ECE 5671/6671 LAB 6

Wound-Field Synchronous Generators

1.0 Introduction

This lab is designed to explore the characteristics of Wound Field Synchronous Generators (WFSG). The WFSG of this lab is obtained by using a Doubly Fed Induction Generator (DFIG) operating in synchronous mode with constant rotor currents. First, the DFIG is synchronized with the grid as a synchronous generator. Then, the excitation current is varied and the resulting changes in line current and real and reactive powers are observed. Then, the motor torque is varied; the resulting changes in real and reactive powers are observed and the real versus reactive power curve is plotted.

1.1 Lab Objectives

The following are the objectives of this lab:

- Learn about the basics of WFSGs and how they operate
- Learn how to sync a WFSG to the grid
- Learn about the relationship between the real power and the torque of the prime mover
- Learn about the relationship between the reactive power and the excitation current

The following equipment is needed to complete this lab:

- DC generator, frame mounted, with coupler
- DFIG generator
- Grid Connection box
- dSPACE I/O box
- PEDB with ribbon cable and +12V supply
- Current sensor board
- Box of cables

2.0 Simulink Model:

The Simulink model (lab_6.mdl) is provided in order to capture generated voltages, currents, real power, and reactive power. It will also control the rotor excitation current, prime mover voltage, and grid connection board relay. Figure 1 shows what the model should look like.

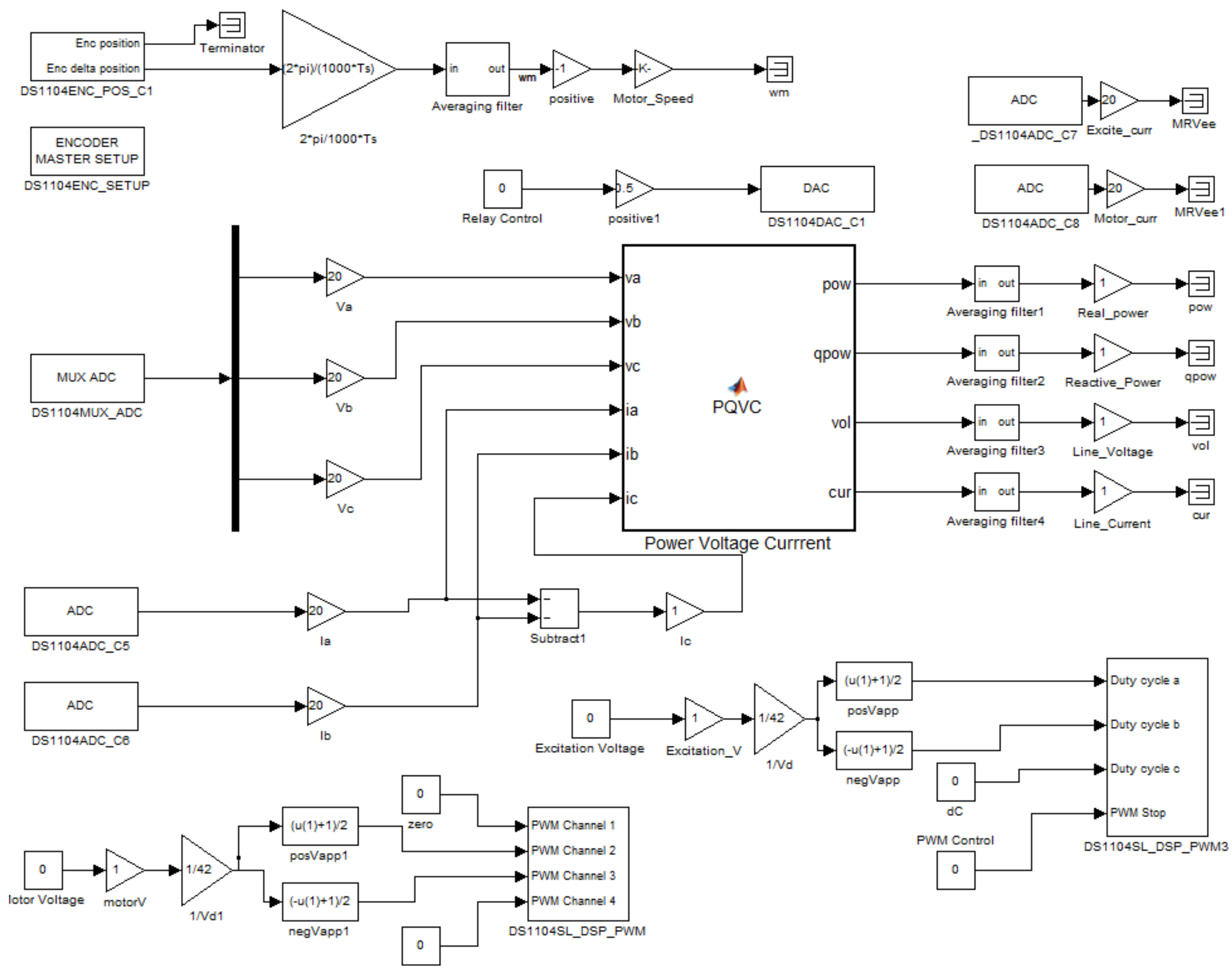


Figure 1: Simulink model for Lab 6

- Open Matlab and open the provided model.
- In the MATLAB command prompt, set Ts = 1e-4.
- Save the .mdl file into the working MATLAB directory as lab_6.mdl.
- Press CTRL+B to build the system description file for use in dSPACE.

3.0 dSPACE Setup:

Next, open the dSPACE .lax file provided to control and capture the experimental data. Begin by opening the dSPACE Control-Desk software. The provided .lax file should look like figure 2.

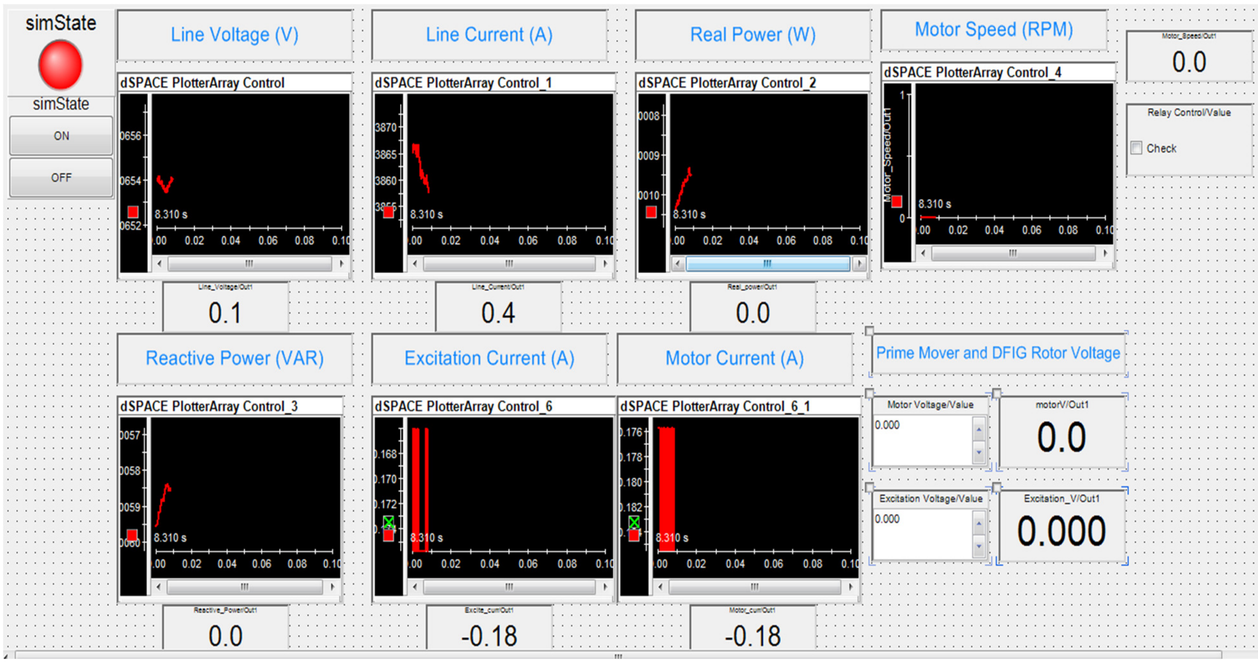


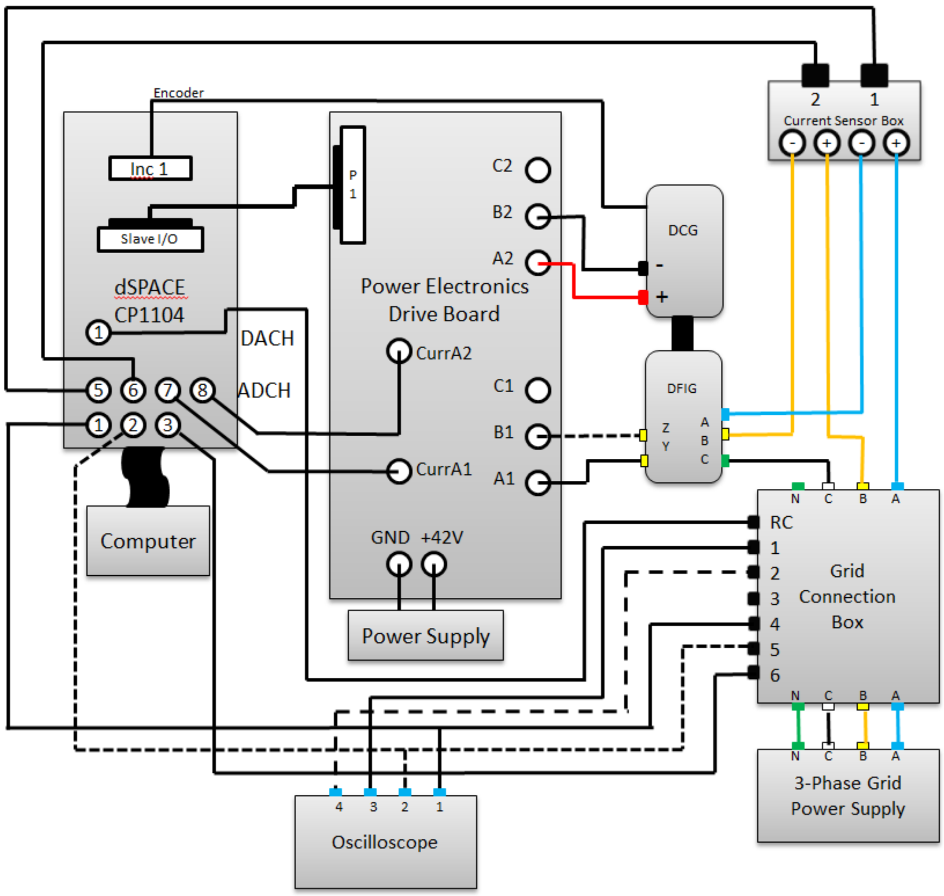
Figure 2: dSPACE .lax file for lab 6

- Create a new Project + Experiment framework, choosing the appropriate **.sdf** file.
- Select *Layouting* > *Import layout* and select the .lax file provided as lab_6.lax.

4.0 Experimental Setup:

The following steps need to be followed carefully in order to sync the DFIG to the grid and perform the experiments.

- Remember to reference Appendix III of lab #5 when placing components on the desktop
- Make sure that the dSPACE break-out box is well connected to the computer.
- Refer to the cable connection table in the appendix when connecting all components.
- The current sensor board will be utilized to measure the line current of the DFIG. Connect phase A on the DFIG through the current sensor to phase A on the generator side of the grid connection box (DFIG A → current sensor black, current sensor red → grid connection box phase A). Connect phase B on the DFIG through the current sensor in the same fashion. Connect DFIG phase C directly to phase C on the grid connection box.



- Connect the BNC from the current sensor channel measuring phase A to ADCH 5 on the dSPACE I/O box and the channel measuring phase B to ADCH 6.

- The three generator voltages will be measured using the dSPACE ADCH 1, 2, and 3. Use BNC cables to connect generator phases A, B, and C on the grid connection box to ADCH 1, 2, and 3, respectively. (Phases A and B must be monitored on an oscilloscope to verify sequence and compare with the grid phases A and B). Use BNC splitters that will allow the DFIG phases A and B to be connected to ADCH1 and 2 as well as two channels on the oscilloscope simultaneously.

- The PEDB will be used to control the DC motor and the excitation current applied to the DFIG rotor windings. In order to measure the excitation current and the current drawn by the DC motor, use two BNC cables to connect the curr. A1 and curr. A2 ports on the inverter board to dSPACE ADCH 7 and ADCH 8, respectively.

- Make sure that the Three Phase **Grid** power supply is **OFF** and connect all three phases to the Grid side of the grid connection box using 4 Banana-Banana wires.

- Phases A and B of the grid must be monitored on an oscilloscope. Use two BNC cables to connect the grid phases A and B BNC terminals on the grid connection box to two channels on the oscilloscope. You may replace the recommended cables in the table with regular thick BNC cables from the rack if, during the experiment, there are difficulties seeing the grid phase voltages on the oscilloscope. But keep in mind to return these cables back to the rack.

- Connect the DFIG ports Y and Z to the PEDB phases A1 and B1, respectively. (A1 → Y, B1 → Z).

- Connect the DC motor to the PEDB phases A2 and B2, respectively. DC motor (A2 → red, B2 → black).

- dSPACE will be used to control the relay on the grid connection board via DACH1. Use a BNC cable to connect DACH1 to the relay control terminal on the grid connection box.

- Finally, connect the encoder cable to the DC motor encoder output, and connect the other end of the cable to the INC 1 input on the dSPACE box.

- At this stage, you are done with the system connections. Redirect your attention to dSPACE.

- Now, turn on the grid power box. You must be able to see still sine waves of phases A and B of the grid on the oscilloscope. Make sure that the DC regulated power supply is set to 42V. Also, set the current supply of the power supply to maximum value. Turn on the power supply. Begin to increase the speed of the prime mover (Motor_V) in dSPACE and confirm that the speed is being read into dSPACE as positive. (If this is not the case, make sure that the inverter gain is placed in-line with the velocity data collection in the Simulink model as shown in figure 1.) While the motor & generator are spinning, the RPM meter in the layout should indicate how fast the motor/generator set are spinning. Increase to 1800 RPM. Next, increase the excitation voltage that is connected to the generator's rotor to roughly 3V. Check the oscilloscope and make sure that you see the phase A sinusoid generated by the DFIG. You should also be able to see phase B generated by the DFIG, but we will concentrate on phase A in the next section.

5.0 Connecting the DFIG to the Grid:

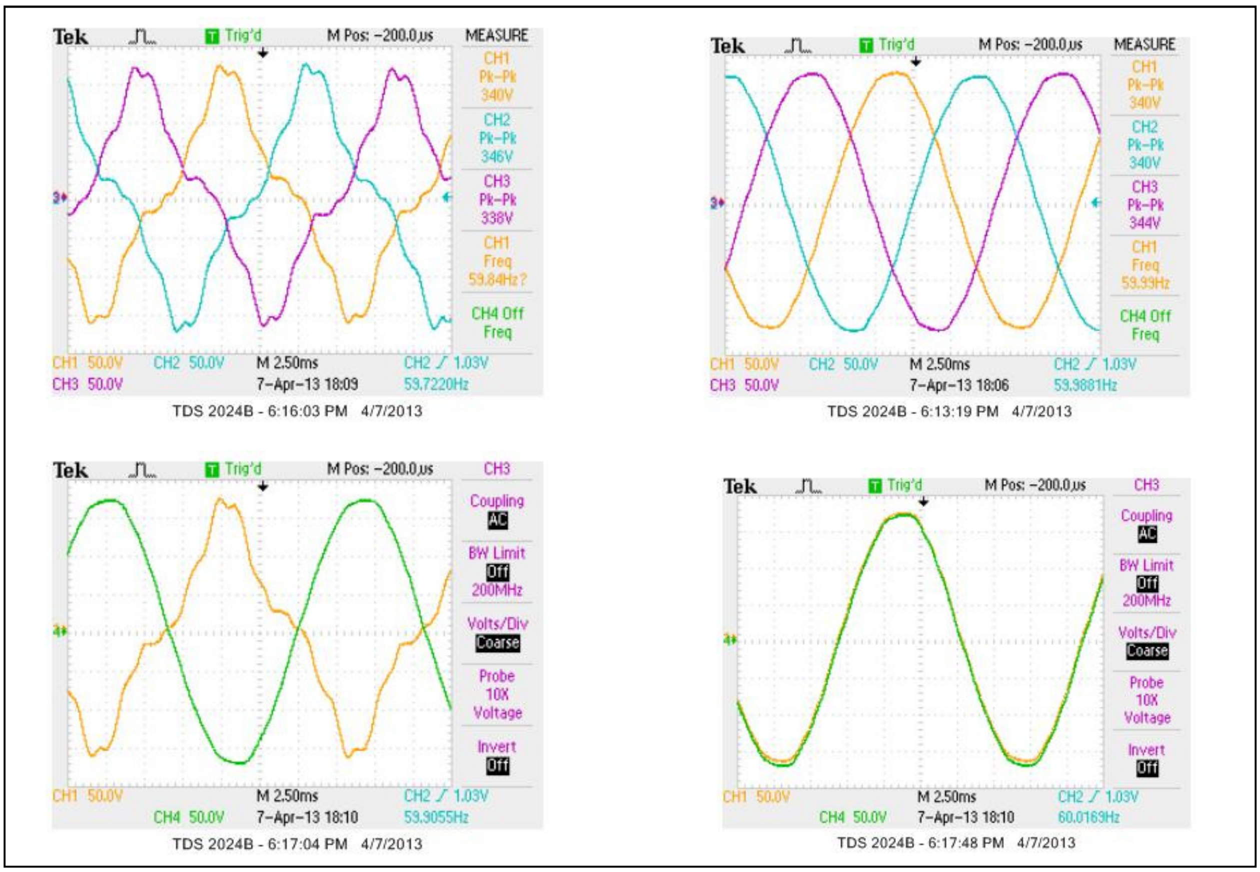
- Make absolutely sure that the phase sequence of the DFIG is identical to the Grid's sequence. Use the oscilloscope to verify. **<u>Ask</u>** the TA to verify your setup and the phase sequence of both the generator and the grid.

- View Channel A of the grid side and Channel A of the generator side simultaneously (turn OFF channels for the B phases to avoid distraction during this process). Make sure that the peak-peak voltage magnitude of the DFIG's generated back EMF matches that of the grid by controlling the rotor excitation voltage.

- Make sure that the frequency of the DFIG is slightly higher than the grid's frequency so that, when the generator is connected to the grid, it will be generating a small amount of power. This corresponds to the DFIG rotating slightly faster than 1800 RPM.

- When the generator and grid channels overlap, check the relay control box in dSPACE. This will activate the grid connection relay and the generator will be connected to the grid.

- If the signals on the oscilloscope are no longer lined up and the system begins to operate rough, immediately deactivate the grid connection relay in dSPACE. This is caused by phase mismatch between the generated signals and the grid. Ask your TA for help.



- The top left plot above shows the voltage sequence of the DFIG; this is what is expected to be seen during phase verification.

- The top right plot shows the grid voltages. It is important that the DFIG and grid have the same phase sequence.

- The bottom plots show the two phase A voltages before and after they are connected.

6.0 Experiments while Varying the Excitation Current (3 Data Sets Obtained):

Perform the following experiments after the DFIG is synced to the grid:

- Gather data at three different torque (DC motor current) levels (use a different constant DC motor voltage for each one such as 16, 16.5, and 17V). Record data while sweeping the excitation current from 1.8 to 4 Amps. Right click on the excitation voltage numeric input window and change the increment to 0.1 in order to get a smooth increase in measurements. This data can be used to make the following plots:

    - V-Curve: Plot 3 V-curve plots at three different torque levels on the same axes. The V-curve is a plot of the stator current or line current versus rotor current or excitation current. Comment on these plots in your report.

    - Real power vs. excitation current**:** Plot the real power vs. excitation current for the 3 torque levels on the same plot. Comment on these plots in your report.

    - Reactive power versus excitation current**:** Plot the reactive power vs. excitation current for the 3 torque levels on the same plot. Comment on these plots in your report.

7.0 Experiments while Varying the DC Motor Current (3 Data Sets Obtained):

At this point, the DFIG should still be synced to the grid.

- Gather data at three different excitation current levels (2.5, 3, and 3.5A are good values to use). Record data while sweeping the motor current from ~0 to 4 Amps. Right click on the motor voltage numeric input window and change the increment to 0.1 in order to get a smooth increase in measurements. This data can be used to make the following plots:

    - Real power vs. DC motor current: Plot the real power vs. motor current for the 3 excitation current levels on the same plot. Comment on these plots in your report.

    - Reactive power vs. DC motor current: Plot the reactive power vs. motor current for the 3 excitation current levels on the same plot. Comment on these plots in your report.

    - Reactive power vs. real power: Plot the reactive power vs. real power for the 3 excitation current levels on the same plot. Comment on these plots in your report.

Note on captured data:

The data captured will be extremely noisy. Use of the following second order Butterworth filter will result in clean data plots:

```
[b,a] = butter(2,1e-4);
Variable_Filtered = filtfilt(b,a,Variable_to_be_filtered);
```

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.

- Describe the objectives of this lab in your own words.
- Include the equipment number of all major components used
- Describe the steps that you took to sync the DFIG to the grid
- Include the following plots with comments in your report (all should have three datasets in one plot)
  - V-curves
  - Real power versus excitation current curves
  - Reactive power versus excitation current curves
  - Real power vs. DC motor current curves
  - Reactive power vs. DC motor current curves
  - Reactive power vs. real power curves
- Include any irregularities you noticed in the data you collected.
- Provide a conclusion summarizing the concepts and procedures covered in this lab. (Also, 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)
#6	3 - banana	Y/B/W	24”	Hirel Board (A1 & B1 only)	Rotor (Y & Z only)
#7	2 - banana	R/Blk	24”	Hirel Board (A2 & B2)	DC Motor Terminals(+/-)
#8	2 - banana	R/Blk	32”	Power Supply(+/-)	Hirel Board (+/-)
#9	3 - BNC	W/B/Y	24”	Grid Connect Box $(A/B/C)_{gen}$	dSPACE (ADCH 1&2&3) w/ T
#12	2 - BNC	W/B	32”	dSPACE (ADCH 1 & 2) w/ T	Oscilloscope
#10	1 - BNC	Blk	24”	dSPACE (DACH 1)	Grid Connect Box Relay
#15	3 - BNC	W/B/Y	24”	Grid Connect Box $(A/B)_{grid}$	Oscilloscope
#11	2 - BNC	W/B	32”	Current Sensor Board (A/B)	dSPACE (ADCH 5 & 6)
#13	1 - BNC	B	32”	Hirel (curr. A1)	dSPACE (ADCH 7)
#14	1 - BNC	R	32”	Hirel (curr. A2)	dSPACE (ADCH 8)