ECE 431 Electric Machinery Name: Solutions

Test #1 February 20, 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.

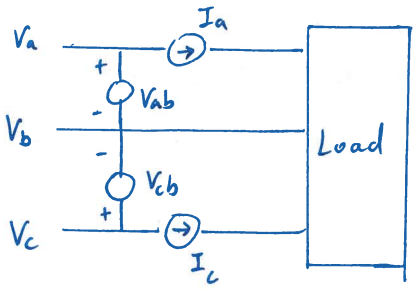
Q1. (20 Points)

A 480 V three-phase source is supplying a wye-connected load of 20 + j5 Ω per phase.

a) Draw a schematic showing how you would use the two watt-meter method to measure total power and compute the readings of each meter. (voltage, current, power)

b) A capacitor bank is connected in parallel to the load to bring the power factor to unity. Find the phase current supplied by the source after compensation.

a) (5)



$V_a = 480/\sqrt{3}$ V

$I_a = \frac{V_a \angle 0^\circ}{20 + j5} = 13.44 \angle -14.04^\circ$ A (2)

$\theta = 14.04^\circ$

$V_1 = V_2 = 480$ V (2)

$I_1 = I_2 = 13.44$ A

$P_1 = 480 \cdot 13.44 \cdot \cos(30^\circ + 14.04^\circ)$ (3)

$= 4637.5$ W

$P_2 = 480 \cdot 13.44 \cdot \cos(30^\circ - 14.04^\circ)$ (3)

$= 6202.5$ W

b)

$P_{total} = P_1 + P_2$ (5)

$= 10840$ W

$I_{new} = \frac{P_{total}}{3 \cdot \frac{480}{\sqrt{3}}}$

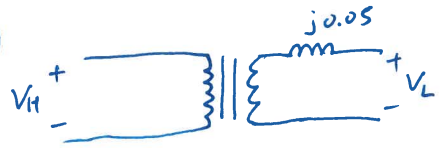
$= 13.04$ A

Q2. (20 Points)

A single-phase transformer is rated at 50 kVA, 60 Hz, 4160/480 V. The nameplate shows 5% series impedance. Assume low magnetizing current and negligible series resistance.

a) A single-phase load is connected to the transformer LV side, drawing 50 kVA at unity power factor and rated voltage. Compute the load regulation.
b) If the transformer is to be used in a 50Hz grid, how should the ratings be changed for safe operation within the transformer capabilities?

a)



Rated Voltage $\rightarrow V_L = 1.0\angle 0^\circ$ pu

Rated power, Unity p.f. $\rightarrow I_L = 1.0\angle 0^\circ$ pu

$$V_H = 1.0 + 1.0(j0.05)$$
$$= 1.0013\angle 2.86^\circ \text{ pu}$$

$$\% \text{ Load Regulation} = \frac{|V_H| - 1.0}{1.0} \times 100\%$$
$$= 0.1249\%$$

(9)

b) Flux density in core should be kept constant

$\rightarrow$ V/f should maintain a constant ratio

$$V_{H,new} = \frac{50}{60} \times 4160$$
$$= 3466.7 \text{ V}$$

(3)

$$V_{L,new} = \frac{50}{60} \times 480$$
$$= 400 \text{ V}$$

(3)

Current rating remains constant

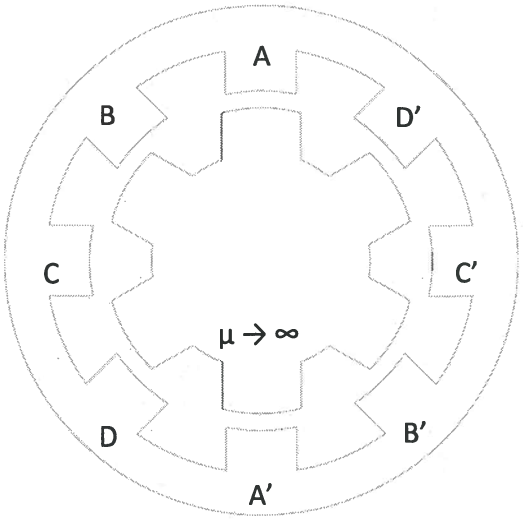
$$\rightarrow \text{KVA rating} = \frac{50}{60} \times 50\text{k}$$
$$= 41.7 \text{ KVA}$$

(5)

Q3. (30 Points)

A switched reluctance machine with an 8/6 configuration has the following parameters:

- Rotor outer radius = 6 cm
- Air gap, g = 1 mm
- Rotor pole angle = π/6 rad
- Stator pole angle = π/6 rad
- Axial length, l = 10 cm
- Total turns per phase = 100



Assume infinite reluctance when the poles are unaligned, and ignore the effects of fringing and saturation.

a) Starting from the position as shown, using single phase excitation, what should be the excitation sequence to obtain a counter-clockwise rotation of the rotor?
b) How fast would the rotor spin (in rpm) if excitation is applied at a frequency of two pulses per millisecond?
c) Phase A current is set to 1A, with all other currents set to zero. Plot the phase A inductance and torque as a function of θ as the rotor is rotated counter-clockwise.
d) If the rotor and stator pole angles are both reduced to π/8, plot the new phase A inductance and torque under the same conditions.

(5)

a) A → D → C → B → A

(5)

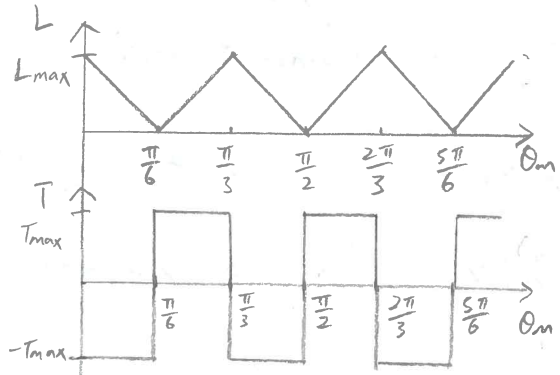
b) $f = 2\,kHz$

$S = 4 \cdot 6 = 24$

$n = \frac{f}{S} \times 60$

$= 5000\ rpm$

c)



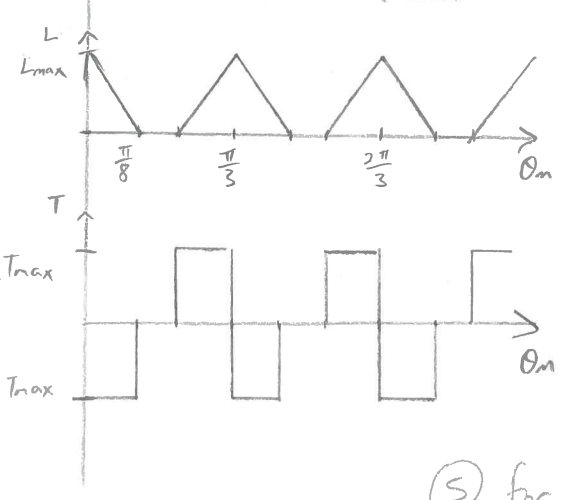
$L_{max} = \frac{100^2 \mu_0 (0.06)(0.1)(\pi/6)}{2 \cdot 0.001}$

$= 0.01974\ H$

$T_{max} = \frac{1}{2}(1^2)\frac{L_{max}}{\pi/6}$

$= 0.01885\ Nm$

d)



$L_{max} = \frac{100^2 \mu_0 (0.06)(0.1)(\pi/8)}{2 \cdot 0.001}$

$= 0.0148\ H$

$T_{max} = 0.01885\ Nm$

(5) for each plot.

Q4. (30 Points)

a) An induction motor is rated to operate at 850 rpm, based on your judgement, what is:

i. synchronous speed of this motor?

ii. the rated slip?

iii. the frequency of the rotor currents at rated speed?

b) You are an engineer in search of a motor to drive a load whose torque profile is given by

$$T_{load} = 50 + 0.2\,\omega_m \text{ Nm}$$

A three-phase, 4 pole, 480 V, 60 Hz motor with the following parameters is available:

$$R_1 = R_2' = 0.5\ \Omega,\ X_1 = X_2' = 1\ \Omega,\ X_m = 100\ \Omega,\ R_C = 400\ \Omega$$

i. Can this induction motor start when the load is applied?

ii. What is the peak inrush current when it is started at rated voltage?

iii. By estimation or otherwise, calculate the slip of the motor when driving this load.

a) i) $N_s = 900$ rpm (5)

ii) $s = \frac{50}{900} = 0.0556$ (5)

iii) $f_r = sf_s = (0.0556)(60)$ (5)

$= 3.336$ Hz

b) i) $T_{start} = \frac{4}{2}\frac{3}{120\pi}\frac{\left(\frac{480}{\sqrt{3}}\right)^2(0.5)}{1^2+2^2}$

$= 122.3$ Nm (5)

Yes, the motor will start

ii)

$$I_{start} = \frac{480/\sqrt{3}}{0.5 + 1j + \left(\frac{1}{400} + \frac{1}{100j} + \frac{1}{0.5+1j}\right)^{-1}}$$

$= 124.6 \angle -63.5^\circ$ A (5)

iii) $T_e = T_{load}$

$$\frac{4}{2}\frac{3}{120\pi}\frac{\left(\frac{480}{\sqrt{3}}\right)^2\frac{0.5}{s}}{\left[\left(0.5+\frac{0.5}{s}\right)^2+2^2\right]} = 50 + 0.2\left[(1-s)\frac{2}{4}(120\pi)\right]$$

(5)

$s = 0.0389$

Approx ≈ 0.035