

# ECE 470 POWER SYSTEMS I

## Lab # 3 Synchronous Machine Operation

The objective of this lab is to understand how a synchronous machine operates, how power is related to load angle, and what determines the limit of its power output.

### PRE-LAB

#### Complete this work before starting

Do the drill problem on the back of this page. Compare your result with the correct answer, and then devise a spreadsheet to plot  $\delta$  as the load varies.

Review the labs from ECE370 which describe operation of dynamometers. Ensure that you know what changes in loading are caused by adjusting the field currents.

Devise circuit diagrams that will measure: synchronous machine real and reactive power, power factor, voltage and current when:

- the dynamometer is operated as a generator (feeding a resistive load) and the synchronous machine is a motor, and
- the dynamometer is operated as a motor and the synchronous machine is a generator, feeding power back into the 3 $\phi$  supply. **NOTE: It is still possible for the synchronous machine to motor (it depends on the armature current of the dyno) so be sure that both machines want to turn in the same direction.**

Note that the Yokagawa power meter will provide all measurements. Configure the meter with currents flowing in for motoring and out for generating. Be sure to use the 3 phase, 4 wire configuration.

Note also that you should display the current waveform on the oscilloscope along with terminal phase voltage, so that you can tell if the machine is lagging or leading.

### LAB PROCEDURE

#### Get the circuit checked before starting

The lab bench should be arranged with a synchronous machine and a dynamometer mounted on the bedplate. **The excitation current on the synchronous machine should be held constant at 1 Amp. in parts 2 - 5.**

- Measure the synchronous reactance of the synchronous machine.
- Using the circuit from part (a) of the pre-lab, connect the machines for operation with the synchronous machine as a 208 V (line) motor. You should use the fixed supply.
- Vary the load on the dynamometer so that the synchronous machine goes from drawing no-load power to ~450 W in about five increments. Measure the voltage, current, power and power factor at each step. You should use the oscilloscope to determine if the current is lagging or leading
- Apply the spreadsheet from the pre-lab to calculate the excitation voltage ( $|E_f|$ ) and load angle ( $\delta$ ). Confirm that  $|E_f|$  remains roughly constant and plot P vs.  $\delta$ . Determine  $P_{\max}$ .  
$$(E_f/\delta = V_t/Q - jX_S \cdot I_a/\phi \text{ for motoring})$$
- Repeat steps 2 - 4 with the dyno configured as a motor with the synchronous generator feeding power **into** the 3 $\phi$  supply. (Read the **bold** comment in the previous column!)

**NOTE** When the direction of the current reverses (i.e. generating), the expression for calculating  $E_f$  changes to:

$$E_f/\delta = V_t/Q + jX_S \cdot I_a/\phi$$

## Pre-Lab Drill Problem

- a) A 10 kV, 20 MVA, synchronous generator has a synchronous reactance of 1.5 pu. It is delivering 15 MW at 0.8 lag pf and rated terminal voltage. Determine the excitation voltage ( $|E_f|$ ) and the load angle ( $\delta$ ). What is the steady-state stability limit  $P_{max}$ .
- b) Use the results from part (a) to develop a spread-sheet which will calculate  $|E_f|$  and  $\delta$ , as functions of:  $V_t$ ,  $I_a$ , pf and P, for a given  $X_s$ . The columns of the spreadsheet are shown below.

**Note:**  $E_f/\delta = V_t/Q + jX_s \cdot I_a/\phi$  for a generator.  $E_f/\delta = V_t/Q - jX_s \cdot I_a/\phi$  for a motor.  
Remember that current can be lagging or leading.

ECE470	LAB 3	P vs $\delta$		$X_s =$	150								
$V_t$	$I_a$	$P_{3\phi}$	pf	lg(-)/ld(+)	$\phi$	$I_{re}$	$I_{im}$	$E_{re}$	$E_{im}$	$E_{mag}$	$\delta$	$P_{max}$	
120	1.355	-479	0.988	1	0.155075	1.33874	0.209285	151.3928	-200.811	251.4852	-52.9871	599.8746	
120	1.2	-402	0.931	1	0.373653	1.1172	0.438023	185.7035	-167.58	250.1376	-42.0633	600.0437	