Modulhandbuch

Digitalised Energy Systems - Master's Programme

im Summer semester 2024

erstellt am 17/05/24
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>inf340</td>
<td>Uncertainty Modeling for Control in Digitalised Energy Systems</td>
<td>4</td>
</tr>
<tr>
<td>inf5120</td>
<td>Digitalised Energy System Co-Simulation</td>
<td>6</td>
</tr>
<tr>
<td>inf5122</td>
<td>Learning-Based Control in Digitalised Energy Systems</td>
<td>9</td>
</tr>
<tr>
<td>inf341</td>
<td>Robust Control and State Estimation in Digitalised Energy Systems</td>
<td>11</td>
</tr>
<tr>
<td>inf5112</td>
<td>Digitalised Energy System Modeling and Control</td>
<td>13</td>
</tr>
<tr>
<td>inf5114</td>
<td>Digitalised Energy System Requirements Engineering</td>
<td>15</td>
</tr>
<tr>
<td>inf5118</td>
<td>Decentralised Nonlinear Model-Based Control in Digitalised Energy Systems</td>
<td>17</td>
</tr>
<tr>
<td>inf516</td>
<td>Distributed Operation in Digitalised Energy Systems</td>
<td>19</td>
</tr>
<tr>
<td>inf579</td>
<td>Special Topics in 'Digitalised Energy Systems' I</td>
<td>21</td>
</tr>
<tr>
<td>inf581</td>
<td>Special Topics in 'Digitalised Energy Systems' II</td>
<td>23</td>
</tr>
<tr>
<td>inf584</td>
<td>Special Topics in 'Energy Informatics' I</td>
<td>25</td>
</tr>
<tr>
<td>inf585</td>
<td>Special Topics in 'Energy Informatics' II</td>
<td>27</td>
</tr>
<tr>
<td>inf5100</td>
<td>Digital Technology on Energy Markets</td>
<td>29</td>
</tr>
<tr>
<td>inf5102</td>
<td>Power System Components, Networks, Operation</td>
<td>31</td>
</tr>
<tr>
<td>inf5124</td>
<td>Research Project Digitalised Energy Systems</td>
<td>33</td>
</tr>
<tr>
<td>inf5104</td>
<td>Fundamentals of Game Theory in Energy Systems</td>
<td>35</td>
</tr>
<tr>
<td>inf5106</td>
<td>Optimal and Model-Predictive Control</td>
<td>37</td>
</tr>
<tr>
<td>inf5110</td>
<td>Practical Course (Energy Informatics)</td>
<td>39</td>
</tr>
<tr>
<td>inf514</td>
<td>Simulation-based Smart Grid Engineering and Assessment</td>
<td>41</td>
</tr>
<tr>
<td>inf5126</td>
<td>Digitalised Energy System Cyber-Resilience</td>
<td>43</td>
</tr>
</tbody>
</table>
inf5128 - AI in Energy Systems

inf5130 - Socio-technical Energy Systems

inf586 - Current Topics in 'Energy Informatics' I

inf587 - Current Topics in 'Energy Informatics' II

inf591 - Current Topics in 'Digitalized Energy systems'

mam - Master Thesis Module Digitalised Energy Systems
Digitalised Energy System Design and Assessment

inf340 - Uncertainty Modeling for Control in Digitalised Energy Systems

<table>
<thead>
<tr>
<th>Module label</th>
<th>Uncertainty Modeling for Control in Digitalised Energy Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf340</td>
</tr>
<tr>
<td>Credit points</td>
<td>6.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>180 h</td>
</tr>
</tbody>
</table>

**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.

**Methodological competences**
The students:
- students identify fundamentals of uncertainty modelling in control systems
- characterise 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
   - Probability distributions
   - 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
3. Estimation of states, parameters and simulation of uncertain processes
   - Outlook: Markov models
   - Outlook: Bayesian networks
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

- Jaulin, L., Kieffer, M., Didrit, O., Walter, E., Applied Interval Analysis,
- Papoulis, A.: Probability, Random Variables, and Stochastic Processes,
- Rauh, A. Folien/ Skript zur Vorlesung „Uncertainty Modelling for
  Control in DES“.

Links

<table>
<thead>
<tr>
<th>Language of instruction</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (semesters)</td>
<td>1 Semester Semester</td>
</tr>
<tr>
<td>Module frequency</td>
<td>every winter term</td>
</tr>
<tr>
<td>Module capacity</td>
<td>unlimited</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
<td>V+Ü+P</td>
</tr>
<tr>
<td>Previous knowledge</td>
<td>Basic knowledge of the control of linear time-continuous and/or time-discrete systems and/or robust control</td>
</tr>
</tbody>
</table>

Examination

<table>
<thead>
<tr>
<th>Prüfungszeiten</th>
<th>Type of examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Following the event period</td>
<td>Portfolio or written exam</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lehrveranstaltungsform</th>
<th>Comment</th>
<th>SWS</th>
<th>Frequency</th>
<th>Workload of compulsory attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td>2</td>
<td></td>
<td>WiSe</td>
<td>2</td>
</tr>
<tr>
<td>Exercises</td>
<td>1</td>
<td></td>
<td>WiSe</td>
<td>1</td>
</tr>
<tr>
<td>Project</td>
<td>1</td>
<td></td>
<td>WiSe</td>
<td>1</td>
</tr>
<tr>
<td>Präsenzzzeit Modul insgesamt</td>
<td></td>
<td></td>
<td></td>
<td>4 h</td>
</tr>
</tbody>
</table>
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.

### Professional 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.

### Methodological 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 mosaik (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.

Literaturrempfehlungen

Smart Grids:

Multiagentensysteme
• Sutton, R. S.; Barto, A. G.: "Reinforcement Learning", MIT Press, 1998-
• Ferber J.; Kim, S.: "Multiagentensysteme: eine Einführung in die Verteilte Künstliche Intelligenz", Addison-Wesley, 2001

Co-Simulation

Versuchsplanung
• Kleppmann, W.: "Versuchsplanung", Hanser, 2013
• Klein, B.: "Versuchsplanung - DoE", Oldenburg, 2011

Links
Language of instruction
English
Duration (semesters)
1 Semester
Module frequency
every summer term
Module capacity
unlimited
Teaching/Learning method
PR
Previous knowledge
Programming mit Python, Simulation-based Smart Grid Engineering and Assessment
Examination
Prüfungszeiten
Type of examination

Final exam of module
At the end of the lecture time
Practical Work
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.

Lehrveranstaltungsform
Project
<table>
<thead>
<tr>
<th>Frequency</th>
<th>SoSe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workload Präsentzeit</td>
<td>28 h</td>
</tr>
</tbody>
</table>

**SWS** | 2
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
Basic knowledge of control of linear continuous-time and/or discrete-time systems and/or robust control

Skills to be acquired in this module

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
Literaturempfehlungen

- Jian Xin Xu; Ying Tan. Linear and Nonlinear Iterative Learning Control. Springer-Verlag. 2003
- Rauh, A. Folien/ Skript zur Vorlesung „Learning-Based Control in DES“

Links

<table>
<thead>
<tr>
<th>Language of instruction</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (semesters)</td>
<td>1 Semester</td>
</tr>
<tr>
<td>Module frequency</td>
<td>every summer term</td>
</tr>
<tr>
<td>Module capacity</td>
<td>unlimited</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
<td>V+Ü</td>
</tr>
<tr>
<td>Previous knowledge</td>
<td>Basic knowledge of control of linear continuous-time and/or discrete-timesystems and/or robust control</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Examination</th>
<th>Prüfungszeiten</th>
<th>Type of examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final exam of module</td>
<td>At the end of the course</td>
<td>Portfolio or written exam</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lehrveranstaltungsform</th>
<th>Comment</th>
<th>SWS</th>
<th>Frequency</th>
<th>Workload of compulsory attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td>2</td>
<td>SoSe</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Exercises</td>
<td>2</td>
<td>SoSe</td>
<td>28</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Präsenzzeit Modul insgesamt</th>
<th>56 h</th>
</tr>
</thead>
</table>
Digitalised Energy System Automation, Control and Optimisation

inf341 - Robust Control and State Estimation in Digitalised Energy Systems

<table>
<thead>
<tr>
<th>Module label</th>
<th>Robust Control and State Estimation in Digitalised Energy Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf341</td>
</tr>
<tr>
<td>Credit points</td>
<td>6.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>180 h</td>
</tr>
</tbody>
</table>

**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 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.

**Methological 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
Kharitonov 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

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

Literatureempfehlungen

- 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
Teaching/Learning method: V + Ü
Previous knowledge: Basic knowledge of the control of linear continuous-time and/or discrete-time systems or of robust control

Examination Prüfungszeiten Type of examination

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

Lehrveranstaltungsform SWS Frequency Workload of compulsory attendance

Lecture

Exercises

Präsenzzeit Modul insgesamt

SWS Frequency Workload of compulsory attendance

Lecture

Exercises

Präsenzzeit Modul insgesamt

56 h
---

**inf5112 - Digitalised Energy System Modeling and Control**

<table>
<thead>
<tr>
<th>Module label</th>
<th>Digitalised Energy System Modeling and Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf5112</td>
</tr>
<tr>
<td>Credit points</td>
<td>6.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>180 h</td>
</tr>
</tbody>
</table>

**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**
No participant requirements

**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.
- estimate the influence of distributed control concepts and algorithms for decentralised plants and consumers in the so-called Smart Grid energy systems.

**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 permissible 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)
- Intelligent network management (Smart Grids), Aggregation forms, machine learning approaches)

**Literatureempfehlungen**

- Konstantin, P.; Praxisbuch Energiewirtschaft, Springer 2006
- Schwab, A.; Elektroenergiesysteme, Springer 2009
- Kittley, J.L.; Electric Power Principies, John Wiley & Sons, 2010
- Gremmel, H.; ABB Schaltanlagen-handbuch, Cornelsen 2007
- Lehrhoff, S.; Dezentrales vernetztes Energiemanagement, 2010

**Links**

<table>
<thead>
<tr>
<th>Language of instruction</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (semesters)</td>
<td>1 Semester</td>
</tr>
<tr>
<td>Module frequency</td>
<td>every summer term</td>
</tr>
<tr>
<td>Module capacity</td>
<td>unlimited</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
<td>V+Ü</td>
</tr>
<tr>
<td>Previous knowledge</td>
<td>none</td>
</tr>
<tr>
<td>Examination</td>
<td>Prüfungszeiten</td>
</tr>
<tr>
<td>Type of examination</td>
<td>written exam or oral exam</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Final exam of module</th>
</tr>
</thead>
<tbody>
<tr>
<td>At the end of the event</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lehrveranstaltungsform</th>
<th>SWS</th>
<th>Frequency</th>
<th>Workload of compulsory attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td>3</td>
<td>SoSe oder WiSe</td>
<td>42</td>
</tr>
<tr>
<td>Exercises</td>
<td>1</td>
<td>SoSe und WiSe</td>
<td>14</td>
</tr>
</tbody>
</table>

| Präsenzzeit Modul insgesamt | 56 h |

<table>
<thead>
<tr>
<th>Comment</th>
<th>SWS</th>
<th>Frequency</th>
<th>Workload of compulsory attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td>3</td>
<td>SoSe oder WiSe</td>
<td>42</td>
</tr>
<tr>
<td>Exercises</td>
<td>1</td>
<td>SoSe und WiSe</td>
<td>14</td>
</tr>
</tbody>
</table>
inf5114 - Digitalised Energy System Requirements Engineering

Module label
Digitalised Energy System Requirements Engineering

Modulkürzel
inf5114

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
No participant requirements

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.

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 regard 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

Language of instruction: English
Duration (semesters): 1 Semester
Module frequency: every winter term
Module capacity: unlimited
Teaching/Learning method: V+Ü
Previous knowledge: none

Examination
Prüfungszeiten: Type of examination
Final exam of module
At the end of the course: term paper

Lehrveranstaltungsform | Comment | SWS | Frequency | Workload of compulsory attendance
--- | --- | --- | --- | ---
Lecture | | 3 | WiSe | 42
Exercises | | 1 | WiSe | 14

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

Module label
Decentralised Nonlinear Model-Based Control in Digitalised Energy Systems

Modulkürzel
inf5118

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
- 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 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
- 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
- explain the obtained results in short presentations

Self competence
The students:
- critically reflect the achieved results of their project work
- 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
Literaturempfehlungen

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

Links

<table>
<thead>
<tr>
<th>Language of instruction</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (semesters)</td>
<td>1 Semester</td>
</tr>
<tr>
<td>Module frequency</td>
<td>every summer term</td>
</tr>
<tr>
<td>Module capacity</td>
<td>unlimited</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
<td>V + Ü</td>
</tr>
<tr>
<td>Previous knowledge</td>
<td>Basic knowledge of the control of linear continuous-time and/or discrete-time systems or of robust control</td>
</tr>
<tr>
<td>Examination</td>
<td>Prüfungszeiten</td>
</tr>
<tr>
<td>Final exam of module</td>
<td>Type of examination</td>
</tr>
<tr>
<td></td>
<td>At the end of the lecture period</td>
</tr>
<tr>
<td></td>
<td>written exam</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lehrveranstaltungsform</th>
<th>Comment</th>
<th>SWS</th>
<th>Frequency</th>
<th>Workload of compulsory attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td></td>
<td>2</td>
<td>SoSe</td>
<td>28</td>
</tr>
<tr>
<td>Practical training</td>
<td></td>
<td>1</td>
<td>SoSe</td>
<td>0</td>
</tr>
<tr>
<td>Exercises</td>
<td></td>
<td>1</td>
<td>SoSe</td>
<td>28</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Module label</th>
<th>Distributed Operation in Digitalised Energy Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf516</td>
</tr>
<tr>
<td>Credit points</td>
<td>6.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>180 h</td>
</tr>
</tbody>
</table>

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


Links

<table>
<thead>
<tr>
<th>Language of instruction</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (semesters)</td>
<td>1 Semester</td>
</tr>
<tr>
<td>Module frequency</td>
<td>every winter term</td>
</tr>
<tr>
<td>Module capacity</td>
<td>50</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
<td>V+Ü</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Previous knowledge</th>
<th>Fundamentals of Optimization, Fundamentals of Digitized Energy Systems</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Examination</th>
<th>Prüfungszeiten</th>
<th>Type of examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final exam of module</td>
<td>In the current semester and at the end of the event</td>
<td>Portfolio or oral exam or written exam</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lehrveranstaltungsform</th>
<th>Comment</th>
<th>SWS</th>
<th>Frequency</th>
<th>Workload of compulsory attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td></td>
<td>2</td>
<td>WiSe</td>
<td>28</td>
</tr>
<tr>
<td>Exercises</td>
<td></td>
<td>2</td>
<td>WiSe</td>
<td>28</td>
</tr>
</tbody>
</table>

| Präsenzzeit Modul insgesamt | 56 h |


inf579 - Special Topics in 'Digitalised Energy Systems' I

<table>
<thead>
<tr>
<th>Module label</th>
<th>Special Topics in 'Digitalised Energy Systems' I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf579</td>
</tr>
<tr>
<td>Credit points</td>
<td>6.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>180 h</td>
</tr>
<tr>
<td>Verwendbarkeit des Moduls</td>
<td>• Master's programme Digitalised Energy Systems (Master) &gt; Digitalised Energy System Automation, Control and Optimisation</td>
</tr>
<tr>
<td>Zuständige Personen</td>
<td>• Nieße, Astrid (module responsibility)</td>
</tr>
<tr>
<td></td>
<td>• Lehrenden, Die im Modul (Prüfungsberechtigt)</td>
</tr>
<tr>
<td>Prerequisites</td>
<td>No participant requirements</td>
</tr>
<tr>
<td>Skills to be acquired in this module</td>
<td>This module integrates current developments in the field of Digitalised Energy Systems in adequate study courses.</td>
</tr>
</tbody>
</table>

**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
- 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
- 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**

To be announced in the course.

**Links**

**Language of instruction**

English

**Duration (semesters)**

1 Semester

**Module frequency**

unregelmäßig

**Module capacity**

unlimited

**Teaching/Learning method**

1VL + 1Ü

**Previous knowledge**

none

**Examination**

Prüfungszeiten

Type of examination

Final exam of module

At the end of the lecture term

Portfolio, Referat or oral examination

**Lehrveranstaltungsform**

VA-Auswahl

**SWS**

2
| Frequency | siehe Angebotsrhythmus Modul |
inf581 - Special Topics in 'Digitalised Energy Systems' II

<table>
<thead>
<tr>
<th>Module label</th>
<th>Special Topics in 'Digitalised Energy Systems' II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf581</td>
</tr>
<tr>
<td>Credit points</td>
<td>6.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>180 h</td>
</tr>
</tbody>
</table>

**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
- 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**

Will be announced in the course

**Links**
<table>
<thead>
<tr>
<th>Language of instruction</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (semesters)</td>
<td>1 Semester</td>
</tr>
<tr>
<td>Module frequency</td>
<td>irregular</td>
</tr>
<tr>
<td>Module capacity</td>
<td>unlimited</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
<td>V + Ü</td>
</tr>
<tr>
<td>Previous knowledge</td>
<td>none</td>
</tr>
</tbody>
</table>

**Examination**

<table>
<thead>
<tr>
<th>Prüfungszeiten</th>
<th>Type of examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final exam of module</td>
<td>At the end of the lecture period</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lehrveranstaltungsform</th>
<th>Comment</th>
<th>SWS</th>
<th>Frequency</th>
<th>Workload of compulsory attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td></td>
<td>2</td>
<td>siehe Angebotsrhythmus Modul</td>
<td>28</td>
</tr>
<tr>
<td>Exercises</td>
<td></td>
<td>2</td>
<td>siehe Angebotsrhythmus Modul</td>
<td>28</td>
</tr>
</tbody>
</table>

**Präsenzzeit Modul insgesamt**

|                   | 56 h |

---

24 / 57
inf584 - Special Topics in 'Energy Informatics' I

<table>
<thead>
<tr>
<th>Module label</th>
<th>Special Topics in 'Energy Informatics' I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf584</td>
</tr>
<tr>
<td>Credit points</td>
<td>6.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>180 h</td>
</tr>
<tr>
<td>Verwendbarkeit des Moduls</td>
<td>Master's Programme Computing Science (Master) &gt; Angewandte Informatik</td>
</tr>
<tr>
<td></td>
<td>Master's programme Digitalised Energy Systems (Master) &gt; Digitalised Energy System Automation, Control and Optimisation</td>
</tr>
<tr>
<td>Zuständige Personen</td>
<td>Lehnhoff, Sebastian (Prüfungsberechtigt)</td>
</tr>
<tr>
<td></td>
<td>Lehrenden, Die im Modul (Prüfungsberechtigt)</td>
</tr>
<tr>
<td>Prerequisites</td>
<td>No participant requirements</td>
</tr>
</tbody>
</table>

**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
- 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

**Links**
<table>
<thead>
<tr>
<th><strong>Language of instruction</strong></th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Duration (semesters)</strong></td>
<td>1 Semester</td>
</tr>
<tr>
<td><strong>Module frequency</strong></td>
<td>irregular</td>
</tr>
<tr>
<td><strong>Module capacity</strong></td>
<td>unlimited</td>
</tr>
<tr>
<td><strong>Teaching/Learning method</strong></td>
<td>2 events from V, S, Ü, P</td>
</tr>
<tr>
<td><strong>Previous knowledge</strong></td>
<td>none</td>
</tr>
<tr>
<td><strong>Examination</strong></td>
<td>Prüfungszeiten</td>
</tr>
<tr>
<td><strong>Final exam of module</strong></td>
<td>Portfolio or presentation or oral exam</td>
</tr>
<tr>
<td><strong>Lehrveranstaltungsform</strong></td>
<td>VA-Auswahl</td>
</tr>
<tr>
<td><strong>SWS</strong></td>
<td>4</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>siehe Angebotsrhythmus Modul</td>
</tr>
<tr>
<td><strong>Workload Präsenzzeit</strong></td>
<td>56 h</td>
</tr>
</tbody>
</table>
**inf585 - Special Topics in 'Energy Informatics' II**

<table>
<thead>
<tr>
<th><strong>Module label</strong></th>
<th>Special Topics in 'Energy Informatics' II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Modulkürzel</strong></td>
<td>inf585</td>
</tr>
<tr>
<td><strong>Credit points</strong></td>
<td>6.0 KP</td>
</tr>
<tr>
<td><strong>Workload</strong></td>
<td>180 h</td>
</tr>
</tbody>
</table>
| **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** | 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

**Links**

**Language of instruction**

German
<table>
<thead>
<tr>
<th>Duration (semesters)</th>
<th>1 Semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module frequency</td>
<td>irregular</td>
</tr>
<tr>
<td>Module capacity</td>
<td>unlimited</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
<td>2 events form V, S, Ü, P</td>
</tr>
<tr>
<td>Previous knowledge</td>
<td>none</td>
</tr>
</tbody>
</table>

**Examination**

<table>
<thead>
<tr>
<th>Examination</th>
<th>Prüfungszeiten</th>
<th>Type of examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final exam of module</td>
<td>At the end of the lecture period</td>
<td>Portfolio or presentation or oral exam</td>
</tr>
</tbody>
</table>

**Lehrveranstaltungsform**

<table>
<thead>
<tr>
<th>Lehrveranstaltungsform</th>
<th>VA-Auswahl</th>
</tr>
</thead>
</table>

**SWS**

| SWS | 4 |

**Frequency**

| Frequency | siehe Angebotssrhythmus Modul |

**Workload Präsenzeit**

| Workload Präsenzeit | 56 h |
Automation and Electrical Engineering

inf5100 - Digital Technology on Energy Markets

<table>
<thead>
<tr>
<th>Module label</th>
<th>Digital Technology on Energy Markets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf5100</td>
</tr>
<tr>
<td>Credit points</td>
<td>6.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>180 h</td>
</tr>
</tbody>
</table>

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
No participant requirements

Skills to be acquired in this module
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

Links

Language of instruction
English

Duration (semesters)
1 Semester
<table>
<thead>
<tr>
<th><strong>Module frequency</strong></th>
<th>annual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Module capacity</strong></td>
<td>unlimited</td>
</tr>
<tr>
<td><strong>Teaching/Learning method</strong></td>
<td>1VL + 1Ü</td>
</tr>
<tr>
<td><strong>Previous knowledge</strong></td>
<td>none</td>
</tr>
<tr>
<td><strong>Examination</strong></td>
<td>Prüfungszeiten</td>
</tr>
<tr>
<td><strong>Type of examination</strong></td>
<td>written exam or oral exam or</td>
</tr>
<tr>
<td><strong>Final exam of module</strong></td>
<td>Following the event period</td>
</tr>
<tr>
<td><strong>Lehrveranstaltungsform</strong></td>
<td>Comment</td>
</tr>
<tr>
<td>Lecture</td>
<td>2</td>
</tr>
<tr>
<td>Exercises</td>
<td>2</td>
</tr>
<tr>
<td>Präsenzzeit Modul insgesamt</td>
<td></td>
</tr>
</tbody>
</table>
inf5102 - Power System Components, Networks, Operation

<table>
<thead>
<tr>
<th>Module label</th>
<th>Power System Components, Networks, Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf5102</td>
</tr>
<tr>
<td>Credit points</td>
<td>6.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>180 h</td>
</tr>
<tr>
<td>Verwendbarkeit des Moduls</td>
<td>Master's programme Digitalised Energy Systems (Master) &gt; Automation and Electrical Engineering</td>
</tr>
<tr>
<td>Zuständige Personen</td>
<td>Gawlik, Wolfgang (module responsibility) Lehrenden, Die im Modul (module responsibility)</td>
</tr>
<tr>
<td>Prerequisites</td>
<td>No participant requirements</td>
</tr>
</tbody>
</table>
| 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.  
**Methological 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**
<table>
<thead>
<tr>
<th>Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language of instruction</td>
</tr>
<tr>
<td>Duration (semesters)</td>
</tr>
<tr>
<td>Module frequency</td>
</tr>
<tr>
<td>Module capacity</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
</tr>
<tr>
<td>Previous knowledge</td>
</tr>
<tr>
<td>Examination</td>
</tr>
<tr>
<td>Final exam of module</td>
</tr>
<tr>
<td>Lehrveranstaltungsform</td>
</tr>
<tr>
<td>SWS</td>
</tr>
<tr>
<td>Frequency</td>
</tr>
</tbody>
</table>
## inf5124 - Research Project Digitalised Energy Systems

<table>
<thead>
<tr>
<th>Module label</th>
<th>Research Project Digitalised Energy Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf5124</td>
</tr>
<tr>
<td>Credit points</td>
<td>15.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>450 h</td>
</tr>
</tbody>
</table>

### Verwendbarkeit des Moduls
- Master's programme Digitalised Energy Systems (Master) > Automation and Electrical Engineering

### Zuständige Personen
- Lehrenden, Die im Modul (module responsibility)
- Rauh, Andreas (module responsibility)

### Prerequisites
It is recommended to take the Research Project only after having completed the other modules of the two areas "Foundations of Digitised Energy Systems" and "Fundamental Competences"

### Skills to be acquired in this module

#### Professional competence
- The students:
  - identify fundamental research concepts of modelling, control, state estimation, simulation, and optimisation of digitalised energy systems

#### Methological competence
- The students:
  - develop solution ideas in a research-oriented environment.

#### Social competence
- The students:
  - 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

#### Self competence
- The students:
  - critically reflect the achieved results of their project and acknowledge limitations of approaches used.

### Module contents
- Project work in teams of students on the basis of current subject proposals made by all teaching staff of DES
- Fundamental literature review
- Independent derivation of research questions
- Implementation and validation of solution approaches

### Literaturempfehlungen
Will be announced in the course

### Links
- Language of instruction: English
- Duration (semesters): 1 Semester
- Module frequency: every semester
- Module capacity: unlimited
- Teaching/Learning method: 1 PR
- Previous knowledge: It is recommended to take the Research Project only after having completed the other modules of the two areas "Foundations of Digitised Energy Systems" and "Fundamental Competences"

### Examination
<table>
<thead>
<tr>
<th>Prüfungszeiten</th>
<th>Type of examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>accompanying the event</td>
<td>Projekt</td>
</tr>
<tr>
<td>Lehrveranstaltungsform</td>
<td>Practical training</td>
</tr>
<tr>
<td>-----------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>SWS</td>
<td>10</td>
</tr>
<tr>
<td>Frequency</td>
<td>SoSe und WiSe</td>
</tr>
</tbody>
</table>
Computer Science and Energy Informatics

inf5104 - Fundamentals of Game Theory in Energy Systems

<table>
<thead>
<tr>
<th>Module label</th>
<th>Fundamentals of Game Theory in Energy Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf5104</td>
</tr>
<tr>
<td>Credit points</td>
<td>6.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>180 h</td>
</tr>
</tbody>
</table>

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

Useful prior knowledge: Fundamentals of optimization

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

Methological 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

Literaturrempfehlungen

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

Links

<table>
<thead>
<tr>
<th>Language of instruction</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (semesters)</td>
<td>1 Semester</td>
</tr>
<tr>
<td>Module frequency</td>
<td>every summer term</td>
</tr>
<tr>
<td>Module capacity</td>
<td>unlimited</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
<td>V+Ü</td>
</tr>
<tr>
<td>Previous knowledge</td>
<td>Useful prior knowledge: Fundamentals of optimization</td>
</tr>
<tr>
<td>Examination</td>
<td>Prüfungszeiten</td>
</tr>
<tr>
<td>Final exam of module</td>
<td>Following the event period</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lehrveranstaltungsform</th>
<th>Comment</th>
<th>SWS</th>
<th>Frequency</th>
<th>Workload of compulsory attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td></td>
<td>2</td>
<td>SoSe</td>
<td>28</td>
</tr>
<tr>
<td>Exercises</td>
<td></td>
<td>2</td>
<td>SoSe</td>
<td>28</td>
</tr>
</tbody>
</table>

Präsenzzeit Modul insgesamt 56 h
inf5106 - Optimal and Model-Predictive Control

<table>
<thead>
<tr>
<th>Module label</th>
<th>Optimal and Model-Predictive Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf5106</td>
</tr>
<tr>
<td>Credit points</td>
<td>6.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>180 h</td>
</tr>
<tr>
<td>Verwendbarkeit des Moduls</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Master's Programme Computing Science (Master) &gt; Angewandte Informatik</td>
</tr>
<tr>
<td></td>
<td>Master's programme Digitalised Energy Systems (Master) &gt; Computer Science and Energy Informatics</td>
</tr>
<tr>
<td>Zuständige Personen</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rauh, Andreas (module responsibility)</td>
</tr>
<tr>
<td></td>
<td>Lehrenden, Die im Modul (Prüfungsberechtigt)</td>
</tr>
<tr>
<td>Prerequisites</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Useful previous knowledge: Basic knowledge of control of linear continuous-time and/or discrete-time systems or robust control.</td>
</tr>
</tbody>
</table>

Skills to be acquired in this module

The students identify fundamentals of the optimisation of control systems

Professional competence
The students:

- identify fundamentals of the optimisation of control systems
- characterise static and dynamic optimisation problems
- are aware of software implementations for selected test rigs

Methological competence
The students:

- analyse problems of optimal control
- generalise them independently toward novel research-oriented application scenarios

Social competence
The students:

- develop solution ideas for real control engineering tasks in small groups in a project/practical course accompanying the lecture
- communicate their results in short presentations

Self competence
The students:

- critically reflect the achieved results of their project work
- acknowledge limitations of various approaches for optimal control design

Module contents

1. Parameter optimization
   - Unconstrained optimisation
   - Optimisation 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

Literatureempfehlungen

- Föllinger, O.: Optimierung dynamischer Systeme. - Eine Einführung für Ingenieure.
Links

<table>
<thead>
<tr>
<th>Language of instruction</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (semesters)</td>
<td>1 Semester</td>
</tr>
<tr>
<td>Module frequency</td>
<td>every summer term</td>
</tr>
<tr>
<td>Module capacity</td>
<td>unlimited</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
<td>1VL + 1Ü</td>
</tr>
<tr>
<td>Previous knowledge</td>
<td>Useful previous knowledge: Basic knowledge of control of linear continuous-time and/or discrete-time systems or robust control.</td>
</tr>
</tbody>
</table>

Examination

<table>
<thead>
<tr>
<th>Prüfungszeiten</th>
<th>Type of examination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Portfolio or projekt</td>
</tr>
</tbody>
</table>

Final exam of module

at the end of the lecture period

<table>
<thead>
<tr>
<th>Lehrveranstaltungsform</th>
<th>Comment</th>
<th>SWS</th>
<th>Frequency</th>
<th>Workload of compulsory attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td></td>
<td>2</td>
<td>SoSe</td>
<td>28</td>
</tr>
<tr>
<td>Exercises</td>
<td></td>
<td>2</td>
<td>SoSe</td>
<td>28</td>
</tr>
</tbody>
</table>

Präsenzzeit Modul insgesamt

56 h
inf5110 - Practical Course (Energy Informatics)

<table>
<thead>
<tr>
<th>Module label</th>
<th>Practical Course (Energy Informatics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf5110</td>
</tr>
<tr>
<td>Credit points</td>
<td>15.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>450 h</td>
</tr>
</tbody>
</table>

**Verwendbarkeit des Moduls**
- Master's programme Digitalised Energy Systems (Master) > Computer Science and Energy Informatics

**Zuständige Personen**
- Lehnhoff, Sebastian (module responsibility)
- Rauh, Andreas (module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

**Prerequisites**
- MATLAB/Simulink, programming basics in Java or Python, development on embedded systems

**Skills to be acquired in this module**

**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)

Literature recommendations
Will be announced in the course

Links
Language of instruction: English

Duration (semesters)
1 Semester

Module frequency
every Semester

Module capacity
unlimited

Teaching/Learning method
1 PR

Previous knowledge
MATLAB/Simulink, programming basics in Java or Python, development on embedded systems

Examination Prüfungszeiten Type of examination
Final exam of module accompanying the event Portfolio

Lehrveranstaltungsform Practical training

SWS

Frequency
SoSe oder WiSe
inf514 - Simulation-based Smart Grid Engineering and Assessment

<table>
<thead>
<tr>
<th>Module label</th>
<th>Simulation-based Smart Grid Engineering and Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf514</td>
</tr>
<tr>
<td>Credit points</td>
<td>6.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>180 h</td>
</tr>
</tbody>
</table>
| 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

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

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

<table>
<thead>
<tr>
<th>Language of instruction</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (semesters)</td>
<td>1 Semester</td>
</tr>
<tr>
<td>Module frequency</td>
<td>every winter term</td>
</tr>
<tr>
<td>Module capacity</td>
<td>unlimited</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
<td>V+Ü</td>
</tr>
<tr>
<td>Previous knowledge</td>
<td>Basic programming in Java or Python</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Examination</th>
<th>Prüfungszeiten</th>
<th>Type of examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final exam of module</td>
<td>At the end of the lecture term</td>
<td>Written exam or oral exam</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lehrveranstaltungsform</th>
<th>Comment</th>
<th>SWS</th>
<th>Frequency</th>
<th>Workload of compulsory attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td></td>
<td>2</td>
<td>WiSe</td>
<td>28</td>
</tr>
<tr>
<td>Exercises</td>
<td></td>
<td>2</td>
<td>WiSe</td>
<td>28</td>
</tr>
</tbody>
</table>

| Präsenzzeit Modul insgesamt | 56 h |


Innovation Topics and Smart Grids

inf5126 - Digitalised Energy System Cyber-Resilience

Module label: Digitalised Energy System Cyber-Resilience
Modulkürzel: inf5126
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)
- Lehrende, Die im Modul (Prüfungsberechtigt)

Prerequisites
-No participant requirements

Skills to be acquired in this module

This module integrates current developments in cyber resilience and its application to energy systems.

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

Methological 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

Literatureempfehlungen
Will be announced in the course
<table>
<thead>
<tr>
<th>Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language of instruction</td>
</tr>
<tr>
<td>Duration (semesters)</td>
</tr>
<tr>
<td>Module frequency</td>
</tr>
<tr>
<td>Module capacity</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
</tr>
<tr>
<td>Previous knowledge</td>
</tr>
<tr>
<td>Examination</td>
</tr>
<tr>
<td>Type of examination</td>
</tr>
<tr>
<td>at the end of the lecture period</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lehrveranstaltungsform</th>
<th>Comment</th>
<th>SWS</th>
<th>Frequency</th>
<th>Workload of compulsory attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td>1</td>
<td></td>
<td>SoSe</td>
<td>14</td>
</tr>
<tr>
<td>Seminar</td>
<td>1</td>
<td></td>
<td>SoSe</td>
<td>14</td>
</tr>
</tbody>
</table>

| Präsenzzeit Modul insgesamt | 28 h |
inf5128 - AI in Energy Systems

<table>
<thead>
<tr>
<th>Module label</th>
<th>AI in Energy Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf5128</td>
</tr>
<tr>
<td>Credit points</td>
<td>3.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>90 h</td>
</tr>
</tbody>
</table>

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

**Literatureempfehlungen**

**Links**

- Language of instruction: English
- Duration (semesters): 1 Semester
- Module frequency: irregular
- Module capacity: unlimited
<table>
<thead>
<tr>
<th>Teaching/Learning method</th>
<th>V or S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous knowledge</td>
<td>none</td>
</tr>
<tr>
<td>Examination</td>
<td>Prüfungszeiten</td>
</tr>
<tr>
<td>Final exam of module</td>
<td>at the end of the lecture period</td>
</tr>
<tr>
<td></td>
<td>term paper</td>
</tr>
<tr>
<td>Lehrveranstaltungsform</td>
<td>Course or seminar</td>
</tr>
<tr>
<td>SWS</td>
<td>2</td>
</tr>
<tr>
<td>Frequency</td>
<td>SoSe</td>
</tr>
<tr>
<td>Workload Präsenzzzeit</td>
<td>28 h</td>
</tr>
</tbody>
</table>
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:
No participant requirements

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

Literatureempfehlungen

Will be announced in the course
<table>
<thead>
<tr>
<th>Links</th>
<th>Language of instruction</th>
<th>1 Semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language of instruction</td>
<td>English</td>
<td></td>
</tr>
<tr>
<td>Duration (semesters)</td>
<td>1 Semester</td>
<td></td>
</tr>
<tr>
<td>Module frequency</td>
<td>irregular</td>
<td></td>
</tr>
<tr>
<td>Module capacity</td>
<td>unlimited</td>
<td></td>
</tr>
<tr>
<td>Teaching/Learning method</td>
<td>V oder S</td>
<td></td>
</tr>
<tr>
<td>Previous knowledge</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>Examination</td>
<td>Prüfungszeiten</td>
<td></td>
</tr>
<tr>
<td>Final exam of module</td>
<td>at the end of the lecture period</td>
<td>term paper</td>
</tr>
<tr>
<td>Lehrveranstaltungsform</td>
<td>Course or seminar</td>
<td></td>
</tr>
<tr>
<td>SWS</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>WiSe</td>
<td></td>
</tr>
<tr>
<td>Workload Präsenzzeit</td>
<td>28 h</td>
<td></td>
</tr>
</tbody>
</table>
inf586 - Current Topics in 'Energy Informatics' I

<table>
<thead>
<tr>
<th>Module label</th>
<th>Current Topics in 'Energy Informatics' I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf586</td>
</tr>
<tr>
<td>Credit points</td>
<td>3.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>90 h</td>
</tr>
</tbody>
</table>

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)
- Lehrenden, 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

Literaturempfehlungen

Depending on the assigned course
<table>
<thead>
<tr>
<th>Links</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Language of instruction</td>
<td>English</td>
</tr>
<tr>
<td>Duration (semesters)</td>
<td>1 Semester</td>
</tr>
<tr>
<td>Module frequency</td>
<td>irregular</td>
</tr>
<tr>
<td>Module capacity</td>
<td>unlimited</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
<td>V or S</td>
</tr>
<tr>
<td>Previous knowledge</td>
<td>none</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Examination</th>
<th>Prüfungszeiten</th>
<th>Type of examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final exam of module</td>
<td>At the end of the lecture period</td>
<td>Presentation or oral exam</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lehrveranstaltungsform</th>
<th>Course or seminar</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWS</td>
<td>2</td>
</tr>
<tr>
<td>Frequency</td>
<td>SoSe oder WiSe</td>
</tr>
<tr>
<td>Workload Präsenzzeit</td>
<td>28 h</td>
</tr>
</tbody>
</table>
inf587 - Current Topics in 'Energy Informatics' II

<table>
<thead>
<tr>
<th>Module label</th>
<th>Current Topics in 'Energy Informatics' II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf587</td>
</tr>
<tr>
<td>Credit points</td>
<td>3.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>90 h</td>
</tr>
<tr>
<td>Verwendbarkeit des Moduls</td>
<td>Master's Programme Computing Science (Master) &gt; Angewandte Informatik</td>
</tr>
<tr>
<td></td>
<td>Master's programme Digitalised Energy Systems (Master) &gt; Innovation Topics and Smart Grids</td>
</tr>
<tr>
<td>Zuständige Personen</td>
<td>Lehnhoff, Sebastian (module responsibility)</td>
</tr>
<tr>
<td></td>
<td>Lehrenden, Die im Modul (Prüfungsberechtigt)</td>
</tr>
</tbody>
</table>

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
Will be announced in the course
<table>
<thead>
<tr>
<th>Links</th>
<th>Language of instruction</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (semesters)</td>
<td></td>
<td>1 Semester</td>
</tr>
<tr>
<td>Module frequency</td>
<td></td>
<td>irregular</td>
</tr>
<tr>
<td>Module capacity</td>
<td></td>
<td>unlimited</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
<td></td>
<td>V or S</td>
</tr>
<tr>
<td>Previous knowledge</td>
<td></td>
<td>none</td>
</tr>
<tr>
<td>Examination</td>
<td>Prüfungszeiten</td>
<td></td>
</tr>
<tr>
<td><strong>Final exam of module</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>At the end of the lecture period</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Written exam or portfolio or presentation or oral exam</td>
<td></td>
</tr>
<tr>
<td>Lehrveranstaltungsform</td>
<td>Course or seminar</td>
<td></td>
</tr>
<tr>
<td>SWS</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>SoSe oder WiSe</td>
<td></td>
</tr>
<tr>
<td>Workload Präsenzeit</td>
<td>28 h</td>
<td></td>
</tr>
</tbody>
</table>
### inf591 - Current Topics in 'Digitalized Energy systems'

<table>
<thead>
<tr>
<th>Module label</th>
<th>Current Topics in ‘Digitalized Energy systems’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>inf591</td>
</tr>
<tr>
<td>Credit points</td>
<td>3.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>90 h</td>
</tr>
</tbody>
</table>

### 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
- Nieße, Astrid (module responsibility)
- Lehrenden, Die im Modul (Prüfungsberechtigt)

### Prerequisites
- No participant requirement

### 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

Will be announced in the course
<table>
<thead>
<tr>
<th>Links</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Language of instruction</td>
<td>English</td>
</tr>
<tr>
<td>Duration (semesters)</td>
<td>1 Semester</td>
</tr>
<tr>
<td>Module frequency</td>
<td>irregular</td>
</tr>
<tr>
<td>Module capacity</td>
<td>unlimited</td>
</tr>
<tr>
<td>Teaching/Learning method</td>
<td>V or S</td>
</tr>
<tr>
<td>Previous knowledge</td>
<td>none</td>
</tr>
<tr>
<td>Examination</td>
<td>Prüfungszeiten</td>
</tr>
<tr>
<td><strong>Final exam of module</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>At the end of the lecture period</td>
</tr>
<tr>
<td>Lehrveranstaltungsform</td>
<td>Course or seminar</td>
</tr>
<tr>
<td>SWS</td>
<td>2</td>
</tr>
<tr>
<td>Frequency</td>
<td>WiSe</td>
</tr>
<tr>
<td>Workload Präsenzeit</td>
<td>28 h</td>
</tr>
</tbody>
</table>
Abschlussmodul

mam - Master Thesis Module Digitalised Energy Systems

<table>
<thead>
<tr>
<th>Module label</th>
<th>Master Thesis Module Digitalised Energy Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulkürzel</td>
<td>mam</td>
</tr>
<tr>
<td>Credit points</td>
<td>30.0 KP</td>
</tr>
<tr>
<td>Workload</td>
<td>900 h</td>
</tr>
</tbody>
</table>

Verwendbarkeit des Moduls
- Master's programme Digitalised Energy Systems (Master) > Abschlussmodul

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

Prerequisites
- Modules of the study program that are thematically relevant for the topic of the Master's thesis

Skills to be acquired in this module
The students prove that they are able to process and solve complex computer science tasks based on gained scientific knowledge and applied research methods. The students successfully implement a task especially by using their acquired professional and methodological knowledge and their professional and social competences.

The accompanying seminar is used to discuss the master's thesis methodically and content-related. During the seminar the exchange of research and practical experience fosters the students' ability to discuss and evaluate their thesis with other students and experts.

The master's thesis is finished by a colloquium

Professional competences
The students:
- recognise and evaluate applied techniques and methods of their subject and are aware of their limits
- design solutions for complex, possibly vaguely defined or unusual computer science tasks/problems and evaluate these with reference to state of the art computer science and technology
- identify, structure and solve problems/tasks, also in new or developing subject areas
- relate knowledge from different disciplines and apply this new knowledge in complex situations
- develop complex computer systems, processes and datamodels
- 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:
- identify and develop one or more solutions
- evaluate and apply tools, technology and methods sophisticatedly
- examine tasks with technical and research literature, write an academic article and present their solutions academically
- schedule processes and resources
- apply project management techniques
- 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:
- communicate with users and experts convincingly
- make reasonable decisions

Self-competences
The students:
- pursue the overall and special computer science development critically
- implement innovative professional activities effectively and independently
- recognise their abilities and extend them purposefully
- reflect their self-perception and actions with regard to professional,
methodological and social aspects
• develop and reflect self-developed hypotheses to theories independently
• work in their field independently

| Module contents | The content of this module is an independent topic research. The research findings will be presented and discussed in a master’s thesis colloquium |
| Literatureempfehlungen | Will be specified according to the concrete topic |
| Links |  |
| Language of instruction | English |
| Duration (semesters) | 1 Semester |
| Module frequency | every semester |
| Module capacity | unlimited |
| Teaching/Learning method | 1S |
| Previous knowledge | Modules of the study program that are thematically relevant for the topic of the Master’s thesis |
| Examination | Prüfungszeiten | Type of examination |
| Final exam of module | continuous | Preparation and submission of the master's thesis according to the examination regulations. Defense of the master thesis in a final colloquium |
| Lehrveranstaltungsform | Colloquium |
| SWS |  |
| Frequency | SoSe oder WiSe |