

# Preface

Photovoltaic (PV) industry is growing exponentially and the availability of specialized equipment for the laboratory tests is becoming crucial especially for manufacturers and laboratories working in the field of power electronics related to PV plants.

All people, concerned with renewable sources' applications, experience the need of laboratory equipment to carry out measurements and tests. In particular, in the field of PV generators, the difficulties are tied to the use of an actual outdoor plant for performing tests involving the PV source as well as various kinds of loads, such as resistive loads, DC motors, storage batteries, and inverter-connected loads with their maximum power point trackers (MPPT).

A real PV plant needs a wide outer surface and high costs. Moreover, its produced energy is strongly dependent on uncontrollable weather conditions. Finally, the necessary investment to set up an experimental plant for testing purpose can be made more severe by the continuous evolution of the involved technologies. Therefore, an alternative solution to the use of an actual outdoor plant has to be taken into consideration.

The alternative is the setup of a PV emulator, i.e., a suitable laboratory equipment in which voltage and current are the same as in a real source. Such an experimental facility allows measurements and tests to be carried out without the constraints of the environmental conditions and, above all, more cheaply, since the use of an actual PV array is avoided.

Considering that the trend in PV industry moves toward more efficient PV plants, the setup of effective and reliable PV emulators is becoming more and more a challenging issue.

The emulation of a PV generator is performed by two main tasks: the first one is the knowledge of the electrical characteristics of the generator; the latter consists in their realization by a power amplifier.

On the score of such considerations, this book provides an extensive introduction to the modeling of PV generators and to their emulation by means of power electronic converters.

The authors have first focused on the definition of accurate PV source models, including the parameter extraction techniques. Then, they have devised a system to reproduce the behavior of a PV source, by using the characteristic voltage–current curves, obtained by the modeling, as a reference to suitably control a switching DC/DC converter.

The book collects the results of many years of research and development of the authors at the CNR (National Research Council)—ISSIA (Institute of Intelligent System for Automation), Renewable Sources Laboratory (RES).

The primary aim of the book is to guide the reader to design and set up a PV emulator based on controlled power converters, starting from an appropriate modeling of the PV source. The reader is thus allowed to manage a virtual plant in which the dependence of the PV source electrical behavior on weather conditions, partial shadow, and dynamics is accounted for.

On the other hand, the book gives an in-depth tool and an extensive reference in modeling PV generators and the more common topologies of DC/DC converters.

It is worth considering that the overall emulation concept, adopted in this book with reference to PV sources, is general; therefore, it can be easily extended to the other kind of electrical sources, such as fuel cells, batteries, or wind turbines with permanent magnet motor in which the DC output voltage is obtained by a rectifier.

## Outline of the Book

The book is divided into two parts.

Part I embraces the chapters from 1 to 5; it is dedicated to the PV source modeling.

Part II includes the chapters from 6 to 8; it refers to PV emulation issues, including design and realization.

### Part I

**Chapter 1.** This chapter deals with the energy generated inside the Sun that reaches the Earth. It is a fantastic trip in which the reader is involved with the two main concepts of very big (the scale of the universe and the produced energy) and of very small (inside semiconductor).

**Chapter 2.** After its trip as electromagnetic wave, energy reaches the Earth. Now, it is transformed into electric energy. This chapter deals with the behavior of matter, in particular of semiconductor materials, and explains how it can interact with the Sun's irradiance to obtain voltage and current at the terminals of a photovoltaic cell.

**Chapter 3.** In this chapter, the fundamentals on the derivation of PV source circuit models, including parasitic resistance effects and junction non-idealities, are given. Then, the model is extended and generalized to the case of single PV modules and their connection to form a PV field, considering the effects of partial shading as well.

**Chapter 4.** This chapter is devoted to parameters extraction methods for PV static models. The considered identification methods are mainly based on analytical or numerical solutions and use either the rated data given by the manufacturer or the experimental voltage-current (V-I) curves, directly measured at the PV source. A simplified method based on experimental measurement of the remarkable points is presented too. The possibility to simplify the parameter identification by using linear regression methods is explored and some hints on the PV characteristic determination by mapping techniques are given. The PV models, suitably identified, are finally implemented in Matlab/Simulink® environment and simulation results are shown.

**Chapter 5.** This chapter treats the dynamic modeling of PV sources and methods for the identification of its parameters on the basis of experimental measurements.

First, a dynamic model, including capacitive and inductive effects, is analyzed and an identification method based on least square regression (LSR) is proposed. Finally, the nonlinear junction capacitance effects are accounted for.

The corresponding models are implemented both in Simulink® and PLECS® software. Some practical examples show how transient phenomena can be investigated.

## Part II

**Chapter 6.** This chapter gives an overview of PV emulators proposed in the technical literature in the last decades. The most critical and interesting aspects related to their design and operation are emphasized, including hardware structures, control features, dynamics, power ratings, and modularity. A brief survey of commercial solutions is included.

**Chapter 7.** This chapter deals with three main topologies of DC/DC converters: buck, boost, and buck-boost. After a short presentation of linear conversion, fundamentals on switching conversion are explained. The DC/DC converters are analyzed in continuous and discontinuous operating mode and main parameters as gain, critical inductance, and load voltage ripple are calculated. Then, the state space averaging approach is used to achieve the transfer functions in terms of output voltage versus duty cycle and versus input voltage.

**Chapter 8.** This chapter treats the design and realization of a DC/DC converter for emulating purpose. The chapter contains the fundamentals of feedback control and an example of emulator design, realized by a buck converter. In particular, both the PV model and the converter are at first simulated in Matlab-PLECS® environment. Then, the practical implementation of the control algorithm on a DSP board and the power circuit are illustrated and finally experimental results are presented.

## Originality of the Approach

The book has the specificity to propose a novel method for the analysis of several issues related to PV plants operation, doing without the use of a real installation. This approach, leading to the design and setup of a virtual indoor photovoltaic

generator, i.e., the PV emulator, implies the transversal investigation of several disciplines going from solar cell physics to power electronics and control. In this sense, the book gives a new perspective on this subject. As a matter of fact, these disciplines are presented in a synergic way to solve the problem of PV source emulation.

The reader can find, joined in a unique text, all information related to the emulation of a PV source (model choice, parameters identification, software implementation, design and control of the power amplifier) without the necessity of deducing them from different specific books.

Moreover, the PV source emulation approach can be extended to other kind of sources as fuel cells, batteries, or wind turbines with permanent magnet motor connected to a rectifier circuit, simply by using the corresponding model and maintaining the same hardware.

## To Whom this Book is Addressed

This book is intended primarily to meet the demands of postgraduate level students but it should also prove useful to the professional engineers and researchers dealing with the problem of creating an indoor virtual PV plant for testing MPPT techniques, non-ideal operating conditions, control for the grid or load interfacing, etc. Moreover, the book can be useful to:

- Researchers and Engineers who work in the field of renewable sources;
- Engineers and Physicists who deal with PV sources modeling;
- Mathematicians and Statistics who work with parameters identification techniques.

## How to Use the Book

First of all, this book represents a tool to obtain a PV source model and to reproduce it by a power converter.

[Chapter 1](#) gives an overview of the Energy conversion from the Sun to the Earth.

The readers interested on modeling issues can read the first part, in particular [Chap. 2](#) and [3](#); furthermore, they can utilize [Chap. 4](#) to identify the related parameters.

The readers interested on emulation of the source can read the [Chap. 6](#) if they want to have the scenario on existing solutions, or directly [Chaps. 7](#) and [8](#) to design the DC/DC converter for emulation of the source. It should be noted that

the approach used for emulating a PV source can be extended to other sources having their characteristics lying on I–V plane.

## Prerequisites

Readers should be familiar with basic semiconductor physics, circuit analysis, and with the fundamentals of DC/DC converters circuits and control. The book has been conceived as an advanced textbook, designed primarily to meet the demands of a course taught at postgraduate (M.Sc., Ph.D. etc.) level. However, the authors have made an effort to present each subject to be understandable by MSc students. For this reason, the book can be also used as supporting test in some Engineering or Physics courses.

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