SCHOOL OF ELECTRICAL ENGINEERING
AND TELECOMMUNICATIONS

A Single Stage Grid-connected PV System

by

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Abstract

The review of current design of single phase grid-connected photovoltaic system, initial model of the system and the concept of hardware-in-the-loop simulation are presented in this paper. A model of the system including solar cell model, MPPT controller, converter controller are developed both in Matlab and RT-LAB. Some initial results demonstrate the overall system performance.

Acknowledgements

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Abbreviations

BE Bachelor of Engineering

EE&T School of Electrical Engineering and Telecommunications

SSGPVC Single Stage Grid-connected PV Converter

DSP digital signal processor

AC Alternating Current

DC Direct Current

PV Photovoltaic

PVS Photovoltaic System

MPPT maximum power point tracking

HIL hardware-in-the-loop

SIL software-in-the-loop

ADC analog to digital converter

DAC digital to analog converter

SOGI second order generalized integrator

GPIO general purpose input output

CPU central processing unit

FPGA field-programmable gate array

IC incremental conductance

PO perturb and observe

PLL phase-locked loop

PI proportional integral

Contents

Chapter 1

Introduction

Having a set of clear requirements to their thesis is important to student finalising their BE, or other, degree. Such requirements are both in relation to the physical appearance of the thesis, as well as the writing style and organisation. The present document tries to concisely state the theses requirements while appearing in layout and structure as a thesis itself.

Chapter 2 explains the background for this document. Chapter 3 states the style and submission related requirements to theses submitted at the school. Chapter 4 explains content related requirements to theses and how to avoid some commonly seen problems. Chapter 5 evaluates the thesis requirements template. Finally, Chapter 6 draws up conclusions and suggests ways to further improve the thesis requirements template.

Chapter 2

Background

2.1 General Introduction

Photovoltaic System (PVS) is type of power system which convert solar power into electricity by means of photovoltaic effect. PVS have many advantages and become more and more popular nowadays compared with traditional fossil fuel based energy generation method. It has became a vital part of renewable energy or green energy, since it generate zero green house gas during operation. The module or panel price have experienced huge decline since middle of 2008[2], which makes the the whole Photovoltaic (PV) industry prospered. According to the literature, PV cell is able to become an important alternate renewable energy source till 2040[7].

Power electronic is a vital part for solar power generation. Typically, a single stage grid-connected PV converter (SSGPVC) consist of a solar panel which absorb and convert sunlight into electricity and one or more stages of power converters that transform the electricity from direct current (DC) into alternating current (AC), as well as other accessories for mounting and connecting different components. 2.1 indicate a general configuration of PVS. Due to the output characteristic of a typical solar cell and the need to inject power into the grid, there

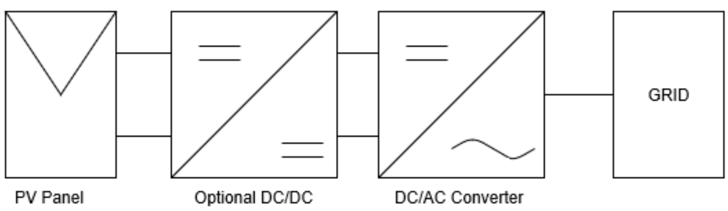

Figure 2.1: Typical PV system block diagram

are at least two stages in a grid-connected PVS conventionally. The use of optional DC/DC convert(s) is to extract maximum power from upstream solar cells or units, of which is also known as maximum power point tracking (MPPT). Additionally, it is able to provide required voltage for next stage inverter to work with a appropriate duty cycle. The functionality of DC/AC converter is to inject sinusoidal current whose phase may or may not be synchronized with grid voltage(depends on applications) into grid.

Currently, there are various configurations for grid-connected PVS including centralized structure, the string structure, the multi-string structure and ac-module structure.[14]. Especially, multi-string and ac-module structure have been used in a broad range of applications. Although multi-string configuration have many advantages like reducing loss due to solar panel unbalanced and a centralized MPPT over centralized configuration, it also suffers from lacking redundancy and scalability. With optional DC/DC converter, the overall system efficiency is compromised compared with a SSGPVC.

As a result, ac-module configuration which is based on SSGPVC is gaining more and more attention. The ac-module configuration is consist of only one power electronics devices which can integrate MPPT function and convert DC into AC at the same time. Current design of PVS requires for simplicity, modularity and efficiency. Those requirements are exactly the advantages of the single stage system. However, there are some issues related to the grid-connected system. The sinusoid power injected into the grid caused by the fluctuation in the dc link is one of the issue.[3] It can force the MPPT function to be voided so that the system can not operate at the maximum power point. Due to complexity of such converter and power rating limitations, SSGPVC is often used in residential PV generation applications.

Although the SSGPVC has some limitations, it is worth to improve the system performance and make it a better solution. It's 'apply and plug' characteristic can be consider to be a general solution to various grid-connected PV applications.

2.2 Hardware-in-the-loop Simulation

Nowadays, the complexity of various digital algorithms for power electronic applications, circuit topology is rising incredibly, which makes the simulation and development of power electronics related product increasingly time-consuming.[12] In order to fulfill the need for fast prototyping, verified the controller functionalities without implementation of hardware, and avoid hazardous situation while testing the controller on a real hardware, the hardware-in-the-loop (HIL) simulation or more specific processor-in-the-loop (PIL) simulation is deployed and used intensively for such applications.

High-performance embedded system enabled a power electronic revolution. The increasing demand for digital controlled power electronics system requires the development to verify the controller functionalities before the controllers are tested on a real hardware platform. PIL allow developers test and verify processors' performance on a simulator which host the virtual hardware, so it become a crucial part of developing a digital controlled power electronics system.

Compared with traditional software-in-the-loop (SIL) simulation, HIL and PIL simulation is another level of simulation which runs way faster than the SIL simulation. In conventional SIL simulation for power electronics application, the time it takes to run the simulation is often longer than the simulation time span of interest, which means, for example, people need to speed more than one second in order to generate one second of results. On the contrary, the HIL and PIL simulation run in real-time without sacrificing simulation time step resolution. If one second is spent on the simulation process, results for one second can be generated with corresponding resolution that preserves all the transient state of prototype under simulation.

Comparing HIL simulation with PIL simulation, the PIL simulation offers a more close-to-real results since in many applications the functionalities needed is hard to abstract and model using software. In PIL simulation, the controller functionalities are executed inside by a real controller, so the developers do not need to worry about how to implement a precise controller model inside software environment.

Fig.2.2 illustrate a basic setup for PIL simulation. The power converter operate inside the real time computer. There are multiple ways that the real controller can communicate with

Figure 2.2: The basic PIL system

the real time simulator. The simulator is capable of generating necessary voltage or current signal through digital to analog converter (DAC) so that the external controller can sense the signal and generate proper trig signal feeding back to the real time computer. The real time computer also have general purpose input output (GPIO) to read all the controller generated signal and carry them into runtime simulation. Another way mentioned in this papar[12] is to use direct file exchange and there is a solution support this method with any type of controller architecture.

For the sake of running PIL simulation, a power converter testbed needed to be implement inside the software environment. The real time computer has equipped with a powerful central processing unit (CPU) as well as field-programmable gate array (FPGA) acceleration card. For the sake of fully utilize the computation power of the simulator, the model should be construct complying to some rules and regulations. But converting an existing converter model into real time simulation compatible model requires a bit of work and experience which is described in detailed in chapter **??**.

2.3 Previous work

PIL simulation has been used for PV application. In paper,[5] a two stages PVS was implemented using RT-LAB which is a software for controlling the real time simulator. In this paper, the simulation setup compose of a solar panel model, a grid-connected inverter and a DC/DC converter in the software environment. Also, there is a physical controller controlling DC/DC converter so that the author could perform PIL simulation. This paper proves that it is feasible to use PIL for PVS simulation and gave a detailed example of how to implement real time simulation model using the corresponding software. The major improvement to the results of the paper would improving the pulse width modulation (PWM) frequency of the controller since the state-of-art digital controlled converter's PWM can be as high as a few mega hertz while in the paper the PWM frequency is only a few kilo hertz. Also, make use of the FPGA acceleration card in the real time simulator would be beneficial to provide finer time resolutions and enable higher PWM processing capabilities.

Chapter 3

Style and Submission Requirements

Requirements for other parts of the thesis work can be found on the thesis Moodle page [9]. The requirements below are for the written thesis only.

3.1 Format

The following format specifications must be adhered to for the thesis report (the LaTeX template available from the school ensures this):

1. The thesis must be typeset on *A4 size page format* using a legible *12 pt font*.
2. The thesis must be prepared using a *word-processor* of the student's choice.
3. The thesis must be submitted electronically in *Portable Document Format* (pdf) with all *fonts embedded*.
4. *Margins* on all sides must be no less than 25 mm.
5. *1.5 line spacing* (about 8 mm per line) must be used.
6. All pages must be *numbered*. The main body of the thesis must be numbered consecutively from beginning to end. Other sections must either be included or have their own logical numbering system.
7. The *title page* must contain the following information:
   (a) University and School names.

(b) Title of Thesis/Project.

(c) Name of Author and student ID.

(d) The degree the thesis is submitted for.

(e) Submission date (month and year).

(f) Supervisor's name.

3.2 Other physical appearance

Other requirements to the physical appearance of the thesis report are:

1. If a hardcopy is requested by supervisor or assessor, the report must be *printed* and *spiral bound* (at the student's own cost).

2. Formulas must be *typed* (not cut-and-pasted in). Complicated or difficult-to-type objects may be *neatly hand-drawn* and *scanned in high resolution*.

3. *Graphs, diagrams and photographs* should be inserted as close as possible to their *first reference* in the text. Rotated graphs etc are to be arranged so as to be conveniently read, with the bottom edge to the right-hand side of the page. *Graphs and diagrams must be legible!*

4. Relevant *computer programs* and *engineering drawings* should be included in the thesis, usually in an appendix.

3.3 Submission

Finally, here are some requirements to the submission procedure.

1. All students are required to write and submit *individual thesis reports*. The *author* of the thesis is *responsible* for the preparation of the thesis, proofreading the manuscript and having corrections made as necessary, and uploading the thesis before the deadline.

2. A *thesis summary sheet* must be included in the thesis report. This summary sheet is designed to assist in determining the overall input by students into the thesis work. The guidelines for completing the summary sheet and the summary sheet form can be downloaded from the thesis Moodle site.

3. In some cases, the thesis work may involve *several students* working on a *larger project*. Thus, some aspects of the work may have been carried out independently whilst other aspects may have been done as a group. The thesis reports must be *clearly distinguishable*, and appropriately cross referenced to each other. The common work overlapping between the thesis reports must be clearly identified.

4. There is a *page limit* of 100 pages for the main body of the thesis.

5. If applicable, relevant data and program files should be put on a *CD-rom* and submitted directly to the thesis supervisor for archiving.

Chapter 4

Content Requirements

Students should consult the literature (e.g. [10, 11, 4, 1, 13]) and other resources for material on how to write a good thesis. The present document is only a very brief introduction as to what is expected.

4.1 Structure

Most theses are structured similarly to the present document. The main part of the thesis can be structured in many different ways, however, but must contain: a *problem definition*, *scope* and work *motivation*; a contemporary *literature review* on the thesis problem and relevant related works; relevant *theory* and *considerations* on how to solve the problem; a description of the *solution method* (dimensioning, construction, etc.); presentation of *results* (measurements, simulations, etc.); a *discussion* of the results (validity, deviations, comparison with previous solutions, etc.); and finally the *conclusions*.

4.2 Style of writing

1. Audience: The thesis must be addressed to engineers at the same level as the student but without the special knowledge gained during the thesis work. Such a third-person must be able to reconstruct the results on the basis of the thesis alone.

2. Every used concept/symbol/abbreviation which is not widely know must be *defined*. The wording should be *short* and *concise*; a suitable length is 40–70 pages (plus appendices). Readable(!) *figures* and *graphs* enhance comprehensibility.

3. Units. *SI units* must be used. Units must be used correctly throughout the thesis.

4.3 Documentation

1. The work must be well documented; i.e. enclosed must be the *complete schematics* of designed electronic circuits/test set-ups and/or a *program listing*, and/or etc. Documentation of *simulation results* and/or *measurement results* likewise.

2. References: For every declaration/equation/method/etc., which is not widely known, a *reference to the literature* must be given (or a 'proof' if it is the authors own work). In case material is copied verbatim, quotes and references must be used. This is also the case when referring to partners work in larger projects. Figures not of the student's own making must have the source referenced in the figure caption.

3. Plagiarism: Failure to give proper references to the literature is *plagiarism*. Plagiarism is considered serious offence and severe penalties may apply.

4.4 Avoiding common problems

The thesis project, including the thesis report, is expected to be a professionally executed body work. Solutions to some commonly seen report problems are given below.

4.4.1 Figure quality

If at all possible, students should create their own figures using suitable software packages, as shown in the example in Figure 4.1. It is possible to use bitmap figures (as opposed to vector graphics) that are not photographs, but it must be ensured that the resolution is high and that lines and text are clear and have good contrast. Legibility is key: the pdf files generated from the used word processor should be verified for legibility early.

When graphs are including in the thesis, again it must be ensured that the plotting software generates clear, legible outputs and that axes have clear labels as shown in Figure 4.2.

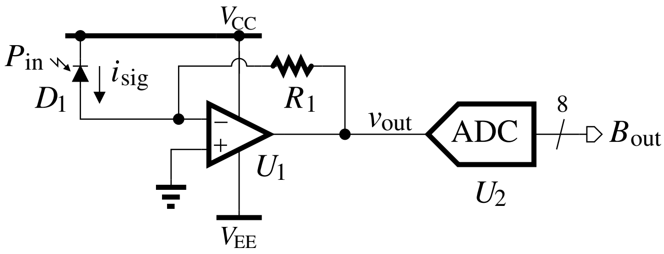

Figure 4.1: Schematic of electronic circuit.

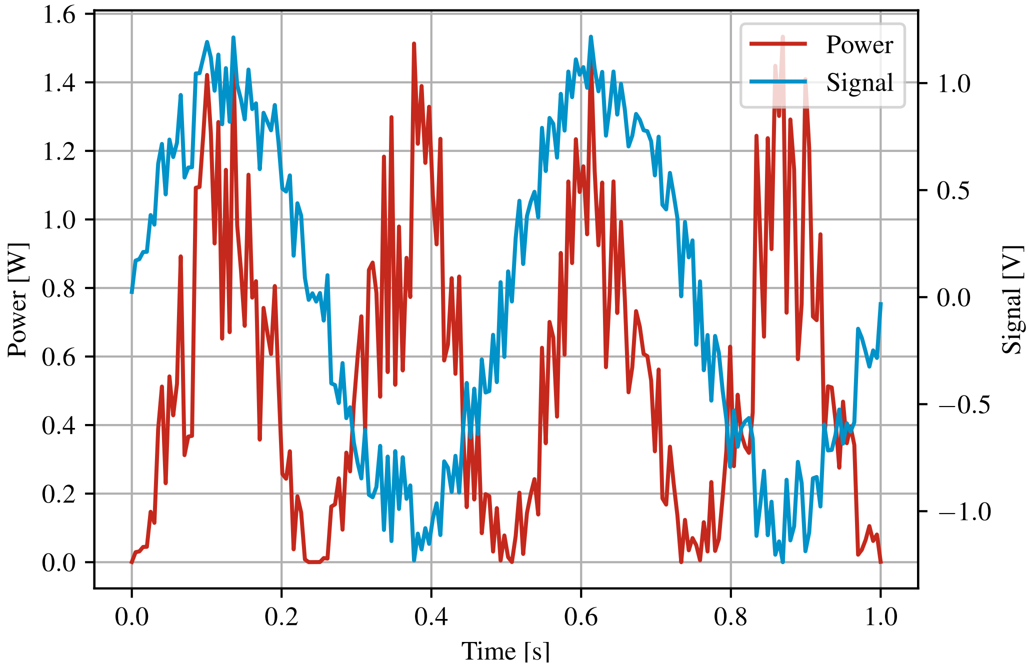

Figure 4.2: Plot of some random data.

4.4.2 Attention to detail

It is key to a good document that the author pays attention to detail. This includes concise definitions and descriptions, making sure that concepts are explained in a logical order that the reader can follow, and that consistent symbol use is diligently practiced. For instance: "the output voltage, v_{out} in Figure 4.1 is given by Equation 4.1, where it is assumed that $R_1 = 1\,\mathrm{k}\Omega$".

$$v_{out} = -R_1 \cdot i_{sig} \tag{4.1}$$

4.4.3 Story telling

It is important that the reader knows where the writing in thesis is heading at all times. An early introduction of high-level conceptual design of the proposed solution can be a good help, as can a well defined thesis scope. Developing well-constructed, logical arguments for the work also greatly help in convincing the reader of the thesis merits.

Chapter 5

Evaluation

This chapter is mainly provided for the purpose of showing a typical thesis structure. There are no more thesis requirements described.

5.1 Results

The result of this work is the present document, being both a LaTeX template and a thesis requirement specification.

5.2 Discussion

The dual function of this document somewhat de-emphasises the primary purpose of the document, namely the thesis requirements. It would be better, perhaps, if these could be stated on a few concise pages.

Chapter 6

Conclusion

A thesis requirements/template document has been created. This serves the dual purposes of giving students specific requirements to their theses — both style and content related — while providing a typical thesis structure in a LaTeX template.

6.1 Future Work

Extract the requirements from the template in order to have very concise requirements.

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Appendix 1

In the source code for this document, some commonly used LaTeX operations can be found. The typesetting opportunities with LaTeX are vast, and there exist an enormous collection of packages that give added functionality. Modern LaTeX distributions come with many of the most common packages (some used in this document) and many more can be found on the web.