Name: _________________ Partners: _________________ _________________

ENGR 318 ELECTROMECHANICAL ENERGY CONVERSION LAB 6

Three-Phase Machines

1. Configure the induction machine as a Y and connect from the incoming power (three phase, 208 $V_{\ell-\ell}$) through the power meter to the Y terminals. Activate power and confirm that the rotation is clockwise. Once both the average and reactive power are reasonably stable, record their values. Notice that the reactive power is very significant compared to the rated average power. Think about the name of the machine while you turn the power off. Calculate the power factor based on the rated average power.

P = ______ W Q = _______ VAR pf = ____ _____ P_{rated} = _____ W

2. Configure the synchronous machine as a Y. Move the line feed for the induction machine to the synchronous machine armature using the same phase order. Connect the field circuit to the fixed dc source (120 V_{DC} - 2 A) and confirm that the field is switched out. **Note that a synchronous machine must not be started with the field activated.** Start the machine and confirm clockwise rotation. Activate the field and observe that the reactive power changes as you vary the field current by means fo R_f. Record data for the extreme resistor settings and calculate the power factors based on rated average power.

R_{fmax} P = ______ W Q = ______ VAR pf = _____ ____ P_{rated} = ______ W

R_{fmin} P = ______ W Q = ______ VAR pf = ____ _____ for P_{rated}

3. Using the rated power and the measured reactive power (induction machine), calculate the capacitance to obtain pf_d = 0.9 lag and choose the best available value.

(Calculate here.)

Calculated C_Y = ____ C_Δ = ____ μF/phase Available C = ____ μF/phase

4. Switch the synchronous machine field off and move the synchronous machine line feed to the induction machine. Connect the compensation capacitors to the induction machine, record your results and calculate the power factors based on rated average power.

Expected: P = ______ W Q = ______ VAR pf = _____ _____ for P_{rated}

Observed: P = ______ W Q = ______ VAR pf = _____ _____ for P_{rated}

5. Connect the synchronous machine to the line feed from the power meter in parallel with the induction machine and its capacitors. Start both machines, activate the field of the synchronous machine and observe the range of reactive power while adjusting the field current. Record the power readings for R_{max} and R_{min}. Drop the power, switch the synchronous field off and calculate the power factors using the rated average power of the induction machine..

R_{max} P = ______ W Q = ______ VAR pf = _____ _____ for P_{rated}

R_{min} P = ______ W Q = ______ VAR pf = _____ _____ for P_{rated}

This connection illustrates how a synchronous machine can operate as a capacitive load. The power industry will sometimes use synchronous machines with no mechanical load for power factor correction in the place of a capacitor bank. Its effective equivalent capacitance is readily adjustable by changing the dc field current. These installations are known as synchronous condensers.

6. Disconnect the induction machine and the capacitors while keeping the synchronous machine connections (field off). Select Position 7 on the meter switch in the power unit and set the variable voltage control to 110 V_{dc}. Turn the power off. Connect the dc machine armature to the adjustable 0 -120 V_{dc} source. Connect from the fixed 120 V_{dc} source through the shunt field, into the field resistor and then back to the source. Verify that the rotation is clockwise. **Request connection of a belt drive between the dc and synchronous machines.**

Set both field controls to point straight up, activate the power and then adjust the dc machine field resistor to generate rated power ($P < 0$) from the synchronous machine into the power grid. The synchronous machine is now acting as a generator, absorbing mechanical power from the dc machine and delivering electrical power to the incoming three-phase line.

Adjust the synchronous machine field current to obtain 0 reactive power and set the dc machine field to obtain 0 average power. Repeat if necessary. Using a strobe light, record the reference angle of the rotor. Increase the driver power to generate 175 W ($P < 0$). Repeat adjustments of the synchronous field current and the dc machine field current to generate 175 W and 0 VAR, then record the new rotor angle and calculate the corresponding torque angle.

For P = Q = 0, φ_{ref} = ______°

For P = 175 W, Q = 0, φ = ______° Torque angle $\delta = 2(\varphi - \varphi_{ref})$ = ______°

Finally, vary the synchronous field current to obtain the extreme values of the rotor and torque angles. Calculate the power factors based on measured average power.

P_1 = _____ W Q_1 = _____ VAR pf_1 = ____ ___ φ_1 = ____ ° δ_1 = _____°

P_2 = _____ W Q_2 = _____ VAR pf_2 = ____ ___ φ_2 = ____ ° δ_2 = _____°

Power Factor Correction

Existing Power — $\mathbf{S} = P + jQ$, $Q > 0$ (Inductive, lagging)

Existing Power Factor — $pf = \cos(\theta)$, $\theta = \tan^{-1}(Q/P)$

Desired Power Factor — pf_d

Desired Complex Power — $\mathbf{S}_d = P(1 + j\tan(\cos^{-1}(pf_d))) = P + jQ_d$

Note: $\mathbf{S}_d = P + jQ_d = P(1 + jQ_d/P)$, $Q_d = P\tan(\theta_d) = P\tan(\cos^{-1}(pf_d))$

Reactive Power of the compensation capacitor $\mathbf{S}_c = 0 + jQ_c$, $Q_c < 0$

$\mathbf{S}_d = \mathbf{S} + \mathbf{S}_c$, therefore $\mathbf{S}_c = \mathbf{S}_d - \mathbf{S} = (P + jQ_d) - (P + jQ) = j(Q_d - Q) = jQ_c$

Compensation capacitors are generally sized by VARs for a given voltage rating. For this example, you would specify $|Q_c|$ VARs at 480 V_{rms}.

To get the capacitance value $jQ_c = \mathbf{V}\mathbf{I}^* = \mathbf{V}(\mathbf{V}/(-jX_c))^* = -j\omega C|\mathbf{V}|^2$, $X_c = 1/(\omega C)$

$C = (Q - Q_d)/(\omega|\mathbf{V}|^2) = P[\tan(\cos^{-1}(pf)) - \tan(\cos^{-1}(pf_d))]/(\omega|\mathbf{V}|^2)$ μF