UNIKASSEL VERSITÄT

Fraunhofer IWES

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

Table of Contents

1. Fundamentals of Mathematics and Engineering for Wind Energy

Fundamentals of mathematics and engineering for wind energy		
Application of Software Tools	Mathematics	Solid Mechanics
Fluid Mechanics	Electrical Engineering	Design of Mechanical and Electrical Components

<table>
<tr><td>Module level
Master</td><td>Credits
6</td><td>Language
English</td><td>Return
Annual</td></tr>
<tr><td colspan="4">Module designation

Application of Software Tools</td></tr>
<tr><td colspan="4">Course(s)
Application of Software Tools</td></tr>
<tr><td>Person responsible for the module</td><td colspan="3">Prof. Dr.-Ing. Sigrid Wenzel</td></tr>
<tr><td>Lecturer</td><td colspan="3">1. Dipl.-Inf. Markus Schmitz
2. Dr. Stefan Kopecz
3. Dipl.-Ing. Tobias Gleim M.Sc.
4. Prof. Dr.-Ing. Olaf Wünsch</td></tr>
<tr><td>Workload</td><td colspan="3">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)</td></tr>
<tr><td>Relation to curriculum</td><td colspan="3">Basic studies, compulsory optional subject</td></tr>
<tr><td>Type of teaching, contact hours</td><td colspan="3">Skype, virtual classrooms, online presentations, online transmission.</td></tr>
<tr><td>Requirements according to examination regulations</td><td colspan="3">None</td></tr>
<tr><td>Recommended prerequisites</td><td colspan="3">None</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td colspan="4">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</td></tr>
<tr><td>Study and examination requirements and forms of examination</td><td colspan="3">Written homework (10-25 pages)</td></tr>
<tr><td>Media employed</td><td colspan="3">Slides</td></tr>
</table>

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

Mathematics

Course(s)

Mathematics of Differential Equations

Person responsible for the module	Prof. Dr. rer. nat. habil. Andreas Meister
Lecturer	Prof. Dr. rer. nat. habil. Andreas Meister
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 (20–30min)
Media employed	Online script

Reading list

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

<table>
<tr><td>Module level
Master</td><td>Credits
6</td><td>Language
English</td><td>Return
Annual</td></tr>
<tr><td colspan="4">Module designation

Fluid Mechanics</td></tr>
<tr><td colspan="4">Course(s)
1. Advanced Fluid Dynamics
2. Experimental Methods in Fluid Mechanics</td></tr>
<tr><td>Person responsible for the module</td><td colspan="3">Prof. Dr.-Ing. Martin Lawerenz, Prof. Dr.-Ing. Olaf Wünsch</td></tr>
<tr><td>Lecturer</td><td colspan="3">1. Prof. Dr.-Ing. Olaf Wünsch
2. Prof. Dr.-Ing. Martin Lawerenz</td></tr>
<tr><td>Workload</td><td colspan="3">1. Workload: 120 h (20h online presentations, 60h private study, 40 h exercises)
2. Workload: 60h (7h online sessions, 14h lecture, 14h exercises, 25h examination preparation)</td></tr>
<tr><td>Relation to curriculum</td><td colspan="3">Basic studies, compulsory optional subject</td></tr>
<tr><td>Type of teaching, contact hours</td><td colspan="3">Skype, virtual classrooms, online unit, digital communications, telephone</td></tr>
<tr><td>Requirements according to examination regulations</td><td colspan="3">None</td></tr>
<tr><td>Recommended prerequisites</td><td colspan="3">None</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td>Study and examination requirements and forms of examination</td><td colspan="3">Written Test (120 min) or online oral examination (30 min)</td></tr>
<tr><td>Media employed</td><td colspan="3">Online script</td></tr>
<tr><td colspan="4">Reading list
Baker, R. C.: Flow Measurement Handbook, Cambridge University Press, 2000
Durst, F.: Fluid Mechanics. Springer-Verlag, Berlin, 2009
Goldstein, R. J. (E.):Fluid Mechanics Measurements, Springer Verlag Berlin, 1983</td></tr>
</table>

Homsy,G.M.; Aref, H.: Multimedia Fluid Mechanics, Cambridge University Press, Cambridge, 2004
Krause, E.: Fluid Mechanics. Springer-Verlag, Berlin, 2005
Kundu, P.K.; Cohen, I.M.; Dowling, D.R.: Fluid Mechanics. Elsevier, Amsterdam, 2012
Spurk, J.H.; Aksel, N.: Fluid Mechanics. Springer-Verlag, Berlin, 2008
Tavoularis, S.: Measurements in Fluid Mechanics, Cambridge University Press, 2005
Tropea, Cameron; Yarin, Alexander L. & Foss, J. F. (Eds.):Springer Handbook of Experimental Fluid Mechanics, Springer-Verlag Berlin Heidelberg, 2007
White, F.M.: Fluid Mechanics. McGraw-Hill Inc., New York, 2003

Module level Master	Credits 6	Language English	Return Annual
Module designation Solid Mechanics			
Course(s) Solid Mechanics			
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		
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.			
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			
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 R.C. Hibbeler, Engineering Mechanics, Pearson, different volumes R.C. Hibbeler, Mechanics of Materials, Prentice Hall, 2008 Gross et al., Engineering Mechanics, Springer, different volumes			

Module level	Credits	Language	Return
Master	6	English	Annual

Module designation

Electrical Engineering

Course(s)

Electrical Engineering

Person responsible for the module	Prof. Dr. rer. nat. Clemens Hoffmann
Lecturer	Dr.-Ing. Aleksandra Sasa Bukvic-Schäfer Dr.-Ing. Antonio Notholt-Vergara
Workload	180h (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

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	Credits	Language	Return
Master	6	English	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. Dripl.-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

S. Heier and R. Waddington, *Grid Integration of Wind Energy Conversion Systems*, Wiley-Blackwell, 2nd edition, 2006.

E. Hau and H. von Renouard, *Wind Turbines: Fundamentals, Technologies, Application, Economics*, Springer; 2nd edition, 2005.

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

Specialization of engineering applications / Simulation and Structural Technology of Wind Energy Systems		
Rotor Aerodynamics	Strength Durability and Reliability	Rotor Blades
Computational Fluid Dynamics	Nonlinear Computational Structural Mechanics	Towers
Theoretical Fluid Mechanics	Linear Computational Structural Mechanics	On and Offshore Foundations

Module level Master	Credits 6	Language English	Return Annual

Module designation

Rotor Aerodynamics

Course(s)

Rotor Aerodynamics

Person responsible for the module	Prof. Dr.-Ing. Martin Lawerenz
Lecturer	Prof. Dr.-Ing. Martin Lawerenz
Workload	180 h (42 h lecture, 42 h exercises, 21 h online sessions, 75 h examination preparation)
Relation to curriculum	Specialist studies, simulation and structural technology, elective
Type of teaching, contact hours	Online unit, telephone, Adobe Connect, telephone, digital communications
Requirements according to examination regulations	Module Fluid Mechanics
Recommended prerequisites	Modules Theoretical Fluid Mechanics and Computational Fluid Dynamics

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.
   - 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.

– Loading of Boundary Layer & Separation. – Aerodynamic Losses. – Definition. – Losses in 2-D Flow. – Losses in 3-D Flow. 6) Boundary Conditions. – Inflow Wind. – Wind Shear. – Gust Loads. – Flow near the Tower. 7) Aerodynamic Design of the Rotor. – 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.

Study and examination requirements and forms of examination	Written Test (60min) or online oral examination (30 min.)
Media employed	Online script

Reading list

Hansen, M. O. L.: Aerodynamics of Wind Turbines, 2nd Edition, Earthscan, London, 2008

Spera, D.: Wind Turbine Technology: Fundamental Concepts of Wind Turbine Engineering *ASME Press, 2009*

Module level Master	Credits 6	Language English	Return Annual
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 Cebeci, T.: Analysis of Turbulent Flows. Elesevier Ltd, Oxford, 2004 Durbin, P.A.: Statistical Theory and Modeling for Turbulent Flows. John Wiley & Sons Ltd, Chichester, 2011 Heinz, S.: Statistical Mechanics of Turbulent Flows. Springer-Verlag, Berlin, 2003 Landau, L.D.; Lifshitz, E.M.: Course of Theoretical Physics, Volume 6 - Fluid Mechanics. Butterworth-Heinemann, Oxford, 2000 Pope, S.B.: Turbulent Flows. Cambridge University Press, Cambridge, 2000 Raichel, D.R.: The Science and Applications of Acoustics. Springer Science+Business Media Inc. , New York, 2006 C. Hirsch: Numerical Computation of Internal and External Flows, Part 1 and 2, Wiley. E. F. Toro :Riemann Solvers and Numerical Methods for Fluid Dynamics , Springer.			

R. J. LeVeque: Finite Volume methods for Hyperbolic Problems , Cambridge University Press.
D. Kröner: Numerical Schemes for Conservation Laws, Teubner.

Module level Master	Credits 6	Language English	Return Annual
Module designation Strength and Reliability			
Course(s) Strength and Reliability			
Person responsible for the module	Prof. Dr.-Ing. A. Ricoeur		
Lecturer	Prof. Dr.-Ing. A. Ricoeur		
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			

Module level Master	Credits 6	Language English	Return Annual
Module designation Towers			
Course(s) Towers			
Person responsible for the module	Prof. Dr.-Ing. Detlef Kuhl		
Lecturer	Prof. Dr.-Ing. Detlef Kuhl		
Workload	180h (30h contact time, 90h private study, 60h homework)		
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	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 level Master	Credits 6	Language English	Return Annual
Module designation On and Offshore Foundations			
Course(s) On and Offshore Foundations			
Person responsible for the module	Prof. Dr.-Ing. Oliver Reul		
Lecturer	Prof. Dr.-Ing. Oliver Reul		
Workload	180 h (20 h contact time/online presentations, 80 h private study, 80 h homework)		
Relation to curriculum	specialist studies Simulation and Structural Technology, elective		
Type of teaching, contact hours	Online unit, online presentations, digital communication		
Requirements according to examination regulations	Module Solid Mechanics		
Recommended prerequisites	Modules Mathematics, Fluid Mechanics, Application of Software Tools		

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	
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 Fleming, W.G.K., Weltman, A. J., Randolph, M.F., Elson, W.K. (2009) Piling Engineering. 3rd ed.; Taylor & Francis Group; ISBN 978-0-203-93764-8 Randolph, M.F., Gourvenec, S. (2011) Offshore Geotechnical Engineering. Spon Press; ISBN 978-0-415-47744-4 Tomlinson, M.J. (2001) Foundation Design and Construction. 7th ed.; Pearson Education Ltd; ISBN 978-0-13-031180-1 Whitlow, R. (2000) Basic Soil Mechanics. 4th ed.; Pearson Education Ltd; ISBN 978-0582381094	

Module level Master	**Credits** 6	**Language** English	**Return** Annual
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 A. Meister, J. Struckmeier: Hyperbolic Partial Differential Equations, Vieweg. C. Hirsch: Numerical Computation of Internal and External Flows, Part 1 and 2, Wiley. E. F. Toro: Riemann Solvers and Numerical Methods for Fluid Dynamics , Springer. R. J. LeVeque: Finite Volume methods for Hyperbolic Problems , Cambridge University Press. D. Kröner: Numerical Schemes for Conservation Laws ,Teubner. A. J. Chorin, J. E. Marsden: A Mathematical Introduction to Fluid Mechanics , Springer.			

Module level Master	Credits 6	Language English	Return Annual
Module designation Linear Computational Structural Mechanics			
Course(s) Linear Computational Structural Mechanics			
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)		
Relation to curriculum	Specialist studies, Simulation and Structural Technology, elective		
Type of teaching, contact hours	Chapter-Checks, virtual classroom, online scripts, digital communication		
Requirements according to examination regulations	Modules Mathematics, Solid Mechanics		
Recommended prerequisites	Module Application of Software Tools		

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

Reading list

Textbooks on the linear finite element method, e.g.

Zienkiewicz & Taylor (2000): The Finite Element Method. Volume 1. The Basis

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.

Babuska, Szabo & Katz (1981): The p-Version of the Finite Element Method. SIAM Journal on Numerical Analysis, (18), 515-545

Hughes, Cottrell & Bazilevs (2005): Isogeometric Analysis: CAD, Finite Elements, NURBS, Exact Geometry and Mesh Refinement. Computer Methods in Applied Mechanics and Engineering, (194), 4135-4195

Hughes & Hulbert (1988): Space-Time Finite Element Method for Elastodynamics: Formulations and Error Estimates. Computer Methods in Applied Mechanics and Engineering, (66), 339-363

Module level Master	Credits 6 ECTS	Language English	Return Annual

Module designation Nonlinear Computational Structural Mechanics	
Course Nonlinear Computational Structural Mechanics	
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)
Relation to curriculum	Specialist studies, Simulation and Structural Technology, elective
Type of teaching, contact hours	Chapter Checks, virtual classroom, online scripts, digital communication
Requirements according to examination regulations	Modules Mathematics, Solid Mechanics
Recommended prerequisites	Modules Application of Software Tools, Linear Computational Structural Mechanics

Module objective / intended learning outcomes

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:

- 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

Content

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.

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

Reading list

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

Zienkiewicz & Taylor (2000): The Finite Element Method. Volume 2. Solid Mechanics

Crisfield (1993,1997): Non-Linear Finite Element Analysis of Solids and Structures. Volume 1: Essentials. Volume 2: Advanced Topics

Belytschko, Liu & Moran (2000): Nonlinear Finite Elements for Continua and Structures

Wriggers (2008): Nonlinear Finite Element Methods

Particular journal papers as basis of homeworks , e.g.

Geers (1999): Enhanced Solution Control for Physically and Geometrically Non-Linear Problems. Part I - The Subplane Control Approach. Part II - Comparative Performance Analysis. International Journal for Numerical Methods in Engineering, (46), 177-230

Betsch & Steinmann (2001): Conservation Properties of a Time FE Method - Part II: Time-Stepping Schemes for Non-Linear Elastodynamics. International Journal for Numerical Methods in Engineering, (50), 1931-1955

Ibrahimbegovic & Mamouri (2002): Energy Conserving/Decaying Implicit Time-Stepping Scheme for Non-linear Dynamics of Three-Dimensional Beams Undergoing Finite Rotations. Computer Methods in Applied Mechanics and Engineering, (191), 4241-4258

Module level Master	Credits 6	Language English	Return: Annual
Module designation Rotor Blades			
Course(s) Rotor Blades			
Person responsible for the module	Prof. Dr.-Ing. Hans-Peter Heim		
Lecturer	Prof. Dr.-Ing. Hans-Peter Heim		
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 (120min) or online oral examination (45min)
Media employed	Online script
Reading list **Polymer chemistry:** Polymerwerkstoffe, *G.W. Ehrenstein*, Hanser / Kunststoffkunde, *O. Schwarz*, Vogel 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	

3. Specialization: Energy System Technology of Wind Energy Systems

Specialization of engineering applications / Energy System Technology of Wind Energy Systems		
Construction and Design of the Nacelle System	Wind Energy Meteorology	Control and Operational Management for Wind Turbines and Wind Farms
Energy Storage	Reliability, Availability, Maintenance Strategies	Technical and Energy Economic Aspects of Grid Integration
	Micro Meteorology for Wind Engineers	

Module level Master	Credits 6	Language English	Return Annual
Module designation Construction and Design of the Nacelle Systems			
Course(s) Nacelle Systems Design			
Person responsible for the module	Prof. Dr. rer. nat. Clemens Hoffmann		
Lecturer	Prof. Dr.-Ing. Jan Wenske		
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.

Media employed	Online script, teaching video

Reading list

Hau, E.: Wind Turbines: Fundamentals, Technologies, Application, Economics. Springer-Verlag, Berlin Heidelberg, 3rd ed. 2012

I.N. Bronshtein, K.A. Semendyayev, G. Musiol, H. Muehlig, H. Mühlig: Handbook of Mathematics, Springerverlag, Berlin Heidelberg New York, 4rd. ed. 2004

Karl-Heinrich Grote, Erik K. Antonsson: Springer Handbook of Mechanical Engineering, Springer-Verlag, Berlin Heidelberg, 2009

Module level	Credits	Language	Return
Master	6	English	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	
Study and examination requirements and forms of examination	Assignments (6 in total, 70% of the final grade), quizzes (10% of the final grade), oral (20% of the final grade)
Media employed	Canvas LMS
Reading list Lecture Notes and videos	

Module level Master	Credits 6	Language English	Return Annual
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, 60, 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 mico 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

Simon Haykin: Neural Networks. A Comprehensive Foundation. 2. edition, international edition = Reprint. Prentice-Hall, Upper Saddle River NJ u. a. 1999, ISBN 0-13-273350-1.

John Hertz, Anders Krogh, Richard G. Palmer: Introduction to the Theory of Neural Computation. Addison-Wesley, Reading MA u. a. 1999, ISBN 0-201-51560-1 (Santa Fé Institute studies in the sciences of complexity.Lecture notes 1 = Computation and neural systems series).

Teuvo Kohonen: Self Organizing Maps. 3. edition. Springer, Berlin u. a. 2001, ISBN 3-540-67921-9 (Springer Series in Information Sciences 30 = Physics and Astronomy online Library).

Helge Ritter, Thomas Martinetz, Klaus Schulten: Neural Computation and Self-Organizing Maps. An Introduction. Addison Wesley, Reading MA 1992, ISBN 0-201-55442-9 (Computation and neural Systems Series).

Raul Rojas: Theorie der Neuronalen Netze. Eine systematische Einführung. 4.. Springer, Berlin u. a. 1996, ISBN 3-540-56353-9 (Springer-Lehrbuch).

Andreas Zell: Simulation neuronaler Netze. 4. unveränderter Nachdruck. Oldenbourg, München u. a. 2003, ISBN 3-486-24350-0.

Module level	Credits	Language	Return
Master	6	English	Annual

Module designation

Control and Operational Management for Wind Turbines and Wind Farms

Course(s)

Control of Wind Turbines and Wind Farms

Person responsible for the module	Prof. Dr. rer. nat. Clemens Hoffmann
Lecturer	Dipl.-Ing. Boris Fischer, Dipl.-Ing. Melanie Hau
Workload	180 h (30 h contact time, 60 h homework / presentation, 90 h private study)
Relation to curriculum	Specialist studies, Electrical Systems Technology, elective
Type of teaching, contact hours	Online units, virtual classrooms, online presentations
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 (15min) 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.

Module level	Credits	Language	Return
Master	6	English	Annual

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

1. Turan Gonen: *Electrical Power Transmission System Engineering Analysis and Design*. ISBN-10: 1439802548; ISBN-13: 978-1439802540
2. Olivia E. Robinson: *Electric Power Systems in Transition (Electrical and Engineering Developments).* ISBN-10: 1616689854; ISBN-13: 978-1616689858
3. James J. Burke: *Power Distribution Engineering: Fundamentals and Applications* (Electrical and Computer Engineering). ISBN-10: 0824792378; ISBN-13: 978-0824792374
4. Mohamed El-Hawary: *Electrical Power Systems: Design and Analysis* (IEEE Press Power Systems Engineering Series) ISBN-10: 078031140X; ISBN-13: 978-0780311404
5. Thomas Ackermann: *Wind Power in Power Systems.* ISBN-10: 0470974168; ISBN-13: 978-0470974162
6. J. Lewis Blackburn: *Protective Relaying: Principles and Applications* (Power Engineering (Willis)). ISBN-10: 1574447165; ISBN-13: 978-1574447163
7. Juan M. Gers, Ted Holmes: *Protection of Electricity Distribution Networks*. ISBN-10 0863413579; ISBN-13 978-0863413575

Module level	Credits	Language	Return
Master	6	English	Annual

Module designation

Energy Storage

Course

Energy Storage

Person responsible for the module	Prof. Dr. rer. nat. Clemens Hoffmann
Lecturer	Prof. Dr.-Ing. Ingo Stadler
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

Study and examination requirements and forms of examination	Written exam (90min) or online oral examination (45min)
Media employed	Online script
Reading list Reading list will be provided by lecturer via the online platform Moodle.	

Module level	Credits	Language	Return
Master	6	English	Annual

Module designation

Reliability, Availability, Maintenance Strategies

Course(s)

Reliability, Availability, Maintenance Strategies

Person responsible for the module	Prof. Dr. rer. nat. Clemens Hoffmann
Lecturer	Dipl-Ing. Stefan Faulstich, Dipl.-Ing. Berthold Hahn
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 (120min) or online oral examination (45min)
Media employed	Online script

Reading list

- Tavner, Peter: Offshore Wind Turbines – Reliability, availability and maintenance, ISBN 978-1-84919-229-3
- Walford C.A.: Wind Turbine Reliability: Understanding and Minimizing Wind Turbine Operation and Maintenance Costs, SANDIA REPORT, SAND2006-1100
- Wiggelinkhuizen, E., et al: Assessment of condition monitoring techniques for offshore wind farms, Journal of Solar Energy Engineering

4. Additive Key- Competences: Energy and Law

Additive Key-Competences: Energy and Law		
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 level	Credits	Language	Return
Master	3	English	Annual

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	
Study and examination requirements and forms of examination	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.
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 Contract Law			
Course Contract 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 / 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 level Master	Credits 3	Language English	Return Annual
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

Module level Master	Credits 3	Language English	Return Annual
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 h online presentations, 20 h private study, 60 h 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 (60min), essay and/or term paper (10-15 pages), online presentation of homework (15min)

Media employed	Online transmission facilities
Reading list Reading list will be provided by lecturer via the online platform Moodle.	

Module level	**Credits**	**Language**	**Return**
Master	3	English	Annual
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 Sträter, O., Siebert-Adzic, M. & Schäfer, E. (2012) Gesundes Führen für effiziente Organisationen der Zukunft. In Grote, S. (Hrsg.), Zukunft der Führung. Heidelberg: Springer Gabler. Schuler, H. (1995) (Hrsg.) Lehrbuch Organisationspsychologie. Hans Huber. Bern, Göttingen, Toronto, Seattle. Sträter, O. (2005) Cognition and safety - An Integrated Approach to Systems Design and Performance Assessment. Ashgate. Aldershot. (ISBN 0754643255) Whitmore, J. (1994). Coaching für die Praxis - Eine klare, prägnante und praktische Anleitung für Manager, Trainer, Eltern und Gruppenleiter. Frankfurt/M.: Campus Tuckman, B. (1965) Development Sequence in Small Groups", Psychological Bulletin, 63 (6), S. 384-399			

Module level Master	Credits 3	Language English	Return Annual
Module designation Project Management			
Course(s) Project Management			
Person responsible for the module	Prof. Dr.-Ing. Detlef Kuhl		
Lecturer	Stefan Bauch, Anja Rösen		
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 and 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,			

2012
Identifying and Managing Project Risk: Essential Tools for Failure-Proofing Your Project, Tom Kendrick, 2009
Making Things Happen: Mastering Project Management (Theory in Practice); Scott Berkun, 2008
Developing Wind Power Projects: Theory and Practice, Tory Wizelius, 2006
Project Management in Construction (McGraw-Hill Professional Engineering), Sidney Levy, 2006.