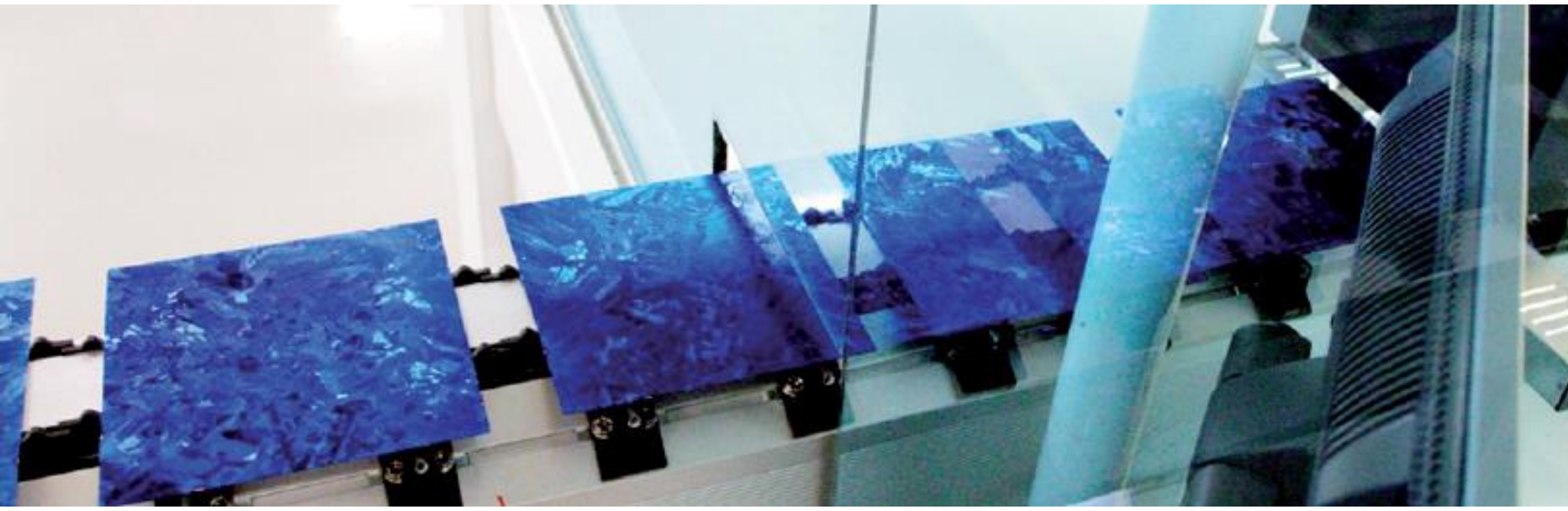
Master

Photovoltaics Engineering Science

Module Manual



Contents

All modules are self-contained and do not rely on each other (prerequisites only as mentioned at the end of the respective description).

The modules of semester 1 (cf. schedule below) are usually taught in the winter semester, the others in the summer semester.

The program can be started either in the winter or summer semester.

Photovoltaics Engineering Science (M. Sc.)

Semester	Credits (≈ Tuition Hours per Week)					
	1 … 5	… 10	… 15	… 20	… 25	… 30
1.	Physics of the Solar Cell	Crystalline Silicon Solar Cells	Thin Film Solar Cells	Cell and Materials Diagnostics	Solar System Applications	German Language
2.	Solar Modules and Components	System and Component Reliability	System Design, Monitoring, Yield and Performance Analysis, Markets	Storage Systems	Electric Grids, Solar Energy Integration	Business Studies
3.	Master Thesis					

PES/01 Physics of the Solar Cell (PSC)

Compulsory module

Program	Photovoltaics Engineering Science (Master of Science)	
Lecturer	Prof. Dr. Norbert Bernhard	
Semester	1. or 2.	
Workload	150 hours, including 75 teaching hours	
Forms of tuition	Lecture	30 h
	Exercises	30 h
	Computer exercises	15 h
	Self study	75 h
Forms of Media	Blackboard, Transparencies, Presentations, Computer Pool	
Awarded Credit	5 Credit Points	
Language	English	
Examination	Written examination (2 h) or oral examination (30 min)	

Target skills:

The students shall gain a fundamental physical understanding of the function principle of a solar cell. They shall be able to understand the influence of various physical parameters on the performance of a solar cell. They shall gain a basic understanding of the theoretical formalism on which modern solar cell simulation programs are based on. They shall be able to perform various calculations or estimations analytically or numerically. They should be able to simulate important solar cell functionalities and their dependence on critical parameters on the computer (programs AFORS-HET and PC1D are used).

Contents:

- Fundamentals of the electronic band structure of a semiconductor
- Density of states distribution function and effective density of states at band edges
- Doping in semiconductors, Fermi-Dirac statistics, Boltzmann approximation
- Electron transport in semiconductors, drift and diffusion currents
- Charge carrier mobility and diffusion coefficient
- Electrostatics of the p/n junction (charge density, electric field strength, electric potential)
- The non-illuminated p/n junction in steady state
- Diode equation and IV characteristics
- Charge carrier generation and recombination
- Dielectric function, absorption coefficient, absorption profiles
- Photogeneration of charge carriers, direct and indirect semiconductors
- Recombination mechanisms (radiative, SRH, Auger, surface recombination)
- Fermi level, quasi-Fermi levels, electrochemical potential
- The illuminated p/n junction in steady state
- Semiconductor equations and their solution
- Solar cell equation (diode equation under illumination)
- Diffusion and drift determined charge carrier collection
- Semiconductor heterojunctions and metal-semiconductor junctions
- Heterojunction solar cells and Schottky cells
- Metal-insulator heterojunction (MIS cell)
- Chemical and field-effect surface passivation
- Physical limitations of the conversion efficiency
- Photons and Bose-Einstein statistics; the solar cell as thermodynamic engine

Literature:

- Peter Würfel and Uli Würfel: Physics of Solar Cells, 3rd ed., Wiley VCH, Weinheim, 2016
- Jenny Nelson: The Physics of Solar Cells, Imperial College Press, London, 2003

Prerequisites:

- Physics knowledge according to Engineering Science Bachelor´s degree; especially: electrodynamics, thermodynamics, optics, atomic and solid state physics
- Mathematics according to Engineering Science Bachelor´s degree: infinitesimal calculus (differentiation and integration), differential equations, complex numbers

PES/02 Crystalline Silicon Solar Cells (CSSC) **Compulsory module**		
Program	Photovoltaics Engineering Science (Master of Science)	
Lecturer	Prof. Dr. Jörg Bagdahn / Prof. Dr. Norbert Bernhard	
Semester	1. or 2.	
Workload	150 hours, including 75 teaching hours	
Forms of tuition	Lecture	30 h
	Exercises (or seminar)	30 h
	Laboratory experiments (and excursions)	15 h
	Self study	75 h
Forms of Media	Blackboard, Transparencies, Presentations, Laboratory experiments	
Awarded Credit	5 Credit Points	
Language	English	
Examination	Written examination (2 h) or oral examination (30 min)	

Target skills:

The students shall gain a fundamental understanding of the properties and manufacturing processes of the silicon base material and the silicon wafers. They shall acquire an understanding of the structure, types and manufacturing processes of crystalline silicon solar cells. They shall be able to understand the interdependence between process parameters in the production process and performance parameters of the final solar cell.

Contents:

- Silicon production from raw materials; production of poly-crystalline base material
- Crystal growth; role of defects in crystals; doping of base material
- Production of multi-crystalline wafers
- Wafering (slurry and diamond-wire sawing)
- Saw damage removal and texturing etch (alkaline, acidic, plasma)
- Theory of the emitter diffusion (Fick´s laws, diffusion equation, analytical solutions)
- Diffusion process in the horizontal quartz furnace and the conveyor belt furnace
- Emitter formation by ion implantation
- Selective emitters
- Removal of phosphorus glass layer
- Monitoring of the doping density
- Anti-reflective coatings
- Surface passivation
- Metal contacts, screen printing process
- Anneal and firing process
- Back-surface field
- Alternative metallization processes
- Wafer edge isolation
- Passivated emitter and rear cell (PERC), back-side passivation
- n-doped base layer, p-doped emitter
- Interdigitated back-contact cell (IBC)
- Heterojunction with Intrinsic Layer (HIT) cell and other advanced concepts

Literature:

- Konrad Mertens: Photovoltaics: Fundamentals, Technology and Practice; Wiley, 2014
- Antonio Luque, Steven Hegedus (ed.): Handbook of Photovoltaic Science and Engineering, 2nd ed., Wiley, 2011
- Original research and review articles (e.g. Proc. EU PVSEC)

Prerequisites:

- Physics knowledge according to Engineering Science Bachelor
- Chemistry (or materials science) knowledge according to Engineering Science Bachelor
- Mathematics according to Engineering Science Bachelor´s degree: infinitesimal calculus (differentiation and integration), differential equations, complex numbers

PES/03 Thin Film Solar Cells (TFSC) **Compulsory module**		
Program	Photovoltaics Engineering Science (Master of Science)	
Lecturer	Prof. Dr. Norbert Bernhard	
Semester	1. or 2.	
Workload	150 hours, including 75 teaching hours	
Forms of tuition	Lecture	30 h
	Exercises (or seminar)	30 h
	Laboratory experiments (and excursions)	15 h
	Self study	75 h
Forms of Media	Blackboard, Transparencies, Presentations, Laboratory experiments	
Awarded Credit	5 Credit Points	
Language	English	
Examination	Written examination (2 h) or oral examination (30 min)	

Target skills:

The students shall gain a fundamental understanding of the various thin film technologies, which are used for manufacturing thin film solar cells. They shall acquire an overview of the various thin film solar cells types and shall be able to recognize similarities and differences between the various cell types.

Contents:

- Fundamentals of vacuum technology
- Deposition technologies (PVD, CVD, galvanic, chemical bath deposition)
- Laser technologies
- Contact technologies (soldering, bonding, welding)
- Transparent conducting oxides (TCOs)
- Amorphous silicon and micromorphous silicon solar cells
- Copper indium (gallium) diselenide (sulfide) solar cells
- Cadmium telluride solar cells
- Perovskite solar cells
- Dye sensitized solar cells
- Organic solar cells
- Gallium arsenide based solar cells.

Literature:

- Konrad Mertens: Photovoltaics: Fundamentals, Technology and Practice; Wiley, 2014
- Roland Scheer, Hans-Werner Schock: Chalcogenide Photovoltaics, Wiley, 2011
- C. Brabec, V. Dyakonow, U. Scherf (ed.): Organic Photovoltaics, Wiley, 2008
- Original research and review articles (e.g. Proc. EU PVSEC)

Prerequisites:

- Physics knowledge according to Engineering Science Bachelor
- Chemistry (or materials science) knowledge according to Engineering Science Bachelor

PES/04 Cell and Materials Diagnostics (CMD) **Compulsory module**		
Program	Photovoltaics Engineering Science (Master of Science)	
Lecturer	Prof. Dr. Manfred Füting / Dr. Christian Hagendorf	
Semester	1. or 2.	
Workload	150 hours, including 75 teaching hours	
Forms of tuition	Lecture	30 h
	Exercises (or seminar)	30 h
	Laboratory experiments (and excursions)	15 h
	Self-study	75 h
Forms of Media	Blackboard, Transparencies, Presentations, Laboratory experiments	
Awarded Credit	5 Credit Points	
Language	English	
Examination	Written examination (2 h) or oral examination (30 min)	

Target skills:

The students shall gain fundamental knowledge in methodology and analytical techniques for characterization of solar cells and materials of photovoltaic modules. Lectures, exercises and excursions will provide an overview on typical electrical, optical, microstructural and element-analytical methods that are used in industrial defect diagnostics as well as material characterization in research and development. The typical workflow of solar cell/module loss analysis, defect localization, sample preparation and microstructural root cause analysis will be taught at examples from applied research projects.

Contents:

- Introduction to solar cell and materials diagnostics
- Electrical and optical characterization, advanced spatially resolved methods
- Methodology and workflow in PV-cell and materials defect diagnostics (c-Si-PV, thin film-PV, next generation solar cells)
- PV-module defect diagnostics and non-destructive testing methods (case studies: PID,)
- Microstructure diagnostics of materials by SEM, ESEM, TEM, STEM, FIB, AFM… and analytical methods (EDX, WDX, EBSD, EELS, XPS, AES, SIMS…)
- conventional and advanced FIB sample preparation
- In situ microscopy for function testing and technology optimization

Literature:

- Antonio Luque (Editor), Handbook of Photovoltaic Science and Engineering, Wiley 2011
- Christiana Honsberg, Stuart Bowden, www.pveducation.org, internet, 2017
- L. Reimer, P. H. Hawkes, Scanning Electron Microscopy, Springer 2010
- H. Kohl, L. Reimer, Transmission Electron Microscopy, Springer, 2008
- P. H. Hawkes, J. C.H. Spence, Science of Microscopy, Springer, 2007
- H. Bethge, J. Heydenreich, Electron Microscopy in Solid State Physics, Elsevier, 1987

Prerequisites:

- Physics knowledge according to Engineering Science Bachelor´s degree; especially: electrodynamics, thermodynamics, optics, atomic and solid state physics
- Mathematics according to Engineering Science Bachelor´s degree: infinitesimal calculus (differentiation and integration), differential equations, complex numbers

PES/05 Solar System Applications (SSA) **Compulsory module**		
Program	Photovoltaics Engineering Science (Master of Science)	
Lecturer	Prof. Dr. Henry Bergmann	
Semester	1. or 2.	
Workload	150 hours, including 75 teaching hours	
Forms of tuition	Lecture	30 h
	Exercises (or seminar)	30 h
	Laboratory experiments (and excursions)	15 h
	Self-study	75 h
Forms of Media	Blackboard, Transparencies, Presentations, Laboratory experiments	
Awarded Credit	5 Credit Points	
Language	English	
Examination	Written examination (2 h) or oral examination (30 min)	

Target skills:

The students shall gain in the beginning an introducing understanding of the photovoltaic effect and typical differences between several photovoltaic cell constructions. They should be enabled to create experimental conditions for measuring characteristic curves and to simulate curves using mathematical methods. Course participants should understand the technical structure and behavior of typical components of photovoltaic systems including boundary engineering conditions. They should be enabled to create PV systems in principle, for both grid-connection and stand-alone conditions. Finally they are able to calculate and quantify technical and economic system parameters and to analyses methods of system optimization and avoiding of mismatching.

Contents:

- The energetic potential of sun irradiation
- How to measure sun irradiation power
- The photovoltaic effect
- Solar cell characteristics, simulation, introduction to physics of the solar cell
- Types of solar cells (structure, peculiarities, production-based methods for increasing efficiency) and overview to production technologies
- Photovoltaic systems and their components
- Generator specifics – roofs, facades, stand-alone systems, trackers
- Electrical design of module configurations
- Cabling, Boost and buck converters, Inverters
- Pumps and other specific electrical loads
- General aspects of batteries and charge controllers
- Lightning protection and other safety problems
- Sizing and economy of photovoltaic system, systems design

Literature:

- DGS, Planning and Installing Photovoltaic Systems - A Guide for Installers, Architects and Engineers, 3rded., 2013
- Mertens, K., Photovoltaics: Fundamentals, Technology and Practice, Wiley, 2014
- Quaschning, V., Regenerative Energiesysteme, 9th ed., Hanser, 2015
- Boxwell, M., The Solar Electricity Handbook - 2016 Edition, is a simple, practical guide to using electric solar panels and designing and installing photovoltaic PV systems, Greenstream Publishing 2016
- Wenham, S.R. et al., Applied Photovoltaics, 2nd ed., Earthscan, 2010

Prerequisites:

- Physics knowledge according to Engineering Science Bachelor´s degree; especially: optical properties of material, energy band models etc.
- Fundamentals of electrical engineering: electronic devices (diode, transistor, capacitance etc.), DC circuits, series and parallel connection of devices, AC circuits (1 phase, 3 phases)

PES/06 Solar Modules and Components (SMC) **Compulsory module**		
Program	Photovoltaics Engineering Science (Master of Science)	
Lecturer	Prof. Dr. Norbert Bernhard	
Semester	1. or 2.	
Workload	150 hours, including 75 teaching hours	
Forms of tuition	Lecture	30 h
	Exercises	30 h
	Computer exercises	15 h
	Self study	75 h
Forms of Media	Blackboard, Transparencies, Presentations, Laboratory experiments	
Awarded Credit	5 Credit Points	
Language	English	
Examination	Written examination (2 h) or oral examination (30 min)	

Target skills:

The students shall gain a fundamental understanding of the structure and function of a solar module. They shall be able to understand the main differences between crystalline Si and thin film modules. They shall understand the series and parallel connection of solar cells to a module. They shall understand how a bypass diode can protect the module in case of partial shading and recover at least a part of the electric energy production. They shall understand the components of a modules and their role in the modules. They shall acquire a basic understanding of the circuit design and function of a solar inverter and of the principle of maximum power point tracking.

Contents:

- Structure of crystalline silicon solar modules
- Structure of thin film solar modules
- Nominal and performance parameters of solar modules, data sheets
- Dependence of module parameters on irradiance and temperature
- Series and parallel connection of identical solar cells
- Series and parallel connection of non-identical solar cells
- Shading impact on solar module performance
- Bypass diodes
- Manufacturing process of solar modules
- Solar glass (properties and manufacturing)
- Encapsulation of solar modules (polymers and processes)
- Back-sheets for solar modules
- Double-glass modules
- Joining technologies (soldering, welding, glueing)
- Solar inverters (internal circuit concepts and operation principle)
- Fundamentals of maximum power point tracking
- Boost and buck converters

Literature:

- Konrad Mertens: Photovoltaics: Fundamentals, Technology and Practice; Wiley, 2014
- Heinrich Häberlin: Photovoltaics, System Design and Practice, Wiley 2012
- Harry Wirth, Karl-Anders Weiß, Cornelia Wiesmeier: Photovoltaic Modules: Technology and Reliability, De Gruyter, 2016

Prerequisites:

- Fundamentals of electrical engineering: DC circuits, series and parallel connection of devices, ideal and linear current source, diode equation, bipolar and Schottky diodes, power electronics (power MOSFET, IGBT, thyristor), AC circuits
- Fundamentals of chemistry or materials science: inorganic chemistry, organic chemistry (especially polymers), phase diagrams

PES/07 System Design, Monitoring, Yield and Performance Analysis, Markets (SMYM)	**Compulsory module**	
Program	Photovoltaics Engineering Science (Master of Science)	
Lecturer	Prof. Dr. Norbert Bernhard	
Semester	1. or 2.	
Workload	150 hours, including 75 teaching hours	
Forms of tuition	Lecture	30 h
	Exercises	30 h
	Computer exercises	15 h
	Self study	75 h
Forms of Media	Blackboard, Transparencies, Presentations, Computer Pool	
Awarded Credit	5 Credit Points	
Language	English	
Examination	Written examination (2 h) or oral examination (30 min)	

Target skills:

The students shall gain a fundamental understanding of the system design, monitoring, yield and performance analysis of a solar system. They should be able to perform a planning of solar system and calculate the energy yield forecast by using a commercial solar system planning software (program PVsyst is used). She shall acquire a basic understanding how the PV market works.

Contents:

- Solar irradiance (direct, diffuse, albedo)
- Geographic distribution of irradiance
- Models for estimation of diffuse portion
- Dependence of direct, diffuse and albedo irradiance on module inclination
- Radiation monitoring (pyranometers, reference cells)
- Shading analysis
- Different system concepts (string inverter, central inverter, master-slave, module inverter)
- Series and parallel connections of modules
- Reserve current regime, string diodes, string fuses
- Generator junction box, circuit breakers, surge arresters
- Solar cable sizing
- Power and voltage sizing of the inverter; inverter data sheets
- System monitoring, normalized yields and losses
- Yield forecast
- Elementary economic considerations
- Solar system planning software
- Market development in the past, scenarios for the future

Literature:

- Konrad Mertens: Photovoltaics: Fundamentals, Technology and Practice; Wiley, 2014
- Heinrich Häberlin: Photovoltaics, System Design and Practice, Wiley 2012
- Deutsche Gesellschaft für Sonnenenergie (DGS; Ed.): Planning and Installing Photovoltaic Systems, 3rd ed., 2013, Routledge

Prerequisites:

- Fundamentals of electrical engineering: DC circuits, series and parallel connection of devices, AC circuits (1 phase, 3 phases)

PES/08 System and Component Reliability (SCR) **Compulsory module**		
Program	Photovoltaics Engineering Science (Master of Science)	
Lecturer	Prof. Dr. Jörg Bagdahn (responsible), in cooperation w/ lecturers from the Fraunhofer Center for Silicon Photovoltaics (CSP)	
Semester	1. or 2.	
Workload	150 hours, including 75 teaching hours	
Forms of tuition	Lecture	30 h
	Exercises (or seminar)	30 h
	Laboratory experiments (and excursions)	15 h
	Self study	75 h
Forms of Media	Blackboard, Transparencies, Presentations, Laboratory experiments	
Awarded Credit	5 Credit Points	
Language	English	
Examination	Written examination (2 h) or oral examination (30 min)	

Target skills:

The students shall gain a fundamental understanding of impact parameters for the reliability of PV systems and components. They shall understand the physical mechanisms of failure processes and the test procedure how to monitor degradation processes. They shall understand accelerated test procedures to forecast the expected lifetime of solar cells and modules.

Contents:

- Reliability and failure modes of solar cells and solar modules
- Metals: mechanical properties and failure modes (elasticity, plasticity, fatique, failure of solder joints and ribbons)
- Module soiling
- Potential induced degradation (PID) of solar modules
- Optical properties and characterization of solar modules
- Mechanical testing of metals
- “Snail trails” in solar modules
- Failure of brittle materials
- IEC standards for module reliability; IEC module tests
- Mechanical design of modules, thermo-mechanical simulation
- Electrical characterization of solar modules
- Outdoor testing of solar modules: mobile flashing
- Polymer materials; characterization and degradation of EVA
- Mechanical testing of polymers, especially EVA
- Mechanical testing of glass
- Outdoor characterization and yield analysis
- Building integrated photovoltaics (BIPV); glass for buildings

Literature:

- Konrad Mertens: Photovoltaics: Fundamentals, Technology and Practice; Wiley, 2014
-

Prerequisites:

- Physics knowledge according to Engineering Science Bachelor´s degree; especially: mechanics, electrodynamics, thermodynamics, optics
- Fundamentals of chemistry or materials science: inorganic chemistry, metals, glass, organic chemistry (especially polymers), phase diagrams

PES/09 Storage Systems (SS) **Compulsory module**		
Program	Photovoltaics Engineering Science (Master of Science)	
Lecturer	Prof. Dr. Henry Bergmann	
Semester	1. or 2.	
Workload	150 hours, including 75 teaching hours	
Forms of tuition	Lecture	30 h
	Exercises (or seminar)	30 h
	Laboratory experiments (and excursions)	15 h
	Self-study	75 h
Forms of Media	Blackboard, Transparencies, Presentations, Laboratory experiments	
Awarded Credit	5 Credit Points	
Language	English	
Examination	Written examination (2 h) or oral examination (30 min)	

Target skills:

The students shall gain a principle understanding of the necessity to apply energy-converting and storing system now and in a probable future. They should be enabled to understand the working principles, benefits and limitations of existing energy storing systems. They shall gain to quantify electrical and thermal parameters in electrochemical systems such as batteries, fuel cells and electrolyzers for hydrogen generation. The students have to acquire the ability of assessing and choosing storage strategies for detailed (photovoltaic) system requirements.

Contents:

- Introduction (current development, storing and converting systems)
- Main parameters of selected storage systems
- Pumped Hydro
- Heated Water Storage (solar and non-solar systems)
- Compressed Air
- Hydrogen (in brief)
- Flywheels
- Electromagnetic systems
- Capacitors
- Batteries, Flow Batteries and Fuel Cells (in brief)
- Thermodynamic fundamentals of batteries, flow batteries and fuel cells
- Fundamentals of battery application
- Aspects of the solar/wind hydrogen projects

Literature:

- Papers as indicated in the worksheets
- Huggins, R.A. Energy Storage, Springer, 2nd ed., Heidelberg 2016
- Schmidt, V., Electrochemical Process Engineering, Wiley 2006
- Sorensen, B. (ed.), Solar Energy Storage, Elsevier, London 2015
- Pera, M.-C. et al., Electrochemical Components, Wiley, London 2013

Prerequisites:

- Physics knowledge according to Engineering Science Bachelor´s degree; especially: basic terms of Energy Engineering
- Fundamentals of Electrical Engineering (course-related selection)

PES/10 Electric Grids and Solar Energy Integration (EGSI) **Compulsory module**		
Program	Photovoltaics Engineering Science (Master of Science)	
Lecturer	Prof. Dr. Ralph Gottschalg	
Semester	1. or 2.	
Workload	150 hours, including 75 teaching hours	
Forms of tuition	Lecture	30 h
	Exercises (or seminar)	30 h
	Laboratory experiments (and excursions)	15 h
	Self study	75 h
Forms of Media	Blackboard, Transparencies, Presentations, Laboratory experiments	
Awarded Credit	5 Credit Points	
Language	English	
Examination	Written examination (2 h) or oral examination (30 min)	

Target skills:

The students shall gain a fundamental physical understanding of the function of a solar cell. They shall be able to understand the influence of various physical parameters on the performance of a solar cell. They shall gain a basic understanding of the theoretical formalism on which modern solar cell simulation programs are based on. They shall be able to various calculations or estimations analytically or numerically. They should be able to simulate important solar cell functionalities and their dependence on critical parameters on the computer (programs AFORS-HET and PC1D are used).

Contents:

- Overview of electric grids: transmission grids (AC and DC) and distribution grids (AC)
- Voltage levels of electric grids (high-voltage, medium-voltage, low-voltage) and interfaces
- Balance of feed-in power and delivered power, grid control
- Active and reactive power management of public grids
- Connection of PV power plants to the electric grid (to medium-voltage or low-voltage grid)
- Reactive power management and other grid serving features of PV inverters
- Actual and emerging standards for grid connection of PV inverters
- Centralized vs. decentralized public grid design
- Controllable local transformers for low-voltage grid stabilization at high PV integration levels
- Battery systems (or other storage systems) for grid stabilization
- PV grid integration complementary with other renewable or non-renewable energy forms
- Smart grids vs. classical grid control
- Future challenges and developments

Literature:

- Vincent J. Winstead: Electric Power Systems: Electrical Grid Fundamentals and Sustainable Power Integration, Taylor and Francis, publication date March 2018 announced
- Heinrich Häberlin: Photovoltaics, System Design and Practice, Wiley 2012
- Further?

Prerequisites:

- Fundamentals of electrical engineering: DC circuits, AC circuits (1 phase, 3 phases), impedances and admittances, active and reactive power in an AC circuit, transformers, fundamentals of power electronics
- Mathematics: calculation with complex numbers; infinitesimal calculus (differentiation)

PES/11 German Language (GL) **Compulsory module**		
Program	Photovoltaics Engineering Science (Master of Science)	
Lecturer	Ms. Antje Fechner (or other teacher of the Language Center of Anhalt University)	
Semester	1. or 2.	
Workload	150 hours, including 75 teaching hours	
Forms of tuition	Lecture	30 h
	Exercises	30 h
	Language laboratory or seminar	15 h
	Self study	75 h
Forms of Media	Blackboard, Transparencies, Presentations, Language Laboratory	
Awarded Credit	5 Credit Points	
Language	English or German (for more advanced levels)	
Examination	Written examination (2 h) or oral examination (30 min)	

Target skills:

The students shall be able to conduct simple communications of daily life in German (beginners). For more advanced entrance qualifications the students shall improve their knowledge in oral and written usage of the German language. Fore entrance levels of B2 and C1 (European reference frame), the students shall acquire the ability to discuss PV related topics in German in oral and written form.

For German native speakers (or very advanced speakers, level C2) this module will be replaced by another module of soft skills (e.g. another foreign language or any other soft skills module offered by the university). The target skills are then analogous.

Contents:

- German vocabulary and grammar according to the entrance level
- Oral communication in German
- Reading German texts
- Writing German texts
- Entrance level B2 or C1: German vocabulary and technical terms related to PV

Literature:

- Anne Buscha, Szilvia Szita: Begegnungen (level according to entrance level), Schubert-Verlag
- Anne Buscha, Szilvia Szita: Grammatik (level according to entrance level), Schubert-Verlag

Prerequisites:

- English: good knowledge of the English language (at least level B2)
- German: none

<table>
<tr><td colspan="3">PES/12 Business Studies (BS)
Compulsory module</td></tr>
<tr><td>Program</td><td colspan="2">Photovoltaics Engineering Science (Master of Science)</td></tr>
<tr><td>Lecturer</td><td colspan="2">Prof. Dr. Helmut Büchel</td></tr>
<tr><td>Semester</td><td colspan="2">1. or 2.</td></tr>
<tr><td>Workload</td><td colspan="2">150 hours, including 75 teaching hours</td></tr>
<tr><td rowspan="4">Forms of tuition</td><td>Lecture</td><td>30 h</td></tr>
<tr><td>Exercises</td><td>30 h</td></tr>
<tr><td>Seminar</td><td>15 h</td></tr>
<tr><td>Self study</td><td>75 h</td></tr>
<tr><td>Forms of Media</td><td colspan="2">Blackboard, Transparencies, Presentations</td></tr>
<tr><td>Awarded Credit</td><td colspan="2">5 Credit Points</td></tr>
<tr><td>Language</td><td colspan="2">English</td></tr>
<tr><td>Examination</td><td colspan="2">Written examination (2 h) or oral examination (30 min)</td></tr>
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Target skills:
An important goal of the course consists in teaching basic economic principles. The students shall aquire the ability to evaluate the financial perspectives of projects by using appropriate computational methods. Starting with the analysis of balance sheets and profit loss accounts the earnings aspects as well as the financial stability of firms are judged.
The students learn how to finance projects with credits.
Furthermore some basic concepts of Marketing are introduced.

Contents:

- Economic key figures
- Balance sheets
- Profit loss accounts
- Practical application at evaluating companies
- Amortization method
- net present value method
- method of internal interest rate
- Applicated to analyze projects
- Markowitz approach
- Credits
- Marketing research
- Consumer behavior
- Marketing strategies

Literature:

- Business Studies - Fourth Edition (Englisch) Taschenbuch, 2008 von Dave Hall, Rob Jones, Carlo Raffo, Iain Chambers, Dave Gray
- Edexcel AS/A level Business 5th edition Student Book and ActiveBook, 2015 von Dave Hall, Carlo Raffo, Dave Gray, Alain Anderton, Rob Jones
- Foundations of Finance, Global Edition, 2016 von Arthur J. Keown, John D. Martin, J. William Petty
- Principles of Marketing, Global Edition, 2017 von Philip T. Kotler, Gary Armstrong

Prerequisites:
Knowledge of the English language
Elementary Mathematics

PES/13 Master Thesis (Including Colloquium) **Compulsory module**		
Program	Photovoltaics Engineering Science (Master of Science)	
Lecturer	depending on specific topic	
Semester	3.	
Workload	900 hours	
Forms of tuition	Master thesis	750 h
	Colloquium	150 h
Awarded Credit	30 Credit Points	
Language	English	
Examination	Written thesis and oral presentation and defense (30 min)	

Target skills:

The students shall be able to use and show the ability to transfer basic theoretical knowledge to specific scientific questions.

Contents:

Literature:

Depending on chosen specific topic

Prerequisites:
all compulsory modules of 1. and 2.semester