

Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science
 6.061/6.690 Introduction to Power Systems

Quiz 2

Solutions

May 18, 2011

Closed Book: Two Handwritten Crib Sheets Allowed

Please put your answers in the spaces provided on the quiz. You may, if you wish, turn in your work on additional sheets of paper. Hopefully you will get all the answers correct so I don't have to look at those sheets.

Problem 1 A Permanent Magnet DC machine (remember: this is just like a separately excited machine with fixed field excitation) has a measured armature resistance of 1Ω . When the rotor is locked so it can't rotate and the machine is driven by a current of 1 Ampere, the motor produces a torque of 1 N-m. This means $K = 1\text{N-m/A} = \text{V/Rad/Sec}$

1. If the machine is connected to a terminal voltage of 100 Volts DC, with mechanical loading of zero, how fast does it turn?
 $K\Omega = V$ or $\Omega = 100\text{Rad/Sec}$
2. If the shaft is loaded with a torque of 5 N-m, what terminal voltage is required to make the motor turn at a speed of 100 Radians/Second? $I = 5\text{A}$, so $V = K\Omega + RI = 105\text{V}$

Problem 2 1. If the gap $g = 1\text{mm}$, what is the total lifting force?

$$\frac{NI}{g} = \frac{1,600}{2 \times 10^{-3}} = 800,000\text{A/m}$$

so $B = 1\text{T}$ and force per unit area is $F = \frac{B^2}{2\mu_0} = 400,000\text{N/m}^2$ Since area $A = 2 \times .01 = .02\text{m}^2$, total force is $f = .02 \times 400,000 = 8,000\text{N}$.

2. Assume the material saturates abruptly at a flux density of 2 T. What is the maximum lift force and at what gap does it occur?
 B will double if g is halved. Force is proportional to B^2 , so $f = 4 \times 8,000 = 32,000\text{N}$ and $g = .5\text{mm}$

Problem 3 The induction motor equivalent circuit could be transformed as shown in Figure 1

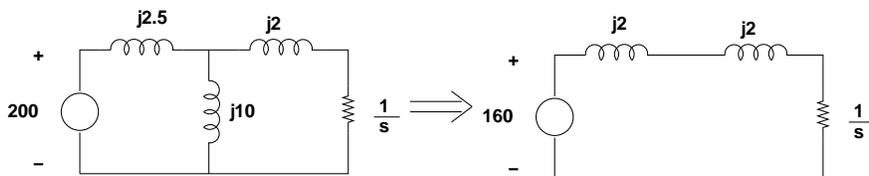


Figure 1: Equivalent Circuit

This is because $V' = 200 \times \frac{10}{12.5} = 160$ and $X' = 2.5 \parallel 10 = 2.0$.

1. At what rotational speed does the motor achieve maximum (breakdown) torque? (Give this in radians/second.)

This will happen when $\frac{R_2}{s} = 4\Omega$, or $s = \frac{1}{4}$. Then $\omega = .75 \times 200 = 150\text{Rad/s}$ Mechanical speed is $\Omega = \frac{\omega}{p} = 75\text{Rad/s}$

2. What IS that maximum torque?

$$I_2^2 = \frac{160^2}{4^2 + 4^2} = 160 \times \frac{160}{32} = 800A^2$$

$$T = 3 \frac{p}{\omega} |I_2|^2 \frac{R_2}{s} = 3 \times \frac{2}{200} \times 800 \times 4 = 12 \times \frac{800}{100} = 96\text{n-m}$$

Problem 4 The machine is tested at its rated speed and, with a field current of 1000 Amperes, open circuit terminal voltage is measured to be 10,000 Volts, *Peak* in each phase.

$$E_{af} = \omega M I_f, \text{ or } M = \frac{10,000}{400 \times 1,000} = \frac{10}{400} = 25\text{mH}$$

With the terminals short circuited and operated at rated speed with a field current of 1000 Amperes, phase current is measured to be 1000 Amperes, *Peak*.

$$X_d = \frac{10,000\text{V}}{1,000\text{A}} = 10\Omega$$

1. The machine is operated with a balanced three-phase current source that puts 1000 Amperes *Peak* in each phase winding. With 1000 Amperes DC in the field winding, what is the maximum torque the machine can produce?

$$T_e = \frac{3}{2} p M I_f \sin \delta \quad T_{\max} = \frac{3}{2} \times 2 \times .025 \times 10 \times 10^6 = 75,000\text{N-m}$$

2. Now the machine is operated with a balanced three-phase voltage source that puts 10,000 Volts *Peak* across each phase winding. What is the maximum torque the machine can produce if the field current is 1,000 A?

$$T_e = \frac{3}{2} \frac{p}{\omega} \frac{V E_{af}}{X} \sin \delta \quad T_{\max} = \frac{3}{2} \times \frac{2}{400} \times \frac{10,000^2}{10} = \frac{3}{4} \times 10^5 = 75,000\text{N-m}$$

3. Now, operating as a generator with 10 kV terminal voltage across each phase winding and a current of 1,000 A *both Peak values*, and at unity power factor:

- Draw a phasor diagram for this operation, showing internal voltage (E_{af}), terminal voltage and voltage across machine reactance.

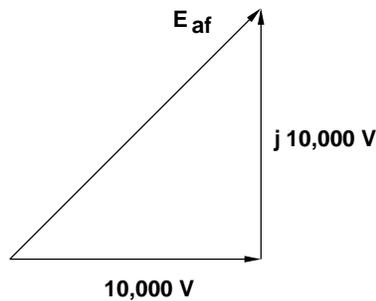


Figure 2: Required vector diagram

- What is the torque angle δ ?

$$\delta = \frac{\pi}{4} = 45^\circ$$

- What is the field current? $I_f = \sqrt{2} \times 1000 = 1,424.2\text{A}$

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