

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

Problem Set 6

Issued October 10, 2005

Due October 19, 2005

Reminder: Quiz on October 24, in class. Venue is Problem Sets 1-6 (This one). One hand-written 'Crib Sheet' allowed.

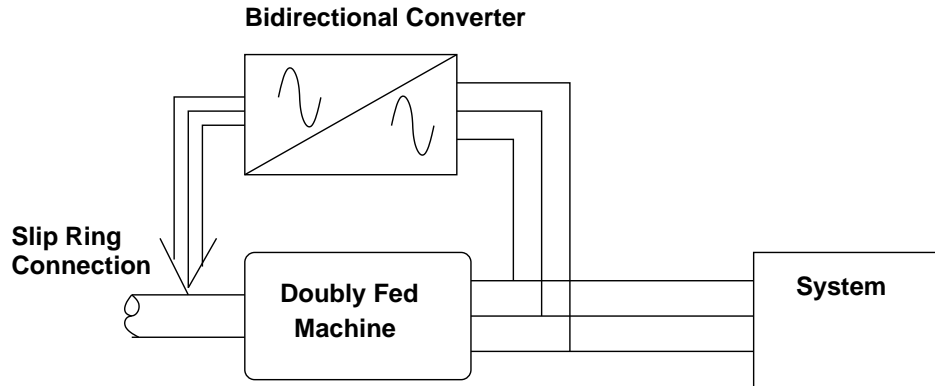


Figure 1: Doubly Fed Machine

Problem 1: Figure 1 shows a doubly fed machine in an arrangement that might be used for generation. The 'system' is the power system into which the machine would be generating, and you may think of it as a voltage source. The power electronics package (the bidirectional converter) is controlled in such a way as to inject or withdraw current from the rotor of the machine through its slip ring connections. You may treat this converter as a black box, assuming that its power interactions with the system are at unity power factor. A schematic diagram of this machine is shown in Figure 2. Referred to the stator terminals, the magnetizing reactance is $X_m = 1.8\Omega$ and the leakage reactances are both $X_1 = X_2 = 9m\Omega$. The machine is rated at 2 MVA, 600 Volts, line-line, RMS.

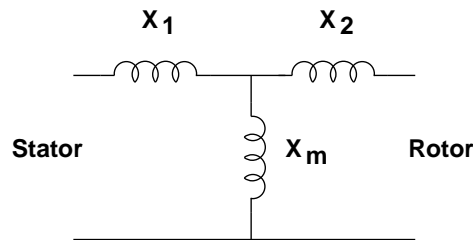


Figure 2: Doubly Fed Machine Single Phase Equivalent

We want to consider how this machine would perform were we to use it as a generator to extract power from a variable speed source such as a windmill. Assume for the first two

parts of this problem that shaft speed will vary between 80% and 120% of synchronous speed. (Synchronous speed is 60 Hz).

1. Begin by assuming that the stator of the machine is delivering 2 MW at unity power factor to the system at nominal voltage (what is the peak value of *phase* voltage if line-line voltage is 600 V, line-line?) Find the value of real and reactive power injected into the slip rings over the speed range of 80% to 120% of synchronous.
2. Now, assume that the power output to the system is 2 MW at unity power factor. Find and plot, over the same speed range, real power from the stator and real and reactive power into the rotor winding through the slip rings.
3. One application for this sort of machine is to extract energy from rotating kinetic energy storage (a 'flywheel'). In this case we want to keep the speed range a bit narrower (why?), and will track a transient of from 110% down to 90% of synchronous, supplying the system with the same 2 MW of power at unity power factor.
 - (a) First, assume that the speed range is narrow enough that torque (and so rate of deceleration) does not vary a lot. So we will assume that speed decreases at a constant rate over the transient. Assume that there is enough inertia in the flywheel that it takes 10 seconds to decelerate from 110% to 90% of synchronous speed. (What is that inertia?)
 - (b) Assuming that the rotor is wound with five times the number of turns as the stator, find voltage and current at the slip rings.
 - (c) Now transform the rotor frame voltage and current into the rotor phase coordinates. Note you will need to find the instantaneous angle between phase A of the rotor and the rotating coordinate system used to find voltages and currents. Plot slip ring voltage and current over the ten seconds of the transient.

Problem 2: Induction Motor

This concerns a real, 10 horsepower induction motor. The rotor diameter is 5.7" and the active length is 7.125". The air-gap dimension (rotor to stator spacing) is 0.010". (Yes, this motor is 'made in the USA'). Here are some details on the winding:

This is a four pole motor but the winding is called 'consequent pole'. This means that each phase winding is wound around only two poles. Thus each phase winding has two groups, and in this case each group has three coils. The coil span for each of these three groups is 7, 9 and 11 slots, respectively. (The stator has 36 slots). Each coil (they are all the same) has 16 turns.

1. Compute the winding factor for the space fundamental and for the two 'belt' harmonics (order 5 and 7).
2. Compute the magnetizing reactance for this machine, assuming it is to be operated at 60 Hz.
3. If all coils of a phase are connected in series and if the three-phase winding is connected in 'star' (same as 'wye'), and if the machine is operated with line-line voltage of 480 V, RMS, what is the *peak* value of flux density in the air-gap when the machine is running at no load? (Assume air-gap voltage is equal to terminal voltage).