COURSE SYLLABUS
2019-2020

GENERAL INFORMATION

Course information	
Name	Operation of electric power systems
Code	DIE-IND-522
Degree	Máster Universitario en Ingeniería Industrial (MII)
Year	1st
Semester	1st (Fall)
ECTS credits	6
Type	Mandatory
Department	Electrical Engineering
Area	Power systems
Coordinator	Michel Rivier Abbad

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DETAILED INFORMATION

Contextualization of the course

Contribution to the professional profile of the degree

In the professional profile of the Master's Degree in Industrial Engineering (MII), this course provides students with the fundamentals and advanced concepts of the operation of electric power systems. In particular, the course delves into the technical and economic aspects of the joint operation of the generation system and the transmission network both in centralized and liberalized systems (electricity markets).

Graduate students registered in this course have taken previously courses on electric circuits, electrical engineering (balanced and unbalanced three-phase systems), load flow analysis, fault studies, and control of power systems. The aim of this course is to provide the students with the necessary knowledge, concepts and tools to understand how power systems are operated in the real world, and to present the most relevant technical and economic issues that have to be considered to reflect the current practices in this field.

By the end of the course, students will understand the main characteristics of the different activities present in electric power industry (generation, transmission, distribution, and retailing), will understand and discuss the theoretical principles behind the generation scheduling problem from the short to the medium term (economic dispatch, unit-commitment, and hydrothermal coordination), and will have well-formed criteria to identify the main practical implications in each case taking into account the particularities of the different generation technologies (thermal, hydro and renewable energy sources). Additionally, from the regulatory point of view, the students will be able to explain the main differences between the centralized paradigm (still present in many countries) and the decentralized paradigm that have led to the creation of many electricity markets around the world during the last decades. The students will understand the functioning of electricity markets (energy and ancillary services), the concept of locational based marginal pricing, and the implications that network, environmental and/or other types of constraints can have on the resulting electricity prices.

Prerequisites

Although not strictly required, students taking this course should be familiar with power flow analysis (in particular with the DC linear approximation) and with optimization techniques.

CONTENTS

Contents

Part 1:

Chapter 1: Overview of the technical and economic operation of electric power systems.

1.1 Technical and functional description of a power system.
1.2 Introduction to the operation of power plants in a centralized and decentralized context.
1.3 Costs of the electric power system.
1.4 Generation mix. Fixed costs and variable costs. Consumption input-output curves.
1.5 Reliability and not supplied energy.
1.6 Basic generation expansion problem formulation in a centralized scheme

Chapter 2: Economic Dispatch of generation units
2.1 Single-node Economic Dispatch **2.2** System marginal cost. **2.3** Network-constrained Economic Dispatch. Loss factors and network capacity constraints. **2.4** Consideration of additional technical and environmental constraints.
Chapter 3: Unit-Commitment and hydrothermal coordination
3.1 Weekly scheduling. **3.2** Scheduling of energy-limited units. **3.3** Hydrothermal coordination in the short and in the long term. **3.4** Water value.
Chapter 4: The electricity market.
4.1 Economic theory of perfectly competitive markets. **4.2** Economic theory of oligopolistic markets. **4.3** Description of the Spanish electricity market: daily and intraday markets, ancillary services, and market of technical constraints. **4.4**: The electricity tariff.

Competences and Learning Outcomes	
Competences	
General Competences	
G1.	To have knowledge of the scientific and technological aspects of: mathematical, analytical and numerical methods in engineering, electrical engineering, energy engineering, chemical engineering, mechanical engineering, continuum mechanics, industrial electronics, automation, manufacturing , materials, quantitative methods in management, industrial computing , planning , infrastructure , etc.
CG5.	To perform strategic planning and apply it to both constructive and production, quality and environmental management systems.
CG6.	To manage projects, installations, plants, companies and technology centers, both technically and economically.
CG12.	To have knowledge, to understand, and to be able to apply the necessary legislation in the exercise of the profession of Industrial Engineer.
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.
CB2.	To be able to apply and integrate the acquired knowledge, with a deep understanding of the scientific fundamentals, and to demonstrate problem-solving abilities in new and imprecisely defined environments, as multidisciplinary researchers or highly skilled professionals .
CB7.	To take the responsibility for their own professional development and specialization in one or more fields of study.

Competences of the module "Industrial technologies"
CMT1. Knowledge and ability to analyze and design systems for the generation, transmission and distribution of electrical energy. CMT6. Knowledge and ability to understand, analyze, operate and manage the different energy sources.
Competences of the module "Facilities, plants and complementary constructions"
CMI1. Ability to design, build and operate industrial facilities.
Learning outcomes
By the end of the course students should be able to: **LO1.** Have an overview of the structure and operation of power systems. Generation, transmission, Distribution and retail business. **LO2.** Understand the aspects that affect the generation expansion planning and operation of a power system. **LO3.** Apply mathematical programming techniques to optimize and analyze the operation of the electricity power system. **LO4.** Analyze the results obtained by decision support models for planning the operation of power systems **LO5.** Know the technical and economic foundations of the electricity markets. **LO6.** Understand and analyze the effect of technical and environmental constraints on the planning and operation of the generation system, and on the electricity energy price. **LO7.** Know the structure and functioning of the Spanish electricity market.

TEACHING METHODOLOGY

General methodological aspects	
In-class activities	**Competences**
1. Lectures. Master class presentations of the main concepts and procedures. It will include theoretical concepts, along with worked-practical examples to support the explanation. Active participation will be encouraged by raising open questions to foster discussion and student participation **(20 hours)**	**CG1, CG12, CB1, CMT1, CMT2 y CMI1**
2. Problem-solving sessions. Resolution of the basic problems of each chapter to place the student in context. The resolution will be carried out in class by the lecturer and the students cooperatively **(30 hours)**	**CG5, CG6, CB2, CMT1, CMT2 y CMI1**
3. Group problem-solving and strategy. The instructor will suggest illustrative exercises that the students will solve in small groups, and will guide the discussion of the obtained solutions **(4 hours)**	**CG12, CB7, CMT1, CMT2 y CMI1**

4. **Simulation of the power system operation**. Students compete in a simulated market, making operating decisions of the generating plants making their offers and / or using decision support tools similar to those used in the energy management departments of the electric companies (generation economic dispatch, unit assignment, etc). **(6 hours)** 5. **Tutoring.** These sessions will be organized in groups and individually upon request. The objective is to solve any question raised after having studied the material explained in class, as well as to guide them on their learning process.	**CG5, CG6, CB7, CMT1, CMT2 y CMI1**
Out-of-class activities	**Competences**
The main objective of out-of-class work is to understand and grasp the theoretical concepts of the subject, as well as to be able to apply this knowledge to solve different types of problems.	
1. **Study of the theoretical concepts**. The student must make a personal work subsequent to the lectures to understand and internalize the insights offered in this subject **(40 hours)**	**CB1 CB2, CMT1, CMT2 y CMI1**
2. **Solving practical exercises outside of school hours.** The student must apply and internalize the knowledge provided in the subject by solving practical problems. The correction in class of these problems will be held by any student or teacher as appropriate. The individual correction of each problem will be made by the students themselves or other companion as appropriate (method of exchange). Solving these problems will require a previous time to assimilate the concepts **(60 hours**)	**CG4, CB7, CMT1, CMT2 y CMI1**
3. **Simulation of market and operation decision making.** Students compete in a simulated market, making operating decisions of the generating plants making their offers and / or using decision support tools similar to those used in the energy management departments of the electric companies (generation economic dispatch, unit assignment, etc.) **(10 hours)**	**CMT1, CMT2 y CMI1**

ASSESSMENT AND GRADING CRITERIA

Assessment activities	Grading criteria	Weight
Examinations: • Final Exam	- To have acquired the minimum knowledge required to pass the course. - Application of theoretical concepts to solve practical problems. - Critical analysis and interpretation of numerical exercises' results. - Clarity of expression, layout and logical organization of written communication.	**65%**
Performance Evaluation: • Quizzes and tests during class hours around weeks 8 and 12. Participation during problem-solving sessions, and guided discussions. Assignments and out-off-class activities.	- Demonstrate the concepts' understanding. - Application of the theoretical concepts to practical problem-solving. - Analysis and interpretation of the results obtained in problem-solving.	**35%**

Grading Criteria

Regular examination period

- 70%: Final exam grade.
- 30%: Performance evaluation. Quizzes and tests during class hours around weeks 8 and 12 (20%), assessment of exercises and assignments (in-class and out-class), and participation (10%)

In order to pass the subject in the regular examination period, a minimum grade of 5 over 10 points will be required in the final exam.

Retakes

- 20%: Performance evaluation during the course. Quizzes and tests during class hours (15%), assessment of exercises and assignments (in-class and out-class), and participation (5%)
- 80%: Retake Final exam grade.

In order to pass the subject, a minimum grade of 5 over 10 points will be required in the retake final exam.

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 Academicas) of the ICAI School of Engineering. Therefore, 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.

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
• Performance evaluation (quizzes and tests)	Weeks 8 and 12 (to be confirmed along the course)	
• Final exam	Regular examination period	
• Information search assignment	Weeks 2,3 and 4	
• Market simulation, strategy games and exercises	Weeks 2, 3, and 11-14	
• Review and self-study of the concepts covered in the lectures	After each lesson	
• Problem-solving	Weekly	
• Hand-in solved problems for correction		To be indicated
• Quizzes and tests preparation	Weeks 8 and 12	
• Final exam preparation	May and June	

STUDENT WORK-TIME SUMMARY		
IN-CLASS HOURS		
Lectures	**Problem-solving**	**Simulations, group work and strategy games**
20	30	10
OUT-OF-CLASS HOURS		
Self-study of theoretical contents	**Self-study of practical concepts and problem-solving**	**Collaborative assignments and simulation sessions**
60	50	10
	ECTS credits:	**6 (180 hours**

[1] A detailed work plan of the subject can be found in the course summary sheet (see the last page). Nevertheless, this schedule is tentative and may vary to accommodate the learning speed.

BIBLIOGRAPHY AND RESOURCES

Basic bibliography

Textbooks

- Allen J. Wood, Bruce F. Wollenberg, Gerald B. Sheble. Power Generation, Operation and Control, 3rd Edition. Wiley. December 2013.
- Antonio Gómez-Expósito, Antonio Conejo, Claudio Cañizares (editores). Electric Energy Systems – Analysis and Operation. CRC Press. 2009.

Complementary bibliography

Textbooks and web pages

- A. Gómez Expósito (Coordinador). Análisis y Operación de Sistemas de Energía Eléctrica. Mc Graw Hill. 2002.
- Red Eléctrica de España: www.ree.es
- OMIE: www.omie.es
- Comisión Nacional de los Mercados y la Competencia: www.cnmc.es

	IN-CLASS ACTIVITIES			ACTIVIDADES NO PRESENCIALES				Learning outcomes	
Week	h/w	Lecture & Problem solving	Assessment	h/w	Self-study	Problem-solving	Individual and in-gropu assignments	Learning outcomes	Description
1	4	Introduction (1 hour) + Theory Chapter 1 (3 hours)		4	Study and assimilate concepts Chapter 1 (4 hours)			LO1 and LO6	Have an overview of the structure and operation of power systems .Analyze the results obtained by decision support models for planning the operation of power systems
2	4	Theory Chapter 1 (1 hour) + problems Chapter 1 (3 hours)		8	Study and assimilate concepts Chapter 1 (2 hours)	Optimal generation mix (4 hours)	Information searching (2 hours)	LO2 and LO3	Understand the aspects that affect the generation expansion planning of a power system. Understand the aspects that affect the generation expansion planning of a power system.
3	4	Theory Chapter 1 (2 hours) + problems Chapter 1 (2 hours)		8	Study and assimilate concepts Chapter 1 (2 hours)	Optimal generation mix including hydro (4 hours)	Information searching (2 hours)	LO1 and LO2	Have an overview of the structure and operation of power systems. Understand the aspects that affect the generation expansion planning of a power system.
4	4	Theory Chapter 2 (1 hour) + problems Chapter 1 (1 hour) + bidding game (2 hours)		8	Finish the stydy of concepets Chapter 1 (2 hours)	Basic bidding game in the electricity market + Generation expansion (4 hours)	Information searching (2 hours)	LO3 and LO6	Understand the aspects that affect the technical and economic operation of the generation system. Analyze the results obtained by decision support models for planning the operation of power systems.
5	4	Theory Chapter 2 (3 hours) + problems Chapter 2 (1 hour)		8	Study and assimilate concepts Chapter 2 (2 hours)	Start economic dispatch problems (without network) (6 hours)		LO4 and LO8	Discuss the influence of the electricity sector in other economic sectors. Understand and analyze the effect of technical and environmental constraints on the planning and operation of the generation system, and on the electricity price formation.
6	4	Theory Chapter 2 (2 hours) + problems Chapter 2 (2 hours)		8	Study and assimilate concepts Chapter 2 (2 hours)	Finish economic dispath problems without network, and start the ones considering network constraints (6 hours)		LO3 and LO5	Understand the aspects that affect the technical and economic operation of the generation system. Apply mathematical programming techniques to optimize the operation of the electricity system with economic criteria.
7	4	Theory Chapter 2 (1 hour) + problems Chapter 2 (3 hours)		8	Study and assimilate concepts Chapter 2 (2 hours)	Finish problems of economic dispatch with network (6 hours)		LO3 and LO7	Understand the aspects that affect the technical and economic operation of the generation system. Know the technical and economic foundations of the electricity markets, understanding the role of ancillary services.
8	4	Theory Chapter 3 (2 hours)	Quizz & Test: Chapters 1 y 2 (2 hours)	8	Finish study of Chapter 2's concepts and start studying the ones of Chapter 3 (3 hours)	Review of economic dispatch problems (5 hours)		LO3	Understand the aspects that affect the technical and economic operation of the generation system.
9	4	Theory Chapter 3 (3 hours) + problems Chapter 3 (1 hour)		6	Study and assimilate concepts Chapter 3 (2 hours)	Unit commitment (4 hours)		LO4	Discuss the influence of the electricity sector in other economic sectors.
10	4	Theory Chapter 3 (3 hours) + problems Chapter 3 (1 hour)		8	Study and assimilate concepts Chapter 3 (2 hours)	Unit commitment (6hours)		LO3 and LO4	Understand the aspects that affect the technical and economic operation of the generation system. Discuss the influence of the electricity sector in other economic sectors.
11	4	Theory Chapter 3 (2 hours) + problems Chapter 3 (2 hours)		10	Study and assimilate concepts Chapter 3 (4 hours)	Hydrothermal coordination (6 hours)		LO3 and LO6	Understand the aspects that affect the technical and economic operation of the generation system. Discuss the influence of the electricity sector in other economic sectors.
12	4	Theory Chapter 4 (1 hour) + computer simulations (2 hours)	Quizz & Test: Chapters 2 y 3 (1 hour)	10	Finish study of Chapter 3's concepts and start studying the ones of Chapter 4 (3 hours)	Review of UC and hydrothermal coordination problems (3 hours)	Computer simulation, market game and others (4 hours)	LO5	Apply mathematical programming techniques to optimize the operation of the electricity system with economic criteria
13	4	Theory Chapter 4 (2 hours) + computer simulations (2 hours)		9	Study and assimilate concepts Chapter 4 (3 hours)		Computer simulation, market game and others (6 hours)	LO6	Analyze the results obtained by decision support models for planning the operation of power systems.
14	4	Theory Chapter 4 (2 hours) + problems Chapter 4 (2 hours)		9	Study and assimilate concepts Chapter 4 (3 hours)	Electricity markets (2 hours)	Computer simulation, market game and others (4 hours)	LO6	Analyze the results obtained by decision support models for planning the operation of power systems.
15	4	Theory Chapter 4 (1 hour) + problems Chapter 4 (3 hours)		8	Study and assimilate concepts Chapter 4 (4 hours)	Electricity markets (4 hours)		LO9	Know the structure and functioning of the electricity market in Spain