ECE 431 Electric Machinery Name: Solutions

Test #2 April 5, 2019 NetID: ____________________

You may use one 2-sided sheet of your own hand-written notes as reference.

Please do all work on this test. Label any solutions that are written on the backs of pages or on any spare sheets.

Q1. (35 Points)

A 480V (line voltage), 4 pole, 60 Hz synchronous motor is drawing 30A from the grid at 0.95 lagging power factor. The motor is operating with a field current of 5A and a synchronous reactance of 10 ohms.

a) Calculate the internal voltage and load angle.
b) Draw the phasor diagram corresponding to this operating condition, and using dashed lines, overlay the phasor diagram when operating at unity power factor with constant excitation.
c) Calculate the armature current, internal voltage, load angle of the synchronous motor when it is operated at unity power factor with constant excitation.

a) $\theta = -\cos^{-1} 0.95$

$= -18.19°$

$I_a = 30 \angle -18.19° \text{ A}$

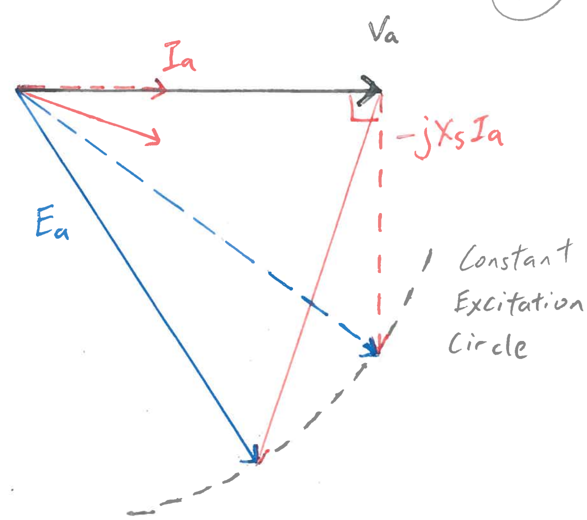
$V_a = \frac{480}{\sqrt{3}} = 277.13 \angle 0° \text{ V}$

$E_a = V_a - jX_s I_a$

$= 338.96 \angle -57.23° \text{ V}$

(10)

b) (15)



c) $|E_a| = 338.96 \text{ V}$

$|V_a| = 277.13 \text{ V}$

$|X_s I_a| = \sqrt{|E_a|^2 - |V_a|^2}$

$= 195.17 \text{ V}$

$I_a = \frac{|X_s I_a|}{10} = 19.52 \angle 0° \text{ A}$ — (5)

$E_a = V_a - jX_s I_a$

$= 338.96 \angle -35.13° \text{ V}$ — (5)

Q2. (30 Points)

A synchronous generator with a synchronous reactance of 0.5pu is supplying the grid at rated voltage, rated KVA and 0.85 lagging power factor. A fault occurs and reduces the generator output voltage to 0.5pu. After the fault is cleared, the output voltage is restored to rated voltage.

a) Calculate the initial internal voltage(pu) and load angle.
b) Draw the power curves for the generator and mark out the areas and angles that are required to evaluated generator stability using the equal area criterion.
c) Write out the equations required to calculate the critical angle. DO NOT solve for the critical angle.

a) $\theta = -\cos^{-1} 0.85$

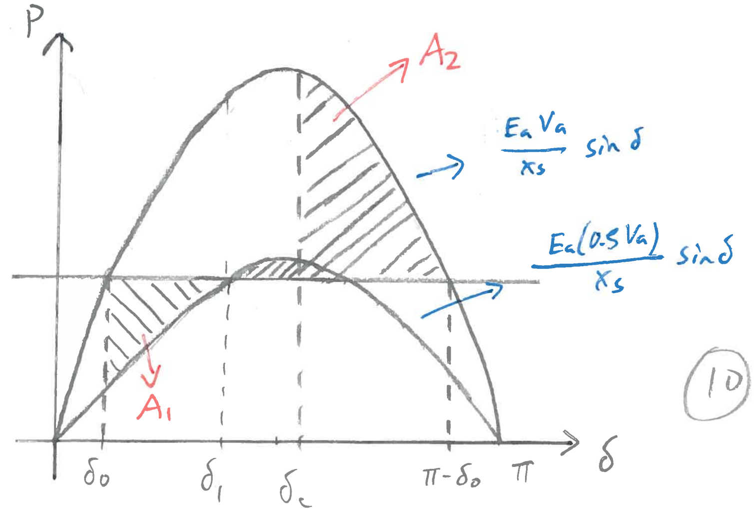
$= -31.79°$

$I_a = 1.0 \angle -31.79°$ pu

$E_a = V_a + j X_s I_a$

$= 1.33 \angle 18.59°$ pu (10)

$\delta_0 = 18.59° = 0.3245$ rad

b) 

c) $A_1 = \int_{\delta_0}^{\delta_1} 0.85 - \frac{E_a \cdot (0.5 V_a)}{X_s} \sin\delta \, d\delta$

$= \int_{\delta_0}^{\delta_1} 0.85 - 1.33 \sin\delta \, d\delta$

$A_2 = \int_{\delta_c}^{\pi-\delta_0} \frac{E_a V_a}{X_s} \sin\delta - 0.85 \, d\delta + \int_{\delta_1}^{\delta_c} \frac{E_a(0.5 V_a)}{X_s} \sin\delta - 0.85 \, d\delta$

$= \int_{\delta_c}^{\pi-\delta_0} 2.66 \sin\delta - 0.85 \, d\delta + \int_{\delta_1}^{\delta_c} 1.33 \sin\delta - 0.85 \, d\delta$

(10)

$A_1 = A_2$

Q3. (35 Points)

A DC shunt motor has an armature resistance of 0.05 Ohms and a field resistance of 180 Ohms. A no-load speed of 1840 rpm is obtained when the motor is connected to a 200V supply. The motor is now connected to a load at the same voltage. Assume the load torque can be approximated by the following relationship,

$$T_{load} = 36 + 0.5\omega \text{ Nm}$$

a) Calculate the motor speed at load
b) Calculate the speed if the supply voltage is reduced to 120V
c) What is the efficiency of the DC motor when operated at the new voltage?

$I_f = \frac{200}{180} = 1.11 A$

At no-load ; $I_a = 0$

$E_a = 200V$, $\omega = 192.68$ rad/s

$E_a = K_f I_f \omega$ $\quad K_f = 0.935 \frac{V \cdot S}{A \cdot rad}$

a) $T_{load} = T_{motor}$

$36 + \frac{\omega}{2} = K_f I_f I_a$

$= K_f I_f \frac{V_a - E_a}{R_a}$

$36 + \frac{\omega}{2} = K_f I_f \frac{V_a - K_f I_f \omega}{R_a}$

$\omega = 186.7$ rad/s

(10)

b) $I_f = \frac{120}{180} = 0.667 A$

$36 + \frac{\omega}{2} = K_f I_f \frac{V_a - K_f I_f \omega}{R_a}$

$\omega = 176.45$ rad/s

(10)

c) $T = 36 + \frac{\omega}{2}$

$= 124.22$ Nm

$E_a = K_f I_f \omega$

$= 110.04$ V

$I_a = \frac{V_a - E_a}{R_a}$

$= 199.16 A$

~~$P_{in} = V_a I_a = 23899$ W~~ $P_{in} = V_a (I_a + I_f)$

$= 23979$ W

$P_{out} = T\omega = 21919$ W

$\eta = \frac{P_{in}}{P_{out}} \times 100$ ~~$= 91.71\%$~~

$= 91.41\%$

(15)