CAS Photovoltaics and the Renewable Energy Grid

Module Handbook

(as of November 2021)

CAS: PG "Photovoltaics and the Renewable Energy Grid"
Module Handbook

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Version 3.04

Title Picture
Multi-Megawatt PV-Kraftwerk.

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Contents

1. General Regulations

1.1. Profile and Concept of the CAS

The following academic and examination regulations hold for the Certificate of Advanced Studies (CAS) Photovoltaics and the Renewable Energy Grid at the University Freiburg.

CAS are modular and follow the European Credit Transfer System (ECTS) for confirmation of study performance. One CAS represents a study performance of 10 to 15 ECTS.

CAS PG - Photovoltaics and the Renewable Electricity Grid

Decentralized electricity generation and fluctuating availability pose a challenge on grid stability. This module provides comprehensive understanding of interaction between PV systems and the power grid. It is about control aspects of PV Systems and the integration of a huge amount of PV energy in the electricity grid.

Starting with basic issues of energy and efficiency, grid technology will be discussed to balance complex systems with available storage components.

PG1 - Solar Energy Integration and Economics

This course is done in Partnership with the Pennsylvania State University.
This Module is structured to train the students for solar energy integration particularly in Solar PV, and economics. In this course social and sustainability aspects are also discussed.

PG2 - Grid Integration and Control of PV Systems

This module is developed to give comprehensive knowledge about grid integration and control and also includes simulation of power grid control systems.

1.2. Pricing

The price for a CAS Module is 250 € per ECTS. For the CAS Module “PG - Photovoltaics and the Renewable Electricity Grid” with 10 ECTS the overall fees are 2500 €.

The fees will be invoiced and have to be paid via bank transfer before the start of the respective module.

The price includes full access to our E-learning resources for the semester(s) of studying. Access to the online resources of the University library of the University of Freiburg via VPN, from all around the world. All required reading materials. Examination in study centers. Lab workshops and events during the on-campus phases in Freiburg. There are no hidden extra costs.

1.3.Study Format

The CAS is designed as a part-time postgraduate program and integrates the various possibilities offered by distance learning and by information and communication technology (multimedia learning).

During the study period, students work through the audio and video lectures, the readings and the exercise sheets that are provided on the learning platform. Self-study of the provided reading material supports the understanding. Online meetings with the lecturers and tutors are arranged for the students during this self-study phase to ask questions, discuss problems and exercise sheets. To independently contact lectures and tutors in each course, a forum is provided. In order to strengthen the learning effect, each course has an exam, presentation or scientific report at the end of the semester.

E-Lectures

Short e-lectures are provided for online learning. The e-lectures function as introduction into a topic and as overview of a specific field within a module. The e-lectures have a length of around 20 minutes and a narrow focus on a specific topic.

Reading Material

Reading material is available for each topic to support the e-lectures or provide an alternative entry into the course's content. The most relevant books and journal publications are provided. References through the e-lectures point towards the most relevant parts.

Regular Online Meetings

Online meetings are an important way to discuss with your lecturer and/or tutor about the reading materials, e-lectures as well as exercises and tests. The Online Meetings are scheduled in such a way that all students from different time zones have a chance to attend. They can also be scheduled individually with the lectures or tutors. If it happens that students could not attend an online meeting, the recordings of the meetings made available to all students can be watched afterwards.

Oral Presentations

In the seminar type courses the assessment takes place in form of an oral presentation. The student has to prepare a presentation and present it in front of the group. This can either take place in Freiburg during the on-campus phase (usually in October) or via the webinar environment.

Exercise Sheets

Most of the courses offered in the Module use exercise sheets. The exercise sheets will be provided online during the semester. The students should hand in the solutions to the exercise sheets typically one week before the respective online meeting in order to discuss problems faced during solving. A standard solution will be provided during or after the online meeting. The exercise sheets may contribute to the student's final grade, and the exam problems in many courses follow the same logic as the problems covered in the exercise sheets.

1.4. Exam Regulations

Exams can be taken here in Freiburg, or in study centers in various countries all around the world. The date of the exam will be issued in the first weeks of each course. The students have to enroll for the exam, and to define in advance where they plan to take it. Once enrolled for an exam, the non-participation will be graded as fail.

In order to pass the written exams of the different courses, students need to achieve at least the grade 4.0 (sufficient) in the German grading system (see Table 1) The written exams take place in Freiburg during the Campus Phase or simultaneously worldwide at a Goethe-Institute or a recognized partner university. The exam, presentation or lab journal of each part (course/ seminar/ hands-on) must be passed to successfully complete a module. The final grade is composed from the single grades of each part, weighted after the arithmetic mean considering the ECTS credit points for each course. For being awarded credit points it is required that students:

- Take active part in each course/ seminar/ hands-on of the module and in its online meetings.
- Study on their own (self-study) and independently prepare and rework the lectures and reading materials.
- Take the exams, perform presentations in the seminars and participate in the hands-on course including writing a lab journal during the Campus Phase.

Grading system

Grades are awarded according to the German grading scale (1-5) specified in the table below.

Table 1: Grades according to the German and ECTS grading system and their definition.

ECTS system	German system	
A	1	excellent/ outstanding performance
B	2	good performance that meets the standard completely and is above-average
C	3	satisfactory/ average performance
D	4	sufficient/ standard has been met but with a number of notable errors
F	5	insufficient/ failed

For a finer evaluation of assessed work, decimal grades may be given by raising or lowering the grade by 0.3. The grades 0.7, 4.3, 4.7 and 5.3 are barred. An overview about the awarded grades can be seen in Table 2

Table 2: Numerical grades and their awarded names.

Decimal Grade	Grade awarded
1.0 to 1.5	very good
1.6 to 2.5	good
2.6 to 3.5	satisfactory
3.6 to 4.0	sufficient
more than 4.0	insufficient

Failing and Repeating of Exams

Any assessment in a given subject which is graded as "insufficient" (5.0) or which is considered a fail can be repeated once. During the whole study program, a maximum of two subject-specific assessments that were considered a fail can be repeated more than one time, meaning repeated twice

2. Responsible Persons

2.1. Scientific Director

Professor Dr. Anke Weidlich
University of Freiburg
Department of Sustainable Systems Engineering – INATECH
Chair for Control and Integration of Grids
Solar Info Center, 4th floor (stairs "West"), room 04.003
79110 Freiburg, Germany

2.2. Program Coordination

Philipp Bucher
Program Coordinator
University of Freiburg
Department of Sustainable Systems Engineering – INATECH
Georges-Koehler-Allee 10
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2.3. Admission and Examination Board

The admission and examination board of SEE consists of three professors as main members and one professor in the function of a deputy. The board is elected for a period of three years. From 2019 to 2021 the members are:

- Prof. Dr. Anke Weidlich, INATECH
- Prof. Dr. Stefan Glunz, INATECH
- Dr. Mirko Schäfer, INATECH

As deputy acts:

- Prof. Dr. Moritz Diehl, IMTEK

3. Overview of all CAS

This section gives an overview about all Certificates of Advanced Studies, currently offered by the Solar Energy Engineering department of the University of Freiburg.

CAS fundamental modules:

CAS 1 „Solar Cells and Photovoltaic Systems” | 10 ECTS

Courses	*Start*	*Lecturer*	*ECTS*	*Type*	*Institute*
1.1 – Solar Cells	Oct.	U. Würfel	5	Lecture	ISE/FMF
1.2 – Photovoltaic Systems	Oct.	O. Stalter	5	Lecture	ISE

CAS 2 „Solar Thermal Energy Technology” | 10 ECTS

Courses	*Start*	*Lecturer*	*ECTS*	*Type*	*Institute*
2.1 – Fundamentals of Solar Thermal Collectors	Oct.	W. Platzer	5	Lecture	ISE
2.2 – Design of Solar Thermal Systems	Apr.	W. Platzer	5	Lecture	ISE

⇨ ***Remark:** total module duration of 12 months / 2 Semesters.*

CAS 3 „Crystalline Silicon Photovoltaics“ | 10 ECTS

Courses	*Start*	*Lecturer*	*ECTS*	*Type*	*Institute*
3.1 – Feedstock and Crystallization	Apr.	M. Schubert	2	Lecture	ISE
3.2 – Silicon Solar Cells – Structure and Analysis	Apr.	S. Glunz	2	Lecture	ISE/IMTEK
3.3 – Solar Cell Production Technology	Apr.	R. Preu	2	Lecture	ISE
3.4 – Silicon Module Technology and Reliability	Apr.	H. Wirth	1	Lecture	ISE
3.5 – Hands-on Solar Cell Processing	Apr.	J. Rentsch	3	Lab	ISE

⇨ ***Remark:** module requires an on-campus stay of 2 full days in the Fraunhofer ISE laboratories in Freiburg.*

CAS specialization modules:

CAS CM „Solar Cell Characterization and Modelling “ | 10 ECTS

Courses	*Start*	*Lecturer*	*ECTS*	*Type*	*Institute*
CM1.1 – Material and Solar Cell Characterization	Oct.	M. Schubert	3	Lecture	ISE
CM1.2 – Hands-on Measurement Instrumentation	Oct.	J. Haunschild	2	Lab	ISE
CM2.1 – Numerical Simulation of Solar Cells	Oct.	J. Schumacher	5	Lecture	ZHAW

⇨ ***Remark:** module requires an on-campus stay of 2 full days in the Fraunhofer ISE laboratories in Freiburg.*

CAS PG „Photovoltaics and the Renewable Electricity Grid“ | 10 ECTS

Courses	*Start*	*Lecturer*	*ECTS*	*Type*	*Institute*
PG1 1 – Solar Energy Integration and Economics	Apr.	Anke Weidlich	5	Lectuer	INATECH
PG1.2 – Grid Integration and Control of PV Systems	Apr.	B. Wille-Haussmann	5	Lecture	ISE

CAS ST „Advanced Solar Cell Technologies” | 10 ECTS

Courses	*Start*	*Lecturer*	*ECTS*	*Type*	*Institute*
ST1.1 – Inorganic Thin-Film Solar Cells	Oct.	M. Powalla	4	Lecture	ZSW
ST1.2 – III-V Solar Cells and Concentrator Systems	Oct.	G. Siefer	3	Lecture	ISE
ST2.1 – New Concepts for PV Energy Conversion	Oct.	U. Würfel	2	Lecture	ISE/FMF
ST2.2 – Advanced Solar Cell Processing	Oct.	M. Heinrich	1	Seminar	ISE

4. Detail of the Modules

CAS PG "Photovoltaics and the Renewable Energy Grid"

This CAS is designed for students who want to gain professional knowledge in renewable energy integration into the grid and economics of renewable energy. This elective track consists of two parts that cover all the crucial aspects of grid integration and economics.

1. The first course of this elective is structured to train students for solar energy integration, particularly in Solar PV and economics. Solar energy is expected to become the world's primary energy resource in the upcoming decades. One of the most relevant problems is integrating photovoltaic (PV) power into the electric grid system. Information and education on technologies, control strategies, economic aspects, and stakeholder relationships that enable the adaptation of PV systems into existing grid infrastructure are in high demand by current and future energy professionals. The course will facilitate comprehension of the implications, challenges, and possible solutions for a predominantly renewable energy system, specifically focusing on the role of solar PV power.
2. The second course will give comprehensive knowledge about grid integration and control, including computer-based simulations distinguished by different voltage levels.

Total ECTS	**Duration**	**Offer Frequency**
10	18 Weeks	Starting each April
Teaching Methods	• Recorded lectures (asynchronous), • Live-virtual meetings (synchronous), • Exercises • Grid optimization with Typhoon HIL.	
Responsible Instructor	Prof. Dr. Anke Weidlich	
Grading	Graded (PL)	
Courses	Grid Integration of Solar Energy • PG1.1 - Solar Energy Integration and Economics • PG1.2 - Grid Integration and Control	

Course #PG1.1: Solar Energy Integration and Economics		
ECTS	**Lecturer**	**Tutor**
5	Prof. Dr. Anke Weidlich	Nick Harder

Course Content

This course covers the following topics:

- Characteristics of Solar Energy in Power Systems (generation patterns and forecasts, demand and supply matching, netload, grid parity, impact on electricity prices, the role of solar in highly renewable energy scenarios)
- Grid Integration Challenges (frequency control and possible contributions of solar PV, power quality in the distribution grid, inverter control strategies, storage)
- Economic Assessment (investment appraisal, levelized cost of electricity, learning curves, the value of solar generation/intermittency, market integration, optimal system sizing, and design decisions, economic comparison of different PV technologies, thermal vs electric usage of solar energy, support schemes)
- Business Models and Applications of Solar PV Systems (self-consumption, communities, off-grid solutions, microgrids)

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework

Approximate Workload (Total 150 h):

- 12 h recorded lectures
- 12 h live-online meetings
- 50 h exercises
- 76 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand the technical challenges of integrating solar power into the electricity grid.
- ✓ Evaluate economic strategies to increase renewable energies' share (particularly solar energy) in the energy mix.
- ✓ Analyse the possible contribution of PV plants, inverter technologies, and control strategies from a cost-benefit viewpoint.
- ✓ Compare the latest models for utilizing PV power: Community PV and Microgrid solutions.

Assessment

- Written exam
- Graded (PL)

Software and Literature

Literature:

- Infield, D. and Freris, L.: Renewable Energy in Power Systems, 2nd edition, Wiley 2020.
- Glover, J. D., M. S. Sarma, T. J. Overbye: Power System Analysis & Design, 6th edition, Cengage Learning, 2017.
- Wood, A. J., B. F. Wollenberg; G. B. Sheblé: Power Generation, Operation and Control, 3rd edition, Wiley, 2013.

Course #PG1.2: Grid Integration and Control		
ECTS	**Lecturer**	**Tutor**
5	Dr. Bernhard Wille-Haussmann	Jakob Ungerland

Course Content

This course covers the following topics:

- Introduction
- Modelling of Power Systems
- Transmission Grid - Frequency Control
- Flexible AC Transmission Systems (FACTS)
- Distribution Grid- Voltage Control

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework

Approximate Workload (Total 150 h):

- 12 h recorded lectures
- 12 h live-online meetings
- 50 h exercises with Typhoon HIL
- 76 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand the control hierarchy of power systems.
- ✓ Understand the planning criteria depending on the voltage level.
- ✓ Perform power system simulations.
- ✓ Develop grid integration strategies.
- ✓ Evaluate grid integration measures for distributed generators.

Assessment

- Written assignment (project work)
- Graded (PL)

Software and Literature

Software:

- Typhoon HIL

Literature:

- J. Randolph and G. M. Masters, Energy for Sustainability: Foundations for Technology, Planning, and Policy, Island Press, 2018.
- J. D. Glover, T. Overbye and M. Sarma, Power System Analysis and Design, 6th ed., Cengage Learning, 2017.
- A. E. Fitzgerald, C. Kingsley and S. D. Umans, Electric Machinery, McGraw Hill, 2003.
- S. N. Vukosavic, Electrical Machines, Springer-Verlag New York, 2013.
- G. Andersson, Script: Power System Analysis, ETH Zürich, 2019.

5. Teaching Staff

The teaching staff is composed of professors and lecturers of the University of Freiburg, the Fraunhofer Institute for Solar Energy Systems, and private lecturers with expertise in the field of photovoltaics and solar energy engineering.

(A list of all lectures and tutors is attached in the appendix, Table 3)

Lecturers and Tutors

Table 3: Complete list of Lecturers and Tutors of CAS - PG "Photovoltaics and the Renewable Energy Grid"

Name	Institution	Code	Course(s)
Anke Weidlich (Prof. Dr.)	INATECH	PG1	Solar Energy Integration and Economics
Wille-Haußmann, Bernd (Dr.)	Fraunhofer ISE	PG1.2	Grid Integration and Control of PV Systems