6.061 / 6.690 Introduction to Electric Power Systems
Spring 2007

Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science
6.061/6.979 Introduction to Power Systems

Problem Set 11

Issued: Ses #20
Due: Ses #22

Problem 1: This problem concerns a drive system for a 'light rail' transit vehicle (aka Trolley Car). The drive system is to be based on a DC motor, and we will be looking at various attributes of design choices. To begin, assume a series connected machine which, with a terminal voltage of 600 VDC and a rotational speed of 125 radians/second draws 1000 A and produces 500 kW of shaft power.

1. Estimate the electrical parameters of this machine (motor constant and resistance) and plot torque vs. speed and current vs. speed when the motor is connected to a 600 VDC source. Plot these over the range of zero to 250 radians/second.
2. Now the machine is used to drive a vehicle. In this part of the question we will be finding input power during acceleration.
   (a) Assume that the thing is geared so that the motor is turning at 125 radians/second when the trolley car is traveling at 10 meters/second (about 22 MPH).
   (b) Assume also that the car weighs 20,000 kg.
   (c) Assume rolling resistance is negligible (the thing is on steel wheels), but there is some bearing friction and windage. Assume this is describable as a retarding force proportional to the square of speed (so that the power is cubic with speed) and that at 10 meters/second this is 50 kW.
   (d) Assume also that current to the motor is controlled by a resistive controller which is nothing more than a continuously variable resistor in series with the motor. (A practical controller would have descrete steps of resistance, but for simplicity we assume an infinite number of steps).

   The car is to be accelerated from zero to 10 meters per second at a constant acceleration of $1m/s^2$ (about 1/10 g). Find and plot current and power drawn from the source, assuming a 600 volt source on the trolley wires.
3. Now the resistive controller is to be replaced by a 'buck' converter (called in this trade a 'chopper'). Assume an ideal (lossless) converter. Find and plot current and power drawn from the source for the same acceleration transient.
4. **For 6.690**. Assume the series connected motor has an inductance of 1 Hy. Someone goofs and leaves the controller in the maximum speed (zero series resistance) position and the car is switched 'on'. For the first ten seconds of the ensuing transient, calculate and plot car speed, current and power drawn. Assume the track is clear so the thing does not derail nor hit something.

Problem 2: In an effort to provide for 'dynamic' (resistive) braking, it is decided to switch to a separately excited motor. Two candidate motors are considered:

1. Motor A has a base speed of 125 radians/second.
2. Motor B has a base speed of 62.5 radians/second.

Both of these motors produce rated power of 500 kW with terminal current of 920 A at their base speed, with terminal voltage of 600 VDC. The field winding, connected directly across the 600 VDC line, draws 12 kW.

1. Estimate and plot the power drawn by our trolley car driven by each of these two motors during acceleration from zero to five meters/second.
2. **For 6.690** It is generally considered bad form to cause steps of acceleration. Most controllers limit the rate of change of acceleration (called 'jerk rate'). Assuming Motor A and an ideal buck converter controller, calculate and plot car speed, current drawn and power input for an acceleration transient from stopped to 10 meters/second assuming a jerk rate limit of $0.5 m/s^3$. Note that the field is fed from the line side of the chopper.