Coursework 1

Important notes:

- Coursework report should **not** be longer than **3000 words** (excluding contents, tables, figures, and references)
- Ensure the title of coursework, date, your name and matriculation number are included on the front cover.
- Coursework weight is **50% of total module mark**. Coursework marks will be distributed over questions as indicated.
- In lab sessions, more than one method to export Simulink scope plots, curves, and data to your report will be indicated. You must use one of the indicated methods. **Snapshots of waveforms are not acceptable.** An example method is given by the end of CW1 brief.
- It is important you aid any explanations/comments you provide in this course work with appropriate academic references, whenever possible.

- Plagiarism

Please note the following School statement on Plagiarism: "The deliberate and substantial unacknowledged incorporation in your submission of material derived from work (published or unpublished) of another is prohibited. In such cases the work submitted is classified as illegal and will result in further action being taken by the University which may include recording a failure.

Modelling and operation of a Renewable Power Plant

Introduction

In this exercise, you will learn about the components and operation of a renewable power plant (RPP) using Matlab coding and Simulink models. The RPP consists of a 200kW solar farm divided into two 100kW arrays, and a 6MW wind farm built of four 1.5MW doubly-fed induction generator wind turbines (DFIG-WTs).

<u>The specific purposes are:</u>

- To understand the relation between voltage and current of a photovoltaic solar panel under various operating conditions.
- To understand the operation of a PV array under various operating conditions by means of Simulink modelling.
- Develop understanding of DFIG-WT fault ride through methods by means of modelling and simulation.
- Understanding operation under ac system faults.

Tasks

a) Complete and run the solar farm Simulink model and plot I-V and P-V curves. [Total: 50 marks]

Open the file named “200kW_solar_farm.slx” in Matlab. Familiarize yourself with the model and included descriptions. You will notice the solar array blocks clearly marked.

1) Open the “block parameters” of the ‘PV array’ block view its parameters and click the ‘help’ button to review its Matlab documentation and familiarize with its controls. Adjust the array structure such that eventually the power plant is composed of two arrays. Each of the two arrays is sized for ‘roughly’ 100kW, 400A, and 270V. Note that you will need to use more than one ‘PV array’ block to reflect the solar farm structure. Connect a dedicated DC/DC converter block at the terminals of each ‘PV array’ block and parallel connect the outputs of the converter blocks to feed the PV inverter. The solar panels used are of the model Sunpower SPR-315E-WHT-D whose detailed datasheet can be found here. **<u>Submit your functional Simulink model alongside your report.</u>**

   [10 marks]

2) Run the model at the set levels of irradiance and temperature. Export output power profiles of each solar farm section. Export a plot of the corresponding I-V and P-V curves of one of the two 100kW arrays and locate the operating points on these curves.

   [10 marks]

3) Change the temperature and irradiance profiles inside the “irradiance” and “temperature” blocks, respectively, to the “random” selection. Run the model and export the output

power profiles of one solar farm section. Comment on the difference with the case in 2)
[10 marks]

4) Use the equations in Appendix A to plot the I-V ad P-V characteristics of the selected PV panel at STC knowing that I_o= 0.1 nA. **[5 marks]**

5) Use the equations in Appendix A to plot the I-V ad P-V characteristics of one string of any of the solar farm arrays at STC knowing that I_o= 0.1 nA. **[5 marks]**

6) Repeat your I-V plot in 5) for a temperature of 45°C and irradiance levels G = 900 W/m^2, 650 W/m^2, and 450 W/m^2. **[5 marks]**

7) Critically analyse your graphs as to how the change of irradiance and temperature affects the operation and output of the solar panel. **[5 marks]**

[**Hint:** For your calculations, define a vector for the appropriate range of voltage values, and make sure to plot your equations such that the characteristic curve extends between I = 0 and I_m]

You **must** include your Matlab code to your report.

b) DFIG-WT performance under grid faults (fault-ride through capability)
[50 marks]

Open the DFIG-WT model you saved in your week 3 exercise. The model represents 1 of the six wind turbines present in the wind farm. The model is based on the DFIG-WT configuration shown in Fig.1. For an easier understanding of the effects of a short circuit fault on the operation of DFIG-WT, perform this task at constant wind speed of 10.5m/s.

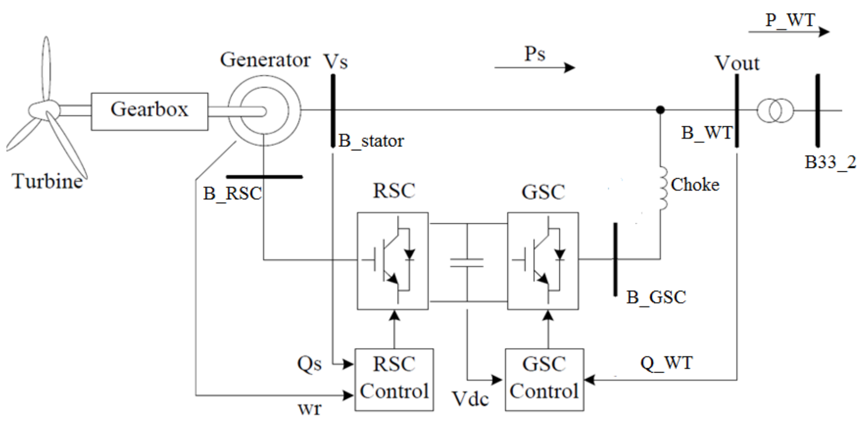

Fig. 1 DFIG-WT configuration

In a DFIG-WT, under an AC fault, the back-to-back converters are the most vulnerable components of the WT. Consider the IGBTs of both the RSC and the GSC in the considered WT model are rated to 1.7kV and 2.5kA. For each of the following types of faults at the point of connection of the wind farm, run your DFIG-WT Simulink model and export rotor current and DC link voltage waveforms to your report. Also, indicate in each case – with a brief explanation – whether the WT can ride through the fault without protection or not.

i) Three phase fault [Open the “Fault” block and select the parameters (tick the box): Phase A Fault, Phase B Fault and Phase C and Ground] **[5 marks]**

ii) Double line to ground fault [Open the “Fault” block and untick: Phase C]

[5 marks]

iii) Single line to ground fault [Open the “Fault” block and untick: Phase B.]
[5 marks]

In the DFIG-WT, overcurrents and overvoltages can damage RSC and GSC IGBT switches. To protect the RSC against high rotor currents, crowbar circuits can be used. To protect the RSC and the GSC from overvoltages, chopper circuit can be used across the DC link. A chopper circuit is composed of a resistor bank and one IGBT (or more IGBTs in parallel) connected across the DC link capacitor terminals. When the measured DC link voltage exceeds a certain threshold voltage (V_{on}), the controller sends a turn-on signal to the chopper IGBT(s) to switch resistor bank in the circuit and dump any excess energy in the DC link to maintain its voltage within limits. The controller turns off the chopper circuit when the DC link voltage drops back to near the steady state voltage (V_{off}).

iv) Sketch a schematic diagram of the WT (as in Fig 1) with the crowbar circuit and chopper circuit included. **[5 marks]**

v) Design a chopper circuit (i.e. select the ratings of its components) to protect the DC-link and converters from overvoltages under fault. Consider the following:

- Choose V_{on} within the range 1450V-1500V and V_{off} within the range 1330V-1380V.
- To design your chopper circuit power rating, the simplest rule is: your chopper may need to dump all RSC power [assuming a worst-case fault scenario when the RSC exports its maximum power to the DC link and the GSC is unable to export any power to the grid]. So, the chopper circuit needs to have the same power rating as the RSC.
- By knowledge of chopper circuit power, calculate the chopper resistor bank resistance considering that its voltage during operation is V_{on}.

Using the above considerations show the full design of your chopper circuit (i.e. the resistance of the resistor bank, current flow in the IGBT switch when on, voltage of the IGBT when off, power rating of the resistor bank). **[7 marks]**

vi) Model your chopper circuit in your DFIG-WT Simulink model using a resistor and an IGBT (with antiparallel diode). Use a ‘relay’ block from ‘Simulink library’ to model and control the turn on and off voltages of the chopper circuit. Run the model under the three phase AC fault and measure the current and the voltage of the chopper circuit when in operation and export waveforms to your report.
[8 marks]

vii) In your model, find the amount of energy absorbed by the chopper resistor bank under the three phase AC fault. [Hint: use an integrator block to integrate power measurement into energy. You can measure energy by a scope or a display block]
[5 marks]

viii) Which of the following devices from Table I will you pick up to build your chopper circuit? Make sure that the IGBT used does not get loaded to more than 60% of its rated current (safety margin). **[5 marks]**

Table I

Switch	Current rating (A)	Voltage rating (kV)
IGBT_1	750	1.7
IGBT_2	1000	1.7
IGBT_3	1500	1.7
IGBT_4	2500	1.7

ix) Select the voltage and current ratings of each semiconductor device used in the simplest crowbar circuit (a diode bridge + IGBT(s) + resistor) that can be used to protect the RSC against overcurrent. Select your IGBT device(s) from Table 1, and look up ABB/Hitachi rectifier diode catalogue for appropriate commercially available diode devices [**HINT**: You can access ABB/Hitachi diode catalogue here and learn about rating parameters of diodes and select the appropriate device from the available list of devices.] **[5 marks]**

End of Questions

Appendix A

The PV cell is a P-N junction similar to a diode. The diode V-I equation gives an expression for the current through a diode as a function of voltage. This equation for an ideal diode is expressed as:

$$I = I_o \left(e^{\frac{qV}{kT}} - 1\right) \quad (1)$$

where:
I = the net current flowing through the diode;
I_o = "dark saturation current", the diode leakage current density in the absence of light;
V = applied voltage across the terminals of the diode;
q = absolute value of electron charge;
k = Boltzmann's constant; and
T = absolute temperature (K).

In darkness (in the absence of light), the solar cell acts similar to a diode and its operation in darkness will be according to (2). Note that (2) is the same as (1) with a reversed sign to reflect the reference current direction of the solar cell being out of the positive voltage terminal of the cell, unlike the reference current direction in a diode which is considered into the positive terminal of the diode.

$$I = I_o \left(1 - e^{\frac{qV}{kT}}\right) \quad (2)$$

The I-V curve of a solar cell under light is the superposition of the I-V curve of the solar cell diode in the dark and the light-generated current (I_L). The light has the effect of shifting the IV curve upward where power can be extracted from the solar cell. So, illuminating a cell adds to the normal "dark" currents in the diode so that the solar cell I-V equation becomes:

$$I = I_L - I_o \left(e^{(\frac{qV}{kT})} - 1\right) \quad (3)$$

Irradiance level (G) can be considered in the cell I-V relation of (3) as shown in (4), where G_r is the reference level of Irradiance being 1000W/m^2.

$$I = \left(I_L \times \frac{G}{G_r}\right) - I_o \left(e^{(\frac{qV}{kT})} - 1\right) \quad (4)$$

Appendix B

Tips and Instructions

There is more than one way you can export neat and clear plots from Simulink scopes. You are free to do it the way you prefer as long as the figures are neat, clear, and readable **(and not of a black background!)**.

One way to export high quality neat waveform from Simulink scopes to your report in a few simple steps is as follows. This guideline also (starting from step 2) applies to editing figures/plots generated from Matlab command line.

When you double click the scope and see the waveform in a new window follow these steps:

1- Go to File menu; choose "print to figure" .... [A new Matlab figure window will open]

2- Save the Matlab figure to your drive: File --> Save as..   [Save the file as a Matlab figure (*.fig) for later edits or retrieval if needed]

3- Go to View menu; click "Property Editor" .. [An edit panel will appear below the graph/plot]

4- In the edit panel; change figure colour (bottom left of the panel) from black to white.... [You will notice axes background colour turns to white]

5- Click on the plotted curve(s) and edit plot colour, line type and width, etc.

6- Click anywhere in the figure background to return to the graph edit panel where you can directly change X and Y axes labels and the limits displayed in your graph by selecting the relevant X or Y Axis tab.

7- Go to "Font" tab to change the font name and size ... [This is an important step to provide readable font sizes for markers]

8- After finishing edits, save the graph from "File" menu as a ".jpg" or ".tif" image file.

9- Make sure to save your edits on the figure file you saved earlier (*.fig).

The image file can be then exported/copied to your report. Make sure to include proper caption and figure number to your figure in the report.

End of CW1