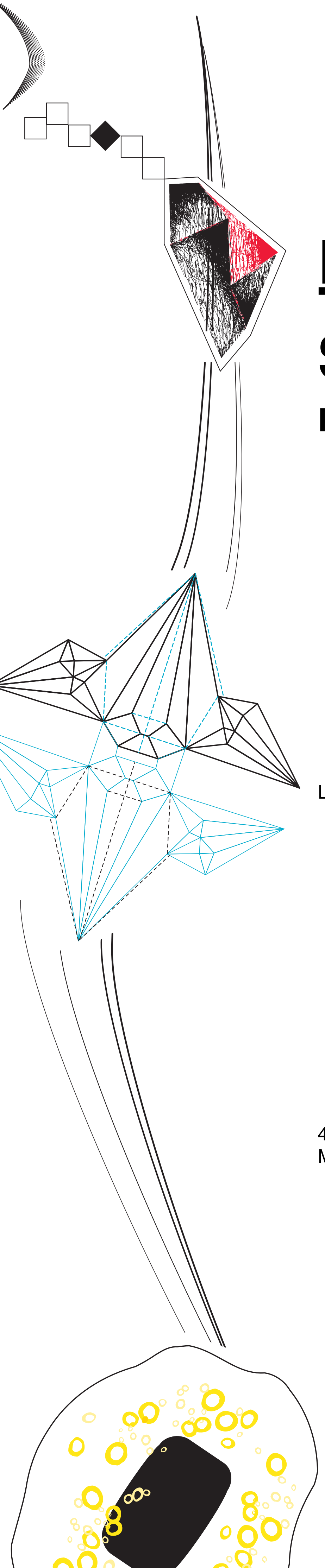

LECTURE NOTES
Faculty of Electrical Engineering,
Mathematics and Computer Science

DESIGN OF A GRID-TIED INVERTER FOR SOLAR POWER

PROJECT MANUAL MODULE 2

Luuk Spreeuwers

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Module 2 EE

UNIVERSITY OF TWENTE.

Contents

CHAPTER 1

ABOUT THE SUBJECT OF THE PROJECT

1.1 Introduction

Despite attempts to reduce use of electrical power, reality is that the world requires more and more of it. Upcoming economies like China and India require more electrical power to sustain their industrial growth. Furthermore, every household contains an incredible and still increasing number of electrical devices. Since the stores of fossil fuels are rapidly depleting and there is much resistance against nuclear power with its risks, we have to quickly deploy sustainable energy sources like wind and solar. An advantage of solar power is that it contains no moving parts, is easy to install and requires virtually no maintenance.

"Photovoltaics (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photovoltaics include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulfide. Due to the growing demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years." (Wikipedia [2])

There is a number of ways to use the DC power generated by solar panels:

- Direct usage by electric device
- Store in battery for later use
- Invert to AC power to drive devices in a stand-alone configuration (island)
- Invert to AC power and feed into the power grid (grid-tied)

For large solar power systems and normal households, the last option is the most attractive, because the power grid acts as a storage. If more power is generated than needed at a certain moment in the house, the power is fed into the grid. If less power is generated the additional required power is obtained from the grid.

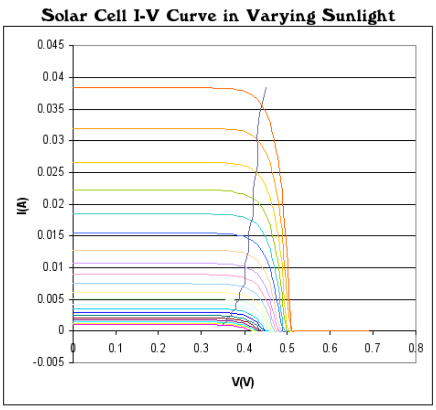
1.2 Inverter

In order to convert the DC power generated by the solar panels into AC power that can be fed into the net, a so-called power inverter is required. The power inverter has 3 important functions:

- Create such a load to the solar panels that maximum power transfer is realised
- Convert the DC power into AC power
- Adapt the voltage and phase to those of the grid

1.2.1 MPPT

In lecture 3 of Electric Circuits we will see how a load can be chosen to realise maximum power transfer from a power source. A solar panel, however, is a complex power source of which the internal resistance depends on the irradiation.



This means that to realise maximum power transfer, the load must be constantly adapted to the changing internal resistance. This process is called **Maximum Power Point Tracking** (MPPT), see [3, 1].

1.2.2 Invert DC to AC

The most frequently used approach to convert DC to AC is by creating a pulse-width modulated square wave by flipping polarity of the DC voltage using electronic switches. The square wave can be turned into a sinusoidal signal using filtering (see lecture 12 & 13 of Electric Circuits on convolution).

1.2.3 Adapt to grid

To adapt the voltage a transformer can be used or a form of a step-up converter. The latter can be realised using e.g. an RC or RL circuit with electronic switches. Finally, the phase has to be adapted to the phase of the grid. This is done by sensing the phase of the grid and synchronise the electronic switches that are used to create the AC power from the DC power. In order to inject the power of the solar system into the grid, the voltage of the inverter should be slightly higher than that of the grid. The grid can be seen as a power source with an extremely low internal resistance, which implies that the inverter should be have as a current source. Some details can be found in [1].

1.3 Assignment

It is a pity that almost all designs for solar power inverters are ”closed” designs. Very few attempts exist towards an ”open source” design solar power inverter. Your assignment is to develop a solar power inverter which converts the DC power to AC power with maximum efficiency. For this aim, you will have a 12V 20Wp solar panel to your availability and its power has to be fed into a 12V AC power grid (for safety). You will have to implement the 3 main functions of the inverter: MPPT, inversion to AC and adaptation to the grid. You will work in groups of 8 students.

1.4 Contest and Prize

This project has a contest aspect as well. During the closing event of the project, we will measure the transfered power under conditioned circumstances. The team whose inverter delivers most power to the grid or the team that has implemented most or best functionality wins a **PIE** and everlasting honour. Successful designs may be published as open source solar power inverter designs.

BIBLIOGRAPHY

[1] *How Inverters Work*,
James Worden and Michael Zuercher-Martinson,
SOLARPRO, April/May 2009

[2] *Photovoltaics*,
Wikipedia,
http://en.wikipedia.org/wiki/Photovoltaics

[3] *Maxmimum power point tracking*,
Wikipedia,
http://en.wikipedia.org/wiki/Mppt

CHAPTER 2

ORGANISATION

2.1 Groups

The project will be carried out in groups of 6 students. These are the same groups you formed at the beginning of the module.

2.2 Division of tasks

All students must be involved in all of the following tasks:

- Literature research
- Planning
- Design and development of the inverter
- Reporting
- Final presentation

A division of tasks between students should therefore rather be according to subject than according to the list above. Some of the above tasks have already been (partly) addressed in the ”Project Organisation and Report” course. The main subjects are:

- Maximum Power Point Tracking
- Convert DC to AC
- Adapt to grid (phase and amplitude)

The advice is to work with 2 students on a main subject in close interaction with the others in the group. Note that the division of tasks should be balanced as each student will be graded individually. This means that each member of the group should get a comparable portion of the total work, otherwise he or she cannot pass the project!

2.2.1 Place and time

The work on the project takes place in ”Westzaal” in the Zilverling building. The project itself starts today, but the main period you can work on realisation is from January 18, 2019, 13.45. The Westzaal will then be continuously available until 31 January, the date of the closing event. During this period, there will be full time assistance for the project from 8.45 to 17.30.

2.2.2 Materials

There are 3 shared experimental setups with a solar panel and a and a ”low voltage power grid connection” with power monitoring facilities. The grid connection is a low voltage type for safety reasons and is separated from the 220V grid by a transformer. Absorbed and generated power, however, are measured on the primary side, i.e. the 220V side of the transformer. This means, some loss in the transformer has to be taken into account. The setup also includes a ”sun in a box” consisting of a very strong lamp (as it is winter, we cannot rely on the real sun at the moment). The solar panel can be placed at different distances from the lamp to mimic different irradiations (see fig. 2.1.)

The solar panel is rated 18V, 20 Watt, but the maximum voltage it can deliver at open circuit is much higher (above 30V).

Furthermore, basic materials will be available, like capacitors, inductors and electronic switches (power FETs). Also you can use your own Arduino based microcontroller. If you need to order materials, please report to the supervisors. Often components can be obtained from e.g. Farnell within 1-2 days. The costs of the materials should be limited to 150 euros.

Note that all components should be used within their power, voltage and current limitations. Furthermore, there are capacitors with (ELCO) and without polarity. You can destroy an ELCO if you connect it the wrong way and it may result in a kind of an explosion!

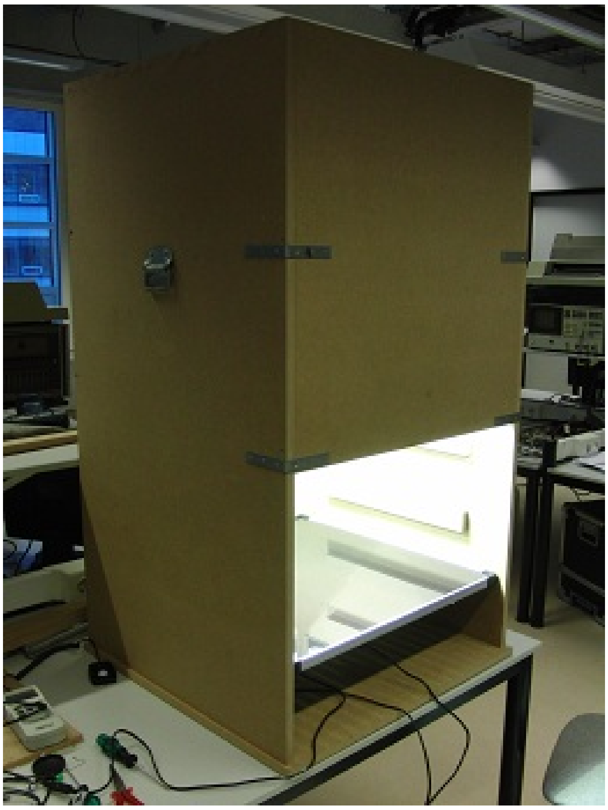


Figure 2.1: Sun in a box with solar panel at 70 cm distance

2.2.3 Setup

The laboratory setup is given in figure 2.2.

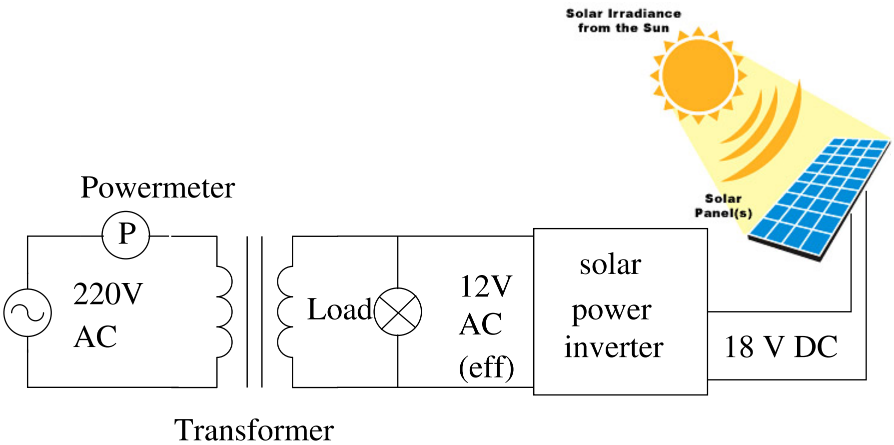


Figure 2.2: Laboratory setup

A low voltage grid is created using a transformer. At the low voltage side, a load (e.g. a lamp) can be connected. At the primary side of the transformer (the 220V side) a power meter is connected that registers power that is delivered by the grid or power that is fed into the grid. The solar power inverter that is to be designed, converts the DC power of the solar panel to low voltage AC that is fed into the low voltage grid at the secondary side of the transformer. The effective AC voltage at the secondary side is 12V if a load is connected. Note that the peak-to-peak voltage is much higher, first because if no load is connected the voltage is higher and second because the peak-to-peak voltage is higher than the effective voltage. To deliver power to the grid, the voltage dilivered by the inverter has to be above this unloaded voltage. The low voltage grid and power meter are integrated in a box.

New: As of 2017/18 a new type of box has been developed which also contains a solar panel simulator. Also there are more boxes, so there is one available for each group.

THIS BOX MUST REMAIN IN THE INSTRUMENT CLOSET AND MUST BE PLUGGED INTO THE AC GRID AT ALL TIMES! IT IS STRICTLY FORBIDDEN TO REMOVE THE BOX FROM THE INSTRUMENT CLOSET!

There are 3 setups like this including a solar panel which have to be shared among all groups.

2.3 Supervision

The supervisors are listed in the table below.

Name	Role	phone	e-mail
Gerolf Meulman	Student Assistant		g.r.meulman@student.utwente.nl
Sjoerd Rozendaal	Student Assistant		s.p.rozendal@student.utwente.nl
Jose Aponte	Student Assistant		j.m.aponteurmeneta@student.utwente.nl
Sjoerd van der Belt	Student Assistant		s.p.vandenbelt@student.utwente.nl
Herkan Barkman	Student Assistant		a.h.barkman@student.utwente.nl
Jasper VInkenvleugel	Student Assistant		j.t.vinkenvleugel@student.utwente.nl
Matheas Moujaly	Student Assistant		m.moujaly@student.utwente.nl
Tamarlan Askarzade	Student Assistant		t.askarzade@student.utwente.nl
Lars Holm	Student Assistant		l.holm@student.utwente.nl
Geert Jan Laanstra	Project coordinator	2840	g.j.laanstra@utwente.nl
Luuk Spreeuwers	Module coordinator	3368	l.j.spreeuwers@utwente.nl

Normally, for the duration of the project, from 18 January 2019 to 31 January 2019, during day time there will be at least 1 supervisor present in the Westzaal. If it happens that no supervisor is present and you need assistance, please contact the supervisors by telephone or e-mail. Normally, you would first contact the student assistants and the technicians and only in special cases the project leader.

Apart from regular meetings with supervisors (see section on reporting), you can ask them for advice or help e.g. to order materials. Supervisors will also keep an eye on if you work orderly and keep the place tidy.

CHAPTER 3

REPORTING

3.1 Journal

During the project, you are supposed to keep track of your actions and progress (e.g. in a journal).
It helps to work in a structured way, e.g.:

- write down what you plan to do that day/week
- report the results
- write down what next steps are to be taken

3.2 Meetings with supervisor

A number of meetings with the supervisor(s) is scheduled and given in the table below:

Date	objective	what to report
18 January	Organisation	Planning, 1st setup, task division
25 January	Progress	progress, setup of report and presentation
31 January	Closing event	final report, presentation, demonstration, drinks

The initiative for the exact time of the meeting lies with the students. For a meeting, always take your journal with you and a printed version of the required documentation (like planning etc).

Each student has to write a part of the final report and to contribute to the final presentation and demonstration. They must be able to answer questions on the operation of the complete system. The final report has to be handed in on the morning of the closing event on 31 January, 2019. In addition each group has to demonstrate their resulting inverter and make a short presentation (max 10 minutes) for those present. Each presentation should consist of two parts: an overview with a block schema and a more in depth presention of a part of the complete system. The selection of the latter will be done in agreement with the supervisors.

3.3 Template of report

You have already worked on your report during the ”Project Organisation and Report” course. This means that roughly 50-75% of your report is already in an advanced draft status. This project is about the design of a solar power inverter. The template of the report is therefore based on the ”design structure” where the following main questions have to be answered:

- Introduction
  - Introduce the subject of the report, catch the readers’ attention
  - Place the subject into context
  - Formulate the (high level) research questions
- Analysis
  - Describe the background; some of this you can find in section 1 of this document. This normally includes a short section on used literature where you got the information (including references).
  - Also supply some information on existing solutions.
  - Precisely define the research questions: what is to be designed
  - Describe what the circuit should do, what are its input/output etc.

  - Include a block diagram, describe the main parts and used aproaches on a high level. Details follow ing the design part.
  - An overview of the remainder of the report

- Design
  - This describes the design in detail as opposed to the more global description in the Analysis
  - Describe the steps used in the design, subdivision in smaller parts, initial experiments to e.g. determine the characteristics of the components (e.g. solar panel). If you use information from other sources, describe what information you use and use proper references.
  - Describe the actual design: the building blocks, the schematic and its operation in detail

- Experiments and results
  - Describe how you measured the operation and efficiency of the various parts and the total
  - Describe the results of the measurements

- DIscussion
  - Analyse the results and discuss them
  - Describe why certain parts do not work as expected
  - Also discuss possible improvements

- Conclusion
  - Summarise the research questions
  - Summarise the answers and results you found
  - Summarise the Discussion

The references should contain sufficient information to find the used articles. E.g. for articles in journals/conferences this means: author, title, journal/conference, year, pages. The total report should not be more than about 20 pages long.

Chapter 4

Grading

Each student will obtain an individual grade (i.e. members of a group can and will get different grades). This means you will have to clearly mark which parts of the reports and journals and the final presentation are yours. The proper operation of the final inverter circuit is not a requirement to pass the project (but it helps).

For the assessment of the project the following is taken into account (with approx. weighting factors):

- (60%) Report
- (20%) Presentation
- (10%) Operation of circuit
- (10%) Originality of solution

In order to pass Module II, you need a grade of ≥ 5.5 for the project.

CHAPTER 5

CHALLENGE & COMPETITION & CLOSING EVENT

5.1 Competition

To make the project more interesting and challenging, the groups of students work in a competition. The group who either realises the most efficient complete solution or, in case there are no working complete solutions, the most complete solution or most original (partial) solution, wins a prize. The prize includes at least a pie, but if we succeed in interesting the solar industry in our project, may include additional rewards. The jury consists of the teachers and supervisors of the module. The winning team will be chosen at the end of the closing event on 31 January, 2018.

5.2 Closing event

The closing event takes place on 31 January, 2018. It basically takes all day. In the morning the reports will have to be handed in. Next, presentations follow (10 minutes per group). In the afternoon you have to build up your design in a presentable way, explain its operation and convince the jury why your system is the best. For completely working systems, we will measure the efficiency for a calibrated illumination setup in order to determine who is the winner of the competition.

Finally the winner of the competition is announced and the afternoon is concluded with drinks and some snacks.