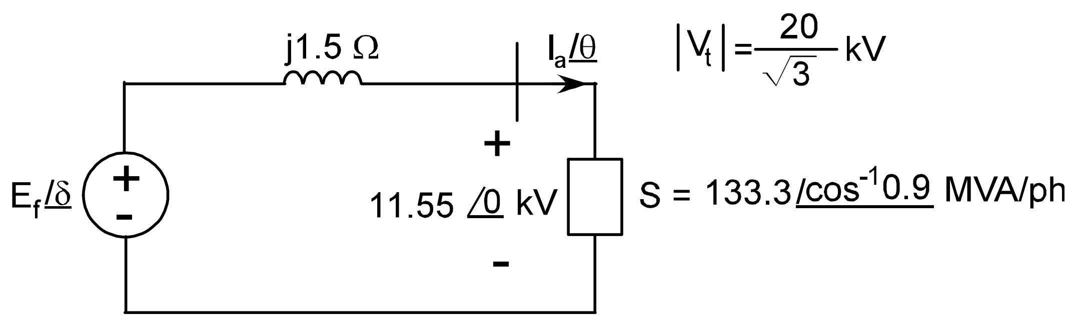
ECE370 POWER & ENERGY SYSTEMS
Homework Set 6 - Solutions

6.1 A 400 MVA, 20 kV, synchronous generator has a synchronous reactance of 1.5 Ω. The per-phase excitation voltage is determined by $|E_f| = 115 \cdot I_f$. Determine:

a) The single-phase equivalent circuit.
b) The load angle (δ) when rated load is supplied at rated voltage and 0.9 lagging.
c) The field current required.
d) The phasor diagram, drawn to scale using a protractor.
e) If the generator's OCC is given below, what is the %VR?

a) The single-phase equivalent circuit is:



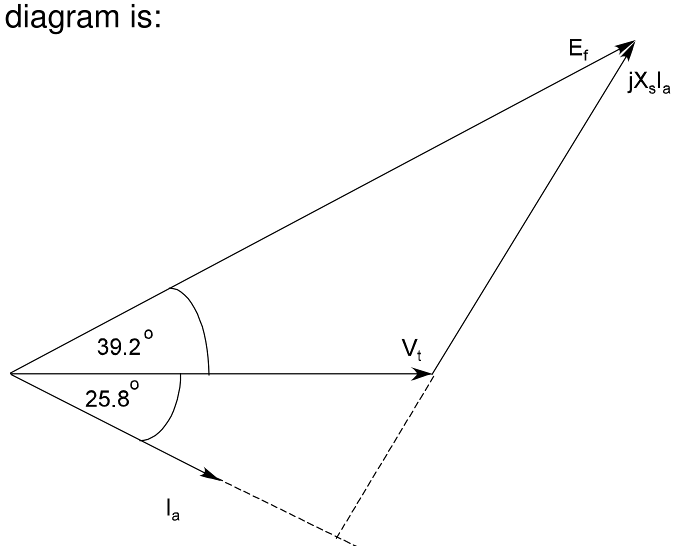
b) The current is: $\boldsymbol{I_a} = \left(\frac{S}{V_t}\right)^* = \frac{133.33\ x\,10^6 \angle -25.8}{11.55\ x\,10^3 \angle 0} = 11.55 \angle -25.8\ kA$

The excitation voltage is: $\mathbf{E_f}\underline{/\delta} = 11547\underline{/0} + j1.5 \times 11547\underline{/-25.8^0} = 25.65\underline{/39.2^0}$ kV

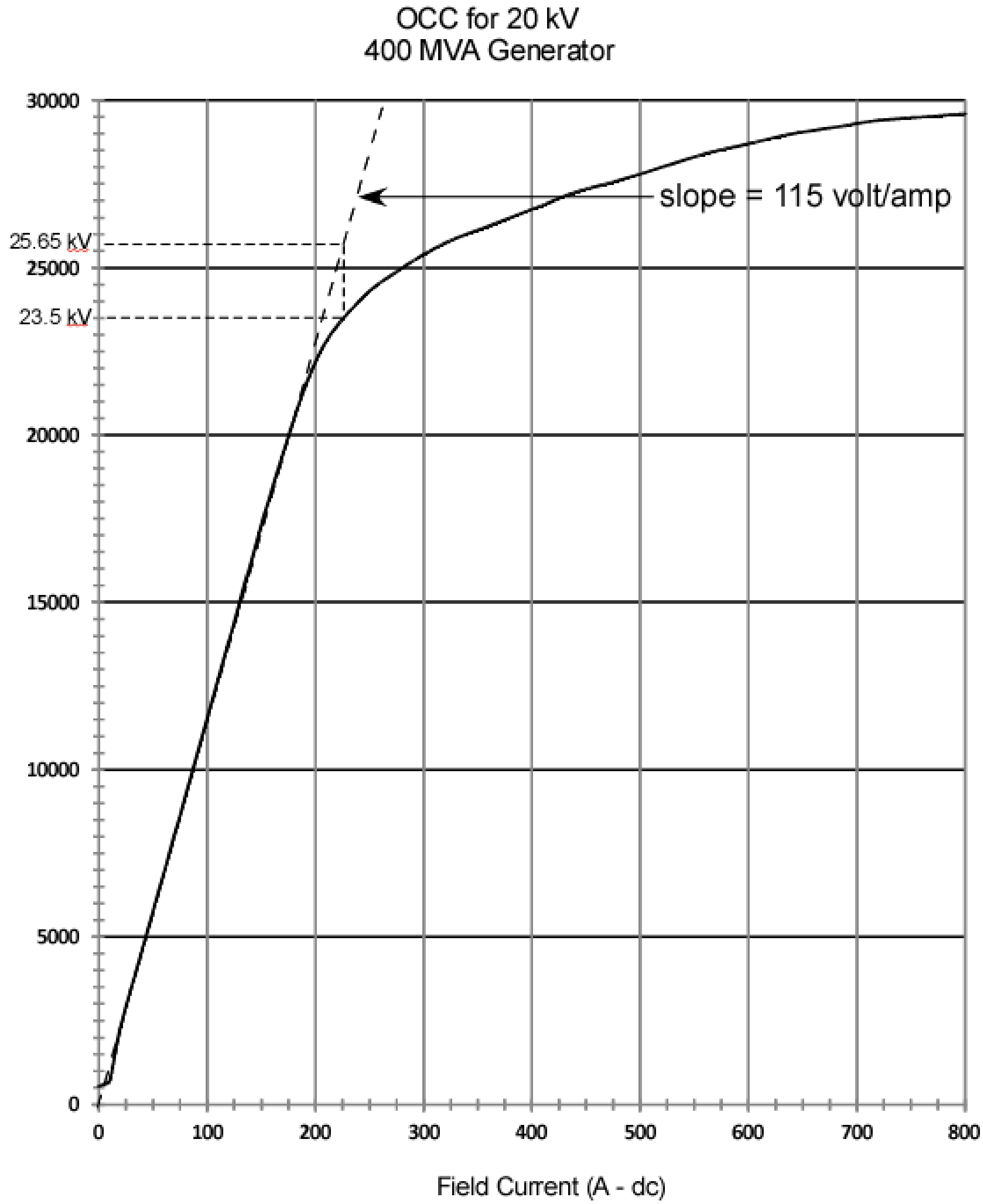
The load angle is the angle between $\boldsymbol{E_f}$ and $\boldsymbol{V_t}$ ∴ $\boxed{\delta = 39.2^0}$

c) The necessary field current is: $I_f = \frac{|E_f|}{K} = \frac{25.65\ x\,10^3}{115} \boxed{= 214.4 \quad A}$

d) The phasor diagram is:



e) The effect of saturation is accounted for as follows:

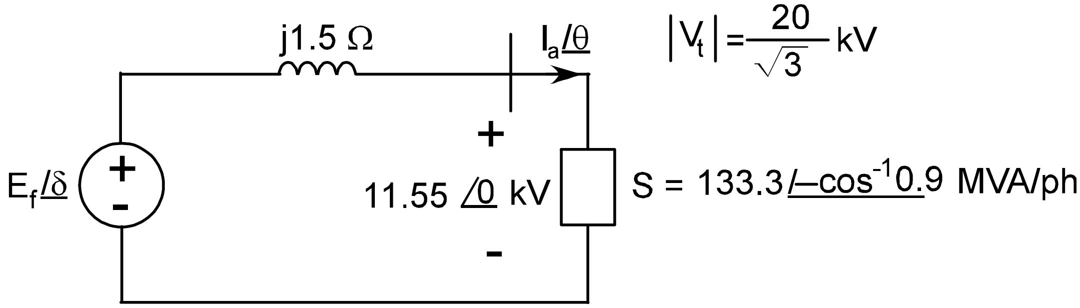


E_f' is read from the graph as 23.5 kV

$$VR = \frac{23.5 - 11.55}{11.55} \, x \, 100\% \; \boxed{= 103.5\%}$$

6.2 Repeat problem 6.1 if the pf is 0.9 lead.

a) The single-phase equivalent circuit is:



$$|V_t| = \frac{20}{\sqrt{3}}\ kV$$

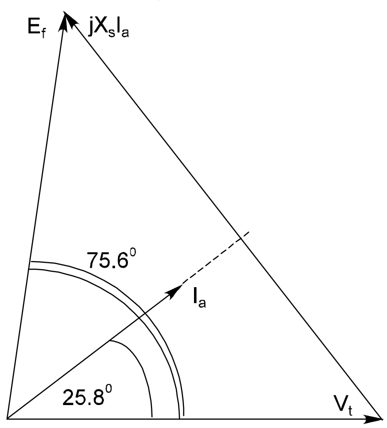
b) The current is: $\boldsymbol{I_a} = \frac{S}{V_t}^{*} = \frac{133.33\ x\,10^{6}\angle 25.8}{11.55\ x\,10^{3}\angle 0} = 11.55\angle 25.8\ kA$

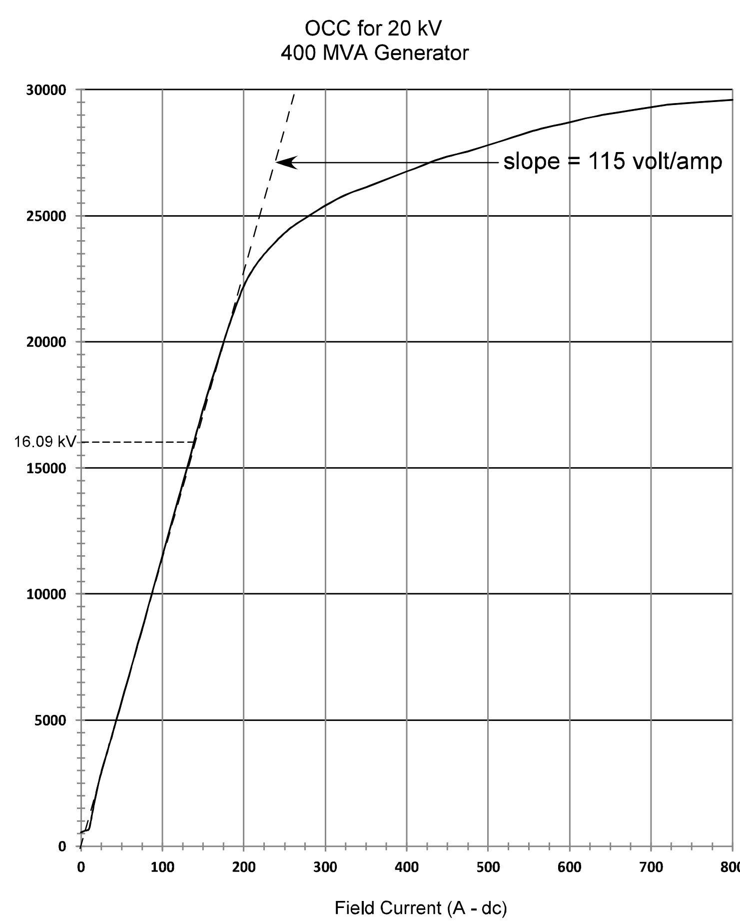
The excitation voltage is: $\mathbf{E_f}\underline{/\delta} = 11547\underline{/0} + j1.5 \times 11547\underline{/25.8^0} = 16.09\underline{/75.6^0}$ kV

The load angle is the angle between $\boldsymbol{E_f}$ and $\boldsymbol{V_t}$ ∴ $\boxed{\delta = 75.6^0}$

c) The necessary field current is: $I_f = \frac{|E_f|}{K} = \frac{16.09\ x\,10^{3}}{115} \boxed{= 139.9\ A}$

d) The phasor diagram is:





e) The effect of saturation is accounted for as follows:

$E_f' = 16.09$ kV is in the linear region:

$$VR = \frac{16.09 - 11.55}{11.55}\ x\,100\%$$

$\boxed{= 39.37\%}$

6.3 A synchronous generator has four poles and is running at 1500 rpm. The generator supplies a six-pole induction motor, which is used to drive a load at a speed of 750 rpm. Determine the frequency of the rotor current of the motor.

$$f_g = \frac{P_g n_g}{120} = \frac{(4)(1500)}{120} = 50 \text{ Hz}$$

$$n_{s,m} = \frac{120 f_g}{P_m} = \frac{(120)(50)}{6} = 1000 \text{ rpm}$$

$$s_m = \frac{n_{s,m} - n_m}{n_{s,m}} = \frac{1000 - 750}{1000} = 0.25$$

$$f_{r,m} = s_m f_g = (0.25)(50) = 12.5 \text{ Hz}$$

6.4 A three-phase, 100-hp, 480-V, 60-Hz, induction motor runs with no load on the shaft and is observed to run at 1194 rpm. Determine (a) the number of poles and (b) the frequency of the rotor currents at no load.

(a) $n = 1194$ rpm

$n_s = 1200$ rpm

$$p = \frac{120 f}{n_s} = \frac{(120)(60)}{1200} = 6 \text{ poles}$$

(b)

$$s = \frac{n_s - n}{n_s} = \frac{1200 - 1194}{1200} = 0.005$$

$$f_r = sf = (0.005)(60) = 0.3 \text{ Hz}$$

6.5 At full load, the motor of Problem 6.4 slows down to 1146 rpm. Find the frequency of the rotor currents.

$$s = \frac{n_s - n}{n_s} = \frac{1200 - 1146}{1200} = 0.045$$

$$f_r = sf = (0.045)(60) = 2.7 \text{ Hz}$$

6.6 A three-phase, six-pole induction motor is operating at 960 rpm from a ***50-Hz***, 230-V supply. The voltage induced in the rotor when the motor is blocked is 180 V. Determine:

a) Slip speed
b) Rotor frequency
c) Rotor voltage at 960 rpm

$$n_s = \frac{120f}{p} = \frac{(120)(50)}{6} = 1000 \text{ rpm}$$

ⓐ slip speed $= n_s - n = 1000 - 960 = 40$

ⓑ $$s = \frac{n_s - n}{n_s} = \frac{1000 - 960}{1000} = 0.04$$

$$f_r = sf = (0.04)(50) = 2 \text{ Hz}$$

ⓒ $$V_r = s V_{bl} = (0.04)(180) = 7.2 \text{ V}$$