# M.Sc. Electrical Engineering and Information Technology (PO 2014)

**Electrical Power Engineering**
Date: 01.09.2021

TECHNISCHE UNIVERSITÄT DARMSTADT

Department of Electrical Engineering and Information Technology

Module manual: M.Sc. Electrical Engineering and Information Technology (PO 2014)
Electrical Power Engineering
Date: 01.09.2021

Department of Electrical Engineering and Information Technology
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# Contents

# 1 Fundamentals

| Module name<br>Advanced Power Electronics | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-gt-2010 | **Credit Points**<br>5 CP | **Workload**<br>150 h | **Self study**<br>90 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>English | | | **Module owner**<br>Prof. Dr.-Ing. Gerd Griepentrog | | |

| | |
|---|---|
| 1 | **Content**<br>Switch mode power supplies (insulating DC/DC-converters) Realistic behavior of power semiconductors: Basics of semiconductor physics; Behavior of diode, bipolar transistor, SCR, GTO, MOSDFET and IGBT, Important circuits for switching real semiconductors with low losses<br>Forced commutation of SCRs, Loss reducing snubbers, quasi- resonant circuits, resonant switching.<br>Topologies and control strategies for multilevel converter<br>Thermal design and thermo mechanical aging of power electronics systems |
| 2 | **Learning objectives / Learning Outcomes**<br>After an active participation in the lecture, especially by asking all questions on topics which you did not fully understand as well by solving all exercises prior to the respective tutorial (i.e. not just shortly before the examination) you should be able to<br>1.) Explain und understand the cross sectional layers and the basic modes of operation for power semiconductors (diode, thyristor, GTO. Mosfet and IGBT). Describe the steady state and dynamic behavior of these devices.<br>2.) Identify the circuit diagrams for isolating DC/DC converters, especially for use in switched mode power supplies. Calculate the currents and voltages in these circuits using defined simplifications.<br>3.) Describe the functions of gate dive-circuits for ITGBTs.<br>4.) Calculate the thermal behavior and design the cooling equipment for a voltage source inverter equipped with IGBT modules.<br>5.) Describe the stress reliving circuits to reduce switching losses in IGBTs.<br>6.) Calculate the current and voltage characteristics in quasi-resonant and resonant circuits used in power electronics.<br>7.) Explain multilevel converters such as 3L-NPC and MMC<br>8.) Know the main concepts for cooling of power electronics incl. the ability to design a cooling concept and should know main aspects which influence lifetime |
| 3 | **Recommended prerequisite for participation**<br>BSc ETiT or equivalent, especially Power Electronics and Basics of Semiconductors |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Written Examination, Duration: 90 min, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Written Examination, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc EPE, Wi-ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |

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|---|---|
| 8 | **References**<br>Script available in Moodle for download<br>Literature:<br>• Schröder, D.: “Leistungselektronische Schaltungen”, Springer-Verlag, 1997<br>• Mohan, Undeland, Robbins: Power Electronics: Converters, Applications and Design; John Wiley Verlag; New York; 2003<br>• Luo, Ye: “Power Electronics, Advanced Conversion Technologies”, Taylor and Francis, 2010 |

**Courses**

| Course Nr. | Course name | Instructor | Type | SWS |
|---|---|---|---|---|
| 18-gt-2010-vl | Advanced Power Electronics | Prof. Dr.-Ing. Gerd Griepentrog | Lecture | 2 |
| 18-gt-2010-ue | Advanced Power Electronics | Prof. Dr.-Ing. Gerd Griepentrog, M.Sc. Vefa Karakasli | Practice | 2 |

<table>
<tr><td colspan="7">Module name<br>Power Systems II</td></tr>
<tr><td colspan="2">Module Nr.<br>18-hs-2030</td><td>Credit Points<br>5 CP</td><td>Workload<br>150 h</td><td>Self study<br>90 h</td><td>Duration<br>1</td><td>Cycle offered<br>WiSe</td></tr>
<tr><td colspan="4">Language<br>German</td><td colspan="3">Module owner<br>Prof. Dr.-Ing. Jutta Hanson</td></tr>
<tr><td>1</td><td colspan="6">Content<br>This lecture covers the essential aspects of the operation and analysis of power systems. The following topics will be covered:<ul><li>Operation of synchronous generators (steady-state operation, power chart, steady-state stability, transient stability, transient behavior)</li><li>Calculation of short-circuit currents (Decaying three-phase short-circuit currents)</li><li>Neutral grounding in MV- and HV-Systems (Systems with isolated neutrals, resonant grounding and solidly grounded neutrals)</li><li>Network Protection</li></ul></td></tr>
<tr><td>2</td><td colspan="6">Learning objectives / Learning Outcomes<br>At the end of the lecture, the student should have a profound understanding of synchronous generator behavior, decaying short-circuit currents and their calculation and a basic understandning of neutral point treatment and network protection. The different types of power system stability are known.</td></tr>
<tr><td>3</td><td colspan="6">Recommended prerequisite for participation<br>Knowledge comparable to “Energieversorgung I” or basic knowledge of power system equipment and calculations using symmetrical components.</td></tr>
<tr><td>4</td><td colspan="6">Form of examination<br>Module Final Examination:<ul><li>Module Examination (Technical Examination, Optional, Standard Grading System)</li></ul></td></tr>
<tr><td>5</td><td colspan="6">Grading<br>Module Final Examination:<ul><li>Module Examination (Technical Examination, Optional, Weighting: 100 %)</li></ul></td></tr>
<tr><td>6</td><td colspan="6">Usability of this module<br>MSc ETiT, MSc EPE, MSc Wi-ETiT</td></tr>
<tr><td>7</td><td colspan="6">Grade bonus compliant to §25 (2)</td></tr>
<tr><td>8</td><td colspan="6">References<br>A script of the lecture, tutorials and past exams are available via Moodle.</td></tr>
<tr><td colspan="7">Courses</td></tr>
<tr><td rowspan="2"></td><td>Course Nr.<br>18-hs-2030-vl</td><td colspan="5">Course name<br>Power Systems II</td></tr>
<tr><td colspan="4">Instructor<br>Prof. Dr.-Ing. Jutta Hanson, M.Sc. Christina Fuhr, M.Sc. Benjamin Braun, M.Sc. Anna Pfendler</td><td>Type<br>Lecture</td><td>SWS<br>2</td></tr>
<tr><td rowspan="2"></td><td>Course Nr.<br>18-hs-2030-ue</td><td colspan="5">Course name<br>Power Systems II</td></tr>
<tr><td colspan="4">Instructor<br>Prof. Dr.-Ing. Jutta Hanson, M.Sc. Christina Fuhr, M.Sc. Benjamin Braun, M.Sc. Anna Pfendler</td><td>Type<br>Practice</td><td>SWS<br>2</td></tr>
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| **Module name**<br>Energy Converters - CAD and System Dynamics | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-bi-2010 | **Credit Points**<br>7 CP | **Workload**<br>210 h | **Self study**<br>135 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>English | | | **Module owner**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | |

| | |
|---|---|
| 1 | **Content**<br>Design of cage-rotor and wound-rotor induction machines: Calculation of forces, torque, losses, efficiency, cooling and temperature rise. Transient machine performance of converter-fed dc machines and line-fed and inverter-fed ac machines. Theory is illustrated by examples: Sudden short circuit, load step, run up. For control design transfer functions of machines are derived. In the exercise lessons demonstration examples of power transformer and induction motor design are given. The students design one induction machine in small groups by themselves. Transient performance calculation is trained by using Laplace-Transformation and MATLAB. |
| 2 | **Learning objectives / Learning Outcomes**<br>With active collaboration during lectures by asking questions related to those parts, which have not been completely understood by you, as well as by independent solving of examples ahead of the tutorial (not as late as during preparation for examination) you should be able to:<br>• do and explain the electromagnetic design of an induction machine both analytically and with use of computer program,<br>• understand and predict the thermal performance of electrical drives in a simplified way,<br>• calculate the instationary performance of separately excited DC drives<br>• to predict the dynamical performance of AC polyphase machines with space vector theory and use the MATLAB/Simulink package for this purpose. |
| 3 | **Recommended prerequisite for participation**<br>Bachelor of Science in Electrical Engineering, Power Engineering or similar |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc MEC, MSc EPE |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Detailed textbook and collection of exercises; Complete set of PowerPoint presentation<br>Leonhard, W.: Control of electrical drives, Springer, 1996<br>Fitzgerald, A.; Kingsley, C.: Kusko, A.: Electric machinery, McGraw-Hill, 1971<br>McPherson, G.: An Introduction to Electrical Machines and Transformers, Wiley, 1981<br>Say, M.: Alternating Current Machines, Wiley, 1983<br>Say, M.; Taylor, E.: Direct Current Machines, Pitman, 1983<br>Vas, P.: Vector control of ac machines, Oxford Univ. Press, 1990<br>Novotny, D,; Lipo, T.: Vector control and dynamics of ac drives, Clarendon, 1996 |

**Courses**

| | Course Nr. | Course name | | |
|---|---|---|---|---|
| | 18-bi-2010-vl | Energy Converters - CAD and System Dynamics | | |
| | **Instructor** | | **Type** | **SWS** |
| | Prof. Dr. techn. Dr.h.c. Andreas Binder | | Lecture | 3 |
| | **Course Nr.** | **Course name** | | |
| | 18-bi-2010-ue | Energy Converters - CAD and System Dynamics | | |
| | **Instructor** | | **Type** | **SWS** |
| | Prof. Dr. techn. Dr.h.c. Andreas Binder | | Practice | 2 |

| Module name | | | | | |
|---|---|---|---|---|---|
| High Voltage Technology II | | | | | |
| **Module Nr.**<br>18-hi-2010 | **Credit Points**<br>4 CP | **Workload**<br>120 h | **Self study**<br>75 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Volker Hinrichsen | | |

| | |
|---|---|
| 1 | **Content**<br>Layered Dielectrics, Methods of Field Control and Potential Control, Breakdown in Gases (air and SF6), Breakdown in Vacuum, Surface Discharges, Lightnings and Lightning Protection, Travelling Waves on Conductors; Excursion to a substation |
| 2 | **Learning objectives / Learning Outcomes**<br>The students are now able to optimize insulation systems also by choice of the dielectrics, by capacitive, refractive or resistive internal grading systems or by external geometrical/capacitive grading elements; they have understood why equipment is designed as it is and how and where it can or has to be optimized if requirements from service are changing; they have understood the physical phenomena behind the dielectric breakdown of gases and do know which are the main influencing parameters; they know the effect of strongly inhomogeneous electrode configurations and of extremely large gaps; they know the time dependencies of a dielectric breakdown and their impact on dielectric strength under impulse voltage stress; they are able to identify critical surface discharge configurations, know about the problems under severe external pollution of insulators and how to solve them; they are thus qualified to predict the dielectric strength of any electrode configuration under any kind of voltage stress and to design a particular required dielectric strength of equipment; they are particularly enabled to realize the demands of emerging UHV systems and to manage them; they have understood the mechanism of thunderstorms and lightning flashes and are able to derive protective measures for buildings, substations and overhead lines; they are skilled to calculate travelling wave effects and their effect on fast-front overvoltages and to develop adequate countermeasures. |
| 3 | **Recommended prerequisite for participation**<br>High Voltage Technology I |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Written Examination, Duration: 120 min, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Written Examination, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc Wi-ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>• all lecture slides (ca. 460 pcs.) available for download<br>• Kind, Feser: High-voltage test techniques, SBA publications<br>• Kind, Kärner: High-voltage insulation technology, Vieweg |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-hi-2010-vl | High Voltage Technology II | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Volker Hinrichsen | | Lecture | 2 |

| | **Course Nr.**<br>18-hi-2010-ue | **Course name**<br>High Voltage Technology II | | |
|---|---|---|---|---|
| | **Instructor**<br>Prof. Dr.-Ing. Volker Hinrichsen | | **Type**<br>Practice | **SWS**<br>1 |

| **Module name**<br>Power Laboratory I | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-bi-2091 | **Credit Points**<br>4 CP | **Workload**<br>120 h | **Self study**<br>75 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>German and English | | | **Module owner**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | |

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|---|---|
| 1 | **Content**<br>Safety instructions for laboratory;<br>Topic of experiments:<br>• Electrical energy conversion<br>• Power electronics<br>• High voltage technology<br>• Electrical energy supply<br>• Renewable energies |
| 2 | **Learning objectives / Learning Outcomes**<br>Practical knowledge is gained in measuring and operating electrical devices and apparatus of electrical power engineering in small groups of students. |
| 3 | **Recommended prerequisite for participation**<br>Power Engineering or similar |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Written Examination, Duration: 120 min, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Written Examination, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc MEC, MSc WI-ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Binder, A. et al.: Textbook with detailed description of experiments; Hindmarsh, J.: Electrical Machines and their Application, Pergamon Press, 1991<br>Nasar, S.A.: Electric Power systems. Schaum's Outlines<br>Mohan, N. et al: Power Electronics, Converters, Applications and Design, John Wiley & Sons, 1995<br>Kind, D., Körner, H.: High-Voltage Insualtion Technology, Friedr. Vieweg & Sohn, Braunschweig Wiesbaden, 1985, ISBN 3-528-08599-1 |

**Courses**

| Course Nr. | Course name | Instructor | Type | SWS |
|---|---|---|---|---|
| 18-bi-2091-pr | Power Laboratory I | Prof. Dr. techn. Dr.h.c. Andreas Binder | Internship | 3 |
| 18-bi-2090-tt | Laboratory Briefing | Prof. Dr. techn. Dr.h.c. Andreas Binder | Tutorial | 0 |

| Module name | | | | | |
|---|---|---|---|---|---|
| Power Laboratory II | | | | | |
| **Module Nr.** 18-bi-2092 | **Credit Points** 4 CP | **Workload** 120 h | **Self study** 75 h | **Duration** 1 | **Cycle offered** SoSe |
| **Language** German and English | | | **Module owner** Prof. Dr. techn. Dr.h.c. Andreas Binder | | |

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|---|---|
| 1 | **Content**<br>Practical course on power engineering - Distribution and Application. About 50% of the units are devoted to power distribution and high voltage engineering; About 50% are dealing with application in drive systems, concerning “field-oriented control” of variable speed drives, encoder sytems, linear permanent magnet and switched reluctance machines. |
| 2 | **Learning objectives / Learning Outcomes**<br>Practical knowledge is gained in measuring and operating electrical devices and apparatus of electrical power engineering in small groups of students. |
| 3 | **Recommended prerequisite for participation**<br>Master program: Power Lab 1 |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Written Examination, Duration: 120 min, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Written Examination, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc MEC, MSc WI-ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Text book with detailed laboratory instructions |

**Courses**

| Course Nr. | Course name | Instructor | Type | SWS |
|---|---|---|---|---|
| 18-bi-2092-pr | Power Laboratory II | Prof. Dr. techn. Dr.h.c. Andreas Binder | Internship | 3 |
| 18-bi-2090-tt | Laboratory Briefing | Prof. Dr. techn. Dr.h.c. Andreas Binder | Tutorial | 0 |

# 2 Optional Modules

## 2.1 EET I: Seminars

| **Module name**<br>Calculation of Transients in electrical Power Systems | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-hs-2060 | **Credit Points**<br>6 CP | **Workload**<br>180 h | **Self study**<br>150 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Jutta Hanson | | |

| | |
|---|---|
| 1 | **Content**<br>In two introductory lectures, basics of the modelling and simulation of electric power systems for transient studies are presented. Then, the respective simulation software is introduced and used by the participants in exercises.<br>The participants then work on a given task in the field of modelling and simulation of transients in electric power systems. |
| 2 | **Learning objectives / Learning Outcomes**<br>The goals of education are<br>• Working on a given technical question out of the area of network planning and network calculation<br>• Supervised und individual Elaboration of a simulation software<br>• Individual elaboration of the given technical task<br>• Logical presentation of results in a report<br>• Presentation of the final report (10 mins) |
| 3 | **Recommended prerequisite for participation**<br>Contents of lectures "Energieversorgung“ I and II |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc EPE, MSc Wi-ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Lecture Notes, software manual, exercise task, definition of project task |

**Courses**

| **Course Nr.** | **Course name** | | |
|---|---|---|---|
| 18-hs-2060-se | Calculation of Transients in electrical Power Systems | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Jutta Hanson | | Seminar | 2 |

| **Module name**<br>Design of Electrical Machines and Actuators with Numerical Field Calculation | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-bi-2110 | **Credit Points**<br>5 CP | **Workload**<br>150 h | **Self study**<br>120 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>German and English | | | **Module owner**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | |

| | |
|---|---|
| 1 | **Content**<br>Introduction to Finite Element Method (FEM), Basic examples of electromagnetic devices designed in 2D with FEM, 2D electromagnetic Design of transformers, AC machines, permanent magnet devices; eddy current applications such as squirrel-cage machines (Example: Wind generator); Cooling systems and thermal design: Calculation of temperature distribution within power devices |
| 2 | **Learning objectives / Learning Outcomes**<br>A good knowledge in applying FEMAG and ANSYS software package to basic field problems is gained. |
| 3 | **Recommended prerequisite for participation**<br>Strongly recommended is the attendance of lecture and active co-operation in the tutorial “Energy Converters - CAD and System Dynamics” |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc EPE, MSc ETiT, MSc MEC |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Detailed textbook; User manual FEMAG and ANSYS. Müller, C. Groth: FEM für Praktiker – Band 1: Grundlagen, expert-Verlag, 5. Aufl., 2000 |

**Courses**

| **Course Nr.** | **Course name** | | |
|---|---|---|---|
| 18-bi-2110-se | Design of Electrical Machines and Actuators with Numerical Field Calculation | | |
| **Instructor** | | **Type** | **SWS** |
| Dr.-Ing. Bogdan Funieru | | Seminar | 2 |

<table>
<tr><td colspan="6">Module name<br>Planning and Application of Electrical Drives (Drives for Electric Vehicles)</td></tr>
<tr><td>Module Nr.<br>18-bi-2120</td><td>Credit Points<br>5 CP</td><td>Workload<br>150 h</td><td>Self study<br>120 h</td><td>Duration<br>1</td><td>Cycle offered<br>SoSe</td></tr>
<tr><td colspan="3">Language<br>German</td><td colspan="3">Module owner<br>Prof. Dr. techn. Dr.h.c. Andreas Binder</td></tr>
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|---|---|
| **1** | **Content**<br>Mono- and hybrid drive concepts, motor technology, DC and AC machines, drive systems, car dynamic, energy storage;<br>Seminary work: simulation of car with electric drive train, presentation of seminary work |
| **2** | **Learning objectives / Learning Outcomes**<br>Knowledge on design procedures for electric modulation systems for electric and hybrid cars |
| **3** | **Recommended prerequisite for participation**<br>Bachelor in Electrical Engineering or Mechatronics, “Electrical Drives and Machines” and "Power electronics" recommended |
| **4** | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Standard Grading System) |
| **5** | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Weighting: 100 %) |
| **6** | **Usability of this module**<br>MSc ETiT, MSc MEC, MSc EPE, MSc WI-ETiT |
| **7** | **Grade bonus compliant to §25 (2)** |
| **8** | **References**<br>Textbook; Binder, A.: Electric machines and drives I, Darmstadt Univ. of Technology<br>Mitschke, M.: Dynamik der Kraftfahrzeuge, Springer Verlag Berlin |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-bi-2120-se | Planning and application of electrical drives (Drives for electric vehicles) | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Harald Neudorfer | | Seminar | 2 |

| Module name<br>Energy Converters and Electric Drives | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-bi-2130 | **Credit Points**<br>6 CP | **Workload**<br>180 h | **Self study**<br>135 h | **Duration**<br>1 | **Cycle offered**<br>WiSe/SoSe |
| **Language**<br>German and English | | | **Module owner**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | |

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|---|---|
| 1 | **Content**<br>From the topics of proposed scientific theses, subtasks are derived. Groups of two to four students will work on these subtasks under supervision of a tutor. The focus of the work can be either theo-retical or experimental and contains scientific problems in the field of electric energy conversion and electric drives. For study program Mechatronics this corresponds to the Advanced Design Project. |
| 2 | **Learning objectives / Learning Outcomes**<br>Energy Converters, Electric Drives, Control of Electric Drives, Teamwork, Writing Scientific Reports, Presentation |
| 3 | **Recommended prerequisite for participation**<br>Fundamentals on Electrical Engineering, Three-phase Systems, Mechanics; Lecture „Electrical Machines and Drives“ |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc MEC, MSc ETiT,MSc EPE |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Depending on the project task; manuscripts from the lectures „Electrical Machines and Drives“, „Motor development for electric Drive Systems“, „Regelungstechnik 1“ |

**Courses**

| | | | |
|---|---|---|---|
| **Course Nr.**<br>18-bi-2130-pj | **Course name**<br>Energy Converters and Electric Drives | | |
| **Instructor**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | **Type**<br>Project Seminar | **SWS**<br>3 |

| **Module name**<br>Project Seminar Application in High-Voltage Technology | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-hi-2070 | **Credit Points**<br>8 CP | **Workload**<br>240 h | **Self study**<br>195 h | **Duration**<br>1 | **Cycle offered**<br>WiSe/SoSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Volker Hinrichsen | | |

| | |
|---|---|
| 1 | **Content**<br>Realization of a Project from the Design to the Implementation of High Voltage Setups |
| 2 | **Learning objectives / Learning Outcomes**<br>The students can apply the methodology of design and development from the very first customer requirements specification up to design and type tests and documentation of equipment in high-voltage technology. They have successfully experienced team work and self-independently developed, built and tested a real device from the beginning. |
| 3 | **Recommended prerequisite for participation**<br>High-voltage technology I and II, Power Laboratory I or II |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc Wi-ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>depending on actual project |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-hi-2070-pj | Project Seminar Application in High-Voltage Technology | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Volker Hinrichsen | | Project Seminar | 3 |

| Module name | | | | | |
|---|---|---|---|---|---|
| Application, Simulation and Control of Power Electronic Systems | | | | | |
| **Module Nr.**<br>18-gt-2030 | **Credit Points**<br>8 CP | **Workload**<br>240 h | **Self study**<br>180 h | **Duration**<br>1 | **Cycle offered**<br>WiSe/SoSe |
| **Language**<br>German and English | | | **Module owner**<br>Prof. Dr.-Ing. Gerd Griepentrog | | |

**1 Content**

In an introductory meeting topics according to power electronics and control of drives are given to the students. During the seminary problems can be treated concerning the following topics:

- Simulation of power electronic systems plus analysis and evaluation of the models
- Implementing and startup of power electronic systems, test stand development plus measurement of characteristic parameters
- Modeling and simulation in the field of control of electrical drives
- Implementing and startup of controlled drive systems
- Suggested topics from the students are welcome

The students are working autonomous on the chosen problem. The results are documented in a written report and at the end of the module, a presentation about the problem must be held.

**2 Learning objectives / Learning Outcomes**

The Competences are:

- Autonomous familiarization with a given problem
- Selection and evaluation of appropriate development tools
- Familiarization with the used development tools
- Practical experience in power electronics and control of drives
- Logical presentation of the results in a report
- Presentation skills

**3 Recommended prerequisite for participation**

Lecture „Leistungselektronik 1“ or „Einführung Energietechnik“ and ggf. „Regelungstechnik I“ or similar

**4 Form of examination**

Module Final Examination:

- Module Examination (Study Achievement, Optional, Standard Grading System)

**5 Grading**

Module Final Examination:

- Module Examination (Study Achievement, Optional, Weighting: 100 %)

**6 Usability of this module**

MSc ETiT, MSc Wi-ETiT, MSc MEC

**7 Grade bonus compliant to §25 (2)**

**8 References**

Definition of project task

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-gt-2030-se | Application, Simulation and Control of Power Electronic Systems | | |
| **Instructor**<br>Prof. Dr.-Ing. Gerd Griepentrog, M.Sc. Pavel Makin | | **Type**<br>Seminar | **SWS**<br>4 |

| Module name | | | | | |
|---|---|---|---|---|---|
| Project Seminar Energy Information Systems | | | | | |
| **Module Nr.**<br>18-st-2040 | **Credit Points**<br>6 CP | **Workload**<br>180 h | **Self study**<br>135 h | **Duration**<br>1 | **Cycle offered**<br>WiSe/SoSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr. rer. nat. Florian Steinke | | |

| | |
|---|---|
| 1 | **Content**<br>Students elaborate on a research-oriented subject in the area of computer-systems in a self-responsible manner. They present a written documentation and/or a presentation of the acquired advanced knowledge. They provide a set of alternative solutions to a given problem. |
| 2 | **Learning objectives / Learning Outcomes**<br>Students are able to systematically develop design alternatives to a given problem. They learn to acquire the necessary fundamental knowledge in terms of references and terminology. The found solutions are reflected critically and the students decide for a suitable solution which they are able to argue for and accomplish. |
| 3 | **Recommended prerequisite for participation**<br>no |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References** |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-st-2040-pj | Project Seminar Energy Information Systems | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr. rer. nat. Florian Steinke | | Project Seminar | 3 |

| Module name<br>Project Seminar Network calculation | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-hs-2110 | **Credit Points**<br>6 CP | **Workload**<br>180 h | **Self study**<br>135 h | **Duration**<br>1 | **Cycle offered**<br>WiSe/SoSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Jutta Hanson | | |

| | |
|---|---|
| 1 | **Content**<br>As an introduction, the principles of modeling electrical networks will be presented. Subsequently, a simulation program applicable for network calculation is presented and applied by the participants in computer exercises.<br>The participants then work independently on a given problem from the field of modeling and simulation in the electrical power supply system. |
| 2 | **Learning objectives / Learning Outcomes**<br>• Knowledge of a simulation program used for network calculation<br>• Elaboration of a given technical problem from the field of network planning or calculation<br>• Independent elaboration of the necessary investigations and conception of corresponding simulations<br>• Logical and concise presentation of the results in a report in the format of a scientific paper |
| 3 | **Recommended prerequisite for participation**<br>Lectures „ Power Systems" I und II |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Written/Oral Examination, Standard Grading System)<br>Report and/or Presentation. The type of examination will be announced in the beginning of the lecture. |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Written/Oral Examination, Weighting: 100 %) |
| 6 | **Usability of this module** |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Script, program description, exercise task, project task topic. |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-hs-2110-pj | Project Seminar Network calculation | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Jutta Hanson | | Project Seminar | 3 |

## 2.2 EET II: Practical courses

| Module name<br>Practical Training with Drives | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-bi-2100 | **Credit Points**<br>4 CP | **Workload**<br>120 h | **Self study**<br>75 h | **Duration**<br>1 | **Cycle offered**<br>WiSe/SoSe |
| **Language**<br>German and English | | | **Module owner**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | |

| | |
|---|---|
| 1 | **Content**<br>The purpose of this laboratory is gaining extented knowledge about realization and behaviour of drive systems. An introduction in measurement problems concerning drives is given. The contents of the laboratory is setting drives to work and investigating drive systems under laboratory conditions. Special attention is paid to inverter-fed AC drives. The laboratory experiments are individually coordinated with the previous knowledge of the respective courses (ETiT or MEC). |
| 2 | **Learning objectives / Learning Outcomes**<br>The students get the ability of measurement for electrical motors, generators and transformers. |
| 3 | **Recommended prerequisite for participation**<br>Bachelor of Science in Electrical Engineering, Power Engineering or similar |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Oral Examination, Duration: 30 min, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Oral Examination, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc MEC, MSc WI-ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Textbook with lab instructions;<br>Nürnberg, W.: Die Prüfung elektrischer Maschinen, Springer, 2000;<br>Leonhard, W.: Control of electric drives, Springer, 2000;<br>Textbook – Binder, A.: Motor Developement for Electrical Drive Systems; Lecture notes – Mutschler, P.: Control of Drives |

**Courses**

| Course Nr. | Course name | Instructor | Type | SWS |
|---|---|---|---|---|
| 18-bi-2100-pr | Practical Training with Drives | Prof. Dr. techn. Dr.h.c. Andreas Binder | Internship | 3 |
| 18-bi-2090-tt | Laboratory Briefing | Prof. Dr. techn. Dr.h.c. Andreas Binder | Tutorial | 0 |

<table>
<tr><td colspan="6">Module name<br>Mechatronics Workshop</td></tr>
<tr><td>Module Nr.<br>18-bi-1050</td><td>Credit Points<br>2 CP</td><td>Workload<br>60 h</td><td>Self study<br>45 h</td><td>Duration<br>1</td><td>Cycle offered<br>WiSe/SoSe</td></tr>
<tr><td colspan="3">Language<br>German</td><td colspan="3">Module owner<br>Prof. Dr. techn. Dr.h.c. Andreas Binder</td></tr>
</table>

| | |
|---|---|
| 1 | **Content**<br>During the mechatronic workshop students get the possibility to design and construct their own fixture, which contains a ball track and a ball elevator mechanism. Herefore dimensional plans have to be understood correctly. Afterwards all components (i.e. circuit board, rails and holders) have to be designed and manufactured within the electronic lab and the workshop, where students work independently with turning, drilling and milling machines.<br>The mechatronic workshop allows students to gain practical experience and knowledge in contruction, assembling and PCB layout design. |
| 2 | **Learning objectives / Learning Outcomes**<br>Understanding of construction plans, circuit layout design, practical experience with turning, drilling and milling machines. |
| 3 | **Recommended prerequisite for participation**<br>You have to bring your **own printed** copy of the script. This is mandatory for attending the course. The script will be published on the moodle platform. |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>BSc/MSc ETiT, BSc/MSc MEC |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>• Lecture Notes „Mechatronics Workshop“<br>• J. Dillinger et al.: Fachkunde Metall, Europa-Lehrmittel, 2007<br>• U. Tietze, C. Schenk, E. Gamm: Halbleiter-Schaltungstechnik, Springer, 2012 |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-bi-1050-pr | Mechatronics Workshop | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr. techn. Dr.h.c. Andreas Binder | | Internship | 1 |

| Module name | | | | | |
|---|---|---|---|---|---|
| Laboratory Matlab/Simulink I | | | | | |
| **Module Nr.**<br>18-ko-1030 | **Credit Points**<br>3 CP | **Workload**<br>90 h | **Self study**<br>45 h | **Duration**<br>1 | **Cycle offered**<br>WiSe/SoSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Ulrich Konigorski | | |

| | |
|---|---|
| 1 | **Content**<br>In this lab tutorial, an introduction to the software tool MatLab/Simulink will be given. The lab is split into two parts. First the fundamentals of programming in Matlab are introduced and their application to different problems is trained. In addition, an introduction to the Control System Toolbox will be given. In the second part, the knowledge gained in the first part is applied to solve a control engineering specific problem with the software tools. |
| 2 | **Learning objectives / Learning Outcomes**<br>Fundamentals in the handling of Matlab/Simulink and the application to control engineering tasks. |
| 3 | **Recommended prerequisite for participation**<br>The lab should be attended in parallel or after the lecture “System Dynamics and Control Systems I” |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>BSc ETiT; BSc MEC |
| 7 | **Grade bonus compliant to §25 (2)**<br>In case of E-Learning: Possibility to improve the grade up to 1,0 |
| 8 | **References**<br>Lecture notes for the lab tutorial can be obtained at the secretariat<br>Lunze; Regelungstechnik I<br>Dorp; Bishop: Moderne Regelungssysteme<br>Moler: Numerical Computing with MATLAB |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-ko-1030-pr | Laboratory Matlab/Simulink I | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Ulrich Konigorski, M.Sc. Alexander Steinke | | Internship | 3 |

| **Module name**<br>Laboratory Control Engineering I | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-ko-1020 | **Credit Points**<br>4 CP | **Workload**<br>120 h | **Self study**<br>60 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Ulrich Konigorski | | |

| | |
|---|---|
| 1 | **Content**<br>• Control of a 2-tank system.<br>• Control of pneumatic and hydraulic servo-drives.<br>• Control of a 3 mass oscillator.<br>• Position control of a MagLev system.<br>• Control of a discrete transport process with electro-pneumatic components.<br>• Microcontroller-based control of an electrically driven throttle valve.<br>• Identification of a 3 mass oscillator.<br>• Process control using PLC. |
| 2 | **Learning objectives / Learning Outcomes**<br>After this lab tutorial the students will be able to practically apply the modelling and design techniques for different dynamic systems presented in the lecture ”System dynamics and control systems I” to real lab experiments and to bring them into operation at the lap setup. |
| 3 | **Recommended prerequisite for participation**<br>System Dynamics and Control Systems I |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Written Examination, Duration: 90 min, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Written Examination, Weighting: 100 %) |
| 6 | **Usability of this module**<br>BSc ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Lab handouts will be given to students |

**Courses**

| | | | | |
|---|---|---|---|---|
| | **Course Nr.**<br>18-ko-1020-pr | **Course name**<br>Laboratory Control Engineering I | | |
| | **Instructor**<br>Prof. Dr.-Ing. Ulrich Konigorski | | **Type**<br>Internship | **SWS**<br>4 |

| Module name<br>Laboratory Control Engineering II | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-ad-2060 | **Credit Points**<br>5 CP | **Workload**<br>150 h | **Self study**<br>90 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Jürgen Adamy | | |

| | |
|---|---|
| 1 | **Content**<br>During the laboratory course the following experiments will be conducted: Coupling control of a helicopter, Non-linear control of a gyroscope, Nonlinear multivariable control of an aircraft, Servo control systems, Control of an overhead crane system, Programmable logic control of a stirring process |
| 2 | **Learning objectives / Learning Outcomes**<br>After attending this laboratory course, a student is capable of:<br>• recalling the basics of the conducted experiments,<br>• organize and comprehend background information for experiments,<br>• assemble experimental set-ups based on manuals,<br>• judge the relevance of experimental results by comparing them with theoretically predicted outcomes,<br>• present the results of the experiments |
| 3 | **Recommended prerequisite for participation**<br>System Dynamics and Control Systems II, the attendance of the additional lecture "System Dynamics and Control Systems III" is recommended |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Written Examination, Duration: 180 min, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Written Examination, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc MEC, MSc iST, MSc Wi-ETiT, Biotechnik |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Adamy: Instruction manuals for the experiments (available during the kick-off meeting) |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-ad-2060-pr | Laboratory Control Engineering II | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Jürgen Adamy, M.Sc. Jan Christian Zimmermann | | Internship | 4 |

<table>
<tr><td colspan="6">Module name<br>Planning and Application of Electrical Drives (Drives for Electric Vehicles)</td></tr>
<tr><td>Module Nr.<br>18-bi-2120</td><td>Credit Points<br>5 CP</td><td>Workload<br>150 h</td><td>Self study<br>120 h</td><td>Duration<br>1</td><td>Cycle offered<br>SoSe</td></tr>
<tr><td colspan="3">Language<br>German</td><td colspan="3">Module owner<br>Prof. Dr. techn. Dr.h.c. Andreas Binder</td></tr>
<tr><td>1</td><td colspan="5">Content<br>Mono- and hybrid drive concepts, motor technology, DC and AC machines, drive systems, car dynamic, energy storage;<br>Seminary work: simulation of car with electric drive train, presentation of seminary work</td></tr>
<tr><td>2</td><td colspan="5">Learning objectives / Learning Outcomes<br>Knowledge on design procedures for electric modulation systems for electric and hybrid cars</td></tr>
<tr><td>3</td><td colspan="5">Recommended prerequisite for participation<br>Bachelor in Electrical Engineering or Mechatronics, “Electrical Drives and Machines” and "Power electronics" recommended</td></tr>
<tr><td>4</td><td colspan="5">Form of examination<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Standard Grading System)</td></tr>
<tr><td>5</td><td colspan="5">Grading<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Weighting: 100 %)</td></tr>
<tr><td>6</td><td colspan="5">Usability of this module<br>MSc ETiT, MSc MEC, MSc EPE, MSc WI-ETiT</td></tr>
<tr><td>7</td><td colspan="5">Grade bonus compliant to §25 (2)</td></tr>
<tr><td>8</td><td colspan="5">References<br>Textbook; Binder, A.: Electric machines and drives I, Darmstadt Univ. of Technology<br>Mitschke, M.: Dynamik der Kraftfahrzeuge, Springer Verlag Berlin</td></tr>
<tr><td colspan="6">Courses</td></tr>
<tr><td rowspan="2"></td><td>Course Nr.<br>18-bi-2120-se</td><td colspan="4">Course name<br>Planning and application of electrical drives (Drives for electric vehicles)</td></tr>
<tr><td colspan="3">Instructor<br>Prof. Harald Neudorfer</td><td>Type<br>Seminar</td><td>SWS<br>2</td></tr>
</table>

| Module name | | | | | |
|---|---|---|---|---|---|
| Simulation of Electrical Power Networks | | | | | |
| **Module Nr.**<br>18-hs-2100 | **Credit Points**<br>3 CP | **Workload**<br>90 h | **Self study**<br>60 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Jutta Hanson | | |

| | |
|---|---|
| 1 | **Content**<br>Modeling, simulating and planning electrical power networks with a wide range of nominal voltages under consideration of electrical equipment (overhead lines, cables, transformers, conventional power plants, renewable energy resources und reactive power compensation systems) |
| 2 | **Learning objectives / Learning Outcomes**<br>The learning targets are the following:<br>• Modeling various electrical power systems using the appropriate techniques.<br>• Choice of static and dynamic simulation techniques after analysing the concrete simulation processes.<br>• Understanding the behaviour of various equipment in the electric power system, especially renewable energy resources.Interpretion of results based on the fundamental questions of modeling and simulating electrical power systems. |
| 3 | **Recommended prerequisite for participation**<br>Basics of electrical power systems |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Study Achievement, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc WI-ET, MSc CE |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Script, Presentation Slides, Description of tutorial and basic network data |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-hs-2100-pr | Simulation of Electrical Power Networks | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Jutta Hanson, Dipl.-Ing. Andreas Saciak | | Internship | 2 |

| **Module name**<br>Real Time Applications and Communication with Microcontrollers and programmable Logic Devices | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-gt-2040 | **Credit Points**<br>4 CP | **Workload**<br>120 h | **Self study**<br>75 h | **Duration**<br>1 | **Cycle offered**<br>WiSe/SoSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Gerd Griepentrog | | |

**1 Content**

Microcontroller and programmable logic devices are being used for a variety of control tasks for industrial and residential products and systems. For the control of drives and power electronics, those devices are used for the control of frequency converters or DC/DC converters.
In most of these applications, real time requirements have to be met. Simultaneously a communication interface has to be served.
The module will impart knowledge and expertise on how to realize successfully control task.
More in detail, the following content will be taught:

- Architecture of microcontroller
- Structure and function of FPGAs, tools and programming languages
- Typical peripheral components for microcontrollers
- Capture & Compare, PWM, A/D-converter
- I2C, SPI, CAN, Ethernet
- Programming of microcontrollers in C
- Software: real-time properties, interrupt handling, interrupt latency
- Control of inductive components
- Basic of circuit design for power electronics, Power-MOSFETS, IGBTsNumerical methods

**2 Learning objectives / Learning Outcomes**

Students will be able to:

- Separate a digital control task into HW and SW parts
- Specify the HW-content in a HW description language and implement the SW by means of a micro-controller
- Evaluate the real-time capabilities of a program and to determine upper limits for the response time of the systemTransfer the developed solution to the target system by means of a development kit and debug the software onto the target system.

**3 Recommended prerequisite for participation**

Basic knowledge in programmig language C (syntax, operators, pointer)

**4 Form of examination**

Module Final Examination:

- Module Examination (Technical Examination, Written Examination, Duration: 120 min, Standard Grading System)

**5 Grading**

Module Final Examination:

- Module Examination (Technical Examination, Written Examination, Weighting: 100 %)

**6 Usability of this module**

MSc MEC, MSc ETiT

**7 Grade bonus compliant to §25 (2)**

**8 References**

Script, Instruction for practical lab courses, ppt-Slides; either in hard-copy or for download; User Manuals of the used devices and development kits

**Courses**

<table>
<tr><td rowspan="2"></td><td>Course Nr.<br>18-gt-2040-vl</td><td colspan="3">Course name<br>Real Time Applications and Communication with Microcontrollers and programmable Logic Devices</td></tr>
<tr><td colspan="2">Instructor<br>Prof. Dr.-Ing. Gerd Griepentrog</td><td>Type<br>Lecture</td><td>SWS<br>1</td></tr>
<tr><td rowspan="2"></td><td>Course Nr.<br>18-gt-2040-pr</td><td colspan="3">Course name<br>Real Time Applications and Communication with Microcontrollers and programmable Logic Devices</td></tr>
<tr><td colspan="2">Instructor<br>Prof. Dr.-Ing. Gerd Griepentrog, Prof. Dr.-Ing. Christian Hochberger</td><td>Type<br>Internship</td><td>SWS<br>2</td></tr>
</table>

| Module name<br>Control of Drives | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-gt-2020 | **Credit Points**<br>5 CP | **Workload**<br>150 h | **Self study**<br>90 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>English | | | **Module owner**<br>Prof. Dr.-Ing. Gerd Griepentrog | | |

| | |
|---|---|
| 1 | **Content**<br>Control structures for drives; Design of controllers for drives; VSIs for drives; Space Vectors as basis of modelling AC-machines; Reference frames for description of AC-machines; Control oriented block diagram for DC-drive; Structure and design of the controllers;<br>Control oriented block diagram for Permanent Magnet Synchronous Machine (PMSM); Control oriented block diagram for Induction machine (IM)<br>Torque control for AC-machines using linear or switching controllers. Field Oriented Control and Direct Torque Control for PMSM and IM. Models and observers for rotor flux of IM<br>Speed control, including oscillatory load. Resolver and Encoder. Problem of Motion control |
| 2 | **Learning objectives / Learning Outcomes**<br>After an active participation in the course including solving all exercises prior to the respective tutorial students should be able to:<br>1.) develop the control-oriented block diagrams for the DC-machine operating in base speed range as well as in field weakening range.<br>2.) design the control loops for 1.) concerning the structure and the control parameters.<br>3.) Understand and apply space vectors and master their application in different rotating frames of reference.<br>4.) Develop the dynamic equations of the permanent exited synchronous machine and the induction machine and to simplify these equations by help of suitable rotating reference frames and represent these equations as non-linear control-oriented block diagram.<br>5.) Design the control loops according to 4.) especially the field-oriented control concerning the structure of the control loops and the control parameters.<br>6.) Understand the deduction of equations given in the literature for machine types, which are not discussed in this lecture, e.g. for the doubly fed induction machine.<br>7.) Derive the models and the observers for the rotor flux for the induction machine in different frames of reference and to apprise the benefits and drawbacks of the different solutions.<br>8.) Design the control loops for the super-imposed speed controls even for mechanically oscillating loads. |
| 3 | **Recommended prerequisite for participation**<br>BSc ETiT or equivalent, especially Control Theory and Electrical Machines / Drives |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Written Examination, Duration: 90 min, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Written Examination, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc EPE, MSc MEC, Wi-ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References** |

| | |
|---|---|
| | Lecture notes, instructions for exercises are available in Moodle for download.<br>Literature:<br>• Mohan, Ned: “Electric Drives and Machines”<br>• De Doncker, Rik; et. al.: “Advanced Electrical Drives”<br>• Schröder, Dierk: “Elektrische Antriebe – Regelung von Antriebssystemen”<br>• Leonhard, W.: “Control of Electrical Drives” |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-gt-2020-vl | Control of Drives | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Gerd Griepentrog | | Lecture | 2 |

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-gt-2020-ue | Control of Drives | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Gerd Griepentrog, M.Sc. Ivan Kliasheu | | Practice | 2 |

| Module name | | | | | |
|---|---|---|---|---|---|
| Real Time Applications and Communication with Microcontrollers and programmable Logic Devices | | | | | |
| **Module Nr.** 18-gt-2040 | **Credit Points** 4 CP | **Workload** 120 h | **Self study** 75 h | **Duration** 1 | **Cycle offered** WiSe/SoSe |
| **Language** German | | | **Module owner** Prof. Dr.-Ing. Gerd Griepentrog | | |

**1 Content**

Microcontroller and programmable logic devices are being used for a variety of control tasks for industrial and residential products and systems. For the control of drives and power electronics, those devices are used for the control of frequency converters or DC/DC converters.
In most of these applications, real time requirements have to be met. Simultaneously a communication interface has to be served.
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More in detail, the following content will be taught:

- Architecture of microcontroller
- Structure and function of FPGAs, tools and programming languages
- Typical peripheral components for microcontrollers
- Capture & Compare, PWM, A/D-converter
- I2C, SPI, CAN, Ethernet
- Programming of microcontrollers in C
- Software: real-time properties, interrupt handling, interrupt latency
- Control of inductive components
- Basic of circuit design for power electronics, Power-MOSFETS, IGBTsNumerical methods

**2 Learning objectives / Learning Outcomes**

Students will be able to:

- Separate a digital control task into HW and SW parts
- Specify the HW-content in a HW description language and implement the SW by means of a micro-controller
- Evaluate the real-time capabilities of a program and to determine upper limits for the response time of the systemTransfer the developed solution to the target system by means of a development kit and debug the software onto the target system.

**3 Recommended prerequisite for participation**

Basic knowledge in programmig language C (syntax, operators, pointer)

**4 Form of examination**

Module Final Examination:

- Module Examination (Technical Examination, Written Examination, Duration: 120 min, Standard Grading System)

**5 Grading**

Module Final Examination:

- Module Examination (Technical Examination, Written Examination, Weighting: 100 %)

**6 Usability of this module**

MSc MEC, MSc ETiT

**7 Grade bonus compliant to §25 (2)**

**8 References**

Script, Instruction for practical lab courses, ppt-Slides; either in hard-copy or for download; User Manuals of the used devices and development kits

**Courses**

| | Course Nr. | Course name | | |
|---|---|---|---|---|
| | 18-gt-2040-vl | Real Time Applications and Communication with Microcontrollers and programmable Logic Devices | | |
| | **Instructor** | | **Type** | **SWS** |
| | Prof. Dr.-Ing. Gerd Griepentrog | | Lecture | 1 |
| | **Course Nr.** | **Course name** | | |
| | 18-gt-2040-pr | Real Time Applications and Communication with Microcontrollers and programmable Logic Devices | | |
| | **Instructor** | | **Type** | **SWS** |
| | Prof. Dr.-Ing. Gerd Griepentrog, Prof. Dr.-Ing. Christian Hochberger | | Internship | 2 |

| Module name | | | | | |
|---|---|---|---|---|---|
| Electric Railways | | | | | |
| **Module Nr.**<br>18-bi-2140 | **Credit Points**<br>5 CP | **Workload**<br>150 h | **Self study**<br>105 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>German and English | | | **Module owner**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | |

| | |
|---|---|
| 1 | **Content**<br>• Mechanics of traction<br>• Electrical part of traction vehicles<br>• Converter and motors for electrical traction<br>• Monitoring systems<br>• Comparison of different power supply systems<br>• DC- and AC- systems for light- and heavy rail<br>• Problems of earthing and earth return currents<br>• Sub stations, converters, power plants |
| 2 | **Learning objectives / Learning Outcomes**<br>Comprehension of the basic concepts of electric traction vehicles and power supply for electric railways |
| 3 | **Recommended prerequisite for participation**<br>Basic knowledge in electrical machines and drives |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc MEC, MSc Wi-ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Text book for the lecture. Bendel, H. u.a.: Die elektrische Lokomotive. Transpress, Berlin, 1994. Filipovic, Z: Elektrische Bahnen. Springer, Berlin, Heidelberg, 1995. Steimel, A.: Elektrische Triebfahrzeuge und ihre Energieversorgung. Oldenburg Industrieverlag, 2006. Bäzold, D. u.a.: Elektrische Lokomotion deutscher Eisenbahnen. Alba, Düsseldorf, 1993. Obermayer, H. J.: Internationaler Schnellverkehr. Franckh-Kosmos, Stuttgart, 1994; Guckow, A.; Kiessling, F.; Puschmann, R.: Fahrleitungen el. Bahnen. Teubner, Stuttgart, 1997. Schaefer, H.: Elektrotechnische Anlagen für Bahnstrom. Eisenbahn-Fachverlag, Heidelberg, 1981 |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-bi-2140-vl | Electric Railways | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Harald Neudorfer, Dipl.-Ing. Björn Deusinger, M.Sc. Nicolas Ludwig Erd | | Lecture | 3 |

| **Module name**<br>Power Systems III | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-hs-2080 | **Credit Points**<br>3 CP | **Workload**<br>90 h | **Self study**<br>60 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Jutta Hanson | | |

| | |
|---|---|
| 1 | **Content**<br>System behaviour of innovative equipment in the Transmission System<br>Fields of application:<br>• Power transmission and voltage stability<br>• Ancillary services<br>• Power quality<br><br>Technology of innovative equipment:<br>• Power Electronics theory<br>• Motivation, technical realisation and operation / control of HVDC systems (LCC and VSC)<br>• Motivation, technical realisation and operation / control of power electronic devices for reactive power compensation (SVC, STATCOM, SC)<br>• Practical examples and outlook |
| 2 | **Learning objectives / Learning Outcomes**<br>After successful completion of this module, a student knows the driving forces for the utilisation of innovative equipment (HVDC, reactive power compensation) in power systems. He understands the system behaviour and operation of these devices and has realised the importance of modelling and simulation for safe and reliable design and operation. |
| 3 | **Recommended prerequisite for participation**<br>Contents of "Power Systems I“ |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Written Examination, Duration: 90 min, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Written Examination, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc MEC, MSc Wi-ETiT |
| 7 | **Grade bonus compliant to §25 (2)**<br>Yes |
| 8 | **References**<br>Presentation slides |

**Courses**

| **Course Nr.**<br>18-hs-2080-vl | **Course name**<br>Power Systems III | | |
|---|---|---|---|
| **Instructor**<br>Prof. Dr.-Ing. Jutta Hanson | | **Type**<br>Lecture | **SWS**<br>2 |

| Module name | | | | | |
|---|---|---|---|---|---|
| Electrothermal Processes | | | | | |
| **Module Nr.**<br>18-bi-2070 | **Credit Points**<br>3 CP | **Workload**<br>90 h | **Self study**<br>60 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>German and English | | | **Module owner**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | |

| | |
|---|---|
| 1 | **Content**<br>First the technical and economic importance of electrothermal processes will be pointed out. In addition to that, advantages, characteristics and applications of electroheat processes will be shown by typical examples.<br>The second part of the lecture is about thermotechnical and electrotechnical basics, which are necessary to understand electrothermal processes.<br>The main part of the lecture deals with examples of electrothermal processes, like induction heating (focus), conductive and dielectric heating as well as indirect resistance heating. Examples from industry are shown, and it will be explained how the applications are designed with numerical simulation tools (FEM-based) and analytical methods (calculation of electromagnetic fields).<br>At the end of the lecture special processes like laser applications will be shown. |
| 2 | **Learning objectives / Learning Outcomes**<br>Understanding of design and calculation of electrothermal processes and their applications |
| 3 | **Recommended prerequisite for participation**<br>B.Sc. Electrical Engineering or Mechatronics |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc MEC, MSc EPE, MSc Wi-ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Lecture notes; Fasholz, J., Orth, G.: Induktive Erwärmung, RWE Energie AG, Essen, 4. Aufl., 1991; Nacke, B.; Baake, E. (Hsg.): Induktives Erwärmen, Vulkan-Verlag, 2014 |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-bi-2070-vl | Electrothermal Processes | | |
| **Instructor** | | **Type** | **SWS** |
| Dr.-Ing. Jörg Neumeyer | | Lecture | 2 |

| **Module name**<br>Regulation of Power Supply | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-hs-2010 | **Credit Points**<br>3 CP | **Workload**<br>90 h | **Self study**<br>60 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Jutta Hanson | | |

| | |
|---|---|
| 1 | **Content**<br>• Structure of the German energy economy with focus on electrical power supply<br>• Changes in the regulatory framework (unbundling, grid regulation)<br>• Effects of the "Energiewende" on the energy economy in Germany<br>• Energy turnaround: technologies, energy balance<br>• Renewable energy law (EEG)<br>• Incentive regulation ("Anreizregulierung")<br>• Excursion to Mainova AG |
| 2 | **Learning objectives / Learning Outcomes**<br>A student knows after successful completion of this module the basics, the driving forces and developments of the German energy economy.<br>The effects of the German "Energiewende" and necessary technical changes for the energy sector are also taught. |
| 3 | **Recommended prerequisite for participation**<br>Good knowledge of content of the lecture "Energietechnik" |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc EPE, MSc Wi-ETiT, MSc MEC, MSc iST, MSc iCE, MSc CE |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Lecture Notes |

**Courses**

| **Course Nr.** | **Course name** | | |
|---|---|---|---|
| 18-hs-2010-vl | Regulation of Power Supply | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Ingo Jeromin | | Lecture | 2 |

| Module name | | | | | |
|---|---|---|---|---|---|
| Large Generators and High Power Drives | | | | | |
| **Module Nr.**<br>18-bi-2020 | **Credit Points**<br>4 CP | **Workload**<br>120 h | **Self study**<br>75 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>German and English | | | **Module owner**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | |

| | |
|---|---|
| 1 | **Content**<br>Design of large electric generators: Special cooling methods with air, hydrogen and water, loss evaluation, especially eddy current losses, and measures to reduce the additional losses. Design of big hydrogenerators up to 800 MVA and turbo generators up to 2000 MVA with desing examples. Application of power electronics in large variable speed drives with synchronous motors: Synchronous converter and cyclo-converter. Numerous photographs to illustrate applications, excursion with students to special firms or plants. |
| 2 | **Learning objectives / Learning Outcomes**<br>Expert knowledge in design of generators, large drives, their cooling systems and operational performance is acquired. |
| 3 | **Recommended prerequisite for participation**<br>Physics, Electrical Machines and Drives, Electrical Power Engineering |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc EPE, MSc ETiT, MSc MEC, MSc WI-ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Detailed textbook with calculated examples; Vas, P.: Parameter estimation, condition monitoring, and diagnosis of electrical machines, Clarendon Press, 1993<br>Fitzgerald, A.; Kingsley, C.; Kusko, A.: Electric machinery, McGraw-Hill, 2003<br>Leonhard, W.: Control of electrical drives, Springer, 1996 |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-bi-2020-vl | Large Generators and High Power Drives | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr. Georg Traxler-Samek | | Lecture | 2 |

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-bi-2020-ue | Large Generators and High Power Drives | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr. Georg Traxler-Samek | | Practice | 1 |

| **Module name**<br>Railway Vehicle Engineering | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-bi-2050 | **Credit Points**<br>3 CP | **Workload**<br>90 h | **Self study**<br>60 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | |

| | |
|---|---|
| 1 | **Content**<br>From the comprehensive and interdisciplinary domain of the railway technology (vehicle technology, signal and safety technology, construction engineering and railway operating technology) the lecture picks out the domain of the automotive engineering with the emphasis of the mechanical part. It offers an interrelated introduction into selected chapters of the rail vehicle engineering with special emphasis in the railway-specific technical solutions and procedures. The lecture is divided into 7 chapters, whereby four chapters the theoretical basic topics cover and three chapters the fundamental components of the rail vehicle present.<br>In a one-day excursion, it is possible to gain insights into the production of modern rail vehicles. Participation is voluntary. |
| 2 | **Learning objectives / Learning Outcomes**<br>Basic understanding of mechanical parts of railways and their components. |
| 3 | **Recommended prerequisite for participation**<br>Bachelor in Electrical Engineering, Mechatronics or Mechanical Engineering |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Written/Oral Examination, Duration: 90 min, Standard Grading System)<br>In general, the examination takes place in form of a written exam (duration: 90 minutes). If up to 20 students register in semesters in which the lecture does not take place, there will be an oral examination (duration: 30 min.). The type of examination will be announced within one working week after the end of the examination registration phase. |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Written/Oral Examination, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc MEC, MSc EPE, MSc WI-ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>References/Textbooks: Detailed textbook; Filipovic, Z: Elektrische Bahnen. Springer, Berlin, Heidelberg, 1995. Obermayer, H.J.: Internationaler Schnellverkehr.Franckh-Kosmos, Stuttgart, 1994. |

**Courses**

| **Course Nr.** | **Course name** | | |
|---|---|---|---|
| 18-bi-2050-vl | Railway Vehicle Engineering | | |
| **Instructor** | | **Type**<br>Lecture | **SWS**<br>2 |

| **Module name**<br>High Voltage Switchgear and Substations | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-hi-2020 | **Credit Points**<br>3 CP | **Workload**<br>90 h | **Self study**<br>60 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Volker Hinrichsen | | |

| | |
|---|---|
| 1 | **Content**<br>This lecture covers the basic designs of high voltage substations as well as the design and working principles of high voltage switchgear:<br>• Tyes of switching and stresses induced by switching<br>• Arc behaviour in air, SF6 and vacuum<br>• Types of switchgear: earthing switches, disconnectors and circuit breakers<br>• Design and working principles of earthing switches and disconnectors in air and SF6<br>• Design and working principles of circuit breakers: vacuum breakers, pressured air and SF6 breakers (thermal blast and self-blast chambers)<br>• Stresses of earthing switches and disconnectors by short circuit conditions<br>• Testing of Switchgear<br>• Reliability of Switchgear<br>• Future developments: Intelligent control of switchgear, static switches, superconducting switchgear |
| 2 | **Learning objectives / Learning Outcomes**<br>The student should understand the purpose and working principles of high voltage switchgear as well as their usage in high voltage substations. |
| 3 | **Recommended prerequisite for participation**<br>Prior attendance of the lectures High Voltage Technology I and II is recommended |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Oral Examination, Duration: 45 min, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Oral Examination, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, BSc/MSc iST, MSc Wi-ETiT, MSc EPE |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>A script of the lecture (in German) can be obtained from here: http://www.hst.tu-darmstadt.de/index.php?id=30 |

**Courses**

| **Course Nr.** | **Course name** | | |
|---|---|---|---|
| 18-hi-2020-vl | High Voltage Switchgear and Substations | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr. Claus Neumann | | Lecture | 2 |

| Module name | | | | | |
|---|---|---|---|---|---|
| Power Plants and Renewable Energies | | | | | |
| **Module Nr.**<br>18-hs-2090 | **Credit Points**<br>4 CP | **Workload**<br>120 h | **Self study**<br>75 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Jutta Hanson | | |

**1 Content**

Forms of energy, Characteristics and figures of electricity industry, Importance of power generation – Energy Conversion in thermal processes (Carnot-Process), Categorization of power plants – Operation principle of steam power plants, gas power plants, water power plants, wind power plants, Use of solar energy (Photovoltaics, Solar thermal technology) and further regenerative energy sources (geothermal energy, biomass) – Technologies for Energy Converting and Storing (Power 2 X) – Electrical systems – Grid Connection for power plants

**2 Learning objectives / Learning Outcomes**

Goals are:

- Overview of concepts of power generation by various energy sources
- Comprehension of physical processes
- Operation principle and design of conventional and renewable power plants and storage
- Comprehension of electrical devices and control concepts

**3 Recommended prerequisite for participation**

Basics in Electrical Engineering, Power Engineering

**4 Form of examination**

Module Final Examination:

- Module Examination (Technical Examination, Optional, Standard Grading System)

**5 Grading**

Module Final Examination:

- Module Examination (Technical Examination, Optional, Weighting: 100 %)

**6 Usability of this module**

MSc ETiT, MSc WI-ET, MSc EPE, MSc MEC, MSc CE, MSc MB, MSc WI-MB

**7 Grade bonus compliant to §25 (2)**

**8 References**

Script

**Courses**

| Course Nr. | Course name | Instructor | Type | SWS |
|---|---|---|---|---|
| 18-hs-2090-vl | Power Plants and Renewable Energies | Prof. Dr.-Ing. Jutta Hanson | Lecture | 2 |
| 18-hs-2090-ue | Power Plants and Renewable Energies | Prof. Dr.-Ing. Jutta Hanson, M.Sc. Benjamin Niersbach, M.Sc. Xiong Xiao | Practice | 1 |

| Module name<br>High Voltage Measuring Techniques | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-hi-2050 | **Credit Points**<br>3 CP | **Workload**<br>90 h | **Self study**<br>60 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Volker Hinrichsen | | |

| | |
|---|---|
| 1 | **Content**<br>**1. Measurement of High DC Voltages**<br>1.1 Resistor Voltage Dividers<br>1.2 Electrostatic Voltmeters<br>1.3 Generating Voltmeters<br>1.4 Rod/Rod Gaps<br>1.5 DKD-Calibration of a 1500 kV-DC-Measuring System<br>**2. Measurement of High AC Voltages in High Voltage Transmission Systems**<br>2.1 Inductive Voltage Transformers with Oil and with SF6-Insulation<br>2.2 Capacitor Voltage Transformers<br>2.3 Electronic Voltage Transformers<br>2.4 Electro-Optical Voltage Transformers<br>2.5 Calibration of Voltage Transformers<br>**3. Measurement of High AC Voltages in the Laboratory**<br>3.1 Resistor Voltage Dividers<br>3.2 Capacitor Voltage Dividers<br>3.3 Measuring Sphere Gap<br>3.4 Electronic Peak Voltmeter<br>3.5 DKD-Calibration of a 1200 kV AC-Measuring System<br>**4. Measurement of High Impulse Voltages**<br>4.1 Standard Impulse Voltages and their Normalized Amplitude Frequency Spectra<br>4.2 Designs of R- , C- and RC-Dividers<br>4.3 Computation of the Step Response of Impulse Voltage Dividers<br>4.4 Analytical Calculation of the Response Time of a Divider with a Lead<br>4.5 EMTP-Calculation of the Divider Output Voltage for Lightning Impulse Voltages<br>4.6 DKD-Calibration of a 3 MV Lightning Impulse Measuring System<br>4.7 DKD-Calibration of a 2 MV Switching Impulse Measuring System |
| 2 | **Learning objectives / Learning Outcomes** |

| | |
|---|---|
| | The students learn the fundamentals, the dimensions, the application and the operation of voltage dividers up to 1,5 MV DC, 1,2 MV AC, 3,2 MV LI and 2 MV Si. They know and have understood the standards IEC 60060-2 High-Voltage Measuring systems and the Calibration Procedures of the German Calibration Service (DKD) for High-Voltage Measuring Systems which show that the uncertainty of the High-Voltage Measuring results of approved measuring systems are lower than the maximal permissible uncertainty for Type tests in an accredited High-Voltage Test Laboratory.<br>They know, how the material of the resistors and the Isolationsystem influence the measuring uncertainty, the costs and the the level of the maximal DC Voltage.<br>The students know and understand the equivalent circuits for power frequency of inductive and capacitive voltage transformer and are able to deduce the measuring errors and their dependency of the dimensioning of the magnetic and electric components.<br>The students learn and understand, why an ohmic resistor voltage divider in contrary to a capacitor voltage divider is not applicable for the measurement of high AC voltages. They are able to calculate the influence of the distance between a wall and the capacitor voltage divider with oil-paper insulation on the measuring error.<br>The students know, why capacitor voltage dividers without serious resistors are not applicable to the measurement of lightning impulse voltages. They can describe the advantages and the disadvantages of a low damped capacitor voltage divider as front capacitor of a lightning impulse voltage generator and as voltage divider. They know, why at LI-voltage measurements the test object must be situated between the generator and the divider. The students are able to reduce the interference of steep currents in the walls and in the ground of a high voltage test lab on the secondary voltage signal in the measuring cable from the divider to the recorder. |
| 3 | **Recommended prerequisite for participation**<br>BSc ETiT, BSc Wi-ETiT |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Oral Examination, Duration: 30 min, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Oral Examination, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc Wi-ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>• Breilmann, W.: Skriptum zur Vorlesung " Messverfahren der Hochspannungstechnik" im WS 2014/2015<br>• Kuffel, E.; Zaengl, W.S.: High Voltage Engineering, Fundamentals ISBN-13:987-0750636346; Butterworth Heinemann; July 2000. 539 Seiten; 81,20 Euro.<br>• VDE 0432: Hochspannungs-Prüftechnik: Teil 1: Allgemeine Begriffe und Prüfbedingungen; (2011-10) : 78 Euro<br>• VDE 0432: Hochspannungs-Prüftechnik: Teil 2: Messsysteme (2011-10) : 78 Euro<br>• Schon, K.: Stoßspannungs- und Stoßstrommesstechnik ISBN 978-3-642-13117-2; Springer Heidelberg; September 2010, 285 Seiten; 88 Euro |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-hi-2050-vl | High Voltage Measuring Techniques | | |
| **Instructor** | | **Type** | **SWS** |
| Dr. Ing. Wolfgang Breilmann | | Lecture | 2 |

| Module name | | | | | |
|---|---|---|---|---|---|
| Motor Development for Electrical Drive Systems | | | | | |
| **Module Nr.**<br>18-bi-2032 | **Credit Points**<br>4 CP | **Workload**<br>120 h | **Self study**<br>75 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>English | | | **Module owner**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | |

| | |
|---|---|
| 1 | **Content**<br>For the wide field of the drive technology at low and medium power range from 1 kW up to about 500 kW. . . 1 MW the conventional drives and the current trends of developments are explained to the students. Grid operated and inverter-fed induction drives, permanent-magnet synchronous drives with and without damper cage (“brushless dc drives”), synchronous and switched reluctance drives and permanent magnet and electrically excited DC servo drives are covered. As a "newcomer" in the electrical machines field, the transversal flux machines and modular synchronous motors are introduced. |
| 2 | **Learning objectives / Learning Outcomes**<br>For the students who are interested in the fields of design, operation or development of electrical drives in their future career, the latest knowledge about<br>• modern computational methods (e.g. finite elements),<br>• advanced materials (e.g. high energy magnets, ceramic bearings),<br>• innovative drive concepts (e.g. transversal flux machines) and<br>• measurement and experiment techniques are imparted. |
| 3 | **Recommended prerequisite for participation**<br>Completed Bachelor of Electrical Engineering or equivalent degrees |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc MEC, **not** MSc EPE |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>A detailed script is available for the lecture. In the tutorials design of PM machines, switched reluctance drives and inverter-fed induction motors are explained. |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-bi-2030-vl | Motor Development for Electrical Drive Systems | | |
| **Instructor**<br>Dr.-Ing. Andreas Jöckel | | **Type**<br>Lecture | **SWS**<br>2 |
| **Course Nr.**<br>18-bi-2030-ue | **Course name**<br>Motor Development for Electrical Drive Systems | | |
| **Instructor**<br>Dr.-Ing. Andreas Jöckel | | **Type**<br>Practice | **SWS**<br>1 |

| Module name | | | | | |
|---|---|---|---|---|---|
| New Technologies of Electrical Energy Converters and Actuators | | | | | |
| **Module Nr.**<br>18-bi-2040 | **Credit Points**<br>4 CP | **Workload**<br>120 h | **Self study**<br>75 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>German and English | | | **Module owner**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | |

**1 Content**

Goal: The application of new technologies, i.e. super conduction, magnetic levitation techniques and magneto-hydrodynamic converter principles, are introduced to the students. The physical operation mode in principle, implemented prototypes and the current state of the development are described in detail.
Content:
Application of the superconductors for electrical energy converters:

- rotating electrical machines (motors and generators),
- solenoid coils for the fusion research,
- locomotive- and railway transformers,
- magnetic bearings.

Active magnetic bearings ("magnetic levitation"):

- basics of the magnetic levitation technique,
- magnetic bearings for high speed drives in kW to MW range,
- application for high-speed trains with linear drives.

Magneto-hydrodynamic energy conversion:

- physical principle,
- state of the art and perspectives.

Fusion research:

- magnetic field arrangements for contactless plasma inclusion,
- state of the current research.

**2 Learning objectives / Learning Outcomes**

Basic knowledge in application of superconductivity in energy systems is understood as well as magnetic levitation, magnetohydrodynamics and fusion technology.

**3 Recommended prerequisite for participation**

Physics, Electrical Machines and Drives, Electrical Power Engineering

**4 Form of examination**

Module Final Examination:

- Module Examination (Technical Examination, Optional, Standard Grading System)

**5 Grading**

Module Final Examination:

- Module Examination (Technical Examination, Optional, Weighting: 100 %)

**6 Usability of this module**

MSc EPE, MSc ETiT, MSc MEC, MSc WI-ETiT

**7 Grade bonus compliant to §25 (2)**

**8 References**

Detailed textbook; Komarek, P.: Hochstromanwendungen der Supraleitung, Teubner, Stuttgart, 1995
Buckel, W.: Supraleitung, VHS-Wiley, Weinheim, 1994
Schweitzer, G.; Traxler, A.; Bleuler, H.: Magnetlager, Springer, Berlin, 1993
Schmidt, E.: Unkonventionelle Energiewandler, Elitera, 1975

| Courses | | | | |
|---|---|---|---|---|
| | **Course Nr.**<br>18-bi-2040-vl | **Course name**<br>New Technologies of Electrical Energy Converters and Actuators | | |
| | **Instructor**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | **Type**<br>Lecture | **SWS**<br>2 |
| | **Course Nr.**<br>18-bi-2040-ue | **Course name**<br>New Technologies of Electrical Energy Converters and Actuators | | |
| | **Instructor**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | **Type**<br>Practice | **SWS**<br>1 |

| Module name<br>Overvoltage Protection and Insulation Coordination in Power System | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-hi-2030 | **Credit Points**<br>4 CP | **Workload**<br>120 h | **Self study**<br>75 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>English | | | **Module owner**<br>Prof. Dr.-Ing. Volker Hinrichsen | | |

**1 Content**

- Introduction, basics and overview
- Determination of representative overvoltages
  - Origin and classification of overvoltages
  - Normal distribution of overvoltage probability and derivated variables
  - Operating voltage and temporary overvoltages
  - Slow front overvoltages
  - Fast front overvoltages
  - Characteristics of overvoltage protective devices
  - Operation and design of metal-oxide surge arresters
  - Travelling wave effect and protective distance of surge arresters
  - Representative voltage and overvoltages in the case of using surge arresters
- Determination of coordination withstand voltage
  - Insulation strength for different voltage shapes and geometric configurations (gap factors)
  - Performance criterion
  - Insulation coordination procedure
- Determination of required withstand voltage
  - General remarks
  - Atmospheric correction
  - Safety factor for internal and external insulations
- Standard withstand voltage and testing procedures
  - General remarks
  - Test conversion factors
  - Determination and verification of insulation withstand by type tests
  - Table of test voltages and required clearances

**2 Learning objectives / Learning Outcomes**

The student have understood the main procedures of insulation coordination based on the relevant IEC standard (and the main difference with related IEEE standard procedure) which leads to selection of the electric strength of equipment in relation to the voltages which can appear on the system. In addition, they have learned the origin of different type of overvoltages as well as the protection of equipment against them. The operation and design of surge arresters as an important instrument of insulation coordination in power systems have been understood. The theoretical knowledge about the procedure of insulation coordination has been confirmed and expanded by practical case studies. The students are finally be able to carry out the insulation coordination independetly in any application.

**3 Recommended prerequisite for participation**

High Voltage Technology I and II

**4 Form of examination**

Module Final Examination:

- Module Examination (Technical Examination, Written Examination, Duration: 120 min, Standard Grading System)

**5 Grading**

| | |
|---|---|
| | Module Final Examination:<br>• Module Examination (Technical Examination, Written Examination, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc EPE, MSc Wi-ETiT |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>The related IEC standard can be borrowed during the lecture time. Lecture notes (in English) and other helpful materials can be downloaded from HST homepage: www.hst.tu-darmstadt.de. |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-hi-2030-vl | Overvoltage Protection and Insulation Coordination in Power System | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Volker Hinrichsen, Dr.-Ing. Constantin Balzer, M.Sc. Tobias Trautmann | | Lecture | 2 |

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-hi-2030-ue | Overvoltage Protection and Insulation Coordination in Power System | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Volker Hinrichsen, Dr.-Ing. Constantin Balzer, M.Sc. Tobias Trautmann | | Practice | 1 |

| **Module name**<br>Applied Superconductivity | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-bf-2030 | **Credit Points**<br>3 CP | **Workload**<br>90 h | **Self study**<br>60 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>German and English | | | **Module owner**<br>Prof. Dr. Oliver Boine-Frankenheim | | |

**1 Content**

- Basics of electrical conductivity at DC and RF
- Kamerligh-Onnes experiment, Meissner effect
- Superconductor state diagram
- London equations, Typ I / II Superconductor
- Cooper pairs (briefly: BCS theory, GL theory)
- Flux quantization, Flux vortices
- AC superconductivity, two fluid model, RF cavities
- Cooper pair tunneling, Josephson junctions
- Metrology: SQUIDs, (quantum-) Hall effect
- Superconductor magnetization, Hysteresis, Bean's model
- Applications: Magnets in accelerator and medical technology, precision field and current measurements, energy engineering

**2 Learning objectives / Learning Outcomes**

The students obtain a phenomenological understanding of superconductivity, which enables them to apply superconductors in engineering practice. Starting from Maxwellian electrodynamics, superconductors are in introduced as perfect conductors at zero frequency. Both their DC and AC properties are discussed. Theory shall be reduced as much as possible. Quantum mechanics is not a requirement for the course, however, simplified quantum mechanical models will be introduced. The focus of the lecture is put on applications, e.g. magnet technology or precision metrology.

**3 Recommended prerequisite for participation**

Electrodynamics (Maxwell's equations)

**4 Form of examination**

Module Final Examination:

- Module Examination (Technical Examination, Oral Examination, Duration: 30 min, Standard Grading System)

**5 Grading**

Module Final Examination:

- Module Examination (Technical Examination, Oral Examination, Weighting: 100 %)

**6 Usability of this module**

MSc ETiT, MSc WI-ETiT, MSc iCE, BSc/MSc CE

**7 Grade bonus compliant to §25 (2)**

**8 References**


- W. Buckel, R. Kleiner: „Supraleitung Grundlagen und Anwendungen"; Wiley VCH, 7. Auflage 2013.
- R.G. Sharma; „Superconductivity, Basics and Applications to Magnets"; Springer International Publishing, 2015 (online available).
- H. Padamsee, J. Knobloch, T. Hays: „RF-Superconductivity for Accelerators"; 2nd edition; Wiley VCH Weinheim, 2011.
- P. Seidel (Ed.), „Applied Superconductivity", Wiley VCH Weinheim, 2015.


**Courses**

<table>
<tr><td rowspan="2"></td><td>Course Nr.<br>18-bf-2030-vl</td><td colspan="3">Course name<br>Applied Superconductivity</td></tr>
<tr><td colspan="2">Instructor<br>Dr.-Ing. Uwe Niedermayer</td><td>Type<br>Lecture</td><td>SWS<br>2</td></tr>
</table>

| **Module name**<br>Energy Management and Optimization | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-st-2010 | **Credit Points**<br>6 CP | **Workload**<br>180 h | **Self study**<br>120 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr. rer. nat. Florian Steinke | | |

| | |
|---|---|
| 1 | **Content**<br>The lecture reviews the different levels of energy management. It then focuses on economic dispatch and discusses its different use cases like optimization of self-consumption, virtual power plants, electric vehicle load management or multi-modal neighborhood optimization. Relevant knowledge about the components to be controlled as well as the markets to be addressed is explained.<br>After this introduction to economic dispatch‘s application environment, the lecture focuses on the methods employed. The underlying mathematical formulations as different types of optimization problems (LP, MILP, QP, stochastic optimization) are reviewed. In parallel, a practical introduction to numerical optimization is given (descent algorithms, convergence, convexity, programming languages for the formulation of optimization problems). Moreover, an introduction into simple methods for the prognosis of future values (linear regression) is provided.All methodological learning is accompanied by hands-on exercises using the Matlab/Octave and the GAMS/AMPL software environments. |
| 2 | **Learning objectives / Learning Outcomes**<br>Students know the different use cases and formulations of economic dispatch. They have a basic understanding of the typically employed optimization methods and are able to judge the quality of the achieved results.<br>Moreover, students are independently able to formulate (energy) optimization problems and solve them with the tool GAMS/AMPL. |
| 3 | **Recommended prerequisite for participation**<br>Standard knowledge of linear algebra and multivariate analysis as well as basic knowledge in the use of Matlab/Octave is required. Knowledge of the modules „Kraftwerke & EE“ or „Energiewirtschaft“ is helpful but not necessarry. |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc ETiT, MSc iST, MSc Wi-ETiT, MSc CE |
| 7 | **Grade bonus compliant to §25 (2)**<br>Improvement of grades up to 0.4 compliant to APB §25(2) through bonus system for re-gular attention of exercises and practical courses |
| 8 | **References**<br>Boyd, Vandenberghe: Convex Optimization, Cambridge University Press, 2004A GAMS Tutorial by Richard E. Rosenthal, https://www.gams.com/24.8/docs/userguides/userguide/_u_g__tutorial.html |

**Courses**

| **Course Nr.** | **Course name** | | |
|---|---|---|---|
| 18-st-2010-vl | Energy Management and Optimization | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr. rer. nat. Florian Steinke | | Lecture | 2 |

<table>
<tr><td rowspan="2"></td><td>Course Nr.<br>18-st-2010-pr</td><td colspan="3">Course name<br>Energy Management and Optimization Lab</td></tr>
<tr><td colspan="2">Instructor<br>Prof. Dr. rer. nat. Florian Steinke</td><td>Type<br>Internship</td><td>SWS<br>1</td></tr>
<tr><td rowspan="2"></td><td>Course Nr.<br>18-st-2010-ue</td><td colspan="3">Course name<br>Energy Management and Optimization</td></tr>
<tr><td colspan="2">Instructor<br>Prof. Dr. rer. nat. Florian Steinke</td><td>Type<br>Practice</td><td>SWS<br>1</td></tr>
</table>

| **Module name**<br>Gasinsulated Switchgear and Lines | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-hi-2080 | **Credit Points**<br>3 CP | **Workload**<br>90 h | **Self study**<br>60 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Volker Hinrichsen | | |

**1 Content**

- Introduction, properties of the insulating gas sulfur hexafluoride (SF6) and gas mixture SF6/N2, SF6 handling
- Historical development of gasinsulated systems, life time, statistics on age of installed switchgear, space consumption
- Components and configuration of a GIS (3-phase, 1-phase; bushings, insulators, disconnectors, earthing switches, circuit breakers, instrument transformers, cable boxes, surge arresters, bus bars; particle traps; secondary equipment)
- Test requirements and specifications for GIS
- Insulation coordination and overvoltage protection, response to very fast transients (VFTO)
- Defects in GIS and diagnostic tools
- Gasinsulated medium voltage switchgear
- Gasinsulated lines (design, laying techniques, comparison with cables and overhead lines)
- Current carrying capability, thermo-mechanical stress
- Alternative insulating gases for application in “Eco”-GIS / - GIL (F-ketones, F-nitriles, “Clean Air” etc.)
- Gas-solid insulation systems under DC stress
- Special challenges of HVDC systems (impact factors, particle behavior, test requirements and specifications)

**2 Learning objectives / Learning Outcomes**

The students know the propoerties of the insulating gas sulfur hexafluoride (SF6). They know the climate impact of SF6 and are familiar with adequate gas handling. They are well informed about the alternatives that are actually under discussion and investigated for application in eco-friendly GIS. The students know the pros and cons of gasinsulated systems (GIS) compared with air insulated systems (AIS) in power supply systems, and they have understood, for which applications GIS might be favorable. They know the basic design and configuration of MV and HV GIS and can explain the functionality of each component in such systems. The students have learnt to know the test requirements and are able to distinguish routine-, type and on-site commissioning tests. They know why VFTO have to be especially regarded in the process of insulation coordination and which measures can and have to be taken for overvoltage protection in GIS. The students know the defects typical for GIS and how they can be monitored. They know the laying methods of gasinsulated lines (GIL) and can compare GIL to other transmission options in the power system. Furthermore, they can calculate the current carrying capacity of simple gasinsulated lines and estimate the resulting thermo-mechanical stress. The students have understood the basic differences in the requirements on insulation systems under DC and under AC stress, and what are the consequences on design and testing of DC-GIS and DC-GIL.

**3 Recommended prerequisite for participation**

HST I and HST II

**4 Form of examination**

Module Final Examination:

- Module Examination (Technical Examination, Optional, Standard Grading System)

**5 Grading**

Module Final Examination:

- Module Examination (Technical Examination, Optional, Weighting: 100 %)

**6 Usability of this module**

| | |
|---|---|
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Lecture slides and other information material supporting the lecture can be downloaded from the HST-Homepage: http://www.hst.tu-darmstadt.de. IEC test standards can be leant out for use during the lecturer time. |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-hi-2080-vl | Gasinsulated Switchgear and Lines | | |
| **Instructor** | | **Type** | **SWS** |
| Dr.-Ing. Maria Kosse, M.Sc. David Christopher Kothe | | Lecture | 2 |

| **Module name**<br>Machine Learning & Energy | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-st-2020 | **Credit Points**<br>6 CP | **Workload**<br>180 h | **Self study**<br>120 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr. rer. nat. Florian Steinke | | |

| | |
|---|---|
| 1 | **Content**<br>The analysis and interpretation of data becomes ever more important, also for engineers. Digitalization and Smart Grids are terms to describe a host of novel data-based services in the field of generation, distribution, consumption and marketing of (renewable) energy. The lecture presents the recent developments and their underlying principles of machine learning technology.<br>For a start we will describe the different problem settings of machine learning in a structured way (classification, regression, clustering, dimensionality reductions, time series models, ...) and present for each setting relevant applications from the energy sector (prediction of renewable energy or consumption in multimodal energy systems, fault detection and prediction, data visualization, robust investments decisions, customer analysis, probabilistic load flow, ...).<br>Thereafter we will briefly review necessary tools from optimization and probability theory, as well as introduce probabilistic graphical models. With these tools we will then study for each problem setting one or more machine learning algorithms in detail, together with use cases from the energy domain. Classic algorithms will be developed (e.g. linear regression, k-means, principal component analysis, ...) as well as modern ones (e.g. SVMs, Deep Learning, Collaborative filtering, ...). Practical exercise with Matlab will deepen the understanding and support student's active knowledge. |
| 2 | **Learning objectives / Learning Outcomes**<br>Students understand important machine learning problem settings and some key algorithms for each task. They know common applications thereof in the energy domain. Moreover, the students are able to apply and adapt those methods independently to new applications (not only from the energy domain). |
| 3 | **Recommended prerequisite for participation**<br>• Good knowledge of linear algebra and the foundations of numerical optimization (e.g. from the course 18-st-2010 Energieanagement & Optimierung)<br>• Using Matlab for programming the practical examples should pose no difficulty. A block tutorial on the use of Matlab is offered as 18-st-2030 Matlab Grundkurs. |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Weighting: 100 %) |
| 6 | **Usability of this module**<br>MSc etit, MSc iST, MSc Wi-etit, MSc CE |
| 7 | **Grade bonus compliant to §25 (2)**<br>Notenverbesserungen bis zu 0,4 nach APB §25(2) durch Bonus für regelmäßig besuchte Übungs-/Praktikumstermine und mindestens einmaliges Vorrechnen in den Übungen |
| 8 | **References**<br>• A Géron: Hands on Machine Learning with scikit-learn and Tensorflow, 2017<br>• Friedman, Hastie, Tibshirani: The elements of statistical learning, 2001<br>• Koller, Friedmann: Graphical Models, 2009 |

**Courses**

| | | | | |
|---|---|---|---|---|
| | **Course Nr.**<br>18-st-2020-vl | **Course name**<br>Machine Learning & Energy | | |
| | **Instructor**<br>Prof. Dr. rer. nat. Florian Steinke, M.Sc. Tim Christian Janke | | **Type**<br>Lecture | **SWS**<br>2 |
| | **Course Nr.**<br>18-st-2020-ue | **Course name**<br>Machine Learning & Energy | | |
| | **Instructor**<br>Prof. Dr. rer. nat. Florian Steinke | | **Type**<br>Practice | **SWS**<br>1 |
| | **Course Nr.**<br>18-st-2020-pr | **Course name**<br>Machine Learning & Energy Lab | | |
| | **Instructor**<br>Prof. Dr. rer. nat. Florian Steinke, M.Sc. Tim Christian Janke | | **Type**<br>Internship | **SWS**<br>1 |

| Module name<br>Lightning Physics and Lightning Protection | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-hi-2090 | **Credit Points**<br>3 CP | **Workload**<br>90 h | **Self study**<br>60 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Volker Hinrichsen | | |

**1 Content**

- Introduction
- Thunderstorms and Cloadclassification, formation and electrification
- Lightning, terminology, types, charge transfer, typical parameters
- Streamer- leader process, inception and development in large gaps
- Electric and magnetic fields in vicinity of lightning discharge
- Return stroke models, charge distributions and neutralization
- The Finite-Difference Time Domain Method for solving Maxwell's equations
- Lightning location, the technical use of field information
- Lightning effects in the middle and upper atmosphere
- Lightning hazard and deleterious effects
- Lightning protection and related threats, historical overview, standards and present lightning protection concepts
- Outer lightning protection, Lightning rods, down conductors, grounding systems, potential bonding and separation distances
- Inner lightning protection, surge protection devices, installation, test standards
- Lightning protection on transmission lines, faults and effects, calculation of outage rates and opportunities of improvement
- Lightning and surge protection for wind turbines

**2 Learning objectives / Learning Outcomes**

The students know the inception, development and effects of natural lightning. They are able to differentiate between types of lightning and know all typical parameters, related to different surges and types of lightning. They know that the parameters may devite in different places over the earth and know the reason for this deviation. The students learn about all relevant components of a lightning strike as well as their technical relevance in lightning protection, surge protection and lightning location. The theory and most relevant models of lightning attachment and also its successive return stroke are known. All relevant lightning threats in terms of lightning protection are known and can be calculated.
The students know how a standardized lightning protection system has to look like. They know about lightning protection levels, lightning protection zones and are able to apply measures on building, transmission lines and wind mills. The students know about simulation methodologies used in lightning research, taking into account the full retarded Maxwell equations. The students are aware of the uncertainities in lightning protection and lightning research. They know about open questions in the field of research related to the inception, discharge and effects of lightning.
The students learn about unconventional lightning protection, which cannot be found in the standard, and also get to know why they are not found there. The studentes are sensitised about research results in general.

**3 Recommended prerequisite for participation**

Recommended: BSc ETiT, BSc Wi-ETiT

**4 Form of examination**

Module Final Examination:

- Module Examination (Technical Examination, Oral Examination, Duration: 30 min, Standard Grading System)

**5 Grading**

| | |
|---|---|
| | Module Final Examination:<br>• Module Examination (Technical Examination, Oral Examination, Weighting: 100 %) |
| **6** | **Usability of this module**<br>MSc ETiT, MSc Wi-ETiT |
| **7** | **Grade bonus compliant to §25 (2)** |
| **8** | **References**<br>Lecture slides and other information material supporting the lecture can be downloaded from the HST-Homepage: http://www.hst.tu-darmstadt.de. IEC test standards can be leant out for use during the lecturer time.<br>• Blitz und Blitzschutz, F. Heidler, K. Stimper, ISBN 978-3-8007-2974-6<br>• Handbuch für Blitzschutz und Erdung, P. Hasse, J. Wiesinger, W. Zischank, ISBN 978-3-7905-0657-0<br>• Blitzschutzanlagen: Erlauterungen zu DIN 57 185/VDE 0185, VDE-Verlag, ISBN 978-3-8007-1303-9<br>• Lightning, Physics and Effects, V.A. Rakov, M.A. Uman, ISBN 978-0-521-03541-5<br>• Lightning Physics and Lightning Protection, E.M. Bazelyan, Y.P. Raizer, ISBN 978-0-750-30477-1<br>• Electromagnetic Computation Methods for Lightning Surge Protection Studies, Y. Baba, V.A. Rakov, ISBN 978-1-118-27563-4<br>• Lightning Electromagentics, V. Cooray, ISBN 978-1-84919-215-6<br>• Lightning: Principles, Instruments and Application, H.D. Betz, U. Schumann, P. Laroche, ISBN 978-1-4020-9078-3 |

**Courses**

| Course Nr. | Course name | | |
|---|---|---|---|
| 18-hi-2090-vl | | | |
| **Instructor** | | **Type** | **SWS** |
| Dr.-Ing. Martin Hannig | | Lecture | 2 |

| Module name<br>Electric drives for cars | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-bi-2150 | **Credit Points**<br>4 CP | **Workload**<br>120 h | **Self study**<br>75 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>English | | | **Module owner**<br>Prof. Dr. techn. Dr.h.c. Andreas Binder | | |

| | |
|---|---|
| 1 | **Content**<br>This course introduces the students to the different design aspects of electric drives used in automotive applications, comprising both high power density high speed traction and small mass produced auxiliary drives. Since the target audience comprises students from different degree programmes, the course first reviews basics of electromagnetic power conversion principles and design principles of PM based machines. The discussion of the electric drives themselves comprises the various facets of their design as part of a complex system, such as operating requirements, configurations, material choices, parasitic effects and their mitigation, electric and thermal stress, as well as manufacturing related questions, notably as they affect the design of the mass produced auxiliary drives. |
| 2 | **Learning objectives / Learning Outcomes**<br>At the end of the course, the students will know about design principles of PM based machines, electric drives: topologies, operating areas, dynamic performance and configuration of traction drives for hybrid cars and electric vehicles as they apply to electric drives for cars. In addition to traction drives, they will also be familiar with auxiliary drives used in cars. They will understand the parasitic effects of inverter induced bearing currents, the insulation material used for the electric winding and the winding stress at inverter supply. They will be familiar with the different cooling principles and thermal modelling, as well as the thermal aspects of the integration into the car. They will also know about the main failure modes that may occur with electric drives used for cars, the different lamination sheets used and their manufacturing. |
| 3 | **Recommended prerequisite for participation**<br>Completed Bachelor of Electrical Engineering or equivalent degree. |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Optional, Weighting: 100 %) |
| 6 | **Usability of this module** |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References** |

**Courses**

| Course Nr. | Course name | Instructor | Type | SWS |
|---|---|---|---|---|
| 18-bi-2150-vl | Electric drives for cars | Prof. Dr. Annette Mütze | Lecture | 2 |
| 18-bi-2150-ue | Electric drives for cars | Prof. Dr. Annette Mütze | Practice | 1 |

| Module name<br>Technology and Economics of Multimodal Energy Systems | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-st-2060 | **Credit Points**<br>4 CP | **Workload**<br>120 h | **Self study**<br>75 h | **Duration**<br>1 | **Cycle offered**<br>SoSe |
| **Language**<br>German and English | | | **Module owner**<br>Prof. Dr.-Ing. Stefan Nießen | | |

| | |
|---|---|
| 1 | **Content**<br>Energy economical framework, structures of multimodal energy systems, investment and costing, energy trading, sources for flexibility including storage, regulation, sustainability, social acceptance |
| 2 | **Learning objectives / Learning Outcomes**<br>The students learn the structures of energy supply systems including electricity, primary energies, heating, cooling, transport and water desalination. They understand the underlying principles for the design of energy systems for buildings, sites, cities and countries and are able to assess their adequacy for different international locations considering costs, environmental impact and social acceptance.<br>The students learn to assess the economic viability of investments in energy asssets using new present value and annuity. They learn the functionning of energy markets and different forms of trading and settlement for energy transactions.<br>Based on an analysis of the impact of an increasing share of renewables in the system, the students learn the technology of different sources for flexbility including demand-side-management, different technologies for storage and for the coupling of different modes of energy. Storage technologies include batteries, pumped hydro, hydrogen and inertia. Multimodal coupling technologies include power-heat, heat-cooling, power-heat-water and industrial processes.<br>Energy systems are subject to numerous laws and regulations. Therefore, the students learn different elements that define the regulatory framework such as feed-in tarifs, tax incentives, credit programs, quotas and certificates.<br>The regulations are the result of societal processes. Therefore, the students analyze the different interest groups, origins and impact of public opinion and the perception of risk. |
| 3 | **Recommended prerequisite for participation**<br>A completed Bachelor in any of the following subjects: electrical engineering, mechanical engi-neering, mechatronics, environmental sciences, business administration/engineering (Wirtschaftsingenieurwesen) |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Written/Oral Examination, Duration: 120 min, Standard Grading System)<br>In general, the module is examined by written examination (duration: 120 min.). If 20 students or less apply, the exam is oral (duration: 30 min.). The mode of examination will be communicated within one working week after the end of the exam application phase. |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Written/Oral Examination, Weighting: 100 %) |
| 6 | **Usability of this module** |
| 7 | **Grade bonus compliant to §25 (2)**<br>Grade improvement of 0.4 by successful presentation during the seminar |
| 8 | **References**<br>• Downloadable slides<br>• Book.energytransition.org/en<br>• https://www.agora-energiewende.de/fileadmin2/Projekte/2018/A_word_on/Agora_Energiewende_a-word-on_flexibility_WEB.pdf |

**Courses**

<table>
<tr><td rowspan="2"></td><td>Course Nr.<br>18-st-2060-vl</td><td colspan="3">Course name<br>Technology and Economics of Multimodal Energy Systems</td></tr>
<tr><td colspan="2">Instructor<br>Prof. Dr.-Ing. Stefan Nießen</td><td>Type<br>Lecture</td><td>SWS<br>2</td></tr>
<tr><td rowspan="2"></td><td>Course Nr.<br>18-st-2060-pj</td><td colspan="3">Course name<br>Technology and Economics of Multimodal Energy Systems - simulation game</td></tr>
<tr><td colspan="2">Instructor<br>Prof. Dr.-Ing. Stefan Nießen</td><td>Type<br>Project</td><td>SWS<br>1</td></tr>
</table>

| **Module name**<br>Relativistic Electrodynamics | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-kb-2020 | **Credit Points**<br>5 CP | **Workload**<br>150 h | **Self study**<br>90 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>German and English | | | **Module owner**<br>Prof. Dr.-Ing. Harald Klingbeil | | |

| | |
|---|---|
| 1 | **Content**<br>Basics of tensor analysis (tensor fields, transformation behavior, invariance, Ricci calculus, covariant derivative, differential operators), Lorentz transform, fundamental relativistic effects (time dilation, length contraction, Doppler effect), covariant form of Maxwell's equations, induction law from relativistic point of view, relation to relativistic mechanics, four-vectors and four-tensors, electromagnetic energy-momentum tensor and Maxwell's stress tensor, applications of relativistic electrodynamics |
| 2 | **Learning objectives / Learning Outcomes**<br>The students understand the basic ideas of Special Relativity and are familiar with the scientific vocabulary. They are able to derive and interpret fundamental formulas, and they are familiar with the mathematical tools. The students understand the concept of covariance and a coordinate-free description of physical theories. They are able to quantitatively compute electromagnetic phenomena in the context of Special Relativity. |
| 3 | **Recommended prerequisite for participation**<br>Recommended: "Grundlagen der Elektrodynamik" (18-dg-1010) |
| 4 | **Form of examination**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Oral Examination, Duration: 30 min, Standard Grading System) |
| 5 | **Grading**<br>Module Final Examination:<br>• Module Examination (Technical Examination, Oral Examination, Weighting: 100 %) |
| 6 | **Usability of this module** |
| 7 | **Grade bonus compliant to §25 (2)** |
| 8 | **References**<br>Lecture slides are offered for download. Further references are given in the lecture. |

**Courses**

| Course Nr. | Course name | Instructor | Type | SWS |
|---|---|---|---|---|
| 18-kb-2020-vl | Relativistic Electrodynamics | Prof. Dr.-Ing. Harald Klingbeil | Lecture | 2 |
| 18-kb-2020-ue | Relativistic Electrodynamics | Prof. Dr.-Ing. Harald Klingbeil | Practice | 2 |

| Module name<br>Designing the Energiewende | | | | | |
|---|---|---|---|---|---|
| **Module Nr.**<br>18-st-2080 | **Credit Points**<br>6 CP | **Workload**<br>180 h | **Self study**<br>135 h | **Duration**<br>1 | **Cycle offered**<br>WiSe |
| **Language**<br>German | | | **Module owner**<br>Prof. Dr.-Ing. Stefan Nießen | | |

**1 Content**

Energy technological, economical and political frame of the Energiewende with a focus on electricity in Germany.

The module consists of three elements:

- 6 double-lectures, two of them being tought by Prof. Michèle Knodt from Department of History and Social Sciences, by Prof. Florian Steinke and Prof. Stefan Niessen from Department of Electrical Engineering and Information Technology .
- a seminar consisting of 3 times 90 minutes, during which interdisciplinary teams of students from political and engineering sciences jointly analyse a recent study on the Energiewende and mutually present a short synthesis to each other.
- two half-days practical training during which the interdisciplinary teams based on a computer simulation take their own decisions on the regulatory framework, the expansion of the energy system and its operation. They experience in accellerated mode the impact on CO2 emsissions, costs and security of supply. In the practical part the students apply the learnings practically by means of a computer based serious game. They take the roles of electricity suppliers, industry, private homes and politicians, they take decisions on operation and expansion of the energy system. Through the computer simulation the students experience the consequences of their decisions on costs, CO2 emissions and security of supply in in time-lapse for the persion 2020 to 2050.

**2 Learning objectives / Learning Outcomes**

The students know different methods for techo-economical analysis of energy systems and base parameters of energy systems. Furthermore they have an overview on main technologies for energy conversion and storage today and possible future evolutions. They also comprehend governance basics consisting in EU legal acts, German laws and directives and an overview on the institutions implementing these.

**3 Recommended prerequisite for participation**

A completed Bachelor in any of the following subjects: electrical engineering, mechanical engineering, mechatronics, environmental sciences, business administration/electrical engineering (Wirtschaftsingenieurwesen-Elektrotechnik und Informationstechnik), Political Sciences

**4 Form of examination**

Module Final Examination:

- Module Examination (Study Achievement, Written/Oral Examination, Standard Grading System)

The type of examination will be announced in the first lecture. Possible types include

- a presentation and a report of the parts of the module

**5 Grading**

Module Final Examination:

- Module Examination (Study Achievement, Written/Oral Examination, Weighting: 100 %)

**6 Usability of this module**

**7 Grade bonus compliant to §25 (2)**

**8 References**

- Downloadable slides
- Book.energytransition.org/en
- https://www.agora-energiewende.de/fileadmin2/Projekte/2018/A_word_on/Agora_Energiewende_a-word-on_flexibility_WEB.pdf

**Courses**

| **Course Nr.** | **Course name** | | |
|---|---|---|---|
| 18-st-2080-vl | Designing the Energiewende - lecture | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Stefan Nießen, Prof. Dr. phil. Michèle Knodt, Prof. Dr. rer. nat. Florian Steinke | | Lecture | 1 |
| **Course Nr.** | **Course name** | | |
| 18-st-2080-pr | Designing the Energiewende – serious game | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Stefan Nießen, Prof. Dr. phil. Michèle Knodt, Prof. Dr. rer. nat. Florian Steinke | | Internship | 1 |
| **Course Nr.** | **Course name** | | |
| 18-st-2080-se | Designing the Energiewende - seminar | | |
| **Instructor** | | **Type** | **SWS** |
| Prof. Dr.-Ing. Stefan Nießen, Prof. Dr. phil. Michèle Knodt, Prof. Dr. rer. nat. Florian Steinke | | Seminar | 1 |