ECE 5671/6671 – Lab 5

Squirrel-Cage Induction Generator (SCIG)

1. Introduction

1.1 Objectives

The objective of this lab is to connect a SCIG generator directly to the grid and measure the power produced at various speeds. The SCIG is often used to generate electrical power from wind; in this lab, a DC motor will emulate the wind turbine. After connecting the generator to the grid, the speed of the DC motor will be increased in order to observe the generation of power to the grid. Measurement of active and reactive power with respect to speed will be analyzed. Lastly, self-excited operation of the induction generator will be observed.

The procedures discussed for the remainder of this lab require correct execution of the instructions presented. Upon careful reading and comprehension of directions, proceed with the experiments. Heeding help throughout this handout will distinguish whether a procedure is to be completed on the computer (Matlab, Simulink, or dSPACE) or on the actual equipment.

Equipment needed:

- SCIG generator
- DC generator, frame mounted, with coupler
- dSPACE I/O box
- Three-phase capacitor box
- Grid connection box
- Current sensor board
- Box of cables

1.2 Simulink functions and dSPACE layout

For the experiment, a new Simulink model must be created in order to compile a c-file that creates an **.sdf file** for dSPACE to load. Refer back to Lab 1 if questions arise about this process.

>>Simulink Blocks

Download, open, and examine the provided model (lab_5.mdl) to gain a sense of how this system will work. This is similar to the Simulink model from lab 4. Included are the encoder initialization blocks, position output, speed output, and frequency output. Analog-to-digital channels (ADCH) will capture data (voltage and current). Two ADCH channels will be used for measuring output voltage, and the other two will be used for measuring output current. Figure 1 displays the data capture blocks necessary for the experiments.

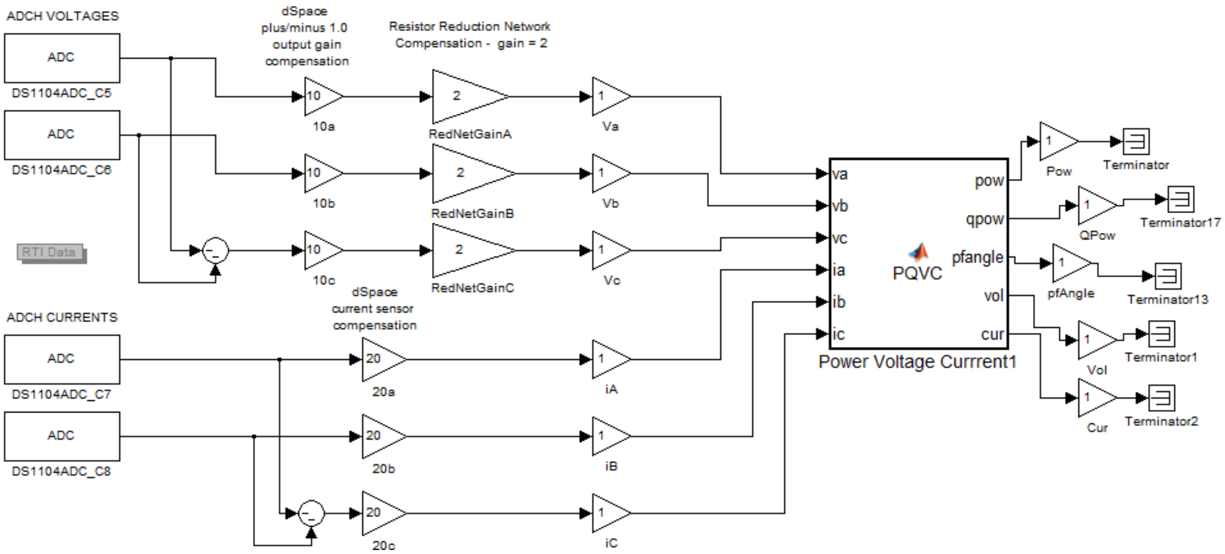


Figure 1. ADCH data capture blocks

As a result of only using two channels to capture phase voltages and only two channels for phase currents, the third phase of each will be computationally constructed. Use of separate summing blocks creates the third phases assuming a balanced system. Once all three phases are established, the lines connect to their respective **10x** or **20x** gains, then to their respective **RedNetGainx** gains (only for voltage), and finally to their respective **Vx** or **iX** gains. Remember that the **10x** and **20x** gains compensate for dSPACE's data capture gains, the **RedNetGainx** gains compensate for the voltage divider network in place to limit the voltages to 10V, and **Vx** and **iX** gains are simply in place for convention and signal identification in dSPACE. Also, a PQVC block is used to calculate the real and reactive power, as well as the peak values of the three-phase voltages and currents.

>>Matlab

The model should reside in the current Matlab directory. This model will correctly build if the value for **Ts** is properly defined. Set **Ts** to 0.0001 by entering Ts = 1e-4.

The RedNetGainx gains for the voltage also need to be defined in Matlab. Set RedNetGain to 2 by entering RedNetGain=2.

The number of pole pairs also needs to be defined in Matlab. Set np = 4 in Matlab.

>>Simulink

Now the model can be built. Ensure that all the model configuration parameters are set to the right specifications including the initial simulation condition (STOP). The Matlab command window may display warnings about ports not being connected, which can be disregarded. These will be mitigated as both connections and progress are made throughout the lab.

2. Preliminary testing

>>Hardware Setup

Follow the steps outlined in the introductory tutorial and Lab 1 to correctly assemble and test the equipment. Also, there is a table in the appendix with a list of cables used for this lab. Each cable bundle has a specific purpose; please refer to this table while assembling the test setup.

!!!CAUTION: THE AC VOLTAGE AT THE GRID IS 220 VOLTS!!!

Please refer to appendix III when placing components on the desktop. The layouts provided have been determined to be the most efficient way to setup the hardware for connecting the cables and to reduce the risk of injury. This appendix should also be referred to in labs 6 and 7.

Connect the DC power supply to the terminals of the DC motor and check the direction of rotation of the DC motor by applying a positive voltage. Note that the voltage applied to the DC motor should be started from about 2.5 – 3V. First connect the ground lead to the supply and then the positive lead. Now is a good time to make sure that the current limit on the supply is set to maximum (rotate the knob completely clockwise). If the DC motor is not rotating counter-clockwise when looking from the generator back towards the motor, change the lead connections of the DC motor. Then, couple the DC motor to the SCIG generator. Hook the encoder cable from the I/O board to the DC motor.

>>dSPACE

Once the Simulink build process from **1.2** has finished in Matlab, use the dSPACE ControlDesk program to run the actual experiment. With dSPACE, create a new *Project* + *Experiment* structure, as described in the tutorial, in the appropriate folder, choosing the right **.sdf** file for variable description. Close the blank layout presented and import the layout downloaded from the lab webpage (lab_5.lax) by clicking on the **Layouting** tab > **Import Layout.** This layout should look like fig. 2 below.

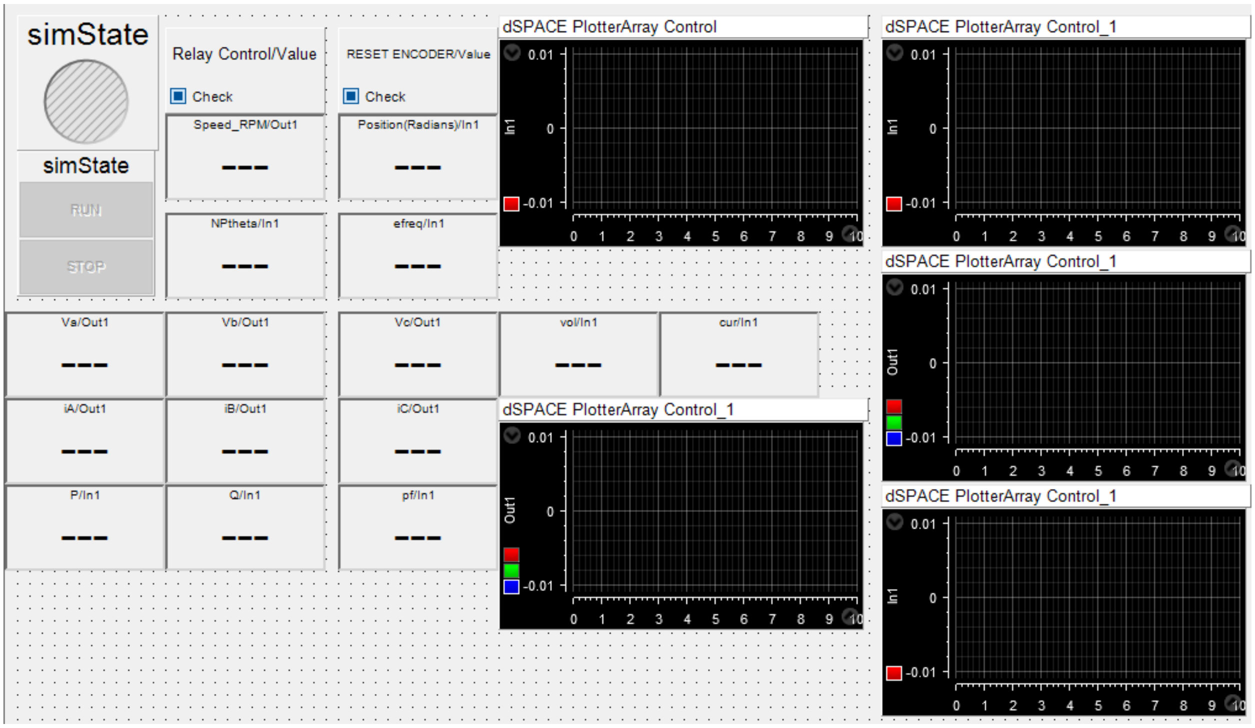


Figure 2. Provided dSPACE layout for experiment.

Engage the dSPACE control desk online and verify that a positive voltage applied to the DC motor results in a positive position reported by the encoder and clockwise rotation of the SCIG when looking towards the SCIG from the motor. Confirm that speed, position, and frequency are being correctly displayed.

3. SCIG connection

Carefully read the instructions below. The proper operation of this system requires a completely correct setup. A layout of the complete system may be viewed in Appendix I.

3.1 System Set-up

<u>>>Hardware Setup</u>

In order to capture voltage and current outputs from the generator, gather the grid connection board and a current sensor board. Follow the figure in appendix I for a correct connection. Connect 2 BNC cables from phases A and B of the generator side of the grid connection box to channels ADCH 5 and 6 respectively (refer to figure 7 in the lab 4 handout). Next, use two BNC cables to connect channels ADCH 7 and 8 on the dSPACE breakout box to the current sensors for phases A and B. Refer to Appendix II of lab 4 to review the connection of the current sensor board and the grid connection box. Connect another BNC cable from DACH1 to the relay control terminal on the grid connection board.

Optional: Noise in this system can distort captured data. To reducethis noise, connect a wire from the frame of the generator to the neutral on the grid connection box.

Once everything is connected, take a picture of your hardware setup to include in the lab report.

3.2 Connection to the grid

ALWAYS TURN OFF THE RELAY BEFORE TRYING TO STOP THE SYSTEM; OTHERWISE THE ELECTRONIC BOARD WILL BE DAMAGED.

The grid connection relay is controlled by the *Relay Control* check box in dSPACE. Selecting this box will activate the relay. To turn off the relay, deselect the *Relay Control* check box. Note that the physical grid connection relay will not operate unless the three-phase grid voltages are plugged in and the three-phase supply is turned on.

On the three phase power supply, the green terminal is the ground.

Proceed with CAUTION when connecting the 3-phase voltage supply and turning it on

>>dSPACE

With everything connected, engage the experiment online and supply a voltage to the DC motor. Ramp the voltage applied to the DC motor up to a voltage that produces a speed slightly over 1800 RPM. This is because, the speed reduces by a small value once the system is connected to the grid, indicating that power is being fed into the grid. Increasing the speed of the dc motor over 1800 RPM is done to ensure that the speed drops to 1800 RPM once it is connected to the grid. Once the generator has reached a steady-state speed, click the *Start Recording* button and then, trigger the relay in the grid connection box in quick succession. At this point, the generator will connect with the grid. Capture 5 seconds of data. Save a data set so it may be unpacked in Matlab using Mat_Unpack. Analyze this data for the report. Provide a plot of the peak phase voltages and currents (about 100 ms showing the AC wave form is sufficient). Also include a plot of the real and reactive powers showing transient behavior as soon as the relay is checked and reaching steady state (about 250 ms)

Comment on what is observed, including the power magnitude at 1800 RPM. If necessary, put the experiment offline so modifications to both the Simulink model and the dSPACE layout can be made.

Data post-processing considerations:

When post-processing captured steady-state data, all of the outputs as well as the real and reactive power should be filtered. You can use any post processing filter of your choice. Refer back to lab 4 for a filter example. Ensure that the plots are smooth without losing too much transient response information.

At this point it would be good to have the TA look over your Simulink model, dSPACE layout, and equipment setup.

4. Power Curves

Now that the SCIG is connected to the grid, it is time to take measurements of active and reactive power for different speeds. This experiment will give an insight of how the SCIG behaves with respect to speed after being connected.

4.1 Generator experiments with grid connection

>>dSPACE

Once the setup and layout are ready for the actual experiments, perform the connection to the grid (3.2) and follow the following steps:

- **i.** At this point, the system should be running at 1800 RPM. Vary the DC supply to the DC motor in order to change the speed from about 1650 RPM to 2050 RPM. Collect data for both speeds (low and high).
- **ii.** Next, record data for about 15 seconds, starting the speed as low as 1650 RPM and continuously varying the speed until 2050 RPM is reached. With the data obtained, plot the speed, the real and reactive powers with respect to time, and the real and reactive powers with respect to speed. Comment on the plots obtained.

In the report, discuss how the power curves relate to the torque as a function of speed.

5. Self-excited Operation

In this part of the lab, we will observe the self-excitation of SCIG. Self-excited operation is possible if capacitors are connected to the stator terminals in order to supply the necessary reactive power. Remove the grid connection box from the system as the high voltages produced by the SCIG could damage it. View these voltages by connecting directly to the oscilloscope with probes. The simplest way to accomplish this is to use 3 BNC-to-alligator cables. Connect one end to the capacitor box terminals, and clip the other end onto the respective oscilloscope probe. Make sure to connect the probe ground clips to each other.

HIGH VOLTAGE IS GOING TO BE PRODUCED; BE CAREFUL AND DO NOT TOUCH THE TERMINALS OF THE GENERATOR OR CAPACITOR BOX.

5.1 System Setup

>>Hardware Setup

In order to observe the self-excited operation of the SCIG, gather the three-phase capacitor box. Connect each terminal to the three phases of the SCIG. Figure 3 shows this connection. Before running the system, connect each of the phases to the oscilloscope to observe the results.

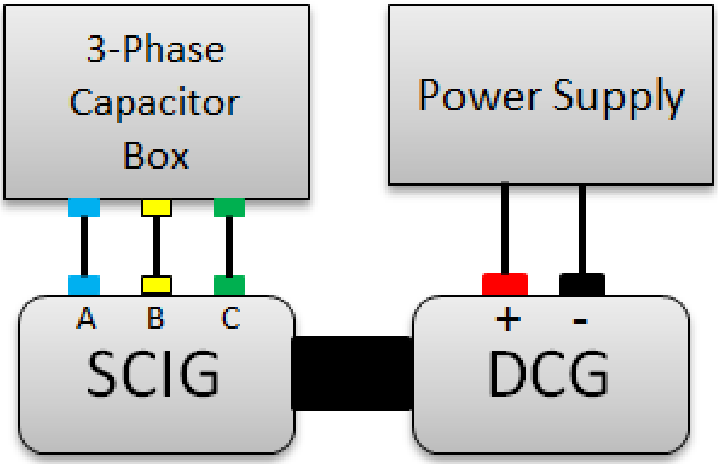


Figure 3. Self- excitation SCIG setup

5.2 Self-excited SCIG

After verifying the connections, start applying a voltage to the DC motor incrementally. Around 36 Volts you should observe a sudden voltage increase at the SCIG. This AC voltage can be observed and recorded in the oscilloscope. Comment on the observations. **BE CAREFUL WITH THE HIGH VOLTAGE**

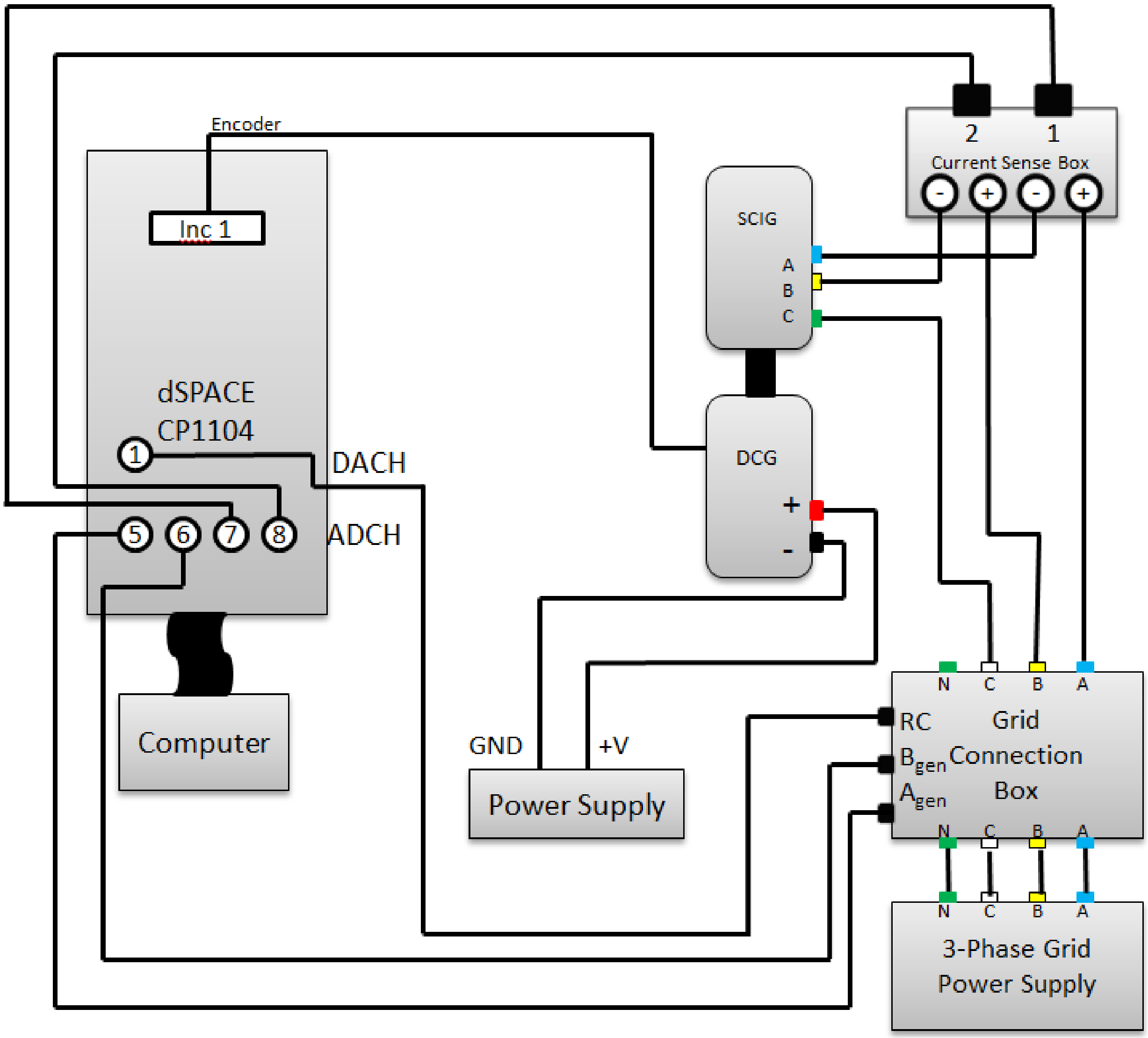
Report Requirements: Consider this requirement list a guide to what would be viewed as a minimum to submit for your lab report. Always include discussion and comments on procedures, observations, and findings.

- Introduction with objectives.
- Include the equipment number of all of the major components used
- Section 3.1
  - Picture of your hardware setup
- Section 3.2
  - Provide a plot of the phase voltages, current, real power (P) and reactive power (Q) after the SCIG has been synced to the grid. Speed should be 1800 RPM.
- Section 4.1
  - Plot of real and reactive power at lowest speed with respect to time
  - Plot of real and reactive power at highest speed with respect to time
  - Plot real and reactive power with respect to speed (low to high RPM)
    - Provide the answer to all questions presented in the procedures.
- Section 5.2
  - Provide the figure capture in the oscilloscope and comment on the results obtained.
- Conclusion (Describe what worked well and did not work well in this lab, and make suggestions for possible improvements.)

Appendix I. Cable List

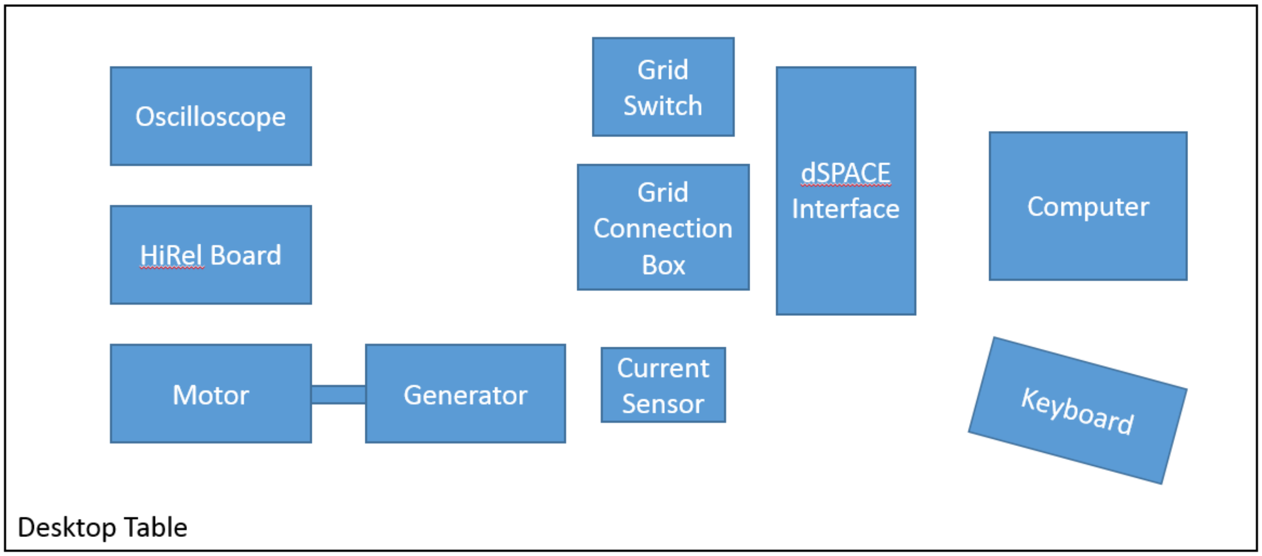
Cable No.	# Cables/Bundle	Colors	Length	From	To
#2	4 - banana	Y/B/W/G	12”	Grid (A/B/C/N)	Grid Connect Box (A/B/C/N)
#3	2 - banana	W/B	12”	Grid Connect Box $(A/B)_{gen}$	Current Sensor
#4	2 - banana	W/B	12”	Current Sensor	Generator Stator (A/B)
#5	1 - banana	Y	24”	Grid Box (C)	Generator Stator (C)
#7	2 - banana	R/Blk	24”	Power Supply(+/-)	DC Motor Terminals(+/-)
#11	2 - BNC	W/B	32”	Grid Connect Box (A/B)	dSPACE (ADCH 5 & 6)
#12	2 - BNC	W/B	32”	Current Sensor Board (A/B)	dSPACE (ADCH 7 & 8)
#10	1 - BNC	Blk	24”	dSPACE (DACH 1)	Grid Connect Box Relay

Appendix II. System Layout



Appendix III. Desktop Layout

South Facing Desk



North Facing Desk