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AC Synchronous Machine Characterization

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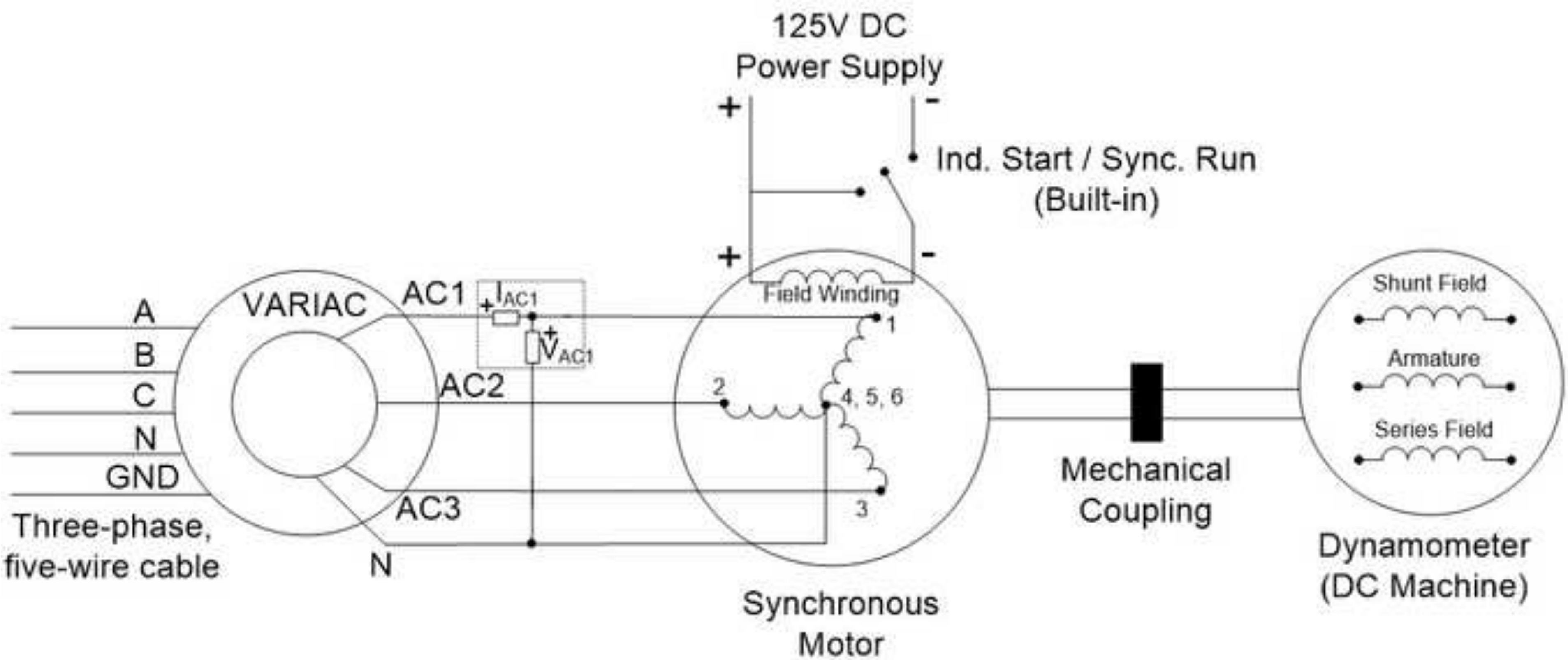

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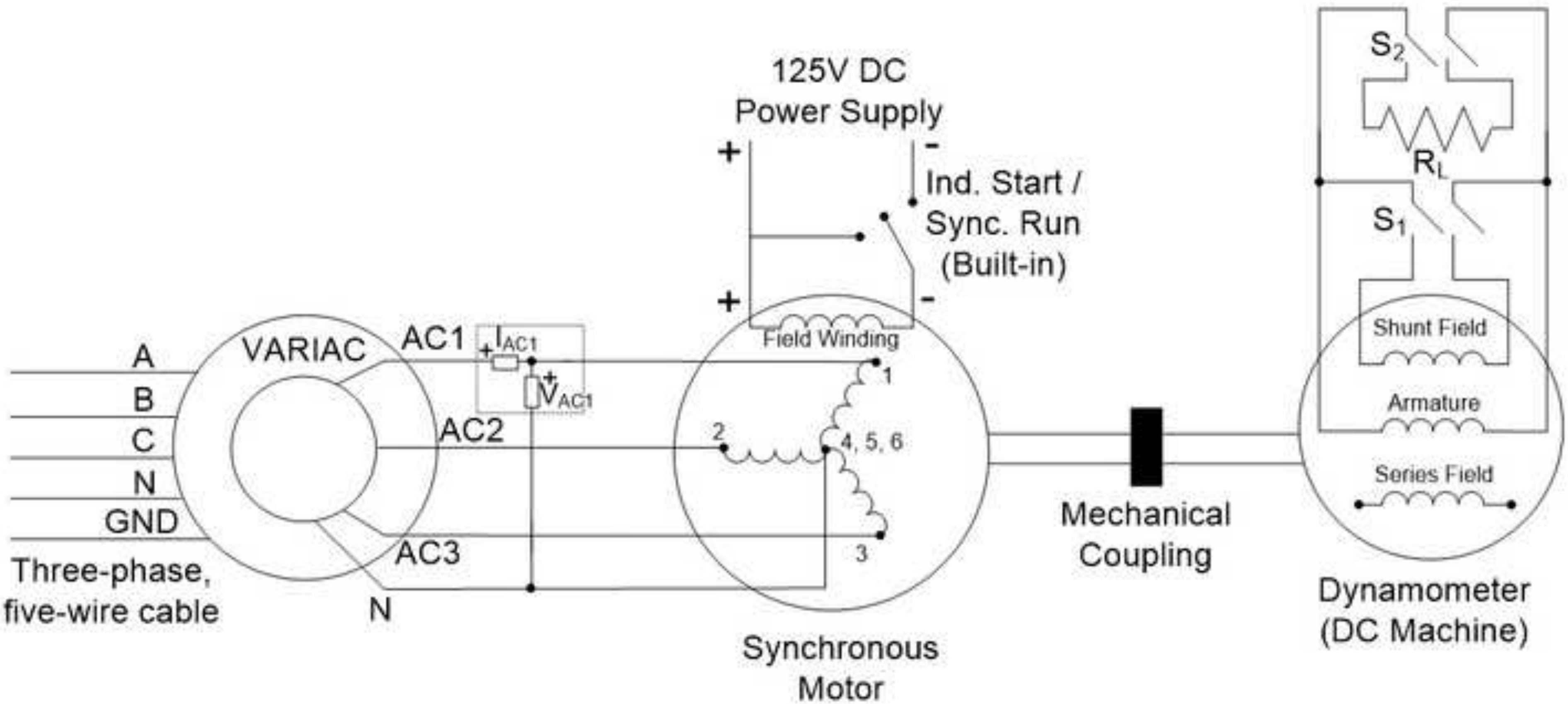

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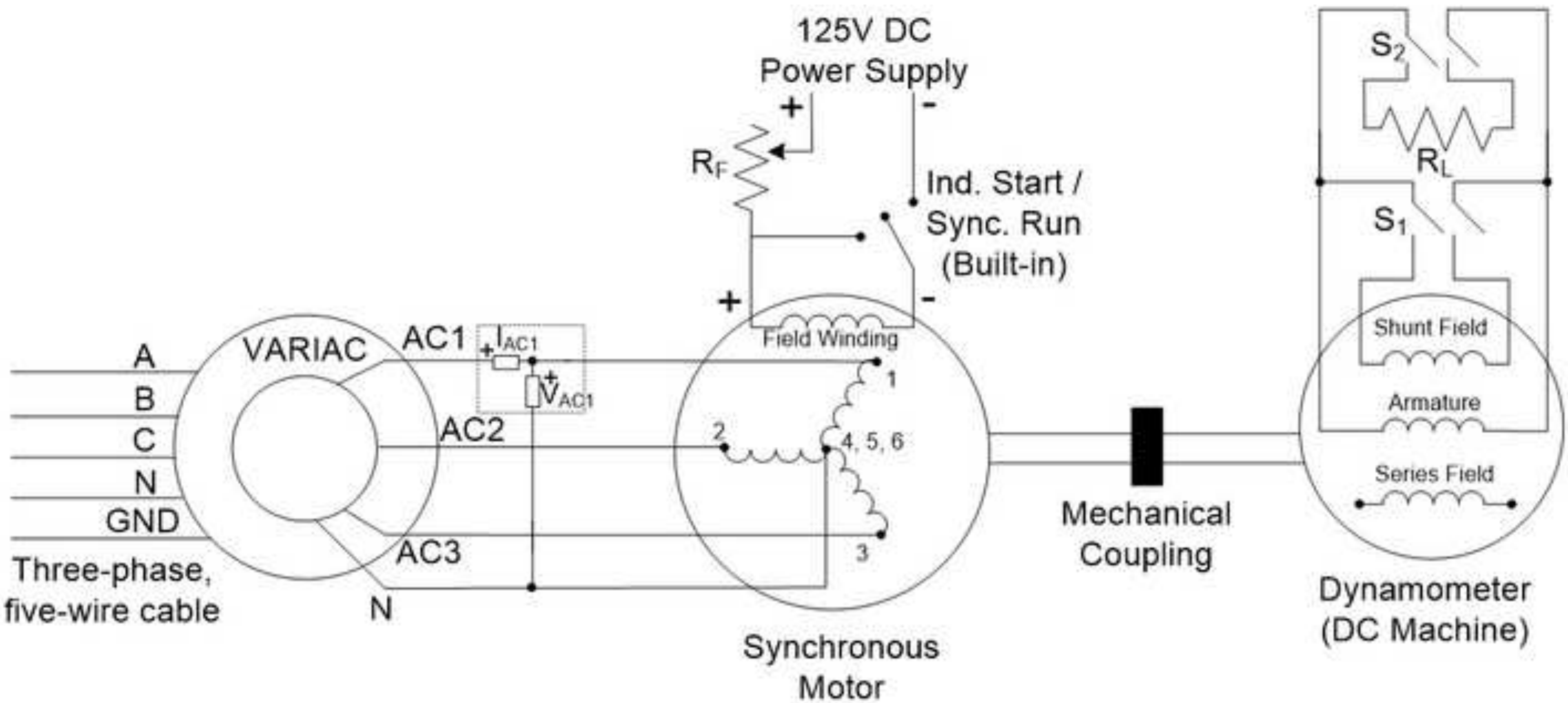

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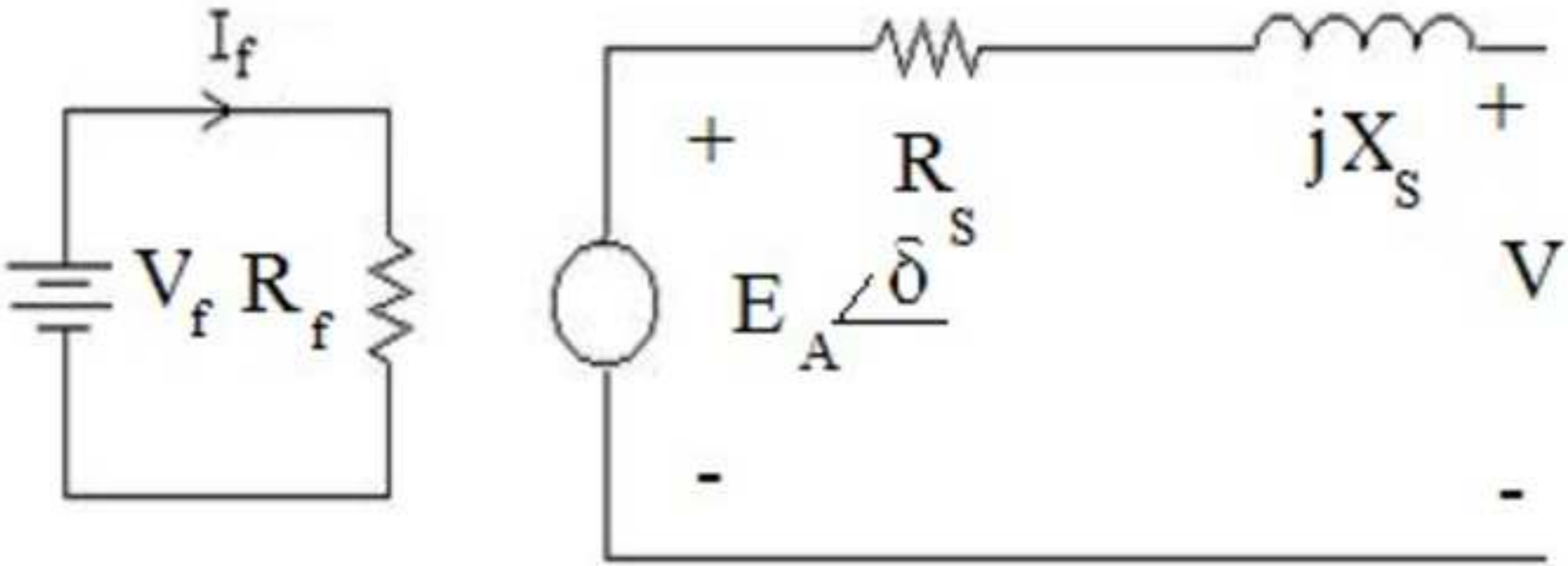

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Electrical Engineering Science Education Title: AC Synchronous Machine Characterization

Overview

The objectives of this experiment are to understand the concepts of starting a three-phase synchronous motor, V-curves for various loads where the load affects the motor power factor, and the effect of loads on the angle between the terminal voltage and back e.m.f.

Three-phase wound-rotor synchronous motors are less popular than permanent magnet rotor synchronous motors due to the brushes required for the rotor field. Synchronous generators are much more common and available in most existing power plants, as they have excellent frequency and voltage regulation. Synchronous motors have the advantage of almost 0% speed regulation due to the fact that the rotor speed is exactly the same as the stator's magnetic field speed, causing the rotor speed to be constant, irrespective of how much the motor's shaft is loaded. ~~and, t~~Thus, they are very suitable for fixed speed applications.

Principles

Synchronous machines rely on the rotating magnetic field concept introduced for induction machines. Three~~-~~-phase currents, flowing in the machine's stator, produce a ~~resulting~~ rotating magnetic field of constant magnitude at a desired frequency. The differe~~n~~nce~~t~~ between the synchronous and asynchronous machines is that the latter has shorted windings or a "squirrel cage" on the rotor side, while synchronous machines have a fixed magnetic field on the rotor side. This magnetic field is either provided by an exciter or permanent magnets. Permanent magnet synchronous machines are becoming more common due to their high efficiency and compact size, but they typically utilize rare earth material, which is undesirable from a strategic material availability perspective. The term synchronous is used, because the rotor magnetic field, which is independent from the stator, locks to the rotating magnetic field and causes the rotor to spin at the same speed (or synchronous speed) as the stator's rotating magnetic field.

To start a three-phase wound-rotor synchronous motor, the field winding is shorted where the machine acts as an induction motor. Once the machine speed is close to synchronous speed, the short circuit is removed and a DC voltage is applied across the field winding. This locks the rotor and stator magnetic fields, and thus, rotor and stator synchronism is achieved. In this lab, the synchronous motor is started by having the top switch on its interface plate in the "Induction Start" position, and once the speed reaches steady state, the switch is flipped to the "Synchronous Run" position.

Procedure

1 DC Test

1.1 Turn on the low-power DC power supply with a short circuit across its terminals.

Commented [AM1]: Provide background information on the motor and how it works. How it differs from the induction motor. How it differs from the permanent magnet rotor synchronous motor. Etc.

Ali: This is now clear in the synchronization experiment. I have copied that text here.

Commented [AM2]: Explain why this is…

Ali: Done

Commented [AM3]: Place the background information in the principles section.

Ali: Done.

Commented [AM4]: This video is related to the AC Synchronous Generator video, correct? Would it be safe to say that this video would precede the other?

Ali: yes, this video comes first.

1.1.1 Limit the current on the low-power DC power supply to 1.8 A.

1.1.2 Turn off the supply and disconnect the short circuit.

1.2 Connect the supply terminals across ports 1 and 4 of the synchronous motor.

1.2.1 Turn on the supply and measure the DC voltage and current. Vary the voltage as needed to reach a current of 1.8 A.

1.2.2 Turn off the supply, then repeat the previous two steps for ports 2 and 5 and ports 3 and 6.

1.3 Disconnect the low-power DC power supply.

2 Synchronous Machine Starting

2.1 Make sure the three-phase disconnect switch, synchronous motor switch, and DC motor switch are all off.

2.1.1 Check that the VARIAC is at 0%.

2.1.2 Wire the VARIAC to the three-phase outlet, and connect the setup shown in **Figure 1**.

2.1.3 Remember to set the 1 to 1000 scaling of the digital power meter current probe.

2.2 Check that the Start/Run switch is in the Start position.

2.3 Turn on the three-phase disconnect switch.

2.4 Quickly increase the VARIAC output until the digital power meter reads around 115 V.

2.5 Measure the armature current I_{AC1}, armature voltage V_{AC1}, real power, and power factor.

2.6 Remember that the phase (line-to-neutral) voltage and phase current on phase A are being measured, so the power factor measurement on the power meter is correctly reflecting the per-phase power factor.

2.7 Measure the torque and speed of the machine.

2.8 Turn on the 125 V DC power supply. Make sure all connections are clear from the supply terminals.

2.8.1 Press the supply "Start" button and set the supply output to 125 V.

2.9 Flip the Start/Run switch to the Run position. Pay attention to how the machine sound changes. The machine sound ~~will~~ becomes smoother as the rotor magnetic field locks to the stator rotating magnetic field.

Commented [AM5]: What do you expect to change here?

Ali: Done.

2.9.1 Record the armature current I_{AC1}, armature voltage V_{AC1}, real power, power factor, and the field voltage and current from the DC power supply display.

2.9.2 Measure and record the torque and speed of the machine.

2.10 Turn off the DC power supply, flip the Start/Run switch to the Start position, and set the VARIAC back to 0%.

2.11 Turn off the three-phase disconnect switch. Leave the rest of the circuit intact.

3 Effect of Load on Torque Angle

3.1 Make sure the three-phase disconnect switch, synchronous motor switch S_1, and DC motor switch S_2 are all off.

3.1.1 Note that while S_1 is on the synchronous motor side, it is used to connect/disconnect the R_L load across the DC machine terminals.

3.1.2 Check that the VARIAC is at 0%.

3.2 Connect the setup shown in **Figure 2** and set R_L to 200 Ω.

3.2.1 Check that the Start/Run switch is in the Start position.

3.2.2 Turn on the three-phase disconnect switch.

3.3 Quickly increase the VARIAC output until the digital power meter reads around 115 V.

3.4 Turn on the 125 V DC power supply. Make sure all connections are clear from the supply terminals.

3.4.1 Press the supply start button and set the supply output to 125 V.

3.4.2 Flip the Start/Run switch to the Run position.

3.4.2.1 Record the armature current I_{AC1}, armature voltage V_{AC1}, real power, power factor, and field voltage and current from the DC power supply display.

3.4.2.2 Measure and record the torque and speed of the machine.

3.4.2.3 Keep the strobe light on near the shaft and measure the initial angle δ_o.

3.4.2.3.1 To set up the strobe light, plug it in-to a regular power outlet and turn it on.

3.4.2.3.2 With the “Coarse” knob, adjust the speed reading on the strobe light to be close enough to 1,800 RPM, which is the synchronous speed of 1 four-pole 60 Hz machine. [Synchronous speed is calculated in rounds per minute (RPM) as $n=120\text{x}f/P$ where f is the frequency and P is the number of poles.

Place the strobe light to face the motor shaft’s edge, and adjust the “Fine” knob until ~~you see as if t~~the shaft ~~is~~appears stationary.. The human eye is tricked to see the shaft as stationary by having the strobe light frequency (or speed reading) match the shaft speed.

Commented [AM6]: When did you set up the strobe light? How is it set up? What are you measuring?

Ali: added 3.4.2.3.1 to 3.4.2.3.4

3.5 Turn on S_1 and repeat steps 3.4.2.1 to 3.4.2.3, but measure the new angle as δ_1.

3.6 Turn on S_2 and repeat steps 3.4.2.1 to 3.4.2.3, but measure the new angle as δ_2.

3.7 Turn off S_2 and change R_L to 100 Ω.

3.7.1 Turn on S_2 and repeat steps 3.4.2.1 to 3.4.2.3, but measure the new angle as δ_3.

3.8 Turn off the DC power supply, flip the Start/Run switch to the Start position, turn off S_1 and S_2, and set the VARIAC back to 0%.

3.9 Turn off the three-phase disconnect switch. Leave the rest of the circuit intact.

4 Effect of Field Current on Power Factor

This section investigates one side of the V-Curve.

Commented [AM7]: Perhaps we film this segment as part of the application section? Thoughts?

Ali: Yes, I think this is a good application of power factor correction as described in applications. However, with the lab setup we have we cannot get a nice power factor, but we can show power factor variation to relay the idea.

4.1 Make sure the three-phase disconnect switch, synchronous motor switch S_1, and DC motor switch S_2 are all off.

4.1.1 Check that the VARIAC is at 0%.

4.2 Connect the setup shown in **Figure 3**, which is only different from **Figure 2** by adding the series field resistor R_F, and set R_L to 200 Ω.

4.2.1 Set R_F to the 10 Ω position. R_F does not require measurement for this experiment, since the goal is to vary field current only.

4.2.2 Check that the Start/Run switch is in the Start position.

4.3 Turn on the three-phase disconnect switch.

4.3.1 Quickly increase the VARIAC output until the digital power meter reads around 115 V.

4.4 Turn on the 125 V DC power supply. Make sure all connections are clear from the supply terminals.

4.4.1 Press the supply start button and set the supply output to 125 V.

4.4.2 Flip the Start/Run switch to the Run position.

4.4.2.1 For R_F = 10, 6, 3, and 1, record the armature current I_{AC1}, armature voltage V_{AC1}, real power, power factor, field voltage and current from the DC power supply display.

4.4.2.2 Measure and record the torque and speed of the machine.

4.4.2.3 Reset R_F to 10 Ω.

4.5 Turn on S_1, and repeat steps 4.4.2.1 to 4.4.2.3.

4.6 Turn on S_2, and repeat steps 4.4.2.1 to 4.4.2.3.

4.7 Turn off S_2 and change R_L to 100 Ω.

4.7.1 Turn on S_2, and repeat steps 4.4.2.1 to 4.4.2.3.

4.8 Turn off the DC power supply, flip the Start/Run switch to the Start position, and set the VARIAC back to 0%.

4.9 Turn off the three-phase disconnect switch and disconnect the setup.

Representative Results

The DC phase resistance can be estimated from the DC test as the ratio of DC voltage to DC current when applied between a phase terminal and the neutral. The field resistance can be measured in a similar manner by applying DC voltage to the field winding and measuring the field current. The synchronous reactance (X_s), back e.m.f. of the machine (E_A), and its related constant k_φ can be found from the real power ($P_{3\varphi}$) measurement into the machine: $P_{3\varphi}=3V_\varphi E_A\cos(\delta)/X_s$ (ignoring the stator resistance R_s) and basic power flow equations for the per-phase equivalent circuit (**Figure 4**).

V-curves determine the power factor of the machine as seen by the source (grid). The V-curves demonstrate that the machine can provide reactive power (leading power factor) under certain conditions, and therefore, acts like a capacitor that can enhance voltage stability on the grid. When operating under such a condition, the machine is termed "synchronous condenser."

Applications

Synchronous machines are common in applications requiring constant speed on the motor's shaft with very tight speed regulations. Such applications include electrical clocks and hard disk drives, but extend to synchronous condensers, which are synchronous motors operating in the leading power factor region to provide reactive power to a load. Power factor correction is another term used with synchronous condenser applications. Note that the most common synchronous motors are permanent magnet motors, while the most common synchronous generators are wound-rotor synchronous generators.

Commented [AM8]: *Can reference the Synchronous Generator video here…*

Ali: yes

Legend

Figure 1: A schematic of the setup to start the synchronous motor.

Figure 2: A schematic of the setup to study the effect of load on torque angle.

Figure 3: A schematic of the setup to study the effect of changing the field current.

Figure 4: A schematic of the per-phase equivalent circuit used for the representative results.