ENGINEERING PROGRAMME

2024-2025

Year 2 / Year 3

Specialisation option

Renewable Energies and Grid Integration

OD ENRRES

PROGRAMME SUPERVISOR
Boris CONAN

Autumn Semester

Course unit	ECTS Credits	Track	Course code	Title
UE 73	12	Core course	COSEL ENTRE EOLE1 EOLE2	Control of electrical machines Major challenges of energy transition Wind energy I Wind energy II
UE 74	13	Core course	COREL FOREL PRAO1 SDSE SOLAR_ENRRES	Power grid control Power grid operation Project Call for tender response 1 Digital Environments for the energy sector Solar energy

Spring Semester

Course unit	ECTS Credits	Track	Course code	Title
UE 83	2	Core course	EMERG ESERE HYDRO PRAO2 SMART	Emerging technologies Socio-economic, regulatory and environmental issues Hydropower Project Call for tender response 2 Smart grids for renewable energy

Control of electrical machines [COSEL]

LEAD PROFESSOR(S): Malek GHANES

Requirements

Objectives

After completing the course, the candidate should acquire the following in-depth knowledge and understanding:

- Electrical quantities: single-phase and three-phase voltages, currents and powers
- Power electronics
- Photovoltaic (PV) systems with storage, Control issues
- Electrical machines, Control issues
- Wind power systems, Control issues

Course contents

I. Single-phase and three-phase voltages, currents and powers

II. Power electronics
  1. Overview
  2. Choppers (part III)
  3. Inverters (parts III and IV)
  4. Rectifiers (part IV)

III. stand-alone PV system
 1. PV: photovoltaic cell, module, field
 2. Battery
 3. Controller
  3.1 On/Off controller
  3.1 PWM controller (with chopper)
  3.2. MPPT controller (with chopper)
 4. Inverter

IV. Electrical machines and their control

V. Control of wind energy systems

- Tutorial on parts I, II, III and IV
- Practical exercises on Part III
- Exam

Course material

Fekik, A., Ghanes, M., Denoun, H., (2023). Power Electronics Converters and their Control for Renewable Energy Applications, Elsevier, 1st Edition-June 1. https://doi.org/10.1016/C2020-0-04639-6

Assessment

Collective assessment: EVC 1 (coefficient 0.5)

Individual assessment: EVI 1 (coefficient 0.5)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	18 hrs	4 hrs	8 hrs	0 hrs	2 hrs

ENGINEERING - OD ENRRES

Year 2 / Year 3 - Autumn Semester - Course Unit 73 / 93

Major challenges of energy transition [ENTRE]

LEAD PROFESSOR(S): Jean-Marc BEN GUIGUI

Requirements

Objectives

- Analyze and critique different energy transition scenarios
- Evaluate the material needs, as well as their possible criticality, for the main renewable energies (wind, solar, hydraulic), and consider the end of life of the means of production
- Understand the phenomena, mechanisms and interactions between energy and ecological issues to successfully reduce environmental impact
- Acquire methods to design, evaluate and pilot renewable energy production systems

Course contents

Part 1: Energy mix and the part played by renewable energies in energy transition
- The importance of renewable energies,
- Consistency with climate change mitigation (IPCC SSP),
- Possible interactions with other planetary thresholds,
- The methods of scenario development (role of experts, citizens, lobbies, etc.).
- Studies of the different possible scenarios: A. Lovins ("Reinventing fire"), Négawatt, RTE, ADEME, WWS, etc.

Part 2: Material intensity of renewable energies, criticality of materials, end of life of means of production
- Families of materials for renewable energy, properties & recyclability.
- Material intensity of renewable energies (quantities of materials needed to produce energy) and end of life of renewable energy production systems.
- Resources and criticality of materials for renewable energy.
- Analysis of the "materials" aspect of different energy transition scenarios.

Part 3: Methods and tools for the design, evaluation and management of renewable energy production systems
- Finiteness of resources and planetary limits
- Return on energy investment
- Sobriety, energy efficiency and renewable energies
- Methods and tools for the design, evaluation and management of renewable energy production systems
- Accounting for greenhouse gas (GHG) emissions
- Life cycle analysis (LCA): From the extraction of raw materials to the end of life
- Case studies on the environmental assessment of renewable energy production systems

Course material

Bihouix, P., & De Guillebon, B. (2020). Quel futur pour les métaux? EDP sciences.
Boutaud, A., & Gondran, N. (2020). Les limites planétaires. La Découverte.
Fizaine, F. (2015). Les métaux rares : opportunité ou menace ? Enjeux et perspectives associés à la transition énergétique. Editions Technip.
IEA (2021), The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions
Jancovici, J. M. (2013). Transition énergétique pour tous: ce que les politiques n'osent pas vous dire. Odile Jacob.
Jancovici, J. M (2004). L'avenir climatique-Quel temps ferons-nous. Editions du Seuil, 285 p.
Jolliet, O., Saadé, M., & Crettaz, P. (2010). Analyse du cycle de vie: comprendre et réaliser un écobilan (Vol. 23). PPUR Presses polytechniques.

Jedliczka, M., Marignac, Y., Salomon, T. (2015). Manifeste NégaWatt: En route pour la transition énergétique !. France: Babel.
Pitron, G. (2018). La guerre des métaux rares: la face cachée de la transition énergétique et numérique. Éditions Les liens qui libèrent.
Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., ... & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. Science, 347(6223).
Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. S., Lambin, E., ... & Foley, J. (2009). Planetary boundaries: exploring the safe operating space for humanity. Ecology and society, 14(2).
Vidal O. (2018). Matières premières et énergie : les enjeux de demain. ISTE Group.

Assessment

Collective assessment: EVC 1 (coefficient 0.4)
EVC 2 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	16 hrs	0 hrs	0 hrs	0 hrs

Wind energy I [EOLE1]

LEAD PROFESSOR(S): Boris CONAN

Requirements

Objectives

To know the current deployment of onshore and offshore wind energy, and the challenges of future deployments
Acquire a good understanding of the operation of wind turbines
Acquire a basic understanding of atmospheric physics in order to understand and estimate the wind resource and its specificities
Estimate the performance of wind turbines and the wake effects in wind farms
Acquire and use the concepts of airfoil and rotor aerodynamics

Course contents

- The main figures of wind energy, the potential of implantation and installed wind energy capacity in the world and in Europe, the main development issues
- The components of a standard wind turbine and the general principles of operation (rotor, transmission chain, generator)
- Basics of meteorology and the atmospheric boundary layer: global meteorological mechanisms, characteristics and physics of the atmospheric boundary layer, wind resource.
- Electricity production and park effects
- Airfoil aerodynamics, theories and models
- Rotor aerodynamics, theories and models

Numerical exercises accompany this programme to learn how to analyse tmospheric data, estimate wind turbine output, estimate wind farm effect losses and study the performances and aerodynamic loads acting on a horizontal axis wind turbine.

Course material

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

Assessment

Collective assessment: EVC 1 (coefficient 0.5)

Individual assessment: EVI 1 (coefficient 0.5)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	4 hrs	10 hrs	0 hrs	2 hrs

Wind energy II [EOLE2]

LEAD PROFESSOR(S): Laurent STAINIER

Requirements

Basics of continuum mechanics (linear elasticity)

Objectives

- Understand mechanical challenges in the design and operation of wind turbines
- Acquire a basic understanding of structural dynamics, and in particular slender structures such as (Horizontal Axis) Wind Turbines
- Understand the fundamentals of interactions between structural vibrations and aerodynamic flow, and their consequences on wind turbine design

Course contents

- Bases of structural mechanics: beam theory, numerical models based on finite elements (4h CM, 4h TD)
- Structural dynamics and vibrations: eigenmodes and eigenfrequencies, modal analysis, specificities of rotating systems (4h CM, 4h TD, 4h TP)
- Introduction to aero-mechanical coupling: notions of divergence and flutter illustrated on the typical section simplified model, equations for the coupled system, solution methods (4h CM, 2h TD, 4h TP)

Practical work will consist of numerical exercises on simplified wind turbine models.

Course material

- Énergie éolienne, 2019 (3ème éd.), Dunod.
- Wind Energy Explained, Theory Design and Application, 2009 (2nd edition), Wiley.
- Advances in Wind Turbine Blade Design and Materials, 2013, Woodhead Publishing.
- A Modern Course in Aeroelasticity, 2022 (6th edition), Springer.

Assessment

Collective assessment: EVC 1 (coefficient 0.5)

Individual assessment: EVI 1 (coefficient 0.5)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	6 hrs	8 hrs	0 hrs	2 hrs

Power grid control [COREL]

LEAD PROFESSOR(S): Bogdan MARINESCU

Requirements

Objectives

- Know how to analyse stability and structural properties of a large-scale power system
- Acquire bases for robust control for different grid objectives (control of generators, damping of grid power oscillations, ...)

Course contents

- Performances & robustness of large-scale systems ; loop-shaping and basic principles
- Multi-input/multi output systems o State-space form & DAE representations
  Structural properties & model reduction
- Robust control techniques
  o Methodologies (internal model principle, H2/H infinity, ...)
  o Power systems study cases: control for mixed local and grid objectives

Course material

- T. Kailath, Linear Systems, Prentice-Hall, 1980.
- J. Doyle, B. Francis, A. Tannenbaum, Feedback Control Theory, MacMillan 1990. www.ebooksdirectory.com
- Ph. de Larminat, Automatique, 2ème éd. Hermès, 1996.
- H. Bourlès, Systèmes linéaires – de la modélisation à la commande, Hermès, 2006.
- M. Ilic, J. Zaborsky, Dynamics and Controls of Large Electric Power Systems, Willey 2000.

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	6 hrs	8 hrs	0 hrs	2 hrs

ENGINEERING - OD ENRRES

Year 2 / Year 3 - Autumn Semester - Course Unit 74 / 94

Power grid operation [FOREL]

LEAD PROFESSOR(S): Vinu THOMAS

Requirements

Objectives

Acquire the bases of the dynamic operation of power grids. After completing this module, students will be able to:
- Understand and analyze the main dynamic phenomena of interconnected power systems
- Know the basic and classic regulations of power grids
- Use grid dedicated simulation softwares
- knowledge of the electricity sector (fields of activity of companies like RTE, EDF or equipment manufacturer such as, for example, Alstom, Siemens, ABB)

Course contents

- Electricity production and grid management (general notions)
- Load flow
- Basic dynamics (frequency/voltage) of a power grid; generation/consumption balance
- Stability (voltage, frequency/transient, small-signal/oscillatory)
- Primary/secondary/tertiary regulations;
- Voltage & frequency system services
- Zoom on the French and European grids

Course material

P. Kundur, Power System Stability and Control, McGraw-Hill, 1994.
G. Rogers, Power System Oscillations, Kluwer Academic, 2000.
M. Ilic, J. Zaborsky, Dynamics and Control of Large Electric Power Systems, Wiley, 2000.
P.W. Sauer, M.A. Pai, Power Systems Dynamics and Stability, Prentice Hall, 1998.
J. Cladé, Electrotechnique, Eyrolles, 1989.

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
English	3	16 hrs	6 hrs	8 hrs	0 hrs	2 hrs

Project Call for tender response 1 [PRAO1]

LEAD PROFESSOR(S): Sandrine AUBRUN

Requirements

Main skills provided by the disciplinary option ENRRES

Objectives

The simulation aims to experiment, using methods similar to a serious game, with the steps and activities carried out by a developer of electricity or heat production projects during the phases of responding to a bid for tenders (technical, managerial and commercial activities). In addition to the knowledge acquired during the ENR-RES education program, this simulation should enable students to reinforce/use a certain number of cross-cutting skills essential to this type of function: being autonomous; listening, arguing one's choices and negotiating; finding information and prioritising it; cutting up, distributing and carrying out tasks; organising one's working time; developing one's analytical and synthesising spirit.
The construction of the bid for tenders is entrusted to a player in the energy sector. He builds a relevant tender that responds to current challenges. He will be responsible for evaluating the technical, managerial and commercial performance of the competing groups throughout the project. It will surround itself with energy actors to lead the different stages of the simulation and ensure that the final evaluation is based on professionally relevant criteria.

Course contents

Discovering the bid for tenders
First attempt to define the technical offer, associated business model
Meeting with stakeholders to refine the response to the tender

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	1	0 hrs	0 hrs	0 hrs	32 hrs	0 hrs

Digital Environments for the energy sector [SDSE]

LEAD PROFESSOR(S): Bertrand MICHEL

Requirements

Objectives

- Understanding of the basic concepts of data mining
- Understanding the basic concepts of statistical learning
- Practice using standard Python libraries
- Application to case studies in the energy field

Course contents

- Basics of Python language
- Concepts of statistics and visualization of data
- Introduction to statistical learning
- Basic methods for classification
- CART et random forests
- Predictive methods in the field of energy

Course material

- The Elements of Statistical Learning, Data Mining, Inference, and Prediction. Trevor Hastie, Robert Tibshirani, Jerome Friedman, 2009 Springer.
- Hands-On Machine Learning with Scikit-Learn and TensorFlow by Aurelien Geron, O'Reilly 2017.

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	0 hrs	16 hrs	0 hrs	0 hrs

Solar energy [SOLAR_ENRRES]

LEAD PROFESSOR(S): Pierre MARTY

Requirements

Objectives

To understand and master the detailed concepts of solar collection and all solar energy conversion systems. Students will be expected to master the fundamental equations and large orders of magnitude, to be able to perform "corner of the table" calculations to quickly analyze a solution while developing a sharp critical sense.

Course contents

1 - Solar radiation
2 - Thermal solar
3 - Concentrated solar power
4 - Passive solar
5 - Photovoltaic solar

Course material

J. Bernard, Energie Solaire Calculs & Optimisation Génie Energétique Niveau B, 2e édition. Paris: Ellipses Marketing, 2011.
J.-P. Oliva et S. Courgey, La conception bioclimatique: Des maisons économes et confortables en neuf et en réhabilitation. terre vivante, 2006.
« Le capteur solaire à eau chaude », Energie+. https://www.energieplus-lesite.be/index.php?id=16760 (consulté le janv. 24, 2019).
Syndicat des énergies renouvelables, « Principe de fonctionnement du solaire thermodynamique », 2012.
W. Weiss et M. Spörk-Dür, « Solar Heat Worldwide », IEA Solar Heating & Cooling Programme, 2020. Consulté le: oct. 13, 2020. [En ligne]. Disponible sur: https://www.iea-shc.org/solar-heat-worldwide.

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	20 hrs	10 hrs	0 hrs	0 hrs	2 hrs

Emerging technologies [EMERG]

LEAD PROFESSOR(S): Ernesto MURA

Requirements

Objectives

The objective of this course is to present an overview of different emerging technologies in the context of renewable energies, their management, transport and storage.

Course contents

The course is divided into 4 main parts:
- Part 1: biomass: fundamentals of biomass combustion, industrial applications, control of pollutant emissions
- Part 2: geo energy: principle, presentation of different technologies, industrial applications
- Part 3: energy storage and transport (excluding electrical energy): heating networks, hydrogen sector, synthetic fuels, power-to-X
- Part 4: thermodynamic energy storage: presentation of the different technologies and their characteristics (energy density, efficiency), case studies

Course material

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	15 hrs	15 hrs	0 hrs	0 hrs	2 hrs

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Year 2 / Year 3 - Spring Semester - Course Unit 103 / 83

Socio-economic, regulatory and environmental issues [ESERE]

LEAD PROFESSOR(S): Boris CONAN

Requirements

Objectives

- To know the legal tools available to the developer of a renewable energy electricity production project
- To master the local avoidance, reduction, compensation and support measures related to the implementation of a renewable energy project on a territory.
- Understand the functioning of the energy market
- Acquire skills in the scenarisation of the French electricity mix
- Identify and analyse different past, present and future economic models in several renewable energy sectors (wind, solar, biomass, hydrogen) and their uses
- Understand the environmental and societal impacts of the development of renewable energies.

Course contents

- Regulation of the energy sector
- Functioning of energy markets
- Economic models and project financing
- Environmental and societal impacts of renewable energy

Course material

- JP Hansen, J Percebois, Energie : Economie et politiques, 2010, Ed. De Boeck
- S Méritet, JB Vaujour, Economie de l'énergie, 2015, Ed. Dunod.
- DR. Biggar, MR Hesamzadeh, The Economics of Electricity Markets, 2014, Wiley IEEE.
- Lepercq, T. (2019), Hydrogène le nouveau pétrole, Ed. Le Cherche-Midi
- Grandidier J.Y., Luneau, Y. (2017), Le vent nous portera
- Alexander Osterwalder et Yves Pigneur (2010),
- Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers
- 100 % d'énergies renouvelables d'ici 2050, rapport WWF-Ecofys (2011)
- Livre blanc des energies renouvelables par le syndicat de Energies Renouvelables https://www.energies-renouvelablesfr.com/attachment/359715/

Assessment

Collective assessment: EVC 1 (coefficient 0.5)

Individual assessment: EVI 1 (coefficient 0.5)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	15 hrs	0 hrs	0 hrs	1 hrs

Hydropower [HYDRO]

LEAD PROFESSOR(S): Alban LEROYER

Requirements

Objectives

Understand hydro-electric installations as a whole and master the underlying scientific and technological bases.

Course contents

- Key figures in hydraulics, How hydraulic systems work

- Free surface hydraulics:
  o Flow characteristics
  o Permanent uniform flow
  o Non-uniform and permanent flow
  o Barré St Venant equations

- Hydraulic Machines
  o General information on the application sectors of Hydraulics and classification of hydraulic machines (roto-dynamic and volumetric)
  o Technology of roto-dynamic machines

- Design of dam

-Design of a small hydro-electric system

Course material

Hydrodynamics of Pumps, C.E. Brennen, Oxford University Press

Techniques de l'ingénieur, B470 -> B474, B4313, BM4281, B4300, B4302, B4304 , B4306, B4308

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	20 hrs	6 hrs	4 hrs	0 hrs	2 hrs

Project Call for tender response 2 [PRAO2]

LEAD PROFESSOR(S): Sandrine AUBRUN

Requirements

Main skills of the disciplinary option ENRRES

Objectives

The simulation aims to experiment, using methods similar to a serious game, with the steps and activities carried out by a developer of electricity or heat production projects during the phases of responding to a bid for tenders (technical, managerial and commercial activities). In addition to the knowledge acquired during the ENR-RES education program, this simulation should enable students to reinforce/use a certain number of cross-cutting skills essential to this type of function: being autonomous; listening, arguing one's choices and negotiating; finding information and prioritising it; cutting up, distributing and carrying out tasks; organising one's working time; developing one's analytical and synthesising spirit.
The construction of the bid for tenders is entrusted to a player in the energy sector. He builds a relevant tender that responds to current challenges. He will be responsible for evaluating the technical, managerial and commercial performance of the competing groups throughout the project. It will surround itself with energy actors to lead the different stages of the simulation and ensure that the final evaluation is based on professionally relevant criteria.

Course contents

Drawing up the response to the bid for tenders
Finalisation of the proposed technical solutions and the associated business model
Response to the call for tenders with a report + oral presentation to stakeholders

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	2	0 hrs	0 hrs	0 hrs	48 hrs	0 hrs

Smart grids for renewable energy [SMART]

LEAD PROFESSOR(S): Bogdan MARINESCU

Requirements

Objectives

The objective of this course is to raise awareness of the operation of power electronic converters, (both hardware and control), to understand the impact of such converters on the grid today and how they can help stabilising it, but also to look into the future grid to understand the limitations of present controls, and to define what new controls that will prevent the share of renewable energy into the grid to be limited.

Course contents

- introduction to power electronics from components (IGBT and other technos) to their topologies (2 levels, 2 levels with neutral point, MMC...)
- control of voltage source inverters (PWM, vector, filtering)
- Reminder of the network operation. (active / reactive power, flow and voltage constraints)
- Grid-following control for converters, under which objectives?
- Legacy ancillary services for the network (voltage control, frequency control)
- RTE's role in connections, European grid codes, HVDC connection, renewable and synchronous machines
- the implementation of ancillary services in grid-following control.
- specific Ancillary services for renewable (cf new European codes RfG/HVDC, LFSM, reactive current injection, virtual inertia) and their implementation
- the limitations of grid-following control, and grid-forming control
- the state of the art of grid-forming, grid needs and challenges in future developments.

Course material

A.Monti, F. Milano, E. Bomprad, X. Guillaud, Converter-based Dynamics and Control of Modern Power Systems, Academic Press 2020.

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	20 hrs	6 hrs	4 hrs	0 hrs	2 hrs