PROGRAMME SYLLABUS

Erasmus Mundus Joint Master

EU-CORE

European Master on Control of Renewable Energy Systems

CENTRALE NANTES

UNIVERSITY OF ZAGREB

BRANDENBURGISCHE TECHNISCHE UNIVERSITÄT COTTBUS - SENFTENBERG

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Syllabus of courses offered in Centrale Nantes

Course 1 – Renewable Energy Systems		
Credits: 4	**Fall Semester**	**Compulsory: Yes**
Lectures: 12	Tutorial: 14	Lab: 4
Professor: P. Marty		
Objectives: At the end of the course, students will be able to: • Understand and master the major energy, climate and environmental issues of this century • master the fundamental concepts and the major orders of magnitude • perform "back of an envelope" calculations to quickly analyse a solution while developing a sharp critical sense		
Assessment: Written exam and practical work report		
Recommended texts and further readings: P. Hawken, Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming, Penguin, 2017 H. Ritchie, Not the End of the World: How We Can Be the First Generation to Build a Sustainable Planet, Little, Brown Spark, 2024 B. Gates, How to Avoid a Climate Disaster: The Solutions We Have and the Breakthroughs We Need, Penguin, 2021		

Course 2 – Wind Energy 1		
Credits:	**Fall Semester**	**Compulsory: Yes/No**
Lectures: 17	Tutorial: 4	Lab: 10
Professor: Sandrine AUBRUN		
Objectives: The aim of the course is to give the basics on the fluid mechanical aspects of a wind turbine operation that is needed to address, in an expert way, a problem of wind turbine or wind farm control. After drawing the overall panorama of the current wind energy capacity worldwide and in Europe, the general operating principles of a wind turbine and its components are described. Then, the course addresses all the fluid mechanical aspects of the system: the driving source of energy, i.e. the wind, the wind resource assessment and the power production, the airfoil and rotor aerodynamics, the wake effects.		
Assessment: Written exam and practical work report		

Recommended texts and further readings: - Introduction to wind energy systems 2013, Springer-Verlag Berlin and Heidelberg GmbH & Co. K - Wind Energy Handbook, 2001 John Wiley & Sons, Ltd - Wind energy explained, - Theory, Design and Application. 2009 John Wiley & Sons, Ltd - Wind resource assessment - A practical guide to developing a wind project. 2012 John Wiley & Sons, Ltd

Course 3 – Wind Energy 2		
Credits:	**Fall Semester**	**Compulsory: Yes/No**
Lectures: 18h	Tutorial: 4h	Lab: 8h
Professor: Sandrine AUBRUN		
Objectives: The aim of the course is to give the basics on the structural mechanical aspects of a wind turbine operation that is needed to address, in an expert way, a problem of wind turbine or wind farm control. It gives also an introduction to the additional multi-physics aspects for floating wind turbine. The course addresses the mechanical aspects of the system: the dynamics and vibrations of the structural components, the aero-mechanical couplings and the additional complexities led by floating wind turbine concepts.		
Assessment: Written exam and practical work report		
Recommended texts and further readings: - Wind Energy Handbook, 2001 John Wiley & Sons, Ltd - Wind energy explained, - Theory, Design and Application. 2009 John Wiley & Sons, Ltd - Wind resource assessment - A practical guide to developing a wind project. 2012 John Wiley & Sons, Ltd - Advances in Wind Turbine Blade Design and Materials, 2013, Woodhead Publishing. - A Modern Course in Aeroelasticity, 2022 (6th edition), Springer.		

Course 4 – Power Conversion		
Credits: 4	**Fall Semester**	**Compulsory: Yes**
Lectures: 16	Tutorial: 4	Lab: 10
Professor: M. Hamida		
Objectives: This course covers the analysis and synthesis of the main structures in the energy conversion chain. For the sources section, the aim is to present a broad overview of the various conventional and		

renewable energy sources. For static converters, the aim is to understand the operation and analyse the waveforms of converters such as three-phase rectifiers, choppers and inverters. For electrical machines, the aim is to master the principle of electromagnetic conversion and to model synchronous and asynchronous machines in steady state. At the end of the course, students will be able to: • Understand the operation of different renewable energy sources. • Understand the operation of different types of static converters and their uses in renewable energy systems. • Know the modelling and simulation of the different components of electrical conversion chain.
Assessment: Written exam and practical work report
Recommended texts and further readings: - CHAKRABORTY, Sudipta, SIMÕES, Marcelo G., et KRAMER, William E. Power electronics for renewable and distributed energy systems. *A Sourcebook of Topologies, Control and Integration*, 2013. - MUELLER, Markus et POLINDER, Henk (ed.). Electrical drives for direct drive renewable energy systems. 2013.

Course 5 – Linear Control Systems		
Credits: 4	**Fall Semester**	**Compulsory: Yes**
Lectures: 18h	Tutorial: 4h	Lab: 8h
Professor: G. Lebret		
Objectives: The aim of the course is to give the basics of the analysis and controller synthesis of Linear Multivariable systems by a state space approach. Analysis will consider, time domain response, modal decomposition, controllability and observability. Controller synthesis will introduce state feedback, observers and state estimated feedback. The loop transfer recovery (LTR) technics will be detailed to give robust stability to the control laws.		
Assessment: Written exam and practical work report		
Recommended texts and further readings: - *"Linear Multivariable Control, A Geometric Approach",* W.M. Wonham. Springer Verlag, 1985 - *"Modern control systems"*, R.C. Dorf et R.H. Bishop, 12th. edition, Pearson Prentice Hall, 2011 - *"Control system design"*, G.C. Goodwin, S.F. Graebe and M.E. Salgado, Prentice Hall, 2001 - "Essential on Robust Control', K. Zhou, Prentice Hall, 1998		

Course 6 – Nonlinear Control Systems		
Credits: 4	**Fall Semester**	**Compulsory: Yes/No**
Lectures: 12h	Tutorial: 6h	Lab: 12h
Professor: Franck PLESTAN		
Objectives: The goal of this course is to give the basis of modern nonlinear control theory. Structural analysis (accessibility, observability) and control/estimation of nonlinear systems are considered. Many examples taken on renewable energy and power systems demonstrate the feasibility of the methodologies. After completing this course, the students will be able to: - understand the theoretical foundations on the control of nonlinear systems, - apply advanced nonlinear control on a variety of systems		
Assessment: Written exam and practical work report		
Recommended texts and further readings: G. Conte, et al., Algebraic Methods for Nonlinear Control Systems. Theory and Applications, Springer, 2006. A. Isidori, Nonlinear Control Systems. 2nd edition, Springer, 1989. Y. Shtessel et al., Sliding Mode Control and Observation, Birkhauser, 2014. H. Khalil, Nonlinear systems – 2nd edition, Prentice Hall, 1996.		

Course 7 – Wind Power Project		
Credits:	**Fall Semester**	**Compulsory: Yes/No**
Lectures:	Tutorial:	Lab: 32
Professor: M. Hamida		
Objectives: The objective is for students to carry out these projects using scientific research methodology: Several topics are proposed in the framework of projects on electric propulsion/traction and its control. Bibliographic research Development of a critical thinking skills Report writing		
Assessment: Written report and oral presentation		
Recommended texts and further readings:		

Syllabus of courses offered in University of Zagreb

Course 1 — Control and Grid Integration Techniques for Renewable Energy Sources		
Credits: 5	**Summer Semester**	**Compulsory: Yes**
Lectures: 30	Tutorial: 15	Lab: 12
Professors: Igor KUZLE, Mario VAŠAK, Ninoslav HOLJEVAC		

Objectives: Renewable energy sources are the main pillar of low-carbon energy systems of the future. However, their intermittance represents a disturbance on energy grids that needs to be counteracted with proper regulations and control. It also leads to often significant changes of operating regimes of renewable energy plants which is challenging for their control. The course sheds light on these key aspects and puts focus on wind and solar energy as the most exploited forms of renewable energy today. The objectives are as follows:

- Understand capacities for integration of renewable energy sources in electricity grids and their specifics.
- Get to know technical conditions for integration related to voltage and frequency, as well as fault-ride-through requirements.
- Understand the connection of individual wind turbines in a wind farm to the grid and grid conditions for wind farm connection.
- Understand the set-up and model of the inverter that enables the connection to the grid of a renewable energy source with internal direct current circuit.
- Adopt a classical vector control of the inverter, as well as the inverter output power control – active and reactive, and their interplay.
- Adopt the models of photovoltaic cells, modules and arrays.
- Know the basic structure of a photovoltaic plant.
- Understand control algorithms for the photovoltaic array maximum power point tracking.
- Adopt the full-scale grid inverter control for photovoltaic systems.
- Learn types of generators used in wind turbines, their corresponding generator converter control and the connection with grid-side inverter, including chopper brake.

Assessment: Written exam, Laboratory exercises, Oral exam

Recommended texts and further readings:

The notes of the course will be given by the lecturers.

Further readings:

R. Teodorescu and M. Liserre, Grid Converters for Photovoltaic and Wind Power Systems, John Wiley & Sons, 2011.

Course 2 — Predictive Control		
Credits: 5	**Summer Semester**	**Compulsory: Yes**
Lectures: 45	Tutorial: 0	Lab: 8
Professors: Mato BAOTIĆ, Branimir NOVOSELNIK		

Objectives:

Predictive control uses predictions of the controlled system evolution to decide on control actions that should be applied. Its applications are steadily rising especially for complex systems under constraints which are often incurred in renewables-based energy systems. It is based on mathematical optimization which requires a significant computational effort and specific implementations. The objectives are as follows:

- Understand optimality conditions and convex optimization.
- Use and implement linear quadratic regulators and trackers.
- Use receding horizon control and model predictive control algorithms with linear constraints.
- Apply predictive control with constraints in renewable energy systems.

Assessment: Written exam, Laboratory exercises, Oral exam

Recommended texts and further readings:

The notes of the course will be given by the lecturers.

Further readings:

F. Borrelli et al., Predictive Control for Linear and Hybrid Systems, Cambridge University Press, 2017.

J. B. Rawlings and D. Q. Mayne, Model Predictive Control, Nob Hill Pub, 2009.

S. P. Boyd and L. Vandenberghe, Convex Optimization, Cambridge University Press, 2004.

J. M. Maciejowski, Predictive Control, Pearson Education, 2002.

Course 3 — Estimation Theory		
Credits: 5	**Summer Semester**	**Compulsory: Yes**
Lectures: 45	Tutorial: 10	Lab: 12
Professors: Ivan PETROVIĆ, Mario VAŠAK, Ivan MARKOVIĆ		

Objectives:

Estimation theory deals with estimation of system states and parameters from noisy measurements. Methods covered in the course find applications in almost all disciplines and fields of science and technology. The objectives of the course are as follows:

- Introduce basic mathematical concepts in state estimation and system identification from probability theory and stochastic processes.
- Introduce Bayes method and elaborate linear estimation in static and dynamic systems with focus on basic Kalman filter, and then on Extended Kalman filter.
- Understand non-parametric and parametric identification methods for linear systems.

• Adopt the model structure selection and model validation procedures in identification, with understanding of bias-variance conflict in identification. • Consequently learn importance of grey-box models in which both physical knowledge and estimation of parameters based on data are combined.
Assessment: Written exam, Laboratory exercises, Oral exam
Recommended texts and further readings: The notes of the course will be given by the lecturers. Further readings: D. Simon, Optimal state estimation, John Wiley & Sons, 2006. L. Ljung, System Identification: Theory for the User, Prentice Hall, New Jersey, 1999.

Course 4 — Optimal Sizing and Operation of a Photovoltaic System with Storage		
Credits: 5	**Summer Semester**	**Compulsory: Yes**
Lectures: 30	Tutorial: 10	Lab: 10
Professors: Mario VAŠAK, Vinko LEŠIĆ		
Renewable energy systems are complex to size and operate due to their often inherent volatility in production stemming from varying environmental conditions. Their planning and operation needs to be an optimal compromise of costs and gains, which is not easy to assess in such dynamic conditions without a proper mathematical optimization support. The aim of the course is to show how mathematical optimization can be used to support planning the investment in a photovoltaic system combined with a battery storage system, jointly with deciding on the optimal operation policy of these systems. Focus is put on formulation of convex mathematical programs, foremost linear programs which can be used in a similar fashion also for a more general constellation of an energy hub. More in detail the objectives are: • Learn simple models of photovoltaic systems and battery storages that can be used in optimization based on energy balance laws, together with main determinants regarding the cost for the corresponding investment and system maintenance, including parts replacement after their lifetime expires. • Learn the main determinants for assessment of costs/gains for energy exchange with the electricity grid. • Formulate the models and energy exchange conditions in the form of an optimization criterion and constraints of a mathematical optimization problem for a specific location, characterized with full-year meteorological data, data on yearly profile of energy consumption existing for the location, and possible orientations in which the photovoltaic system can be placed.		
Assessment: Written exam, Laboratory exercises, Oral exam		
Recommended texts and further readings: The notes of the course will be given by the lecturer. Further readings:		

S. Boyd and L. Vandenberghe, Convex Optimization, Cambridge University Press, 2004. J. Twidell and T. Weir, Renewable Energy Resources, Routledge, 2021.

Course 5 — Energy-efficient Buildings Control		
Credits: 5	**Summer Semester**	**Compulsory: Yes**
Lectures: 19	Tutorial: 0	Lab: 12
Professors: Mario VAŠAK, Anita BANJAC		
Objectives: Energy consumption in the buildings sector amounts to 30% of overall energy consumed in the world, and thereby buildings consume about 50% of energy on ensuring proper climate conditions in them. Exactly for that reason buildings are a cornerstone of a future zero-carbon energy system: they must integrate a significant amount of renewable energy, foremost solar-based, efficiently consume energy to provide proper comfort and share responsibility in future energy systems regulation through demand response. Control in buildings, especially predictive control, becomes essential in achieving these goals. The objectives of the course are as follows: • Learn the grey-box modelling approaches for building indoor comfort control. • Understand the solar resource and its influence on the building indoor climate. • Use standard PID/hysteresis control techniques for maintaining indoor comfort. • Apply predictive control for energy-efficient indoor climate control and optimal coupling with building renewable energy sources in energy market participation and demand response provision.		
Assessment: Written exam, Laboratory exercises, Oral exam		
Recommended texts and further readings: The notes of the course will be given by the lecturer. Further readings: S. Boemi et al., Energy Performance of Buildings, Springer, 2016.		

Course 6 — Seminar on Control, Estimation and Optimization in Solar Energy		
Credits: 3	**Summer Semester**	**Compulsory: Yes**
Lectures: 0	Tutorial: 0	Lab: 0 (Project: estimated 60 h of student’s work; Presentation of own results: 20 min; Listening and discussing at presentations of other students: 3 h)
Professor: All lecturers		
Objectives:		

- Extend study on a specific topic within the area of control, estimation and optimization for solar energy systems, potentially also related to energy storages, grids and other types of renewable energy.
- Improve presentation and communication skills, as well as writing skills.
- Discuss selected topics with other students, teachers and industry/academia associates.
- Students will present, within small groups, latest concurrent developments in the area which they will back with practical examples elaborated by them.
- Each student will explore and present one of the topics agreed on with the selected supervisor.

Assessment: Written report on and presentation of the performed project

Recommended texts and further readings:

Will be provided to the student on case-by-case basis from the selected supervisor.

Course 7 — Croatian Language and Culture		
Credits: 2	**Summer Semester**	**Compulsory: Yes**
Lectures: 26	Tutorial: 0	Lab: 0

Professor: Darko MATOVAC, Ranka ĐURĐEVIĆ

Objectives: The students will learn basics of the Croatian language — they will learn how to communicate orally and in written in Croatian at the A1 level according to the Common European Framework of Reference for Languages. They will be also acquainted with the most important facts of the Croatian culture, with focus on contemporary culture and academic life. The goal of the course is:

- Increase students' European social perspectives and broaden their knowledge on Croatia.

Assessment: Written and oral exam

Recommended texts and further readings:

The notes of the course will be given by the lector.

Further readings:

D. Matovac, Basic Croatian Grammar, Croatian University Press, 2022.

S. L. Udier, Croatia at First Sight – Textbook of Croatian Culture. FF Press, 2016.

Syllabus of courses offered in Brandenburg University of Technology Cottbus-Senftenberg

Course Geothermal Energy		
Credits: 6	Fall Semester	Compulsory: No
Lectures: 2h per week	Tutorial: 2h per week	Lab: 0h
Professor: M. Ragwitz		
Objectives: The module provides an overview of geothermal technologies and their application for the generation of electricity, heating & cooling and for underground thermal energy storage. The students understand the geothermal heat source, properties of the subsurface and thermal transfer mechanisms. They apply knowledge to the basic design of local heat distribution systems, the integration of low temperature geothermal heat sources and ground-source heat pumps in the energy supply systems and the use of geothermal storage options for the balancing of seasonal heating&cooling demands with asynchronous supply and demand cycles as well as the basic economic considerations of geothermal energy generation and heat network integration.		
Assessment: Written examination (duration 60 minutes) 60 %, 2 Seminar works (creating presentation slides) including presentation (duration 15 minutes, presentation ca. 10 slides) 40 %		
Recommended texts and further readings: – R. di Pippo: Geothermal Power Plants Principles, Applications, Case Studies and Environmental Impact 4th Edition, Elsevier, 2015 – George L. Danko: Model Elements and Network Solutions of Heat, Mass and Momentum Transport Processes, Springer-Verlag GmbH. 2016.		

Course Hydrogen and Fuel Cells		
Credits: 6	Fall Semester	Compulsory: No
Lectures: 3h per week	Tutorial: 1h per week	Lab: 0h
Professor: L. Röntzsch		
Objectives: Students are introduced to the complete chain of hydrogen energy technology, covering hydrogen production, storage, distribution, and utilization. Each module of the course explores the physico-chemical principles underlying specific hydrogen technologies, provides a detailed description of the technology (including material selection and production aspects), and illustrates its applications through practical examples. The course also incorporates graded presentations or a graded laboratory course, enhancing hands-on learning and practical application of theoretical knowledge.		

Assessment: Written exam (80 min) (75 % of final grade), Graded presentation, ~20 min, or graded laboratory course, ~90 min (25 % of final grade)
Recommended texts and further readings: – Compendium of Hydrogen Energy, Volumes 1-4 (Woodhead, 2015). – Hydrogen - Its Technology and Implications, Volumes 1-5 (CRC Press, 2018). – Fuel Cells and Hydrogen Production (Springer Science, 2019). – Hydrogen Energy - Challenges and Solutions for a Cleaner Future (Springer, 2019). – Hydrogen Production Technologies (Wiley, 2017). – Handbook of Hydrogen Energy (CRC Press, 2014). – Hydrogen Safety (CRC Press, 2013).

Course Electrochemical and Chemical Energy Storage and Conversion		
Credits: 6	**Fall Semester**	**Compulsory: No**
Lectures: 2h per week	Tutorial: 2h per week	Lab: 0h
Professor: F. Mauß		
Objectives: The lecture deals with electrochemical and chemical processes which are important for renewable energy storage and conversion. The lecture incorporates recent research from the Energy Innovation Center of BTU Cottbus-Senftenberg. Students acquire in-depth knowledge of thermodynamic processes, the reaction mechanisms of electro-catalysis, turbulent combustion of fuels and measurement devices to characterize surface and gas phase reactions. They are familiar with the simulation of the teached processes. Students gain in-depth knowledge of the subject area and are able to make scientifically sound judgments.		
Assessment: Written examination, 90 minutes		
Recommended texts and further readings: – Teaching material		

Course Control of Power-to-X, Storage and X-to-Power Systems		
Credits: 6	**Fall Semester**	**Compulsory: No**
Lectures: 2h per week	Tutorial: 2h per week	Lab: 0h
Professor: J. Schiffer		
Objectives: On the completion of this module, students should be able to: • Model power-to-X, storage, and X-to-power systems from a control-oriented perspective. • Select a suitable control architecture and design controllers for such systems. • Characterize the behavior of the closed-loop system from the point of view of the plant owner as well as the grid operator.		
Assessment:		

Recommended texts and further readings:

Course Thermal Process Engineering and Equilibrium Thermodynamics		
Credits: 6	**Fall Semester**	**Compulsory: No**
Lectures: 2h per week	Tutorial: 2h per week	Lab: 0h
Professor: F. Mauß		
Objectives: The module provides knowledge about equilibrium thermodynamics and its important technical applications. Based on the fundamentals in thermodynamics of mixtures, the student will learn how to calculate phase equilibria of real multicomponent systems. Upon successful completion of this course, students will be able to calculate equilibrium processes as absorption and extraction. The apparatuses for this separation processes can be dimensioned.		
Assessment: Written examination, 90 minutes		
Recommended texts and further readings: – Coulson, John M.: Coulson & Richardson's chemical engineering volume 2. Butterworth-Heinemann, Oxford 2002. – Felder, Richard M.; Rousseau, Ronald: Elementary principles of chemical processes. Wiley, New York 2000. – Reid, Robert; Prausnitz, John; Pohling, Bruce: The properties of gases and liquids. McGraw Hill, New York 1987. – Seader, J. D.; Henley, E.J.: Separation Process Principles. Wiley-VCH, Chichester 2006. – Hillert, Mats: Phase equilibria, phase diagrams and phase transformations. Cambridge Univ. Press, Cambridge 2008.		

Course Advanced Methods in Process, Energy and Systems Engineering		
Credits: 6	**Fall Semester**	**Compulsory: No**
Lectures: 2h per week	Tutorial: 2h per week	Lab: 0h
Professor: H. Arellano-Garcia		
Objectives: The module requires a basic background in calculus and linear algebra, thus allowing easy understanding of mathematical reasoning. In addition, numerous examples in process, energy, environmental and systems engineering will demonstrate key concepts and algorithms. The practical exercises will involve theoretical derivations and small-size numerical problems in modelling systems like matlab, python, octave, GAMS thus putting knowledge into practice.		
Assessment: Written Examination (90 min)		
Recommended texts and further readings: – Advanced Optimization for Process Systems Engineering. Ignacio E. Grossmann, Cambridge University Press		

– Optimization for Chemical and Biochemical Engineering: Theory, Algorithms, Modeling and Applications. Vassilios S. Vassiliadis, Walter Kähm, Ehecatl Antonio del Rio Chanona, Cambridge University Press – Systematic Methods of Chemical Process Design. Lorenz T. Biegler, Ignacio E. Grossmann, Arthur W. Westerberg, Prentince Hall – Nonlinear Programming: Concepts, Algorithms, and Applications to Chemical Processes. Lorenz T. Biegler, SIAM, 2010

Course Optimisation in Process and Energy Systems Engineering		
Credits: 6	**Fall Semester**	**Compulsory: No**
Lectures: 2h per week	Tutorial: 1h per week	Lab: 0h
Professor: H. Arellano-Garcia		
Objectives: After participating in this module, the students master the basic knowledge, in terms of mathematical optimization methods and tools. Relevant examples from Energy and Process Engineering are used to enhance the understanding of the various tools and methods taught. The focus is on the formulation of the problems and the approaches for their mathematical solution. The methods covered are applied in accompanying calculation exercises.		
Assessment: Written examination (90 min)		
Recommended texts and further readings: – T. F. Edgar, D. M. Himmelblau, Optimization of Chemical Processes, McGraw-Hill, New York, 2001 – L. T. Biegler, I. E. Grossmann, A. W. Westerberg, Systematic Methods of Chemical Process Design, Prentice Hall, New Jersey, 1997 – C. A. Floudas, Nonlinear and Mixed-Integer Optimization, Oxford University Press, 1995 – J. Nocedal, S. J. Wright, Numerical Optimization, Springer, 2006 – R. Baldick, Applied Optimization, Formulation and Algorithms for Engineering Systems, Cambridge University Press, 2006		