500 MVA, 3-phase, 4-pole, Y-connected synchronous generator connected to 22 kV infinite bus (line-to-line)

Prime mover power (i.e. mechanical power) is set to 300 MW, $X_s = 1,2\,\Omega$

a) Find E and load angle for a power factor of 0.8 lagging.

b) Double check the load angle from the power expression.

c) The field current is changed, and the power factor is adjusted to unity at 300 MW. Calculate the new load angle and the E.

$$S_{rated} = 3 V_{ph} I_{ph} = 3 \frac{22kV}{\sqrt{3}} I_{ph} = 500MVA \Rightarrow I_{ph(rated)} = 13,1\,kA$$

$$\omega_s = \frac{2\pi 50}{(4/2)} = 50\pi\ rad/s \Rightarrow (1500\ rpm)$$

(ω_s: mechanical synchronous speed)

$$P_{mech} = T.\omega_s$$

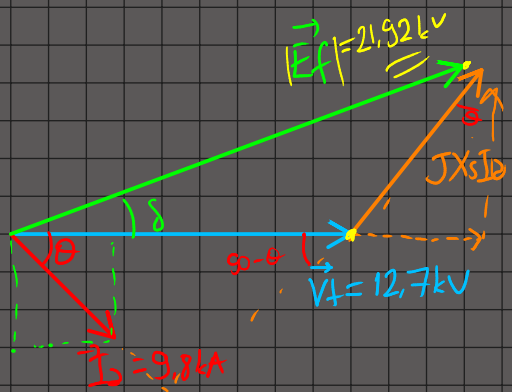
$$300MW = T.\,50\pi \Rightarrow T = 1,91\,M.Nm$$

a) $pf = 0,8$ lagging

$$P = 3.V_{ph}.I_{ph}.\cos(\theta) \Rightarrow 300MW = 3.\left(\frac{22kV}{\sqrt{3}}\right).I_{ph}.0,8$$

($\frac{22kV}{\sqrt{3}} = 12,7kV$)

$$I_{ph} = 9,8\,kA$$



$$|jX_s\vec{I}_a| = 1,2.9,8kA = 11,8kV$$

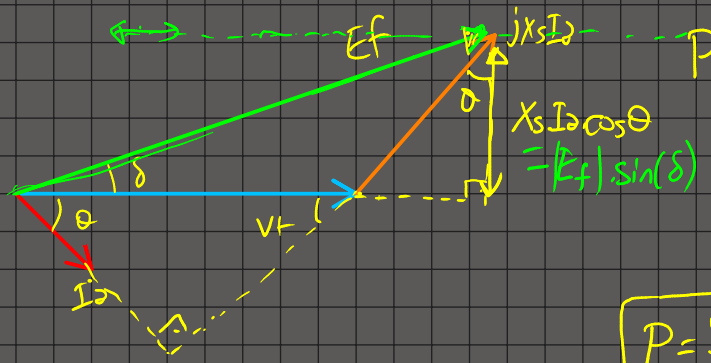
$$\vec{E}_f = \vec{V}_t + jX_s\vec{I}_a \qquad |E_f| = \overbrace{\qquad}^{0,8}$$

$$\vec{E}_f = (12,7kV + 11,8kV.\underbrace{\sin(\theta)}_{0,6}) + J.11,8kV.\cos(\theta)$$

$$|E_f| = \sqrt{(12,7k + 11,8k.0,6)^2 + (11,8.0,8)^2} = 21,92kV$$

$$\sin(\delta) = \frac{I_a.X_s\cos(\theta)}{|E_f|} = 0,43 \Rightarrow \boxed{\delta = 25,5^\circ}\ \checkmark$$

b) $P = \frac{3 \cdot V_t \cdot E_f \cdot \sin(\delta)}{X_s} \Rightarrow \frac{3 \cdot 12{,}7kV \cdot 0{,}43}{1{,}2} = 300MW$



$P = 3V_{ph} \cdot I_{ph} \cdot \cos(\theta)$

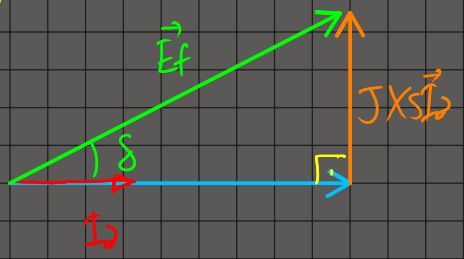
$X_s I_a \cos(\theta) = E_f \cdot \sin(\delta)$

$I_a \cos(\theta) = \frac{E_f \cdot \sin(\delta)}{X_s}$

$$\boxed{P = \frac{3 V_t \cdot E_f \cdot \sin(\delta)}{X_s}}$$

$P = T_1 \omega$

c) 300MW ⇒ unity pf



$P = 3 V_p I_p \cdot \overbrace{\cos(\theta)}^{1}$

$300MW = 3 \cdot \frac{22kV}{\sqrt{3}} \cdot I_a$

$I_a = 7{,}84kA$

$|Ef| = \sqrt{(12{,}7kV)^2 + (7{,}84 \cdot 1{,}2)^2}$

$$\boxed{|Ef| = 15{,}8kV}$$

$\sin(\delta) = \frac{7{,}84 \cdot 1{,}2}{15{,}8} \Rightarrow \boxed{\delta = 36{,}7°}$

↳ double check

$P = \frac{3 V_{ph} \cdot E_f \cdot \sin(\delta)}{X_s} = \frac{3 \cdot 12{,}7k \cdot 15{,}8k \sin(36{,}7°)}{1{,}2} = 300MW$