Course unit title	***DESIGN FOR RENEWABLE ENERGY SYSTEMS***
Course unit code	2E12
Type of course unit	Elective
Semester	2
Number of ECTS credits allocated	5
Name of lecturer(s)	Michal JANDERA (CTU); Lecturer (UC); Lecturer (UNINA); Lecturer (UPT); Lecturer (ULg); Milan Veljkovic (LTU); Lecturer(Associate 1); Lecturer (Associate2).
Learning outcomes of the course unit	**Aim** The aim of this course is to give students an understanding of the behaviour of steel tubular towers for wind turbines, using analytical and numerical methods and to practice design calculations. In addition other lattice towers and different types of concrete towers combination will be discussed The Eurocodes are used throughout the course to calculate the structural resistance. The "International version of the codes" will be used in the course and students will have opportunity to borrow prepared compendiums which will be returned afterwards. This version of the Eurocodes is prepared by the international experts and is not nationally adjusted. The course describes different part of the tower: foundation, instability phenomena which are limiting for the resistance of a tower, different types of connections, as well as load analysis and safety strategy based on partial safety factors, tower production and maintenance. Understanding of economical and technical aspect involved in planning, design and construction of the wind farm, onshore and offshore will be provided. The aim is to have an understanding of theoretical background and engineering (design) models, and the resistance according to codes. Design concerning instability, assembling connections, foundations, design of details prone to fatigue load are based on theoretical models and design standards for win tower certification and Eurocodes. Exercises using FE method, using commercially available software, are optional and may be performed to compare analytical and numerical results. Previous experience in FE analysis is not requested but it is advantageous. **Skills** The course is conceived in order to give students following skills: - Understanding and quantifying difference in sustainability

	aspects between different electrical energy resources. - To be able to access costs of the tower using simplified approach and basic sustainability assessment. - Understanding of the load analysis, interaction of dynamic effects caused by the wind and mechanical performance of the turbines. - Understanding of the instability phenomena and a basic background theory. - Understanding and knowledge on how to calculate design resistance of a tower according to Eurocodes. - Understanding basics of manufacturing and maintenance of different tower types. - Understanding of behaviour and basic elements of design of best-practice details of assembling bolted joints. . - To be able to understand and have orientation in actual renewable energy economy at the world and European level. - Knowledge in how to performed FE analysis and interpret obtained results, optional skill.
Mode of delivery	Frontal lessons, seminar k and home work
Prerequisites and co-requisites	No requirements
Course contents	Seven topics, listed below are covered in the course. Design loads, including background of the approximation of external loads to design values of the cross-section forces, and resistance of the tower, including the foundation are main topics of the course. Basic theory of practical methods used to approximate cyclic loading is given. Assembling connections of the towers are considered focusing on design of bolts. One of the most important parts of structural design is to identify the engineering model and define different failure modes that may occur for a chosen design load of a tower. The design resistance is checked for each failure mode. In the compulsory assignments students practice use of the structural codes and engineering models for calculation of cross section forces, critical forces and the design resistance. Elastic stability of circular cylindrical shell, considering axial load and combination of axial load and bending moment will be given. Post-buckling behaviour of a perfect and imperfect shell will analysed to understand background of the design rules. Finite element method is used to calculate resistance of the tower for

	axial force and combination of axial force and bending moment, and to estimate design force in the bolts of the flange connection ("unsymmetrical T-stub connection).
Recommended or required reading	Tutorial examples will be prepared in due time in format of handouts in following areas sustainability assessment, costs analysis, shell stability, flange connection-one half of the T-stub. Peer reviewed papers from journals and different web sources will be provided. Background material of research projects developed by the teachers Choosen chapters related to selected topics of theory of stability and connections Eurocodes ECCS recommendations Guidelines, Standards
Planned learning activities and teaching methods	**1 Introduction wind power potential** 1.1 - Installed capacities Installed capacity and production, by countries and regions 1.2 - Trends Position of the wind tower business, comparison of various renewable resources and conventional energy power. **1.3. –** Sustainibalty aspect of electrical energy generated from different sources. Nuclear power vs. fosil power vs. renewable power of wind, hydro and solar. 1.3 - Wind resource assessment Speed persistence, tower height, site selection **Possible project assignment in area of following topics** Calculation of the payoff time for a certain type of wind power plant. Calculation of the payoff time for a renewable power facility. Sustainability assessment of a certain type of wind power plant **2 Wind tower design** 2.1 - How wind turbine works Rotor, nacelle 2.1 - Tower structural concepts Steel, hybrid, concrete, lattice 2.3 - Costs, preferences Comparison between different tower concepts, 2.4 - Rules, standards, recommendations, guidelines Eurocodes, GL-guidelines, DNV-guidelines, IEC-standards **3 Loads**

3.1 - Safety and reliability
Structural safety, structural reliability, code calibration
3.2 - Load types,
Aerodynamic blade loads, gravity loads,
3.3 - Design load cases,
Rules of thumb,
3.4 - Design approximation of wind loads,
10-minute mean, wind shear, design tables, section loads
3.5 - Fatigue load,
Damage equivalent loads, Rainflow count, load spectra, Stress range, S-N curves, the Palmgren-Miner rule
3.6 - Applying design loads on FE models,
Linear extrapolation of tower DEL
3.7 - Seismic loading,

4 Foundation
4.1 - General about possible solutions
4.2 - Design of fundament

5 Tower connection
5.1 - Design checks,
Failure modes
5.2 - Flange connection
Use of the provided extreme load tables, cross-section forces, design of bolts
5.3 - Friction connection
Design of bolts, structural detailing, loss of the pre-tension force
5.4 - Numerical example

Possible project assignment in area of following topics,
Hand calculation part
Design of flange connections.
Design of friction connections
Various levels of complexity could be addressed by FEA, without and with the contact elements.
The flange connection, segment part in tension.
Considerations of the T-stub connection, symmetric vs. unsymmetrical T-stub.

6 Stability concepts
6.1 - Concept of elastic stability
Circular cylindrical shells (buckling of circular cylindrical shells, axial compression, combined bending and axial compression)
6.2 - Post-buckling behaviour
Perfect shell, imperfect shell
6.3 - Openings

	Concentration of stresses, stiffening 6.4 - Design approach Design according EC3 **Possible project assignment,** Tower resistance FEA vs hand-calculation methods Buckling of the a tower, Axial and combination axial-bending moment Non-linear analysis Initial imperfections, axial and combination axial-bending moment Analysis of lower segments including the opening in compression. **7. Fabrication and maintenance** 7.1 - Production Description of the production process, cutting rolling, welding, tolerances 7.2 - Transport Size limits, organization, temporary stiffening 7.3 - Maintenance of the tower Inspection intervals, design for life time
Assessment methods and criteria	Approved compulsory assignments will be necessary to prepare a public presentation at the end of the course on the work performed during the course. Grading system. Passed or not passed. A certificate awarding ECCS credits after the course accomplishment may be provided upon the request.
Language of instruction	English