Module handbook of the
Online-M.Sc. Wind Energy Systems
Faculty of Civil and Environmental Engineering

University of Kassel/
Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)

Status: August, 10th 2016

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### 1. Fundamentals of Mathematics and Engineering for Wind Energy

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Module designation

Application of Software Tools

Course(s)

Application of Software Tools

Person responsible for the module
Prof. Dr.–Ing. Sigrid Wenzel

Lecturer
1. Dipl.–Inf. Markus Schmitz
2. Dr. Stefan Kopecz
3. Dipl.–Ing. Tobias Gleim M.Sc.
4. Prof. Dr.–Ing. Olaf Wünsch

Workload

Workload:
1. 45 h (5 h online presentations, 10 h private study, 30 h homework)
2. 45 h (5 h online presentations, 10 h private study, 30 h homework)
3. 45 h (5 h online presentations, 10 h private study, 30 h exercises)
4. 45 h (5 h online presentations, 10 h private study, 30 h homework)

Relation to curriculum
Basic studies, compulsory optional subject

Type of teaching, contact hours
Skype, virtual classrooms, online presentations, online transmission.

Requirements according to examination regulations
None

Recommended prerequisites
None

Module objective / Intended learning outcomes

The students should be able to design and implement structured programs using the object–oriented paradigm and know how to apply different simulation programs. The students have the ability to apply MATLAB to distinguish mathematical problems, as well as the finite volume software OpenFoam, in order to simulate fluid flows in technical apparatus. Additionally, the students have the ability to apply a semi–commercial finite element software to simulate structural components of wind power plants and to transfer their knowledge to classical commercial finite element packages as e.g. Abaqus, ANSYS, Nastran. In particular, geometrical modeling, meshing, static and dynamic analyses and the interpretation of the results are familiar to the students.

Content

1. Object–oriented Programming with Java
   Introduction to the OO–paradigm, data structures and methods, recursive functions, programming example.
2. Application of MATLAB
   Introduction to MATLAB, numerical solution of large linear systems, post processing
3. Application of MATLAB finite element software
   Introduction to mesh generation, linear static and dynamic structural analyses, post-processing, simulation of wind power plants components
4. Application of OpenFoam
   Introduction to OpenFoam, discretization of basic geometries and mesh generation, handling of OpenFoam, examples of fluid flow simulations

Study and examination requirements and forms of examination
Written homework (10–25 pages)

Media employed
Slides
Reading list
Reading list will be provided by lecturer via the online platform Moodle.
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<th>Credits</th>
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<td>Master</td>
<td>6</td>
<td>English</td>
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### Module designation

**Mathematics**

### Course(s)

**Mathematics of Differential Equations**

<table>
<thead>
<tr>
<th>Person responsible for the module</th>
<th>Prof. Dr. rer. nat. habil. Andreas Meister</th>
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<tr>
<td>Lecturer</td>
<td>Prof. Dr. rer. nat. habil. Andreas Meister</td>
</tr>
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| Workload                          | 180 h (30h contact study, 60h exercises, 90h private study) |

| Relation to curriculum            | Basic studies, compulsory optional subject |

| Type of teaching, contact hours   | Virtual classrooms |

| Requirements according to examination regulations | None |

| Recommended prerequisites          | None |

### Module objective / intended learning outcomes

This course provides an introduction to both ordinary and partial differential equations as well as fundamental numerical methods. These ingredients represent basic knowledge for subsequent courses in the field of fluid mechanics and mechanics of materials.

At the end of the course, the students should:
- Understand the basic theory for solving ordinary differential equations.
- Have experience in solving ordinary differential equations analytically.
- Have knowledge of partial differential equations, as well as the behavior of their solution in the context of standard elliptic, parabolic and hyperbolic problems.
- Be able to choose and apply adequate numerical methods for different scientific tasks like interpolation, numerical integration, linear and nonlinear systems of equations and systems of ordinary differential equations.

### Content

- Ordinary and partial differential equations
  - Analytic solution of ordinary differential equations
  - Classification of partial differential equations
  - Analytic solution of the wave and heat equation
- Numerical Mathematics
  - Interpolation
  - Numerical integration
  - Methods for linear systems of equations
  - Methods for nonlinear systems of equations
  - Methods for systems of ordinary differential equations

### Study and examination requirements and forms of examination

Written exam (90 – 120 min) or online oral examination (20 – 30 min)

### Media employed

Online script

### Reading list

Reading list will be provided by lecturer via the online platform Moodle.
Module level
Master

Credits
6

Language
English

Return
Annual

Module designation

Fluid Mechanics

Course(s)
1. Advanced Fluid Dynamics
2. Experimental Methods in Fluid Mechanics

Person responsible for the module
Prof. Dr.-Ing. Martin Lawerenz, Prof. Dr.-Ing. Olaf Wünsch

Lecturer
1. Prof. Dr.-Ing. Olaf Wünsch
2. Prof. Dr.-Ing. Martin Lawerenz

Workload
1. Workload: 120 h (20h online presentations, 60h private study, 40 h exercises)
2. Workload: 60h (7h online sessions, 14h lecture, 14 h exercises, 25h examination preparation)

Relation to curriculum
Basic studies, compulsory optional subject

Type of teaching, contact hours
Skype, virtual classrooms, online unit, digital communications, telephone

Requirements according to examination regulations
None

Recommended prerequisites
None

Module objective / intended learning outcomes
1. Students know how to model the fluid flow in wind energy systems and apply basic calculation methods in order to predict pressure, velocities, forces and momentums in technical systems.

2. Upon completion of the course, students will have abilities in terms of:
   - Knowledge: Methods and devices to analyse the flow-field experimentally.
   - Skills: Performing measurements and flow-field analysis and visualization using probes and optical sensors.

   Competencies: Establishing appropriate experimental setups, assessment of the measured data.

Content
1. Advanced Fluid dynamics
   - Fluid- and aerostatic
   - Dynamic of incompressible and compressible fluid flow
   - Balance of mass and momentum
   - Friction flow
   - Dimensional analysis and similarity

2. Experimental Methods in Fluid mechanics
   - Flow-Field Parameters.
   - Pressure Measurement.
   - Velocity Measurement
   - Flow Visualization.
   - Post-Processing & Data Reduction, Error Estimation.

Study and examination requirements and forms of examination
Written Test (120 min) or online oral examination (30 min)

Media employed
Online script

Reading list
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<thead>
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<th>Title</th>
<th>Publisher</th>
<th>Location</th>
<th>Year</th>
</tr>
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<tbody>
<tr>
<td>Krause, E.</td>
<td>Fluid Mechanics</td>
<td>Springer-Verlag</td>
<td>Berlin</td>
<td>2005</td>
</tr>
<tr>
<td>Spurk, J.H.; Aksel, N.</td>
<td>Fluid Mechanics</td>
<td>Springer-Verlag</td>
<td>Berlin</td>
<td>2008</td>
</tr>
<tr>
<td>Tavoularis, S.</td>
<td>Measurements in Fluid Mechanics</td>
<td>Cambridge University Press</td>
<td>Cambridge</td>
<td>2005</td>
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</table>
**Module level**
Master

**Credits**
6

**Language**
English

**Return**
Annual

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**Module designation**

**Solid Mechanics**

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**Course(s)**

**Solid Mechanics**

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**Person responsible for the module**
Prof. Dr.–Ing. habil. D. Kuhl

**Lecturer**
Prof. Dr.–Ing. habil. D. Kuhl

**Workload**
180h (20h contact time, 60h private study, 40h exercises)

**Relation to curriculum**
Basic studies, compulsory optional subject

**Type of teaching, contact hours**
Online presentations, digital communication

**Requirements according to examination regulations**
None

**Recommended prerequisites**
None

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**Module objective / intended learning outcomes**

Students know the fundamentals of linear elasticity and continuum mechanics. They know how to apply basic equations to technical problems and are able to calculate stress, strain or deformation in wind energy plant components under loading.

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**Content**

- Cauchy stress and strain (tensor formulation)
- Hooke’s Law, plain strain vs. plain stress, anisotropic material behavior
- Balance laws of thermomechanics
- Basics of linear elasticity
- Introduction to stability problems
- Introduction to the theory of plates and shells
- Introduction to inelastic material laws

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**Study and examination requirements and forms of examination**

Written exam (90 min) and online oral examination (30 min). The examination results are combined with a weighting of 1:1 in the final grade.

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**Media employed**

Online script

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**Reading list**

R.C. Hibbeler, Engineering Mechanics, Pearson, different volumes
Gross et al., Engineering Mechanics, Springer, different volumes
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**Module designation**

**Electrical Engineering**

**Course(s)**

**Electrical Engineering**

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<td>Lecturer</td>
<td>Dr.-Ing. Aleksandra Sasa Bukvic–Schäfer Dr.-Ing. Antonio Notholt–Vergara</td>
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<td>Recommended prerequisites</td>
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**Module objective / intended learning outcomes**

At the end of the module students have basic knowledge of electrical engineering in the field of wind energy systems, with a particular focus on energy-related systems, simulation, control and regulation. The students should understand the mechanisms and functions of electrical machinery and equipment and have a basic understanding of control and regulation procedures. The ability to analyze systems to model and simulate this module rounds off at the system level.

**Content**

- Tracking System
- Converter
- Adjustment control and business management
- Electrical net

**Study and examination requirements and forms of examination**

Written exam (120 min) or online oral examination (30 min) or written homework (25 pages) with presentation of the homework (30 min). The final grade for the module is a combination of the written homework (75%) and presentation (25%) grades.

**Media employed**

Online script

**Reading list**

Reading list will be provided by lecturer via the online platform Moodle.
Module level
Master

Credits
6

Language
English

Return
Annual

Module designation
Design of Mechanical and Electrical Components

Course(s)
1. Mechanical Aspects of Wind Energy
2. Electrical Aspects of Wind Energy

Person responsible for the module
Prof. Dr. rer. nat. Clemens Hoffmann

Lecturer
Prof. Dipl.-Ing. Henry Seifert
Prof. Dr. Siegfried Heier

Workload
180 h (30h contact time, 150h private study)

Relation to curriculum
Basic studies, compulsory optional subject

Type of teaching, contact hours
Skype, virtual classrooms, digital communications

Requirements according to examination regulations
None

Recommended prerequisites
None

Module objective / intended learning outcomes
The students should be able
- to design different wind turbine components
- to compute the rotor-blade aerodynamics and determine the optimum blade setting angles for design mean flow speed
- to compute the forces and performance curves for the wind turbine
- to determine the basic wind turbine dimensions
- to compare different design concepts for power delivery systems
- to design the different gear boxes and mechanical drives in the machine house
- to understand the safety and braking systems needed in the machine house
- to design the different tracking mechanisms
- to compute the different aerodynamic, structural and dynamic loads on the wind turbine blades and tower
- to estimate the extra loads from the mechanical systems connected to the wind turbine
- to distinguish between the different materials used to construct the rotor blades
- to design rotor blades using different available materials and technology
- to distinguish and know about the different types of towers and support used for wind turbines
- to make a preliminary design for a tubular, concrete or lattice tower and suitable foundation
- to understand the different legislation requirements and transportation facilities needed to build and operate a wind turbine/farm
- to plan for a new wind farm and to develop a Gantt chart to define when the different design, construction, testing and operation stages will commence
- to understand the different safety measures and necessary scheduled maintenance for wind turbines
- to take appropriate steps to apply for wind farm certification.

The students should be able
- to understand and know the different WEC devices and functions
- to describe the different components of WECS
- to calculate the blade setting and obtain the performance curves
- to match the turbine to a suitable generator
- to describe the suitable drive train
- to understand the different problems related to grid integration
- to understand and know the different types of grids
- to understand schemes for control of the grid
- to design wind turbine control concepts for island, grid and interconnected operation

**Module content**
Mechanical drive train and machine house: comparison of different design concepts, blade adjustment system, rotor brake, step up gears, generator coupling, tracking of wind direction, machine house design, aesthetic criteria; loads and structural demands: static aerodynamic and structural loads on blades and towers, dynamic loads on blades and towers, modeling to calculate the loads and structural demands, mechanical components and control system loads; rotor blades in composite construction: materials, composite material construction, rotor blade construction, rotor blade connection to the hub; towers and foundation: design and varieties, steel tube towers, concrete tower, lattice tower, foundation; planning, installation and operation: project planning, legislations for land and environmental operation, transport facilitations for wind farm, plant erection, testing and operation, safety aspects, service and maintenance; certification of wind power plants; field excursion to German wind farm sites.

Construction and functional structures of WEC; main components of wind energy converters: rotor blade with pitch drive, input torque, generator, mechanical drive train; grid integration: different electrical networks, grid influences, grid control; control concepts and operational results: island grid operation of WECs, grid operation, interconnection operation; control system design and plant simulation: plant components characteristics, development of mathematical models for control and simulation, dimensioning of the controllers.

**Study and examination requirements and forms of examination**
Written exam (120 min) or online oral examination (30 min) or written homework (25 pages) with presentation of the homework (30 min). The final grade for the module is a combination of the written homework (75%) and presentation (25%) grades.

**Media employed**
Online script

**Reading list**
2. **Specialization: Simulation and Structural Technology of Wind Energy Systems**

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**Module designation**

**Rotor Aerodynamics**

**Course(s)**

**Rotor Aerodynamics**

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<th><strong>Person responsible for the module</strong></th>
<th>Prof. Dr.-Ing. Martin Lawerenz</th>
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<tr>
<td><strong>Lecturer</strong></td>
<td>Prof. Dr.-Ing. Martin Lawerenz</td>
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| **Workload** | 180 h  
(42 h lecture, 42 h exercises, 21 h online sessions, 75 h examination preparation) |
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**Module objective / intended learning outcomes**

Upon completion of the course, students will have ability to assess and analyze the flow field of wind turbine rotors and will be able to perform basic aerodynamic design of the blades.

- **Knowledge:** Aerodynamics of wind turbine rotor
- **Skills:** Performance estimation of wind turbine, aerodynamic design of rotors, numerical simulation methods.
- **Competencies:** Analysis and assessment of wind turbine flow-field, and the corresponding energy transmission.

**Content**

1) Introduction.

2) Basic Aerodynamics.
   - Coordinate System & Velocity Triangle.
   - Aerodynamic Variables.
   - Dimensionless Parameters.
   - Conservation Laws.

3) Wind Turbine Model.
   - 2-D Representation of Wind Turbine Flow-Field.
   - Betz’s Law of Maximum Power.
   - 2-D Representation of Wind Turbine Flow-Field.
   - Extensions for Vortical Flow.

4) Blade Element Method.
   - Classical Blade Element Method.

5) Airfoil Aerodynamics.
   - Potential Flow.
     - Streamline Curvature Method.
     - Stream-Function Method.
   - Viscous Flow.
     - Boundary Layer Concept.
     - Laminar and Turbulent Boundary Layers.
6) Boundary Conditions.
   - Inflow Wind.
   - Wind Shear.
   - Gust Loads.
   - Flow near the Tower.

   - Objectives.
   - Constraints.
   - Optimization Methods.
   - Optimization of Wind Turbine Rotor.

8) Numerical Simulation of Wind Turbine Flow (Examples).
   - Steady-state Navier–Stokes Simulation.
   - Unsteady Navier–Stokes Simulation.
     - Rotor–Tower Interaction.
     - Dynamic Inflow.

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<th>Study and examination requirements and forms of examination</th>
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Reading list


ASME Press, 2009
Module designation

Theoretical Fluid Mechanics

Course(s)

1. Basics of 3D fluid flow
2. Basics of Hyperbolic Systems and Fluid Structure Interaction

Person responsible for the module

Prof. Dr. Andreas Meister, Prof. Dr.-Ing. Olaf Wünsch

Lecturer

1. Prof. Dr.-Ing. Olaf Wünsch
2. Prof. Dr. Andreas Meister

Workload

1. Workload: 90 h (15 h online presentations, 45 h private study, 30 h exercises)
2. Workload: 90 h (15 h online presentations, 45 h private study, 30 h exercises)

Relation to curriculum

Specialist studies, Simulation and Structural Technology, elective

Type of teaching, contact hours

Skype, virtual classrooms, online presentations, digital communication

Requirements according to examination regulations

None

Recommended prerequisites

Module Fluid Mechanics

Module objective / intended learning outcomes

Students know how to model and calculate analytically complex and 3D fluid flow in wind energy systems.

Content

1. Balance of mass, momentum and energy for Newtonian fluids (gaseous and liquid, formulation in integral and differential form, vortex transportation equation, acoustic phenomena)
   Turbulent flow (physical basics of turbulence, models for numerical simulations)
2. Theory of characteristics
   Fluid structure interaction

Study and examination requirements and forms of examination

Written exam (120 min) or online oral examination (30 min) or written homework (25 pages) with presentation of the homework (30 min). The final grade for the module is a combination of the written homework (75%) and presentation (25%) grades.

Media employed

Online script

Reading list

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**Module designation**

**Strength and Reliability**

**Course(s)**

**Strength and Reliability**

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<tr>
<th><strong>Person responsible for the module</strong></th>
<th>Prof. Dr.–Ing. A. Ricoeur</th>
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<tbody>
<tr>
<td><strong>Lecturer</strong></td>
<td>Prof. Dr.–Ing. A. Ricoeur</td>
</tr>
</tbody>
</table>

**Workload**

Workload: 180 h (30 h contact time, 150 h private study)

**Relation to curriculum**

Specialist studies, Simulation and Structural Technology, elective

**Type of teaching, contact hours**

Online presentations, digital communication, Skype

**Requirements according to examination regulations**

None

**Recommended prerequisites**

Modules Mathematics and Solid Mechanics

**Module objective / intended learning outcomes**

Students know different approaches to evaluate strength and reliability of materials. They know how to apply these concepts to the design of wind plant structural components and are able to perform numerical fracture mechanical as well as classical strength calculations.

**Content**

- Concept of local stress analysis, strength hypotheses
- Concept of fatigue and service strength
- Fracture mechanical concepts:
  - energy release rate
  - path-independent conservation integrals
  - cohesive zone models
  - stress intensity factors
  - crack weight functions
  - fatigue crack growth
- Fundamentals of numerical fracture mechanical analyses
- Introduction to damage mechanics concepts

**Study and examination requirements and forms of examination**

Written exam (90 min) and online oral examination (30 min).

The examination results are combined with a weighting of 1:1 in the final grade.

**Media employed**

Online script

**Reading list**

Gross, Seelig: Fracture Mechanics, Springer

T.L. Anderson: Fracture Mechanics, CRC Press
<table>
<thead>
<tr>
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<tr>
<td>Master</td>
<td>6</td>
<td>English</td>
<td>Annual</td>
</tr>
</tbody>
</table>

**Module designation**

**Towers**

**Course(s)**

**Towers**

<table>
<thead>
<tr>
<th><strong>Person responsible for the module</strong></th>
<th>Prof. Dr.–Ing. Detlef Kuhl</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lecturer</strong></td>
<td>Prof. Dr.–Ing. Detlef Kuhl</td>
</tr>
<tr>
<td><strong>Workload</strong></td>
<td>180h (30h contact time, 90h private study, 60h homework)</td>
</tr>
<tr>
<td><strong>Relation to curriculum</strong></td>
<td>Specialist studies, Simulation and Structural Technology, elective</td>
</tr>
<tr>
<td><strong>Type of teaching, contact hours</strong></td>
<td>Skype, virtual classrooms, online presentations, digital communication</td>
</tr>
</tbody>
</table>

**Requirements according to examination regulations**

None

**Recommended prerequisites**

None

**Module objective / intended learning outcomes**

At the end of the course
- students know the basic construction of towers for wind turbines (lattice tower, concrete tower, steel tube tower) and their connection to cable and foundation.
- they have the knowledge of static and dynamic structural behavior of the tower.
- they understand reduced mechanical models and their analytical solution.
- they are able to generate finite element models of the towers and to interpret the approximate solution for the design and use of towers.
- they understand mathematical optimization methods and application to optimize the various tower designs.

**Content**

- Construction of towers
- Steel tower and calculation concepts
- Steel concrete tower and calculation concepts
- Fundaments, swimming fundaments
- Fundaments of concrete technology
- Grouted joints
- Strength characteristics, deformational behavior and fatigue behavior
- Durability

**Study and examination requirements and forms of examination**

Written exam (120 min) or online oral examination (30 min) or written homework (25 pages) with presentation of the homework (30 min). The final grade for the module is a combination of the written homework (75%) and presentation (25%) grades.

**Media employed**

Online script

**Reading list**

Reading list will be provided by lecturer via the online platform Moodle.
### Module designation

**On and Offshore Foundations**

### Course(s)

**On and Offshore Foundations**

<table>
<thead>
<tr>
<th>Person responsible for the module</th>
<th>Prof. Dr.–Ing. Oliver Reul</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecturer</td>
<td>Prof. Dr.–Ing. Oliver Reul</td>
</tr>
<tr>
<td>Workload</td>
<td>180 h (20 h contact time/online presentations, 80 h private study, 80 h homework)</td>
</tr>
<tr>
<td>Relation to curriculum</td>
<td>specialist studies Simulation and Structural Technology, elective</td>
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<tr>
<td>Type of teaching, contact hours</td>
<td>Online unit, online presentations, digital communication</td>
</tr>
<tr>
<td>Requirements according to</td>
<td>Module Solid Mechanics</td>
</tr>
<tr>
<td>examination regulations</td>
<td></td>
</tr>
<tr>
<td>Recommended prerequisites</td>
<td>Modules Mathematics, Fluid Mechanics, Application of Software Tools</td>
</tr>
</tbody>
</table>

### Module objective / intended learning outcomes

The objective of the module is to establish a framework for understanding the material behavior of soils and to become familiar with foundation solutions for WES for a broad range of subsoil conditions and environmental boundary conditions.

The students know that soils are multiphase media. They are able to identify and estimate material parameters controlling the deformation and strength of different soil types with special focus on cyclic loading conditions. The students know laboratory tests and site investigation methods to investigate the subsoil conditions at the WES foundation site.

The students know possible foundation types for WES, i.e. shallow foundations or piled foundations, and understand the options and limitations of these foundations depending on subsoil and loading conditions. They are able to calculate deformations and capacity of WES foundations based on classical geotechnical analysis methods. The students know numerical modeling techniques for the simulation of WES foundation behavior.

For a given WES, the students have are able to select an appropriate foundation type considering subsoil and loading conditions as well as environmental boundary conditions.

### Content

- Material behavior of soils
  - Soil as a multiphase media
  - Deformation
  - Strength
  - Soil response to cyclic loading
  - Laboratory testing to establish soil parameters
- Site investigation
  - On shore
  - Off shore
- Foundation types
  - Shallow foundations
  - Piled foundations
- Load estimates for foundations
On shore
- Off shore
- Analysis of foundations
  - Deformations (Serviceability Limit State)
  - Capacity (Ultimate Limit State)
- Numerical modeling of foundation behavior

<p>| Study and examination requirements and forms of examination | Written exam (120 min) or online oral examination (30 min) or written homework (25 pages) with presentation of the homework (30 min). The final grade for the module is a combination of the written homework (75%) and presentation (25%) grades. |
| Media employed | Online script |</p>
<table>
<thead>
<tr>
<th>Module level</th>
<th>Credits</th>
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<tbody>
<tr>
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</tbody>
</table>

**Module designation**  
*Computational Fluid Dynamics (CFD)*

**Course(s)**  
1. **Methods of Numerical Simulation**  
2. **Mesh Generation and Applications**

**Person responsible for the module**  
Prof. Dr. Andreas Meister, Prof. Dr.-Ing. Olaf Wünsch

**Lecturer**  
1. Prof. Dr. Andreas Meister  
2. Prof. Dr.-Ing. Olaf Wünsch

**Workload**  
1. Workload: 90 h (15 h online presentations, 45 h private study, 30 h exercises)  
2. Workload: 90 h (15 h online presentations, 45 h private study, 30 h exercises)

**Relation to curriculum**  
Specialist studies, Simulation and Structural Technology, elective

**Type of teaching, contact hours**  
Skype, virtual classrooms, online presentations, digital communication

**Requirements according to examination regulations**  
Module Fluid Mechanics

**Recommended prerequisites**  
Modules Fluid Mechanics, Theoretical Fluid Mechanics, Mathematics

**Module objective / intended learning outcomes**  
Students know how to develop and apply methods for numerical simulations.

**Content**  
- **Methods of Numerical Simulation**  
  - Part 1 Introduction to general numerical methods  
  - Part 2 Advances in Finite Volume schemes and applications  
- **Mesh generation and Application**  
  - Part 1 Discretization of flow domains and mesh generation (structured/unstructured meshes, grid generation techniques, quality of meshes)  
  - Part 2 Applications of CFD (simulations of fluid flow in technical apparatus)

**Study and examination requirements and forms of examination**  
Multiple-choice-test (30min) and online oral examination (30 min) or Written exam (120 min). The final grade for the module is a combination of the written homework (75%) and presentation (25%) grades.

**Media employed**  
Online script

**Reading list**  
### Module objective / intended learning outcomes

This course provides an introduction to linear computational structural mechanics using the finite element method and dynamics solution procedures. It is based on the fundamental education in mathematics, solid mechanics and application of software tools. Subsequent courses in solid mechanics structural technology and fluid structure interaction as one component of the fluid mechanics courses use basic knowledge of computational structural mechanics. The present course is continued in Nonlinear Computational Structural Mechanics.

At the end of the course, the students should:

- Understand the basic theory of the finite element method including the initial boundary value problem, the weak formulation and the discretization in space and time
- Have knowledge of different finite element formulations, their advantages and disadvantages, their strengths and limitations
- Understand the static solution process using the finite element methods
- Know the eigenvalue analysis and its application to wind power plants
- Know different types of time integrations schemes and their properties
- Be able to develop a basic finite element program using MATLAB
- Be familiar with the application of finite element programs in the static and dynamic analysis of wind power plant components

### Content

The course Linear Computational Structural Mechanics covers the theoretical basis, the development and the application of the finite element method. Special attention is given to the requirements for the static and dynamic analysis of wind power plants.

- Brief summary of linear continuum mechanics
- Weak formulation of elastostatics and elastodynamics
- Development of 1D finite element methods
- Development of 3D and 2D finite element methods
- Development of 2D and 3D truss and beam elements
- Assembly, static analysis and post-processing
- Eigenvalue analysis
- Explicit and implicit dynamic solution within the time domain
- Linear finite element program development
- Numerical analyses of components of wind power plants using a MATLAB finite element code

<table>
<thead>
<tr>
<th>Study and examination requirements and forms of examination</th>
<th>Written exam (120 min) or online oral examination (30 min) or written homework (25 pages) with presentation of the homework (30 min). The final grade for the module is a combination of the written homework (75%) and presentation (25%) grades.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Media employed</strong></td>
<td>Online materials as lecture notes, presentations, interactive learning modules and chapter checks, virtual classroom.</td>
</tr>
</tbody>
</table>

**Reading list**
- Textbooks on the linear finite element method, e.g.
  - Hughes (1987): The Finite Element Method. Linear Static and Dynamic Finite Element Analysis
  - Bathe (1996): Finite Element Procedures
  - Szabo & Babuska (1991): Finite Element Analysis

- Particular journal papers as basis of homeworks, e.g.
<table>
<thead>
<tr>
<th><strong>Module level</strong></th>
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<th><strong>Language</strong></th>
<th><strong>Return</strong></th>
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</thead>
<tbody>
<tr>
<td>Master</td>
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<table>
<thead>
<tr>
<th><strong>Module designation</strong></th>
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<tbody>
<tr>
<td>Nonlinear Computational Structural Mechanics</td>
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<table>
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<tr>
<th><strong>Course</strong></th>
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<tbody>
<tr>
<td>Nonlinear Computational Structural Mechanics</td>
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</tbody>
</table>

| **Person responsible for the module** | Prof. Dr.–Ing. Detlef Kuhl |
| **Lecturer** | Prof. Dr.–Ing. Detlef Kuhl |

| **Workload** | 180 h (30h contact time, 90h private study, 60h homework) |

<table>
<thead>
<tr>
<th><strong>Relation to curriculum</strong></th>
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</thead>
<tbody>
<tr>
<td>Specialist studies, Simulation and Structural Technology, elective</td>
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</table>

<table>
<thead>
<tr>
<th><strong>Type of teaching, contact hours</strong></th>
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<tbody>
<tr>
<td>Chapter Checks, virtual classroom, online scripts, digital communication</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Requirements according to examination regulations</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Modules Mathematics, Solid Mechanics</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Recommended prerequisites</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Modules Application of Software Tools, Linear Computational Structural Mechanics</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Module objective / intended learning outcomes</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>This course provides a brief introduction to geometrically nonlinear continuum mechanics and subsequently an intensive study of nonlinear computational structural mechanics using the finite element method and solution procedures for nonlinear structural statics and dynamics. The present course continues on from Linear Computational Structural Mechanics. At the end of the course, the students should:</td>
</tr>
</tbody>
</table>

- Understand the basic theory of the geometrically non-linear finite element method including the initial boundary value problem, the weak formulation and the discretization in space and time
- Understand the necessity and the procedure of linearization in continuum mechanics, at the element, structural and algorithmic levels
- Interpret the linear finite element method as special case of the nonlinear finite element method
- Understand the static solution process using load and arc-length controlled Newton–Raphson and their control parameters iteration schemes
- Know the methods of computational stability analysis and their control parameters
- Know different types of time integrations schemes and their properties with regard to nonlinear dynamics
- Be able to develop a basic nonlinear finite element program using MATLAB
- Be familiar with the application of nonlinear finite element programs to the static and dynamic analysis of wind power plant components |

<table>
<thead>
<tr>
<th><strong>Content</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>The course Nonlinear Computational Structural Mechanics provides the theoretical basis, the development and the application of the geometrically non-linear finite element method. Special attention is given to the requirements for the static and dynamic analysis of wind power plants undergoing large deformations and rotations.</td>
</tr>
</tbody>
</table>

- Geometrically nonlinear continuum mechanics |
- Weak formulation of nonlinear elastostatics and elastodynamics
- Consistent linearization
- Development of nonlinear 1D, 2D, and 3D finite element methods
- Development of Crisfield 3D truss element
- Development of 2D and 3D beam elements
- Static load and arc-length controlled Newton-Raphson solution procedures
- Explicit and implicit solution of nonlinear dynamics
- Nonlinear finite element program development
- Nonlinear numerical analyses of components of wind power plants using a MATLAB finite element code

### Study and examination requirements and forms of examination

<table>
<thead>
<tr>
<th>Study and examination requirements and forms of examination</th>
<th>Written exam (120 min) or online oral examination (30 min) or written homework (25 pages) with presentation of the homework (30 min). The final grade for the module is a combination of the written homework (75%) and presentation (25%) grades.</th>
</tr>
</thead>
</table>

### Media employed

- Online materials as lecture notes, presentations, interactive learning modules and chapter checks. Online classroom.

### Reading list

- Textbooks on the nonlinear finite element method, e.g.

- Particular journal papers as basis of homeworks, e.g.
<table>
<thead>
<tr>
<th>Module level</th>
<th>Credits</th>
<th>Language</th>
<th>Return</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master</td>
<td>6</td>
<td>English</td>
<td>Annual</td>
</tr>
</tbody>
</table>

**Module designation**

**Rotor Blades**

**Course(s)**

**Rotor Blades**

<table>
<thead>
<tr>
<th>Person responsible for the module</th>
<th>Lecturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prof. Dr.-Ing. Hans-Peter Heim</td>
<td>Prof. Dr.-Ing. Hans-Peter Heim</td>
</tr>
</tbody>
</table>

**Workload**

Workload 180h (150 h private study, 20 h exercises, 10 h contact time)

**Relation to curriculum**

Specialist studies, Simulation and Structural Technology, elective

**Type of teaching, contact hours**

Chapter–Checks, online scripts, Skype, digital communication

**Requirements according to examination regulations**

None

**Recommended prerequisites**

Basic modules

**Module objective / intended learning outcomes**

This course provides fundamental knowledge of polymer material properties and polymer processing.

The design, manufacturing, mechanical properties and testing of polymer materials for rotor blades will be presented.

The student should learn the fundamental knowledge of polymer materials and polymer processing.

The conventional structure of a rotor blade is known and the processing methods for the skin and core materials, as well as for the sandwich manufacturing.

At the end of the module all students are able to understand the manufacturing process and obtain comprehensive knowledge of component construction and characterization.

**Content:**

- Polymer material properties
  - structure, chemical compound (thermoplast, thermoset, elastomer)
  - fiber reinforcement, design of fiber reinforced components
  - mechanical properties (temperature and time dependency)
- Processing technology
  - injection moulding
  - extrusion, foam extrusion
  - resin transfer moulding (RTM)
  - reaction Injection Moulding (RIM)
  - tape laying and Prepreg processing
  - introduction in polymer processing
  - hand lamination
- Sandwich materials
  - structure of rotor blades
  - composites / skin materials
  - core materials
  - processing technology (bonding, lamination,...)
- Material characterization
  - mechanical testing
  - quasistatic, toughness, fatigue
  - Physical characterization
Structural analysis, density, thermal analysis, fiber orientation

**Study and examination requirements and forms of examination**
- Written examination (120 min) or online oral examination (45 min)

**Media employed**
- Online script

**Reading list**

**Polymer chemistry:**
- Polymer materials, *J. L. Halary*, Wiley

**Processing:**
- Einführung in die Kunststoffverarbeitung, *W. Michaeli*, Hanser
- Polymer Processing, *G. J. Morton-Jones*, Springer

**Characterization:**
- Polymer testing, *W. Grellmann*, Hanser

<table>
<thead>
<tr>
<th>Construction and Design of the Nacelle System</th>
<th>Wind Energy Meteorology</th>
<th>Control and Operational Management for Wind Turbines and Wind Farms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Micro Meteorology for Wind Engineers</td>
<td></td>
</tr>
<tr>
<td>Module level</td>
<td>Credits</td>
<td>Language</td>
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<tr>
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</tr>
<tr>
<td>Master</td>
<td>6</td>
<td>English</td>
</tr>
</tbody>
</table>

**Module designation**

**Construction and Design of the Nacelle Systems**

**Course(s)**

**Nacelle Systems Design**

<table>
<thead>
<tr>
<th>Person responsible for the module</th>
<th>Prof. Dr. rer. nat. Clemens Hoffmann</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecturer</td>
<td>Prof. Dr.-Ing. Jan Wenske</td>
</tr>
</tbody>
</table>

**Workload**

180 h (20 h online presentations, 40 h private study, 120 h exercises)

**Relation to curriculum**

Specialist studies, Electrical Systems Technology, elective

**Type of teaching, contact hours**

Online script, lecture video, digital communication

**Requirements according to examination regulations**

None

**Recommended prerequisites**

Modules Mathematics, Solid Mechanics, Electrical Engineering, Design of Mechanical and Electrical Components

**Module objective / intended learning outcomes**

The students know the basic structure and design methods for the gondola system of modern horizontal axis wind turbines. Herein the nacelle system comprises, besides the classic drive train with main shaft, bearing, gear, clutch, brake and generator, also the hub including the blade journal bearings and pitch systems, as well as other auxiliary systems such as the azimuth drive, cooling and lubrication systems. The purely electrical subsystems like main inverter, system transformers, switch gear etc. are presented, but not in depth with regard to their detailed design. The students know the common variants and functions of electrical nacelle systems.

The main mechanical components including the nacelle structures can be calculated and dimensioned with respect to given turbine performance requirements, extreme and fatigue loads from the rotor side. Fundamental advantages and disadvantages of drive train concepts can be identified and discussed professionally by the students. Based on the knowledge provided in this module, they should be able to develop their own concepts and to create more detailed drive train constructions or at least to write detailed specification for nacelle/WT drive train components.

**Content**

- Introduction of extreme and operational fatigue loads for WT drive trains / design criteria
- Basic principles and diversification of current WT drive trains (introduction to the main variants)
- Calculation and design principle of WT shafts, coupling, suspension and nacelle supporting structure
- Basic knowledge and design principles of gear transmission for WT (geared & hybrid drives)
- Design of the auxiliary nacelle systems (cooling, lubrication, brakes, hydraulic systems, E-Drives)
- Basic design principle for WT generators (IG, DFIG, EESG, PMSG) in geared and direct drive variants / comparison of characteristics due to design parameter
- Variations and functions of electrical Nacelle systems (Converter, transformer, switch gear, etc.)
- Introduction of 1–6 degree of freedom drive train system dynamics / comparison of mechanical drive train characteristics drive train modeling for digital system simulation and controller design.

**Study and examination requirements and forms of examination**

Online oral examination (20min) and online presentation (15min). The examination results are combined with a weighting of 1:1 in the final grade.
<table>
<thead>
<tr>
<th>Media employed</th>
<th>Online script, teaching video</th>
</tr>
</thead>
</table>

**Reading list**


Module level
Master

Credits
6

Language
English

Return
Annual

Module designation

Micro Meteorology for Wind Engineers

Course(s)

Micro Meteorology for Wind Engineers

Person responsible for the module
Prof. Dr. rer. nat. Clemens Hoffmann

Lecturer
Associate Prof. Jacob Berg, DTU, Denmark

Workload
180h (10h presentations, 10h discussions, 50h self-study, 30h exercises & quizzes, 60h assignments, 20h examination (incl. preparation)

Relation to curriculum
Specialist studies, Electrical Systems Technology, elective

Type of teaching, contact hours
Canvas LMS: Lecture notes, online discussions, videos, quizzes and assignments

Requirements according to examination regulations
none

Recommended prerequisites
Modules Mathematics, Solid Mechanics, Fluid Mechanics, Application of Software Tools

Module objective / intended learning outcomes

The student will obtain a general understanding of atmospheric turbulence and wind resources for use in wind energy related applications.

A student who has met the objectives of the course will be able to:

A. Apply simple statistical concepts in describing time series of the wind, e.g. the mean, moments and probability density functions.
B. Analyze meteorological time series using more advanced statistical tools such as the correlation function, spectra and cross-spectra.
C. Explain the basic mechanisms responsible for winds in the atmosphere.
D. Explain the concept of the atmospheric boundary layer and how it is affected by atmospheric stability and the Coriolis force.
E. Use micro-meteorological concepts such as roughness length, momentum flux and the geostrophic drag law.
F. Qualitatively explain how various types of terrain and the topography affect the atmospheric flow.
G. Apply the concepts mentioned above to estimate the wind energy resource in a simple terrain.
H. Describe atmospheric turbulence by means of variances, spectra and coherence, and explain the connection to dynamic loads on structures.
I. Characterize a few in situ and remote wind sensors.
J. Explain wind-related aspects of the IEC 61400–1 standard for wind turbine safety.

Content

10 sub-modules (weeks):

1) Course Introduction
2) Wind Energy and Meteorology and the IEC standard
3) Working with data in meteorology – probabilities and statistics
4) Atmospheric turbulence in the boundary layer
5) Instruments and time series
6) Spectral properties and Fourier simulations
7) RANS, Drag law and siting
8) The turbulence spectrum and loads
9) Extreme winds
10) Flow in Heterogeneous terrain

<table>
<thead>
<tr>
<th>Study and examination requirements and forms of examination</th>
<th>Assignments (6 in total, 70% of the final grade), quizzes (10% of the final grade), oral (20% of the final grade)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Media employed</td>
<td>Canvas LMS</td>
</tr>
</tbody>
</table>

Reading list
Lecture Notes and videos
Module designation

Energy Meteorology

Course

1. Mathematical Analysis of Prognoses and Model Development
2. Wind Energy Meteorology

Person responsible for the module
Prof. Dr. rer. nat. Clemens Hoffmann

Lecturer
1. Prof. Dr. rer.nat Heinrich Werner
2. Dr. Bernhard Lange

Workload
1. 90 h (10h online presentations, 20h private study, 60h homework)
2. 90 h (10h online presentations, 20h private study, 60h homework)

Relation to curriculum
Specialist studies, Electrical Systems, elective

Type of teaching, contact hours
Online unit, virtual classrooms, online presentations, Skype

Requirements according to examination regulations
Module Application of Software Tools

Recommended prerequisites
None

Module objective / intended learning outcomes

Knowledge: Students know the different types of neural networks and their application to technical problems. They can judge the ability of different types of neural networks to solve different prognosis problems in wind power forecasting.

Skills: Students are able to construct neural models for the Weather–Power situations in wind power forecasting in the framework of Matlab, to train and analyse them, and to build these Models into user application programs.

Competencies: Students know how to present new Models to a non-expert audience, to explain advantages and disadvantages of new approaches, and to make competent statements about the system confidence.

General knowledge: Students should have a general knowledge about wind in the atmosphere and the underlying physical, meteorological and micro meteorological theory. They should understand how wind is on the one hand the source of the power produced from wind turbines, on the other hand responsible for the loads on the turbines. They should learn the meteorological knowledge for the integration of wind power into the electricity supply system.

Wind potential / Wind power resource: The students should gain the ability to assess, analyze and judge the wind power potential and resource. They should gain knowledge about state–of–the–art methods in wind measurement, characterization and modeling.

Design conditions: The students should understand how the design of wind turbines depends of the wind conditions. They should know the design parameters used for wind turbine design and have the ability to assess these parameters.

Wind power integration: They should know the basic challenges of integrating a weather dependent energy source like wind power in the electricity supply system. They should understand how wind power forecasts can help to integrate wind power and acquire knowledge about the methods used for wind power prediction.

Content
1. 
Tools for data analysis and modeling (introductory level)
Neural networks as a Tool for data analysis and modeling (introductory level)
Models for data with functional behavior, feed forward networks (basic level)
Training methods in feed forward networks (advanced level)
Models for data with relational behavior, feedback networks (basic level)
Training methods in feedback networks (advanced level)
Application perspectives in wind power prognosis (advanced level)
Implementation perspectives in wind power prognosis (advanced level)
Confidence considerations in wind power prognosis (advanced level)

2. Introduction
- Origin of wind
- Fundamentals of atmospheric flow
- Micrometeorology of wind
- Wind Potential / Resources
- Design conditions
- Special–temporal behavior of wind
- Wind power forecasting
- Wind power production simulation

| Study and examination requirements and forms of examination | Written exam (120 min) or online oral examination (30 min) or written homework (25 pages) with presentation of the homework (30 min). The final grade for the module is a combination of the written homework (75%) and presentation (25%) grades. |

| Media employed | Online script |

Reading list
### Module level

<table>
<thead>
<tr>
<th>Master</th>
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</table>

### Module designation

**Control and Operational Management for Wind Turbines and Wind Farms**

### Course(s)

**Control of Wind Turbines and Wind Farms**

<table>
<thead>
<tr>
<th>Person responsible for the module</th>
<th>Prof. Dr. rer. nat. Clemens Hoffmann</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecturer</td>
<td>Dipl.-Ing. Boris Fischer, Dipl.-Ing. Melanie Hau</td>
</tr>
<tr>
<td>Workload</td>
<td>180 h&lt;br&gt;(30 h contact time, 60 h homework / presentation, 90 h private study)</td>
</tr>
<tr>
<td>Relation to curriculum</td>
<td>Specialist studies, Electrical Systems Technology, elective</td>
</tr>
<tr>
<td>Type of teaching, contact hours</td>
<td>Online units, virtual classrooms, online presentations</td>
</tr>
</tbody>
</table>

#### Requirements according to examination regulations

None

#### Recommended prerequisites

None

### Module objective / intended learning outcomes

This course deals with control-related topics for both wind turbines and wind parks. At the end of the course, the students should be familiar with main control problems in wind energy and should be able to apply common solutions. This comprises the following fields:

- Aims of control and important interactions, e.g. turbine control system – structural loads, wind park control – electrical grid
- Systematic controller design
- Insight into advanced research topics

### Content

- Modeling of wind turbines and wind parks for control applications
- Grid codes and basics of grid control
- Strategies for controlling
  - Wind turbines below and above rated wind speed
  - Wind farms for active and reactive power provision
- Certification guidelines and common simulation tools

### Study and examination requirements and forms of examination

Written Homework (12–15 pages) and Online Presentation (15 min) or Multiple choice test (30 min, 33% of the grade), online oral examination (20 min, 66% of the grade)

### Media employed

Online script

### Reading list

Reading list will be provided by lecturer via the online platform Moodle.
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<th>Module level</th>
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<th>Language</th>
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<tbody>
<tr>
<td>Master</td>
<td>6</td>
<td>English</td>
<td>Annual</td>
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</tbody>
</table>

**Module designation**

**Technical and Economic Aspects of Grid Integration**

**Course(s)**

1. **Electrical Engineering Aspects of Grid Integration**
2. **Economic Aspects of Grid Integration**

**Person responsible for the module**

Prof. Dr. rer. nat. Clemens Hoffmann

**Lecturer**

1. Dr. Philipp Strauß, Thomas Degner (tbc.), Gunter Arnold (tbc.), Nils Schäfer (tbc.)
2. Dr. Kurt Rohrig, Reinhard Mackensen, Patrick Hochloff

**Workload**

1. 90 h (10h online presentations, 10h contact time, 30h exercises, homework, 40h private study)
2. 90 h (10h online presentations, 10h contact time, 30h exercises, homework, 40h private study)

**Relation to curriculum**

Specialist studies, Electrical Systems Technology, elective

**Type of teaching, contact hours**

Virtual classrooms, online presentations, digital communication, Skype

**Requirements according to examination regulations**

Modules of Basic studies

**Recommended prerequisites**

None

**Module objective / Intended learning outcomes**

1) Students know about methods of network planning within a wind farm and electrical design of transformer stations for grid connection of wind farms. They are familiar with system perturbations of wind farms, corrective measures for ensuring the required voltage and current quality, and the tasks of protection for the generating plant and the grid resources. They are able to define requirements for qualities of wind turbines and wind farms in Germany and are familiar with application, architecture and functionality of information and communication technology (ICT) in wind farms.

2) Students are familiar with general aspects of grid integration and support schemes. They know about the role and opportunities of ICT. They are able to describe the mechanism of energy and power markets and are familiar with risk management and portfolio management for wind energy traders. They have knowledge about frequency control, balancing, control power, ancillary services, flexibility options and virtual power plants.

Competencies: integration of knowledge, skills and social and methodological capacities in working or learning situations

**Content**

The course **Electrical Engineering Aspects of Grid Integration** provides basic knowledge on grid integration of wind energy systems. The grid integration is shown as a building block in the chain of power generation to supply the distribution or transmission network. Characteristics of this block determine authorization for the connection to the electrical power system and conformity of the wind farm with the operation of the existing network.

The course **Economical Aspects of Grid Integration** provides basic energy-economical knowledge on grid integration of wind energy systems. The economic aspects of grid integration consider wind turbines equal in energy supply systems regarding market of power and control power and other ancillary services. Furthermore, the opportunities for flexibility (virtual power plants, storage, load
management, network expansion), the importance of forecasting and control of wind farms and wind farm clusters will be covered.

Support Schemes: description and impact
Role and opportunities of ICT: Standards, interfaces, architecture
Energy and Power Markets: description and impact
Portfolio Management, Trading of Wind Energy: forecasts and probability
Ancillary Services: Frequency Control, Balancing, Control Power, Voltage Control
Flexibility Options: Demand Side Management, Grid Extension, Storage
Virtual Power Plants: technical and economic aspects

Study and examination requirements and forms of examination
Written exam (90min) or online oral examination (45min)

Media employed
Online script

Reading list
<table>
<thead>
<tr>
<th>Module level</th>
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</thead>
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</tbody>
</table>

**Module designation**

**Energy Storage**

**Course**

**Energy Storage**

<table>
<thead>
<tr>
<th>Person responsible for the module</th>
<th>Prof. Dr. rer. nat. Clemens Hoffmann</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecturer</td>
<td>Prof. Dr.-Ing. Ingo Stadler</td>
</tr>
</tbody>
</table>

**Workload**

180h (20h contact time, 20h online presentations, 80h private study, 60h exercises, homework)

**Relation to curriculum**

Specialist studies, Electrical Systems Technology, elective

**Type of teaching, contact hours**

virtual classrooms, online presentations, digital communication

**Requirements according to examination regulations**

None

**Recommended prerequisites**

Basic studies modules

**Module objective / intended learning outcomes**

- Students know the requirement for energy storage within energy systems
- Students are able to distinguish energy storage needs in different energy systems
- Students are familiar with theories behind storage technologies on different time levels and system integration levels
- Students are able to compare energy storages according to the system needs and economic viability

**Content**

- History of energy storage and future storage needs
- Energy storage in different time frames
- Energy storage in advance of electricity generation
  - Conventional primary energy storages as coal, natural gas and uranium
  - Different forms of biomass
- Electrical energy storage
  - Stored and pumped stored hydro power
  - Compressed air power
  - Battery technologies
  - Electrical energy storage (capacitors and coils)
  - Fly wheels
  - Hydrogen and from chemical storage derived from hydrogen
  - Alternative concepts
  - Energy storage after usage of electricity (Demand Response und DSM)
  - Heat storage in general
  - Storage heating
  - Buildings as heat storage
  - Heat storage in combination with CHP
  - Heat storage in combination with heat pumps
  - Cold storages in general
  - Cooling houses, freezers and refrigerators
  - Icestorage
  - Communication technologies for Demand Response
- Economy of energy storage
- Legal framework of energy storage
<table>
<thead>
<tr>
<th><strong>Study and examination requirements and forms of examination</strong></th>
<th>Written exam (90min) or online oral examination (45min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Media employed</strong></td>
<td>Online script</td>
</tr>
<tr>
<td><strong>Reading list</strong></td>
<td>Reading list will be provided by lecturer via the online platform Moodle.</td>
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<tr>
<td>Module level</td>
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</tr>
<tr>
<td>Master</td>
<td>6</td>
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</table>

**Module designation**

Reliability, Availability, Maintenance Strategies

**Course(s)**

Reliability, Availability, Maintenance Strategies

<table>
<thead>
<tr>
<th>Person responsible for the module</th>
<th>Prof. Dr. rer. nat. Clemens Hoffmann</th>
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</thead>
<tbody>
<tr>
<td>Lecturer</td>
<td>Dipl.-Ing. Stefan Faulstich, Dipl.-Ing. Berthold Hahn</td>
</tr>
</tbody>
</table>

**Workload**

180 h (30 h contact time and 150 h private study)

**Language**

English

**Relation to curriculum**

Specialist studies, Electrical Systems Technology, elective

**Type of teaching, contact hours**

Online presentations, digital communication

**Requirements according to examination regulations**

None

**Recommended prerequisites**

Module Mathematics

**Module objective / intended learning outcomes**

Students know different approaches regarding collection and analysis of reliability data in order to use the information for maintenance optimization. They know regulatory requirements, industry standards and optimization strategies. They are able to apply these strategies to the operation and maintenance of wind farms and to make use of experience gained during wind turbine operation as well as additional information coming from different monitoring systems.

**Module content**

- Maintenance of wind turbines
  - regulatory requirements
  - activities
  - strategies
- Wind turbine reliability
  - definitions
  - failure statistics
  - influence on availability and cost of energy
- Reliability based maintenance
  - acquisition of maintenance information
  - statistical analysis of failure behavior
  - qualitative analyzing techniques (e.g. FMEA)
- Condition based maintenance
  - condition monitoring systems
  - structural health monitoring
  - appropriate sensors

**Study and examination requirements and forms of examination**

Written exam (120 min) or online oral examination (45 min)

**Media employed**

Online script
**Reading list**

### Additive Key-Competences: Energy and Law

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<th>Occupational Safety On and Offshore</th>
<th>Personnel Management</th>
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<tbody>
<tr>
<td>Planning and Construction of Wind Farms</td>
<td>Business Administration of Wind Turbines and Wind Farms</td>
<td>Project Management</td>
</tr>
<tr>
<td></td>
<td>Contract Law</td>
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</tbody>
</table>

- Energy Law
- Occupational Safety On and Offshore
- Personnel Management
- Planning and Construction of Wind Farms
- Business Administration of Wind Turbines and Wind Farms
- Project Management
- Contract Law
Module designation

**Business Administration and Management of Wind Turbines and Wind Farms**

Course

**Business Administration and Management of Wind Turbines and Wind Farms**

Person responsible for the module

Prof. Dr.-Ing. Detlef Kuhl

Lecturer

Dipl. Volkswirt (Master of Economics) Wilfried Schäfer

Workload

90 hours (5h contact study, 75h private study, 8h examination preparation, 2h examination)

Relation to curriculum

Additive key skills, elective

Type of teaching, contact hours

Digital communication, virtual classrooms

Requirements according to examination regulations

None

Recommended prerequisites

Module: Project Financing

Module objective / intended learning outcomes

Students are familiar with different reporting needs and requirements of shareholders and senior debt providers. They can create their own reviews/reports for a project. Students gain knowledge of contract management and insight in common main contracts in wind projects. They can create a financial planning tool and use it for plan-actual check including changes and adjusting future expectations into the planning and creating a risk model.

They become aware of differences in the subsidy schemes in Europe (Feed-in-Tariff, Green Certificates) and how to include this in financial planning. A major point is to learn examples of business decisions in case studies (foundation, accidents, risk assessment of new upcoming problems) and to build Post Closing Actions Lists. Issues arising at the end of the lifetime of wind turbines are covered i.e. decommissioning / dismantling and repowering of turbines.

Another goal is to become familiar with different subsidy schemes and principles of ring-fencing projects. Precondition is an analytical and structural approach to addressing issues and challenges in wind project management. Main concern is to build competencies: integration of knowledge, skills and social and methodological capacities in working or learning situations with relation to technical, legal and economic aspects of wind project.

Content

- Reporting
  - Needs of investors for reporting on performance of a wind project
  - Differences between community based investors and financial investors
  - Structure of a reporting
  - Annual meeting of shareholders and annual reports
  - Creating a structure for one’s own reporting/review
- Structure
  - Contract management of wind projects
  - Organigram of wind projects
  - Responsibilities of a managing director of wind project companies
- Finance
- Liquidity planning
- Principles of financial modeling
- Creating a financial model for wind projects
- Creating a risk model
- Modify input to see impact on outcome (scenario analysis)

- Special aspects
  - Direct marketing of electricity
  - Duration of payment of high Feed-in-Tariff (Germany)
  - Dealing with accidents (Crane)
  - Dealing with special maintenance issues (Foundation repair)
  - Subsidy schemes
  - Repetitive inspections
  - Post-Closing Action Lists (PCAL)
  - Dismantling and repowering of turbines

<table>
<thead>
<tr>
<th>Study and examination requirements and forms of examination</th>
<th>Written exam (60 min) or written homework (15 pages) with presentation of the homework (15 min). The final grade for the module is a combination of the written homework (75%) and presentation (25%) grades.</th>
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<tbody>
<tr>
<td>Media employed</td>
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<tr>
<td>Reading list</td>
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<tr>
<td>Master</td>
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</table>

**Module designation**

**Contract Law**

**Course**

**Contract Law**

<table>
<thead>
<tr>
<th>Person responsible for the module</th>
<th>Prof. Dr.-Ing. Detlef Kuhl</th>
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<tbody>
<tr>
<td>Lecturer</td>
<td>Jian Bani</td>
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</tbody>
</table>

**Workload**: 90 h (5 h online presentations, 45 h private study, 40 h homework)

**Relation to curriculum**: Additive key skills, elective

**Type of teaching, contact hours**: Online material, electronic material, virtual classroom, digital communication, Skype

**Requirements according to examination regulations**: None

**Recommended prerequisites**: None

**Module objective / Learning outcomes:**

A thoroughly elaborated contractual structure is a key success factor for any national or international wind energy project. In this respect, typically a wide range contractual relations and complex contractual risks has to be thoroughly considered and addressed prior to implementing a project. This module aims to provide students with a thorough understanding of relevant key contractual relations and issues that need to be taken into consideration in the development of any wind energy project.

**Achieved Knowledge**: Students know the key contractual relations and risks that need to be addressed in the development of any wind energy project.

**Achieved Skills**: Students are able to identify and assess key contractual relations and issues to be addressed when developing a wind energy project in their respective professional position.

**Content**

- Introduction to typical contractual structure/relations and key issues of wind energy projects
- Legal Issues of Project Finance of Wind Energy Projects
- Property/Land Use Issues
- Grid connection
- Concessions Contracts
- Power Purchase Agreements
- Operation and Maintenance
- Specific legal/contractual aspects of offshore wind energy projects*all with specific focus on aspects relevant to wind energy

**Study and examination requirements and forms of examination**

Written homework (10 pages) with online presentation of the homework (15 min)

**Media employed**: Online script

**Reading list**: Reading list will be provided by lecturer via the online platform Moodle.
Module designation

Energy Law

Course

Energy Law

Person responsible for the module
Prof. Dr.-Ing. Detlef Kuhl

Lecturer
Jian Bani

Workload
90 h (5 h online presentations, 45 h private study, 40 h homework)

Relation to curriculum
Additive key skills, elective

Type of teaching, contact hours
Online material, electronic material, virtual classroom, digital communication, Skype

Requirements according to examination regulations
None

Recommended prerequisites
None

Module objective:
The legal and regulatory framework conditions are a key success factor for any national or international wind energy project. An investment decision should only be taken by project developers if the applicable legal and regulatory conditions provide adequate conditions for the smooth development and operation of an envisaged project. This module aims to provide students with a thorough understanding of existing legal and regulatory best practice for wind energy projects and of key legal and regulatory issues that need to be taken into consideration in the development of any wind energy project.

Achieved knowledge: Students know the legal and regulatory best practice for wind energy projects and the key legal and regulatory issues that need to be taken into consideration in the development of any wind energy project.

Achieved skills: Students are able to assess the general adequacy of existing legal and regulatory framework conditions and risks that may be encountered when developing a wind energy project in their respective professional position.

Content*
- The importance of legal and regulatory framework conditions for development and operation of wind energy projects
- Introduction to European Renewable Energy Law and Policy/European legal and regulatory framework conditions
- Support Scheme Options for the promotion of renewable energy: FITs, premiums, quota, green certificates
- Key Aspects of Authorization, certification and licensing procedures
- Grid Issues: Grid Connection, connection cost, access, transmission and distribution, dispatch
- Selected Best Practices of National Renewable Energy Legislation
- Specific Legal Aspects of off-shore renewable energy (wind, wave and tidal energy)

*all with specific focus on aspects relevant to wind energy

Study and examination requirements and forms of examination
Written homework (10 pages) with online presentation of the homework (15 min)

Media employed
Online script

Reading list:
Reading list will be provided by lecturer via the online platform Moodle.
Module level: Master  Credits: 3  Language: English  Return: Annual

Module designation
Planning and Construction of Wind Farms

Course(s)
Planning and Construction of Wind Farms

Person responsible for the module: Prof. Dr.-Ing. Detlef Kuhl
Lecturer: Eng. Stefan Bauch, Lisa Keaton B.A.

Workload: 90h
(15h online presentations, 30h private study, 45h homework)

Relation to curriculum: Additive key skills, elective
Type of teaching, contact hours: Skype, telephone, virtual classroom, digital communication
Requirements according to examination regulations: None
Recommended prerequisites: None

Module objective / intended learning outcomes
The students are able to do a micrositing for a wind farm using all available (project) information, taking into account the site conditions, local and other restrictions. The students will gain the ability to know, which influence different conditions/restrictions are during the planning process and what are the consequences. Additionally, the students know how the construction of the infrastructure of a wind farm and the erection of wind energy converters will take place.

Content
- Micrositing
  - Which wind energy converter for which site
  - Basics of micrositing
- Emissions
  - Basics of micrositing
  - Noise
  - Shadow
  - Other
- Restrictions during the planning process
- Grid connection
- Construction of wind farms
  - Transport
  - Subsoil
  - Foundation
  - Site access
  - Erection

Study and examination requirements and forms of examination
Written homework (15 pages) with online presentation of the homework (20 min) and online oral examination (10 min). The final grade for the module is a combination of the written homework (50%), presentation (25%) and oral examination (30%) grades.

Media employed: Online script

Reading list
Erich Hau/ Wind Turbines: Fundamentals, Technologies, Application, Economics
Erich Hau/ Windkraftanlagen: Grundlagen, Technik, Einsatz, Wirtschaftlichkeit
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**Module designation**

**Occupational Safety On and Offshore**

**Course**

**Occupational Safety On and Offshore**

**Person responsible for the module**
Prof. Dr.-Ing. Detlef Kuhl

**Lecturer**
Gerhard Sartory

**Workload**
90 hours
(10 hours online presentations, 20 hours private study, 60 hours private study, including examination preparation)

**Relation to curriculum**
Additive key skills, elective

**Type of teaching, contact hours**
Online unit, telephone, Skype, virtual classrooms, online presentations, online transmission, home study

**Requirements according to examination regulations**
No examination regulations so far

**Recommended prerequisite**
None

**Module objective / intended learning outcomes**
- Legislation on Occupational Health & Safety and Compliance Monitoring
- Causes of accidents and safety policy consequences
- Methods for promoting safety, health, and environment
- Ergonomics at the workplace, alcohol and drug consumption at the workplace
- Procedures and work permits
- Exposure to noise, working on electrical systems and equipment, exposure to radiation
- Transport routes and ladders
- Risk Assessments, HAZID and HAZOP methods
- High and low-lying workplaces, confined space
- Fire protection and emergency management
- Emergency response procedures and rescue chain
- First Aid; Paramedic
- Medical fitness examination certificates
- Safety training, survival and rescue at heights training regulation and requirements
- Handling of hazardous substances and wastes as well as provisions under water law
- Offshore environment protection requirements
- Schusiko, HSE concept development for offshore BSH project certification process

**Achieved knowledge: Students know** the legal and regulatory best practice for wind energy projects and the key legal and regulatory issues that need to be taken into consideration in the development of any wind energy project.

**Achieved skills: Students are able to assess** the general requirements of existing legal and regulatory framework conditions and risks that may be encountered when developing a wind energy project in their respective professional position.

**Content**
- The importance of HSE legal and regulatory framework conditions for development and operation of wind energy projects
- Key aspects of authorization, certification and licensing procedures
- Selected best practices of national HSE renewable energy legislation
- Specific legal aspects of off-shore renewable energy (wind, wave and tidal energy)

**Study and examination requirements and forms of examination**
- Multiple choice test (60 min), essay and/or term paper (10–15 pages), online presentation of homework (15 min)
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</table>
Module designation
Personnel Management

Course(s)
Personnel Management

Person responsible for the module
Prof. Dr. phil. Oliver Sträter

Lecturer
Prof. Dr. phil. Oliver Sträter

Workload
90h
(15h contact time, 45h private study, 30h exercises)

Relation to curriculum
Additive key skills, elective

Type of teaching, contact hours
Online unit, virtual classrooms, digital communication

Requirements according to examination regulations
None

Recommended prerequisites
None

Module objective / intended learning outcomes
The course provides personnel management and leadership theories in accordance with relevant international instruments and internationally applicable requirements for managers. The requirements will be demonstrated in small group exercises and practical problem solving sessions. Students will gain a basic qualification in order to fill leadership positions.

Content
During the seminar, different management theories, as well as their individual’s leadership skills, the handling of problems and intervention techniques are taught. The students will also be able to link leadership to the Management Excellence concept under the European Foundation for Quality Management (EFQM). Topics are:

- management and leadership excellence
- principles of human information processing
- leadership and management
- delegation and motivation
- meeting management and problem management
- coaching and mentoring
- creating value

Study and examination requirements and forms of examination
Written exam (60min) or online oral examination (15min)

Media employed
Online script

Reading list


## Module designation

**Project Management**

### Course(s)

**Project Management**

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<tr>
<th>Person responsible for the module</th>
<th>Prof. Dr.-Ing. Detlef Kuhl</th>
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</thead>
<tbody>
<tr>
<td>Lecturer</td>
<td>Stefan Bauch, Anja Rösen</td>
</tr>
</tbody>
</table>

### Workload

90 h
(15 h online presentations, 45 h private study, 30 h exercises)

### Relation to curriculum

Additive key skills, elective

### Type of teaching, contact hours

Online unit, virtual classrooms, digital communication

### Requirements according to examination regulations

None

### Recommended prerequisites

Module Planning and Construction of Wind Farms

## Module objective / intended learning outcomes

Students will be able to build the proper structures for managing a wind park project as a whole and as multiple sub-projects. Students will also be able to adapt and change these plans as the needs and circumstances of the project change.

Sub-projects addressed include site selection, development, environmental impact assessment, tendering, construction, operation and maintenance. Students will become familiar with all the tasks contained in these sub-projects and learn strategies to manage each.

## Content

This module will address first the principles of general project management and then, in the second part of the course, apply these principles to project management for wind farms.

General project management principles which will be covered include:

- Defining and project scope
- Project planning using Microsoft Project
- Division of tasks and follow-up
- Monitoring and controlling scope and progress
- Risk management
- Closing the project
- Project management types: traditional, critical chain, agile, extreme

These principles will be applied to the sub-projects of wind power as described in the “module objective” section. Tasks for each part will be defined from the perspective of relevant project participants and case studies conducted in class or as homework.

### Study and examination requirements and forms of examination

Written homework (15 pages) with online presentation of the homework (20 min) and online oral examination (10 min).

The final grade for the module is a combination of the written homework (50%), presentation (25%) and oral examination (30%) grades.

### Media employed

Online script

### Reading list

Effective Project Management: Traditional, Agile, Extreme, Robert K. Wysocki, 2011
Results Without Authority: Controlling a Project When the Team Doesn't Report to You, Tom Kendrick,
Making Things Happen: Mastering Project Management (Theory in Practice); Scott Berkun, 2008
Developing Wind Power Projects: Theory and Practice, Tory Wizelius, 2006