Syllabus:
Construction and Design of the Nacelle-Systems

Online M.Sc. Wind Energy Systems // SS 2018

Instructor

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Course goals

The students know the basic structure and design methods for the nacelle system of modern horizontal axes 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, students 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 drivetrain components.

Pre-requisites

Successful completion of the fundamental Modules Mathematics, Solid Mechanics, Electrical Engineering, Design of Mechanical and Electrical Components.

Seminar structure, seminar location and times

Synchronous teaching concept:

Online sessions will be held in a block format with online presentations and question/discussion sessions alternately. These online sessions of different time duration are scheduled for Tuesdays from 5:00-9:00 p.m. (UTC+2) in the calendar weeks named in the syllabus. Online sessions will be held via Adobe Connect in eCampus.

Asynchronous teaching concept:

This module “Construction and Design of the Nacelle-Systems” will include an online laboratory where the students can conduct their own remote experiments via internet and the online platform (Moodle). There will be enough laboratory time available for students, to work flexible and independently from the other online sessions. A special planning tool will be provided at the online platform to manage the booking of experimental time slots. The system will send back results (measurements, video streams) of the experiments to Moodle. The students will work on exercises, given at the end of the online sessions and available on Moodle, to amplify the presented learning objectives within self-study. Solutions will be also available time shifted on Moodle.
Construction and Design of the Nacelle-Systems
Online M.Sc. Wind Energy Systems // Summer Semester 2018

During the module the students will work on their own project to apply what they’ve learned. The students shall develop the project by themselves, supported by the lecturer, regarding their specific interests. The students shall present the results of their project work at the end of the module during a specific online session. These presentations will be graded and are one part of the complete grading for this module.

General procedure for questions about content from students:

All questions on understanding the material, example or exercise should be directed to your fellow students in the online forums (Moodle) first! Within the online question/discussion sessions every second week, there will enough time to answer any questions which could not be answered already by your classmates.

Participation requirements

During this module there will be four real-time class sessions (online presentation by the lecturer), which students are required to attend (questions/discussion sessions). During the course a sufficient and flexible online laboratory time for remote experimental work will be enabled, at least 120 minutes access time per student. One or two (depending on the number of participants) real-time class sessions are scheduled for the presentations of the project work by the students, which all students should attend if possible (those who are not able to attend online, should record their presentation and send it to the lecturer, who will make it available on the online platform, for offline discussion within the forum). In general all slides of the presentations (online or offline) will be uploaded to the online platform. The overall time for real-time class online sessions within this module incl. presentation and examination sessions will be approx. 25h for each student.

Embedding in Curriculum

Table 0.1 shows the present lecture Construction and Design of the Nacelle-Systems embedded in the specialist studies Energy System Technology in the master course Wind Energy Systems. The present lecture is based on the knowledge of the modules of Fundamental Studies of Mathematics and Engineering. In particular, very good knowledge of Design of Mechanical and Electrical Components of Wind Energy Systems, Solid Mechanics and Electrical Engineering is essential for the successful graduation of the present module. Since in the present module addresses more details and background knowledge regarding the specific design of the mechatronic nacelle system including the drivetrain as its central element, already provided in module Design of Mechanical and Electrical Components, it is quite important to understand the topics of the fundamental modules mentioned above. The present module is extended to more concrete calculation procedures for pre-engineering of new concepts and assessment and comparison of already existing technical solutions. The present module can be combined with the Control and Operational Management of Wind Turbines in order to obtain an entire insight into wind turbine dynamics and to learn how environment conditions and control characteristics influences the design requirements. Furthermore, this module is fundamental to understand the very close link between design and reliability, availability maintenance strategies for the herein addressed mechatronic systems.
Table 1: Embedding of the Module in Online M.Sc. Wind Energy Systems

<table>
<thead>
<tr>
<th>Present course</th>
<th>Strong basis</th>
<th>Strong interaction</th>
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<tbody>
<tr>
<td>Master Thesis (at academia or industry)</td>
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</table>

### Specialization: Simulation and Structural Technology (each 6 ECTS-Credits)
- Rotor Aerodynamics
  - Strength Durability and Reliability
  - Rotor Blades
- Computational Fluid Dynamics
  - Nonlinear Computational Structural Mechanics
  - Theoretical Fluid Mechanics
- On- and Offshore Foundations
  - Linear Computational Structural Mechanics
  - Towers

### Specialization: Energy System Technology (each 6 ECTS-Credits)
- Wind Energy
  - Meteorology
- Energy Storage
- Construction and Design of Nacelle-Systems
  - Control and Operational Management of Wind Turbines and Wind Farms

### Additive Key-Competences: Energy and Law (each 3 ECTS-Credits)
- Contract Law
- Occupational Safety On- and Offshore
- Energy Law
- Project Management
- Planning and Constructions of Wind Farms
- Business Administration and Management of Wind Turbines and Wind Farms
- Personal Management

|-----------------------------------------------|------------------------|-------------|----------------|-------------------------------|----------------|

### Texts, reading and other materials

Readings will either be scanned and posted on Moodle, or are available on the internet. All online seminars (beside the question/discussion sessions) will be recorded and made available on Moodle.

The following shall be provided on the online platform Moodle:

- Slides of the real-time presentations
- Exercises – Solution examples
- Online-Laboratory management system
- Collected special information for self-studies
- Literature reference list

Students have to take care within their own responsibility:

- Publicly Accessible Standard Literature
- Online search in the WWW
Hardware and software requirements

All students will need a headset and a computer for this course, ideally Windows. In addition to the usual Microsoft office programs (Word, Excel, PowerPoint), the access to a standard Matlab software installation should be possible.

Examination

The following assignments will be considered and weighted in your overall course grade:

1. Presentation of project work (weighting 50%), duration: ~10min.
2. Individual oral examination (weighting 50%), duration: ~25min.

Grading policy

The grading scale used in this course is the same as for all WES courses. For all single assignments, the following scale is used:

<table>
<thead>
<tr>
<th>Category</th>
<th>Grade range</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>1,0, 1,3</td>
<td>Excellent performance</td>
</tr>
<tr>
<td>Good</td>
<td>1,7, 2,0, 2,3</td>
<td>Performance significantly above average</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>2,7, 3,0, 3,3</td>
<td>Average performance</td>
</tr>
<tr>
<td>Sufficient</td>
<td>3,7, 4,0</td>
<td>Performance which, despite some shortcomings, meets the minimum standards of the course</td>
</tr>
<tr>
<td>Fail</td>
<td>5,0</td>
<td>Does not meet minimum course requirements</td>
</tr>
</tbody>
</table>
### Unit 1
**17 April**

**Theory - wind turbine drivetrain loads / endurance strength of machine parts**

**Content**

Brief introduction to the planned session sequence and the content of the module "construction and design of the nacelle system".

Definition of system boundaries for the drivetrain as the central element of the nacelle at a wind turbine with a horizontal axis. Characterization and calculation of loads at the mechanical drivetrain (gravity, wind forces, internal excitations, etc.) as basis for the analysis of existing and design of new concepts.

Fundamentals of machine parts dimensioning (analysis of load, tension / compression / bending / shear and torsion, superposed stresses, equivalent stress-states and failure hypothesis, load cases as well as typical material characteristics, notch effect, sizing as well as static and fatigue strength calculation).

*Duration of the online sessions 3 x 45 min. via Adobe Connect*

*The original session will be recorded and offline accessible.*

**homework/preparation/wrap-up**

Self-study of literature / presentation slides and reports on the actual topic, which is provided at the online platform Moodle.

Exercises for this unit, which can be edited offline by the students, made available on Moodle. The corresponding solutions will be time shifted (about 2 weeks) accessible. The exercises are not graded, but shall serve the students self-assessment.

### Unit 2
**17 April**

**Theory - Characteristic machine elements in wind turbine drivetrains**

**Content**

Introduction to the theory and dimensioning (analysis) of characteristic machine elements in drivetrains of wind turbines. In terms of their function, the abstraction in mechanical equivalent circuits, their calculation, used materials and their variants (types). Discussed machine elements will be: fixings and contact elements (weld, bolts and pins, radial carrier, pressed and bolted connections, elastic dampers and springs), shafts, bearings, gear drives, clutches, brakes.

*Duration of the online sessions 3 x 45 min. via Adobe Connect*

*The original session will be recorded and offline accessible.*
Self-study of literature / presentation slides and reports on the actual topic, which is provided at the online platform Moodle.

Exercises for this unit, which can be edited offline by the students, made available on Moodle. The corresponding solutions will be time shifted (about 2 weeks) accessible. The exercises are not graded, but shall serve the students self-assessment.

**Unit 3**
**8 May**

**Theory – WTG drivetrain concepts / Different types of mechatronic systems**

**Content**

Different types of wind turbines in the current power range between 500 kW and 8 MW will be presented and discussed in detail, as well as corresponding mechatronic drivetrain concepts in their structure, function and properties. A simple classification methods for drivetrain topologies will be presented, to classify the various concepts and to enable a high grade comparison of different solutions.

One focus is on the elaboration of the respective advantages and disadvantages of the currently applied concepts. An outlook on future medium term trends and the potential use of new technologies for turbines of the next generation, concludes this online learning unit.

*Duration of the online sessions 3 x 45 min. via Adobe Connect*

*The original session will be recorded and offline accessible.*

Self-study of literature / presentation slides and reports on the actual topic, which is provided at the online platform Moodle.

Exercises for this unit, which can be edited offline by the students, made available on Moodle. The corresponding solutions will be time shifted (about 2 weeks) accessible. The exercises are not graded, but shall serve the students self-assessment.
Various generator / converter systems for wind turbines in the current power range between 500 kW and 8 MW will be presented and discussed in their structure, function and properties. Followed by a brief introduction to the fundamentals and operation of today’s power electronic converters with a DC intermediate circuit for the variable-speed operation of modern wind turbines. Characteristics and fundamentals of energy conversion by means of various types of generators (asynchronous and synchronous machines) and their designs for different drivetrain concepts will be presented. Advantages and disadvantages of the different systems are discussed in detail.

In addition the topic of electrical grid connection of wind turbines is introduced. The relevant electrical and electromechanical subsystems and components are presented and discussed as well as the basics of their dimensioning. The current regulations and guidelines of the electrical characteristics of a wind power plant (electrical power system services, Power Quality) will be explained as well as the basics of grid-side control of WTG.

*Duration of the online sessions 3 x 45 min. via Adobe Connect*

*The original session will be recorded and offline accessible.*

Self-study of literature / presentation slides and reports on the actual topic, which is provided at the online platform Moodle.

Exercises for this unit, which can be edited offline by the students, made available on Moodle. The corresponding solutions will be time shifted (about 2 weeks) accessible. The exercises are not graded, but shall serve the students self-assessment.

Exercise within the online laboratory regarding dynamic and static operation and operation management of variable speed WTG. Students shall create a short report of their experimental results and send it to the lecturer (not graded).
# Unit 5

## 5 June

**Theory – Drivetrain analysis & modeling / similarity theory**

### Content

Introduction to the methodology of physical discretization for mathematical modeling, simulation and analysis of the dynamic system characteristics of wind turbine drivetrains. By way of example, the methodology is explained in detail. Subsequently, the current methods of mathematical modeling are presented. Application examples are intended to illustrate the relative advantages of different modeling approaches. The calculation of natural frequencies and mode shapes is explained step by step and illustrated using case studies. The procedure shown is initially limited on one mechanical degree of freedom (rotation) systems, concludes with an outlook in regards of extension to several mechanical degrees of freedom.

The dynamic transfer function of mechanical components is derived and corresponding transfer blocks for system description as signal flow diagram or block diagram will be defined.

It is introduced into the similarity theory and its application to wind turbines, particularly in regard to the drivetrain and the nacelle. Using case studies, the potential for rough estimations and plausibility checks are explained. Finally general rules and model laws will be summarized in a kind of “work-tool box” (formulary).

*Duration of the online sessions 3 x 45 min. via Adobe Connect*

*The original session will be recorded and offline accessible.*

### homework/

**preparation/wrap-up**

Self-study of literature / presentation slides and reports on the actual topic, which is provided at the online platform Moodle.

Exercises for this unit, which can be edited offline by the students, made available on Moodle. The corresponding solutions will be time shifted (about 2 weeks) accessible. The exercises are not graded, but shall serve the students self-assessment.

Exercise within the online laboratory regarding mathematical modelling and model validation of a WTG drivetrain. Students shall create a short report of their experimental results and send it to the lecturer (not graded).
## Content

Basic theory of permanent-magnet synchronous generator design, including winding system, magnetic circuit calculation, efficiency estimation, torque ripple estimation, introduction of eddy currents and their design consequences as well as the applied principles of generator cooling.

Introduction to theory of modern field oriented control techniques for PMSG. Discussion of already existing generator designs and development trends. Briefly presentation of additional parasitic phenomenons e.g. bearing currents which should be taken into account for design assessment and new concepts.

Introduction of a simplified cost model for the Generator/Converter system. The session shall cover all currently known drivetrain concepts, from classic fast running, over hybrid to direct-drive designs (but always related to PMSG).

*Duration of the online sessions 3 x 45 min. via Adobe Connect*

*The original session will be recorded and offline accessible.*

## homework/preparation/wrap-up

Self-study of literature / presentation slides and reports on the actual topic, which is provided at the online platform Moodle.

Exercises for this unit, which can be edited offline by the students, made available on Moodle. The corresponding solutions will be time shifted (about 2 weeks) accessible. The exercises are not graded, but shall serve the students self-assessment.

Exercise within the online laboratory regarding torque and speed control PM-synchronous generators. Students shall create a short report of their experimental results and send it to the lecturer (not graded).
**Unit 7 + Exam Preparation**  
3 July

### Theory – Ancillary systems within the nacelle system of WTG

**Content**

Presentation and discussion of currently applied pitch and yaw drive systems and their hydraulic and electromechanical design. Basics of dimensioning, their controls and the related safety concepts.

Brief introduction of the hydraulic circuit and drive technology (function, circuit symbols, dimensioning) used in WTG and deepening the understanding by means of simple calculations examples and using analogies from electrical engineering.

Presentation, classification and discussion of different cooling concepts various types of wind turbines in the power range of 500kW to 8 MW. Fundamentals of cooler design (heat conduction, heat transfer and convection) and approaches to simplify the estimation of losses and the determination of the required cooling demand as one key aspect for new system designs.

Short discussion of current lubrication systems within modern wind turbines.

Brief repetition of the operation management basics of modern wind turbines with variable speed operation, incl. Maximum-Power-Point-Tracking in partial load operation and speed respectively power limitation in the full-load operation. Presentation of equipment for the system operation control (PLC, actuators, sensors, bus systems, SCADA systems, automation levels). Information about the state of the art in condition monitoring system for the drivetrain monitoring (Procedures, technologies, limitations).

*Duration of the online sessions 3 x 45 min. via Adobe Connect*

*The original session will be recorded and offline accessible.*

**homework/ preparation/wrap-up**

Self-study of literature / presentation slides and reports on the actual topic, which is provided at the online platform Moodle.

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### EXAMINATION

Individual online oral exams will be held in July/Aug.!