

## GENERAL INFORMATION

Course information	
Name	Electric Power Systems
Code	MEPI-512
Degree	Official Master's Degree in the Electric Power Industry (MEPI)
Year	1 <sup>st</sup>
Semester	Fall
ECTS credits	6 ECTS
Type	Compulsory
Department	Electrical Engineering
Area	Power Systems
Coordinator	Luis Rouco Rodríguez

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## DETAILED INFORMATION

<b>Contextualization of the course</b>
<b>Contribution to the professional profile of the degree</b>
<p>The objective of the course is for the student to become knowledgeable about physical and functional structure of electric power systems and to be familiar with the methods to analyze and control electric power systems. In particular, the specific objectives are:</p> <ul style="list-style-type: none"> <li>• To understand the physical and functional structure of electric power systems</li> <li>• To be able to analyze DC, single phase and three-phase AC circuits</li> <li>• To understand the main control systems (load-frequency and voltage) of electric power systems and to analyze using appropriate mathematical models the performance of these control systems</li> <li>• To understand the steady-state models of electric power systems (power flow problem) and to solve power flow problems using different approaches and models</li> </ul>
<b>Prerequisites</b>
Students willing to take this course should have taken courses in linear algebra and calculus

## CONTENTS

<b>Contents</b>
<b>Part I: Introduction to Power Systems</b>
<b>Chapter 1. Physical and Functional Structure of Electric Power Systems</b>
<p>1.1 Demand 1.2 Generation 1.3 Transmission and Distribution 1.4 Market Operation and System Operation 1.5 Retailing</p>
<b>Chapter 2. Functional Description of Electric Power Systems</b>
<p>2.1 Time Scales 2.2 Expansion Planning 2.3 Operation Planning 2.4 Operation 2.5 Supervision and Control 2.6 Protection</p>
<b>Chapter 3. Future Trends</b>
<p>3.1 New Transmission and Distribution Technologies 3.2 Integration of Renewable Energy Sources 3.3 Smart Grids</p>
<b>Chapter 4. Power System Basic Analysis Tools</b>
<p>4.1 DC Circuits Review 4.2 Single-phase AC Circuits Review 4.3 Three-phase AC Systems 4.4 Per unit magnitudes</p>

<b>Part II: Technical Analysis of Power Systems</b>
<b>Chapter 5. Frequency Control</b>
5.1 Principles of Control Systems 5.2 Principles of Frequency Control 5.3 Primary Regulation 5.4 Secondary and Tertiary Regulation
<b>Chapter 6. Voltage Control</b>
6.1 Principles of voltage control 6.2 Voltage control of transmission lines 6.3 Voltage control by generator excitation 6.4 Voltage control by ULTC transformers
<b>Chapter 7. Power Flow</b>
7.1 Models of power system components 7.2 Network model 7.3 Formulation of power flow problem 7.4 Solution by Newton's method 7.5 DC load flow 7.6 Contingency analysis by DC load flow 7.7 Optimal load flow
<b>Chapter 8. Power Flow</b>
7.1 Models of power system components 7.2 Network model 7.3 Formulation of power flow problem 7.4 Solution by Newton's method 7.5 DC load flow 7.6 Contingency analysis by DC load flow 7.7 Optimal load flow
<b>Laboratory</b>
<b>Laboratory session # 1. Frequency control</b>
Load regulation. Primary regulation. Secondary regulation. Computer laboratory
<b>Laboratory session # 2. Voltage control</b>
Voltage control of a synchronous generator at open circuit. Voltage control of a synchronous generator connected to an infinite grid by excitation control and by transformer tap control. Electric machines laboratory
<b>Laboratory session # 3. Power flow</b>
AC power flow data structure and solution. Generator voltage control. Contingency analysis. Optimal power flow. Computer laboratory

## Competences and Learning Outcomes

### Competences

#### General Competences / Basic Competences

CB1. Haber adquirido conocimientos avanzados y demostrado, en un contexto de investigación científica y tecnológica o altamente especializado, una comprensión detallada y fundamentada de los aspectos teóricos y prácticos y de la metodología de trabajo en uno o más campos de estudio.

#### Specific Competences

- CE1. Tener una visión general de la estructura y funcionamiento de los sistemas de energía eléctrica, así como de cuáles son las tendencias futuras desde la perspectiva tecnológica en los sistemas de energía eléctrica.
- CE2. Conocer los modelos de los componentes del sistema de energía eléctrica (generadores, transformadores y líneas) y de las técnicas apropiadas para el análisis de los sistemas eléctricos en régimen permanente y transitorio.

### Learning outcomes

By the end of the course students should be able to:

- LO1. Understand the importance of physical structure of electric power systems
- LO2. Understand the importance of functional structure of electric power systems
- LO3. Be able to analyze DC, single-phase and three-phase AC circuits
- LO4. Understand the mechanisms of frequency control of electric power systems and its implementation details
- LO5. Understand the mechanisms of voltage control of electric power systems and its implementation details
- LO6. Understand the rationale of power flows in electric power systems
- LO7. Run power flow simulations

## TEACHING METHODOLOGY

General methodological aspects	
<p>This course will provide the students with basic concepts and tools they will require in the following courses. To obtain a good understanding of the different concepts, it is necessary to combine theory and practice. As the students will have to assimilate a wide range of knowledge in a short period of time, their commitment will be essential as well.</p>	
In-class activities	Competences
<p><b>Lectures (54 hours):</b> Presentation of the theoretical concepts by the instructors with proven experience in developing decision support tools for the power sector. These lectures will include dynamic presentations, case studies, and the participation and interaction with students.</p>	CB1, CE1, CE2
<p><b>Laboratory sessions (6 hours):</b> Under the instructor's supervision, students will apply the concepts and techniques covered in the lectures. The sessions will take place in a computer laboratory.</p>	CB1
Out-of-class activities	Competences
<p><b>Personal study of the material (100 hours):</b> This is an individual activity by the students, in which they will read, analyze and question the readings provided as background material, and that will be discussed with other students and lecturers in the classroom.</p>	CB1, CE1, CE2
<p><b>Individual term papers (20 hours):</b> Learning activities that will be carried out individually, outside of the classroom.</p>	CB1
<p><b>Tutoring (up to 10 hours):</b> for groups or individual students will be organized upon request.</p>	–

## ASSESSMENT AND GRADING CRITERIA

Assessment activities	Grading criteria	Weight
Exams	<ul style="list-style-type: none"> <li>Understanding of the theoretical concepts.</li> <li>Application of these concepts to problem-solving.</li> </ul>	90%
Reports	<ul style="list-style-type: none"> <li>Application of theoretical concepts to real problem-solving.</li> <li>Interpretation and critical analysis of numerical results.</li> <li>Written communication skills.</li> </ul>	10%

## GRADING AND COURSE RULES

The student has two periods of final evaluation during one academic year. The first one (regular assessment) will be carried out throughout the course. In case that this was not passed obtaining 5 or more points, the student has another opportunity of final evaluation (Retake) at the end of the academic year. The dates of retake evaluation period will be announced in the web page.

Grading
<p><b>Regular assessment</b></p> <p>Theory will account for 90% of the grade, of which:</p> <ul style="list-style-type: none"> <li>1<sup>st</sup> Exam: Power system structure &amp; functional description up to medium term decisions (13/60)</li> <li>2<sup>nd</sup> Exam: Functional description &amp; DC-AC circuits &amp; Three Phase Systems (13/60)</li> <li>3<sup>rd</sup> Exam : Frequency control (10/60)</li> <li>4<sup>th</sup> Exam: Voltage control (14/60)</li> <li>5<sup>th</sup> Exam: Power flow (10/60)</li> </ul> <p>The exams are a combination of a multi-option test and problems. Assignment reports will account for the remaining 10%. There are 3 assignments that the students must do individually following the instructions of the professor: frequency control, voltage control and power flow.</p>
<p><b>Retake</b></p> <p>A single retake final exam that will account for 90% of the grade. Assignment reports (handed out in the regular assessment) will account for the remaining 10%.</p>
<p><b>Course rules</b></p> <p>Class attendance is mandatory according to Article 93 of the General Regulations (<i>Reglamento General</i>) of Comillas Pontifical University and Article 6 of the Academic Rules (<i>Normas Académicas</i>) of the ICAI School of Engineering. Not complying with this requirement may have the following consequences:</p> <ul style="list-style-type: none"> <li>Students who fail to attend more than 15% of the lectures may be denied the right to take the final exam during the regular assessment period.</li> <li>Regarding laboratory, absence to more than 15% of the sessions can result in losing the right to take the final exam of the regular assessment period and the retake. Missed sessions must be made up for credit.</li> </ul> <p>Students who commit an irregularity in any graded activity will receive a mark of zero in the activity and disciplinary procedure will follow (cf. Article 168 of the General Regulations (<i>Reglamento General</i>) of Comillas Pontifical University).</p>

## WORK PLAN AND SCHEDULE<sup>1</sup>

In and out-of-class activities	Date/Periodicity	Deadline
First exam	10/10	
Second exam	5/11	
Third exam	12/11	
Fourth exam	10/12	
Fifth exam	14/01	
Lab sessions	7/11, 3/12 and 9/01	
Review and self-study of the concepts covered in the lectures	After each lesson	–
Lab preparation	Before every session	–
Assignments		Between one and three weeks after the publication of the assignments (3)

STUDENT WORK-TIME SUMMARY			
IN-CLASS HOURS			
Lectures	Problem-solving	Laboratory sessions	Assessment
35	11	6	8
OUT-OF-CLASS HOURS			
Self-study	Problem-solving	Assignments	Tutoring
65	35	20	10
<b>ECTS credits:</b>			<b>6 (180 hours+up to 10 hours for tutoring)</b>

## BIBLIOGRAPHY

Basic bibliography
<ul style="list-style-type: none"> <li>▪ D. Laloux &amp; M. Rivier, "Technology and Operation of Electric Power Systems", in Regulation of the Power Sector, J.I. Pérez Arriaga, Ed. (p. 1-46), Springer, 2013.</li> <li>▪ A. Gómez Expósito, A. J. Conejo, C. Cañizares, Electric Energy Systems: Analysis and Operation, CRC Press, 2009.</li> </ul>
Complementary bibliography
<ul style="list-style-type: none"> <li>▪ A.J. Wood &amp; B.F. Wollenberg, <i>Power Generation, Operation and Control (2<sup>nd</sup> ed.)</i>. John Wiley &amp; Sons, 1996.</li> <li>▪ O. I. Elgerd, <i>Electric Energy Systems Theory: An Introduction, 2<sup>nd</sup> ed.</i>, Mc Graw Hill, 1982.</li> <li>▪ A. R. Bergen &amp; V. Vittal, <i>Power System Analysis, 2<sup>nd</sup> ed.</i>, Prentice Hall, 2000.</li> <li>▪ J. J. Grainger &amp; W. D. Stevenson, <i>Power System Analysis</i>, Mc Graw Hill, 1994.</li> <li>▪ P. Kundur, <i>Power System Stability and Control</i>, Mc Graw Hill, 1994.</li> </ul>

<sup>1</sup> A detailed work plan of the subject can be found in the course summary sheet (see following page). Nevertheless, this schedule is tentative and may vary to accommodate the rhythm of the class.

Week	IN-CLASS ACTIVITIES			OUT-OF-CLASS ACTIVITIES			LEARNING OUTCOMES		
	h	LECTURE & PROBLEM SOLVING	LAB	ASSESSMENT	h	SELF-STUDY		LAB PREPARATION AND REPORTING	OTHER ACTIVITIES
1	2	Intro to electric power systems			4	Review and self-study			LO1
1	2	Power Systems Structure: Demand			4	Review and self-study			LO1
2	2	Power Systems Structure: Generation			4	Review and self-study			LO1
2	2	Power systems structure: Transmission and Distribution, Market and System Operation			4	Review and self-study			LO1
3	2	Functional description of power systems: two main organisational paradigms			4	Review and self-study			LO2
3	2	Functional description of power systems: long term decisions			4	Review and self-study			LO2
4	2	Functional description of power systems: medium term decisions			4	Review and self-study			LO2
4	1	Functional description of power systems: short term decisions			2	Review and self-study			LO2
4	4			Power System Structure & Functional description up to medium term decisions: First exam					LO1, LO2
5	1	Functional description of power systems: Future trends			2	Review and self-study			LO2
5	1	DC Circuits			2	Review, self-study and problem-solving			LO3
5	2	AC Circuits			4	Review, self-study and problem-solving			LO4
6	2	Three Phase Systems (part 1)			4	Review, self-study and problem-solving			LO4
6	2	Three Phase Systems (part 2)			4	Review, self-study and problem-solving			LO4
7	2	Frequency control: Principles of control systems			4	Review, self-study and problem-solving			LO5
7	2	Frequency control: Principles of frequency control			4	Review, self-study and problem-solving			LO5
8	2	Frequency control: Primary, secondary and tertiary regulation			4	Review, self-study and problem-solving			LO5
8	1	Functional description of power systems: Future trends			2	Review and self-study			LO2
8	1			Functional Description & DL-RL circuits & Three Phase Systems: Second exam					LO2, LO3, LO4
9	2		Frequency control: Computer laboratory session		10		Review, self-study and numerical simulation	Assignment on frequency control	LO5
9	2			Frequency control: Third exam					LO5
10	2	Voltage control: Principles of voltage control			4	Review, self-study and problem-solving			LO6
10	2	Voltage control: Principles of voltage control			4	Review, self-study and problem-solving			LO6
11	2	Voltage control: Voltage control of transmission lines			4	Review, self-study and problem-solving			LO6
11	2	Voltage control: Voltage control with generators			4	Review, self-study and problem-solving			LO6
12	2	Voltage control: Voltage control with transformers			4	Review, self-study and problem-solving			LO6
12	2		Voltage control: Electric machines laboratory session		8		Review and self-study	Assignment on voltage control	LO6
13	2			Voltage control: Fourth exam					LO6
13	2	Power flow: Models			4	Review, self-study and problem-solving			LO7
14	2	Power flow: AC power flow			4	Review, self-study and problem-solving			LO7
14	2	Power flow: DC power flow and optimal power flow			4	Review, self-study and problem-solving			LO7
15	2		Power flow: Computer laboratory session		10		Review, self-study and numerical simulation	Assignment on power flow	LO7
15	2			Power flow: Fifth exam					LO7