EPE-ECCE 2013 tutorial on:

# Technology, Design and Exploitation of PV Power Plants

## PRESENTERS


ABENGOA

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## SCOPE AND BENEFITS

The objective of this tutorial is to offer a comprehensive review of essential aspects involved in the design and exploitation of modern PV power plants, covering both technical and operational aspects. A review of PV panel technologies will offer a vision of the PV technology currently installed by integrators, as well as presentation of the most promising new trends in PV cells. The elements in charge of processing power in PV power plants, inverters will be presented by describing both their hardware and control structures. A special attention will be paid to the control system of grid-interactive PV power plants. The synchronous power control concept will be presented as an effective solution to effectively integrate PV power plants in distributed power systems. Design of PV plants will be also covered in this tutorial, including design optimization aspects. Finally, the methodology for defining a business model, considering the influence of both technical and financial factors along the life-cycle of the PV power plant, will be presented.

## CONTENTS

The tutorial will be organized in five lectures covering the following topics:

### PV panels

This lecture will start by conducting a review of PV cell technologies, including crystalline silicon, thin-film, and multi-junction cells, and even presenting some embryonic technologies, such as dye and organic cells. After that, modelling techniques for PV cells, modules and plants will presented and their characteristic parameters will be identified. This will allow presenting some techniques for characterizing PV panels. Finally, diagnosis techniques based on I-V curve analysis and imaging techniques for detecting degradation processes and faults, which are crucial aspects for maintenance activities and optimum yield, will be presented.

### PV inverters

Inverters are a key element in PV power plants. This lecture will review the topology of the inverters commonly used in PV plants with focus on efficiency, ranging from low-power modular inverters to central inverters used to process power of large strings. Some examples from PV inverters manufacturers will be presented. The main structure of the control system of a generic PV inverter will be also presented in this lecture, as well as the most common functionalities regarding monitoring and diagnosis. Once inverter structure and control are reviewed, some simplified models including efficiency, reliability and availability to be used in the design of PV power plants will be presented.

### PV plants control

This lecture deals with control aspects of PV power plants are considered. The control structure of a PV power plant will be presented, as well as the interactions between the PV plant operator, the system operator and the utility. New trends in the IEC 61850 standard regarding advanced PV power plants management functions will be presented. Regarding grid connection, new trend in grid codes, which demand PV plants to participate in grid regulation in a similar manner as conventional synchronous generators do, will be discussed. This lecture will pay special attention to modern control techniques for PV power plants based on synchronous power concepts, which improve the interaction with the electrical grid and guarantee the effective integration of the PV plants. Relevant study cases to demonstrate the effectiveness of the synchronous power control technique, at both the transmission and the distribution levels, will be presented.

### PV plants design

This lecture is focused in presenting technical issues related to the design of PV power plants, as well as some aspects regarding design optimization. The lecture will start by presenting some techniques and tools for solar resource evaluation and providing design guidelines for PV module selection and PV array configuration. Possible solutions regarding PV inverter sizing and cabling layout will be presented, including additional electrical equipment, such as transformers and protections. Some relevant aspects regarding power losses analysis, yield evaluation and performance ratio will be also provided, in order to justify some cost functions for optimizing the design of the PV plant. Finally, an example of an optimization procedure for maximizing energy production and minimizing power losses in the PV power plant will be presented.

### PV plants economics

This lecture introduces the methodology used to analyse financial requirements and returns of a PV plant, as well as the technique for managing uncertainties, in order to design the business model of a given project. Techniques for designing energy and cost models that allow understanding the economic impact of engineering decisions in a PV plant project will be presented. This lecture will introduce the methodology for handling the wide variety of parameters considered in complex cost of energy calculations in order to make decisions regarding economic optimization along the life-cycle of the PV plant. Finally, this lecture will provide master guidelines to design a business model for the PV plant that allows allocating costs and incomes, considering performance predictions and risks, and estimating the profits resulting from the operation of the PV power plant.

## SCHEDULE (to be updated)

Monday, September 2nd - Tutorial day

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| 09:30 - 10:15 | Part 1: PV Panels |
| 10:15 - 11:00 | Part 2: PV Inverters |
| 11:00 - 11:30 | Coffee break |
| 11.30 - 12:15 | Part 3: PV Plant Control |
| 12:15 – 13:00 | Part 4: PV Plant Design |
| 13:00 - 14:00 | Lunch break |
| 14:00 - 14:45 | Part 5: PV plant Economics |

## LOCATION (to be updated)

University of Lille….

## WHO SHOULD ATTEND

This tutorial is intended to electrical and control engineers and researchers dealing with distributed generation and interested in going deeply into essential issues related to the design, integration and exploitation of PV power plants.

**Technical Level**: Medium to advanced

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## ABOUT THE INSTRUCTORS

Pedro Rodriguez received the M.Sc. and Ph.D. degrees in electrical engineering from the Technical University of Catalonia (UPC), Spain. He has been a Postdoctoral Researcher at the CPES, Virginia Tech, USA and at the Department of Energy Technology, Aalborg University (AAU), Denmark. He joined the faculty of UPC in 1990, where he became the Director of the research centre on Renewable Electrical Energy Systems. He is still linked to the UPC as a part time Professor. He was also a Visiting Professor at the AAU for five years, working as a co-supervisor of the Vestas Power Program.

He joined Abengoa in 2011, where he currently is the Director of the Technology Area on Electrical Engineering, from Abengoa Research. He has co-authored one book and more than 150 papers in technical journals and conference proceedings. He is the holder of 9 licensed patents. His research interests include integration of distributed generation systems, smart grids, and design and control of power converters. Pedro Rodriguez is a senior member of the IEEE, a member of the administrate committee of the IEEE Industrial Electronics Society (IES), the general chair of IEEE-IES Gold and Student Activities, the vice-chair of the Sustainability and Renewable Energy Committee of the IEEE Industry Application Society and a member of the IEEE-IES Technical Committee on Renewable Energy Systems. He is an Associate Editor of the IEEE Transaction on Power Electronics.

Remus Teodorescu received the Dipl. Ing. degree in electrical engineering from Polytechnical University of Bucharest, Romania in 1989, and PhD. degree in power electronics from University of Galati, Romania, in 1994. In 1998, he joined Aalborg University, Institute of Energy Technology, power electronics section where he currently works as full professor

He has more than 200 papers published, 1 book – Grid Converters for PV and Wind Power Systems - ISBN: 978-0-470-05751-3, Wiley, 2011 and 5 patents. He is the co-recipient of the Technical Committee Prize Paper Awards at IEEE IAS Annual Meeting 1998, and Third-ABB Prize Paper Award at IEEE Optim 2002. He is a Fellow Member of IEEE, Associate Editor for IEEE Power Electronics Letters and chair of IEEE Danish joint IES/PELS/IAS chapter. His areas of interests are: design and control of power converters used in renewable energy systems, distributed generation mainly wind power and photovoltaics, computer simulations, digital control implementation. Remus Teodorescu is the founder and coordinator of the Green Power Laboratory at Aalborg University focusing on the development and testing of grid converters for renewable energy systems and the coordinator of the Vestas Power Program, a five year program including 10 PhD students focusing on power electronics, power systems and energy storage related to wind power plants.

Dezso Sera received his B.Sc. and M.Sc. degrees in Electrical Engineering from the Technical University of Cluj, Romania in 2001 and 2002, respectively.

In 2005, he graduated from the M.Sc. program at Aalborg University, Denmark, in the Department of Energy Technology (DET) and in 2008 he received his PhD degree from the same department, where he currently works as Associate Professor. Since 2009 he has been the coordinator of the Photovoltaic Systems and Microgrids Research Programme at DET.

His research area is within photovoltaic power systems: modelling, characterisation, diagnostics and maximum power point tracking (MPPT), PV inverters and grid integration of PV power.

Tamas Kerekes obtained his Electrical Engineer diploma in 2002 from Technical University of Cluj, Romania, with specialization in Electric Drives and Robots. In 2005, he graduated the Master of Science program at Aalborg University, Department of Energy Technology in the field of Power Electronics and Drives. In 2009 he received his PhD degree from Aalborg University. Currently he is working as an Associate Professor at the same Department.

Since he started his PhD at the Department of Energy Technology his main interest is on PV inverter modelling, control and topologies as well as modulation techniques with focus on transformerless PV inverter systems.