## GENERAL INFORMATION

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

| Instructor | |
|---|---|
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| Instructor | |
|---|---|
| Name | Michel Rivier Abbad |
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| Instructor | |
|---|---|
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## DETAILED INFORMATION

| Contextualization of the course |
|---|
| **Contribution to the professional profile of the degree** |
| 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:<br>• To understand the physical and functional structure of electric power systems<br>• To be able to analyze DC, single phase and three-phase AC circuits<br>• 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<br>• To understand the steady-state models of electric power systems (power flow problem) and to solve power flow problems using different approaches and models |
| **Prerequisites** |
| Students willing to take this course should have taken courses in linear algebra and calculus |

## CONTENTS

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

## Part II: Technical Analysis of Power Systems

### Chapter 5. Frequency Control

5.1 Principles of Control Systems
5.2 Principles of Frequency Control
5.3 Primary Regulation
5.4 Secondary and Tertiary Regulation

### Chapter 6. Voltage Control

6.1 Principles of Voltage Control
6.2 Voltage Control and Reactive Power Compensation of Loads
6.3 Voltage Control of Transmission Lines
6.4 Voltage control by generator excitation
6.5 Voltage control by ULTC transformers

### Chapter 7. Power Flow

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 Power flow solution with control means
7.6 Fast decoupled load flow
7.7 DC load flow
7.8 Contingency analysis by DC load flow
7.9 Optimal load flow

### Chapter 8. Power Flow

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 Power flow solution with control means
7.6 Fast decoupled load flow
7.7 DC load flow
7.8 Contingency analysis by DC load flow
7.9 Optimal load flow

## Laboratory

### Laboratory session # 1. Frequency control

Load regulation. Primary regulation. Secondary regulation.
Computer laboratory

### Laboratory session # 2. Voltage control

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

### Laboratory session # 3. Power flow

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. | To have acquired and demonstrated advanced knowledge in a context of scientific and technological research (or in a highly specialized area), detailed and informed understanding of the theoretical and practical aspects in one or more fields of study, and the related work methodology |
| **Specific Competences** | |
| CE1. | Understand the physical and functional structure of electric power systems. |
| CE2. | To be able to analyze DC and AC (single-phase and three-phase) electric circuits |
| CE3. | To be familiar with the control systems of electric power systems. |
| CE4. | To be familiar with the methods to analyze electric power systems in steady-state. |
| **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 | |
|---|---|
| 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. | |
| **In-class activities** | **Competences** |
| **Lectures (54 hours):** 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. | CB1, CE1, CE2, CE3, CE4 |
| **Laboratory sessions (6 hours):** 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. | CB1, CE3, CE4 |
| **Out-of-class activities** | **Competences** |
| **Personal study of the material (100 hours):** 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. | CB1, CE1, CE2, CE3, CE4 |
| **Individual term papers (20 hours):** Learning activities that will be carried out individually, outside of the classroom. | CB1, CE3, CE4. |
| **Tutoring (up to 10 hours):** for groups or individual students will be organized upon request. | – |

## ASSESSMENT AND GRADING CRITERIA

| Assessment activities | Grading criteria | Weight |
|---|---|---|
| Exams | ▪ Understanding of the theoretical concepts.<br>▪ Application of these concepts to problem-solving. | 90% |
| Reports | ▪ Application of theoretical concepts to real problem-solving.<br>▪ Interpretation and critical analysis of numerical results.<br>▪ Written communication skills. | 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

#### Regular assessment

Theory will account for 90% of the grade, of which:

- 1st Exam: Power system structure & functional description up to medium term decisions (13/60)
- 2nd Exam: Functional description & DC-AC circuits & Three Phase Systems (13/60)
- 3rd Exam : Frequency control (10/60)
- 4th Exam: Voltage control (14/60)
- 5th Exam: Power flow (10/60)

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.

#### Retake

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%.

#### Course rules

Class attendance is mandatory according to Article 93 of the General Regulations (*Reglamento General*) of Comillas Pontifical University and Article 6 of the Academic Rules (*Normas Académicas*) of the ICAI School of Engineering. Not complying with this requirement may have the following consequences:

- 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.
- 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.

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 (*Reglamento General*) of Comillas Pontifical University).

## WORK PLAN AND SCHEDULE[1]

| In and out-of-class activities | Date/Periodicity | Deadline |
|---|---|---|
| First exam | 10/10 | |
| Second exam | 7/11 | |
| Third exam | 16/11 | |
| Fourth exam | 21/12 | |
| Fifth exam | 25/01 | |
| Lab sessions | Weeks 9, 12 and 15 | |
| 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 |
| | | **ECTS credits:** | **6 (180 hours+up to 10 hours for tutoring)** |

# BIBLIOGRAPHY

**Basic bibliography**

- D. Laloux & 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.
- A. Gómez Expósito, A. J. Conejo, C. Cañizares, Electric Energy Systems: Analysis and Operation, CRC Press, 2009.

**Complementary bibliography**

- A.J. Wood & B.F. Wollenberg, *Power Generation, Operation and Control (2nd ed.).* John Wiley & Sons, 1996.
- O. I. Elgerd, *Electric Energy Systems Theory: An Introduction, 2nd ed.,* Mc Graw Hill, 1982.
- A. R. Bergen & V. Vittal, *Power System Analysis, 2nd ed.,* Prentice Hall, 2000.
- J. J. Grainger & W. D. Stevenson, *Power System Analysis*, Mc Graw Hill, 1994.
- P. Kundur, *Power System Stability and Control*, Mc Graw Hill, 1994.

[1] 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.

UNIVERSIDAD PONTIFICIA ICAI ICADE COMILLAS MADRID

**COURSE SYLLABUS 2015-2016**

| | IN-CLASS ACTIVITIES | | | | OUT-OF-CLASS ACTIVITIES | | | | LEARNING OUTCOMES |
|---|---|---|---|---|---|---|---|---|---|
| Week | h | LECTURE & PROBLEM SOLVING | LAB | ASSESMENT | h | SELF-STUDY | LAB PREPARATION AND REPORTING | OTHER ACTIVITIES | Learning Outcomes |
| 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 | 1 | | | 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 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 & DC-AC circuits & Three Phase Systems: Second exam | | | | | LO2, LO3,LO4 |
| 9 | 2 | | Frequency control: Computer laboratory session | | 10 | | Review, self-study and numerical simulation | Assigment 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 | Assigment 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 |