Massachusetts Institute of Technology

Department of Electrical Engineering and Computer Science

6.685 Electric Machines

Problem Set 4 — Issued September 24, 2005

Due October 5, 2005

Problem 1: In this problem you will write a program for your favorite mathematical assistant to cause it to generate a capability curve for a synchronous generator. Then you will use this program to generate a capability curve for the generator described in the following table:

VA Rating	250	MVA
Voltage Rating	24	kV (line-line, RMS)
	7967	V (line-neutral, RMS)
D-Axis Synchronous Inductance	12.2	mHy
Q-Axis Synchronous Inductance	9.8	mHy
Field-Phase Mutual Inductance	52	mHy

1. To start, note that this machine will have a stability limit for operation at low field excitation (corresponding to high absorbed reactive power). For a round rotor machine this limit is reached at a torque angle of 90°, but this machine has saliency so you must determine the value of angle for which stability is reached. Compute and plot the angle and corresponding value of field current at the stability threshold for this machine, against real power. *Hint:* The stability limit is reached when the derivative of torque with respect to angle is zero. Since torque is proportional to real power, you can use the derivative of power with angle.
2. Since the capability curve is to be plotted as reactive power (Q) vs real power (P), you must determine the value of Q at the stability limit. Actually, the underexcited reactive power limit may be either statility or armature (current) capacity. So determine the underexcited limit Q as a function of real power P.
3. There is also a limit for over-excited operation. That limit might be field current and it might be armature current. To establish the field current limit, assume that this machine can reach the armature current limit for power factor of 0.8 and above, but for power factors below that the machine is field current limited. Find the torque angle and corresponding field current limits for over-excited operation at the defining power factor.
4. For torque angles less than this power-factor determined condition, real and reactive power are simply determined by torque angle and internal voltage E_{af} which is fixed at its limit.
5. For values of real power greater than this power factor determined situation real and reactive power are on the armature current (heating) limit and so are easy to compute.
6. Generate the complete capability curve. You should be able to identify those parts of the capability chart which are limited by armature current, by field capability and by stability.

Problem 2: In this problem you will be considering an ordinary three phase winding. Assume the thing has length $\ell = 3$m, rotor radius $R = 1$m, air-gp $g = 5$cm and use the fact that $g \ll R$. Assume this is a four-pole machine.

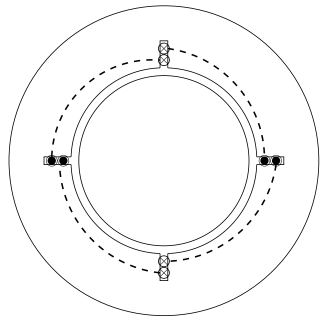

Figure 1: 4 Pole Concentrated Coils

1. To start, assume that there is a single coil around each pole as shown in Figure 1.Thus there are four 'slots' with two coil halves in each slot. Compute and plot the magnetic flux density produced across the air-gap. Assume each coil has one turn and that the coils are connected in series. The winding is carrying a current of 10,000 A.
2. express this as a Fourier series. Get your favorite mathematical assistant to plot the sum of the first several terms of this series (that is, the sum of the first several *space harmonics*. Compare the sum of the Fourier series with the 'exact' solution.(ignore the width of the slots).
3. Next, assume an actual three phase winding, located in two slots per pole per phase, each coil having $N_c = 1$ turn. (What is the angular spacing between slots if this is to be a regular three phase winding?). With current $I = 10,000$A in each coil of one phase, find the Fourier series for the magnetic flux density produced across the air-gap and plot the field around the periphery of the rotor for two cases:
   - For the case of m=2 and the winding is full pitched, and
   - For the case of m=2 and the winding is short pitched by one slot. Note that for this case each of the coils must be regarded as *two* coils with five turns each. One of these is shifted so that each half of the winding occupies three slots: the middle of the three has two coil halves, the outer two slots have one half each.

   Do you get the result you expect? How many space harmonics is it necessary to use to fairly represent the field?
4. If you consider only the space fundamental, what is the synchronous reactance of the complete three phase winding?