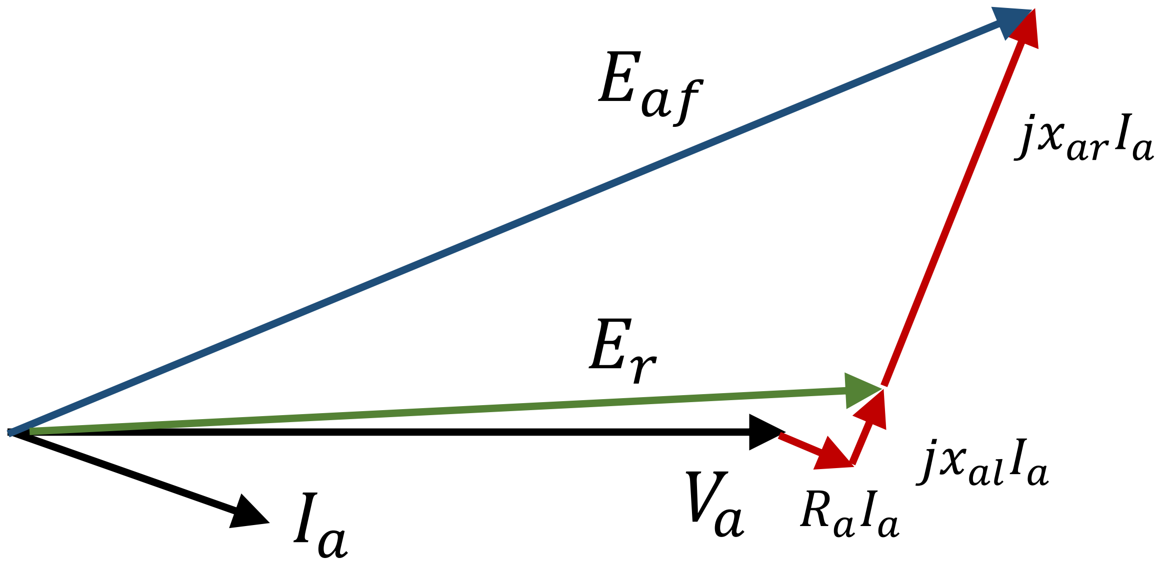
Remark 2: Comparison of E_r and V_a

Remark 3: Comparison of E_{af} and V_a

Steady-State Power-Angle Characteristic



$$E_{af} = V_a + R_a I_a + (jx_{al} + jx_{ar}) I_a$$



Remark 1: Size of diagram?

Remark 2: Comparison of E_r and V_a

Remark 3: Comparison of E_{af} and V_a

Example 1: A 460-V, 50-kW, 60-Hz, three-phase synchronous motor has a synchronous reactance of $x_s = 4.2\ \Omega$, stator resistance of $0.1\ \Omega$ and an armature-to-field mutual inductance, M=max(Laf(θ)) = 83 mH. Armature leakage reactance is 5% of synchronous reactance. The motor is operating at rated terminal voltage and an input power of 40 kW.

Calculate the magnitude and phase angle of the line-to- neutral generated voltage E_{af}, air gap voltage E_r and the field current I_f if the motor is operating at (a) 0.85 power factor lagging, (b) unity power factor, and (c) 0.85 power factor leading.

Solution (a):

$$V_a = \frac{460}{\sqrt{3}} < 0^{\circ}, I_a = \frac{40000}{\sqrt{3}460 * 0.85} < -cos^{-1}(0.85), \quad R_a = 0.1\Omega, \quad x_{al} = 0.21\Omega, \quad x_{ar} = 3.99\ \Omega$$

$$E_{af} = V_a - R_a I_a - (jx_{al} + jx_{ar})I_a = 265.6 < 0 - 0.1(59 < -31.8) - 4.2 < 90(59 < -31.8)$$

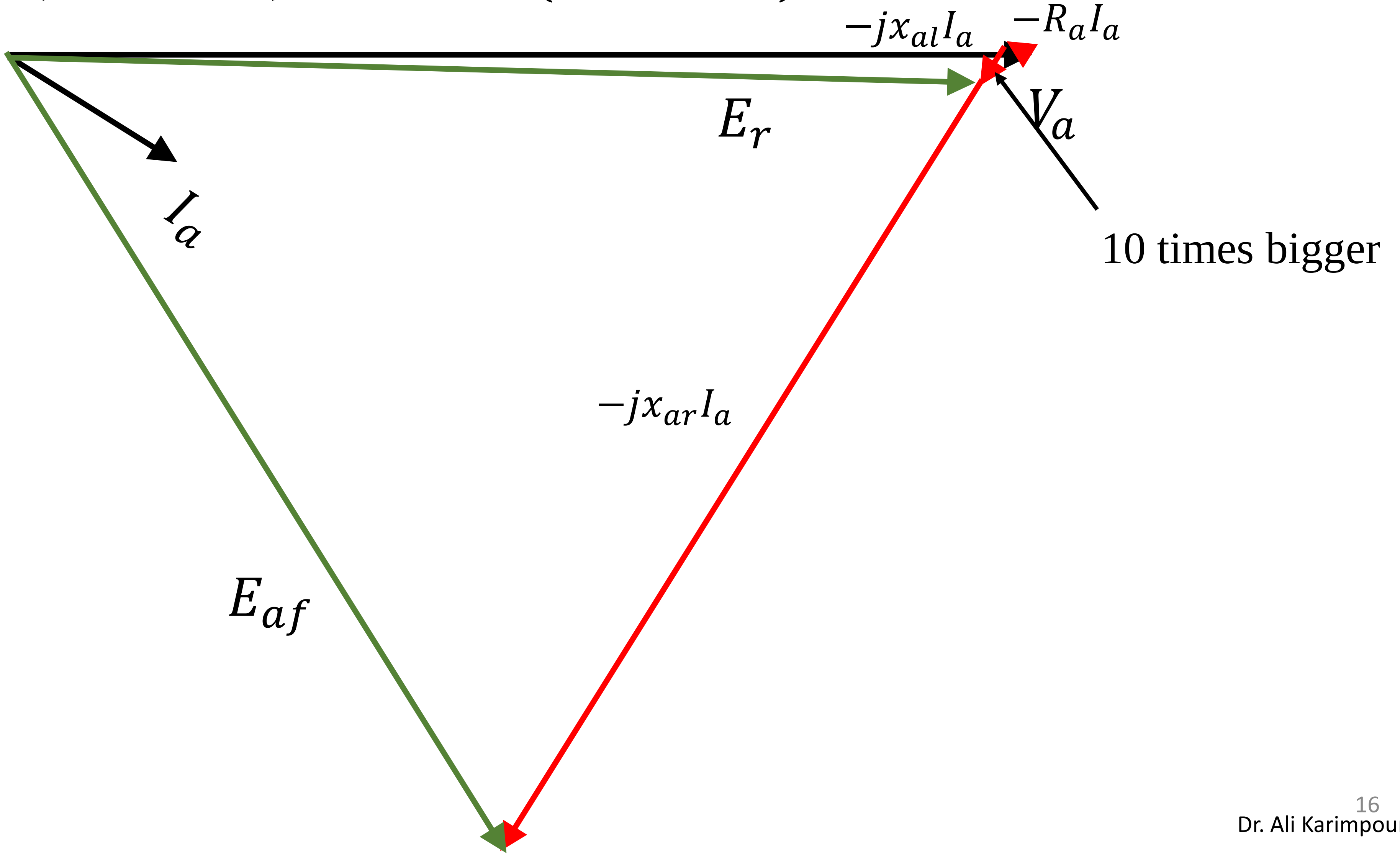
$$E_r = V_a - R_a I_a - jx_{al} I_a = 265.6 < 0 - 0.1(59 < -31.8) - 0.21 < 90(59 < -31.8)$$

Solution (a): $E_{af} = 265.6 < 0 - 0.1(59 < -31.8) - 4.2 < 90(59 < -31.8)$

$= 245 < -58$

$E_r = 265.6 < 0 - 0.1(59 < -31.8) - 0.21 < 90(59 < -31.8)$

$= 254 < -1.7$



$\sqrt{2}E_{af} = M\omega I_f$

$I_f = 11\ A$

Example 2: A 200-MVA , 15.75-kV, 50-Hz, three-phase synchronous generator has a synchronous reactance of x_s = 2.64 **Ω**, and stator resistance of 0.0012 **Ω** (r=1.1 m, g=0.1 m, l=4.62 m, N_r=126(0.8 winding factor) , N_a=10(0.8 winding factor)). Armature leakage reactance is 3% of synchronous reactance. The generator is operating at rated terminal voltage and provides its rated output at 0.8 power factor lag.

a) Calculate the magnitude and phase angle of the line-to- neutral generated voltage E_{af}, air gap voltage E_r and corresponding phasor diagram.

b) Calculate the field current I_f .

Solution:

$$V_a = \frac{15750}{\sqrt{3}} < 0^{\circ}, I_a = \frac{200000000}{\sqrt{3}15750} < -cos^{-1}(0.8),\ R_a = 0.0012\Omega,\ x_{al} = 0.079\Omega,\ x_{ar} = 2.561\Omega,$$

$$E_{af} = V_a + R_a I_a + (jx_{al} + jx_{ar})I_a = 9093 < 0 + 0.0012(7331 < -37) + 2.64 < 90(7331 < -37)$$

$$E_r = V_a + R_a I_a + jx_{al} I_a = 9093 < 0 + 0.0012(7331 < -37) + 0.079 < 90(7331 < -37)$$

Solution:

$$E_{af} = 9093 < 0 + 0.0012(7331 < -37) + 2.64 < 90(7331 < -37)$$

$$=25857 < 36.8$$

$$E_r = 9093 < 0 + 0.0012(7331 < -37) + 0.079 < 90(7331 < -37)$$

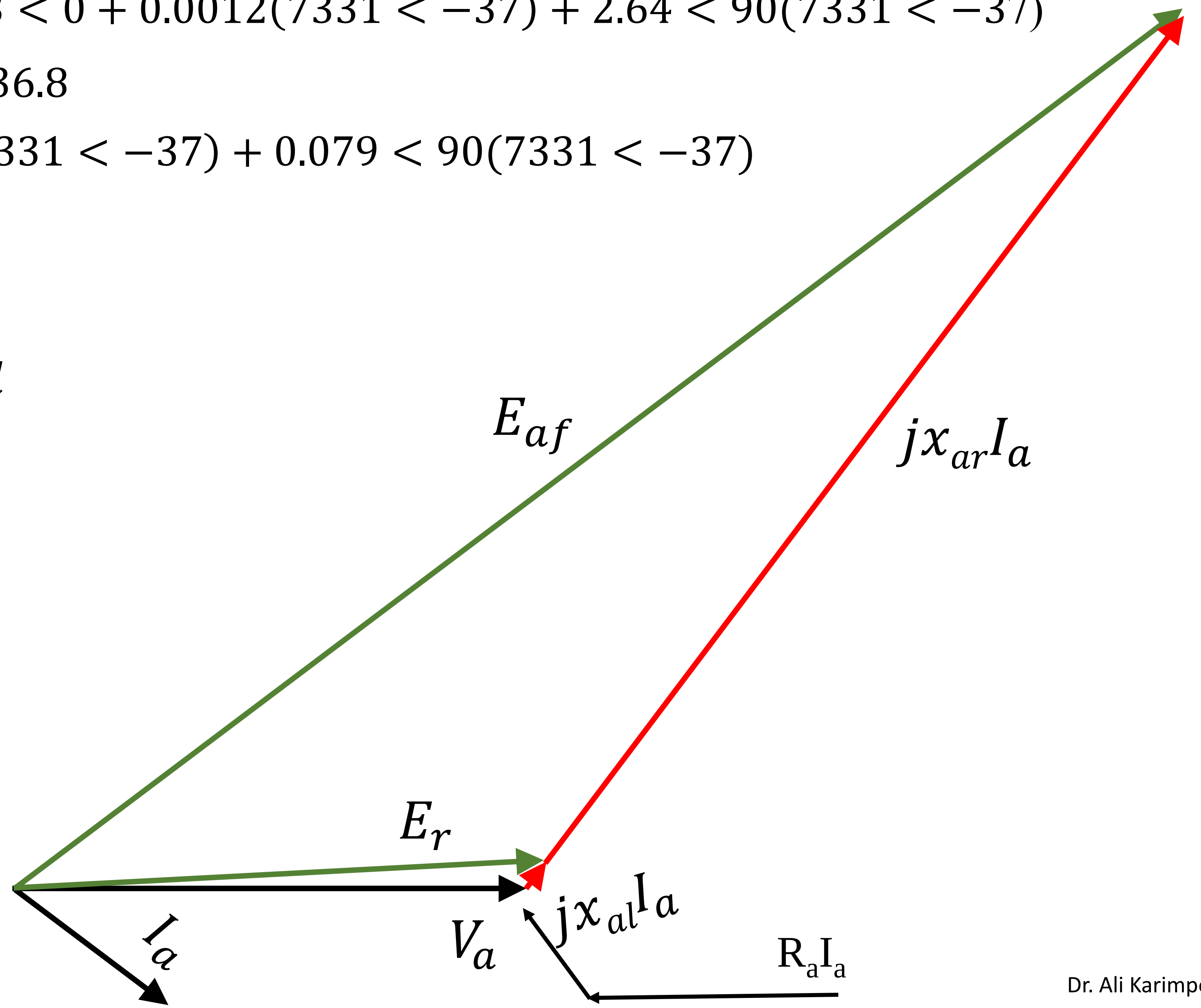
$$= 94596 < 2.8$$

$$M = \frac{4k_{\omega r}N_r k_\omega N_a}{\pi g}\mu_0 r l$$

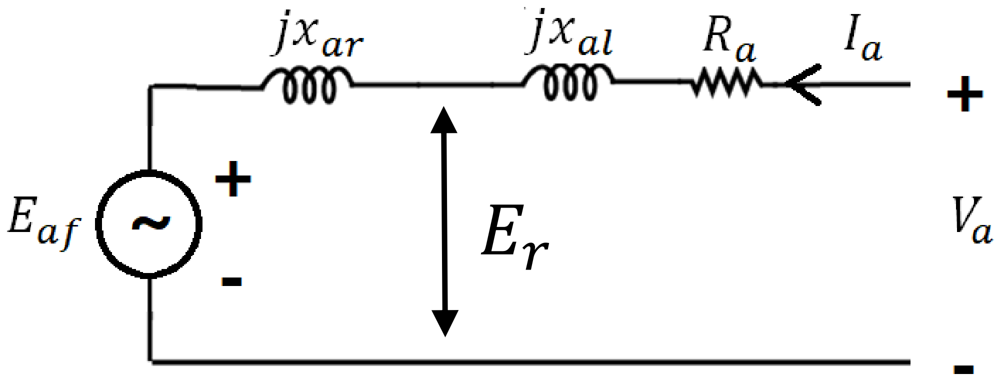
$$M = 0.0656\ \mathrm{H}$$

$$\sqrt{2}E_{af} = M\omega I_f$$

$$I_f = 1775\ A$$



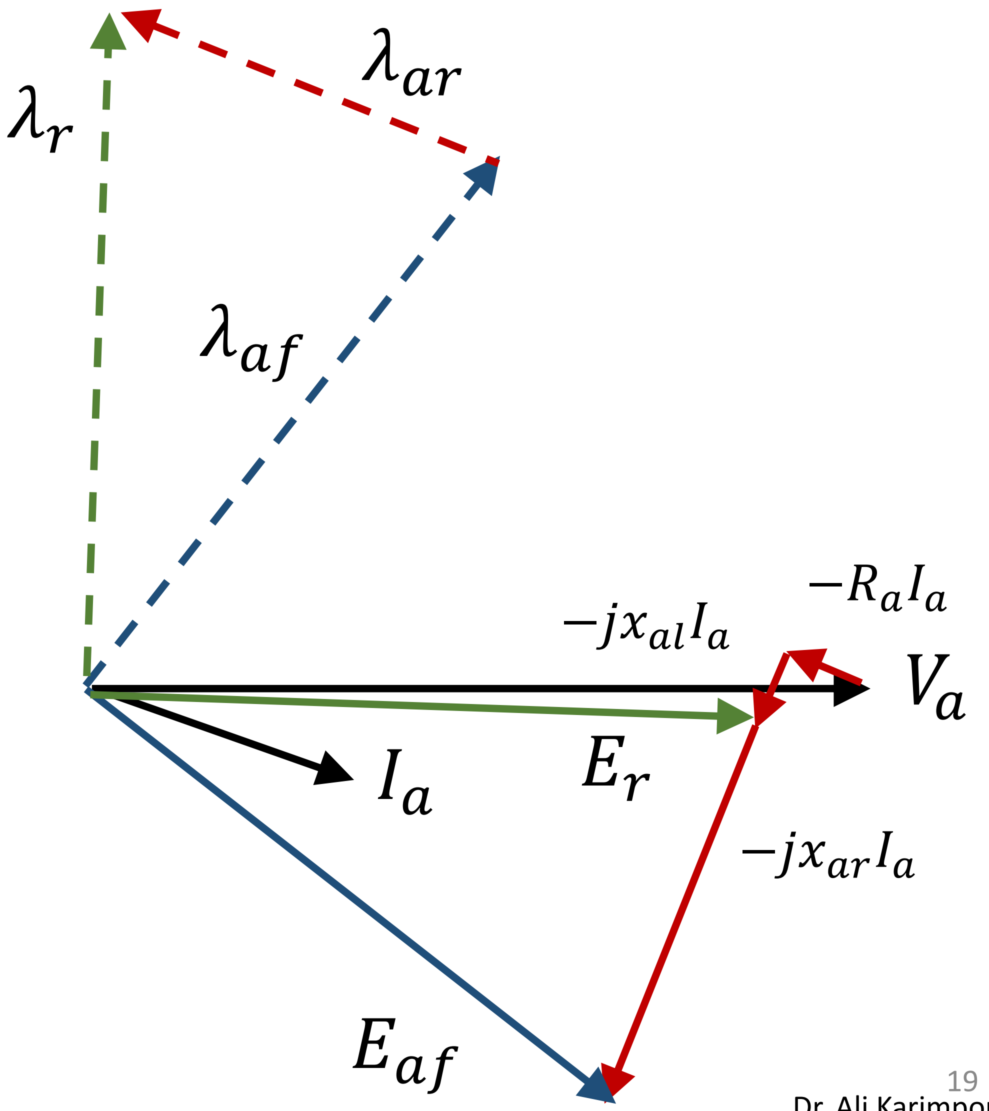
Steady-State Power-Angle Characteristic



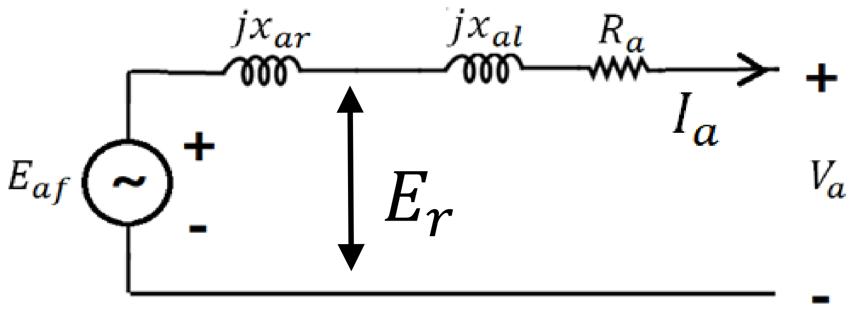
$$V_a = R_a I_a + (jx_{al} + jx_{ar}) I_a + E_{af}$$

Different Flux in Cylindrical

Synchronous Motor

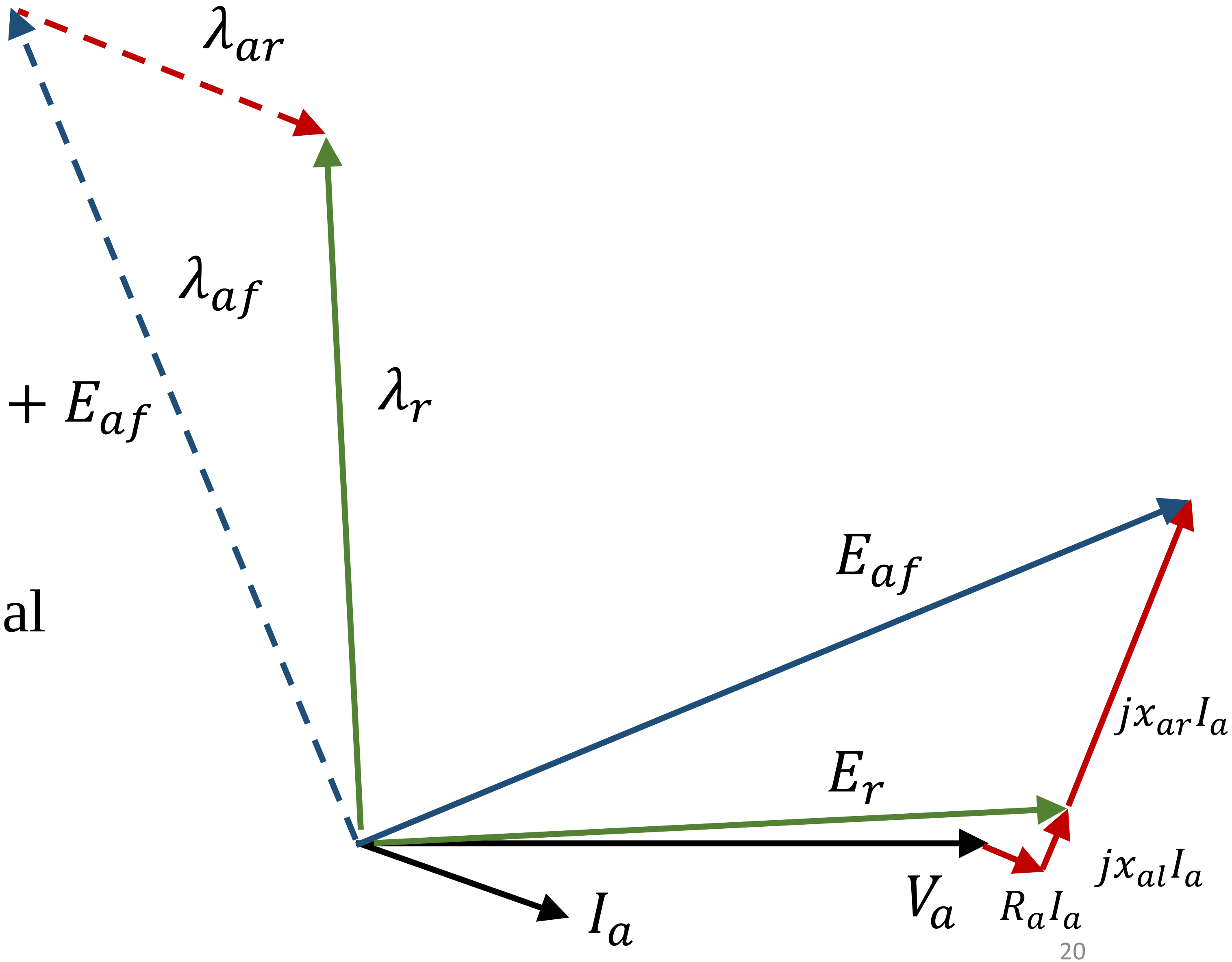


Steady-State Power-Angle Characteristic



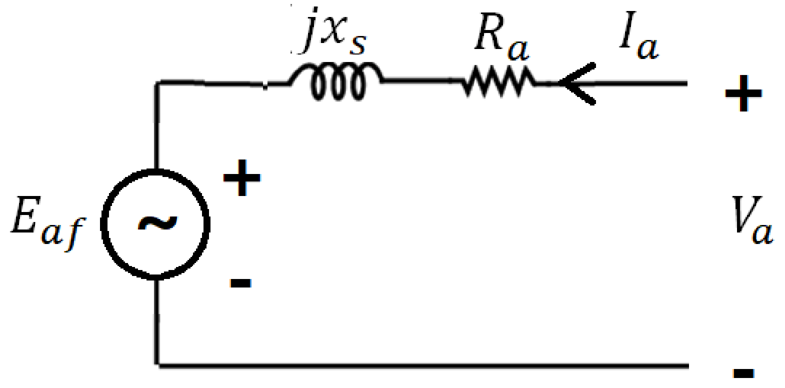
$$V_a = -R_a I_a - (jx_{al} + jx_{ar}) I_a + E_{af}$$

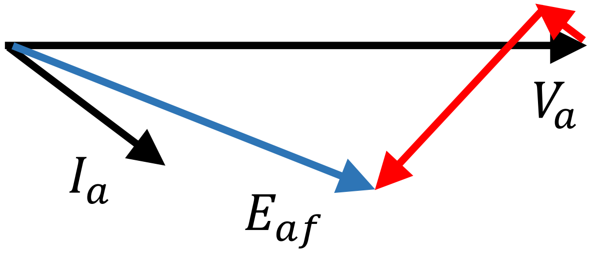
Different Flux in Cylindrical Synchronous Generator



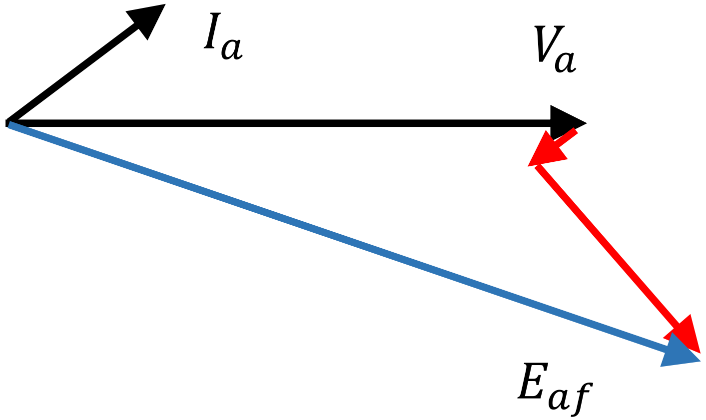
Steady-State Power-Angle Characteristic

Active and reactive power in synchronous motor

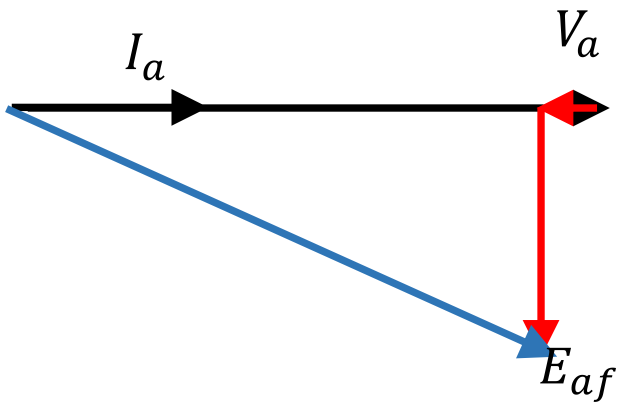




Motor that absorb reactive power (L)



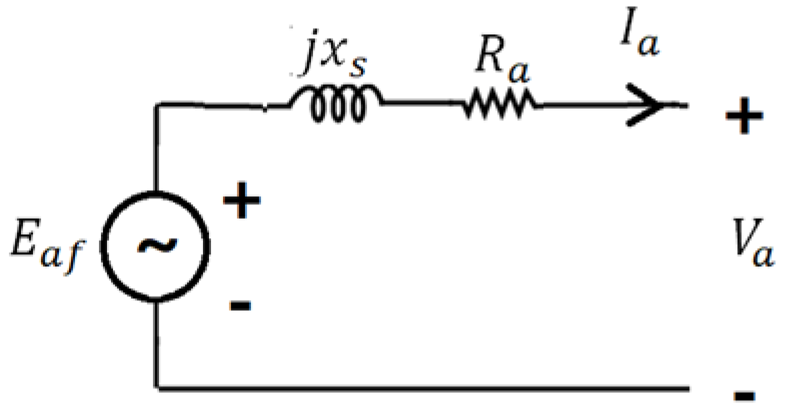
Motor that produce reactive power (C)

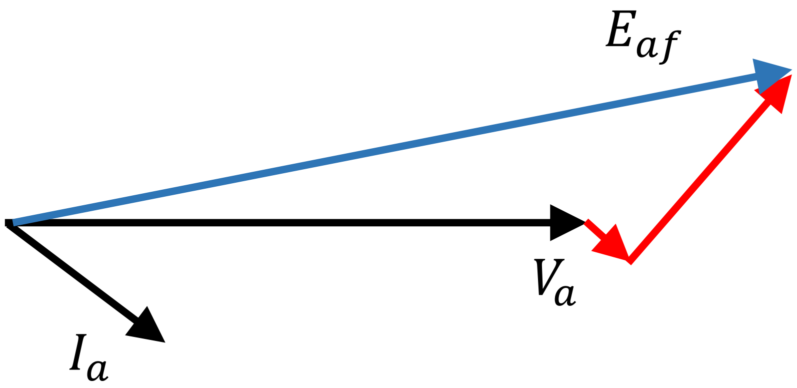


Motor with no reactive power

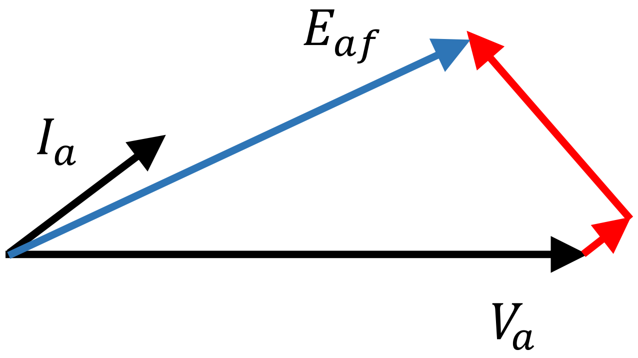
Steady-State Power-Angle Characteristic

Active and reactive power in synchronous generator

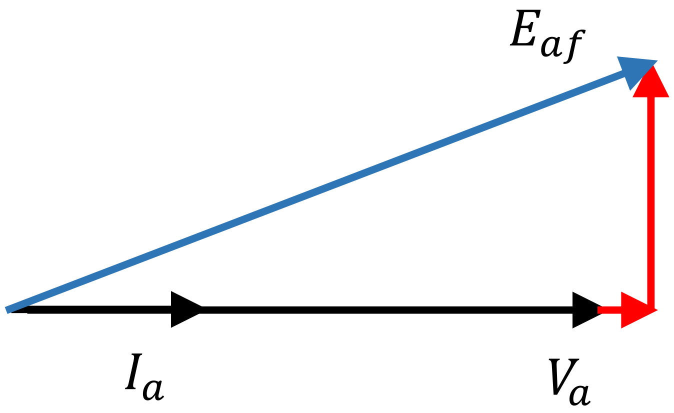




Generator that produce reactive power (C)



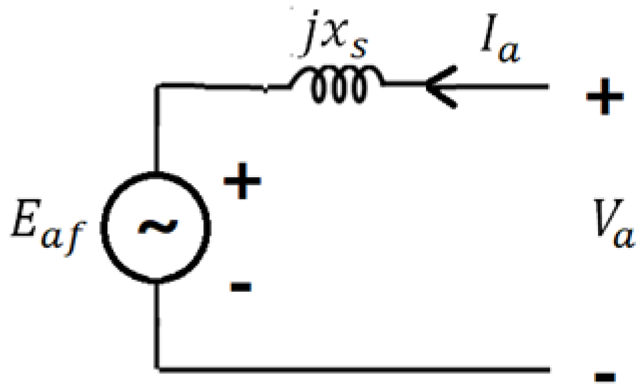
Generator that absorb reactive power (L)

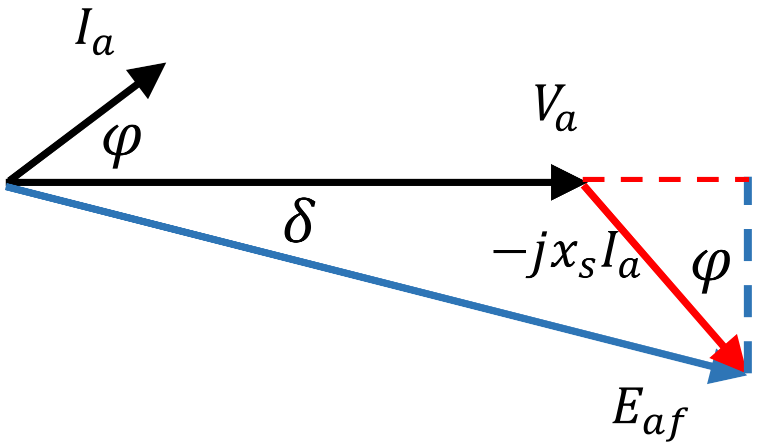


Generator with no reactive power.

Steady-State Power-Angle Characteristic

Active and reactive power in synchronous motor





$$P = \sqrt{3}|V_{LL}||I_a|cos\varphi \; = 3|V_a||I_a|cos\varphi$$

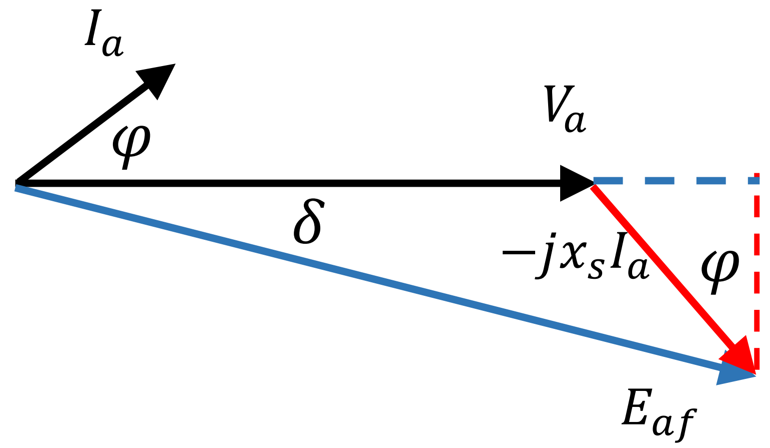
$$= \frac{3|V_a|}{x_s} x_s|I_a|cos\varphi \; = \frac{3|V_a|}{x_s}|E_{af}|sin\delta \; = \frac{|V_{LL}||E_{afLL}|}{x_s} sin\delta$$

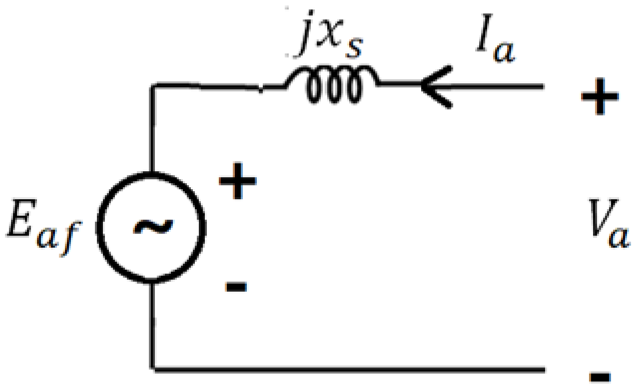
Remark: It is also valid for synchronous generator.

Steady-State Power-Angle Characteristic

Active and reactive power

in synchronous motor





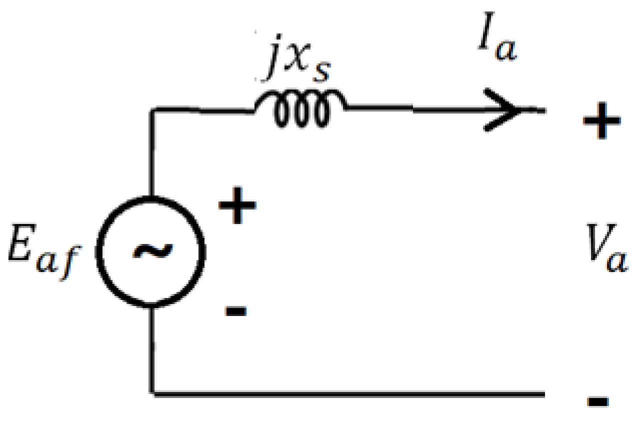
$$Q = \sqrt{3}|V_{LL}||I_a|sin\varphi \; = 3|V_a||I_a|sin\varphi$$

$$= \frac{3|V_a|}{x_s}x_s|I_a|sin\varphi \; = \frac{3|V_a|}{x_s}(|E_{af}|cos\delta - |V_a|)$$

$$= \frac{|V_{LL}|}{x_s}(|E_{afLL}|cos\delta - |V_{LL}|)$$

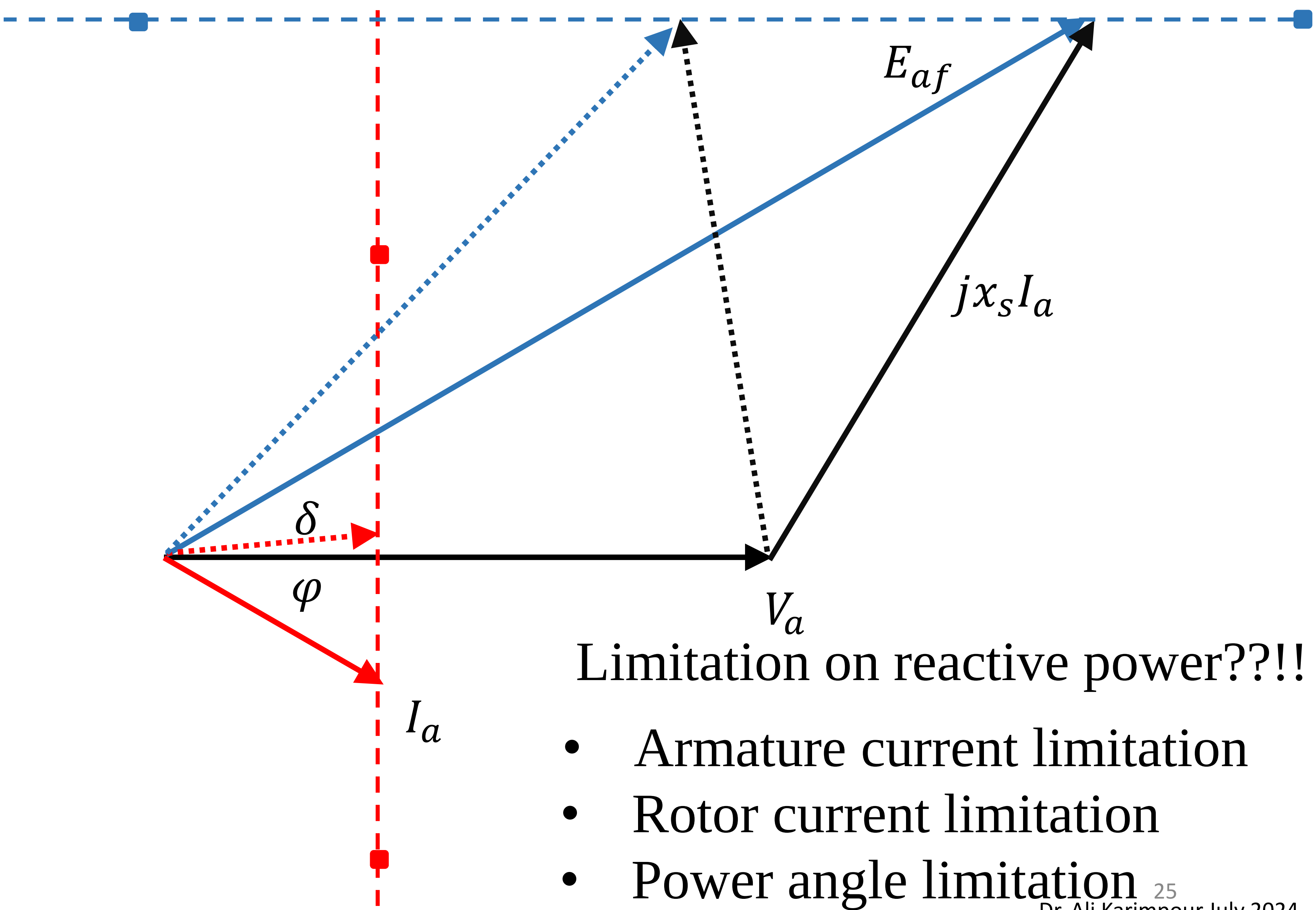
Remark: It is also valid for synchronous generator.

Constant active power locus in synchronous generator/motor



$$P = \sqrt{3}|V_{LL}||I_a|cos\varphi$$

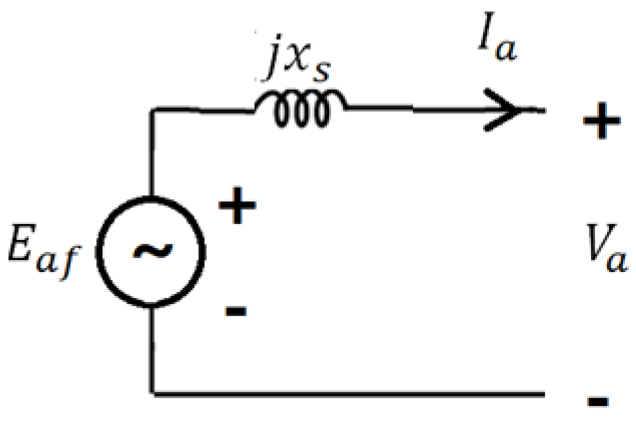
$$= \frac{|V_{LL}||E_{afLL}|}{x_s} sin\delta$$

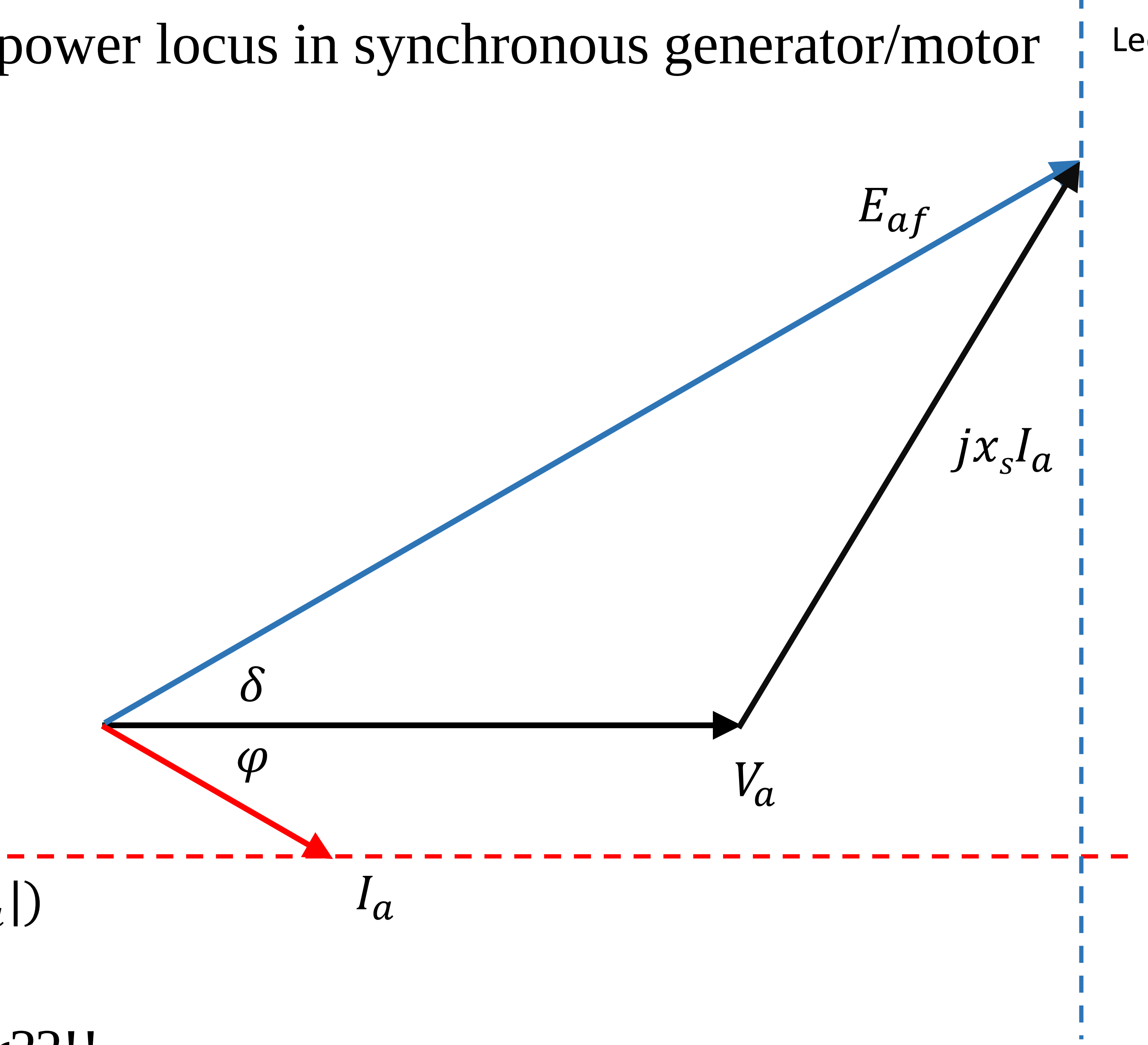


Limitation on reactive power??!!

- Armature current limitation
- Rotor current limitation
- Power angle limitation

Constant reactive power locus in synchronous generator/motor





$$Q = \sqrt{3}|V_{LL}||I_a|sin\varphi$$

$$= \frac{3|V_a|}{x_s}(|E_{af}|cos\delta - |V_a|)$$

Limitation on active power??!!

Steady-State Power-Angle Characteristic

Per Unit Calculation

S_b =? ? V_b =? ? Z_b=? ?

Ansaldo Geneartor: A 200-MVA , 15.75-kV, 50-Hz, three-phase synchronous generator has a synchronous reactance of $x_s = 2.64\ \Omega$.

$$S_b = 200\ MVA$$

$$V_b = 15.75\ KV$$

$$Z_b = \frac{15.75^2}{200} = 1.24\ \Omega$$

Example 3: A 200-MVA , 15.75-kV, 50-Hz, three-phase synchronous generator has a synchronous reactance of x_s = 2.64 Ω, and negligible stator resistance. The generator is operating at rated terminal voltage and provides 75% of its rated output at unit power factor.

a) Calculate the generated voltage E_{af}(Line-Line), and corresponding phasor diagram.

b) Repeat part (a) in p.u.

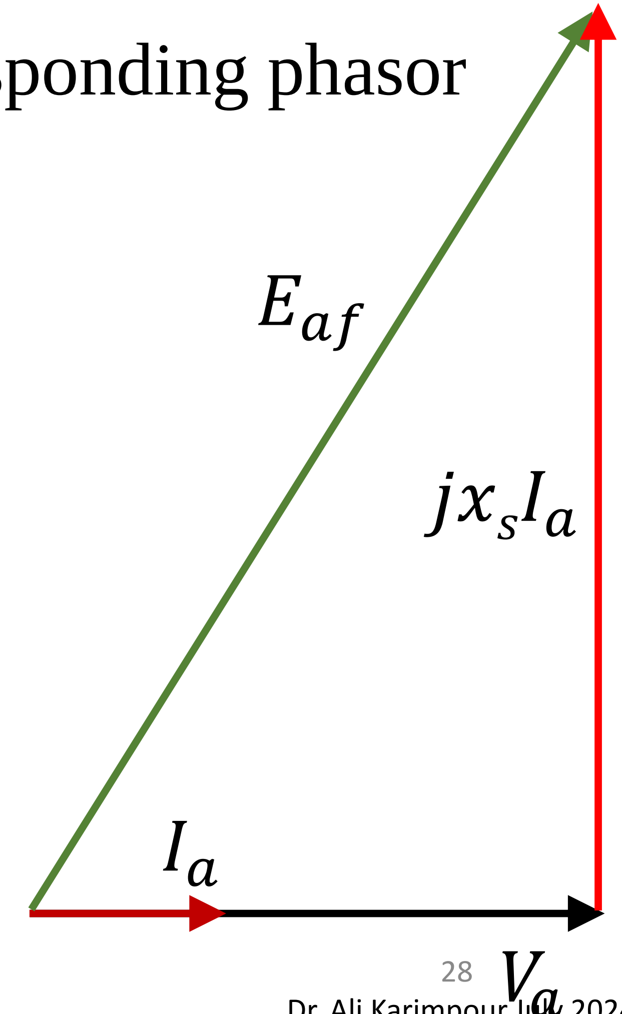
Solution(a):

$$V_a = \frac{15750}{\sqrt{3}} < 0^{\circ}, I_a = \frac{200000000 * 0.75}{\sqrt{3}15750} < 0 \ , R_a = 0, \quad x_s = 2.64\Omega$$

$$E_{af} = V_a + jx_s I_a$$

$$= 9093 < 0 + (2.64 < 90)(5499 < 0) = 17130 < 58$$

$$E_{af_{LL}} = \sqrt{3}17130 = 29670 \text{ V}$$



Example 3: A 200-MVA , 15.75-kV, 50-Hz, three-phase synchronous generator has a synchronous reactance of $x_s = 2.64\ \Omega$, and negligible stator resistance. The generator is operating at rated terminal voltage and provides 75% of its rated output at unit power factor.

a) Calculate the generator voltage E_{af}(Line-Line), and corresponding phasor diagram.

b) Repeat part (a) in p.u.

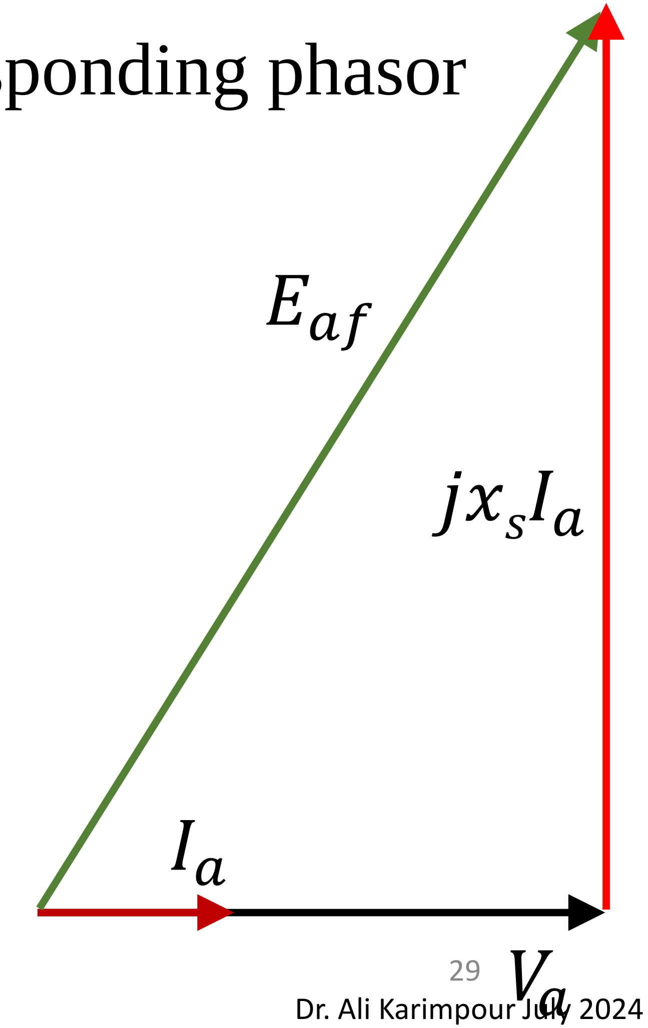
Solution(b):

$V_a = 1 < 0^{\circ}, I_a = 0.75 < 0$, $x_s = \frac{2.64\ \Omega}{1.24\ \Omega}\ p.u. =$2.129 p.u.

$E_{af} = V_a + jx_s I_a$

$= 1 < 0 + (2.129 < 90)(0.75 < 0)$=$1.884 < 58$

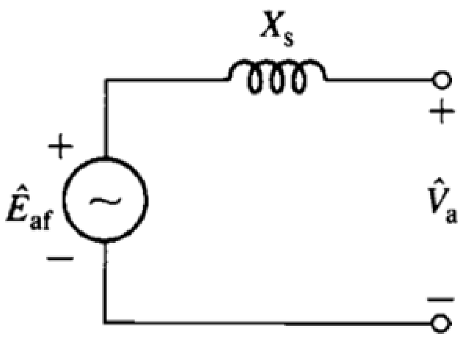
$E_{af_{LL}} = 1.88\ p.u. = 1.88 * 15750$ =29673 V



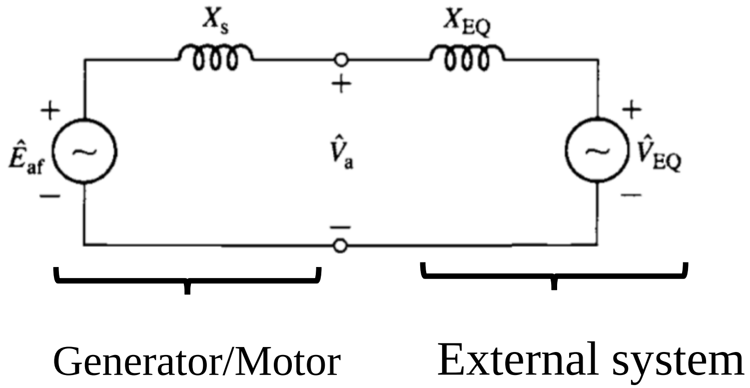
Steady-State Power-Angle Characteristic

Different working condition for a synchronous machine

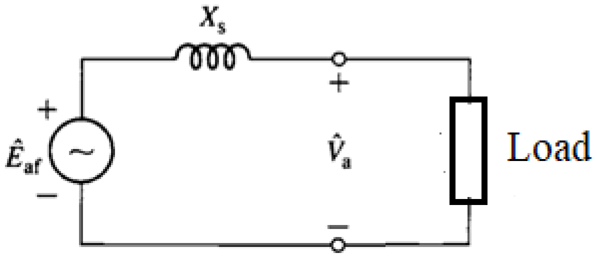
- Machine connected to an infinite bus. ($\hat{V}_a = cte.$)



- Machine connected to real system. ($\hat{V}_a \; isn't \; cte.$)



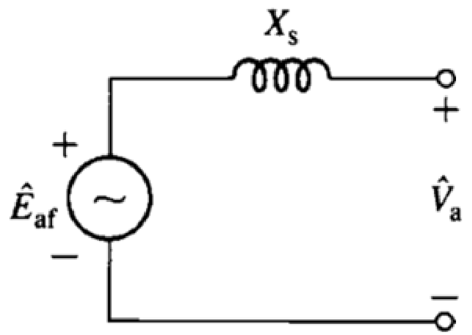
- Machine(generator) connected to a load. ($\hat{V}_a \; isn't \; cte.$).



Steady-State Power-Angle Characteristic

Different working condition for a synchronous machine

- Machine connected to an infinite bus. ($\hat{V}_a = cte.$)



What happens when the machine connected to infinite bus?

In this situation the terminal voltage of the machine constant.

Example 4: A 200-MVA , 15.75-kV, 50-Hz, three-phase synchronous generator has a synchronous reactance of $x_s = 2.64\ \Omega$, and negligible stator resistance. The generator is operating at rated terminal voltage(connected to infinite bus) and provides its rated output at 0.8 power factor lag.

a) Calculate the generated voltage E_{af}, and corresponding phasor diagram.

b) Consider that the active power is constant but rotor(field) voltage reduced by 20% draw the new phasor diagram.

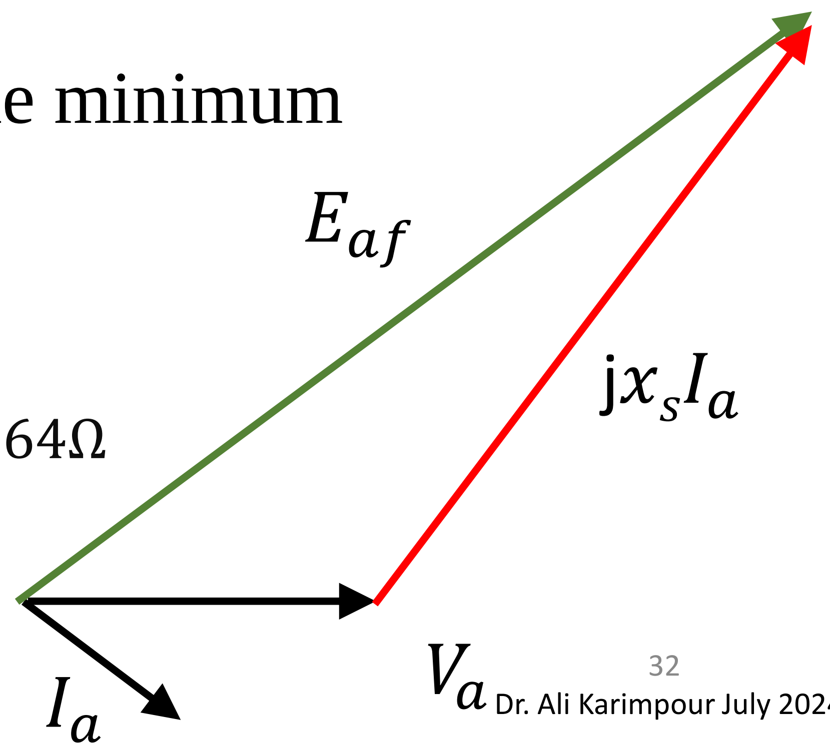
c) Consider that the active power is constant what is the minimum admissible rotor voltage.

Solution(a):

$$V_a = \frac{15750}{\sqrt{3}} < 0^{\circ}, I_a = \frac{200000000}{\sqrt{3}15750} < -cos^{-1}(0.8),\ R_a = 0,\ x_s = 2.64\Omega$$

$$E_{af} = V_a + jx_s I_a$$

$$= 9093 < 0 + (2.64 < 90)(7331 < -37) = 25855 < 36.8$$



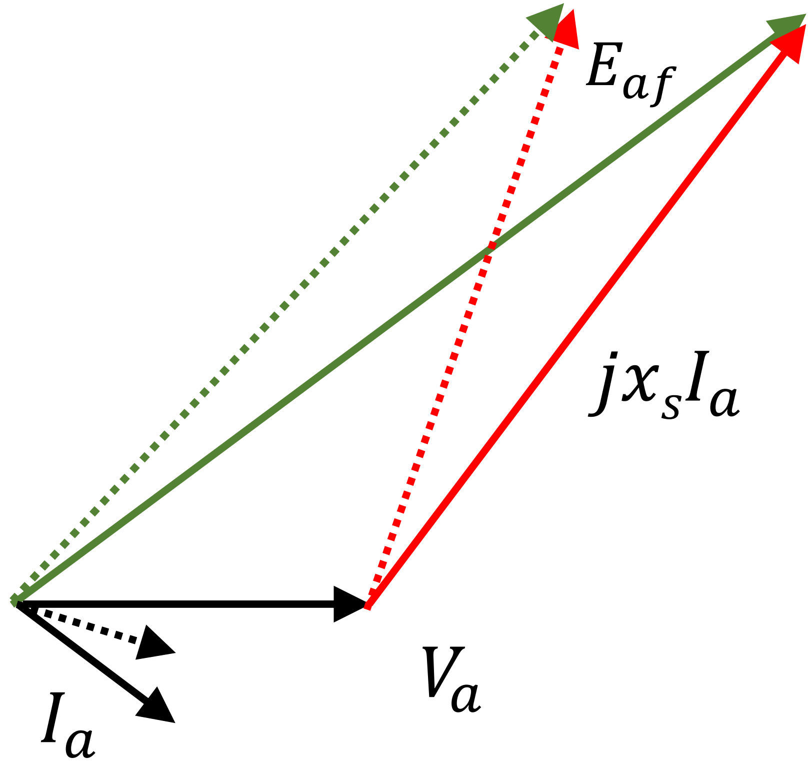
Solution(b): Analytical solution

$$|E_{af}| = 0.8 * 25855 = 20684$$

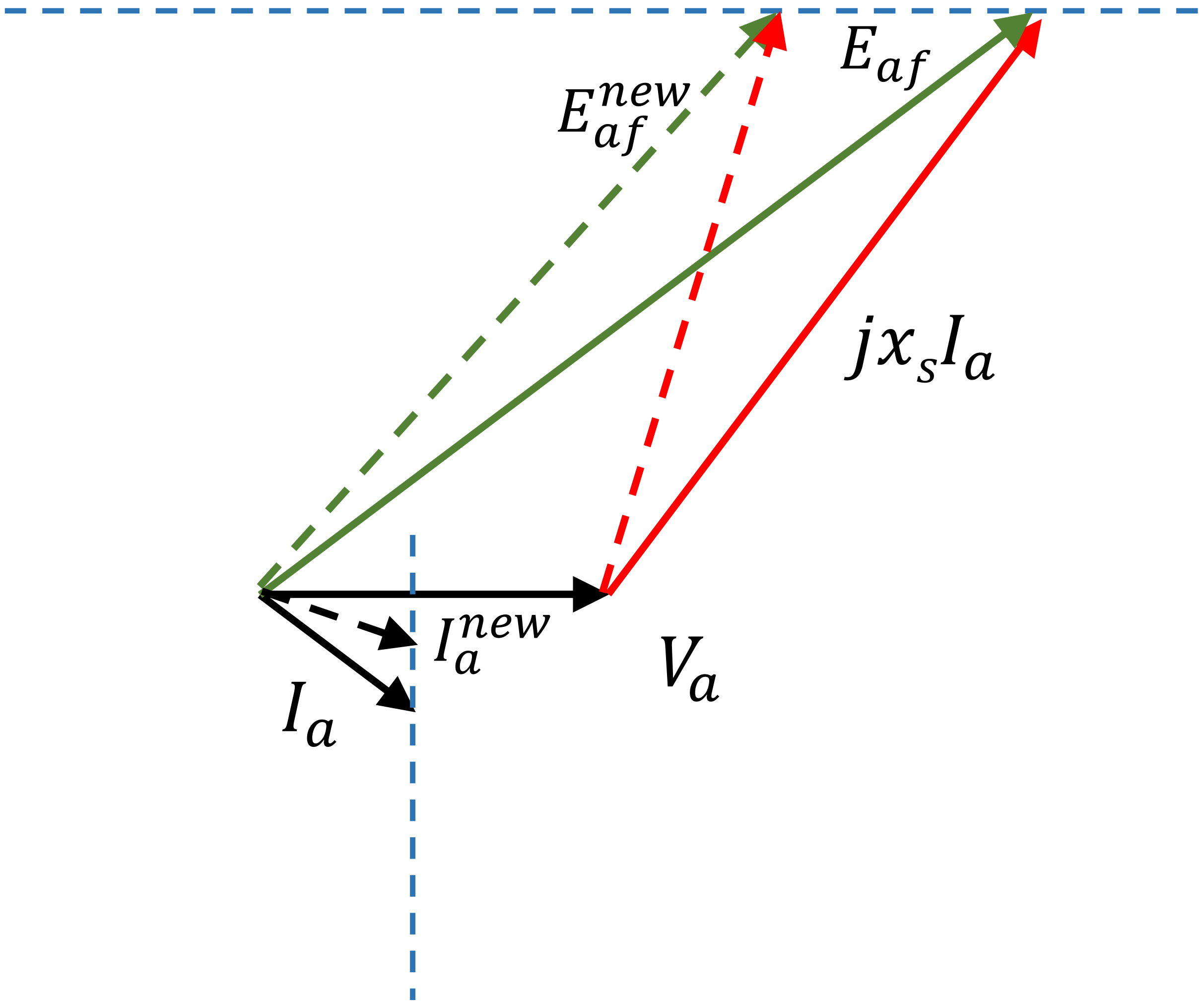
$$160000000 = \frac{3 * 20684 * 9093}{2.64} sin\delta_1 \qquad \delta_1 = 48.5°$$

$$20684 < 48.5 = 9093 < 0 + (2.64 < 90)(I_a < \varphi_1)$$

$$I_a < \varphi_1 = 6123 < -16.6$$



Solution(b): Graphical solution

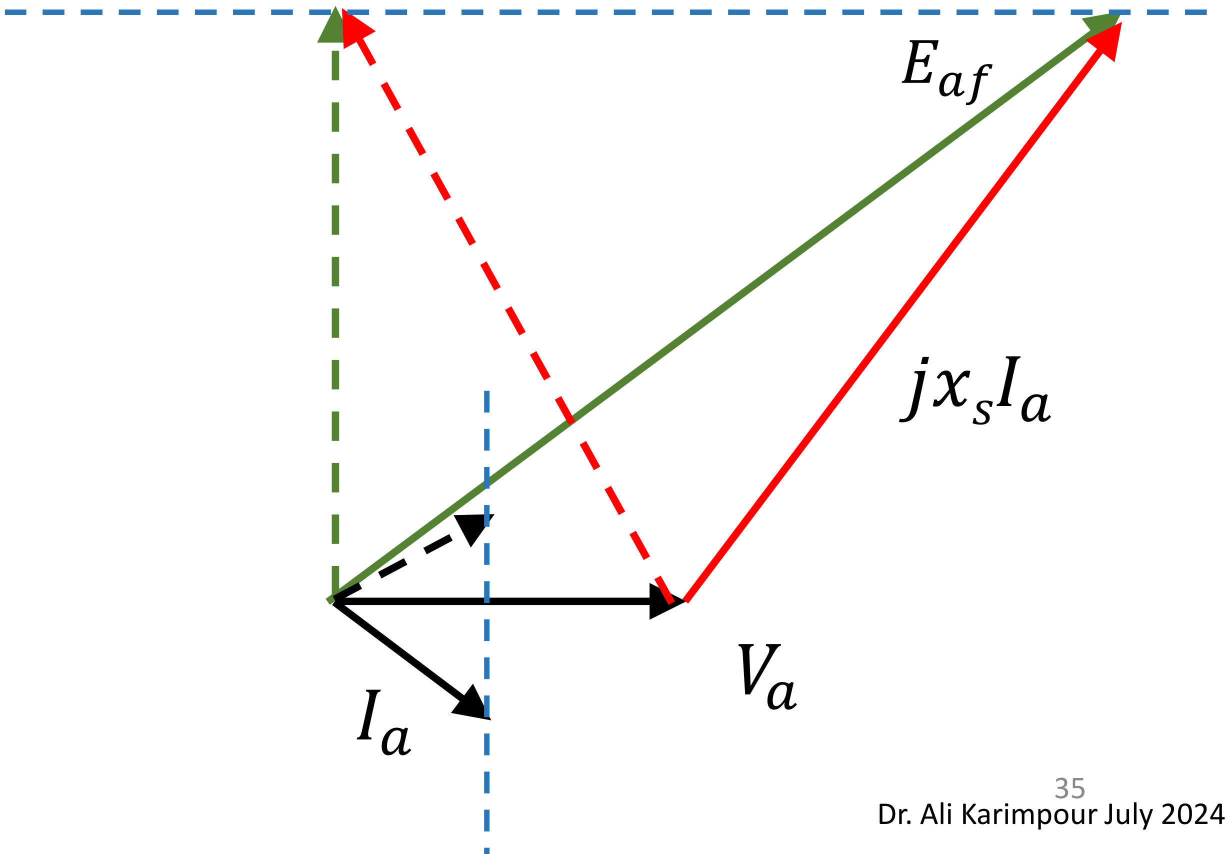


Solution(c):

$$160000000 = \frac{3 * E_{af}^{min} * 9093}{2.64} sin90$$

E_{af}^{min} =15684

maximum reduction of rotor voltage =1-15684/25855=0.4



Example 5: A 1.5 MW, 2300-V, unity-power-factor, three-phase, 50 Hz, 4 poles, Y-connected, synchronous motor has a synchronous reactance of 1.0 p.u. For this problem all losses may be neglected.

a) Motor connected to rated voltage and working in the nominal condition. Derive phasor diagram and generated voltage in this situation.

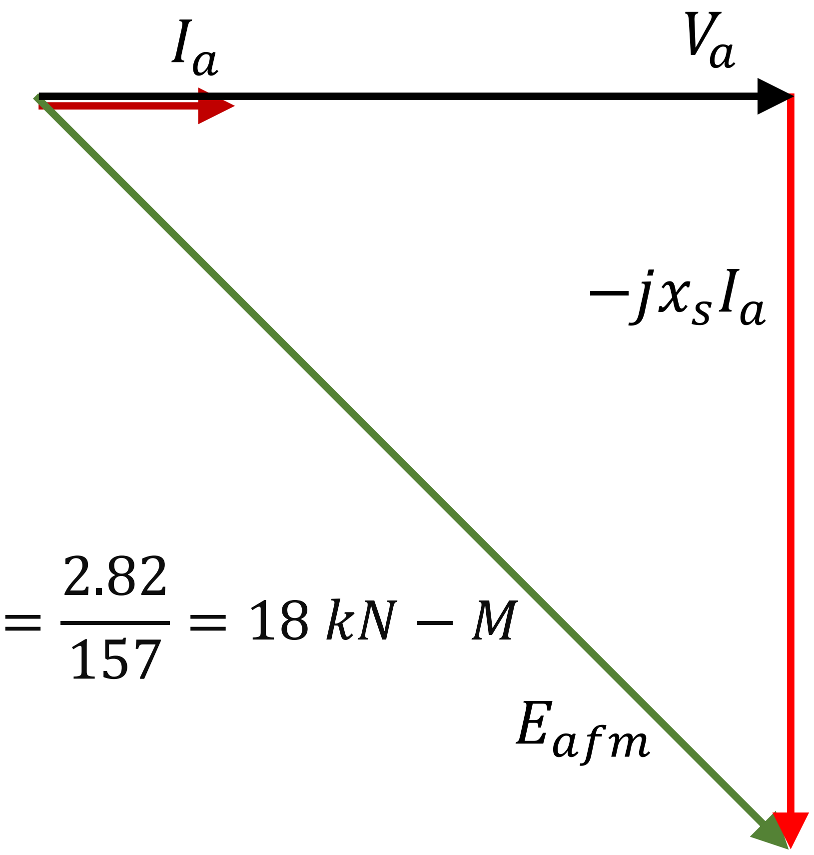
b) What is the breakdown torque(T_{max}) of motor?

c) Derive torque versus power angle(δ) characteristic and torque versus speed characteristic.

d) Specify the power angle(δ) for output torque of 50% of T_{max} (Note that there are two equilibrium point and just one of them is acceptable.)

Solution(a):

$V_a = 1 < 0^{\circ}$ $\qquad I_a = 1 < 0^{\circ}$



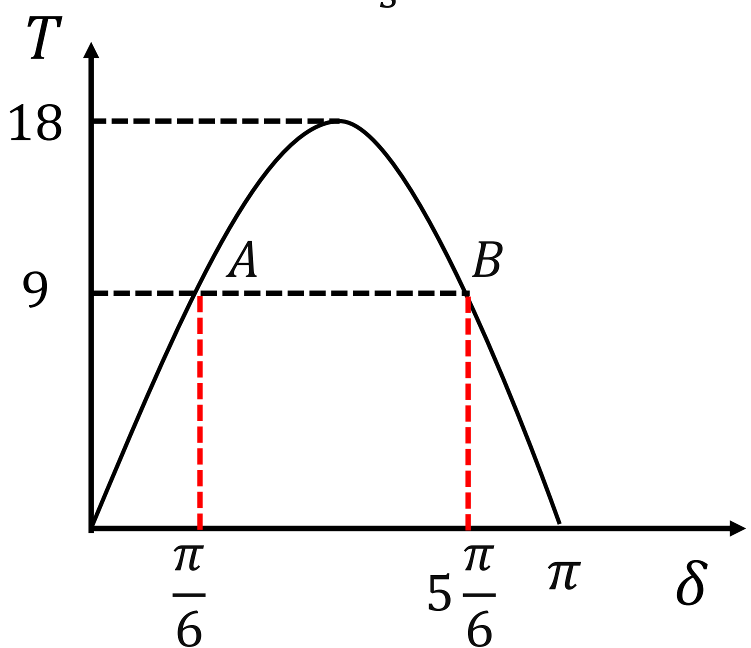
$E_{af} = V_a - jx_sI_a = 1 < 0 - (1 < 90)(1 < 0) = 1.41 < -45°$

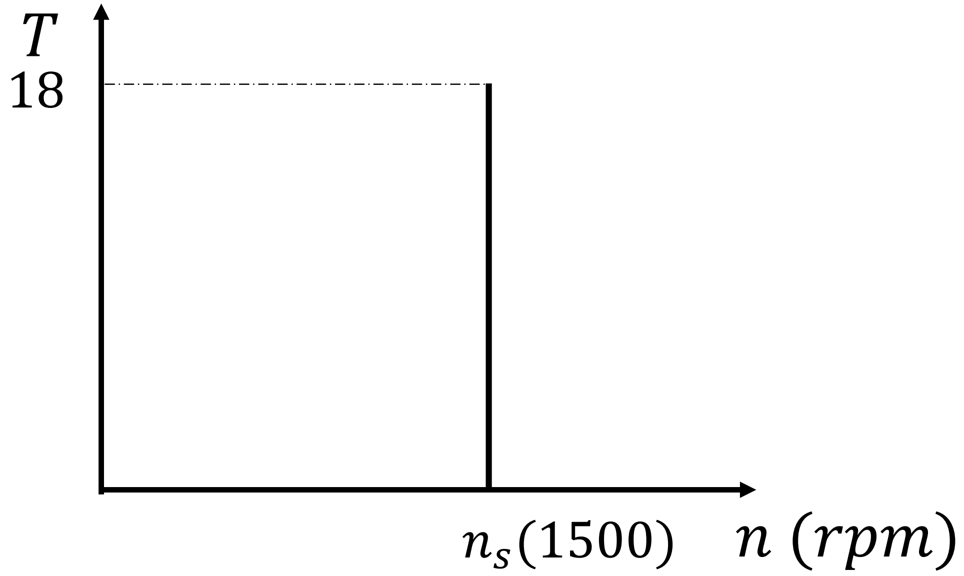
(b): $P = \frac{|E_{afL\_L}||V_{aL-L}|}{x_s} \sin\delta$

$P_{max} = \frac{|E_{afL\_L}||V_{aL-L}|}{x_s} \sin 90 = 1.41\, p.u. = 2.82\ MW$ $\qquad T_{max} = \frac{2.82}{157} = 18\ kN-M$

(c)

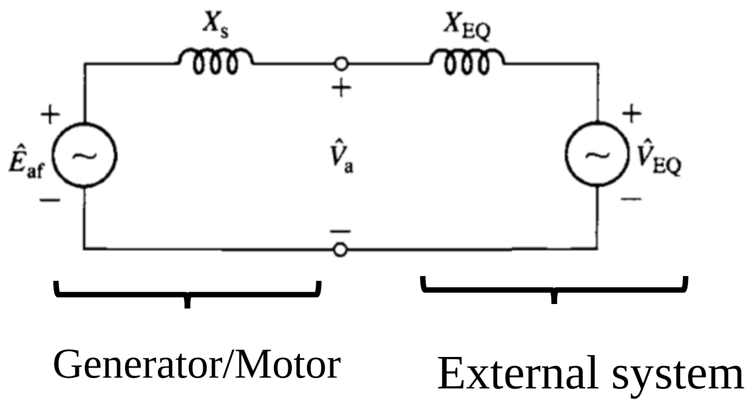
(d)





Steady-State Power-Angle Characteristic

Different working condition for a synchronous machine



- Machine connected to real system. ($\hat{V}_a$ $isn't\ cte$.)

What happen when the machine is not connected to infinite bus?

In this situation the terminal voltage of the machine is not constant.

X_{EQ}=0	Infinite bus
Smaller X_{EQ}	A strong power network
Bigger X_{EQ}	A weak power network

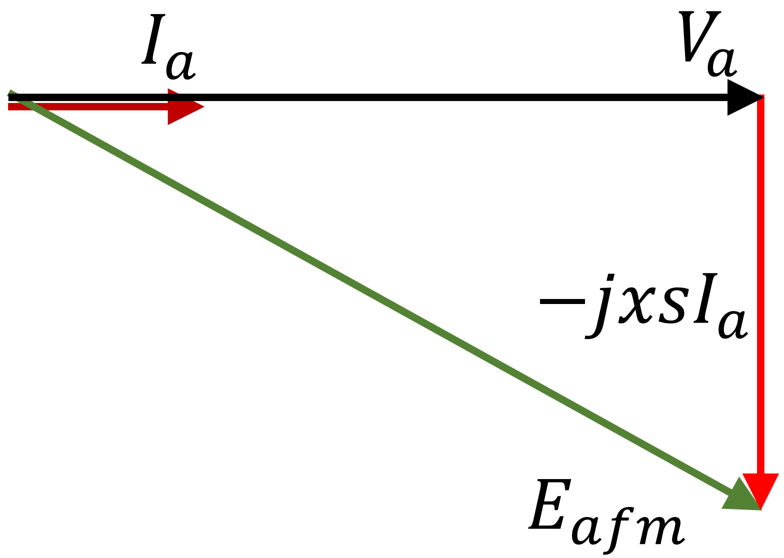
Example 6: A 2000-hp, 2300-V, unity-power-factor, three-phase, Y-connected, 30-pole, 60-Hz synchronous motor has a synchronous reactance of 1.95 Ω/phase. For this problem all losses may be neglected.

a) Compute the maximum power and torque which this motor can deliver if it is supplied with power directly from a 60-Hz, 2300-V infinite bus. Assume its field excitation is maintained constant at the value which would result in unity power factor at rated load. Repeat part (a) in p.u.

b) Instead of the infinite bus of part (a), suppose that the motor is supplied with power from a three-phase, Y-connected, 2300-V, 1500-kVA, two-pole, 3600 r/min turbine generator whose synchronous reactance is 2.65 Ω /phase. The generator is driven at rated speed, and the field excitations of generator and motor are adjusted so that the motor runs at unity power factor and rated terminal voltage at full load. Calculate the maximum power and torque which could be supplied corresponding to these values of field excitation.

Solution(a):

$$V_a = \frac{2300}{\sqrt{3}} < 0^{\circ} = 1328 < 0^{\circ} \qquad P = 2000 * 746 = 1492000\, W$$



$$I_a = \frac{1492000}{\sqrt{3} \times 2300 \times 1} < cos^{-1}(0) = 374.5 < 0°$$

$$E_{afm} = V_a - jx_{sm}I_a$$

$$= 1328 < 0 - (1.95 < 90)(374.5 < 0) = 1517 < -29°$$

Solving in p. u.

$$V_b = 2300\ \ V \qquad S_b = 1492000\ \ VA \qquad Z_b = \frac{2300^2}{1492000} = 3.5456$$

$$E_{afm} = V_a - jx_{sm}I_a = 1 < 0 - (\frac{1.95}{3.5456} < 90)(1 < 0) = 1.1413 < -29°$$

$$|E_{afmLL}| = (1.1413)(2300) = 2625\, V \quad |E_{afm}| = \frac{2625}{\sqrt{3}} = 1517\, V$$

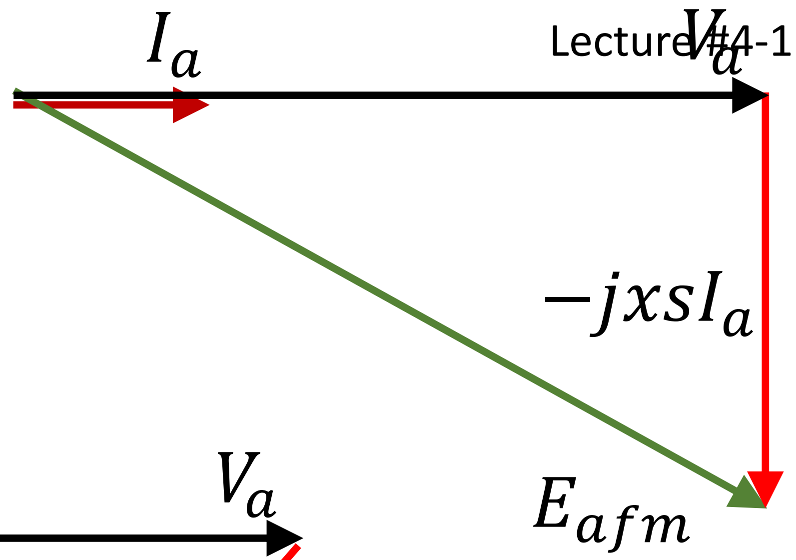
$$|E_{afLL}| = (1.1413)(2300) = 2625\,V$$

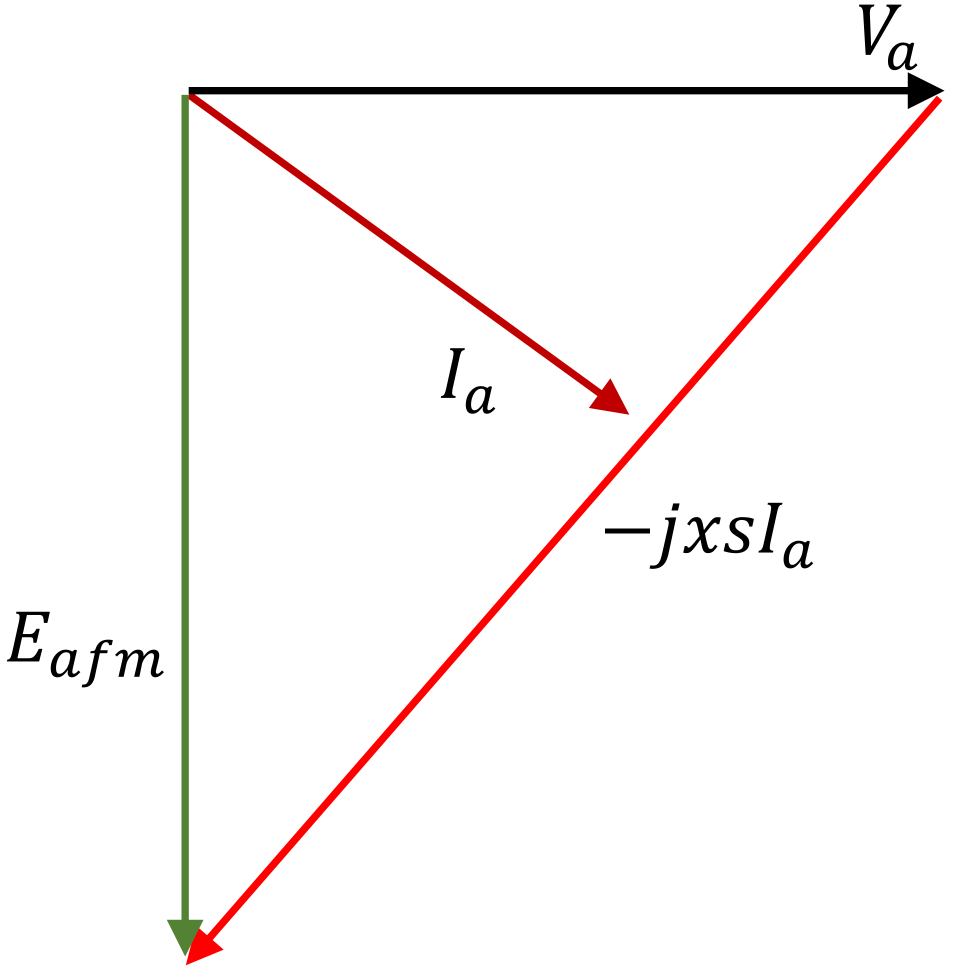
$$P_{max} = \frac{2300\times2625}{1.95} sin90 = 3096 \text{ KW}$$

$$\omega_s = 2\pi\frac{n_s}{60} = \frac{2\pi}{60}\frac{120f_s}{p} = 8\pi$$

$$T_{max} = \frac{P_{max}}{8\pi} = 123.2 \text{ kN.M}$$

$$I_a = ??$$





Solution(b):

$$V_a = \frac{2300}{\sqrt{3}} < 0^{\circ} = 1328 < 0^{\circ} \quad P = 2000 * 746 = 1492000\,W$$

$$I_a = \frac{1492000}{\sqrt{3} \times 2300 \times 1} < cos^{-1}(0) = 374.5 < 0°$$

$$E_{afm} = V_a - jx_{sm} I_a$$

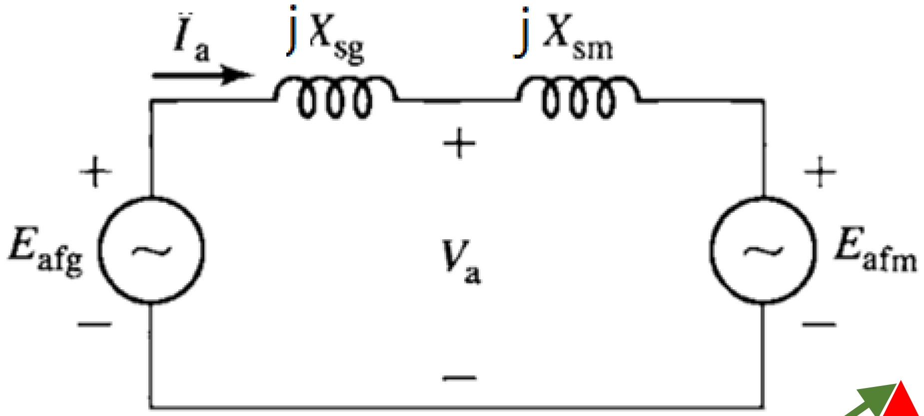
$$= 1328 < 0 - (1.95 < 90)(375.4 < 0) = 1517 < -29°$$

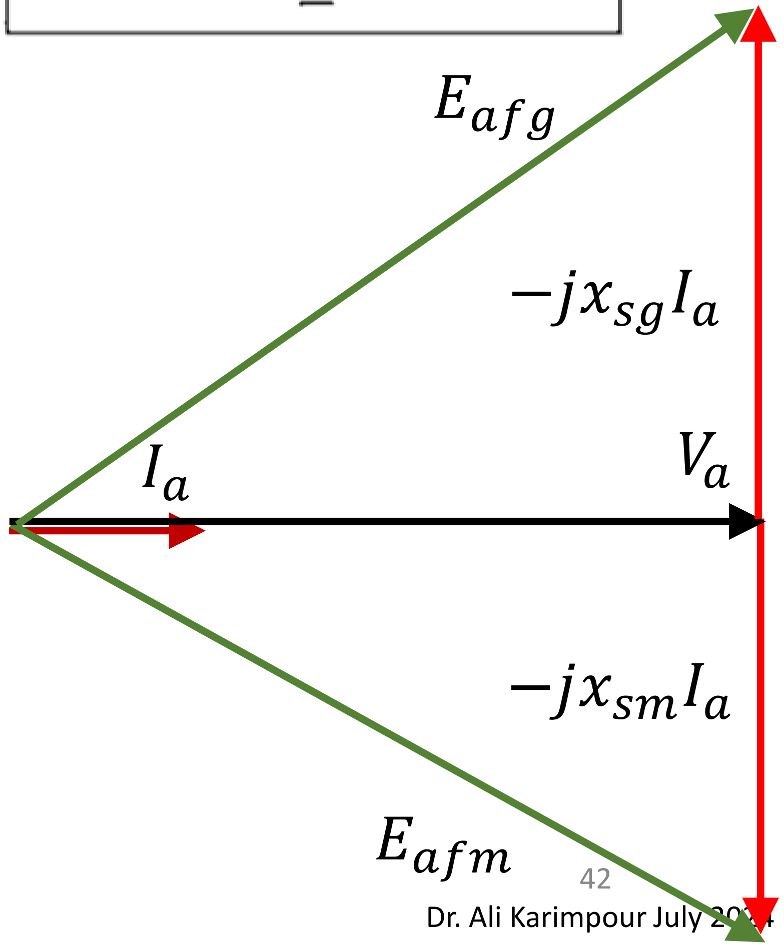
$$E_{afg} = V_a + jx_{sg} I_a$$

$$= 1328 < 0 + (2.65 < 90)(375.4 < 0) = 1659 < 37°$$

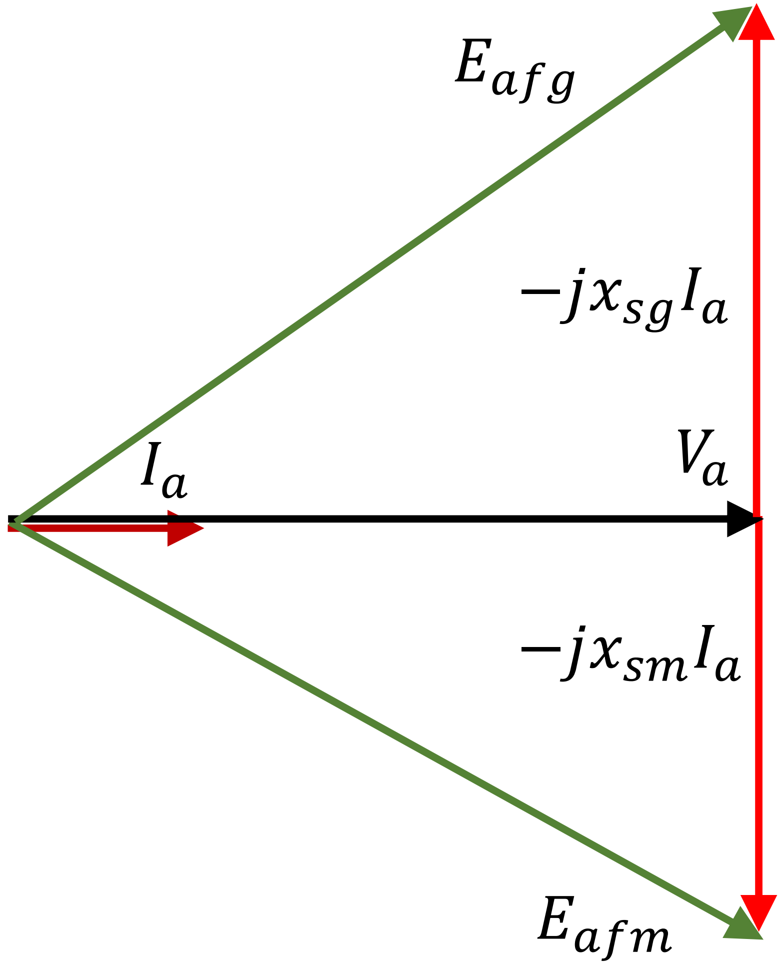
$$P_{max} = \frac{3 \times 1517 \times 1659}{1.95+2.65} sin90 = 1641\text{KW}$$

$$T_{max} = \frac{P_{max}}{8\pi} = 65.3 \text{ kN.M}$$





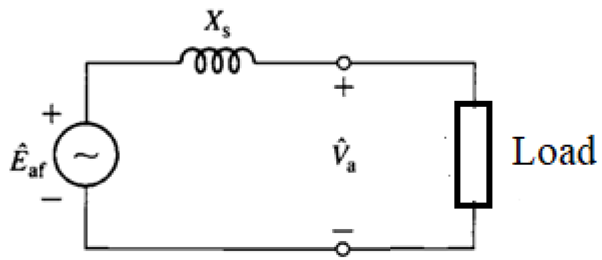
Exercise 1: Try to find terminal voltage and armature current in the maximum power output



Steady-State Power-Angle Characteristic

Different working condition for a synchronous machine

- Machine(generator) connected to a load. ($\hat{V}_a$ $isn't\ cte.$).



Assume a generator with zero armature resistance is connected to a load.

Assume the speed of the generator, determined by an external prime mover, is constant, but the input torque can vary.

The field winding current can be constant or adjusted by the user.

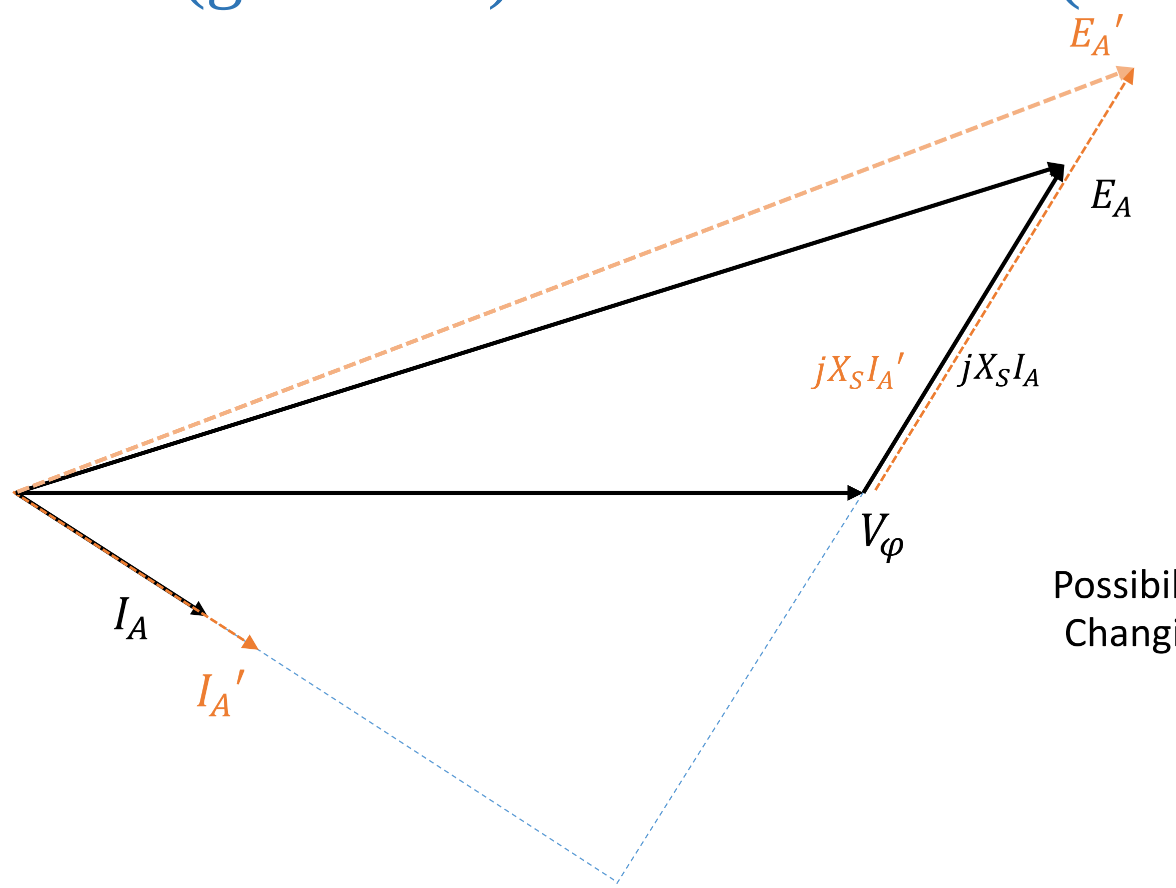
Why Might the user change the field current?

Examine the effect of load variation on terminal voltage (variation in I_A).

- Variation in the Magnitude of Current $|I_A|$
- Variation in the Phase of Current $<I_A$

Steady-State Power-Angle Characteristic

Machine(generator) connected to load(Isolated generator)



Changing the Magnitude of Load Current (Phase Lag Scenario)

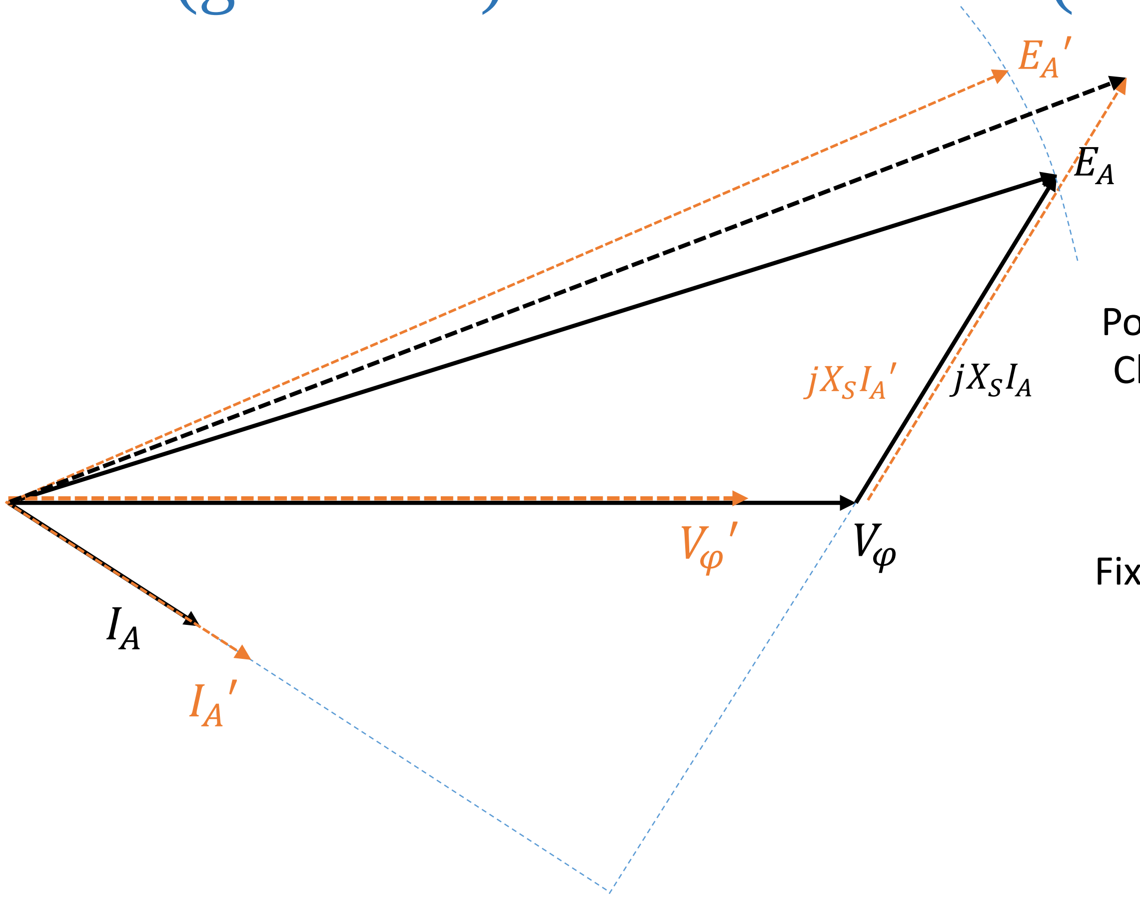
Possibility of Changing I_F → Possibility of Changing E_a → Fixing Terminal Voltage V_φ

What is the required change in field current?

Analytical solution?

Steady-State Power-Angle Characteristic

Machine(generator) connected to load(Isolated generator)



Changing the Magnitude of Load Current (Phase Lag Scenario)

Possibility of Changing I_F → Possibility of Changing E_a → Fixing Terminal Voltage V_φ

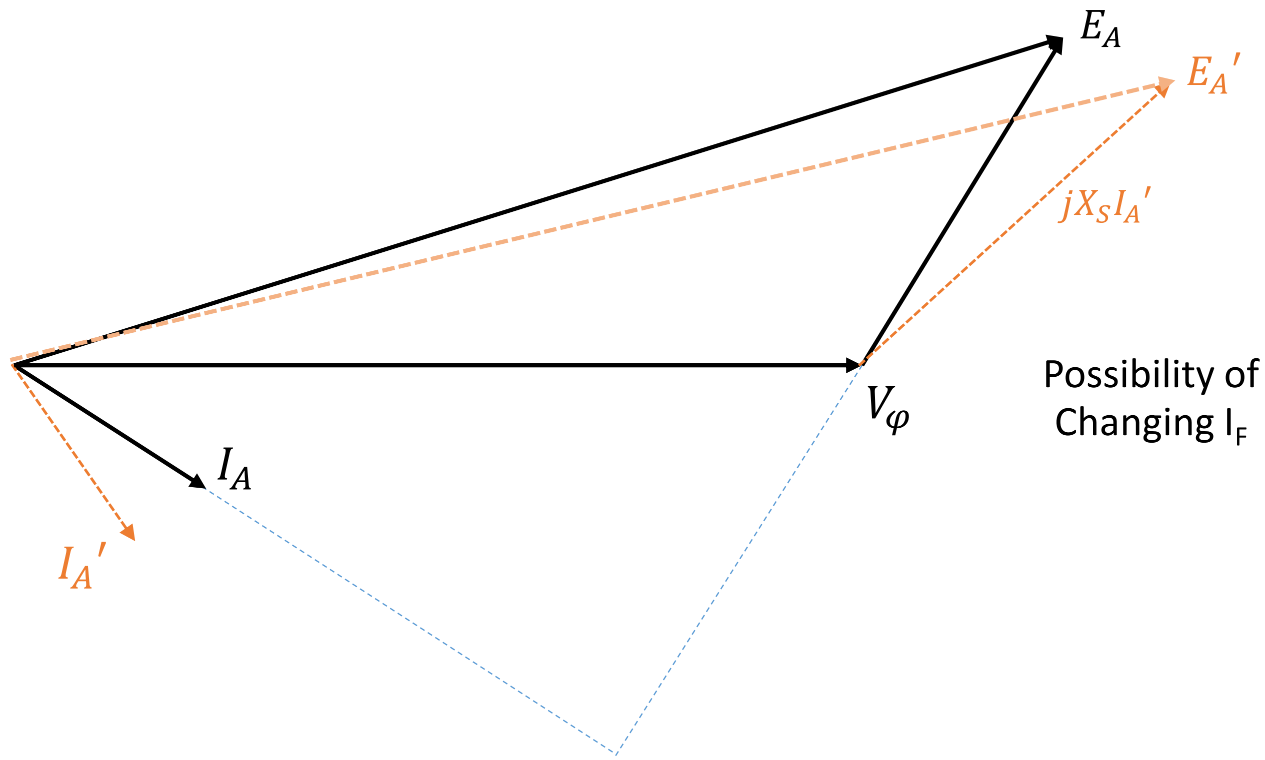
Fixing of I_F → Fixing of E_a → Possibility of Changing Terminal Voltage V_φ

Analytical solution?

What is the effect of increasing the load current magnitude on the phase terminal voltage of the generator for different types of loads (lagging, leading, and unity power factor)?

Steady-State Power-Angle Characteristic

Machine connected to load(Isolated generator)



Changing the Phase of Load Current(Phase Lag Scenario)

Possibility of Changing I_F → Possibility of Changing E_a → Fixing Terminal Voltage V_φ

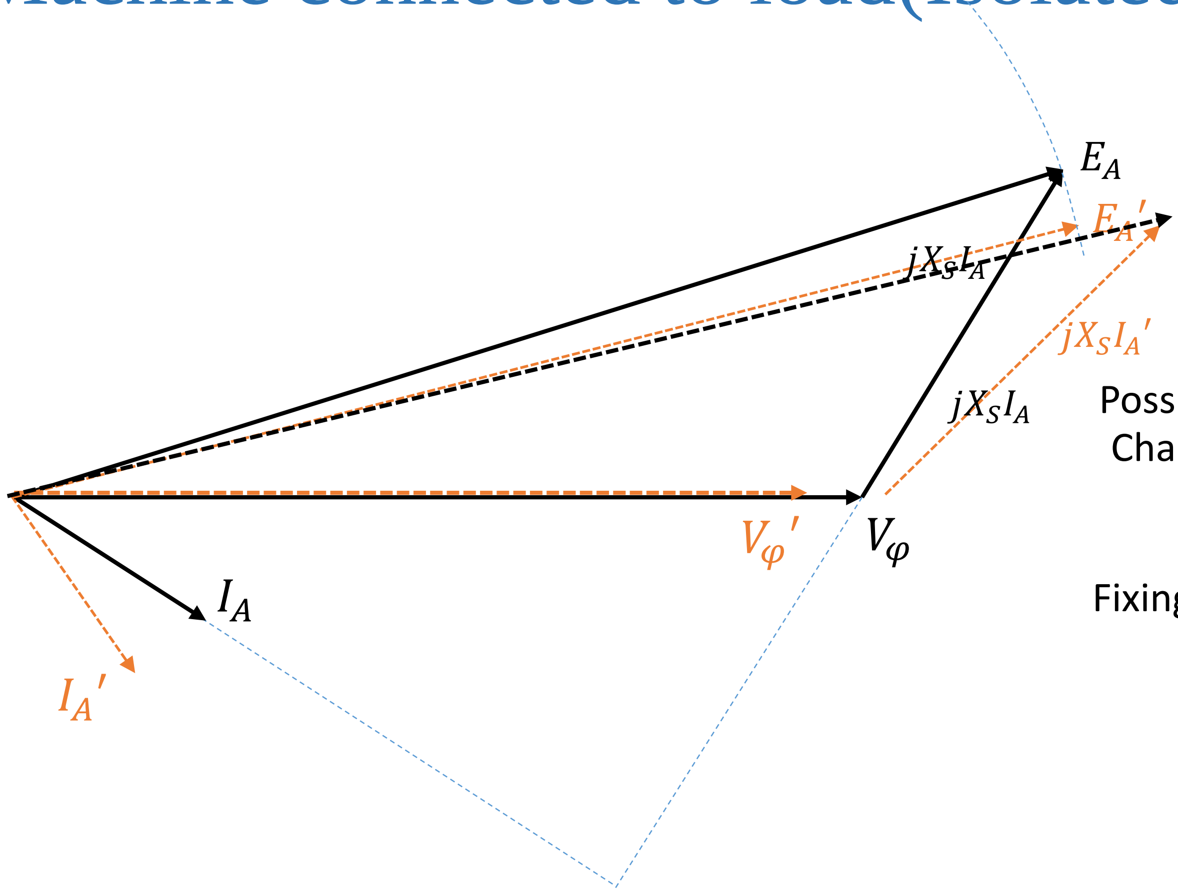
What is the required change in field current?

Analytical solution?

Steady-State Power-Angle Characteristic

Machine connected to load(Isolated generator)

تغییر زاویه جریان بار در ژنراتور تنها



Changing the Phase of Load Current (Phase Lag Scenario)

Possibility of Changing I_F → Possibility of Changing E_a → Fixing Terminal Voltage V_φ

Fixing of I_F → Fixing of E_a → Possibility of Changing Terminal Voltage V_φ

Analytical solution?

What is the effect of increasing the load current phase on the phase terminal voltage of the generator for different types of loads (lagging, leading, and unity power factor)?

Voltage regulation in synchronous Machines

$$\boxed{VR = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100\%}$$

Voltage regulation in synchronous generator

A synchronous machine with a synchronous reactance of 1.28 per unit is operating as a generator at a real power loading of 0.6 per unit connected to a system with a series reactance of 0.07 per unit. An increase in its field current is observed to cause a decrease in armature current.

a. Before the increase, was the generator supplying or absorbing reactive power from the power system?

b. As a result of this increase in excitation, did the generator terminal voltage increase or decrease?

c. Repeat parts (a) and (b) if the synchronous machine is operating as a motor.

عملا در موتورهای سنکرون در حال کار چگونه می توان توان راکتیو موتور را تنظیم کرد

با تغییر جریان آرمیچر	با تغییر جریان میدان
با تغییر راکتانس سنکرون	هیچکدام

ولتاژ تولید شده یک ژنراتور سنکرون 2000 ولت و ولتاژ ترمینال آن 1800 ولت است کدام عبارت قطعا برقرار است

ژنراتور در حال مصرف توان راکتیو است.	ژنراتور نه توان راکتیو تولید می کند و نه مصرف
ژنراتور در حال تولید توان راکتیو است.	با داشتن زاویه بین دو ولتاژ امکان اظهار نظر فراهم است.

توان تلفاتی باد و اصطکاک یک ماشین سنکرون

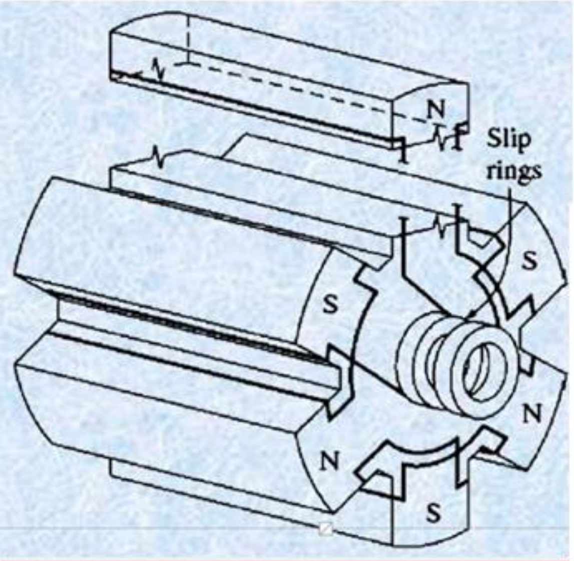
نمی توان اظهار نظر کرد	بستگی به تولید یا مصرف توان راکتیو دارد.
بستگی به میزان بار ماشین دارد.	ثابت است.

ولتاژ تولید شده یک ژنراتور سنکرون 3600 ولت و ولتاژ ترمینال آن 1800 ولت است اگر زاویه بین آن دو 60 درجه باشد آنگاه

با اطلاعات داده شده نمی توان اظهار نظر کرد.	ژنراتور در حال مصرف توان راکتیو است.
ژنراتور نه توان راکتیو تولید می کند و نه مصرف	ژنراتور در حال تولید توان راکتیو است.

رتور یک ماشین سنکرون 50 در شکل دیده می شود

سرعت کار دائم این موتور چند است؟



قدری کمتر از 1000 دور بر دقیقه	1000 دور بر دقیقه
قدری کمتر از 750 دور بر دقیقه	750 دور بر دقیقه

ژنراتور سنکرونی به ولتاژ نامی خود متصل است. مقاومت آرمیچر صفر و راکتانس نشتی بسیار کوچک است توان آهنی (فوکووهیسترزیس)

متناسب با جریان آرمیچر است.	متناسب با جریان میدان است
با توجه به کوچک بودن راکتانس نشتی خیلی کم است	با تقریب خوبی ثابت فرض می شود.

ژنراتور سنکرونی به ولتاژ نامی خود متصل است. تلفات اهمی سیم پیچ استاتور

به مجذور جریان میدان بستگی دارد.	هیچکدام
به جریان استاتور بستگی دارد.	با تقریب خوبی ثابت فرض می شود.