Hydroelectric systems analysis

1. General overview

UPM Code	Credits	Type	Specialization	Language
	4.5	Optional	Hydraulics, energy and environment	English

Name in Spanish	Análisis de sistemas hidroeléctricos
Subject	Hydroelectric systems analysis
Department	Hydraulics, energy and environment
Web page	
Semester	Fourth semester

2. Teaching staff

Name	Evaluation jury	Group	Office hours	Place	E-mail address
Juan Ignacio Pérez Díaz	Chair	All	J y V, 11:00-14:00	Lab. De ingeniería eléctrica	*ji.perez@upm.es*
Jose Ignacio Sarasúa Moreno	Secr.	All	J y V, 11:00-14:00	Lab. Electro	*Joseignacio.sarasua@upm.es*
José Ángel Sánchez Fernández	Member	All	L y X, 12-15 V, 16-18	Lab. Electro	*Joseangel.sanchez@upm.es*

NOTE. The person on the first place is the course coordinator.

3. Previous knowledge

Courses that must be taken in advance:

Scientific training extension module

Other learning requirements:

Basic knowledge of linear algebra; Basic knowledge of linear programming; Basic knowledge of matlab; Use of Microsoft Excel; Basic knowledge of pressure pipes and hydraulic similarity; Basic knowledge of statistics.

4. Assigned competences

Code	Competence
CE-A1	Scientific-technical and methodological qualification for the design, analysis, planning, operation and maintenance of civil works.
CE-A6	Knowledge of the regulation framework of civil engineering systems.
CE-A7	Knowledge and ability to devise innovative solutions in civil engineering systems.
CE-A8	Ability to devise innovative and sustainable for operation and management of civil engineering systems.
CG5	English language usage
CG8	Planning and organization

Code	Competence
CB6	Possess and understand knowledge that provide a basis to be original in the development and application of ideas in a research context
CB7	Ability to apply the acquired knowledge and to resolve problems in new or barely known environments within wider contexts (or multidisciplinary) related to the area of knowledge
CB9	Communicate conclusions and knowledge to different types of audiences in a clear and concise manner
CB10	Learning abilities that allow the students to continue studying in a self-managed or autonomous manner

5. Learning results

Code	Learning results	Competences linked
RA1	The student applies and evaluates advanced mathematical models for the design and operation of hydro and hydrothermal power systems.	CE-A1, CE-A7, CE-A8, CG8, CB6, CB7, CB9, CB10
RA2	The student knows and understands the regulation framework of liberalized electricity markets.	CE-A6, CG5

6. Indicators of achievement

Code	Basic	Indicators of achievement	RA linked
IL1	Yes	Formulates and resolves the economic dispatch of thermal generating units by means of mathematical programming techniques and correctly interprets the results.	RA1
IL2	Yes	Obtains the generation characteristic of a hydroelectric plant from the performance curves of the turbines and the plant design parameters.	RA1
IL3	Yes	Formulates and resolves the short term scheduling of a hydrothermal power system by means of mathematical programming techniques and correctly interprets the results.	RA1, RA2
IL4	Yes	Formulates and resolves the short term scheduling of a hydroelectric power plant by means of mathematical programming techniques and interprets correctly the results.	RA1, RA2
IL5	Yes	Knows the basic aspects of how the electricity markets of the Spanish electric power system operate.	RA2
IL6	Yes	Knows the basic aspects of how the markets of load-frequency control services of the Spanish electric power system operate.	RA2
IL7	Yes	Understand and correctly applies the dynamic programming principle of optimality to the long-term scheduling of a hydroelectric power plant, and obtains from the results recommendations for the short-term operation of the plant.	RA1, RA2
IL8	No	Determines by means of dynamic programming and simulation, the annual firm energy of a new hydroelectric power plant, considering different pre-design power plant parameters.	RA1, RA2

NOTE. Basic: Indicator that must be achieved to pass the subject.

7. Evaluation methods and criteria

Code, name of evaluation methods, brief description of evaluation methods, criteria, place and period of evaluation	Weight

7.1. Evaluation through "continuous assessment"

EI1. Attendance and participation **10%**

Description: Attendance and participation in the lectures.

Evaluation criteria: It will be ranked from 0 to 10 points, proportionally to the percentage of lectures attended and to the participation of the student.

Place and period: The attendance control will be carried out in the classroom during all lectures.

EI2. Resolution of practical exercises **65%**

Description: The student will have to submit several practical exercises related to the contents taught during the lectures.

Evaluation criteria: Each exercise will be ranked from 0 to 10 points. The evaluation of this part will be the arithmetic mean of the delivered exercises.

Place and period: The exercises will be done outside the class time.

EI3. Final Work **25%**

Description: The students will have to present in groups a work describing the methodology followed to determine the annual firm energy of a new hydroelectric power plant, considering different pre-design power plant parameters.

Evaluation criteria: The work will be ranked from 0 to 10 points.

Place and period: The final work will be done outside the class time.

Result of the evaluation through "continuous assessment"

The final score will be the weighted average of the results obtained in the evaluation items 1 to 3, previously described. The course will be passed if the final score is equal or greater than 5.

7.2. Evaluation through "final exam only"

Description: The exam will consist of a series of theoretical and/or practical exercises, related to the contents taught during the lectures.

Evaluation criteria: The maximum points of each question will be indicated in the statement of the exam. The exam will be ranked from 0 to 10 points.

Place and period: To be determined by the Head of Studies.

Result of the evaluation through "final exam only"

The final score will be the one obtained in the final exam. The course will be passed if the final score is equal or greater than 5.

8. Course content

Units, sections and descriptors	Indicators of achievement linked
Unit 1. Introduction to electric power systems. Historic evolution of electric power systems. Configuration and structure of the electric power systems. Operation of the electric power system.	IL5, IL6
Unit 2. Review of mathematical programming. Linear programming. Mixed integer linear programming. Non-linear programming.	IL2, IL3, IL4
Unit 3. Optimization software: Solver (MS Excel); GAMS	IL2, IL3, IL4

Unit 4. Economic dispatch of thermal generating units. Problem statement. Basic aspects of the performance of a thermal generating unit. Hourly production cost curve. Analytical solution by direct application of the Karush-Kuhn-Tucker conditions. λ iteration. Graphic solution. Resolution with Excel Solver and/or GAMS. Economic dispatch with transport losses.	IL1
Unit 5. Spanish electricity market. Liberalized electricity markets organization models. Market agents. Types of energy bids. Day-ahead market. Intraday markets. Power generation schedules. Ancillary services markets. Components of the final energy price.	IL5, IL6
Unit 6. Short-term hydropower scheduling. Problem statement. Generation characteristic of a hydroelectric unit. Generation characteristic of a hydropower plant. Short-term scheduling of a hydrothermal power system. Analytical solution without considering start-ups and shut-downs by direct application of the Karush-Kuhn-Tucker conditions. ν iteration. λ-ν iteration. Resolution by Excel Solver and/or GAMS by mixed integer linear programming. Short-term hydropower scheduling. Analytical solution without considering start-ups and shut-downs by direct application of the Karush-Kuhn-Tucker conditions. Water value. ν iteration. Resolution by Excel Solver and/or GAMS by mixed integer linear programming. Short-term scheduling of a pumped-storage power plant. Consideration of plant participation in the secondary regulation market. Short-term scheduling of a hydropower plant in a random environment.	IL2, IL3, IL4
Unit 7. Long-term scheduling of hydropower systems Problem statement. Dynamic programming. Resolution of a long-term scheduling of a hydroelectric power plant by dynamic programming with Matlab. Stochastic dynamic programming. Introduction to the Markov chains. Water value. Determination of the firm energy of a hydroelectric power plant.	IL7, IL8

9. Description of teaching methodology

Theory lessons:

The teacher will explain the concepts necessary to understand the course contents in order for the student to achieve the expected indicators. The teacher will use appropriate practical examples and logical reasoning to develop the scientific and technical abilities of the student. The participation of students will be encouraged by means of discussions on the taught topics.

Practice lessons:

Practice lessons will be aimed at solving exercises and case-studies. Practice lessons are intended as a correlation between the content of theory lessons and engineering practice, in order for the student to achieve the ability to apply the acquired knowledge in the future career. A special emphasis will be put on the use of commercial software tools, which are currently used currently in hydropower companies.

Laboratory classes:

Tutorials of the optimization software used in the course will be given during practice lessons.

Independent work:

As indicated in 7.1, in case of choosing continuum assessment, the student shall submit five practical exercises related with the contents taught during the sessions.

Group work:

IL8 will be done in group. The group size will depend on the number of students enrolled on the course.

Office hours

Office hours are intended as a complement for the students to ask questions on the course content. The students can attend to office hours on the places and hours indicated above, as well as ask their questions by email.

10. Bibliography and resources

Basic bibliography:

Nandalal, K.D.W. y Bogardi, J.J., *Dynamic Programming Based Operation of Reservoirs. Applicability and Limits*. Cambridge University Press, 2007.

Wood, A.J. and Wollenberg, B.F., *Power generation operation and control* (2nd edition). John Wiley & Sons, 1996

Complementary bibliography:

Allen, R.B. and Bridgeman, S.G., Dynamic programming in hydropower scheduling, *ASCE Journal of Water Resources Planning and Management*, vol. 112, no. 3, pp. 339-353, 1986.

Arce, A., Ohishi, T. and Soares, S., Optimal dispatch of generating units of the Itaipú hydroelectric plant, *IEEE Transactions on Power Systems*, vol. 17, no. 1, pp. 154-158, 2002.

Bertsekas, D., *Dynamic Programming. Deterministic and stochastic models*. Prentice-Hall, 1987.

Castillo, E., Conejo, A., Pedregal, P., García, R. y Alguacil, N., *Building and Solving Mathematical Programming Models in Engineering and Science*. John Wiley and Sons, 2001.

Chang, G.W., Aganagic, M., Waight, J.G., Medina, J., Burton, T., Reeves, S. and Christoforidis, M., Experiences with mixed integer linear programming based approaches on short-term hydro scheduling, *IEEE Transactions on Power Systems*, vol. 16, no. 4, pp. 743-749, 2001.

El-Hawary, M.E. and Christensen, G.S., *Optimal economic operation of electric power systems*. Academic Press, 1979.

Finardi, E.C. and da Silva, E.L., Unit commitment of single hydroelectric plant, *Electric Power Systems Research*, vol. 75, no. 2-3, pp. 116-123, 2005.

García-González, J., Parrilla, E. and Mateo, A., 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, 2007

Kazempour, S.J., Moghaddam, M.P., Haghifam, M.R. and Yousefi, G.R., Risk-constrained dynamic self-scheduling of a pumped-storage plant in the energy and ancillary service markets, *Energy Conversion and Management*, vol. 50, no. 5, pp. 1368-1375, 2009.

Pérez-Díaz, J.I., Wilhelmi, JR and Arévalo Muñoz, L, Optimal short-term operation schedule of a hydropower plant in a competitive electricity market, *Energy Conversion and Management*, vol. 51 (12), pp. 2955-2966, December 2010.

Pérez-Díaz, J.I., Wilhelmi, J.R. and Sánchez-Fernández, J.A., Short-term operation scheduling of a hydropower plant in the day-ahead electricity market, *Electric Power Systems Research*, vol. 80 (12), pp. 1535-1542, December 2010.

Piekutowski, M.R., Litwinowicz, T. and Frowd, R.J., Optimal short-term scheduling for a largescale cascaded hydro system, *IEEE Transactions on Power Systems*, vol. 9, no. 2, pp. 805-811, 1994.

Revelle, C.S., Earl Whitlatch, E. and Wright, J.R., *Civil and environmental systems engineering*. Prentice Hall, 1997.

Rau, N.S., *Optimization principles. Practical applications to the operation and markets of the electric power industry*. IEEE Series on Power Engineering, John Wiley & Sons, 2003.

Web resources:

Web site of the subject, virtual platform (MOODLE).

Specific equipment:

Library of the electrical engineering laboratory (EICCP).

Table 1. Time schedule

Week (see Note 1)	Theory lessons	Practice lessons	Laboratory classes (see Note 2)	Independent work	Evaluation activities	Other activities	Hours
1	Unit 1 3 h 45 min			Study Unit 1 4 h			7 h 45 min
2	Units 1 and 2 1 h 15 min, 2 h 30 min			Study Units 1 and 2 5 h			7 h 45 min
3	Unit 2 3 h 45 min			Study Unit 2 5 h			7 h 45 min
4	Units 2 and 3 1 h 15 min, 1 h 15 min			Study Unit 3 5 h			7 h 45 min
5	Units 3 and 4 1 h 15 min, 1 h 15 min	Unit 3 1 h 15 min		Study Units 3 and 4 5 h			9 h 45 min
6	Units 4 and 5 1 h 15 min, 1 h 15 min	Unit 4 1 h 15 min		Study Unit 4 and 5 7 h	Exercise 1		7 h 15 min
7	Units 5 and 6 2 h 30 min, 1 h 15 min			Study Units 5 and 6 5 h			7 h 45 min
8	Unit 6 2 h 30 min	Unit 6 1 h 15 min		Study Unit 6 7 h	Exercise 2		7 h 45 min
9	Unit 6 3 h 45 min			Study Unit 6 7 h	Exercise 3		7 h 45 min
10	Unit 6 2 h 30 min			Study Unit 6 7 h	Exercise 4		7 h 45 min
11	Unit 7 2 h 30 min	Unit 7 1 h 15 min		Study Unit 7 7 h	Exercise 5		7 h 45 min

Week (see Note 1)	Theory lessons	Practice lessons	Laboratory classes (see Note 2)	Independent work	Evaluation activities	Other activities	Hours
12	Unit 7 3 h 45 min			Study Unit 7 8 h			7 h 45 min
13	Unit 7 1 h 15 min	Unit 7 1 h 15 min		Study Unit 7 8 h	Final Work		7 h 45 min
Hours	**40 h**	**7 h 30 min**		**80 h**			**127 h 30 min**

NOTE 1. Exact dates are shown in the academic calendar.

NOTE 2. Exact dates are shown in the academic calendar.