6.061 / 6.690 Introduction to Electric Power Systems
Spring 2007

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

Problem Set 8

Issued: Ses #16
Due: Ses #17

The first few parts of this problem set are concerned with the same synchronous machine (a very large generator) which is characterized by the following parameters:

| | | |
|---|---|---|
| Number of Poles | p | 4 |
| Field to Armature Mutual Inductance (Peak) | $M$ | 37.5 mHy |
| Armature Phase Self Inductance | $L_a$ | 1.9 mHy |
| Armature Phase-to-Phase Mutual Inductance | $L_{ab}$ | -0.86 mHy |
| Field Winding Resistance | $R_f$ | 165 mΩ |
| Armature Winding Resistance (per phase) | $R_a$ | 1 mΩ |
| Rotational Speed | | 1800 RPM |
| Terminal Voltage (RMS, Line-Line) | $V_a$ | 26 kv |
| Rated Power | | 1300 MVA |
| Frequency | | 60 Hz |

Some of the following questions involve hypothetical operation of this machine in a fashion that would definitely void the warranty and most likely destroy the machine. You might want to point out the dangerous features of these questions. If in the future you gain control of a machine of this type, DO NOT operate it as suggested in this homework set!

**Problem 1:** If this machine is operated synchronously with a balanced *current* source of RMS amplitude 28 kA and a field current of 3,500 A,

1. Calculate and plot a (constant current magnitude) torque-angle curve for this operation.
2. At what (current) torque angle does this machine reach its rated torque as a generator?
3. Calculate and plot terminal *voltage* magnitude (RMS is OK) vs. torque angle.

**Problem 2:** Now the machine is operating as a synchronous generator, connected to a 26 kilovolt, (RMS, Line-Line) 60 Hz voltage source.Initially, the field current is still 3,500 A.

1. Calculate and plot the (constant voltage magnitude) torque-angle curve for this operation.
2. At what torque angle does the machine reach its rated torque as a generator?
3. Sketch a phasor diagram for operation at rated torque, showing the same quantities as in Problem 1.
4. What field current is required for operation at rated power and unity power factor?
5. What is the electrical efficiency of the machine when it is operating as a generator at rated power, unity power factor? (Note that what you calculate will be unrealistically high as it ignores core loss, friction and windage).

**Problem 3: for 6.690** In this part of the problem we will examine ways of characterizing operation of this machine. You will probably want to use MATLAB to do the heavy lifting here. Be sure to include limits to machine stability (torque angles do not go beyond 90 degrees), armature current and field current.

1. The *Compounding Curve* for a machine is a chart showing field current required for operation of the synchronous machine as a function of terminal volt-amperes for a fixed value of power factor. Estimate and plot compounding curves for operation of this machine for operation as a motor for power factors of unity, 0.8, 0.9, 0.5 and zero (mechanically unloaded), both over and under-excited. For the compounding curve you do not need to consider the field current limit.
2. The *Vee curve* is a chart showing armature current vs. field current for operation at fixed real power. Compute and plot vee curves for operation at 20machine rating of 1,300 MVA. Note that you may have to be concerned with stability limits in the underexcited condition and with magnitude of armature and field current. Do not carry the plot beyond 1,300 MVA in the armature. Assume the field current limit is what you estimated for 0.9 power factor, over-excited operation.

**Problem 4** A rough sketch of a 6/4 VRM is shown in Figure 1. The poles are all 30 electrical degrees wide and there are four rotor and six stator poles. A rather highly idealized flux/current characteristic for this machine is shown in Figure 2. Assuming the rather fanciful notion that you can take full advantage of this characteristic and limiting current to 10 A, what average torque can this machine produce?

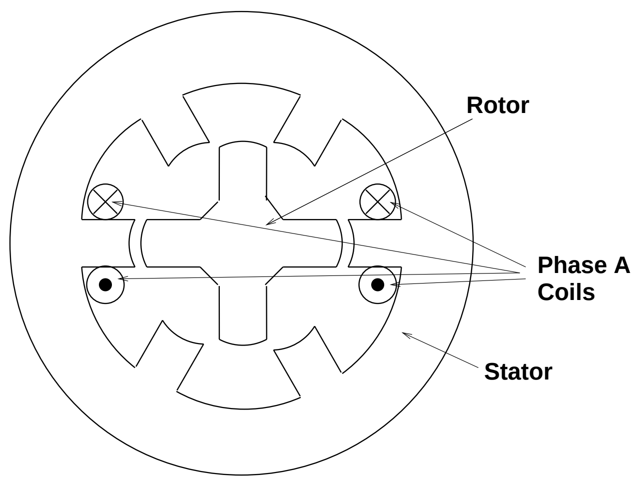


Figure 1: Rough Sketch of VRM

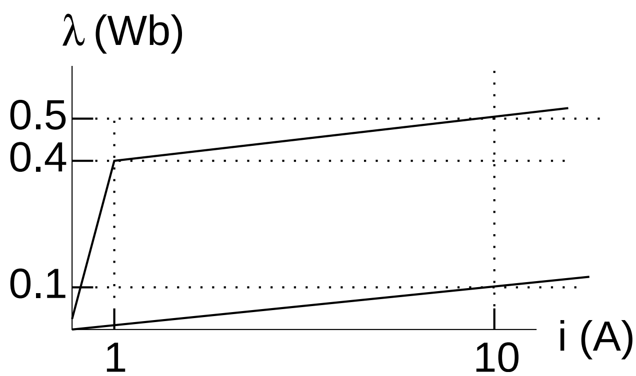


Figure 2: Maximum and Minimum Flux Characteristics