COURSE SYLLABUS
2019-2020

GENERAL INFORMATION

Course information	
Name	Decision support models in the electric power industry
Code	MOD
Degree	Master in the Electric Power Industry (MEPI)
Year	1st
Semester	1st (Fall)
ECTS credits	6 ECTS
Type	Compulsory
Department	Electrical Engineering
Area	Power Systems
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DETAILED INFORMATION

Contextualization of the course

Contribution to the professional profile of the degree

The overall objective of this course is that students understand the importance of decision support models in the electric power industry, and to know their theoretical foundations and scope, both from the perspective of utilities, operators and regulators.

Prerequisites

Students willing to take this course should be familiar with optimization techniques.

CONTENTS

Contents

Theory
(Laboratory sessions marked in red)

Chapter 1. Introduction

1.1. Electricity characteristics
1.2. Hierarchy of planning models. Planning functions in a centralized and in a deregulated framework

Chapter 2. Short-term generation planning

2.1. Unit commitment and economic dispatch
2.2. Chronological demand and time representation
2.3. Conventional generation: thermal, storage hydro and pumped storage hydro
2.4. Mathematical formulation
2.5. Use of a prototype model, input data and analysis of the results
2.6. Practical session

Chapter 3. Medium-term generation planning

3.1. Monotonic demand and time representation
3.2. Dual variables: system marginal cost and water value
3.3. Use of a prototype model, input data and analysis of the results
3.4. Practical session

Chapter 4. Network constrained economic dispatch

4.1. Active and reactive load flow equations
4.2. Direct current load flow
4.3. Network losses
4.4. Mathematical formulation
4.5. Use of a prototype model, input data and analysis of the results
4.6. Practical session

Chapter 5. Impact of renewable energy sources in the short-term generation planning

5.1. Uncertainty modeling. Operation reserves
5.2. Stochastic unit commitment
5.3. Use of a prototype model, input data and analysis of the results
5.4. Practical session

Chapter 6. Medium-term stochastic hydrothermal scheduling

6.1. Hydro scheduling
6.2. Hydroelectric system modeling. Cascaded hydro reservoirs
6.3. Uncertainty modeling of stochastic hydro inflows. Scenario tree generation
6.4. Stochastic optimization formulation

6.5. Use of a prototype model, input data and analysis of the results
6.6. Practical session

Chapter 7. Generation reliability

7.1. Deterministic and stochastic reliability measures
7.2. State table. Monte Carlo simulation
7.3. Probabilistic production cost model
7.4. Use of a prototype model, input data and analysis of the results
7.5. Practical session

Chapter 8. Introduction to electricity markets

8.1. Fundamental and quantitative approaches. Classification of electricity market models
8.2. Nash equilibrium. Market-clearing procedures

Chapter 9. Short-term strategic generation planning and bidding

9.1. Residual demand
9.2. Self-unit commitment model
9.3. Bidding on the day-ahead market
9.4. Uncertainty modeling of competitors

Chapter 10. Medium-term market equilibrium model

10.1. NLP optimality conditions
10.2. Cournot conjecture. Conjectural variation. Hydrothermal Cournot model
10.3. Model based on the mixed. complementarity problem
10.4. Use of a prototype model, input data and analysis of the results

Chapter 11. Long-term generation expansion planning

11.1. Modeling techniques
11.2. Centralized models
11.3. Competitive equilibrium models
11.4. System dynamics models

Chapter 12. Long-term transmission expansion planning

12.1. Centralized models
12.2. Equilibrium models
12.3. Use of a prototype model, input data and analysis of the results
12.4. Practical session

Chapter 13. Long-term distribution expansion planning

13.1. Planning and operation of electricity smart distribution grids
13.2. Reference model

Chapter 14. Time series analysis and forecasting

14.1. Time series analysis
14.2. Demand forecasting. Electricity price forecasting
14.3. Renewable generation forecasting
14.4. Practical session

Chapter 15. Risk management in electricity markets

15.1. Basics of risk management
15.2. Market risk management
15.3. Models for measuring and managing market risk
15.4. Example

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

CE3. Understanding the importance of decision support models in the area of power systems, and why it is necessary to develop planning and operation decisions according to a temporal and functional hierarchy.

CE4. Explain the functions of the various models used in the planning and operation of power systems in a market environment, and know what optimization/simulation techniques are more suited for each case.

Learning outcomes

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

LO1. Understand the importance of models to aid decision making in the planning of power systems.

LO2. Understand why it is necessary to coordinate planning and operating decisions according to a temporal hierarchy (short, medium and long term)

LO3. Explain the functions of the different models in both a centrally planned and in liberalized electricity markets.

LO4. Understand how to apply optimization and simulation techniques, and to identify which is the most appropriate solution for each case.

LO5. Understand the mathematical formulation of the models presented in the course, so that students can apply this knowledge to possible future needs in their professional career.

LO6. Being able to specify, design and code modifications to the models presented in the course.

LO7. Interpret the results obtained by the prototypes used in the practical sessions.

LO8. Develop critical analysis to adequately assess decision support tools as users.

TEACHING METHODOLOGY

General methodological aspects	
The best way of gaining a full understanding of decision support models is to complement the theoretical concepts presented in the classroom with practical sessions, and to schedule a set of out-of-class activities in order to reinforce the learning process of the students.	
In-class activities	**Competences**
▪ **Lectures (40 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, CE3, CE4.
▪ **Practical sessions (20 hours):** Under the instructor's supervision, students, will apply the concepts and techniques covered in the lectures to real problems and will become familiar with the software tools developed for this course. These sessions will take place in the computer room after Topic 2 (Short-term generation planning), Topic 3 (Medium-term generation planning), Topic 4 (Network constrained economic dispatch), Topic 5 (Medium-term stochastic hydrothermal scheduling), and Topic 15 (Time series analysis and forecasting).	CB1, CE3, CE4
▪ **Tutoring (up to 5 hours)** for groups or individual students will be organized upon request.	CB1, CE3, CE4
Out-of-class activities	**Competences**
▪ Personal study of the material (55 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, CE3, CE4
▪ Individual term papers or team assignments (60 hours): Learning activities that will be carried out individually or by pairs, outside of the classroom.	CB1, CE3, CE4.

ASSESSMENT AND GRADING CRITERIA

Assessment activities	Grading criteria	Weight
Exams	▪ Understanding of the theoretical concepts. ▪ Application of these concepts to problem-solving.	70%
Reports	▪ Application of theoretical concepts to real problem-solving. ▪ Ability to use the provided decision support models. ▪ Interpretation and critical analysis of numerical results. ▪ Written communication skills.	30%

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 at the end of course (end of the semester). 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 evaluation periods will be announced in the web page.

Grading

Regular assessment

- **Theory** will account for 70%, of which:
  - Mid-term exam: 35%
  - Final exam: 35%

Each theory exam is a combination of two parts: Part 1 (short questions to elaborate) and Part 2 (multi-option test). The grades of each one of these parts (average considering the mid-term and final exam) must be greater or equal to 3 out of 10 points in order to be weighted in the compilation of the theory grade. If not the minimum of both parts will be the final grade.

- **Assignment reports** will account for the remaining 30%. There are 5 assignments that the students must do by pairs or individually following the instructions of the professor: Short-term generation planning, Medium-term generation planning, Generation Reliability, Risk management in electricity markets, and Time Series.

In order to pass the course, the grade of the Theory part must be greater or equal to 5 out of 10 points and the marks of both the mid-term and the final exams must be at least 3 out of 10 points. Otherwise, the final grade will be the lower of the two marks.

Retake

- **Theory,** 70%:
  - A single retake final exam (combination of short questions and a multi-option test), with the same minimum grade requirements as in the regular assessment.
- **Practical assessment** will account for 30%, of which:
  - **Assignment reports** marks will be preserved, 15%.
  - **Term paper**, 15%**.** Each student will develop individually a decision support model of a particular topic and will apply it to a small case study. The model development and the analysis carried out with it will be reported in a short term paper.

In order to pass the course, the weighted average grade in the retake has to be greater or equal than 5. However, next requirements about the partial grades apply: the mark of the final exam must be greater or equal to 4 out of 10 points and the mark of the term paper must be at least 5 out of 10 points. Otherwise, the final grade will be the lower of the two marks.

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
Mid-term exam	Week 7-9	
Final exam	Week 15	
Lab sessions	Weeks 2,3,4,5,6,7, 11,12, and 13	
Review and self-study of the concepts covered in the lectures	After each lesson	–
Lab preparation	Before every session	–
Assignment report writing		Between one and three weeks after the publication of the assignments (5)
Term paper		Only for retakes
Final exam preparation	January	–

STUDENT WORK-TIME SUMMARY		
IN-CLASS HOURS		
Lectures	Lab sessions	
40	20	
OUT-OF-CLASS HOURS		
Self-study	Assignment reports and readings	Tuition
55	60	5
	ECTS credits:	6 (180 hours)

[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.

BIBLIOGLOPHY

Basic bibliography
• J. García-González, “Decision support models in electric power systems: Unit Commitment, Mid-Term planning model & Transmission constrained Economic Dipatch”, class- notes. ETSI (ICAI), Universidad Pontificia Comillas, 2013. • Wood, J., and Wollenberg, B.F., Sheble, G.B. “Power Generation Operation and Control”, 3rd edition Wiley, New York, 2013. • B. F. Hobbs, M. H. Rothkopf, R. P. O'Neill, H-P. Chao (eds.) “The Next Generation of Electric Power Unit Commitment Models”, Kluwer Academic Publishers 2001 • J. A. Momoh “Electric Power System Applications of Optimization”, 2nd edition. CRC Press. 2008 • Billinton, R. and Allan, R.N. “Reliability Evaluation of Power Systems”, Springer, 1996. • João P. S. Catalão (ed.) Electric Power Systems: “Advanced Forecasting Techniques and Optimal Generation Scheduling” CRC Press 2012 • M. C. Ferris, O. L. Mangasarian and J.-S. Pang “Applications and Algorithms of complementarity”. Chapter 13. A Generation Operation Planning Model in Deregulated Electricity Markets based on the Complementarity Problem. pp. 273-298. Kluwer Academic Publishers. Boston, 2001. • William W.S. Wei., "Time series analysis. Univariate and Multivariate Methods" 2nd edition. Pearson Addison Wesley. 2006.
Complementary bibliography
Short-term planning: Stochastic-UC Padhy, N.P., "Unit commitment-a bibliographical survey," Power Systems, IEEE Transactions on , vol.19, no.2, pp.1196,1205, May 2004 Takriti, S.; Birge, J.R.; Long, E., "A stochastic model for the unit commitment problem," Power Systems, IEEE Transactions on , vol.11, no.3, pp.1497,1508, Aug 1996 J. García-González, R. Moraga, L. Matres-Santos, A. Mateo, "Stochastic joint optimization of wind generation and pumped-storage units in an electricity market", IEEE Transactions on Power Systems. vol. 23

Hydrothermal coordination:

- J.W. Labadie "Optimal Operation of Multireservoir Systems: State-of-the-Art Review" JOURNAL OF WATER RESOURCES PLANNING AND MANAGEMENT MARCH/APRIL 2004 pp. 93-111
- J.M. Latorre, S. Cerisola, A. Ramos, A. Perea , R. Bellido "Coordinated hydro power plant simulation for multi-reservoir systems" Journal of Water Resources Planning and Management 140 (2), 216-227, Feb 2014 10.1061/(ASCE)WR.1943-5452.0000306

Transmission expansion planning:

- Latorre G; Cruz RD; Areiza JM; et al. "Classification of publications and models on transmission expansion planning" IEEE Transactions on Power Systems (18) 2 938-946 May 2003

Market Models:

- A. Mateo, A. Muñoz, J. García-González, "Modeling and forecasting electricity prices with input/output hidden Markov models", IEEE Transactions on Power Systems. vol. 20, no. 1, pp. 13-24, Febrero 2005.
- M. Ventosa, A. Baíllo, A. Ramos, M. Rivier "Electricity Market Modeling Trends Energy Policy" 33 (7): 897-913 May 2005
- J. García-González, J. Román, J. Barquín, A. González, "Strategic bidding in deregulated power systems", 13th Power Systems Computation Conference (PSCC '99). Trondheim, Noruega, 28 Junio - 2 Julio 1999
- Á. Baíllo, M. Ventosa, M. Rivier, A. Ramos, "Optimal offering strategies for generation companies operating in electricity spot markets", IEEE Transactions on Power Systems. vol. 19, no. 2, pp. 745-753, Mayo 2004.
- G. Morales-España, A. Ramos, J. García-González, "An MIP formulation for joint market-clearing of energy and reserves based on ramp scheduling", *IEEE Transactions on Power Systems*. vol. 29, no. 1, pp. 476-488, Enero 2014.

Risk Management:

- Cabero, J., A. Baíllo, S. Cerisola, M. Ventosa, A. García, F. Perán and G. Relaño. 2005. "A Medium-Term Integrated Risk Management Model for a Hydrothermal Generation Company". IEEE Transactions on Power Systems. 20 (3),1379-1388.
- Fleten, S. E., S. W. Wallance and W. T. Ziembra. 1997. "Portfolio management in a deregulated hydropower based electricity industry". Proceedings of the Third International Conference on Hydropower. Trondheim, Norway.
- J. García-González, E. Parrilla, A. Mateo, "Risk-averse profit-based optimal scheduling of a hydro-chain in the day-ahead electricity market", *European Journal of Operational Research*. vol. 181, no. 3, pp. 1354-1369, Septiembre 2007.

Long-Term Analysis:

- Dyner, I. and E. R. Larsen. 2001. "From planning to strategy in the electricity industry". Energy Policy. 29,1145-1154.

- Ghanadan, R. and J. G. Koomey. 2005. "Using energy scenarios to explore alternative energy pathways in California". Energy Policy. 33,1117-1142.
- Grant, R. 1998. "Contemporary Strategy Analysis". Blackwell Publishers: Malden, MA.
- Hobbs, B. F. and P. Meier. 2000. "Energy Decisions and the Environment: A Guide to the Use of Multicriteria Methods". Kluwer Academic Publishers.
- Kadoya, T., T. Sasaki, S. Ihara, E. Larose, M. Sandford, A. K. Gram, C. A. Stephens and C. K. Eubanks. 2005. "Utilizing System Dynamics Modelling to Examine Impact of Deregulation on Generation Capacity Growth". Proceedings of the IEEE. 93 (11)
- Merrill, H. M. and F. C. Schweppe. 1984. "Strategic Planning for Electric Utilities: Problems and Analytic Methods". Interfaces. 14 (1)
- Sánchez, J. J. 2008. "Strategic Analysis of the Long-Term Planning of Electric Generation Capacity in Liberalised Electricity Markets". PhD Thesis, Universidad Pontificia de Comillas: Madrid, Spain.
- Vries, L. De and P. Heijnen. 2006. "The influence of uncertainty upon generation adequacy". Proceedings of IAEE International Conference.Postdam, Germany
- Wogrin, Barquín, Centeno, "Capacity expansion equilibria in liberalized electricity markets: an EPEC approach", IEEE Transactions on Power Systems. vol. 28, no. 2, pp. 1531-1539, Mayo 2013.
- Wogrin, Centeno, Barquín, "Generation capacity expansion in liberalized electricity markets: a stochastic MPEC approach", IEEE Transactions on Power Systems. vol. 26, no. 4, pp. 2526-2532, Octubre 2011.

	IN-CLASS ACTIVITIES			OUT-OFF-CLASS ACTIVITIES					Learning outcomes
Week	h/w	Lectures & in-class participation	Assessment	h/w	Self-study	LAB preparation and reporting	Other activities		Learning outcomes
1	4	Intro. to Decision support models (2h) Unit commitment (2h)		7	Review the slides and class notes (4h)		Reading (press) (1h) Discussions (2 h)		LO1, LO2, LO6
2	4	Unit commitment and hourly scheduling (lab) (2h) Midterm generation planning (KKT) (2h)		7	Review the slides and class notes (4h)	Review LAB slides (0.5 h)	Install GAMS, prototype UC and run basic cases (1.5h), discussions with partner (1)		LO3, LO4, LO6, LO7
3	4	Midterm generation planning (lab) (2h) Transmission constrained economic dispatch (2h)		8	Review and self-study (3 h)	Review LAB slides and prepare Assignment 1 (3.5 h)	Install prototype Midterm and run basic cases (1.5 h)		LO3, LO4, LO5, LO7
4	4	Transmission constrained economic dispatch (lab) (2h) Impact of intermittent generation: Stochastic Unit Commitment (2h)		8	Review and self-study (3 h)	Review LAB slides and prepare Assignment 2 (3.5 h)	Install prototype DC-OPF and run basic cases (1.5 h)		LO6, LO7
5	4	Stochastic Unit Commitment (lab) (2h) Midterm stochastic hydrothermal coordination (2h)		8	Review and self-study (3 h)		Team work assignments 1 & 2 (5 h)		LO3, LO4, LO5, LO7
6	4	Midterm stochastic hydrothermal coordination (lab) (2h) Generation reliability (2h)	Deadline Assigment 1	8	Review and self-study with the focus on the mid-term exam (4 h)	Finish Assigment 1 (3.5 h)	Install prototype Stoch. Hydro-Thermal Coord. and run basic cases (0.5 h)		LO6, LO7
7	4	Generation reliability (lab) (2h) Exam Part 1 (2h)	Mid-term exam	8	Review and self-study with the focus on the mid-term exam (3 h)	Finish Assigment 2 (2 h)	Team work assign. 3 (2h) + tuition (1 h)		LO7, LO8
8	4	Models for liberalized power systemsShort term models in a market environ Self UC: price maker-price taker (2h)	Deadline Assigment 2	8	Review and self-study (3h)	Finish Assigment 2 (2 h)	Team work assignments 3 (2 h) + tuition (1 h)		LO3, LO4
9	4	MCP and Midterm models: market equilibirum (2h) Midterm models: market equilibirum (2h)		7	Review and self-study (3h)	Assigment 3 (4 h)			LO3, LO4, LO5
10	4	Generation expansion (2h) Generation expansion (2h)	Deadline Assigments 3	8	Review and self-study (3h)	Finish Assigment 3 (4 h)	Tuition (1 h)		LO3, LO4, LO5
11	4	Transmission expansion model (2h) Transmission expansion model (Lab) (2h)		8	Review and self-study (4 h)		Install prototype Trans. Expansion and run basic cases (4 h)		LO3, LO4, LO5, LO7
12	4	Reference Model for Distribution networks (2h) Time series models for forecasting (lab) (2h)		8	Review and self-study (3 h)	LAB Preparation (1 h)	Develop assigment 4 (4 h)		LO3, LO4, LO7
13	4	Time series models for forecasting (lab) (2h) Correction and discussion homeworks (2h)		9	Review the slides and class notes (4 h)	Lab preparation (0.5 h) Report Assigment 4 (3.5h)	Review of corrections to identify errors (1 h)		LO7, LO8
14	4	Models for risk management (2h) Models for risk management (2h)	Deadline Assigments 4	9	Review and self-study (4h)	Report Assignment 5 (4h)	Review of corrections to identify errors (1 h)		LO3, LO4
15	4	Correction and discussion homeworks (2h) Final conclusions + Exam (2h)	Deadline Assigments 5 Final Exam	9	Review and self-study (7h)		Tuition (2h)		LO6, LO8