TU Dortmund University

Faculty of
Electrical Engineering and Information Technology

# Module Book

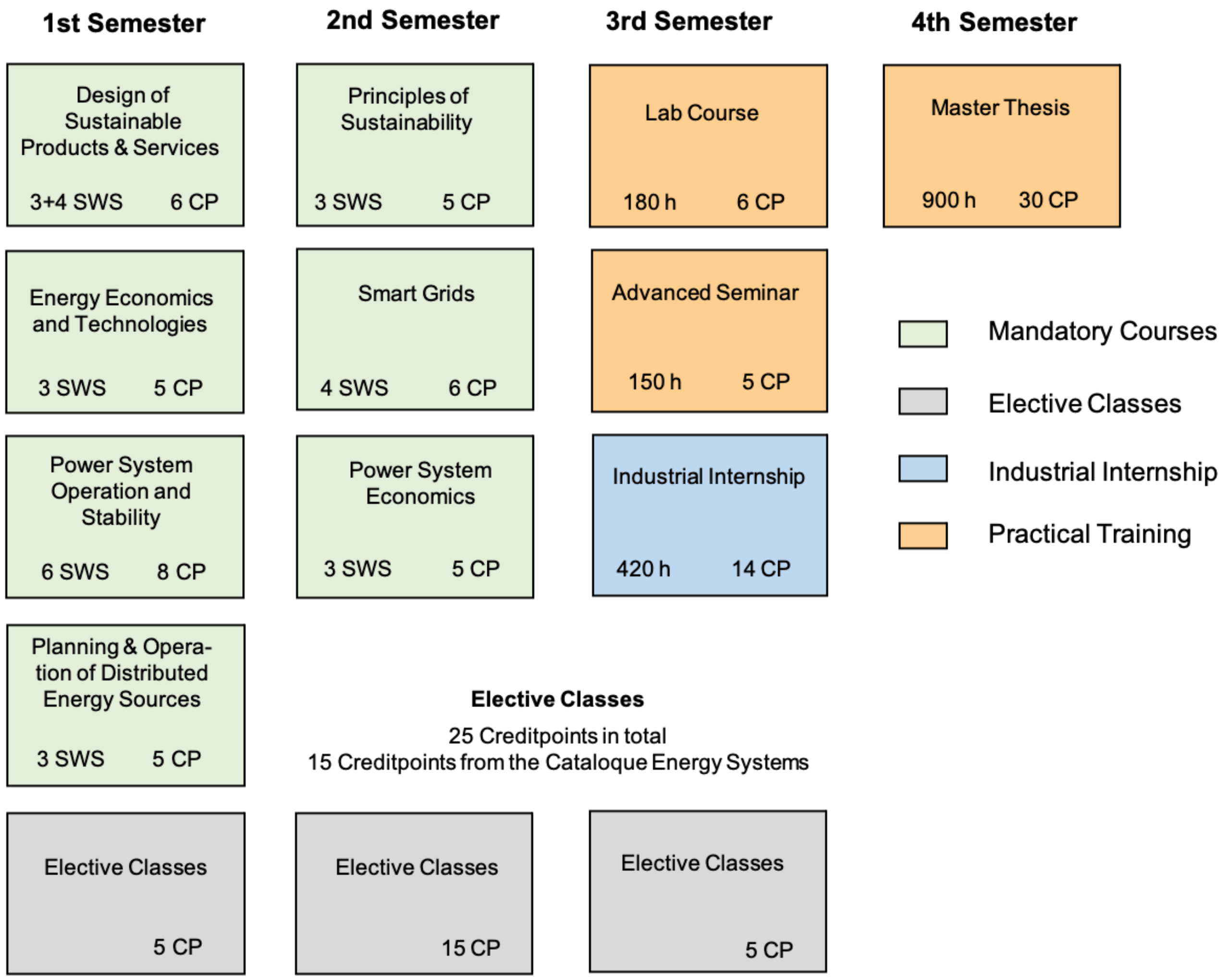
# Master Program

# Sustainable Energy Systems

Aktualisierte Version
gemäß Beschluss des Fakultätsrates vom 03.05.2023

# Table of Contents

# Structure of the Study Program



# Mandatory Courses

Mandatory Courses

In the 1st and 2nd semesters, a total of 40 credit points in 7 modules must be successfully completed in the compulsory area.

## Module M-1: Design of Sustainable Products & Services (DSPS) SES-101

| Turnus | Duration | Study section | CP | Attendance rate | Self-study |
|---|---|---|---|---|---|
| Annually at WS | 1 semester | Xnd semester | 6 | 75 h | 105 h |

**1 Module structure**

| No. | Element / Course | LSF no. | Type | LP | SWS |
|---|---|---|---|---|---|
| 1 | Design of Sustainable Products & Serv. Lecture | 08 0035 | V | 3 | 2 |
| 2 | Design of Sustainable Products & Serv. Exercise | 08 0036 | Ü | 1 | 1 |
| 3 | Design of Sustainable Products & Serv. Practical Training | 08 0037 | P | 2 | 4 |

**2 Course language**:
English

**3 Teaching content of** elements 1 and 2

1. Design processes for products and services taking into account sustainability criteria
2. Cost accounting for production and operation of products and services
3. Calculation and Optimizing of CO2 footprints of products and services
4. Profitability evaluations (net present value calculation, investment decisions)
5. Sustainability as part of the marketing of products (incl. product life cycle, pricing)
6. Organization of companies and projects
7. Business start-up as an option for implementing sustainable product ideas

**Teaching content of** element 3

- Computer-based business simulation as an integrated practical course
- Creation of a business plan for a self-selected, innovative and sustainable product or service offering

**Literature**
Walker, Julia, Alma Pekmezovic, and Gordon Walker. Sustainable development goals: harnessing business to achieve the SDGs through finance, technology and law reform. John Wiley & Sons, 2019.
Kotler, P., Burton, S., Deans, K., Brown, L. & Armstrong, G., 2015. Marketing. Pearson Higher Education.

**4 Competencies**
After completion of the module examination, the students understand the essential business and sustainability aspects of the realization of electrotechnical systems. They will be able to apply suitable methods to take these aspects into account, e.g. to control the sustainable as well as economic use of resources, to evaluate product realization variants and to estimate market potentials.

**5 Exams**
*Module exam:* Written exam (120 minutes)
*Course Credits:*

- In Element 2, 50% of the total points earned are through lecture hall exercises.
- The business plan (elements 2 and 3) must be successfully prepared and presented.
- Successful participation and final presentation of the business simulation in Element 3.

The coursework is a prerequisite for taking the module exam.

**6 Forms of examination and performance**
☒ Module Exam ☐ Partial achievements

**7 Participation requirements**
None

**8 Module type and usability of the module**
Mandatory module in the Master's degree program Sustainable Energy Systems.

| 9 Module Supervisor | Faculty in charge |
|---|---|
| Prof. Dr.-Ing. Christian Wietfeld | Faculty of Electrical Engineering and Information Technology |

<table>
<tr><th colspan="6">Module M-2: Energy Economics and Technologies</th><th colspan="2">SES-102</th></tr>
<tr><td colspan="2">Turnus<br>Annually in winter semester</td><td>Duration<br>1 Semester</td><td>Study section<br>3. Semester</td><td>LP<br>5</td><td>Attendance rate<br>35 h</td><td colspan="2">Self-study<br>115 h</td></tr>
<tr><td rowspan="4">1</td><td colspan="7">Module structure</td></tr>
<tr><td>Nr.</td><td colspan="3">Element / Course</td><td>LSF no.</td><td>Typ</td><td>SWS</td></tr>
<tr><td>1</td><td colspan="3">Energy Economics and Technologies Lecture</td><td>08 xxxx</td><td>V</td><td>2</td></tr>
<tr><td>2</td><td colspan="3">Energy Economics and Technologies Presentations</td><td>08 xxxx</td><td>Ü</td><td>1</td></tr>
<tr><td>2</td><td colspan="7">Course language<br>English</td></tr>
<tr><td>3</td><td colspan="7">Teaching content<br>The course focuses on the technologies and economics of energy transitions and the role of public policy in shaping such processes. The content of the course is inherently interdisciplinary, focusing on the technological, economic, social, and environmental challenges related to energy transitions. The students become familiar with the concepts and tools of energy economics and policy analysis. It covers a diverse set of technologies, policy instruments and strategies to support energy transitions and discusses their effectiveness, efficiency and equitability.<br><br>Literature<br>K. Blok: Introduction to Energy Analysis<br>D. Martinez et. al: Energy Efficiency</td></tr>
<tr><td>4</td><td colspan="7">Competencies<br>After successfully completing the course, students are familiar with technologies, policy strategies and instruments driving the deployment of sustainable energy solutions. Furthermore, students are able to estimate the economic and social impacts of such policies.</td></tr>
<tr><td>5</td><td colspan="7">Exams<br>Module Exam:<br>• oral presentations (date to be confirmed)<br>Power point slides as pdf including to be sent to the instructor a week ahead of the presentation at the latest *<br><br>*All dates will be published two weeks after the start of the lecture at the very latest.</td></tr>
<tr><td>6</td><td colspan="7">Forms of examination and performance<br>☒ Module Exam ☐ Partial achievements</td></tr>
<tr><td>7</td><td colspan="7">Participation requirements<br>None</td></tr>
<tr><td>8</td><td colspan="7">Module type and usability of the module<br>Mandatory module in the Master's degree program Sustainable Energy Systems.</td></tr>
<tr><td>9</td><td colspan="3">Module Supervisor<br>Prof. Stefan Palzer, PhD<br>Lecturer<br>Dr. Sibylle Braungardt</td><td colspan="4">Faculty in charge<br>Faculty of Electrical Engineering and Information Technology</td></tr>
</table>

**Modul M-3: Power System Operation and Stability** **SES-103**

| Turnus | Duration | Study section | LP | Attendance rate | Self-study |
|---|---|---|---|---|---|
| Annually at WS | 1 Semester | 1. Semester | 8 | 70 h | 170 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Power System Operation and Stability Lecture | 08 0146 | V | 4 |
| 2 | Power System Operation and Stability Exercise | 08 0147 | Ü | 2 |

**2 Course language:** English

**3 Teaching content of** elements 1 and 2

The course is structured into two main sections:
**1. Power System Supervision, Operation and Protection**
1.1. Introduction into electrical power systems and its operational tasks
1.2 System architecture of power system control centers
1.3 Algorithms for power system calculation, supervision and operation
1.4 Substation automation and protection architecture
1.5 Power system protection functions and algorithms for short circuit and fault calculation
1.. Future trends in control centres

**2. Power System Stability, Dynamics and Control**
2.1 Stability in electrical power systems
2.2 Dynamic power system modelling and simulation
2.3 Small signal and transient rotor angle stability
2.4 Frequency stability
2.5 Voltage stability and voltage control
2.6 Measures to improve stability

**Literature**
Power System Stability and Control by Kundur
Power System Analysis and Design by Overbye, Glover, Sarma
Power System Operations by Conejo, Baringo

**4 Competencies**
After successful completion of the module, the students understand the architectural structure of power system supervision, control and protection systems as well as their algorithms for handling the operating conditions of electrical power grids from a security and economic perspective. The students are able to analyse the interaction of the supervision, control and protection components.
Furthermore, they have knowledge about all kinds of power system stability necessary for planning and operation. They are able to choose the appropriate models for stability assessment. Based on these, the dynamic behaviour and stability can be calculated and analysed.

**5 Exams**
*Module examination:* oral examination (max. 40 minutes) or written examination (max. 180 minutes).*

*The exact examination modalities will be announced by the 2nd course at the latest.

**6 Prüfungsformen und -leistungen**
☒ Module Exam ☐ Partial achievements

**7 Participation requirements**
None

**8 Module type and usability of the module**
Mandatory module in the Master's degree program Sustainable Energy Systems.

| 9 | **Module Supervisor** | **Faculty in charge** |
|---|---|---|
| | Prof. Dr.-Ing. Christian Rehtanz | Faculty of Electrical Engineering and Information Technology |

**Modul M-4: Planning and Operation of Distributed Energy Sources** **SES-104**

| Turnus | Duration | Study section | LP | Attendance rate | Self-study |
|---|---|---|---|---|---|
| Annually at WS | 1 Semester | 3. Semester | 5 | 35 h | 115 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Planning & Operation of Distributed Energy Sources | 08 XXXX | V | 2 |
| 2 | Planning & Operation of Distributed Energy Sources | 08 XXXX | Ü | 1 |

**2 Course language**

English

**3 Teaching content**

Electrical energy systems are undergoing a massive transformation towards $CO_2$ -neutral technologies for electricity generation. Large-scale power plants are increasingly being replaced by distributed energy conversion plants. This results in new requirements for the operation of distributed resp. decentral supplied electrical energy systems and grids. Within this lecture, different technologies for energy conversion are introduced. In particular, the requirements for system integration, design, grid connection and operation are examined in detail. The lecture is structured into the following topics:

1. Introduction to the implementation of distributed energy systems
2. Technologies of distributed energy conversion and storage
3. Grid connection guidelines and protection of distributed energy conversion systems in low and medium voltage grids
4. Power grid influences and control strategies of converter-based energy conversion
5. Design and evaluation of the economic efficiency of distributed energy conversion systems

**Literature**

Renewable energy conversion systems - 1st Edition, Muhammad Kamran & Muhammad Fazal, ISBN: 9780128235980

**4 Competencies**

After successful completion of the module, the students know the process and the effects of the change from a centralised to a decentralised energy supply. They can classify the associated effects and know a selection of (technical control) measures to increase the integration capability of decentralised energy conversion plants in the electrical distribution grids. Furthermore, they are familiar with the different plant technologies for decentralised and regenerative electrical energy conversion. They know the different connection options and their protection concepts according to the common application rules. They are able to plan and operate decentralised energy conversion plants safely, taking into account the economic and technical boundary conditions.

**5 Exams**

*Module exam:* oral exam (max. 30 minutes) or written exam (max. 90 minutes) *

*The exact examination modalities will be announced by the 2nd course at the latest.

**6 Forms of examination and performance**

☒ Module Exam ☐ Partial achievements

**7 Participation requirements**

Recommended prerequisites: Knowledge of the fundamentals of power engineering and electrical power systems.

**8 Module type and usability of the module**

Mandatory module in the Master's degree program Sustainable Energy Systems.

**9**

| Module Supervisor | Faculty in charge |
|---|---|
| Prof. Dr.-Ing. Christian Rehtanz | Faculty of Electrical Engineering and Information Technology |

<table>
<tr><td colspan="6">Modul M-5: Principles of Sustainability</td><td colspan="2">SES-105</td></tr>
<tr><td colspan="2">Rota<br>Anually summer term</td><td>Duration<br>1 Semester</td><td>Semester<br>2nd Semester</td><td>Credits<br>5</td><td>Attendance<br>35 h</td><td colspan="2">Self-study<br>115 h</td></tr>
<tr><td rowspan="4">1</td><td colspan="7">Module structure</td></tr>
<tr><td>Nr.</td><td colspan="3">Courses</td><td>LSF no.</td><td>Type</td><td>SWS</td></tr>
<tr><td>1</td><td colspan="3">Principles of Sustainability</td><td>08 XXXX</td><td>V</td><td>2</td></tr>
<tr><td>2</td><td colspan="3">Principles of Sustainability</td><td>08 XXXX</td><td>Ü</td><td>1</td></tr>
<tr><td>2</td><td colspan="7">Language<br>English</td></tr>
<tr><td>3</td><td colspan="7">Content<br>1. What is Sustainability?<br>2. Legal framework<br>3. Reporting und Monitoring<br>4. Our CO2 footprint<br>5. Circular Economy in the context of energy supply<br>6. Climate neutral energy supply and demand<br>7. Sustainable solutions for energy systems (2 lectures)<br>8. Social Responsibility<br>9. The Year 2040<br><br>Literature<br>tbd</td></tr>
<tr><td>4</td><td colspan="7">Competencies<br>After the successful completion, students have the necessary solid knowledge on principles of sustainability. They can put sustainable approaches and solutions into the context of the current legal framework and develop appropriate reporting and monitoring methods. The handling of the different levels of sustainability and their necessary interaction is conveyed based on energy systems. The students can derive the impact of new technology and processes on the path of sustainability.</td></tr>
<tr><td>5</td><td colspan="7">Examination<br>Module exam: oral exam (max. 40 minutes) or written exam (max. 90 minutes) *<br>Examination prerequisites: tbd<br><br>* The exact examination modalities will be announced at the latest for the 2nd event.</td></tr>
<tr><td>6</td><td colspan="7">Type and Performance of Examination<br>☒ Module Exam ☐ Accumulated grade</td></tr>
<tr><td>7</td><td colspan="7">Module prerequisites<br>Recommended preconditions: Knowledge about principles of energy technology</td></tr>
<tr><td>8</td><td colspan="7">Module type and usability of the module<br>Mandatory module in the Master's degree program Sustainable Energy Systems.</td></tr>
<tr><td>9</td><td colspan="3">Module Supervisor<br>Hon.Prof. Dr.-Ing. Lars Jendernalik</td><td colspan="4">Faculty in charge<br>Faculty of Electrical Engineering and Information Technology</td></tr>
</table>

| Modul M-6: Smart Grids | | | | | SES-106 |
|---|---|---|---|---|---|
| **Turnus**<br>Annually at SS | **Duration**<br>1 Semester | **Study section**<br>2nd Semester | **LP**<br>6 | **Attendance rate**<br>55 h | **Self-study**<br>125 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Smart Grids Lecture | 08 0102 | V | 3 |
| 2 | Smart Grids Practical works | 08 0103 | P | 1 |

**2 Course language**

Englisch

**3 Teaching content**

This course will handle the following aspects of the changing electrical energy network:

1. Energy transition
2. New Distribution Grid Users
3. Electro-mobility.
4. Conventional Distribution Grid and their Transformation
5. State Estimation
6. Congestion Management (Voltage CM and Thermal CM)
7. Protection and control functions
8. Timeseries Based Planning
9. Grid Automation and future trends

**4 Competencies**

The students successfully finishing the course should be able to
• understand the challenges in todays and future electrical energy distribution grids
• comprehend the multiple areas of research done in the distribution grids
• develop new solution approaches for energy system problems based on their acquired knowledge through lectures and practical works

**5 Exams**

*Module Exam:* oral exam (max. 30 minutes) oder written exam (max. 120 minutes) *
*Prerequesites:* Active participation in practical works (laboratory tasks, presentations, etc.,) is also a prerequisite to participate in the examination

* The responsible lecturer will announce the mode of the examination two weeks after the start of the lecture at the very latest.

**6 Forms of examination and performance**

☒ Module Exam ☐ Partial achievements

**7 Participation requirements**

Basic knowledge in Electrical Energy Engineering

**8 Module type and usability of the module**

Mandatory module in the Master's degree program Sustainable Energy Systems.

**9**

| **Module Supervisor** | **Faculty in charge** |
|---|---|
| Dr.-Ing. Ulf Häger | Faculty of Electrical Engineering and Information Technology |

**Modul M-7: Power System Economics** **ETIT-224**

| **Turnus** | **Duration** | **Study section** | **LP** | **Attendance rate** | **Self-study** |
|---|---|---|---|---|---|
| Annually at SS | 1 Semester | 2. Semester | 5 | 35 h | 115 h |

**1 Module structure**

| **Nr.** | **Element / Course** | **LSF no.** | **Typ** | **SWS** |
|---|---|---|---|---|
| 1 | Power System Economics Lecture | 08 0227 | V | 2 |
| 2 | Power System Economics Exercise | 08 0228 | Ü | 1 |

**2 Course language**

Deutsch

**3 Teaching content**

1. Organization of the electricity market and regulatory framework
2. Regulation in electrical power and energy systems
3. Optimization methods in the electricity industry
4. Unit Commitment
5. Grid charges and transmission rights
6. Modeling and simulation of electricity markets and grids
7. Cross-border electrical energy trading capacities
8. Network congestion management and redispatch optimisation
9.Portfolio optimization and risk management
10. Investment in generation and grid capacity

**Literature**

D. Kirschen: Fundamentals of Power System Economics, Wiley

**4 Competencies**

After successful completion, students have a sound knowledge of market mechanisms and management strategies in grid-based energy supply. They are able to discuss the technical constraints from the power grids to energy supply in economic and business contexts. They are able to apply their knowledge in power system economics to further developments in the technical, market and regulatory context. In addition to the electricity industry in general, the special focus of this lecture is on the electrical network industry.

**5 Exams**

*Module Exam:* oral exam (max. 40 minutes) or written exam (max. 180 minutes) *

*The exact examination modalities will be announced by the 2nd course at the latest.

**6 Forms of examination and performance**

☒ Module Exam ☐ Partial achievements

**7 Participation requirements**

Recommended prerequisites: Knowledge of the basics of power engineering

**8 Module type and usability of the module**

Mandatory module in the Master's degree program Sustainable Energy Systems.

**9**

| **Module Supervisor** | **Faculty in charge** |
|---|---|
| Prof. Dr.-Ing. Christian Rehtanz | Faculty of Electrical Engineering and Information Technology |

# Elective Classes – Cataloque Energy Systems

Elective Classes

A total of 25 credit points must be successfully acquired in the compulsory elective modules (according to the study plan for semesters 1, 2 and 3).

15 of the 25 credit points are to be selected from the Energy Systems catalogue.

10 credit points are freely selectable.

| Modul 2-35: Selected Chapters in High Voltage Technology | | | | | ETIT-288 |
|---|---|---|---|---|---|
| **Turnus**<br>Annually at SS | **Duration**<br>1 Semester | **Study section**<br>2nd Semester | **LP**<br>5 | **Attendance rate**<br>35 h | **Self-study**<br>115 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **Nr.** | **Element / Course** | **LSF no.** | **Typ** | **SWS** |
| | 1 | Selected Chapters in High Voltage Technology (lecture) | 08 0203 | V | 2 |
| | 2 | Selected Chapters in High Voltage Technology (tutorial) | 08 0204 | Ü | 1 |
| 2 | **Course language**<br>Deutsch | | | | |
| 3 | **Teaching content**<br>1. requirements for high-voltage equipment<br>2. technology, structure and design<br>3. insulation systems for DC<br>4. diagnostic methods and technology trends<br>**5.** examples and applications from practice<br>**Literature**<br>Kuffel: High Voltage Engineering Fundamentals,<br>Küchler: High Voltage Engineering - Fundamentals - Technology - Applications | | | | |
| 4 | **Competencies:**<br>Students acquire detailed knowledge of selected operating equipment of power transmission systems. They are familiar with the constructive structure and electrical design and know the technological boundaries which apply for high-voltage devices. The participants are familiar with procedures and measurement methods for quality assurance reasons and diagnostics on high-voltage devices. Examples and applications deepen the knowledge and establish the reference to the operational practice. | | | | |
| 5 | **Exams**<br>*Module Exam:* oral exam (max. 40 minutes) or written exam (max. 180 minutes) *<br><br>*The exact examination modalities will be announced by the 2nd course at the latest. | | | | |
| 6 | **Forms of examination and performance**<br>☒ Module Exam ☐ Partial achievements | | | | |
| 7 | **Participation requirements**<br>Recommended prerequisites: Sufficient knowledge in energy technology, as can be acquired e.g. through participation in the basic module "Field and Network-Based Modelling". | | | | |
| 8 | **Module type and usability of the module**<br>Elective Class in the Master's degree program Sustainable Energy Systems, *Energy Systems Cataloque*. | | | | |
| 9 | **Module Supervisor**<br>Prof. Dr.-Ing. Frank Jenau | **Faculty in charge**<br>Faculty of Electrical Engineering and Information Technology | | | |

## Modul 2-36: Automotive Systems — ETIT-291

| Turnus | Duration | Study section | LP | Attendance rate | Self-study |
|---|---|---|---|---|---|
| Annually at SS | 1 Semester | 2nd Semester | 5 | 35 h | 115 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Automotive Systems (lecture) | 08 0008 | V | 2 |
| 2 | Automotive Systems (tutorial) | 08 0009 | Ü | 1 |

**2 Course language**

Englisch

**3 Lehrinhalte**

1. Vehicle dynamics (tires, longitudinal and lateral dynamics)
2. Actuators in the mechatronic vehicle (steering, braking, and powertrain systems)
3. (Kinematic) vehicle models
4. Sensors measuring vehicle internal quantities (acceleration, yaw rate, steering angle, steering torque, wheel speed, sensor data processing)
5. Vehicle dynamics systems (braking and driving slip control systems)
6. Modern headlight systems and light engineering

**Literature:**
- R. Rajamani: Vehicle Dynamics and Control (Springer)
- U. Kiencke, L. Nielsen: Automotive Control Systems (Springer)

**4 Competencies**

The students acquire a profound knowledge of vehicle dynamics systems (dynamics, sensors measuring vehicle dynamics quantities, actuators, models, simulation, control, and optimization). They are able to understand and solve tasks on vehicle dynamics systems with appropriate methods.

**5 Exams**

*Module Exam:* oral exam (max. 40 minutes) or written exam (max. 180 minutes) *

*The exact examination modalities will be announced by the 2nd course at the latest.

**6 Prüfungsformen und -leistungen**

☒ Module Exam ☐ Partial achievements

**7 Participation requirements**

Recommended prerequisites: Basic knowledge of mechatronics and mechanics.

**8 Module type and usability of the module**

Elective Class in the Master's degree program Sustainable Energy Systems, *Energy Systems Cataloque*.

| 9 Module Supervisor | Faculty in charge |
|---|---|
| Prof. Dr.-Ing. Prof. h.c. Dr. h.c. Torsten Bertram | Faculty of Electrical Engineering and Information Technology |

| **Modul 3-28: Machine Learning in Robotics** | | | | | **ETIT-277** |
|---|---|---|---|---|---|
| **Turnus**<br>Annually at SS | **Duration**<br>1 Semester | **Study section**<br>2nd Semester | **LP**<br>5 | **Attendance rate**<br>35 h | **Self-study**<br>115 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Machine Learning in Robotics (lecture) | 08 0808 | V | 2 |
| 2 | Machine Learning in Robotics (tutorial) | 08 0809 | Ü | 1 |

**2 Course language**

Englisch

**3 Teaching content**

1. Fundamentals of Machine Learning
2. Nonlinear Regression
3. Neural Networks
4. Deep Learning
5. Reinforcement Learning

**Literature:**

Ian Goodfellow, Yoshua Bengio, Aaron Courville, Deep Learning, MIT Press, 2016
Richard Sutton, Andrew G. Barton, Reinforcement Learning an Introduction, 2nd edition, MIT Press, 2018
ausgewählte Veröffentlichungen aus Zeitschriften und Konferenzen

**4 Competencies**

The students acquire a profound knowledge of theoretical concepts and practical applications of machine learning in robotics. Students are able to solve machine learning tasks for supervised and reinforcment learning with methods and algorithms within Matlab and ROS.

**5 Exams**

*Module Exam:* oral exam (max. 40 minutes) or written exam (max. 180 minutes) *

*The exact examination modalities will be announced by the 2nd course at the latest.

**6 Prüfungsformen und -leistungen**

☒ Module Exam ☐ Partial achievements

**7 Participation requirements**

None

**8 Module type and usability of the module**

Elective Class in the Master's degree program Sustainable Energy Systems, *Energy Systems Cataloque*.

**9**

| **Module Supervisor** | **Faculty in charge** |
|---|---|
| apl. Prof. Dr. rer. nat. Frank Hoffmann | Faculty of Electrical Engineering and Information Technology |

| **Modul 2-40 Distributed and Networked Control** | | | | | **ETIT-400** |
|---|---|---|---|---|---|
| **Turnus**<br>Annually at SoSe | **Duration**<br>1 Semester | **Study section**<br>2nd Semester | **LP**<br>5 | **Attendance rate**<br>35 h | **Self-study**<br>115 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Distributed and Networked Control (lecture) | 08 0092 | V | 2 |
| 2 | Distributed and Networked Control (tutorial) | 08 0093 | Ü | 1 |
| 3 | Distributed and Networked Control (lab course) | 08 0094 | P | |

**2 Course language**

Englisch

**3 Teaching content Element 1**

Introduction to distributed control and networked systems
- Cyber-physical systems
- Application domains
- Examples

Algebraic graph theory
- Directed graphs and their description
- Matrix representation of graphs
- Analysis tools for graphs

Consensus in multi-agent control
- Control design for consensus
- Convergence analysis
- Leader-follower networks

Synchronisation
- Modelling and interpretation of coupling structures
- Linear and nonlinear settings
- Kuramoto oscillators
- Power-swing equations

Research outlook and case studies

**Teaching content Elemente 2 und 3**
- Black board exercises, in class computer exercises

**Literature**

Jan Lunze, Networked Control of Multi-Agent Systems, Bookmundo Direct, 2019, ISBN: 9789463867139
Francesco Bullo, Lectures on Network Systems, 2Kindle Direct Publishing, 2019, ISBN: 978-1986425643

**4 Competencies**

The students are able to formulate and to solve problems of modelling and control of networked control systems and distributed control. The students are able to understand and to analyze the interplay of problem formulation, modelling and system-theoretic solution approaches. They know how to apply and to implement distributed and decentralized control schemes for networked linear systems. The students are able to analyze consensus phenomena and synchronization mechanisms arising in coupled systems.

**5 Exams**

*Module Exam:* oral exam (max. 40 minutes) or written exam (max. 180 minutes) *

*The exact examination modalities will be announced by the 2nd course at the latest.

**6 Prüfungsformen und -leistungen**

☒ Module Exam ☐ Partial achievements

| | | |
|---|---|---|
| **7** | **Participation requirements**<br>Required prerequisites:<br>• Basics of control engineering (state space description, LQR control, Lyapunov functions)<br>• Basics of ordinary differential equations | |
| **8** | **Module type and usability of the module**<br>Elective Class in the Master's degree program Sustainable Energy Systems, *Energy Systems Cataloque*. | |
| **9** | **Module Supervisor**<br>Prof. Dr.-Ing. Timm Faulwasser | **Faculty in charge**<br>Faculty of Electrical Engineering and Information Technology |

**Modul 2-47: Practical Distrobuted Optimization in JULIA** ETIT-405

| Turnus | Duration | Study section | LP | Attendance rate | Self-study |
|---|---|---|---|---|---|
| Annually at SoSe | 1 Semester oder Block | 2nd Semester | 5 | 35 h | 115 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Practical Distributed Optimization in julia (lecture) | 08 0328 | V | 1 |
| 2 | Practical Distributed Optimization in julia (tutorial) | 08 0329 | Ü | 2 |

**2 Course language**

Englisch

**3 Teaching content** part 1

- concepts of distributed algorithms and multi-agent systems in the context of computer science, control and optimisation
- distributed and decentralised approaches to solving convex and non-convex optimisation problems
- implementation of the optimisation approaches in the programming language julia (flipped classroom)
- Algorithms covered include
  - Decomposition of Sequential Quadratic Programming and Interior Point methods Dual Decomposition
  - Augmented Lagrangian
  - Augmented Direction of Multipliers Methods (ADMM)
  - Augmented Lagrangian Inexact Newton (ALADIN)
- Application examples from control and automation

**Teaching content** part 2

- Introduction to JULIA
- Implementation of optimisation algorithms in JULIA
- Case studies for technical applications

**Literature**

Boyd, Stephen, Neal Parikh, Eric Chu, Borja Peleato, und Jonathan Eckstein. „Distributed Optimization and Statistical Learning via the Alternating Direction Method of Multipliers“. Foundations and Trends® in Machine Learning 3, Nr. 1 (2011): 1–122.
Bertsekas, Dimitri P., und John N. Tsitsiklis. Parallel and Distributed Computation: Numerical Methods. Athena Scientific, 1997.

**4 Competencies**

Students are able to independently solve problems of multi-agent optimisation in technical applications with the help of mathematical methods. In particular, they are able to analyse application-related problems and to transcribe them into abstract optimisation problems and solve them with the help of suitable multi-agent approaches, i.e. distributed and decentralised optimisation methods.
Students master the basics of the programming language julia and are able to solve optimisation problems in it. They have an overview of established methods for solving convex and non-convex optimisation problems using multi-agent approaches for distributed and decentralised optimisation methods.

**5 Exams**

*Module Exam:* oral exam (max. 30 minutes) *
*Course achievements:* project work accompanying the lecture **

*The exact examination modalities will be announced by the 2nd course at the latest.
** The course work is a prerequisite for participation in the Module Exam.

**6 Forms of examination and performance**

☒ Module Exam ☐ Partial achievements

| | | |
|---|---|---|
| **7** | **Participation requirements**<br>Recommended prerequisites: Prior knowledge of numerical optimisation | |
| **8** | **Module type and usability of the module**<br>Elective Class in the Master's degree program Sustainable Energy Systems, *Energy Systems Cataloque*. | |
| **9** | **Module Supervisor**<br>Prof. Dr.-Ing. Timm Faulwasser<br>**Lecturer**<br>Dr.-Ing. Alexander Engelmann | **Faculty in charge**<br>Faculty of Electrical Engineering and Information Technology |

| **Modul 2-48: Optimal Power Flow Problems** | | | | | **ETIT-406** |
|---|---|---|---|---|---|
| **Turnus**<br>Annually at SoSe | **Duration**<br>1 Semester | **Study section**<br>2nd Semester | **LP**<br>5 | **Attendance rate**<br>35 h | **Self-study**<br>115 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Optimal Power Flow Problems (lecturer) | 08 XXXX | V | 2 |
| 2 | Optimal Power Flow Problems (tutorial) | 08 XXXX | Ü | 1 |

**2 Course language**

Englisch

**3 Lehrinhalte**

The problem of Optimal Power Flow (OPF) in power systems occurs in various formulations and variants in power engineering. In this context, the lecture offers an introduction to different aspects of OPF problems. The following topics are covered:

- Formulation of the OPF problem in AC
- Convex approximations of the OPF problem
- Stochastic formulations of the AC OPF problem
- Dynamic formulations of the OPF problem for transmission and distribution networks considering storage dynamics
- Distributed formulations of the OPF problem
- Outlook on approaches for the coupling of electric grids and gas grids

The solution will be tested practically with the help of standard software (e.g. Matpower or Pan-dapower, powermodels.jl).

**Literature**

Frank, Stephen, Ingrida Steponavice, and Steffen Rebennack. "Optimal power flow: a bibliographic survey I." Energy systems 3.3 (2012): 221-258.
Frank, Stephen, Ingrida Steponavice, and Steffen Rebennack. "Optimal power flow: a bibliographic survey II." Energy systems 3.3 (2012): 259-289.
Capitanescu, Florin. "Critical review of recent advances and further developments needed in AC optimal power flow." Electric Power Systems Research 136 (2016): 57-68.
Faulwasser, Timm, Alexander Engelmann, Tillmann Mühlpfordt, and Veit Hagenmeyer. "Optimal power flow: an introduction to predictive, distributed and stochastic control challenges." at-Automatisierungstechnik 66, no. 7 (2018): 573-589.

**4 Competencies**

After successful participation in the module, the students have basic knowledge of formulating and solving OPF problems. In particular, they are able to recognise the different types of OPF problems, formulate them and solve them with the help of suitable software tools.
Using practical examples, the students have also gained an insight into the diverse application possibilities of the OPF problem in energy technology.

**5 Exams**

*Partial achievements:*

- Written exam (90 minutes) or oral exam (max. 30 minutes)
- Project work accompanying the lecture with written report *

* The overall grade is formed from the arithmetic mean of the partial grades. The exact examination modalities will be announced by the 2nd course at the latest.

**6 Forms of examination and performance**

☐ Module Exam ☒ Partial achievements

| | | |
|---|---|---|
| **7** | **Participation requirements**<br>Recommended prerequisites: Prior knowledge of the fundamentals of electrical power engineering | |
| **8** | **Module type and usability of the module**<br>Elective Class in the Master's degree program Sustainable Energy Systems, *Energy Systems Cataloque*. | |
| **9** | **Module Supervisor**<br>Prof. Dr.-Ing. Timm Faulwasser | **Faculty in charge**<br>Faculty of Electrical Engineering and Information Technology |

| **Modul 3-33: Electric Drive Systems** | | | | | **ETIT-283** |
|---|---|---|---|---|---|
| **Turnus**<br>Annually at WS | **Duration**<br>1 Semester | **Study section**<br>3rd Semester | **LP**<br>5 | **Attendance rate**<br>35 h | **Self-study**<br>115 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **Nr.** | **Element / Course** | **LSF no.** | **Typ** | **SWS** |
| | 1 | Electric Drive Systems (lecture) | 08 0132 | V | 2 |
| | 2 | Electric Drive Systems (tutorial) | 08 0133 | Ü | 1 |
| | 3 | Electric Drive Systems (course lab) | 08 0134 | P | |
| 2 | **Course language**<br>Deutsch | | | | |
| 3 | **Teaching content**<br>1. Structure of electric drive systems<br>2. Principles and modeling of electrical machines<br>3. Variable speed operation and position sensing methods.<br>4. Drive inverters and modulation techniques<br><br>**Literature**<br>Krause: Analysis of Electric Machinery and Drive Systems, IEEE-Wiley Press | | | | |
| 4 | **Competencies**<br>After successful completion, students will be familiar with the essential properties of the electrical machines used in electric drive systems today and with their application in traction and industry. They are able to mathematically describe and design drive control systems consisting of electrical machines and drive inverters. They successfully apply the common methods for speed control including sensorless operation. | | | | |
| 5 | **Exams**<br>*Module Exam:* oral exam (max. 40 minutes) or written exam (max. 180 minutes) *<br>*Course achievements: Successful completion of the lab course attempt in part 3.*<br><br>* The exact examination modalities will be announced by the 2nd course at the latest.<br><br>The course work is a prerequisite for participation in the Module Exam. | | | | |
| 6 | **Forms of examination and performance**<br>☒ Module Exam ☐ Partial achievements | | | | |
| 7 | **Participation requirements**<br>Recommended prerequisites: Fundamentals of electrical machines. | | | | |
| 8 | **Module type and usability of the module**<br>Elective Class in the Master's degree program Sustainable Energy Systems, *Energy Systems Cataloque*. | | | | |
| 9 | **Module Supervisor**<br>Prof. Dr.-Ing. Martin Pfost | **Faculty in charge**<br>Faculty of Electrical Engineering and Information Technology | | | |

| Modul 3-39: Nonlinear Model Predictive Control – Theory and Applications | | | | | ETIT-297 |
|---|---|---|---|---|---|
| **Turnus**<br>Annually at WS | **Duration**<br>1 Semester | **Study section**<br>3rd Semester | **LP**<br>10 | **Attendance rate**<br>75 h | **Self-study**<br>225 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Nonlinear Model Predictive Control – Theory and Applications (lecture) | 08 0271 | V | 4 |
| 2 | Nonlinear Model Predictive Control – Theory and Applications (tutorial) | 08 0272 | Ü | 1 |
| 3 | Nonlinear Model Predictive Control – Theory and Applications (lab course) | 08 0273 | P | 1 |

**2 Course language**

Englisch

**3 Teaching content Elemente1**

Basics of optimal control theory and numerical optimal control
- Optimality condtions for static problems
- Formulation of optimal control problems
- Gateaux derivative
- Pontryagin Maximum Principle
- Indirect and direct solution methods
- Effiiziente derivative computation

Advanced aspects of optimal control
- Existence of optimal solutions
- Dual variables
- Singular problems
- Dissipativity and turnpike properties

Modell predictive control of sampled-data systems
- Basics of MPC
- Sufficient stability conditions with and without terminal constraints
- Economic cost functions
- Differences of continuous time and discrete time formulations
- Design and implementation aspects

Outlook
- Stochastic and robust MPC
- Limits of MPC

Case studies
- Energy efficiency in technical systems, multi-energy systems, and others

**Teaching content Elemente 2 und 3**
- Black board and programming sessions (ca 20h at home and ca 10h in course)

**Literature**

Chachuat, Benoit. *Nonlinear and dynamic optimization: From theory to practice*. Lecture Notes EPFL

**4 Competencies**

The students are able to formulate and to solve problems of operation and control of technical systems on their own. The students are able to understand and to analyze the interplay of problem formulation and efficiency aspects of numerical solutions and to deduce problem-specific formulations. They know how to apply and to implement optimization methods to practical problems. Furthermore, the students can tackle complex problems of predictive control by means of abstraction, they are able to document their results in written form.

The students are able to design predictive controllers for nonlinear systems and to validate them by means of simulation.

<table>
<tr><td>5</td><td colspan="2">Exams<br>Module Exam: oral exam (max. 40 minutes) **<br>Course achievements: Elaboration of a project (simulation and optimisation, effort approx. 50h) and documentation of the results in report form (approx. 20 pages DIN A4).*<br><br>** The exact examination modalities will be announced by the 2nd course at the latest.</td></tr>
<tr><td>6</td><td colspan="2">Prüfungsformen und -leistungen<br>☒ Module Exam ☐ Partial achievements</td></tr>
<tr><td>7</td><td colspan="2">Participation requirements<br>Necessary requirements:<br>• Basics of control engineering (state space description, LQR control, Lyapunov functions)<br>• Basics of ordinary differential equations<br>Recommended prerequisites:<br>• Basic of optimization, Multivariate Control and Optimal Control</td></tr>
<tr><td>8</td><td colspan="2">Module type and usability of the module<br>Elective Class in the Master's degree program Sustainable Energy Systems, Energy Systems Cataloque.</td></tr>
<tr><td>9</td><td>Module Supervisor<br>Prof. Dr.-Ing. Timm Faulwasser</td><td>Faculty in charge<br>Faculty of Electrical Engineering and Information Technology</td></tr>
</table>

**Modul 3-41: Machine Learning and optimal Control** **ETIT-502**

| Turnus | Duration | Study section | LP | Attendance rate | Self-study |
|---|---|---|---|---|---|
| Annually at WS | 1 Semester oder Block | 3rd Semester | 5 | 35 h | 115 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Machine Learning and optimal Control Vorlesung | 08 XXXX | V | 2 |
| 2 | Machine Learning and optimal Control Übung | 08 XXXX | Ü | 1 |

**2 Course language**

English

**3 Content**

Machine Learning (ML) is one of the key technologies of the 21st century; the applications of ML in technical and information technology systems are already ubiquitous. In this context, the lecture offers a system-theoretically and control-technically motivated introduction to different aspects of Machine Learning. Based on the fundamental distinction between unsupervised, supervised and self-reinforcing learning, the following topics are covered:

Reinforcement Learning (dt. selbstverstärkendes Lernen) und seine Verbindung zur optimalen Regelung (insbesondere Ansätze der Hamilton-Jacobi-Bellman-Gleichung und des Dynamic Programming) und zur modell-prädiktiven Regelung

- Reinforcement learning and its connection to optimal control (especially approaches of the Hamilton-Jacobi-Bellman equation and dynamic programming) and to model-predictive control.
- Formulation on discrete and continuous state spaces
- The formulation of supervised deep learning as an optimal control problem
- Data-driven approaches to model-predictive control for linear systems

The application of these ML approaches is formally analysed and practically tested with the help of standard software (e.g. Matlab or Python).

**Literature**

Bishop, C. M. Pattern recognition and machine learning. Springer, 2006.
In der Vorlesung zur Verfügung gestellte Forschungsarbeiten

**4 Competencies**

After successful participation in the module, the students have basic knowledge of machine learning methods and their use in control engineering application contexts. In particular, they are able to recognise the different types of learning problems, formulate them and solve them with the help of suitable software tools.
They are able to explain the fundamental relationships between optimal control and self-reinforcing learning. They are also able to formulate problems of supervised deep learning as optimal control.
With regard to the numerical solution, the students are familiar with basic algorithmic structures and procedures so that they can interpret and evaluate solutions from software tools. Using control engineering examples, the students have also gained an insight into the diverse application possibilities of machine learning.

**5 Exams**

*Partial achievements:*

- Written exam (90 minutes) or oral exam (max. 30 minutes) *

* The exact examination modalities will be announced by the 2nd course at the latest.

**6 Forms of examination and performance**

☒ Module Exam ☐ Partial achievements

| | | |
|---|---|---|
| 7 | **Participation requirements**<br>Recommended prerequisites: Previous knowledge of Fundamentals of Optimal Control (LQR) or numerical optimisation; state space representation and difference equations. | |
| 8 | **Module type and usability of the module**<br>Elective Class in the Master's degree program Sustainable Energy Systems, *Energy Systems Cataloque*. | |
| 9 | **Module Supervisor**<br>Prof. Dr.-Ing. Timm Faulwasser | **Faculty in charge**<br>Faculty of Electrical Engineering and Information Technology |

# Elective Classes

Elective Classes

A total of 25 credit points must be successfully acquired in the compulsory elective modules (according to the study plan for semesters 1, 2 and 3).
15 of the 25 credit points are to be selected from the Energy Systems catalogue.
10 credit points are freely selectable.

| Modul 2-14: 3D Computer Vision | | | | | ETIT-233 |
|---|---|---|---|---|---|
| **Turnus**<br>Annually at SS | **Duration**<br>1 Semester | **Study section**<br>2nd Semester | **LP**<br>5 | **Attendance rate**<br>35 h | **Self-study**<br>115 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | 3D Computer Vision (lecture) | 08 0259 | V | 2 |
| 2 | 3D Computer Vision (tutorial) | 08 0260 | Ü | 1 |

**2 Course language**

Englisch

**3 Teaching content**

1. modelling and calibration of camera systems
2. 3D reconstruction based on several camera images through bundle adjustment
3. determination of point correspondences
4. introduction to 3D reconstruction methods based on projective geometry
5. methods for 3D reconstruction of surfaces based on their reflective properties
6. practical application examples from current research

**Literature**

Horn: Robot Vision; Hartley/Zisserman: Multiple Viewpoint Geometry

**4 Competencies**

After successful completion of the module, the students master the essential basics of 3D image processing, photogrammetry and the linear and non-linear optimisation methods required for this. The students can classify tasks for systems for 3D scene reconstruction from different application areas and solve them independently with independently selected methods.

**5 Exams**

*Module Exam:* oral exam (max. 40 minutes) or written exam (max. 180 minutes) *

* The exact examination modalities will be announced by the 2nd course at the latest.

**6 Forms of examination and performance**

☒ Module Exam ☐ Partial achievements

**7 Participation requirements**

Recommended prerequisites: Good knowledge of linear algebra as well as linear and non-linear optimisation.

**8 Module type and usability of the module**

Elective Class in the Master's degree program Sustainable Energy Systems.

| **9** | **Module Supervisor** | **Faculty in charge** |
|---|---|---|
| | Prof. Dr. rer. nat. Christian Wöhler | Faculty of Electrical Engineering and Information Technology |

| Modul 2-16: Scheduling Problems and Solutions | | | | | ETIT-235 |
|---|---|---|---|---|---|
| **Turnus**<br>Annually at SS | **Duration**<br>1 Semester | **Study section**<br>2nd Semester | **LP**<br>10 | **Attendance rate**<br>80 h | **Self-study**<br>220 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Scheduling Problems and Solutions (lecture) | 08 0385 | V | 4 |
| 2 | Scheduling Problems and Solutions (tutorial) | 08 0386 | Ü | 2 |
| 3 | Scheduling Problems and Solutions (lab course) | 08 0387 | P | 1 |

**2 Course language**

Englisch

**3 Teaching content part 1 und 2**

1. Scheduling language and classes of schedules
2. Complexity
3. Single machine environments: makespan and total weighted completion time, lateness and tardy jobs, total tardiness and a non-regular objective function, a simple bicriterial problem
4. Online problems in single machine environments
5. Parallel machine environments: makespan, total weighted completion time, lateness, and online problems
6. Flow shop, job shop, and open shop problems

**Teaching content part 3:** Practical approaches to solve scheduling problems including the use of Matlab and CPLEX

**Literature**

Michael Pinedo: Scheduling - Theory, Algorithms and Systems, 4th edition, Springer Verlag, ISBN: 978-1-461-41986-0, 2012

**4 Competencies**

After successful completion, the students can classify scheduling problems and apply suitable methods for their processing. They are able to evaluate solution methods with regard to their efficiency and to develop new solution methods for complex scheduling problems on the basis of classical methods.

**5 Exams**

*Module Exam:* oral exam (max. 40 minutes) *
*Study achievements:* Successful completion of the course lab in part 3.
The course work is a prerequisite for participation in the Module Exam.

**6 Forms of examination and performance**

☒ Module Exam ☐ Partial achievements

**7 Participation requirements**

Recommended prerequisites: Good knowledge of fundamentals of discrete mathematics and fundamentals of algorithms.

**8 Module type and usability of the module**

Elective Class in the Master's degree program Sustainable Energy Systems.

**9**

| Module Supervisor | Faculty in charge |
|---|---|
| Prof. Dr.-Ing. Uwe Schwiegelshohn | Faculty of Electrical Engineering and Information Technology |

| **Modul 2-19: Local Networks – Communication and Control** | | | | | **ETIT-238** |
|---|---|---|---|---|---|
| **Turnus**<br>Annually at SS | **Duration**<br>1 Semester | **Study section**<br>2nd Semester | **LP**<br>5 | **Attendance rate**<br>35 h | **Self-study**<br>115 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Local Networks - Communication and Control (lecture) | 08 0802 | V | 2 |
| 2 | Local Networks - Communication and Control (tutorial) | 08 0803 | Ü | 1 |

**2 Course language**

Englisch

**3 Teaching content**

1. basics of networks: technical concepts and applications
2. system examples of wired networks: CAN bus, Ethernet, USB
3. system examples of wireless networks: WLAN, Bluetooth, Zigbee

**Literature**

Surgeon: Ethernet
Rech: Wireless LANs
Miller, Bisdikian: Bluetooth Revealed

**4 Competencies**

After successful completion, the students are able to evaluate the different concepts for local networks with regard to their performance, understand existing standards and build systems as well as assess current further developments of the technology.

**5 Exams**

*Module Exam:* oral exam (max. 40 minutes) or written exam (max. 180 minutes) *

* The exact examination modalities will be announced by the 2nd course at the latest.

**6 Forms of examination and performance**

☒ Module Exam ☐ Partial achievements

**7 Participation requirements**

None

**8 Module type and usability of the module**

Elective Class in the Master's degree program Sustainable Energy Systems.

**9**

| **Module Supervisor** | **Faculty in charge** |
|---|---|
| Prof. Dr.-Ing. Rüdiger Kays | Faculty of Electrical Engineering and Information Technology |

<table>
<tr><td colspan="6">Modul 3-20: Mobile Roboter</td><td>ETIT-269</td></tr>
<tr><td colspan="2">Turnus<br>Annually at SoSe</td><td>Duration<br>1 Semester</td><td>Study section<br>2nd Semester</td><td>LP<br>5</td><td>Attendance rate<br>50 h</td><td>Self-study<br>100 h</td></tr>
<tr><td>1</td><td colspan="6">Module structure<br>
<table>
<tr><td>Nr.</td><td>Element / Course</td><td>LSF no.</td><td>Typ</td><td>SWS</td></tr>
<tr><td>1</td><td>Mobile Roboter (lecture)</td><td>08 0154</td><td>V</td><td>2</td></tr>
<tr><td>2</td><td>Mobile Roboter (tutorial)</td><td>08 0155</td><td>Ü</td><td>2</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="6">Course language<br>Englisch</td></tr>
<tr><td>3</td><td colspan="6">Teaching content<br>
1. Robot Operating System (ROS)<br>
2. Robotics System Toolbox Matlab<br>
3. Sensors, actuators and kinematics of mobile robots<br>
4. Homing and trajectory following<br>
5. Obstacle avoidance (Vector Field Histograms)<br>
6. Localisation<br>
7. Path planning (Rapidly Exploring Random Trees, Probabilistic Roadmap)<br>
8. Navigation (Pure Pursuit, ROS Navigation Stack)<br>
9. Online trajectory optimization<br>
10. Mapping and SLAM<br><br>
Literature<br>
- Siciliano, Khatib: Springer Handbook of Robotics<br>
- ausgewählte Artikel zur mobilen Robotik aus Konferenzen und Zeitschriften</td></tr>
<tr><td>4</td><td colspan="6">Competencies<br>The students acquire a profound knowledge of fundamental concepts and practical experience on mobile robots. Students are able to solve mobile robotic tasks such as obstacle avoidance, navigation and localization in a self-dependent manner with selected methods and algorithms in ROS/Matlab.</td></tr>
<tr><td>5</td><td colspan="6">Exams<br>Module Exam: oral exam (max. 40 minutes) or written exam (max. 180 minutes) *<br>Study achievements:<br>
• Successful completion of at least 75% of the practical exercises in ROS/Matlab for programming mobile robots.<br><br>
The course work is a prerequisite for participation in the Module Exam.<br><br>
* The exact examination modalities will be announced by the 2nd course at the latest.</td></tr>
<tr><td>6</td><td colspan="6">Forms of examination and performance<br>☒ Module Exam ☐ Partial achievements</td></tr>
<tr><td>7</td><td colspan="6">Participation requirements<br>None</td></tr>
<tr><td>8</td><td colspan="6">Module type and usability of the module<br><u>Elective Class</u> in the Master's degree program Sustainable Energy Systems.</td></tr>
<tr><td>9</td><td colspan="3">Module Supervisor<br>apl. Prof. Dr. rer. nat. Frank Hoffmann</td><td colspan="3">Faculty in charge<br>Faculty of Electrical Engineering and Information Technology</td></tr>
</table>

**Modul 2-34: Remote Sensing** **ETIT-287**

| Turnus | Duration | Study section | LP | Attendance rate | Self-study |
|---|---|---|---|---|---|
| Annually at SS | 1 Semester | 2nd Semester | 5 | 35 h | 115 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Remote Sensing (lecture) | 08 0243 | V | 2 |
| 2 | Remote Sensing (tutorial) | 08 0244 | Ü | 1 |

**2 Course language** English

**3 Lehrinhalte**

1. sensor systems for taking aerial and satellite images
2. properties of aerial and satellite images in different spectral ranges
3. correction methods for atmospheric and topographic effects
4. methods for the analysis of image data in remote sensing applications
5. methods for the analysis of spectral data in remote sensing applications
6. orthorectification, georeferencing and coregistration of aerial and satellite imagery
7. classification methods for multi- and hyperspectral imagery data
8. practical application examples from current research

**Literature**

Schowengerdt, R.A.: Remote Sensing: Models and Methods for Image Processing. 3rd Edition, Academic Press, 2007.

**4 Competencies**

After successful completion of the module, the students master the essential basics of remote sensing as well as the signal and image processing methods required for this. The students can classify tasks for remote sensing systems from different application areas and solve them independently with independently selected methods.

**5 Exams**

*Module Exam:* oral exam (max. 40 minutes) or written exam (max. 180 minutes)*

* The exact examination modalities will be announced by the 2nd course at the latest.

**6 Forms of examination and performance**

☒ Module Exam ☐ Partial achievements

**7 Participation requirements**

Recommended knowledge: Sufficient knowledge in basics of electrical engineering, signal processing, image processing

**8 Module type and usability of the module**

Elective Class in the Master's degree program Sustainable Energy Systems.

**9 Module Supervisor**

Prof. Dr.rer.nat. Christian Wöhler

**Faculty in charge**

Faculty of Electrical Engineering and Information Technology

| **Modul 2-42: Hardware Software Codesign** | | | | | **ETIT-402** |
|---|---|---|---|---|---|
| **Turnus**<br>Annually at SS | **Duration**<br>1 Semester | **Study section**<br>2nd Semester | **LP**<br>10 | **Attendance rate**<br>70 h | **Self-study**<br>230 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Hardware Software Codesign (Lecture) | 08 0316 | V | 3 |
| 2 | Hardware Software Codesign (Tutorial) | 08 0317 | Ü | 1 |
| 3 | Hardware Software Codesign (Practical Exercise) | 08 XXXX | P | 2 |

**2 Course language**

English

**3 Teaching content**

1. Design of mixed Hadrware/Software solutions for embedded systems,
2. Understanding of design components
3. Understanding of system-level design paradigms,
4. HW/SW partitioning
5. Optimization methods
6. Performance analysis measures
7. Evaluation methods
8. Modeling and Performance analysis of safety-critical and real-time embedded systems.

**Literature**

[1] „Specification and Design of Embedded Systems", D. Gajski, Prentice Hall 1994, ISBN 0-13-150731-1

[2] „Digitale Hardware/Software Systeme – Synthese und Optimierung", J. Teich, Springer Verlag 1997, ISBN 3-540-62433-3

**4 Competencies**

By attending this course, students will learn the design of complex electronic systems at high level of abstractions. This includes the optimized partitioning, scheduling and evaluation of mixed hardware and software design solutions dedicated to embedded systems. During the Tutorials the students acquire knowledge about advanced related topics in HW/SW codesign and performance analysis for safety-critical and real-time embedded systems.

During the practical exercises to the lecture the students will apply the theoretical knowledge of the lecture considering real-world scenarios to allow a better accessibility to the methods explained. Starting from simple system specification the students will use tools for partitioning, optimization and performance analysis to synthesize the hardware/software system.

**5 Exams**

*Module Exam:* oral exam (max. 40 minutes) or written exam (max. 180 minutes)*

*Study achievements:*

- All students are required to successfully complete 2 out of 4 special assignments in order to be admitted to the final exam.
- All students are required to successfully complete the lab tasks.

* The exact examination modalities will be announced by the 2nd course at the latest.

**6 Prüfungsformen und -leistungen**

☒ Module Exam ☐ Partial achievements

**7 Participation requirements**

Recommended knowledge:

Basic knowledge of computer architectures, basic knowldge of C programming language.

**8 Module type and usability of the module**

Elective Class in the Master's degree program Sustainable Energy Systems .

**9**

| **Module Supervisor** | **Faculty in charge** |
|---|---|
| Prof. Dr.-Ing. Selma Saidi | Faculty of Electrical Engineering and Information Technology |

| Module 2-49: Mobile Radio Networks 1: Fundamentals and Design Aspects | | | | | ETIT-407 |
|---|---|---|---|---|---|
| **Rota**<br>anually SoSe | **Duration**<br>1 Semester | **Semester**<br>2nd | **Credits**<br>5 | **Presence**<br>35 h | **Self-Study Load**<br>115 h |

**1 Module Structure**

| No. | Element / Course | LSF-No. | Type | SWS |
|---|---|---|---|---|
| 1 | Mobile Radio Networks 1: Fundamentals and Design Aspects: Lecture | 08 0104 | V | 2 |
| 2 | Mobile Radio Networks 1: Fundamentals and Design Aspects: Lab Course | 08 0105 | P | 1 |

**2 Language**

English

**3 Content**

1. Market aspects and historical development of mobile communications
2. System aspects (characteristics of propagation, subscriber mobility, resource demand and spectrum allocation, network planning, protocols)
3. TDMA- und CDMA-based cellular networks (2G GSM/GPRS/EDGE, 3G UMTS/HSPA)
4. System architecture of OFDMA-based cellular networks (4G LTE)

The discussion of theoretical content is complemented by practical demonstrations and by case studies on ongoing research and business aspects of mobile radio networks.

**Literature** (respective latest version)

Walke, B.: Mobile Radio Networks, Wiley

Rappaport, Theodore S. Wireless communications: principles and practice. Prentice Hall.

Dahlmann, E.; Parkvall, S.; Sköld, J.: 4G: LTE/LTE-Advanced for Mobile Broadband, Academic Press

**4 Competencies**

After successful completion of the module, students understand the system architectures, protocols, dimensioning and operation of mobile radio networks. Students are able to evaluate the possibilities and challenges of using wireless networks in different deployment environments and fields of application, and to make a technically sound selection. In this way, they acquire the competence to attend more advanced courses or to study more advanced topics for themselves.

**5 Examination**

*Module exam: oral exam (max. 40 minutes) or written exam (max. 180 minutes)**

*Course work: successful completion of lab tasks*

*The exact examination modalities will be announced by the 2nd event at the latest.

**6 Forms of examination and performance**

☒ *Module exam* ☐ Part of modular exam

**7 Participation requirements**

None. Basic knowledge of digital communications and electromagnetic wave propagation is recommended.

**8 Module type and usability of the module**

Elective Class in the Master's degree program Sustainable Energy Systems.

**9**

| Module Supervisor | Faculty in charge |
|---|---|
| Prof. Dr.-Ing. Christian Wietfeld | Faculty of Electrical Engineering and Information Technology |

| **Module 2-50 Mobile Radio Networks 2: Advanced Network Concepts** | | | | | **ETIT-408** |
|---|---|---|---|---|---|
| **Rota**<br>anually SoSe | **Duration**<br>1 Semester | **Semester**<br>2nd | **Credits**<br>5 | **Presence**<br>35 h | **Self-Study Load**<br>115 h |

**1 Module Structure**

| No. | Element / Course | LSF-No. | Type | SWS |
|---|---|---|---|---|
| 1 | Mobile Radio Networks 2: Advanced Network Concepts: Lecture | XXX | V | 2 |
| 2 | Mobile Radio Networks 2: Advanced Network Concepts: Lab Course | XXX | P | 1 |

**2 Language**
English

**3 Content**

1. Local radio networks (WLAN/Wi-Fi, WPAN, Mesh, DECT)
2. Wireless Internet of Things networks (Low Power Wide Area Networks, Cellular-IoT)
3. Advanced features of 4G and 5G networks (Carrier Aggregation, Device-to-Device, Network Slicing, Beamforming, Ultra Reliable and Low Latency Communications)
4. Satellite networks, Aerial Wireless Networks
5. Future mobile network concepts for 5G-Advanced and 6G (e.g. mmWave/THz spectrum, Reflective Intelligent Surfaces, Integration of Artificial Intelligence)

The discussion of theoretical content is complemented by practical demonstrations and by case studies on ongoing research and business aspects of mobile radio networks.

**Literature** (respective latest version)
Liberg, Olof, et al. Cellular Internet of Things: From Massive Deployments to Critical 5G Applications. Academic Press, 2019.
Dahlmann, E.; Parkvall, S.; Sköld, J.: 4G: LTE/LTE-Advanced for Mobile Broadband, Academic Press
P. Marsch, A. Osseiran, J.F. Monserrat, 5G Mobile and Wireless Communications Technology, Cambridge University Press

**4 Competencies**
Upon successful completion of the module, students understand advanced and upcoming mobile radio network concepts and terminology which enables them to characterize research-related challenges of integrating the considered features, assess the feasibility, and to develop design solutions according to design goals. Students further deepen their knowledge base on specific network designs for particular fields of application, and to make a technically sound selection.

**5 Examination**
*Module exam:* oral exam (max. 40 minutes) or written exam (max. 180 minutes)*
*Course work: successful completion of lab tasks*
*The exact examination modalities will be announced by the 2nd event at the latest.

**6 Forms of examination and performance**
☒ *Module exam* ☐ Part of modular exam

**7 Participation requirements**
None. Basic knowledge of mobile radio networks is recommended.

**8 Module type and usability of the module**
Elective Class in the Master's degree program Sustainable Energy Systems.

| 9 | **Module Supervisor** | **Faculty in charge** |
|---|---|---|
| | Prof. Dr.-Ing. Christian Wietfeld | Faculty of Electrical Engineering and Information Technology |

| Modul 2-51: Embedded Autonomy | | | | | ETIT-409 |
|---|---|---|---|---|---|
| **Turnus**<br>anually SoSe | **Duration**<br>1 Semester | **Study section**<br>2nd Semester | **LP**<br>10 | **Attendance rate**<br>70 h | **Self-study**<br>230 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Embedded Autonomy (lecture) | 08 XXXX | V | 3 |
| 2 | Embedded Autonomy (tutorial) | 08 XXXX | Ü | 1 |
| 3 | Embedded Autonomy (lab course) | 08 XXXX | P | 2 |

**2 Course language**

English

**3 Teaching Content**

- Requirements on functional safety
- Providing and preserving trustworthiness in Autonomous Systems
- System Architectures and Platforms for Autonomous Systems
- Verification of Autonomous Systems

**Literature**

Christopher Rouff. “Autonomous and Autonomic Systems: With Applications to NASA Intelligent Spacecraft Operations and Exploration Systems” (NASA Monographs in Systems and Software Engineering). Springer-Verlag, Berlin, Heidelberg, 2007.
Samuel Kounev, Jeffrey O. Kephart, Aleksandar Milenkoski, and Xiaoyun Zhu. „Self-Aware Computing Systems”. Springer Publishing Company, Incorporated, 1st edition, 2017.
Defense Advanced Research Projects Agency (DARPA). Broad Agency Announcement - Assured Autonomy, August 2017
Selma Saidi, Dirk Ziegenbein, Jyotirmoy V. Deshmukh, Rolf Ernst: : “Autonomous Systems Design: Charting a New Discipline”, IEEE Design and Test Magazine 2021.

**4 Competencies**

With the successful participation in the module, students will gain basic knowledge in the platforms used in autonomous systems as well as very recent fields required to the design of safe autonomous systems considering functional and non-functional aspects (e.g., safety, reliability).
During the practical exercises to the lecture the students will learn to implement simple autonomous systems tasks (Sensor fusion and AI computation which pose special demands on the architectures in order to implement the Percieve - Decide - Act loop) on embedded platforms. The students will be able to balance the performance limitations of the platform against the complexity of tasks and therefore find an optimal utilization of the resources.

**5 Exams**

*Partial achievements:*

1. Oral exam (30 minutes) or written exam (90 minutes) and
2. project work with written report *
3. Successful participation part 3

* The overall grade is formed from the arithmetic mean of the sub-grades of sub-performance 1 and 2.
The exact examination modalities will be announced by the 2nd event at the latest.

**6 Forms of examination and performance**

☐ Module Exam ☒ Partial achievements

| | | |
|---|---|---|
| 7 | **Participation requirements**<br>None | |
| 8 | **Module type and usability of the module**<br>Elective Class in the Master's degree program Sustainable Energy Systems. | |
| 9 | **Module Supervisor**<br>Prof. Dr.-Ing. Selma Saidi | **Faculty in charge**<br>Faculty of Electrical Engineering and Information Technology |

| Modul 3-35: Online Problems | | | | | ETIT-292 |
|---|---|---|---|---|---|
| **Turnus**<br>Annually at WS | **Duration**<br>1 Semester | **Study section**<br>3rd Semester | **LP**<br>5 | **Attendance rate**<br>35 h | **Self-study**<br>115h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Online Problems (lecture) | 08 0142 | V | 2 |
| 2 | Online Problems (tutorial) | 08 0143 | Ü | 1 |

**2 Course language**

English

**3 Teaching content**

1. Competitive Analysis
2. Randomized Algorithms
3. Deterministic Algorithms
4. Game-Theoretic Foundations
5. Request-Answer Games

**Literature**

Allan Borodin, Ran El-Yaniv, ONLINE COMPUTATION AND COMPETITIVE ANALYSIS. Cambridge University Press

**4 Competencies**

After successful completion, the students can recognise online problems and apply suitable procedures for their processing. They are able to evaluate solution methods with regard to their efficiency and complexity and to develop new solution methods for online problems on the basis of the methods they have learned.

**5 Exams**

*Module Exam:* oral exam (max. 40 minutes)

**6 Forms of examination and performance**

☒ Module Exam ☐ Partial achievements

**7 Participation requirements**

Recommended prerequisites: Good knowledge of fundamentals of discrete mathematics and fundamentals of algorithms.

**8 Module type and usability of the module**

Elective Class in the Master's degree program Sustainable Energy Systems.

| 9 | Modul Supervisor | Faculty in charge |
|---|---|---|
| | Prof. Dr.-Ing. Uwe Schwiegelshohn | Faculty of Electrical Engineering and Information Technology |

## Modul 2-25: Modeling and Control of Robotic Manipulators ETIT-244

| Turnus | Duration | Study section | LP | Attendance rate | Self-study |
|---|---|---|---|---|---|
| Annually at WS | 1 Semester | 3. Semester | 5 | 35 h | 115 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Modeling and Control of Robotic Manipulators (lecture) | 08 0125 | V | 2 |
| 2 | Modeling and Control of Robotic Manipulators (tutorial) | 08 0126 | Ü | 1 |

**2 Course language**

Englisch

**3 Lehrinhalte**

1. Spatial Representations
2. Direct Kinematics
3. Differential Kinematics
4. Dynamics
5. Actuators and Sensors
6. Motion Control
7. Interaction Control
8. Robotics System Toolbox and ROS

**Literature**

Siciliano, Sciavicco: Robotics: Modelling, Planning and Control (alternativ: Sciavicco, Siciliano: Modelling and Control of Robot Manipulators)
Siciliano, Khatib: Springer Handbook of Robotics

**4 Competencies**

This course provides the students with a profound background of modelling, planning and control of robotic manipulators.
The students acquire practical experience in robot kinematics, dynamics and motion control under ROS/Matlab.

**5 Exams**

*Module Exam:* oral exam (max. 40 minutes) or written exam (max. 180 minutes)*

* The exact examination modalities will be announced by the 2nd event at the latest.

**6 Forms of examination and performance**

☒ Module Exam ☐ Partial achievements

**7 Participation requirements**

Keine

**8 Module type and usability of the module**

Elective Class in the Master's degree program Sustainable Energy Systems .

| 9 | Module Supervisor | Faculty in charge |
|---|---|---|
| | apl. Prof. Dr. rer. nat. Frank Hoffmann | Faculty of Electrical Engineering and Information Technology |

## Modul 3-43: Automated Driving — ETIT-504

| Turnus | Duration | Study section | LP | Attendance rate | Self-study |
|---|---|---|---|---|---|
| Annually at WS | 1 Semester | 3rd Semester | 5 | 35 h | 115 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Automated Driving (lecture) | 08 0215 | V | 2 |
| 2 | Automated Driving (tutorial) | 08 0216 | Ü | 1 |

**2 Course language**

English

**3 Lehrinhalte**

1. Exteroceptive sensors (camera, radar, lidar, ultrasonic, sensor fusion)
2. Conidtional, highly, and fully automated driving:
   a. Situation analysis and interaction-aware trajectory prediction
   b. Trajectory planning and coupled prediction and planning
   c. Control concepts to follow a planned trajectory
3. Machine learning in automated driving
4. Driver monitoring and hand-over models

**Literature:**

I. Goodfellow, Y. Bengio, A. Courville: Deep Learning (MIT Press)
D. Forsyth, J. Ponce (Ed.): Computer Vision: A Modern Approach (Prentice Hall)
selected papers on automated driving, robotics, and deep learning

**4 Competencies**

The students acquire a profound knowledge of automated driving systems. They are able to understand and solve tasks on perception, prediction, planning, control, and driver modelling with appropriate methods.

**5 Exams**

*Module Exam:* oral exam (max. 40 minutes) or written exam (max. 180 minutes)*

* The exact examination modalities will be announced by the 2nd event at the latest.

**6 Prüfungsformen und -leistungen**

☒ Module Exam ☐ Partial achievements

**7 Participation requirements**

Recommended prerequisites: Basic knowledge of mechatronics, mechanics

**8 Module type and usability of the module**

Elective Class in the Master's degree program Sustainable Energy Systems.

**9**

| Module Supervisor | Faculty in charge |
|---|---|
| Prof. Dr.-Ing. Prof. h.c. Dr. h.c. Torsten Bertram | Faculty of Electrical Engineering and Information Technology |

| **Modul 3-45: Mobile and Pervasive Computing** | | | | | **ETIT-506** |
|---|---|---|---|---|---|
| **Turnus**<br>Annually in winter semester | **Duration**<br>1 Semester | **Study section**<br>3rd Semester | **LP**<br>6 | **Attendance rate**<br>50 h | **Self-study**<br>130 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Mobile and Pervasive Computing Lecture | 08 xxxx | V | 2 |
| 2 | Mobile and Pervasive Computing Presentations | 08 xxxx | Ü | 2 |

**2 Course language**

Englisch

**3 Teaching content**

As advanced sensing and communication technologies have been rapidly developed, mobile and pervasive computing technologies have been paid a lot of attention to enable intelligent services in our daily life. These services provide new insights into unstructured and uncertain information from a variety of data sources in sensor-rich environments and mobile devices. The lecture covers theoretical fundamentals in sensing and computing techniques, how to apply them in practical systems, and design principles in mobile and pervasive computing techniques. The content includes the following topics:

- Wireless perception and computing: active and passive wireless sensing techniques, wireless-based localization, wireless-based mobility analytics, wireless-based activity recognition, and applications based on wireless signals.
- Visual & acoustic perception and computing technologies: Visual-based and acoustic-based localization, image registration, and mobility analytics based on visual and acoustic information.
- Mobile sensing and computing: mobile crowdsourcing in smart cities, privacy-preserving sensing techniques for mobile devices, multi-modal data fusion techniques based on smart devices.
- Edge computing and software-defined computing framework: computation task offloading techniques for low-latency and real-time services, service-oriented/user-centric dynamic computing flows among mobile devices, edge devices, and Cloud.

**Literature**

Books:

- Minyi Guo, Jingyu Zhou, Feilong Tang, and Yao Shen, "Pervasive Computing: Concepts, Technologies and Applications", Published by CRC Press, 2020.
- Mohammad S. Obaidat, Mieso Denko, and Isaac Woungang, “Pervasive Computing and Networking”, published by Wiley, 2011.
- Sherali Zeadally (Editor), Nafaâ Jabeur (Editor), "Cyber-Physical System Design with Sensor Networking Technologies", IET Press in London, England, 2015.

Research papers published in areas of mobile computing, pervasive computing, and communication networking e.g. IEEE Percom, IEEE trans. on Mobile Computing, IEEE ICC/WCNC/Globecom/VTC, and ACM/IEEE IPSN.

Slides of all lectures will be available online.

**4 Competencies**

The goal of the lecture is to establish knowledge of the fundamentals, advanced techniques of mobile and pervasive computing. After completing the lecture, students can independently design innovative pervasive computing systems on mobile and smart platforms, decompose dependency between computation modules and software required by applications, and optimize usage of sensing and computing resources in mobile computing systems.

**5 Exams**

*Module Exam:* The final exam is an oral exam (30 minutes).

*Study achievements:* All students need to successfully pass 50% of assignments to be admitted to the final exam. *

*All dates will be published two weeks after the start of the lecture at the very latest.

**6 Forms of examination and performance**

☒ Module Exam ☐ Partial achievements

<table>
<tr><td>7</td><td colspan="2">Participation requirements<br>Recommendations (helpful but not mandatory): knowledge in foundations of algorithms and wireless communications.</td></tr>
<tr><td>8</td><td colspan="2">Module type and usability of the module<br><u>Elective Class</u> in the Master's degree program Sustainable Energy Systems.</td></tr>
<tr><td>9</td><td>Module Supervisor<br>Jun.-Prof. Dr.-Fang-Jing Wu</td><td>Faculty in charge<br>Faculty of Electrical Engineering and Information Technology</td></tr>
</table>

# 3rd Semester

<table>
<tr><td colspan="6">Industrial Internship</td><td colspan="2">ETIT-282</td></tr>
<tr><td colspan="2">Turnus<br>none</td><td colspan="2">Duration<br>12 weeks</td><td colspan="2">Study section<br>3rd Semester</td><td>LP<br>14</td><td>Aufwand<br>12 weeks</td></tr>
<tr><td rowspan="3">1</td><td colspan="7">Module structure</td></tr>
<tr><td>Nr.</td><td colspan="3">Element / Course</td><td>Typ</td><td>Credits</td><td>Time hours</td></tr>
<tr><td>1</td><td colspan="3">Industrial Internship</td><td>P</td><td>14</td><td>420</td></tr>
<tr><td>2</td><td colspan="7">Course language<br>Englisch</td></tr>
<tr><td>3</td><td colspan="7">Teaching Content<br>The industrial internship takes place in the following areas:<br>• Research and development,<br>• Project planning, design, manufacture, assembly, testing and commissioning,<br>• Operation and maintenance,<br>• Marketing, sales, operational organisation, management and training<br>The Internship Office of the Department of Electrical Engineering and Information Technology advises each student on the selection of an internship company and the implementation of the internship. The advice and support includes, in particular, the curricular fit of the internship area offered by the internship company with the student's chosen major. The professional assessment and evaluation of the industrial internship is carried out for each student by a university lecturer of the faculty.</td></tr>
<tr><td>4</td><td colspan="7">Competencies<br>After successful completion of the industrial internship, the students have an insight into the operational processes and organisation in industry as well as into the social structures of companies. Furthermore, they know typical engineering tasks in research and development and/or in production and operation. Finally, they have knowledge of practical procedures in industrial production and/or the use of modern technologies in electrical power engineering.</td></tr>
<tr><td>5</td><td colspan="7">Exams<br>A report book must be prepared on the internship. The evaluation of success and performance is based on the submitted reports (submitted electronically as PDF) and the internship certificate of the company.</td></tr>
<tr><td>6</td><td colspan="7">Forms of examination and performance<br>☐ Module Exam ☐ Partial achievements</td></tr>
<tr><td>7</td><td colspan="7">Participation requirements<br>Recommended knowledge: Knowledge to perform engineering related activities</td></tr>
<tr><td>8</td><td colspan="7">Module type and usability of the module<br>Industrial internship in the Master's degree programme "Sustainable Energy Systems"</td></tr>
<tr><td>9</td><td colspan="3">Module Supervisor<br>Prof. Dr.-Ing. Christian Rehtanz</td><td colspan="4">Faculty in charge<br>Faculty of Electrical Engineering and Information Technology</td></tr>
</table>

<table>
<tr><td colspan="7">Lab Course</td><td colspan="2">ETIT-20P</td></tr>
<tr><td colspan="2">Turnus<br>Half-yearly</td><td>Duration<br>1 Semester each</td><td colspan="2">Study section<br>4th / 5th Semester</td><td>LP<br>6</td><td>Attendance rate<br>90 h</td><td colspan="2">Self-study<br>90 h</td></tr>
<tr><td>1</td><td colspan="8">Module structure<br>
<table>
<tr><td>Nr.</td><td>Element / Course</td><td>LSF no.</td><td>Typ</td><td>CP</td><td>Time hours</td></tr>
<tr><td>1</td><td>Lab Course 1</td><td></td><td>P</td><td>3</td><td>45</td></tr>
<tr><td>2</td><td>Lab Course 2</td><td></td><td>P</td><td>3</td><td>45</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="8">Course language<br>English</td></tr>
<tr><td>3</td><td colspan="8">Lehrinhalte<br>The students complete 2 compulsory elective internships from the range of courses offered by the faculty. If internships with a total of 6 LP are available, only one internship is to be completed.<br>The exact descriptions and information on the internships can be found in the following internship descriptions 1-18 or on the Internet.</td></tr>
<tr><td>4</td><td colspan="8">Competencies<br>After successful completion of the course, students are able to<br>discuss different perspectives on an engineering problem and explain their own views.<br>and to explain their own views. The students are able to structure larger tasks during a group work phase and to derive meaningful work packages. Furthermore, the students understand the methodological approaches and procedures in the context of scientific work in engineering and can apply these to different problems.</td></tr>
<tr><td>5</td><td colspan="8">Exams<br>The examination requirements are deposited in the respective internship descriptions.</td></tr>
<tr><td>6</td><td colspan="8">Forms of examination and performance<br>☐ Module Exam ☒ Partial achievements</td></tr>
<tr><td>7</td><td colspan="8">Participation requirements<br>The participation requirements are listed in the respective internship descriptions.<br>The number of participants is limited. Admission to participation is in accordance with § 9 of the examination regulations.</td></tr>
<tr><td>8</td><td colspan="8">Module type and usability of the module<br>c</td></tr>
<tr><td>9</td><td colspan="3">Module Supervisor<br>Dean of the Faculty of Electrical Engineering and Information Technology</td><td colspan="5">Faculty in charge<br>Faculty of Electrical Engineering and Information Technology</td></tr>
</table>

| LAB 1: Field theoretical simulation | | | | | ETIT-211 |
|---|---|---|---|---|---|
| **Turnus**<br>Annually at WS | **Duration**<br>2 Weeks<br>(Block event) | **Study section**<br>3rd Semester | **LP**<br>3 | **Attendance rate**<br>60 h | **Self-study**<br>30 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | Zeitstunden |
|---|---|---|---|---|
| 1 | Lab | 08 0023 | P | 90 |

**2 Course language**

English

**3 Teaching Content**

1. introduction to the functioning and procedure of numerical field calculation programmes.
2. theory of the numerical methods of field calculation on which the programmes are based
3. transferring electrical engineering problems into suitable calculation models
4. utilisation of symmetry properties, special features of discretisation (calculation accuracy/ duration), types of boundary conditions and degrees of freedom
5. simulation and calculation of selected problems (two-dimensional, rotationally symmetrical) for time-dependent and independent fields, respectively.
6. functional verification and comparison of numerical solutions with analytical calculation results (if possible)
7. export of obtained simulation results for further numerical and graphical processin

**Literature**

Kost: Numerische Methoden in der Berechnung elektromagnetischer Felder

**4 Competencies**

After successful completion of the practical course, the students have acquired basic knowledge about the possibilities and limitations of field calculation programs. They are able to transfer real field-theoretical problems into a calculable arrangement. They also have knowledge that enables them to reduce the computational effort to a necessary level through suitable measures and to assess the quality of a simulation result obtained in this way.

**5 Exams**

Successful completion of 70% of the internship tasks

**6 Forms of examination and performance**

☐ Module Exam ☒ Partial achievements

**7 Participation requirements**

Recommended prerequisites: Knowledge of the basics of
Electrical Engineering, Basic Mathematical Knowledge of Numerical Calculation.
The number of participants is limited. Admission to participation is in accordance with § 9 of the examination regulations.

**8 Module type and usability of the module**

Elective Lab in the Master's degree program Sustainable Energy Systems.

**9**

| Module Supervisor | Faculty in charge |
|---|---|
| Prof. Dr.-Ing. Frank Jenau | Faculty of Electrical Engineering and Information Technology |

| **LAB 2: Simulative performance evaluation of communication networks** | | | | | **ETIT-214** |
|---|---|---|---|---|---|
| **Turnus**<br>Annually at WS | **Duration**<br>2 weeks<br>(block event) | **Study section**<br>3rd Semester | **CP**<br>3 | **Attendance rate**<br>48 h | **Self-study**<br>42 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | Zeitstunden |
|---|---|---|---|---|
| 1 | Lab | 08 0138 | P | 90 |

**2 Course language**

English

**3 Teaching Content**

1. develop the required basics of OMNeT++
   a. Simulation setup
   b. Module and simulation definition/declaration
   c. Simulation of simple communication networks
2. modelling of system properties
   a. Modelling of communication protocols (ISO/OSI)
   b. Consideration of mobility aspects on OMNeT++
   c. Modelling and consideration of communication channel properties
   d. Implementation of complete system scenarios
3. evaluation and optimisation of complex communication systems
   a. Simulation of dynamic communication networks
   b. Tools for statistical analysis
   c. Validation of obtained results

**Literature**

Peterson, Davie: Computer Networks, 4th Edition;
Sinclair: Simulation of Computer Systems and Computer Networks

**A Competencies**

After successful completion of the practical course, the students have a sound knowledge of the performance evaluation and dimensioning of communication systems by means of event-driven simulation. In addition to the actual functions of the OMNeT++ simulation environment, this also includes the implementation and highly accurate simulative realisation of protocol-based processes in communication systems. The graduates of this practical course will be able to abstract even complex networking scenarios and map them realistically in the OMNeT++ simulation environment. Furthermore, the results obtained in this way can be processed accordingly and used for performance evaluation or optimisation based on aspects relevant to communication technology.

**5 Exams**

Successful completion of at least 80% of the tasks set.

**6 Forms of examination and performance**

☐ Module Exam ☒ Partial achievements

**7 Participation requirements**

The number of participants is limited. Admission to participation is in accordance with § 9 of the examination regulations.

**8 Module type and usability of the module**

Elective Lab in the Master's degree program Sustainable Energy Systems.

**9**

| **Module Supervisor** | **Faculty in charge** |
|---|---|
| Prof. Dr.-Ing. Christian Wietfeld | Faculty of Electrical Engineering and Information Technology |

<table>
<tr><th colspan="4">LAB 3: Simulation and control of robot systems</th><th colspan="3">ETIT-216</th></tr>
<tr><td colspan="2">Turnus<br>Annually at WS</td><td>Duration<br>1 Semester</td><td>Study section<br>3rd Semester</td><td>LP<br>3</td><td>Attendance rate<br>48 h</td><td>Self-study<br>42 h</td></tr>
<tr><td rowspan="3">1</td><td colspan="6">Module structure</td></tr>
<tr><td>Nr.</td><td colspan="2">Element / Course</td><td colspan="2">LSF no.</td><td>Typ | SWS</td></tr>
<tr><td>1</td><td colspan="2">Lab</td><td colspan="2">08 0022</td><td>P | 4</td></tr>
<tr><td>2</td><td colspan="6">Course language<br>English</td></tr>
<tr><td>3</td><td colspan="6">Teaching Content<br>1. basic competence: Matlab, Simulink, Robotic Toolbox, Virtual Reality<br>2. attempt: Modelling, kinematics and dynamics<br>3. experiment: path planning and control<br>4. experiment: image-based control<br>Literature<br>Bode: Systeme der Regelungstechnik mit MATLAB und Simulink;<br>Angermann, Beuschel, Rau, Wohlfarth: Matlab – Simulink – Stateflow: Grundlagen, Toolboxen, Beispiele;<br>Siciliano, Sciavicco, Villani, Oriolo: Robotics – Modelling, Planning and Control;</td></tr>
<tr><td>4</td><td colspan="6">Competencies<br>After successful completion of the practical course, the students master the essential practical basics and methods for modelling and simulating robotic systems. The students are able to classify tasks in robotics and solve them independently; they have in-depth knowledge of the control and regulation of robotic manipulators through practical application.</td></tr>
<tr><td>5</td><td colspan="6">Exams<br>The supervisor checks the completion of all subtasks and the protocol during the event.</td></tr>
<tr><td>6</td><td colspan="6">Forms of examination and performance<br>☐ Module Exam ☒ Partial achievements</td></tr>
<tr><td>7</td><td colspan="6">Participation requirements<br>The number of participants is limited. Admission to participation is in accordance with § 9 of the examination regulations.</td></tr>
<tr><td>8</td><td colspan="6">Module type and usability of the module<br>Elective Lab in the Master's degree program Sustainable Energy Systems.</td></tr>
<tr><td>9</td><td colspan="3">Module Supervisor<br>Prof. Dr.-Ing. Prof. h.c. Dr. h.c. Torsten Bertram</td><td colspan="3">Faculty in charge<br>Faculty of Electrical Engineering and Information Technology</td></tr>
</table>

<table>
<tr><td colspan="6">LAB 4: Programming Reconfigurable Hardware</td><td colspan="2">ETIT-350</td></tr>
<tr><td colspan="2">Turnus<br>Annually at WS</td><td>Duration<br>1 Semester</td><td>Study section<br>3rd Semester</td><td>LP<br>3</td><td>Attendance rate<br>45 h</td><td colspan="2">Self-study<br>45 h</td></tr>
<tr><td rowspan="3">1</td><td colspan="7">Module structure</td></tr>
<tr><td>Nr.</td><td colspan="2">Element / Course</td><td colspan="2">LSF no.</td><td>Typ</td><td>SWS</td></tr>
<tr><td>1</td><td colspan="2">Lab</td><td colspan="2">080333</td><td>P</td><td>4</td></tr>
<tr><td>2</td><td colspan="7">Course language<br>Englisch</td></tr>
<tr><td>3</td><td colspan="7">Teaching Content<br>- Design of Hardware Circuit and Logics on FPGAs<br>- Usage of Design and EDA Tools<br>- Practical working with FPGA Plattforms<br>- VHDL Programming<br><br>Literature<br>[1] „ Digital Electronics with DIGILENT BASYS 2 & 3 FPGA Boards “, Andrzej J. Gapinski, Lap Lambert Academic Publishing, 2018, ISBN 9786139929764</td></tr>
<tr><td>4</td><td colspan="7">Competencies<br>By attending this course, students will learn how to work with current FPGA Architectures and Boards. The fundamentals in the usage of tools and programming VHDL will be shown.<br>In multiple practical lessons, VHDL and Xilinx Vivado will be used to implement hardware designs for different tasks. The students will implement practical exercises on a Basys3 Development Board with an Artix 7 FPGA.</td></tr>
<tr><td>5</td><td colspan="7">Exams<br>Successful completion of 70% of the internship tasks</td></tr>
<tr><td>6</td><td colspan="7">Forms of examination and performance<br>☐ Module Exam ☒ Partial achievements</td></tr>
<tr><td>7</td><td colspan="7">Participation requirements<br>Recommended prerequisite:<br>Basic knowledge of computer architectures,<br>Basic knowledge of VHDL programming<br><br>The number of participants is limited. Admission to participation is in accordance with § 9 of the examination regulations.</td></tr>
<tr><td>8</td><td colspan="7">Module type and usability of the module<br>Elective Lab in the Master's degree program Sustainable Energy Systems.</td></tr>
<tr><td>9</td><td colspan="3">Module Supervisor<br>Prof. Dr.-Ing. Selma Saidi</td><td colspan="4">Faculty in charge<br>Faculty of Electrical Engineering and Information Technology</td></tr>
</table>

<table>
<tr><td colspan="6">LAB 5: Control system operation for electrical power grids ETIT-351</td></tr>
<tr><td>Turnus<br>Annually at SoSe</td><td>Duration<br>1 Semester</td><td>Study section<br>3rd Semester</td><td>LP<br>3</td><td>Attendance rate<br>45 h</td><td>Self-study<br>45 h</td></tr>
</table>

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **Nr.** | **Element / Course** | **LSF no.** | **Typ** | **SWS** |
| | 1 | Lab | 08XXXX | P | 4 |

**2 Course language**

English

**3** Control systems are the man-machine interface between the electrical energy transmission system and the actions necessary to keep the system stable and safe throughout the day. Uncertainties due to grid users and volatile renewable energies as well as disturbances in the grid and generation must be monitored and handled appropriately.

**Teaching Content**

1. introduction to the control centre operation of electrical transmission networks
2. operation of a realistic control system
3. carrying out network operation management for regular operating situations on the control centre simulator
4. carrying out network operations for disturbed operating situations on the control centre simulator

**Literature**

Kundur: Power System Stability and Control

**4 Competencies**

After successful completion of the practical course, the students have acquired basic knowledge of control system operation for electrical power grids. They are able to guide a power grid through various normal and disturbed operating situations on the control centre simulator. This creates a deep understanding of the real control system in practice.

Today's possibilities are taught during the practical course using a realistic control system with which the grid operation management personnel are also trained for practice and tried out using operating situations.

**5 Exams**

Completion of all subtasks and preparation of a protocol.

**6 Forms of examination and performance**

☐ Module Exam ☒ Partial achievements

**7 Participation requirements**

Recommended prerequisites: Knowledge of the basics of electrical power engineering, knowledge of information systems for grid operation management.

The number of participants is limited. Admission to participation is in accordance with § 9 of the examination regulations.

**8 Module type and usability of the module**

Elective Lab in the Master's degree program Sustainable Energy Systems.

| | | |
|---|---|---|
| 9 | **Module Supervisor**<br>Dr.-Ing. Ulf Häger | **Faculty in charge**<br>Faculty of Electrical Engineering and Information Technology |

| **LAB 6: High Performance Computing in Python** | | | | | **ETIT-354** |
|---|---|---|---|---|---|
| **Turnus**<br>annually WiSe | **Duration**<br>2 weeks<br>(block event) | **Study section**<br>1st semester | **LP**<br>3 | **Attendance rate**<br>48 h | **Self-study**<br>42 h |

| | | | | | |
|---|---|---|---|---|---|
| 1 | **Module structure** | | | | |
| | **Nr.** | **Element / Course** | **LSF no.** | **Typ** | **Zeitstunden** |
| | 1 | Lab | 08 XXXX | P | 90 |
| 2 | **Course language**<br>English | | | | |
| 3 | **Lehrinhalte**<br>1. Concepts for evaluating the performance of implemented algorithms (Profiling)<br>2. Computational efficient algorithms and application of multiprocessing for speed improvement<br>3. Distributed programming for clusters or networked computers utilizing Pyro<br>4. Connection of existing system via the application of Numba, PyPy, f2py<br>5. NumPy for fast computations<br>6. Cython for speed improvements<br>7. Speeding up an existing loop using OpenMP by building modules for parallelization<br>8. Examplary implementation and evaluation of an algorithm for the design of quantum devices<br><br>**Literature**<br>Gorelick, Ozswald: High Performance Python | | | | |
| 4 | **Competencies**<br>Students gain practical knowledge of developing procedures for the implementation of high performance computing algorithms. They learn about the practical behavior and how the performance characteristics of high performance computing systems can be evaluated as well as what the limits of a hardware-oriented simulation are. Furthermore, students will have gained the essentials of the open-source software framework Python for the realization of high performance computing in engineering applications. They will be able to speed up algorithms for fast computation. | | | | |
| 5 | **Exams**<br>The Supervisor checks the completion and the reports of all subtasks during the course. | | | | |
| 6 | Forms of examination and performance<br>☐ Module Exam ☒ Partial achievements | | | | |
| 7 | **Participation requirements**<br>Basic knowledge in programming.<br>The number of participants is limited. Admission to participation is in accordance with § 9 of the examination regulations. | | | | |
| 8 | **Module type and usability of the module**<br>Elective Lab in the Master's degree program Sustainable Energy Systems. | | | | |
| 9 | **Module Supervisor**<br>apl. Prof. Dr.-Ing. Dirk Schulz | **Faculty in charge**<br>Faculty of Electrical Engineering and Information Technology | | | |

| **Seminar Scientific Work** | | | | | **ETIT-281** |
|---|---|---|---|---|---|
| **Turnus**<br>Half-yearly | **Duration**<br>1 Semester | **Study section**<br>3rd Semester | **LP**<br>5 | **Attendance rate**<br>25 h | **Self-study**<br>65 h |

**1 Module structure**

| Nr. | Element / Course | LSF no. | Typ | SWS |
|---|---|---|---|---|
| 1 | Course Scientific Work: Paper reading | | S | 2 |
| 2 | Seminar Scientific Work | | S | 2 |

**2 Course language**

Englisch

**3 Teaching content** part 1

1. research and selection
2. classification and elaboration
3. summary of contents

**Teaching content** Abschnitt 2

1. elaboration of the content of scientific papers
2. presentation of scientific work to an expert audience
3. discussion of scientific theses and results with an expert audience

The subject from which the scientific topic originates depends on the subject area of the upper seminar.

**4 Competencies**

Students can familiarise themselves with a scientific publication and are able to place the publication in the overall context of the respective field. They can present the content of the publication to an expert audience, answer questions about the content of this publication and discuss the conclusions from this publication with an expert audience. To this end, they are proficient in the presentation techniques customary in scientific lectures. In addition, they can participate in the discussion about the contents of a scientific lecture from their subject area.

**5 Exams**

The student's final presentation is the Module Exam. In addition, the student must actively participate in at least five presentations by other students as coursework.

**6 Forms of examination and performance**

☒ Module Exam ☐ Partial achievements

**7 Participation requirements**

Recommended prerequisites: Good technical knowledge in the respective field of the upper seminar.

**8 Module type and usability of the module**

Elective Course in the Master's degree program Sustainable Energy Systems.

**9**

| **Module Supervisor** | **Faculty in charge** |
|---|---|
| Dean of the Faculty of Electrical Engineering and Information Technology | Faculty of Electrical Engineering and Information Technology |

# Master Thesis

With the Master's thesis, 30 credit points must be successfully acquired.

<table>
<tr><th colspan="3">Modul 4-1: Master Thesis</th><th colspan="3">ETIT-290</th></tr>
<tr><td>Turnus<br>Half-yearly</td><td>Duration<br>1 Semester</td><td>Study section<br>4th Semester</td><td>LP<br>30</td><td>Attendance rate<br>-</td><td>Self-study<br>900 h</td></tr>
<tr><td>1</td><td colspan="5">Module structure<br>
<table>
<tr><th>Nr.</th><th>Element / Course</th><th>LSF no.</th><th>Typ</th><th>SWS</th></tr>
<tr><td>1</td><td>Master Thesis</td><td></td><td>P</td><td>-</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="5">Course language<br>English</td></tr>
<tr><td>3</td><td colspan="5">Teaching Content<br>1. familiarisation with the scientific problem of the task using guidelines.<br>2. analysis of the relevant previous scientific work<br>3. development of solution approaches<br>4. verification and evaluation of the solution approaches<br>5. selection and realisation of the best approach<br>6. scientific description of the methodology and the solution in written form.<br><br>The contents and results of the Master's thesis must be processed and presented to an expert audience. The presentation must take place no later than 6 weeks after submission of the thesis.</td></tr>
<tr><td>4</td><td colspan="5">Competencies<br>The student is able to work independently on a narrowly defined technical-scientific problem from his or her subject area using scientific methods. He or she is able to evaluate relevant preliminary work from the specialist literature, develop new approaches to solutions, evaluate these and finally implement a solution. Furthermore, he or she is able to present the results in writing in a structured way so that the relevant aspects of the solution are understood. The student is also able to present the results to a specialist audience and discuss them at the end.</td></tr>
<tr><td>5</td><td colspan="5">Exams<br>The Master's thesis counts as a Module Exam.</td></tr>
<tr><td>6</td><td colspan="5">Forms of examination and performance<br>☒ Module Exam ☐ Partial achievements</td></tr>
<tr><td>7</td><td colspan="5">Participation requirements<br>Recommended prerequisites: Good scientific knowledge in the respective field of the master thesis<br>Required prerequisites: Acquisition of 80 credit points in the Master's programme.</td></tr>
<tr><td>8</td><td colspan="5">Module type and usability of the module<br>Elective Module in the Master's degree program Sustainable Energy Systems.</td></tr>
<tr><td>9</td><td colspan="2">Module Supervisor<br>Dean of the Faculty of Electrical Engineering and Information Technology</td><td colspan="3">Faculty in charge<br>Faculty of Electrical Engineering and Information Technology</td></tr>
</table>

# Version information

V 1.0: Vom Fakultätsrat der Fakultät für Elektrotechnik und Informationstechnik am 19.05.2010 beschlossene Version des Modulhandbuchs

## Information on the elective modules

Two subject-related modules of 3 SWS each (usually corresponds to 5 LP) can be completed by a joint module examination. In this way, 10 credit points are acquired. There are a number of sensible combinations for this, which can be requested from the respective professors in individual cases.