Syllabus: Energy Storage

Online M.Sc. Wind Energy Systems

Instructors

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Course goals

The conversion of today’s energy supply systems that still are based to a large extent on fossil and nuclear resources into energy supply systems that completely rely on renewable sources is the goal for the next decades. Most renewable sources are of intermittent nature – as it is with the topic of the master course on wind energy – and this will lead to completely new overall system design requirements to maintain reliable energy systems. Reliability of those converted energy systems will rely on mainly three pillars: energy storage, renewable overproduction, and their interconnection by smart grid technologies. This course is about energy storage.

As your master course is about Wind Energy it is not the aim to train you to become energy storage experts. But it is the aim that you get an overview on all possibilities to deal with the challenge of different times of power generation and power demand and its balance.

After having learnt about different technologies to store energy it will be the aim that students can distinguish different storage solutions and are able to choose the appropriate solution for a given storage problem.

Pre-requisites

None

Seminar structure, seminar location and times

This seminar is structured into different sections:

- The Script. It provides the course content in detail and can be read whenever you have time to do so.

- The Lecture Videos. The content of the seminar is presented in videos. The videos can be watched any time you want to do so. At the end of most videos you find questions you will answer and send to the instructor via moodle at given deadlines. This is part of the grading system.

- Online meetings via adobe connect. In those meetings we will discuss and answer your questions. Additionally, each student selects one topic of the seminar and will explain in a short presentation the answers to the questions asked in the end of the videos.

All questions on understanding the material should be directed to your fellow students in the online forums first! At the beginning of each class session, we will have time to answer any questions which could not be answered already by your classmates.
## Participation requirements

Most of the content can be done offline – whenever you have time to do so. But there will be five online, real-time class seminars, which students are required to attend.

## Embedding in Curriculum

**Table** Error! No text of specified style in document.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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</thead>
<tbody>
<tr>
<td><strong>Master Thesis (at academia or industry)</strong></td>
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</tr>
<tr>
<td><strong>Specialization:</strong> Simulation and Structural Technology (each 6 ECTS-Credits)</td>
<td>Specialization: Energy System Technology (each 6 ECTS-Credits)</td>
<td>Additive Key-Competences: Energy and Law (each 3 ECTS-Credits)</td>
</tr>
<tr>
<td>Rotor Aerodynamics</td>
<td>Strength Durability and Reliability</td>
<td>Wind Energy Meteorology</td>
</tr>
<tr>
<td>Computation Fluid Dynamics</td>
<td>Nonlinear Computation Structural Mechanics</td>
<td>Construction and Design of Nacelle-Systems</td>
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<td>Towers</td>
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<td>Contract Law</td>
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### Fundamentals of Mathematics and Engineering for Wind Energy Systems (each 6 ECTS-Credits)

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

## Texts, reading and other materials

Readings will be posted on Moodle, or are available on the internet. All seminars will be recorded and made available on Moodle.

## Hardware and software requirements

All students will need a headset and a computer for this course.
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Examination

The exams consist of different parts:

1. Short answers to the questions posted at the end of each lecture video that you submit via model to the instructor (25 %)

2. one presentation to the other students that deals with the answers of a lecture video (20 %)

3. Written exam with grading talk. Exam questions will be sent to the students 24/48 hours before the oral examination. The answers to these questions must be defended at an oral exam (55 %)

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>
>Zeitangaben und Auflistung der Inhalte der Online Sessions/Videos<

**Seminar 1**
**Oct. 23**

**Get together**

**Content**
- Get to know each other
- Explanation on how the course will be structured
  - How to deal with the videos
  - How to deal with the script
  - How to do homework
  - Examination
  - Questions and answers

**Homework**
None

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**Unit 2**
**Oct. 30 to Nov. 05**

**Introduction to Renewable Energy Systems and the Role of Energy Storage**

**Content**
- Watch videos to the “three pillars of energy transition” and also “Energy through the Ages”
- Since the beginning of time human beings have made use of energy storage. Photosynthesis started as the first energy storage process around 2 billion years ago.
- Only since recently, humans have used fossil energy which is a form of old biomass. On a long term basis it is necessary to make a sustainable use of this biological storage process, to reproduce it technically, and to exploit other energy storage technologies.
- This unit covers the history of energy storage from the perspective of the carbon cycle. It will start with the natural process of photosynthesis, then go through the storage-products biomass, peat, and fossil carriers, and finish in the time of renewables.
- Additionally, it will emphasize the significance of exploiting energy storage

**Homework:**
To answer the questions for “self-examination” and send to the instructor until Nov. 05
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Unit 3
Nov. 06 to Nov. 12

**Energy Storage Classification**

**Content**
- Watch videos on “energy storage classification”
- Without energy storage, the energy supply would be almost impossible. They are a fundamental building block of our energy system. The role that energy storage plays in the energy system is often a subject for discussion: are energy storage systems part of the energy networks or are they “generators” or “consumers”? In which calculation should be the costs of energy storage located? These definitions are very helpful for the classification of energy storage in the energy industry.
- This unit outlines how storage and energy storage systems are defined, which approach is given to their application and how they are classified according to physical, temporal and economic criteria

**Homework**
To answer the questions for “self-examination” and send to the instructor until Nov. 12

Unit 4
Nov. 13 to Nov. 19

**Lead Acid Batteries**

**Content**
- Watch videos on “Lead Acid Batteries”
- To describe electro-chemical energy storage the terms batteries and accumulators are used. Electrochemical systems are composed of electrodes that are connected via an electrolyte that serves as ion-conductive phase. In general electrochemical systems are able to develop electrical energy. In case of an accumulator the energy can be both extracted and stored. The electrical charges are transferred during chemical reactions. In this unit lead-acid batteries are discussed.

**Homework**
To answer the questions for “self-examination” and send to the instructor until Nov. 19
**Unit 5**  
**Nov. 20 to Nov. 26**  

**Lithium Batteries**

**Content**
- Watch videos on “Lithium Batteries”
- To describe electro-chemical energy storage the terms batteries and accumulators are used. Electrochemical systems are composed of electrodes that are connected via an electrolyte that serves as ion-conductive phase. In general electrochemical systems are able to develop electrical energy. In case of an accumulator the energy can be both extracted and stored. The electrical charges are transferred during chemical reactions. In this unit lithium batteries are discussed.

**Homework:**
To answer the questions for “self-examination” and send to the instructor until Nov. 26

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**Seminar 6**  
**Nov. 20**

**Presentations for “self-examination” questions and discussion**

**Content**
- Students present questions for “self-examination” of units 2 to 5 to a selected topic in between 10 and 15 minutes.

**Homework**
None

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**Unit 7**  
**Nov. 27 to Dec. 03**

**Chemical Energy Storage I**

**Content**
- Watch videos on “Chemical Energy Storage I”
- Chemical energy storage is the backbone of the conventional energy supply. Solid (wood & coal), fluent (crude oil) and gaseous (natural gas) energy carriers are different types of energy storage themselves. Also in the energy transition, chemical energy storage plays an important role, especially in its function as long term storage for the current sector, but also as a distributor of fuel for mobility and heat. This unit will, besides the conventional storage technologies, take a deep look into the storage of renewable energies in the form of gaseous (power-to-gas) energy carriers.
- Here the charging process is taken into account.

**Homework**
To answer the questions for “self-examination” and send to the instructor until Dec. 03
### Unit 8: Chemical Energy Storage II
**Dec. 04 to Dec. 10**

**Content**
- Watch videos on “Chemical Energy Storage II”
- Chemical energy storage is the backbone of the conventional energy supply. Solid (wood & coal), fluent (crude oil) and gaseous (natural gas) energy carriers are different types of energy storage themselves. Also in the energy transition, chemical energy storage plays an important role, especially in its function as long term storage for the current sector, but also as a distributor of fuel for mobility and heat. This unit will, besides the conventional storage technologies, take a deep look into the storage of renewable energies in the form of gaseous (power-to-gas) energy carriers.
- Here the charging process is taken into account.

**Homework**
To answer the questions for “self-examination” and send to the instructor until Dec. 10

### Unit 9: Thermal Energy Storage
**Dec. 11 to Dec. 17**

**Content**
- Watch videos on “Thermal Energy Storage”
- Thermal Energy Storage and Wind Energy Systems do not seem to have so much in common. Nevertheless, thermal energy storages are much cheaper than electrical energy storages. In the next chapters sector coupling will be discussed. Whenever it is possible to solve a storage task on the thermal energy sector it has many advantages. Therefore, there thermal stores are discussed, too.

**Homework**
To answer the questions for “self-examination” and send to the instructor until Dec. 17

### Seminar 10
**Dec. 11**

**Content**
- Students present questions for “self-examination” to a selected topic of the units 7 to 9 in between 10 and 15 minutes.

**Homework**
None
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<table>
<thead>
<tr>
<th>Unit 11</th>
<th>Coupling of Energy Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec. 18 to Dec. 24</td>
<td><strong>Content</strong></td>
</tr>
<tr>
<td></td>
<td>• Watch videos on “Coupling of Energy Sectors”</td>
</tr>
<tr>
<td></td>
<td>• Today, more or less the energy sectors for electricity, for heat, for cold, for transport and for gas are almost separated. Here, we will discuss which advantages it will have when those sectors will be interlinked to each other. Especially, for the task of energy storage sector coupling provides many advantages.</td>
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<td><strong>Homework</strong></td>
</tr>
<tr>
<td></td>
<td>To answer the questions for “self-examination” and send to the instructor until Dec. 24. Merry Christmas!</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit 12</th>
<th>Combined Heat and Power and Thermal Energy Storage as an example for Sector Coupling</th>
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</thead>
<tbody>
<tr>
<td>Jan. 02 to Jan. 07</td>
<td><strong>Content</strong></td>
</tr>
<tr>
<td></td>
<td>• Watch videos on “CHP and Thermal Energy Storage”</td>
</tr>
<tr>
<td></td>
<td>• Extremely cheap energy storage can be realized with very large thermal energy storages. In this unit as an example we discuss combined heat and power in combination with thermal energy storage in order to decouple electricity and heat generation.</td>
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<td><strong>Homework</strong></td>
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<tr>
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<td>To answer the questions for “self-examination” and send to the instructor until Jan. 07</td>
</tr>
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</table>

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<thead>
<tr>
<th>Seminar 13</th>
<th>Presentations for “self-examination” questions and discussion</th>
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<tbody>
<tr>
<td>Jan. 08</td>
<td><strong>Content</strong></td>
</tr>
<tr>
<td></td>
<td>• Students present questions for “self-examination” to a selected topic of the units 11 to 12 in between 10 and 15 minutes.</td>
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<td><strong>Homework</strong></td>
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<td>None</td>
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Unit 14
Economics of Energy Storage
Jan. 08 to Jan. 14

Content
- Watch videos on “Energy Storage Economics"
- The aim of this unit is to learn a methodology on how to evaluate the economics of different energy storage solutions. We will see that storage economics depend on many different factors and for different storage tasks different storages will have advantages and disadvantages

Homework
To answer the questions for “self-examination” and send to the instructor until Jan. 14

Unit 15
Examples for Storage Economics and Exam Preparation
Jan. 15 to Jan. 21

Content
- This unit will start with a homework
- The homework will train the procedure discussed in unit 11
- The solution of the homework will be presented and discussed in an online seminar Jan. 15

Homework
To solve an energy storage economics problem

Final Exam

A written exam will be held on xx.xx.xlsx.