# EEEE3112-Power Electronic Applications and Control

## Coursework 2: Design and modulation of a grid-connected full-bridge single phase inverter

### Introduction:

This coursework involves investigating the design, control, and behaviour analysis of a DC to AC converter considering the application of interfacing a solar panel power network to a single-phase AC grid. The coursework encompasses a typical design approach which would be done by typical engineers, staring from the preliminary stages of development, firstly by modelling and then designing the control system of said converter.

All the theory and knowledge to complete the coursework are covered in lectures. Use the lectures as guidance to do your coursework. On the other hand, the coursework is designed to help strengthen your understanding of the taught topics. The taught topics and the coursework are complementary to one another.

Learning how to design and simulate a state-of-the-art converter is an essential skill for a future power electronic engineer, and the works done during the coursework are the standard steps before the construction of a laboratory prototype.

MATLAB will be used for the controller design and PLECS for the power electronics and for the simulation of the full system.

This coursework is worth 30% of the module.

Assessment will be based on a written report, submitted electronically on Moodle. The most important learning outcome of the coursework will be the application of the correct design and validation methodology. You are not expected to write a long essay but rather to be as clear as possible about how you designed the system and how you validated your design. Any additional critical comment/discussion of the results is obviously welcome!

The coursework should be written as a technical document you may be asked to submit to the management of a company and is used to decide whether to put your converter into production or not. Therefore, make sure to write the document as follows:

- If something goes wrong, for instance, you design it wrong and did not explain it properly, you will be considered responsible for it.
- Do not write the coursework as if you are answering examination questions for each of the deliverables provided.

### System under study:

The power conversion system you have to design and simulate is a grid-connected single- phase full-bridge converter, typically used to interface photovoltaic and/or energy storage systems with the AC grid or to power DC loads.

Referring to photovoltaic/energy storage we can represent the system as:

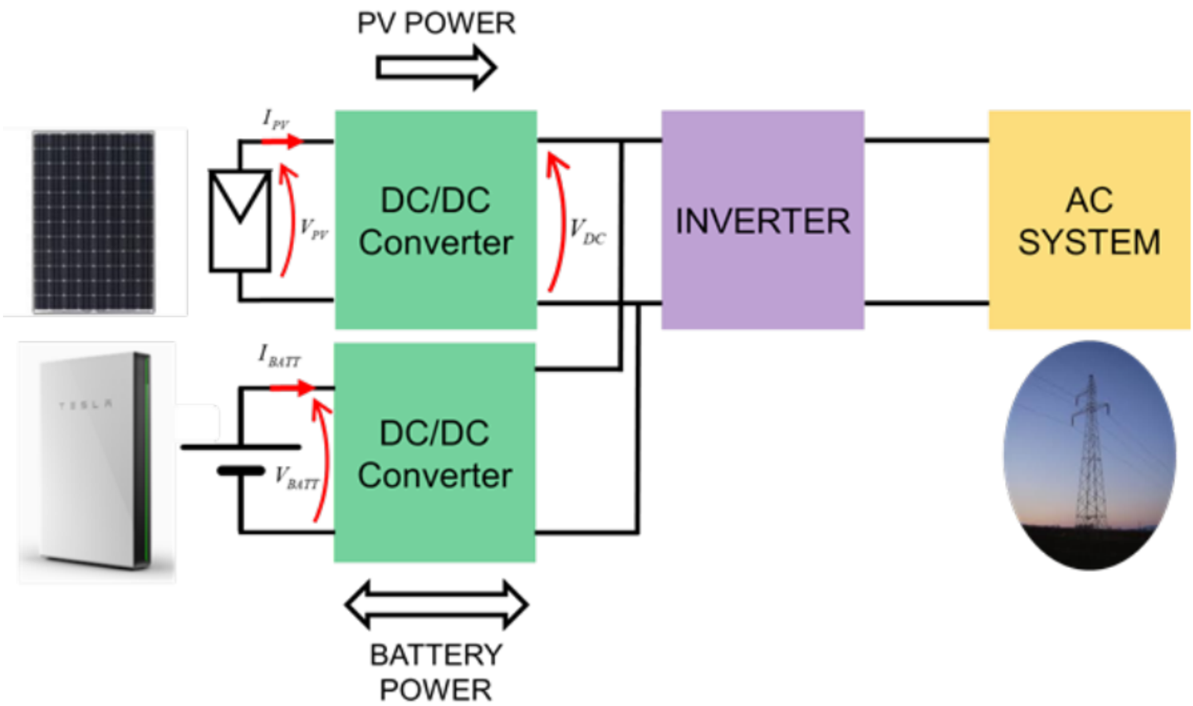


Figure 1: Photovoltaic and energy storage system interfaced to an AC grid

The system looks pretty complex – and it actually is complex if we want to design and build everything we see in the figure. However, our focus will be only on the inverter part, in particular, the design of the converter and of its control:

### Inverter with constant DC source and AC current control

In this part of the coursework, you need to design and simulate an average linear model of the inverter in question. Average linear models are used to verify theory, and to design control systems using mathematically simpler models to that of an actual switching converter.

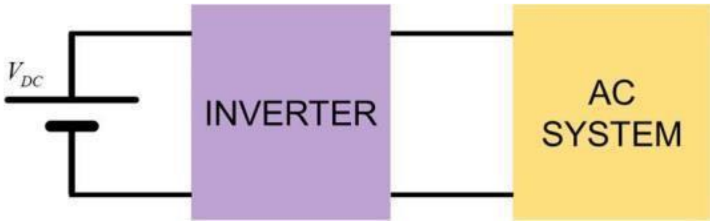


Figure 2: Simplified circuit for AC current control

Table 1 - Design Specification for Converter to be designed

| Specification/Term | Symbol | Value |
|---|---|---|
| DC voltage | $V_{DC}$ | 600V |
| AC RMS voltage | $V_{AC}$ | 240V |
| AC current ripple (peak-peak) | $\Delta I$ | 0.5A |
| Rated power | P | 3kW |
| Inverter switching frequency | $f_{SW}$ | 20kHz |
| Loss in the inductor at rated power | $P_{LOSS}$ | 1%P |
| Reactive power | $Q_{AC}$ | 0 |

**Project deliverables:**

**Note: The tasks are not necessarily sequential**

1. Design the inductor L required in order to connect the converter with the grid respecting the maximum ripple ΔI and calculate the resistor R that models the inductor loss.
2. Calculate the inverter voltage needed to inject the rated power into the grid (rated active power and zero reactive power).

3. Build an average time Plecs model of the system, representing the inverter as a controllable voltage source. Demonstrate that the calculations done in 2 are correct, showing the average power exchanged with the AC grid.

4. Build a switching Plecs model of the system, including the PWM modulator and the full-bridge converter. Feed the PWM modulator with the voltage demand calculated in 2

and demonstrate that the correct average power is exchanged with the AC grid. This should match with the one from 2 and 3.
Hint: Make sure the full-bridge is built as the combination of two half-bridges with independent PWM modulators, as discussed during the lectures. Also, leave the average time model built in 3 in the same file as the one in 4, so that you can check if they match.

5. In 4, show that the average over a switching period of the voltage generated by the full-bridge matches the voltage demand provided to the PWM modulator. In addition, show the Fourier spectrum of the generated voltage and discuss it.

6. From the same switching simulation, demonstrate that the design of L is correct, showing that the current ripple is always below the maximum value.

7. Calculate the transfer function of the plant represented by the converter. The input is the voltage demand to the PWM and the output is the grid current. Implement the equivalent block diagram in Plecs, and compare the result with the simulation in 3. Show the current control block diagram.

8. Design, using Matlab “sisotool”, the current control based on a continuous implementation in the s-domain with the following specifications: Damping factor $\zeta$=0.7, Natural Frequency fo=500Hz ($\omega$o=2*$\pi$*500 rad/s).

9. Implement the controller in the average time Plecs model first, and then in the switching Plecs model. For both models, provide an AC current reference that enables the exchange of a desired active power and zero reactive power. Show that the close loop control can follow the current reference in steady state, commenting on any discrepancies you find. In addition, show the response of the system to the following transients: case A) power step from 0 to P/2 and from P/2 to P and case
B) power step from 0 to −P/2 and from -P/2 to −P and discuss how it relates with the expected closed loop performances.
Hint: make sure you design a simple block the receives the desired AC power reference and generates the required AC current reference.

10. Repeat 8 and 9 using a digital implementation in the z-domain with the following specifications: Damping Factor $\zeta$=0.7, Natural Frequency fo=500Hz ($\omega$o=2*$\pi$*500 rad/s), Sampling Rate fs= fSW ($\omega$S=2*$\pi$*fSW rad/s).