Modulhandbuch

Digitalised Energy Systems - Master's Programme

im Wintersemester 2023/2024

erstellt am 24/09/23
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### Modules for Digitalised Energy Systems

#### Digitalised Energy System Design and Assessment

**inf340 - Uncertainty Modeling for Control in Digitalised Energy Systems**

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<td>Credit points</td>
<td>6.0 KP</td>
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**Verwendbarkeit des Moduls**
- Master's Programme Business Informatics (Master) > Akzentsetzungsmodule der Informatik
- Master's Programme Computing Science (Master) > Technische Informatik
- Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Design and Assessment
- Master's Programme Engineering of Socio-Technical Systems (Master) > Embedded Brain Computer Interaction
- Master's Programme Engineering of Socio-Technical Systems (Master) > Systems Engineering

**Zuständige Personen**
- Rauh, Andreas (Module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

**Prerequisites**
Basic knowledge of the control of linear time-continuous and/or time-discrete systems and/or robust control

**Skills to be acquired in this module**
The students identify fundamentals of uncertainty modelling in control systems as well as problem-specific methods for the consideration of uncertainty during simulation and observer synthesis.

**Professional competences**
The students:
- identify fundamentals of uncertainty modeling in control systems
- characterize problem-specific solution techniques for systems with stochastic and set-based uncertainty
- are aware of software implementations in simulation, control, and state estimation.

**Methological competences**
The students:
- students identify fundamentals of uncertainty modelling in control systems
- characterize problem-specific solution techniques for systems with stochastic and set-based uncertainty
- are aware of software implementations in simulation, control, and state estimation.

**Social competences**
The students:
- analyse problems of control-oriented uncertainty modelling
- analyse fundamental solution techniques on a theoretical basis as well as transfer and generalise them independently toward novel research-oriented application scenarios.

**Self competences**
The students:
- critically reflect the achieved results of their project work
- acknowledge limitations of various approaches for a control-oriented uncertainty modeling.

**Module contents**

1. Mathematical modeling of uncertainty in linear and nonlinear dynamic systems
2. Stochastic modeling approaches
3. Estimation of states, parameters and simulation of uncertain processes
   - Bayesian state estimation for discrete-time systems (linear/nonlinear) and for continuous-time systems (linear)
   - Linear estimation techniques in an extended state-space (Carleman linearization for special system classes)
   - Monte-Carlo methods

4. Set-based approaches
   - Set-based algorithms: Forward-backward contractor and bisection techniques
   - Interval methods for a verified solution of ordinary differential equations and for a stability proof of uncertain systems
   - Estimation of states and parameters as well as simulation of uncertain processes

5. Outlook: Synthesis of controllers and state observers under an explicit description of uncertainty

Literaturempfehlungen

- Rauh, A. Folien/ Skript zur Vorlesung „Uncertainty Modelling for Control in DES“.

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<th>Language of instruction</th>
<th>English</th>
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<tbody>
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Vorkenntnisse / Previous knowledge

Basic knowledge of the control of linear time-continuous and/or time-discrete systems and/or robust control

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Form of instruction

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Präsenzzeit Modul insgesamt

4 h
Successfully completing this lecture will enable the students to mathematically model simple controllable electrical generators and consumers and to simulate them together with appropriate control algorithms within smart grid scenarios. To achieve this goal, student will start with deriving computational models from physical models and by evaluating them. In order to manage the integration of control algorithms, students are taught the principles of cosimulation using the example of the "mosaik" smart grid cosimulation framework. Students are put into the position to understand and apply distributed, agent-based control schemes to decentralised energy generators and/or consumers. As a result, students are able to analyze the requirements for successful application to real power balancing regarding capacity utilization, robustness, and flexibility. In addition, students practically apply the foundations for planning and conducting simulation based experiments as well as the interpretation of the results. Attention is especially paid to a tradeoff between precision and robustness of the results and the necessary efforts (design of experiments) in order to gain as much insight into interdependencies with as few experiments.

**Profesional competence**
The student:
- derive and evaluate computational models from physical models
- use the "mosaik" smart grid cosimulation framework
- analyze the requirements for successful application to real power balancing regarding capacity utilization, robustness, and flexibility
- name the foundations for planning and conducting simulation based experiments as well as the interpretation of the results
- are aware to the tradeoff between precision and robustness of the results and the necessary efforts (design of experiments) in order to gain as much insight into interdependencies with as few experiments.

**Methological competence**
The student:
- model simple controllable electrical generators and consumers
- simulate simple controllable electrical generators and consumers with appropriate control algorithms within smart grid scenarios
- apply distributed agent-based control schemes to decentralised energy generators and/or consumers
- evaluate simulation results
- search information and look into methods to implement models
- propose hypothesis and check their validity with simulation experiments

**Social competence**
The student:
- apply the development technique pair programming
- discuss design decisions
- identify work packages and take responsibility for it

**Self-competence**
The student:
- reflect on their own use of the limited resource power
- accept and use criticism to develop their own behaviour

**Module contents**
In this practical course students:
• mathematically model controllable, modulating electrical energy generators and consumers and translate them to executable simulation models,
• put hands on mosaic (installation, description and configuration of scenarios, conduction of simulations),
• learn the principles of co-simulation of energy systems,
• learn about the challenges of implementing coordination mechanisms (multi-criticality, convergency, quality) on the training,
• apply foundations of design of experiments to practical simulation based experiments.

**Literaturempfehlungen**

**Smart Grids:**

**Multiagentensysteme**

**Co-Simulation**

**Versuchsplanung**
- Klein, B.: "Versuchsplanung - DoE", Oldenbourg, 2011

**Links**

<table>
<thead>
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<td>A practical assignment includes the theoretical preparation, set-up and execution of a design task on the basis of a case study or the experiment as well as the written presentation of the work steps, the steps, the process and the results of the experiment and their critical evaluation.</td>
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inf5122 - Learning-Based Control in Digitalised Energy Systems

Module label: Learning-Based Control in Digitalised Energy Systems

Modulkürzel: inf5122

Credit points: 6.0 KP

Workload: 180 h

Verwendbarkeit des Moduls
- Master's Programme Computing Science (Master) > Angewandte Informatik
- Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Design and Assessment
- Master's Programme Engineering of Socio-Technical Systems (Master) > Embedded Brain Computer Interaction
- Master's Programme Engineering of Socio-Technical Systems (Master) > Human-Computer Interaction
- Master's Programme Engineering of Socio-Technical Systems (Master) > Systems Engineering

Zuständige Personen
- Rauh, Andreas (Module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

Prerequisites
- The students identify fundamentals of learning-based control for dynamic systems.

Professional competences
- The students:
  - identify fundamentals of learning-based control for dynamic systems
  - characterise problem-specific learning techniques
  - are aware of software implementations for selected test rigs.

Methodological competences
- The students:
  - analyse problems of learning-based control
  - generalise them independently toward novel research-oriented application scenarios.

Social competences
- The students:
  - develop solution ideas for real-life control problems within an accompanying project/lab course in small teams
  - explain the obtained results in short presentations.

Self competences
- The students:
  - critically reflect the achieved results of their project work
  - acknowledge limitations of various approaches for learning-based control design.

Module contents

1. Iterative learning control (ILC)
   - Grundlegende 2D-Systemstrukturen
   - Stability criteria
   - Ausgewählte Optimierungsansätze
2. Data-driven neural network modelling vs. first-principle modelling
   - Static function approximations
   - NARX-modelling
3. Design of neural network-based controllers
4. Stability of neural network-based controllers

Literatureempfehlungen
- Jian Xin Xu; Ying Tan. Linear and Nonlinear Iterative Learning


Rauh, A. Folien/Skript zur Vorlesung „Learning-Based Control in DES“

Links

Language of instruction  English
Duration (semesters)  1 Semester
Module frequency  every summer term
Module capacity  unlimited

Modul level / module level

Modulart / type of module  1VL + 1S

Vorkenntnisse / Previous knowledge  Basic knowledge of control of linear continuous-time and/or discrete-timesystems and/or robust control

Examination

Prüfungszeiten  At the end of the course
Type of examination  Portfolio or written exam

Form of instruction  Comment  SWS  Frequency  Workload of compulsory attendance

Lecture  2  SoSe  28
Exercises  2  SoSe  28

Präsenzzeit Modul insgesamt  56 h
Digitalised Energy System Automation, Control and Optimisation

inf341 - Robust Control and State Estimation in Digitalised Energy Systems

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Verwendbarkeit des Moduls

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- Master's Programme Computing Science (Master) > Technische Informatik
- Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Automation, Control and Optimisation
- Master's Programme Engineering of Socio-Technical Systems (Master) > Embedded Brain Computer Interaction
- Master's Programme Engineering of Socio-Technical Systems (Master) > Systems Engineering

Zuständige Personen

- Rauh, Andreas (Module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

Prerequisites

Basic knowledge of the control of linear continuous-time and/or discrete-time systems or of robust control

Skills to be acquired in this module

The students identify fundamentals of robust control and state estimation as well as problem-specific solution techniques and their corresponding software implementation.

Professional competences

- The students identify fundamentals of robust control and state estimation
- Characterize problem-specific solution techniques for different classes of uncertainty
- Are aware of reliable software implementations.

Methodological competences

- The students analyze problems of robust control and state estimation for dynamic systems
- Analyze fundamental solution techniques on a theoretical basis
- Transfer as well as generalize those independently to new fields of applications.

Social competences

- The students develop solution ideas for real-life control problems within an accompanying project in small teams
- Explain the obtained results in short presentations.

Self competences

- The students critically reflect the achieved results of their project work
- Acknowledge limitations of various approaches for robust control and state estimation.

Module contents

1. Robustness of linear systems/ system analysis
   - Boundary crossing theorem of Frazer and Duncan
   - Mikhailov criterion
   - Khantyov criterion
   - Frequency response approaches
2. Selected control design techniques/ control synthesis
   - Parameter-space approach of Ackermann and Kaesbauer
   - Eigenvalue and eigenvalue domain assignment
H-infinity control
- Frequency response approaches (Sensitivity function
  approaches in the frequency domain)

3. Robust LMI-based control techniques
- Lyapunov stability
- Polytopic uncertainty modeling
- Optimality of solutions

4. Duality between control and observer synthesis
- Robust state estimation
- Sliding mode observers

5. Interval methods: Solution of static and dynamic problems (Enclosing
  function values, Branch-and-bound techniques, Verification techniques
  for differential equations)

6. Fundamentals: Fault detection and fault-tolerant control

Literaturempfehlungen

- Gu, D.-W.; Petkov, P.H.; Konstantinov, M.M., Robust Control Design
  with MATLAB, Springer-Verlag, 2013
- Osterlag, E. Mono- and Multivariable Control and Estimation, Springer-Verlag, 2011
- Rauh, A. Folien/ Skript zur Vorlesung „Robuste Regelung und
  Zustandsschätzung“.
- Weinmann, A. Uncertain Models and Robust Control, Springer-Verlag, 1991

Links

Language of instruction  English
Duration (semesters)  1 Semester Semester
Module frequency  every winter term
Module capacity  unlimited

Module level / module level

Modulart / typ of module  1VL + 1S

Vorkenntnisse / Previous knowledge  Basic knowledge of the control of linear continuous-time and/or discrete-time
  systems or of robust control

Examen / Prüfungszeiten / Type of examination

Final exam of module  Written exam: at the end of the lecture period
  Portfolio: during the semester

Form of instruction  Comment  SWS  Frequency  Workload of compulsory attendance

| Lecture | 2 | WiSe | 28 |
| Seminar | 1 | WiSe | 14 |

Präsenzzeit Modul insgesamt  42 h
inf5112 - Digitalised Energy System Modeling and Control

Module label: Digitalised Energy System Modeling and Control

Modulekürzel: inf5112

Credit points: 6.0 KP

Workload: 180 h

Verwendbarkeit des Moduls:
- Master's Programme Computing Science (Master) > Angewandte Informatik
- Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Automation, Control and Optimisation

Zuständige Personen:
- Lehnhoff, Sebastian (Module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

Prerequisites

Skills to be acquired in this module

After successful completion of the course the students should be able to understand the existing structures and technical basis of energy systems to produce, transfer and distribute electricity and their interaction and dependency on each other. They should have developed an understanding for necessary IT- and process control technology components, methods and processes to control and operate electrical energy systems. The students are able to estimate and evaluate the requirements and challenges of ICT and computer science which are caused by the development and integration of unforeseeable fluctuations of decentralised plants.

The students will be able to estimate the influence of distributed control concepts and algorithms for decentralised plants and consumers in the so called Smart Grid energy systems. Regarding the requirements, the students will be able to analyse the safety, reliability, realtime capability and flexibility of Smart Grid energy systems.

Professional competence
The students:

- understand the existing structures and the technical basis of energy systems producing, transferring and distributing electricity and their interaction and dependency on each other.
- develop an understanding for necessary IT- and process control technology components, methods and processes to control and operate electrical energy systems.
- estimate and evaluate the requirements and challenges of ICT and computer science, which are caused by the development, and integration of unforeseeable fluctuations of decentralised plants.

Methodological competence
The students:

- analyse the safety, reliability, realtime capability and flexibility of Smart Grid energy systems
- use advanced mathematical methods to calculate networks

Social competence
The students:

- create solutions in small teams
- discuss their solutions

Self competence
The students:

- reflect their own use of the limited resource power

Module contents

In this course information technology, economical energy industry and technical basic knowledge and methods are analysed by using concrete Smart Grid approaches. The basic calculation methods for an intelligent net management are introduced.
This module deals with the technical and economical framework for a permissable electrical network as well as mathematical modelling and calculation methods to analyse conditions of electrical energy networks (in stationary conditions).

These are:

- the organisation of the EU energy market (regulatory framework, responsibility in liberalisation of electrical energy systems)
- Establishment and operation of electrical energy supply networks (network topology, statutory duties of supply, supply quality/system services, malfunctions and protection systems)
- Network calculation (complex vector representation, effective/idle power, mathematical performance models/net model, transformation: node)
- performance to node voltage and electricity, calculation of conductive current, current flow, fix-point-iteration, Newton-Raphson-Method, voltage drop, transformer model)
- Intelligent network management (Smart Grids), Aggregation forms, machine learning approaches)

**Literaturempfehlungen**

- Gremmel, H.; ABB Schaltanlagen-handbuch, Cornelsen 2007
- Lehnhoff, S.: Dezentrales vernetztes Energiemanagement, 2010

**Links**

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<tr>
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**Modulart / typ of module**

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**Examination**

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**Form of instruction**

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<td>SoSe und WiSe</td>
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**Präsenzzeit Modul insgesamt**

56 h
inf5114 - Digitalised Energy System Requirements Engineering

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<th>Digitalised Energy System Requirements Engineering</th>
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<td>Workload</td>
<td>180 h</td>
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**Verwendbarkeit des Moduls**
- Master's Programme Computing Science (Master) > Angewandte Informatik
- Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Automation, Control and Optimisation

**Zuständige Personen**
- Lehnhoff, Sebastian (Module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

**Prerequisites**

**Skills to be acquired in this module**

- The students will learn different approaches to integrate distributed generation, the regulatory framework, relevant standards and architecture concepts of energy management systems and they are able to apply this knowledge.

This module integrates current computer science developments into the informatics program, especially considering the selected focus area, by appropriate study courses.

**Professional competence**

The students:

- develop and evaluate IT- Architectures for energy management
- model objects of this domain appropriately
- model energy information systems
- realise and differentiate advanced tasks of decentralised energy management

**Methodological competence**

The students:

- name problems for the energy management, analyse these problems systematically and provide solutions
- apply different simulation approaches of decentralised plants and consumers

**Social competence**

The students:

- discuss solutions for the energy management together
- develop use cases in teams
- present self-developed solutions

**Self competence**

The students:

- reflect their actions with regarde to structure and decompose systems
- reflect their own use of the limited resource power

**Module contents**

This module provides the computer science basics for the energy management. It provides the requirements of energy supply information systems with the focus on technical components and the requirements of decentralised and renewable energy plants.

These are:

- Architectures for energy information systems, e.g. SOA, Seamless Integration Architecture (IEC TC 57, OPC-UA)
- Norms and standards of energy industry data models (CIM, 61850)
- Systematisation of energy information system requirements based on ontologies
- Development, analysis and adaption of energy industry reference models and processes
- Methods and technologies to support energy industry processes
- Methods and algorithms to support decision processes of the
decentralised energy plants control
- Smart Grid plants communication, the load management in particular
- Methods for modelling and simulation of power supply system dynamics

Literaturempfehlungen
- Crastan V.: "Elektrische Energieversorgung II", Springer 2004

Links

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At the end of the course

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Präsenzzeit Modul insgesamt 56 h
inf5118 - Decentralised Nonlinear Model-Based Control in Digitalised Energy Systems

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Verwendbarkeit des Moduls
- Master's Programme Computing Science (Master) > Angewandte Informatik
- Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Automation, Control and Optimisation

Zuständige Personen
- Rauh, Andreas (Module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

Prerequisites

Skills to be acquired in this module
The students identify fundamentals of control and state estimation for nonlinear systems.

Professional competence
The students:
- identify fundamentals of control and state estimation for nonlinear systems, characterise problem-specific solution techniques and are aware of software implementations for selected test rigs

Methodological competence
The students:
- analyse problems of nonlinear control and state estimation and generalise them independently toward novel research-oriented application scenarios

Social competence
The students:
- develop solution ideas for real-life control problems within an accompanying project/lab course in small teams and explain the obtained results in short presentations

Self competence
The students:
- critically reflect the achieved results of their project work and acknowledge limitations of various approaches for nonlinear control design.

Module contents

1. Fundamentals of control-oriented modelling
2. Special properties of nonlinear control systems
   - Finite escape time
   - Chaos
   - Limit cycles
   - Equilibria
3. Stability properties/ Stability analysis
   - Local vs. global Stability
   - Lyapunov methods
   - Stability of limit cycles
   - Criteria for the proof of instability
4. Nonlinear control design
   - Control Lyapunov functions
   - Backstepping control
   - Feedback linearization
   - Flatness-based control
5. Nonlinear observer synthesis

Literatureempfehlungen
- Adamy, J.: Nichtlineare Regelungen; Springer Verlag,
2009.
- Rauh, A. Folien/ Skript zur Vorlesung „Decentralised Nonlinear Model-Based Control in DES“.

Links

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| Lehr-/Lernform / Teaching/Learning method | 1VL + 1P + 1Ü |
| Vorkenntnisse / Previous knowledge | Basic knowledge of the control of linear continuous-time and/or discrete-time systems or of robust control |

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Präsenzzeit Modul insgesamt 56 h
inf516 - Distributed Operation in Digitalised Energy Systems

**Module label**
Distributed Operation in Digitalised Energy Systems

**Modulkürzel**
inf516

**Credit points**
6.0 KP

**Workload**
180 h

**Verwendbarkeit des Moduls**
- Master's Programme Computing Science (Master) > Angewandte Informatik
- Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Automation, Control and Optimisation

**Zuständige Personen**
- Nieße, Astrid (Module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

**Prerequisites**

**Skills to be acquired in this module**

After successful completion of this course, the students are able to analyze an application problem in cyber-physical energy systems to decide whether a distributed optimization approach could be usefully applied. Fundamentals of self-organizing systems are understood and can be transferred to specific applications.

Furthermore, the basic concepts of distributed methods can be applied safely and transferred to an application case.

**Professional competence**
The students:
- will be familiar with the basic concepts of distributed optimization and agent systems mentioned above

**Methodological competence**
The students:
- will be able to present the fundamental concepts of distributed optimization and agent systems mentioned above and apply them to application problems in CPES

**Social competence**
The students:
- create solutions in small teams
- present and discuss their solutions
- reflect the solutions of others in a constructive manner

**Self competence**
The students:
- critically question the application of learned methods to a real-world problem

**Module contents**

In this course, fundamentals of agent-based control with applications in cyber-physical power systems are reviewed, discussed, and reinforced in the accompanying programming exercise.

These are:

1. Multi-agent systems
   - Foundations and definitions
   - MAS architectures
   - Agent communication
   - Cooperative and competitive agents MAS
   - Learning in MAS
2. Distributed Optimization
   - CASIMIR
   - Overview on distributed optimization
   - CSP and COP
   - Distributed SCP und COP
3. Self-organizing energy systems
4. Applications
- Virtual Power Plants
- QEMS and Microgrids
- DSM and DR
- Energy market applications
- Swarms for storage management
- Multi-purpose examples
5. Programming part
- Agent framework mango
- Co-simulation framework mosaik
- Power grid simulation pandapower

Literaturempfehlungen


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Präsenzzeit Modul insgesamt 56 h
info579 - Special Topics in 'Digitalised Energy Systems' I

**Module label**
Special Topics in 'Digitalised Energy Systems' I

**Modulkürzel**
info579

**Credit points**
6.0 KP

**Workload**
180 h

**Verwendbarkeit des Moduls**
- Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Automation, Control and Optimisation

**Zuständige Personen**
- Nieße, Astrid (Module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

**Prerequisites**
No participant requirements

**Skills to be acquired in this module**
This module integrates current developments in the field of Digitalised Energy Systems in adequate study courses.

**Competencies**
This module integrates current developments in the field of Digitalised Energy Systems in adequate study courses.

**Professional competences**
The students:
- define and contrast a computer science part, in which they are specialised, in detail or
- evaluate computer science in general
- recognise and evaluate applied techniques and methods of their subject and are aware of their limits
- identify, structure and solve problems/tasks, also in new or developing subject areas
- apply state of the art and innovative methods to solve problems, if necessary from other disciplines
- are aware of the current limits and contribute to the development of computer science research and technology discuss and evaluate recent computer science developments

**Methodological competences**
The students:
- evaluate and apply tools technology and methods
- sophisticatedly combine new and original approaches and methods
- creatively evaluate problems/tasks, including new or developing subject areas of their discipline and apply computer science methods for solutions and research

**Social competences**
The students:
- support Team process by their abilities

**Self competences**
The students:
- pursue the overall and special computer science development critically implement innovative professional activities effectively and independently

**Module contents**
See assigned course description

**Literaturempfehlungen**
Word om der Veranstaltung bekannt gegeben

**Links**

**Language of instruction**
English

**Duration (semesters)**
1 Semester

**Module frequency**
unregelmäßig

**Module capacity**
unlimited

**Modullevel / module level**

**Modulart / typ of module**

**Lehr-/Lernform / Teaching/Learning method**
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inf581 - Special Topics in 'Digitalised Energy Systems' II

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**Verwendbarkeit des Moduls**
- Master's Programme Computing Science (Master) > Angewandte Informatik
- Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Automation, Control and Optimisation

**Zuständige Personen**
- Nieße, Astrid (Module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

**Prerequisites**
No participant requirements

**Skills to be acquired in this module**
This module integrates current developments in the field of Digitalised Energy Systems in adequate study courses.

**Professional competences**
The students:
- define and contrast a computer science part, in which they are specialised, in detail or
- evaluate computer science in general
- recognise and evaluate applied techniques and methods of their subject and are aware of their limits
- identify, structure and solve problems/tasks, also in new or developing subject areas
- apply state of the art and innovative methods to solve problems, if necessary from other disciplines
- are aware of the current limits and contribute to the development of computer science research and technology
- discuss and evaluate recent computer science developments

**Methodological competences**
The Students:
- evaluate tools, technologies and methods
- sophisticatedly combine new and original approaches and methods
- creatively evaluate problems/tasks, including new or developing subject areas of their discipline and apply computer science methods for solutions and research

**Social competences**
The Students:
- support team process by their abilities

**Self-competences**
The Students:
- pursue the overall and special computer science development
- critically implement innovative professional activities effectively and independently

**Module contents**
See assigned course description

**Literaturempfehlungen**
Will be announced in the course

**Language of instruction**
English

**Duration (semesters)**
1 Semester

**Module frequency**
irregular

**Module capacity**
unlimited

**Modullevel / module level**

**Lehr-/Lernform / Teaching/Learning method**
2 events from VL, Ü, S, PR

**Vorkenntnisse / Previous knowledge**
none

**Examination**
Prüfungszeiten
Type of examination
Portfolio or presentation or oral examination

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**Präsenzzeit Modul insgesamt**

56 h
inf584 - Special Topics in 'Energy Informatics' I

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<td>• apply state of the art and innovative methods to solve problems, if necessary from other disciplines</td>
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<td>• support team process by their abilities</td>
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Module contents See assigned course description

Literaturempfehlungen As announced in course

Links

Language of instruction English
Duration (semesters) 1 Semester
Module frequency irregular
Module capacity unlimited

Modullevel / module level

Modulart / typ of module

Lehr- / Lernform / Teaching / Learning method 2 events from VL, S, Ü, P, PR

Vorkenntnisse / Previous knowledge none

Examination Prüfungszeiten Type of examination
Final exam of module At the end of the lecture period Portfolio or presentation or oral exam
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### inf585 - Special Topics in 'Energy Informatics' II

#### Module label
Special Topics in 'Energy Informatics' II

#### Modulkürzel
inf585

#### Credit points
6.0 KP

#### Workload
180 h

#### Verwendbarkeit des Moduls
- Master's Programme Computing Science (Master) > Angewandte Informatik
- Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Automation, Control and Optimisation

#### Zuständige Personen
- Lehnhoff, Sebastian (Module responsibility)
- Lehrende, Die im Modul (Prüfungsberechtigt)

#### Prerequisites
No participant requirements

#### Skills to be acquired in this module
This module integrates current developments in the field in adequate study courses.

**Professional competences**
The students:
- define and contrast a computer science part, in which they are specialised, in detail or evaluate computer science in general
- recognise and evaluate applied techniques and methods of their subject and are aware of their limits
- identify, structure and solve problems/tasks, also in new or developing subject areas
- apply state of the art and innovative methods to solve problems, if necessary from other disciplines
- are aware of the current limits and contribute to the development of computer science research and technology
- discuss and evaluate recent computer science developments

**Methodological competences**
The students:
- evaluate and apply tools, technology and methods sophisticatedly
- combine new and original approaches and methods creatively
- evaluate problems/tasks, including new or developing subject areas of their discipline and apply computer science methods for solutions and research

**Social competences**
The students:
- support team process by their abilities

**Self-competences**
The students:
- pursue the overall and special computer science development critically
- implement innovative professional activities effectively and independently

#### Module contents
See assigned course description

#### LiteratureEmpfehlungen
As announced in course

#### Language of instruction
German

#### Duration (semesters)
1 Semester

#### Module frequency
irregular

#### Module capacity
unlimited

#### Modullevel / module level

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#### Final exam of module
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Automation and Electrical Engineering

inf5100 - Digital Technology on Energy Markets

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Verwendbarkeit des Moduls

- Master's Programme Computing Science (Master) > Angewandte Informatik
- Master's programme Digitalised Energy Systems (Master) > Automation and Electrical Engineering

Zuständige Personen

- Staudt, Philipp (Module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

Prerequisites

This module integrates current computer science developments into the informatics program, especially considering the selected focus area, by appropriate study courses

Professional competence
The students:

- will be able to follow scientific work in the application area of digitalised energy markets, and thus be able to reflect on the current state of research in this area

Methological competence
The students:

- are able to classify energy markets and judge new technological developments based on this classification

Social competence
The students:

- create solutions in small teams
- present and discuss their solutions
- reflect the solutions of others in a constructive manner

Self competence
The students:

- evaluate new technologies regarding their relevance for current energy-economic topics.

Module contents

In this module, theoretical concepts for understanding energy markets are presented and reflected with respect to the questions, how digitalisation of cyber-physical energy systems (CPES) is impacting the development of these markets.

Fundamental concepts are discussed using easy-to-follow examples.

These are:

- Overview on Energy Markets
- Consecutive markets and different time horizons
- Smart Grids and energy markets
- Push-effect of digital technologies on energy market development
- Digitalised processes on energy markets
- Market integration of renewable energy resources

Literatureempfehlungen

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inf5102 - Power System Components, Networks, Operation

Module label: Power System Components, Networks, Operation
Modulkürzel: inf5102
Credit points: 6.0 KP
Workload: 180 h

Verwendbarkeit des Moduls: Master's programme Digitalised Energy Systems (Master) > Automation and Electrical Engineering
Zuständige Personen: Lehrende, Die im Modul (Module responsibility) Gawlik, Wolfgang (Module responsibility)

Prerequisites

Skills to be acquired in this module
The students know the components of electrical energy systems with their individual properties and can assess the mutual dependencies and relationships in the systemic context.

Professional competence
The students:

- can describe components of electrical energy systems and understand their mutual interactions and dependencies in a systemic context.

Methodological competence
The students:

- can model components of the electrical energy system and perform calculations to determine the model parameters and using the model parameters and model properties
- can analyze operating processes, operating states and faults in the electrical energy system and identify mutual interactions
- can dimension operating resources in a systemic context

Social competence
The students:

- can explain the components of electrical energy systems to each other and jointly discuss solutions for typical operating processes and problems in electrical energy systems
- can work together on problems and challenges of the electrical energy system across subjects and disciplines.

Self competence
The students:

- are able to critically reflect on the requirements for components of electrical energy systems and to assess their importance for system operation within the systemic context.

Module contents

Power System Components
Lines, transformers and rotating electrical machines
Power electronics and FACTS
Switchgear and substations
Network structures, AC and DC systems
Power plants and distributed generation
Energy storage and sector coupling
Power System Operation
Load flow, short circuits and protection
Interconnected power systems and Microgrids
Active power and load/frequency control
Reactive power and voltage control
Emergency operation and network restoration

Literaturempfehlungen


Links

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**inf5124 - Research Project Digitalised Energy Systems**

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<td>Lehrende, Die im Modul (Module responsibility) &gt; Rauh, Andreas (Module responsibility)</td>
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<tr>
<td>Prerequisites</td>
<td>The students identify fundamental research concepts of modelling, control, state estimation, simulation, and optimisation of digitalised energy systems</td>
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<td>The students:</td>
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<td><strong>Professional competence</strong></td>
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<td>The students:</td>
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<tr>
<td></td>
<td>• identify fundamental concepts for design and operation of digitalised energy systems, characterise different solution approaches and recognise the implementation of selected aspects such as simulation and optimisation</td>
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<td>The students:</td>
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<td>• develop solution ideas in a research-oriented environment.</td>
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<td><strong>Social competence</strong></td>
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<td>The students:</td>
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<td>• develop solution ideas in small project teams of typically 3 persons, document their results in written form, and explain the obtained results in short presentations</td>
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<td>The students:</td>
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<td>• critically reflect the achieved results of their project and acknowledge limitations of approaches used.</td>
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inf5104 - Fundamentals of Game Theory in Energy Systems

Module label
Fundamentals of Game Theory in Energy Systems

Modulkürzel
inf5104

Credit points
6.0 KP

Workload
180 h

Verwendbarkeit des Moduls
- Master's Programme Computing Science (Master) > Angewandte Informatik
- Master's programme Digitalised Energy Systems (Master) > Computer Science and Energy Informatics

Zuständige Personen
- Nieße, Astrid (Module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

Prerequisites
none

Skills to be acquired in this module

Upon successful completion of the course, students can understand fundamental concepts of game theory, and the relevance of these concepts to applications in energy informatics research.

Professional competence
The students:
- will be able to follow game-theoretic work in the application area of energy systems, and thus be able to reflect on the current state of research in this area

Methodological competence
The students:
- can classify and formalise games and apply solution concepts for the presented types of games. Application examples can be examined for game types and the necessary simplifications can be evaluated.

Social competence
The students:
- create solutions in small teams
- present and discuss their solutions
- reflect the solutions of others in a constructive manner

Self competence
The students:
- derive connections between everyday situations and their game theory conceptualization.

Module contents

In this module, theoretical concepts from game theory are prepared and presented with connections to the application in cyber-physical energy systems (CPES).

Fundamental concepts are discussed using easy-to-follow examples.

These are:
- Game theory and decision theory
- Interdependencies
- Cooperative and non-cooperative game theory
- Utility, discrete and continuous strategy, dominant strategy
- Axioms of game theory
- Theorems of game theory
- Solution concepts for games, e.g. iterated elimination, backward induction
- Multi-step and repeated games
- Partial game perfection
- Discount factor
- Mechanisms design, markets and auctions

In CPES-application examples, references are made to distributed artificial intelligence and multi-agent systems, strategy learning, and operating in markets in energy applications.

**Literaturempfehlungen**

- Fudenberg, Tirole: Game Theory. MIT Press, 1991

**Links**

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### Module Contents

1. Parameter optimization
   - Unconstrained optimization
   - Optimization under equality/inequality constraints
2. Dynamic optimisation (structural optimisation)
   - Bellman’s optimality principle
   - Maximum principle of Pontryagin
   - Special optimisation problems: Minimum time problems, minimum energy, LQR
3. Linear model-predictive control
4. Nonlinear model-predictive control
5. Receding horizon state estimation

### Literature recommendations

- Papageorgiou, M.; Leibold, M.; Buss, M.: Optimierung. Statische, dynamische, stochastische Verfahren für die Anwendung. 3. Aufl.,
### Links

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### Examination

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inf5110 - Practical Course (Energy Informatics)

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| Zuständige Personen           | Lehnhoff, Sebastian (Module responsibility)  
|                               | Rauh, Andreas (Module responsibility)    
|                               | Lehrenden, Die im Modul (Prüfungsberechtigt) |

Prerequisites

Skills to be acquired in this module

The aim of the module is to impart practical competences required in energy informatics for the implementation of control and regulation approaches in the field on plants and in the grid.

**Professional competence**
The students:

- know basic modelling approaches for components in power systems.
- know procedures for parameter identification
- know linear and non-linear methods for closed-loop and optimised control of technical systems
- know basic procedures for dealing with faults and technical malfunctions in control systems
- know the challenges of implementing control approaches on resource-constrained engineered systems in the field

**Methodological competence**
The students:

- select appropriate modelling approaches
- apply methods for parameter identification
- apply methods for the control of technical operating parameters
- implement these approaches on a (virtual) embedded system

**Social competence**
The students:

- discuss the model selection used approaches in the team
- present and discuss results with other students

**Self competence**
The students:

- reflect on the abstract modelling of complex technical systems and processes
- reflect on problems and uncertainties and errors
- recognise the limitations of embedded systems in the field
- accept criticism and understand it as a suggestion for the further development of their own actions

Module contents

**Modelling of components in DES**
- Battery cells (equivalent circuit modelling, thermal model)
- Step-down converter circuits
- Electric drive systems (modelling of complete drive train, including mechanics)

**Parameter identification in DES**
- Design of identification experiments
- Parameter optimisation (time domain/ frequency domain, impedance spectroscopy)
- Design of state observers and (Extended) Kalman Filters
Linear Control

- Output feedback control of electric drive train (PID, including anti-windup)
- Observer-based state feedback control
- Disturbance estimation and compensation

Nonlinear control/ Variable-structure control

- Lyapunov methods for control design
- Flatness-based control techniques
- Robustness analysis
- Real-time implementation of methods for chattering reduction

Optimal control/ MPC

- Charging under state constraints
- Energy optimal battery charging
- Minimum-time solutions
- State of charge equalization
- Thermal state constraints

Fault detection and isolation

- Sensor vs. actuator faults
- Observer-based approaches for inverter circuits
- Observer-based approaches for drive trains
- Fault-tolerant control structures, control reconfiguration

Implementation Studies

- Implementation of a controller on practically relevant hardware
  (vRTU/vIED programming of a network or plant controller)
- Hardware-in-the-loop simulation of the controller (Simulink modelling of the RT environment and compilation on the RT target)

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# inf514 - Simulation-based Smart Grid Engineering and Assessment

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| Verwendbarkeit des Moduls | • Master's Programme Computing Science (Master) > Angewandte Informatik  
                           • Master's programme Digitalised Energy Systems (Master) > Computer Science and Energy Informatics |
| Zuständige Personen | • Lehnhoff, Sebastian (Module responsibility)  
                              • Lehrenden, Die im Modul (Prüfungsberechtigt) |
| Prerequisites | Basic programming in Java or Python                    |
| Skills to be acquired in this module | **Competencies**  
Goal of this module is to teach mathematical and methodological foundations of energy informatics and for conducting large-scale simulation studies  
**Professional competence**  
The students:  
• know methods to analyze black-box objective functions  
• recognize the relation between precision and reliability of expected results and the necessary surplus effort  
• know methods to determine cause-effect relations between input parameters with small numbers of simulations (experiments)  
• evaluate the significance of simulation results  
• characterize (distributed) algorithms by their properties  
• transfer proving techniques to distributed problems  
**Methodological competence**  
The students:  
• choose suitable statistical methods to interpret simulation results  
• apply methods from design of experiments  
• apply significance tests to compare algorithms  
• generate arbitrarily distributed input data  
• present results from algorithm evaluation statistically sound  
**Social competence**  
The students:  
• discuss the own algorithm choice  
• present their results and discuss with other students  
**Self-competence**  
The students:  
• reflect their own usage of the scarce resource energy  
• reflect problems and uncertainties when using statistical methods  
• recognize the limits of simulation studies and their responsibility for choosing correct statistical methods  
• accept criticism and understand it as a suggestion for the further development of their own actions |
<p>| Module contents | The goal of this module is to teach mathematical and methodological foundations of energy informatics and especially for conducting large-scale simulation studies. |
| Literatureempfehlungen | Will be announced in the lecture |
| Links |  |
| Language of instruction | English |
| Duration (semesters) | 1 Semester |
| Module frequency | every winter term |
| Module capacity | unlimited |
| Modullevel / module level |  |
| Modulart / typ of module |  |
| Lehr-/Lernform / Teaching/Learning method | 1 VL + 1 Ü |
| Vorkenntnisse / Previous knowledge | Basic programming in Java or Python |</p>
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Präsenzzeit Modul insgesamt 56 h
Innovation Topics and Smart Grids

inf5126 - Digitalised Energy System Cyber-Resilience

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Verwendbarkeit des Moduls
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- Master's programme Digitalised Energy Systems (Master) > Innovation Topics and Smart Grids

Zuständige Personen
- Lehnhoff, Sebastian (Module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

Prerequisites

Skills to be acquired in this module

**Professional competences**

The students
- recognise the entailed problems and challenges of new digitalization trends such as billion devices on the internet connected to our power grid (televisions, baby monitors, alexa, etc.), smart services, cloud services, outsourcing, Artificial Intelligence, Big Data etc.
- evaluate fraud/ intrusion detection methods
- identify security flaws and vulnerabilities of the energy system

**Methodological competences**

The students
- examine tasks with technical and research literature, write an academic article and present their solutions academically
- evaluate problems of cyber resilience in energy systems
- schedule time processes and resources.

**Social competences**

The students
- communicate with colleagues and experts convincingly.

**Self competences**

The students
- reflect the problems of cyber resilience of energy systems critically and pursue different possible solution strategies.
- reflect self-developed hypotheses and theories independently.

Module contents

- Energy system as critical infrastructure (KRITIS)
- Propagation of phenomena and their dynamics
- Omnipresent conflicts of objectives
- Susceptibility of the energy system to new effects, such as the occurrence of "classic" IT challenges (errors, update management, interactions, ...) and to sophisticated cyber-attacks

Literaturempfehlungen

Will be announced in the course

Links

Language of instruction
- English

Duration (semesters)
- 1 Semester
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| Präsenzzelt Modul insgesamt | 28 h |
inf5128 - AI in Energy Systems

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Prerequisites

Skills to be acquired in this module

The students learn to understand the energy system as self-organizing, self-optimizing and self-healing cyber physical system and how equip the components with of a cyber physical energy system with intelligence and autonomy.

**Professional competences**

The students

- contrast different methods of AI
- define modern use cases of AI applications in energy systems
- identify appropriate AI methods to achieve a given control goal in the energy system
- evaluate risks and drawbacks of AI in energy systems
- apply AI to selected problems

**Methodological competences**

The students

- examine tasks with technical and research literature, write an academic article and present their solutions academically
- evaluate problems of AI in energy systems
- schedule time processes and resources

**Social competences**

The students

- communicate with colleagues and experts convincingly

**Self competences**

The students

- pursue and reflect the integration of AI into energy systems critically
- reflect self-developed hypotheses to theories independently

Module contents

This module integrates current developments in artificial intelligence (AI) and its application to energy systems.

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inf5130 - Socio-technical Energy Systems

Module label: Socio-technical Energy Systems
Modulkürzel: inf5130
Credit points: 3.0 KP
Workload: 90 h

Verwendbarkeit des Moduls
- Master's Programme Computing Science (Master) > Angewandte Informatik
- Master's programme Digitalised Energy Systems (Master) > Innovation Topics and Smart Grids

Zuständige Personen
- Lehnhoff, Sebastian (Module responsibility)
- Bremer, Jörg (Module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

Prerequisites

Skills to be acquired in this module

The students learn to consider human needs right from the beginning in the design process of Human Cyber Physical Energy Systems. A human-centered design is at the core as an approach to interactive systems development that aims to make systems usable and useful by focusing on the users; and to develop systems that are aware of (NOT rationally acting) humans when making decision.

Professional competences
The students
- recognise the energy system as a human cyber physical system with a steadily growing degree of autonomy
- identify the potential for conflict that arises when humans interact with cyber physical systems
- model human-system-interaction
- recognise, evaluate and contrast approaches to self-explaining AI

Methodological competences
The students
- examine tasks with technical and research literature, write an academic article and present their solutions academically
- evaluate problems of socio-technical energy system
- schedule time processes and resources

Social competences
The students
- communicate with colleagues and experts convincingly

Self competences
The students
- pursue the integration of humans and human behaviour into cyber physical energy systems critically
- develop and reflect self-developed hypotheses to theories independently

Module contents

- Simulation (and prediction) of human behaviour and decisions
- Modeling user behaviour in human cyber physical systems
- Self-explaining and justifying AI

Literaturempfehlungen
Will be announced in the course

Links

Language of instruction: English
Duration (semesters): 1 Semester
Module frequency: irregular
Module capacity: unlimited
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inf586 - Current Topics in 'Energy Informatics' I

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**Verwendbarkeit des Moduls**
- Master's Programme Computing Science (Master) > Angewandte Informatik
- Master's programme Digitalised Energy Systems (Master) > Innovation Topics and Smart Grids

**Zuständige Personen**
- Lehnhoff, Sebastian (Module responsibility)
- Lehrende, Die im Modul (Prüfungsberechtigt)

**Prerequisites**
No participant requirements

**Skills to be acquired in this module**
This module integrates current developments in the field in adequate study courses.

**Professional competences**

The students
- define and contrast a computer science part, in which they are specialised, in detail or evaluate computer science in general
- recognise and evaluate applied techniques and methods of their subject and are aware of their limits
- identify, structure and solve problems/tasks, also in new or developing subject areas
- apply state of the art and innovative methods to solve problems, if necessary from other disciplines
- are aware of the current limits and contribute to the development of computer science research and technology
- discuss and evaluate recent computer science developments

**Methodological competences**

The students
- examine tasks with technical and research literature, write an academic article and present their solutions academically
- evaluate problems/tasks, including new or developing subject areas of their discipline and apply computer science methods for solutions and research
- schedule time, processes and resources

**Social competences**

The students
- communicate with users and experts convincingly

**Self competences**

The students
- pursue the overall and special computer science development critically
- develop and reflect self-developed hypotheses to theories independently

**Module contents**
See assigned course description

**Literatureempfehlungen**
Depending on the assigned course

**Links**

**Language of instruction**
English

**Duration (semesters)**
1 Semester

**Module frequency**
irregular

**Module capacity**
unlimited

**Modullevel / module level**

**Modular / typ of module**

**Lehr-/Lernform / Teaching/Learning method**
1S or 1VL
### Previous knowledge

Vorkenntnisse / Previous knowledge: none

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inf587 - Current Topics in 'Energy Informatics' II

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<td>• are aware of the current limits and contribute to the development of computer science research and technology</td>
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<td>• examine tasks with technical and research literature, write an academic article and present their solutions academically</td>
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### Module contents

- See assigned course description

### Literatureempfehlungen

- Will be announced in the course

### Language of instruction

- English

### Duration (semesters)

- 1 Semester

### Module frequency

- irregular

### Module capacity

- unlimited

### Modulelevel / module level

- Modulart / typ of module

- Lehr-/Lernform / Teaching/Learning method

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Abschlussmodul

mam - Master Thesis Module Digitalised Energy Systems

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Zuständige Personen

Prerequisites

Skills to be acquired in this module

Module contents

Literaturempfehlungen

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Modullevel / module level

Modulart / typ of module

Lehr-/Lernform / Teaching/Learning method

Vorkenntnisse / Previous knowledge

Examination

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SWS

Frequency | SoSe oder WiSe |
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