Course guide
295321 - 295SE011 - Modelling and Real-Time Control in Energy Systems

Last modified: 13/06/2025

Unit in charge: Barcelona East School of Engineering
Teaching unit: 710 - EEL - Department of Electronic Engineering.

Degree: MASTER'S DEGREE IN TECHNOLOGIES FOR DISTRIBUTED ENERGY SYSTEMS (Syllabus 2025). (Compulsory subject).

Academic year: 2025 **ECTS Credits:** 6.0 **Languages:** Catalan, Spanish, English

LECTURER

Coordinating lecturer: ROBERT PIQUÉ LÓPEZ

Others: SERGIO GIRALDO MUÑOZ
XAVIER ROSET I JUAN

PRIOR SKILLS

Those necessary depending on the origin of the incoming students.

LEARNING RESULTS

Knowledges:
K4. Identify methods for studying the environmental impact of a distributed electricity system with renewable sources and relate it to the decarbonisation of energy generation.
K1. Identify renewable resources as sources of electrical energy.
K2. Identify the structural and functional particularities and applicable regulations of decentralised electrical systems.

Skills:
S1. Analyse, design and evaluate the reliability and life cycle of decentralised electrical systems based on renewable energy sources. Assess the reliability and life cycle of a distributed system for energy generation from renewable resources.
S3. Assess the impact and needs of new electricity consumption models and relate them to the change in energy model resulting from the decarbonisation of energy sources.
S2. Analyse the electronic subsystems required in a renewable energy plant and evaluate automation and control technologies for energy management of smart electrical grids and microgrids in a decentralised energy system.

Competences:
C3. Develop the ability to evaluate inequalities based on sex and gender to design solutions that resolve them.
C1. Integrate the values of sustainability and understand the complexity of systems, with the aim of undertaking or promoting actions that restore and maintain the health of ecosystems and improve justice, thereby generating visions of sustainable futures.
C2. Identify and analyse problems that require making autonomous, informed and reasoned decisions in order to act with social responsibility following ethical values and principles.

TEACHING METHODOLOGY

AF.1.- Presentation of theoretical content.
AF.2.- Solving exercises, problems, and cases.
AF.3.- Practical work sessions in the laboratory.
AF.4.- Discussion of problems or scientific articles.
AF.5.- Participation in seminars and conferences.
AF.6.- Individual and collaborative work.
AF.7. Sessions in computer or simulation laboratories.

LEARNING OBJECTIVES OF THE SUBJECT

By taking the MCSE-296SE011 course (Real-Time Modeling and Control of Energy Systems), the student will acquire skills related towards knowledge, analysis, design, operation and maintenance oriented towards real-time control of distributed energy systems, based on current methodologies and procedures, and with an emphasis on renewable distributed energy systems, paying special attention to electrical microgrid configurations (smart microgrids).

STUDY LOAD

Type	Hours	Percentage
Hours small group	28,0	18.67
Hours large group	28,0	18.67
Self study	94,0	62.67

Total learning time: 150 h

CONTENTS

1.- INTRODUCTION TO MODELING AND CONTROL OF ENERGY SYSTEMS

Description:
Review of basic concepts required for the subject and description of generic methodologies for modeling and simulating energy systems.

Specific objectives:
Power. Energy. Energy Transfer. Oriented Paths. Power/Energy Flows. Energy System Concept. Functional and Structural Descriptions.
Modeling and Simulation Overview. Causal Modeling/Simulation. Acausal Modeling/Simulation. Examples: PSIM, Simulink, Modelica.

Related activities:
Laboratory practice on basic methodologies for functional and structural, causal and acausal modeling and simulation of energy systems.

Full-or-part-time: 18h
Theory classes: 4h
Practical classes: 4h
Self study : 10h

2.- ELECTRICAL POWER MICROGRIDS. ENERGY MANAGEMENT SYSTEMS

Description:
Basic concepts on electrical microgrids and their energy management systems: essential tools for the European Union's energy and mobility transitions by 2040.

Specific objectives:
EU H2040 Transitions. Microgrid Concept. Building Blocks. Microgrid Types. Connections. Operating Modes. States.
Energy Characterization of Microgrids. Graphs Associated with a Microgrid. Matrices Specific to Graphs. Power (Energy) and Flow Vectors. Basic Vector and Matrix Equations.
Three-Level Energy Management Systems. Structural Characterization. Functional Characterization.

Related activities:
Visit to the EPIC group's photovoltaic facilities.
Study and testing of hybrid inverter-based microgrids at the E3PACS laboratory. Part 1: Structural Aspects (Blogs, Auxiliary Instrumentation, Switching and Protection Elements).

Full-or-part-time: 13h
Theory classes: 4h
Practical classes: 4h
Self study : 5h

3.- GENERALIZED REAL-TIME MODELING AND CONTROL OF STATIC POWER CONVERTERS

Description:
Basic concepts and systematics for the modeling and real-time control of static converters used in energy systems.

Specific objectives:
Switches. Static and Dynamic Characteristics. Ideal Switches. Modulated or Switched Quantities.
Switching Function. Switching Matrix. Connection Function. Connection Matrix.
Internal and External Control of Switches. Dynamic Functional Representation. States and Transitions. Typical Switches. Power Transfer Rules.
Switching Cells. Modulation (or Conversion) Functions. Instantaneous Modeling. Typical Examples for Static Converters in Distributed Electrical Systems.

Related activities:
Study Cases

Full-or-part-time: 20h
Theory classes: 4h
Practical classes: 4h
Self study : 12h

4.- INTRODUCTION TO REAL-TIME CONTROL OF ENERGY SYSTEMS

Description:
Concepts and requirements for real-time control of energetic systems.

Specific objectives:
Energy Processing and Information Processing.
Principles of Interaction, Holism, and Physical Causality. Static, Quasi-static, and Dynamic Modeling.
Building Blocks of Energy Systems: Sources, Converters, Accumulators, and Distributors.
Real-Time Control of Energy Systems.
PIL (Processor-in-the-Loop) Approximation. HIL (Hardware-in-the-Loop) Approximation.

Related activities:
Study and testing of hybrid inverter-based microgrids at the E3PACS laboratory. Part 2: Functional Aspects (Operating Modes and Functional Modes, States, Energy Management System).

Full-or-part-time: 20h
Theory classes: 4h
Practical classes: 6h
Self study : 10h

5.- ENERGETIC MACROSCOPIC REPRESENTATION AND INVERSION-BASED CONTROL

Description:
Energetic Macroscopic Representation (EMR) and Inversion-Based Control (IBC) allow a systematic procedure for the implementation of models and strategies for the real-time control of energy systems.

Specific objectives:
Energetic Macroscopic Representation (EMR). Systems, Subsystems, and Blogs. Gates and Links. REM Formalism. Principles. Action and Reaction. Paths of Action and Reaction Variables. Blogs (Sources, Converters, Accumulators, and Distributors). Adaptation to Real-Time Control of Energy Systems. Blog Modeling Examples.
Inversion-Based Control (IBC). Basic Principle. Tuning Paths. Control Paths. Maximum Inversion Control. Controllers. Sensors/Gatherers. Estimators. Inversion Rules for REM Blocks. Direct Inversion Controllers with and without Disturbance Absorption. Indirect Inversion Controllers with and without Disturbance Absorption. Strategies. HIL Emulation/Simulation under the REM Formalism.
Application Examples.

Related activities:
Examples of EMR+CBI system application.
Introduction to Hardware-in-the-Loop with Typhoon HIL (C) equipment and software.
Includes a training seminar and access to and use of Typhoon HIL Academy resources.

Full-or-part-time: 50h
Theory classes: 10h
Practical classes: 10h
Self study : 30h

6.- PROJECT IN SMALL GROUPS

Description:
Solving a "PBL" project in informal collaborative groups.

Specific objectives:
Each informal collaborative group will solve a specific case of real-time modeling and control of an energy system.

Full-or-part-time: 29h
Theory classes: 2h
Practical classes: 4h
Guided activities: 8h
Self study : 15h

GRADING SYSTEM

The components of the grading polynomial are the Individual Written Exam (EE), Lab and Laboratory Work (PR), Proposed Exercises (EP), and the Resolution of a Specific Case in an Informal Group (TG), with the following weights applied:

Individual Written Exam Grade (EE): 30%
Lab and Laboratory Work Grade (PR): 30%
Proposed Exercises Grade (EP): 20%
Group Work Grade (TG): 20%

Thus, the final grade for the course is given by: N_Course = 0.3 EE + 0.3 PR + 0.20 EP + 0.20 TG

In addition to the scheduled tests indicated above, unscheduled supplementary tests may be administered during class time and without prior notice, such as formative assessment (theory, exercises), problem-solving, improvement of assessment results, etc., which may increase the grades for these scheduled tests. Initially.

According to academic regulations:

This course is considered a continuous assessment course and, therefore, does not have a "final" exam in the traditional sense.

It is not subject to re-assessment.

Completion of practical activities (laboratory work, report writing, and, where applicable, prior preparation for the practicals) is a necessary condition for passing the course. If the practicals are not completed, the final grade for the course will be Fail 3.5.

EXAMINATION RULES.

It is mandatoryto bring, and where appropriate, show, a valid personal identification document (DNI, passport, or student ID).

Online tests, where applicable, will be governed by the regulations that govern them.

In accordance with section 3.1.3 of the Academic Regulations for Undergraduate and Master's Degree Studies at the UPC, completion of laboratory exercises is mandatory to obtain a pass in the course.

OTHER

[Plagiarism / Fraud] Irregular actions that may lead to a significant variation in the grade of one or more students constitute fraudulent performance of an assessment. This action entails a descriptive grade of fail and a numerical grade of 0 for the assessment and the course, without prejudice to any disciplinary proceedings that may arise as a result of the acts committed. (Academic Regulations for Undergraduate and Master's Degrees at the UPC. (Section 3.1.2.)

[UPC Code of Ethics] (Agreement CG/2022/02/30 of the Governing Council, section 4.2) Students, ..., must make efficient and responsible use of all the resources that the University makes available to them, whether tangible or intangible. Therefore, they must not only strive to achieve the highest level of knowledge, but must also pay special attention to the public nature of the resources that society invests in their education. They must maintain a participatory attitude in all training activities, facilitate the work of the teaching staff, and actively participate in the teaching staff evaluation processes. They must also value their personal effort in all actions, demonstrate their honesty and integrity in evaluation processes, and promote these attitudes among their fellow students.

BIBLIOGRAPHY

Basic:
- Systemic design methodologies for electrical energy systems : analysis, synthesis and management. Hoboken, N. J: John Wiley and Sons Inc, 2012. ISBN 9781118569863.
- Sechilariu, Manuela; Locment, Fabrice. Urban DC microgrid : intelligent control and power flow optimization. Amsterdam: Butterworth-Heinemann, 2016. ISBN 9780128037362.
- Rekioua, Djamila; Matagne, Ernest. Optimization of photovoltaic power systems : modelization, simulation and control [on line]. London: Springer, 2012 [Consultation: 12/09/2025]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/978-1-4471-2403-0. ISBN 9786613574985.
- Energy management of distributed generation systems. Rijeka: InTech, 2016. ISBN 9789535124733.
- Distributed energy systems : design, modeling, and control. First edition. Boca Raton (Florida): CRC Press, 2023. ISBN 9781032134253.
- Power electronics in smart electrical energy networks [on line]. London: Springer, 2008 [Consultation: 12/09/2025]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/978-1-84800-318-7. ISBN 9781848003170.
- Bollen, Math H. J.; Hassan, Fainan. Integration of distributed generation in the power system [on line]. Hoboken, New Jersey: Wiley-Blackwell, 2011 [Consultation: 12/09/2025]. Available on: https://onlinelibrary-wiley-com.recursos.biblioteca.upc.edu/doi/book/10.1002/9781118029039. ISBN 9781118029039.

Complementary:
- Bevrani, Hassan; François, Bruno; Ise, Toshifume. Microgrid dynamics and control. Hoboken, New Jersey: Wiley, 2017. ISBN 9781119263708.
- Fritzson, Peter. Principles of object-oriented modeling and simulation with modelica 3. 3 : A cyber-physical approach. New Edition (2nd & subsequent). Hoboken, USA: Wiley, 2015. ISBN 9781118858974.
- Hautier, Jean-Paul; Caron, Jean-Pierre. Convertisseurs statiques. Méthodologie causale de modélisation et de commande. Editions Technip, 1998. ISBN 9782710807452.
- Ghosh, Arindam; Zare, Firuz. Control of power electronic converters with microgrid applications. Hoboken, New Jersey: John Wiley & Sons, Inc, 2023. ISBN 9781119815464.
- Kals, Johannes. ISO 50001 energy management systems : what managers need to know about energy and business administration. New York: Business Expert Press, 2015. ISBN 9781631570094.
- Rigatos, Gerasimos. Intelligent renewable energy systems : modelling and control [on line]. Cham: Springer International Publishing, 2016 [Consultation: 12/09/2025]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/978-3-319-39156-4. ISBN 3319391569.
- Modeling, identification and control methods in renewable energy systems [on line]. Singapore: Springer Singapore, 2019 [Consultation: 12/09/2025]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/978-981-13-1945-7. ISBN 9811319456.

- Keyhani, Ali; Marwali, Mohammad N.; Dai, Min. Integration of green and renewable energy in electric power systems. Hoboken, NJ: Wiley, 2010. ISBN 9780470187760.