Date 25/05/24

Digitalised Energy System Design and Assessment

inf340 - Uncertainty Modeling for Control in Digitalised Energy Systems

Module label	Uncertainty Modeling for Control in Digitalised Energy Systems
Modulkürzel	inf340
Credit points	6.0 KP
Workload	180 h
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 andobserver synthesis. **Professional competences** The students: • identify fundamentals of uncertainty modeling in control systems • characterize problem-specific solution techniques for systems with stochastic and set-based uncertainty • are aware of software implementations in simulation, control, and state estimation. **Methological competences** The students: • students identify fundamentals of uncertainty modelling in control systems • 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, Springer- Verlag, 2001.
- Papoulis, A.: Probability, Random Variables, and Stochastic Processes, McGraw- Hill, 4th Ed., 2002.
- Rauh, A. Folien/ Skript zur Vorlesung „Uncertainty Modelling for Control in DES“.

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

Examination	Prüfungszeiten	Type of examination
Final exam of module	Following the event period	Portfolio or written exam

Lehrveranstaltungsform	Comment	SWS	Frequency	Workload of compulsory attendance
Lecture		2	WiSe	2
Exercises		1	WiSe	1
Project		1	WiSe	1
Präsenzzeit Modul insgesamt				4 h

inf5120 - Digitalised Energy System Co-Simulation

Module label	Digitalised Energy System Co-Simulation
Modulkürzel	inf5120
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
Zuständige Personen	• Bremer, Jörg (module responsibility) • Lehrenden, Die im Modul (Prüfungsberechtigt)
Prerequisites	Programming mit Python, Simulation-based Smart Grid Engineering and Assessment

Skills to be acquired in this module

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

Profesional competence
The student:

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

Methological competence
The student:

- model simple controllable electrical generators and consumers
- simulate simple controllable electrical generators and consumers with appropriate control algorithms within smart grid scenarios
- apply distributed agent-based control schemes to decentralised energy generators and/ or consumers
- evaluate simulation results
- search information and look into methods to implement models
- propose hyphothesis and ckeck 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 executyble 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.

Literaturempfehlungen

Smart Grids:

- Konstantin, P.: "Praxisbuch Energiewirtschaft", Springer, 2006
- Schwab, A.: "Elektroenergiesysteme", Springer, 2009

Multiagentensysteme

- Sutton, R. S.; Barto, A. G.: "Reinforcement Learning", MIT Press, 1998-Weiss, G.: "Multiagent Systems", MIT Press, 2013
- Ferber J.; Kirn, S.: "Multiagentensysteme: eine Einführung in die Verteilte Künstliche Intelligenz", Addison-Wesley, 2001

Co-Simulation

- Ptolemaeus, C.: "System Design, Modeling, and Simulation", UC Berkeley, 2013
- Law, A.: "Simulation Modeling and Analysis", McGraw-Hill, 2015

Versuchsplanung

- Kleppmann, W.: "Versuchsplanung", Hanser, 2013
- Klein, B.: "Versuchsplanung - DoE", Oldenbourg, 2011
- Goos, P.; Jones, B.: "Optimal Design of Experiments", Wiley, 2014
- Box, G. E. P.; Hunter, J. S.; Hunter, W. G.: "Statistics for Experimenters", Wiley, 2005
- Forrester, A.; Sobester, A.; Keane, A.: "Engineering Design via Surrogate Modelling", Wiley, 2008

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	Practikal 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

SWS	2
Frequency	SoSe
Workload Präsenzzeit	28 h

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-timesystems 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. **Methological 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

- Moore, K.L. Iterative Learning Control for Deterministic Systems. London: Springer- Verlag. 1993
- Jian Xin Xu; Ying Tan. Linear and Nonlinear Iterative Learning Control. Springer- Verlag. 2003
- Bristow, D. A.; Tharayil, M.; Alleyne, A. G. "A Survey of Iterative Learning Control A learning-based method for high-performance tracking control". IEEE control systems magazine. Vol. 26. pp. 96–114. 2006
- The Mathworks Inc. Deep Learning Toolbox – Documentation, 2021
- Rauh, A. Folien/ Skript zur Vorlesung „Learning-Based Control in DES“

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

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

Lehrveranstaltungsform	Comment	SWS	Frequency	Workload of compulsory attendance
Lecture		2	SoSe	28
Exercises		2	SoSe	28
Präsenzzeit Modul insgesamt				56 h

Digitalised Energy System Automation, Control and Optimisation

inf341 - Robust Control and State Estimation in Digitalised Energy Systems

Module label	Robust Control and State Estimation in Digitalised Energy Systems
Modulkürzel	inf341
Credit points	6.0 KP
Workload	180 h
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
4. Duality between control and observer synthesis
   - Robust state estimation
   - Sliding mode observers
5. Interval methods: Solution of static and dynamic problems (Enclosing function values, Branch-and-bound techniques, Verification techniques for differential equations)
6. Fundamentals: Fault detection and fault-tolerant control

Literaturempfehlungen

- Ackermann, J. Robust Control, Springer-Verlag, 2002.
- Gu, D.-W.; Petkov, P.H.; Konstantinov, M.M., Robust Control Design with MATLAB, Springer-Verlag, 2013
- Ostertag, 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	Portfolio or written exam

Lehrveranstaltungsform	Comment	SWS	Frequency	Workload of compulsory attendance
Lecture		2	WiSe	28
Exercises		2	WiSe	28
Präsenzzeit Modul insgesamt				56 h

inf5112 - Digitalised Energy System Modeling and Control

Module label	Digitalised Energy System Modeling and Control
Modulkürzel	inf5112
Credit points	6.0 KP
Workload	180 h
Verwendbarkeit des Moduls	• Master's Programme Computing Science (Master) > Angewandte Informatik • Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Automation, Control and Optimisation
Zuständige Personen	• Lehnhoff, Sebastian (module responsibility) • Lehrenden, Die im Modul (Prüfungsberechtigt)
Prerequisites	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. **Methological competence** The students: • analyse the safety, reliability, realtime capability and flexibility of Smart Grid energy systems • use advanced mathemtical methods to calculate networks **Social competence** The students: • create solutions in small teams • discuss their solutions **Self competence** The students: reflect their own use of the limited resource power
Module contents	

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

These are:

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

Literaturempfehlungen

- Konstantin, P.; Praxisbuch Energiewirtschaft, Springer 2006
- Schwab, A.; Elektroenergiesysteme, Springer 2009
- Kirtley, J.L.; Electric Power Principles, John Wiley & Sons, 2010
- Gremmel, H.; ABB Schaltanlagen-handbuch, Cornelsen 2007
- Lehnhoff, S.: Dezentrales vernetztes Energiemanagement, 2010
- Sutton, R.S.; Barto, A.G.: Reinforcement Learning, MIT Press 1998

Links	
Language of instruction	English
Duration (semesters)	1 Semester
Module frequency	every summer 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 event	written exam or oral exam

Lehrveranstaltungsform	Comment	SWS	Frequency	Workload of compulsory attendance
Lecture		3	SoSe oder WiSe	42
Exercises		1	SoSe und WiSe	14
Präsenzzeit Modul insgesamt				56 h

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 **Methological competence** The students: • name problems for the energy management, analyse these problems systematically and provide solutions • apply different simulation approaches of decentralised plants and consumers **Social competence** The students: • discuss solutions for the energy management together • develop use cases in teams • present self-developed solutions **Self competence** The students: • reflect their actions with regarde to structure and decompose systems • reflect their own use of the limited resource power
Module contents	This module provides the computer science basics for the energy management. It provides the requirements of energy supply information systems with the focus on technical components and the requirements of decentralised and renewable energy plants. These are: • Architectures for energy information systems, e.g. SOA, Seamless Integration Architecture (IEC TC 57), OPC-UA • Norms and standards of energy industry data models(CIM, 61850) • Systematisation of energy information system requirements based on ontologies • Development, analysis and adaption of energy industry reference models and processes • Methods and technologies to support energy industry processes • Methods and algorithms to support decision processes of the decentralised energy plants control

- Smart Grid plants communication, the load management in particular
- Methods for modelling and simulation of power supply system dynamics

Literaturempfehlungen	

- Crastan V.: "Elektrische Energieversorgung II", Springer 2004
- Heuck K., Dettman K. D., Schulz D.: "Elektische Energieversorgung I", 7. Aufl., Vieweg 2007
- Konstantin, P.: "Praxisbuch Energiewirtschaft", Springer 2006
- Schwab, A.: "Elektroenergiesysteme, Springer 2009

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
Präsenzzeit 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 stateestimation 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 forselected test rigs **Methological competence** The students: • analyse problems of nonlinear control and state estimation and generalise them independently toward novel research-oriented applicationscenarios **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 inshort presentations **Self competence** The students: • critically reflect the achieved results of their project work • acknowledge limitations of various approaches fornonlinear 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 ◦ Ljapunovmethods ◦ Stability of limit cycles ◦ Criteria for the proof of instability 4. Nonlinear control design ◦ Control Lyapunov functions ◦ Beackstepping control ◦ Feedback linearization ◦ Flatness-based control 5. Nonlinear observer synthesis

Literaturempfehlungen	• Föllinger, O.: Nichtlineare Regelungen 1 / 2. Oldenbourg-Verlag, München, 1989. Adamy, J.: Nichtlineare Regelungen; Springer Verlag, 2009. • Unbehauen, H.: Regelungstechnik II. 9. Aufl., Vieweg-Verlag, 2007. Marquez, H.: Nonlinear Control Systems, Wiley, 2003 • Khalil, H.K.: Nonlinear Systems, Pearson, 2001 • Rauh, A. Folien/ Skript zur Vorlesung „Decentralised Nonlinear Model-Based Control in DES“.

Links	
Language of instruction	English
Duration (semesters)	1 Semester
Module frequency	every summer 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	At the end of the lecture period	written exam

Lehrveranstaltungsform	Comment	SWS	Frequency	Workload of compulsory attendance
Lecture		2	SoSe	28
Practical training		1	SoSe	0
Exercises		1	SoSe	28
Präsenzzeit Modul insgesamt				56 h

inf516 - Distributed Operation in Digitalised Energy Systems

Module label	Distributed Operation in Digitalised Energy Systems
Modulkürzel	inf516
Credit points	6.0 KP
Workload	180 h
Verwendbarkeit des Moduls	• Master's Programme Computing Science (Master) > Angewandte Informatik • Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Automation, Control and Optimisation
Zuständige Personen	• Nieße, Astrid (module responsibility) • Lehrenden, Die im Modul (Prüfungsberechtigt)
Prerequisites	Fundamentals of Optimization, Fundamentals of Digitized Energy Systems
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 **Methological competence** The students: • will be able to present the fundamental concepts of distributed optimization and agent systems mentioned above and apply them to applicationproblems 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 questionthe 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 competetive 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

- Yoav Shoham und Kevin Leyton-Brown Multiagent Systems: Algorithmic, Game- Theoretic, and Logical Foundations New York: Cambridge University Press, 2008, ISBN: 9780521899437
- Michael Wooldridge An introduction to multiagent systems Wiley, 2009, ISBN: 0470519460 3.
- Russell und Peter Norvig Artificial intelligence : a modern approach Boston Pearson, 2018, ISBN: 0134610997;
- Nancy Ann Lynch Distributed algorithms Kaufmann, 2003, ISBN: 1558603484

Links	
Language of instruction	English
Duration (semesters)	1 Semester
Module frequency	every winter term
Module capacity	50
Teaching/Learning method	V+Ü
Previous knowledge	Fundamentals of Optimization, Fundamentals of Digitized Energy Systems

Examination	Prüfungszeiten	Type of examination
Final exam of module	In the current semester and at the end of the event	Portfolio or oral exam or written exam

Lehrveranstaltungsform	Comment	SWS	Frequency	Workload of compulsory attendance
Lecture		2	WiSe	28
Exercises		2	WiSe	28
Präsenzzeit Modul insgesamt				56 h

inf579 - Special Topics in 'Digitalised Energy Systems' I

Module label	Special Topics in 'Digitalised Energy Systems' I
Modulkürzel	inf579
Credit points	6.0 KP
Workload	180 h
Verwendbarkeit des Moduls	• Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Automation, Control and Optimisation
Zuständige Personen	• Nieße, Astrid (module responsibility) • Lehrenden, Die im Modul (Prüfungsberechtigt)
Prerequisites	No participant requirements
Skills to be acquired in this module	This module integrates current developments in the field of Digitalised Energy Systems in adequate study courses. **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 **Methological competences** The students: • evalutate 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 examitnation

Lehrveranstaltungsform	VA-Auswahl
SWS	4

Frequency	siehe Angebotsrhythmus Modul
Workload Präsenzzeit	56 h

inf581 - Special Topics in 'Digitalised Energy Systems' II

Module label	Special Topics in 'Digitalised Energy Systems' II
Modulkürzel	inf581
Credit points	6.0 KP
Workload	180 h
Verwendbarkeit des Moduls	• Master's Programme Computing Science (Master) > Angewandte Informatik • Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Automation, Control and Optimisation
Zuständige Personen	• Nieße, Astrid (module responsibility) • Lehrenden, Die im Modul (Prüfungsberechtigt)
Prerequisites	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
Literaturempfehlungen	Will be announced in the course
Links	

Language of instruction	English
Duration (semesters)	1 Semester
Module frequency	irregular
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 lecture period	Portfolio or presentation or oral examination

Lehrveranstaltungsform	Comment	SWS	Frequency	Workload of compulsory attendance
Lecture		2	siehe Angebotsrhythmus Modul	28
Exercises		2	siehe Angebotsrhythmus Modul	28
Präsenzzeit Modul insgesamt				56 h

inf584 - Special Topics in 'Energy Informatics' I

Module label	Special Topics in 'Energy Informatics' I
Modulkürzel	inf584
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 (Prüfungsberechtigt) • 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 • 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	As announced in course
Links	

Language of instruction	English	
Duration (semesters)	1 Semester	
Module frequency	irregular	
Module capacity	unlimited	
Teaching/Learning method	2 evets from V, S, Ü, P	
Previous knowledge	none	
Examination	Prüfungszeiten	Type of examination
Final exam of module	At the end of the lecture period	Portfolio or presentation or oral exam

Lehrveranstaltungsform	VA-Auswahl
SWS	4
Frequency	siehe Angebotsrhythmus Modul
Workload Präsenzzeit	56 h

inf585 - Special Topics in 'Energy Informatics' II

Module label	Special Topics in 'Energy Informatics' II
Modulkürzel	inf585
Credit points	6.0 KP
Workload	180 h
Verwendbarkeit des Moduls	• Master's Programme Computing Science (Master) > Angewandte Informatik • Master's programme Digitalised Energy Systems (Master) > Digitalised Energy System Automation, Control and Optimisation
Zuständige Personen	• Lehnhoff, Sebastian (module responsibility) • 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
Literaturempfehlungen	As announced in course
Links	
Language of instruction	German

Duration (semesters)	1 Semester	
Module frequency	irregular	
Module capacity	unlimited	
Teaching/Learning method	2 events form V, S, Ü, P	
Previous knowledge	none	
Examination	Prüfungszeiten	Type of examination
Final exam of module	At the end of the lecture period	Portfolio or presentation or oral exam

Lehrveranstaltungsform	VA-Auswahl
SWS	4
Frequency	siehe Angebotsrhythmus Modul
Workload Präsenzzeit	56 h

Automation and Electrical Engineering

inf5100 - Digital Technology on Energy Markets

Module label	Digital Technology on Energy Markets
Modulkürzel	inf5100
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) > 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
Literaturempfehlungen	
Links	
Language of instruction	English
Duration (semesters)	1 Semester

Module frequency			annual		
Module capacity			unlimited		
Teaching/Learning method			1VL + 1Ü		
Previous knowledge			none		
Examination		Prüfungszeiten		Type of examination	
Final exam of module		Following the event period		written exam or oral exam or	
Lehrveranstaltungsform	Comment	SWS		Frequency	Workload of compulsory attendance
Lecture		2		WiSe	28
Exercises		2		WiSe	28
Präsenzzeit Modul insgesamt					56 h

inf5102 - Power System Components, Networks, Operation

Module label	Power System Components, Networks, Operation
Modulkürzel	inf5102
Credit points	6.0 KP
Workload	180 h
Verwendbarkeit des Moduls	• Master's programme Digitalised Energy Systems (Master) > Automation and Electrical Engineering
Zuständige Personen	• Gawlik, Wolfgang (module responsibility) • Lehrenden, Die im Modul (module responsibility)
Prerequisites	No participant requirements
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	

- S Krishna: An Introduction to Modelling of Power System Components, SpringerBriefs in Electrical and Computer Engineering, https://doi.org/10.1007/978-81-322-1847-0
- Richard Marenbach, Johann Jäger, Dieter Nelles: Elektrische Energietechnik, Springer Springer Vieweg Wiesbaden, https://doi.org/10.1007/978-3-658-29492-2

Links			
Language of instruction		English	
Duration (semesters)		1 Semester	
Module frequency		every winter term	
Module capacity		unlimited	
Teaching/Learning method		1 VL	
Previous knowledge		Fundamentals of electrical engineering, electrodynamics	
Examination	Prüfungszeiten		Type of examination
Final exam of module	Following the event period		Written exam
Lehrveranstaltungsform	Lecture		
SWS	4		
Frequency	WiSe		

inf5124 - Research Project Digitalised Energy Systems

Module label	Research Project Digitalised Energy Systems
Modulkürzel	inf5124
Credit points	15.0 KP
Workload	450 h
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	The students identify fundamental research concepts of modelling, control, state estimation, simulation, and optimisation of digitalised energy systems **Professional competence** The students: • identify fundamental concepts for design and operation of digitalised energy systems • characterise different solution approaches • recognise the implementation of selected aspects such as simulation and optimisation **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	Prüfungszeiten	Type of examination
Final exam of module	accompanying the event	Projekt

Lehrveranstaltungsform	Practical training
SWS	10
Frequency	SoSe und WiSe

Computer Science and Energy Informatics

inf5104 - Fundamentals of Game Theory in Energy Systems

Module label	Fundamentals of Game Theory in Energy Systems
Modulkürzel	inf5104
Credit points	6.0 KP
Workload	180 h
Verwendbarkeit des Moduls	• Master's Programme Computing Science (Master) > Angewandte Informatik • Master's programme Digitalised Energy Systems (Master) > Computer Science and Energy Informatics
Zuständige Personen	• Nieße, Astrid (module responsibility) • Lehrenden, Die im Modul (Prüfungsberechtigt)
Prerequisites	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
- Discont factor
- Mechanims design, markets and auctions

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

Literaturempfehlungen	

- Dario Bauso: Game Theory with Engineering Applications. Society for Indstrial and Applied Mathematics, Philadelphia, 2016
- Shoham, Leyton-Brown: Multiagent systems. Cambridge University Press, 2010. http://www.masfoundations.org
- Fudenberg, Tirole: Game Theory. MIT Press, 1991

Links	
Language of instruction	English
Duration (semesters)	1 Semester
Module frequency	every summer term
Module capacity	unlimited
Teaching/Learning method	V+Ü
Previous knowledge	Useful prior knowledge: Fundamentals of optimization

Examination	Prüfungszeiten	Type of examination
Final exam of module	Following the event period	Written exam

Lehrveranstaltungsform	Comment	SWS	Frequency	Workload of compulsory attendance
Lecture		2	SoSe	28
Exercises		2	SoSe	28
Präsenzzeit Modul insgesamt				56 h

inf5106 - Optimal and Model-Predictive Control

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

Literaturempfehlungen	• Anderson, B. D. O., Moore, J. B.: Linear Optimal Control. Prentice Hall, New Jersey, 1971. • Föllinger, O.: Optimierung dynamischer Systeme. - Eine Einführung für Ingenieure.

- Oldenbourg-Verlag, München, 1985.
- Papageorgiou, M.; Leibold, M.; Buss, M.: Optimierung. Statische, dynamische, stochastische Verfahren für die Anwendung. 3. Aufl., Springer-Verlag, Berlin, 2012.
- Rauh, A. Folien/ Skript zur Vorlesung „Optimal and Model-Predictive Control“.

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

Examination	Prüfungszeiten	Type of examination
Final exam of module		
	at the end of the lecture period	Portfolio or projekt

Lehrveranstaltungsform	Comment	SWS	Frequency	Workload of compulsory attendance
Lecture		2	SoSe	28
Exercises		2	SoSe	28
Präsenzzeit Modul insgesamt				56 h

inf5110 - Practical Course (Energy Informatics)

Module label	Practical Course (Energy Informatics)
Modulkürzel	inf5110
Credit points	15.0 KP
Workload	450 h
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	The aim of the module is to impart practical competences required in energy informatics for the implementation of control and regulation approaches in the field on plants and in the grid. **Professional competence** The students: • know basic modelling approaches for components in power systems. • know procedures for parameter identification • know linear and non-linear methods for closed-loop and optimised control of technical systems • know basic procedures for dealing with faults and technical malfunctions in control systems • know the challenges of implementing control approaches on resource-constrained engineeredsystems in the field **Methological competence** The students: • select appropriate modelling approaches • apply methods for parameter identification • apply methods for the control of technical operating parameters • implement these approacheson 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)

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	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

Module label	Simulation-based Smart Grid Engineering and Assessment
Modulkürzel	inf514
Credit points	6.0 KP
Workload	180 h
Verwendbarkeit des Moduls	• Master's Programme Computing Science (Master) > Angewandte Informatik • Master's programme Digitalised Energy Systems (Master) > Computer Science and Energy Informatics
Zuständige Personen	• 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 **Methological 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.
Literaturempfehlungen	Will be announced in the lecture

Links	
Language of instruction	English
Duration (semesters)	1 Semester
Module frequency	every winter term
Module capacity	unlimited
Teaching/Learning method	V+Ü
Previous knowledge	Basic programming in Java or Python

Examination	Prüfungszeiten	Type of examination
Final exam of module	At the end of the lecture term	Written exam or oral exam

Lehrveranstaltungsform	Comment	SWS	Frequency	Workload of compulsory attendance
Lecture		2	WiSe	28
Exercises		2	WiSe	28
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) • Lehrenden, 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 andexperts 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 andtheories independently.
Module contents	• Energy system as critical infrastructure (KRITIS) • Propagation of phenomena and their dynamics • Omnipresent conflicts of objectives • Susceptibility of the energy system to new effects, such as the occurrence of "classic" IT challenges (errors, update management, interactions, …) and to sophisticated cyber-attacks
Literaturempfehlungen	Will be announced in the course

Links	
Language of instruction	English
Duration (semesters)	1 Semester
Module frequency	irregular
Module capacity	unlimited
Teaching/Learning method	V or S
Previous knowledge	none

Examination	Prüfungszeiten	Type of examination
Final exam of module		
	at the end of the lecture period	term paper

Lehrveranstaltungsform	Comment	SWS	Frequency	Workload of compulsory attendance
Lecture		1	SoSe	14
Seminar		1	SoSe	14
Präsenzzeit Modul insgesamt				28 h

inf5128 - AI in Energy Systems

Module label	AI in Energy Systems
Modulkürzel	inf5128
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	• Bremer, Jörg (module responsibility) • Lehrenden, Die im Modul (Prüfungsberechtigt)
Prerequisites	No participant requirements
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 **Methological 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
Literaturempfehlungen	
Links	
Language of instruction	English
Duration (semesters)	1 Semester
Module frequency	irregular
Module capacity	unlimited

Teaching/Learning method	V or S	
Previous knowledge	none	
Examination	Prüfungszeiten	Type of examination
Final exam of module	at the end of the lecture period	term paper

Lehrveranstaltungsform	Course or seminar
SWS	2
Frequency	SoSe
Workload Präsenzzeit	28 h

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 **Methological competences** The students • examine tasks with technical and research literature, write an academic article and present their solutions academically • evaluate problems of socio-technical energy system • schedule time processes and resources **Social competences** The students • communicate with colleagues and experts convincingly **Self competences** The students • pursue the integration of humans and human behaviour into cyber physical energy systems critically • develop and reflect self-developed hypotheses to theories independently
Module contents	• Simulation (and prediction) of human behaviour and decisions • Modeling user behaviour in human cyber physical systems • Self-explaining and justifying AI
Literaturempfehlungen	Will be announced in the course

Links	
Language of instruction	English
Duration (semesters)	1 Semester
Module frequency	irregular
Module capacity	unlimited
Teaching/Learning method	V oder S
Previous knowledge	none

Examination	Prüfungszeiten	Type of examination
Final exam of module	at the end of the lecture period	term paper

Lehrveranstaltungsform	Course or seminar
SWS	2
Frequency	WiSe
Workload Präsenzzeit	28 h

inf586 - Current Topics in 'Energy Informatics' I

Module label	Current Topics in 'Energy Informatics' I
Modulkürzel	inf586
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) • 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 **Methological 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

Links	
Language of instruction	English
Duration (semesters)	1 Semester
Module frequency	irregular
Module capacity	unlimited
Teaching/Learning method	V or S
Previous knowledge	none

Examination	Prüfungszeiten	Type of examination
Final exam of module	At the end of the lecture period	Presentation or oral exam

Lehrveranstaltungsform	Course or seminar
SWS	2
Frequency	SoSe oder WiSe
Workload Präsenzzeit	28 h

inf587 - Current Topics in 'Energy Informatics' II

Module label	Current Topics in 'Energy Informatics' II
Modulkürzel	inf587
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) • 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 **Methological competences** The students • examine tasks with technical and research literature, write an academic article and present their solutions academically • evaluateproblems/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	Will be announced in the course

Links	
Language of instruction	English
Duration (semesters)	1 Semester
Module frequency	irregular
Module capacity	unlimited
Teaching/Learning method	V or S
Previous knowledge	none

Examination	Prüfungszeiten	Type of examination
Final exam of module		
	At the end of the lecture period	Written exam or portfolio or presentation or oral exam

Lehrveranstaltungsform	Course or seminar
SWS	2
Frequency	SoSe oder WiSe
Workload Präsenzzeit	28 h

inf591 - Current Topics in 'Digitalized Energy systems'

Module label	Current Topics in 'Digitalized Energy systems'
Modulkürzel	inf591
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	• 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 **Methological competences** The students • examine tasks with technical and research literature, write an academic article and present their solutions academically • evaluateproblems/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	Will be announced in the course

Links	
Language of instruction	English
Duration (semesters)	1 Semester
Module frequency	irregular
Module capacity	unlimited
Teaching/Learning method	V or S
Previous knowledge	none

Examination	Prüfungszeiten	Type of examination
Final exam of module		
	At the end of the lecture period	Written exam or portfolio or presentation or oral exam

Lehrveranstaltungsform	Course or seminar
SWS	2
Frequency	WiSe
Workload Präsenzzeit	28 h

Abschlussmodul

mam - Master Thesis Module Digitalised Energy Systems

Module label	Master Thesis Module Digitalised Energy Systems
Modulkürzel	mam
Credit points	30.0 KP
Workload	900 h
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	Thestudents 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 Apply state of the art and innovative methods to solve problems, if necessary from other disciplines • 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 disciplineand 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	
Literaturempfehlungen		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		