Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science
6.685 Electric Machines

Problem Set 7

Issued October 14, 2013
Due October 23, 2013

Problem 1: Induction Motor

Here is a description of a 350 kW induction motor:

Voltage	V	600	Line-line, RMS
Frequency	F	60	Hz
Number of Pole Pairs	p	4	
Stator Leakage Reactance	X_1	38	mΩ
Stator Resistance	R_1	17	mΩ
Rotor Leakage Reactance	X_2	114	mΩ
Rotor Resistance	R_2	10	mΩ
Magnetizing Reactance	X_m	3.5	Ω

For this motor, assume core loss at rated frequency and voltage is 10 kW, and that this core loss is proportional to flux density to the power of 2.2 and to frequency to the power of 1.8. That is:

$$P_c = P_{c0} \left(\frac{f}{f_0}\right)^{1.8} \left(\frac{B}{B_0}\right)^{2.2}$$

Assume also that friction and windage loss is proportional to the cube of rotor speed and is 8 kW at rated speed.

Finally, assume that 'stray' loss is 2.5% of output power (8750 Watts at rated power) and is directly proportional to output power.

1. Ignoring all of those added loss elements (Core, Friction, Windage and Stray, generate and plot a torque-speed curve for this motor, at rated terminal voltage and frequency.

2. Now, accounting for the added loss elements, estimate and plot motor efficiency and terminal power factor, while the motor is operated at rated terminal voltage and frequency for mechanical loads between 100 kW and 400 kW. (Yes, we are overloading the machine.)

Problem 2: The very same motor you analyzed in Problem 2 is to be used in an adjustable speed drive application. For lower speeds, the motor is to be driven by a balanced voltage that is proportional to frequency ('constant volts per Hz'). For drive frequency greater than 60 Hz, the terminal voltage is fixed at 600 V, RMS, line-line.

1. Plot torque-speed curves for this motor and drive combination, for frequencies of 20, 40, 60, 80, 100 and 120 Hz. Be sure to use the right terminal voltages.

2. Calculate and plot efficiency and power factor for the motor operating at a power output of 175 kW over a range of speeds from about 450 to 1,800 RPM. Note that you may find it convenient to fix electrical frequency and do a cross-plot, so your plot may not extend exactly between these two speeds.

Problem 3: A picture of the cross-section of a slot is shown in Figure 1. While it is unlikely this slot would be used in an actual induction motor, its geometry is at least tractable. The slot is in material that is perfectly permeable but non-conducting, an approximation to laminated iron. The slot is filled with a conductor with the conductivity of copper (IASC= 5.81×10^7 S/m).

1. Find and plot the impedance per unit length for current carried by the slot in the axial direction (into the paper). That is, volts/meter per ampere. Do this over the frequency range of $1 < f < 1000$ Hz. Plot resistance $R(f)$, reactance $X(f)$, impedance magnitude and angle: $|Z|(f)$ and $\angle Z(f)$. Use log-log coordinates for R, X and $|Z|$ and log-linear coordinates for the angle. You will probably want to use a mathematical assistant to do the heavy lifting and plotting here. The solutions will be done using MATLAB.

2. Now we are going to look into the impact of 'deep bars' on large induction motors. Assume that the bars of the induction motor of Problem 1 are shaped like the bar you just analyzed. Assume that all of the rotor resistance (R_2) and 80% of rotor leakage (X_2) are due to the rotor slots. Re-plot the torque-speed curve of Problem 1, Part 1.
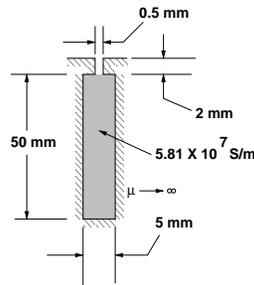

Figure 1: Notional Slot

6.685 Electric Machines
Fall 2013