Master ParisTech REST

Renewable Energy Science and Technology

Graduate Degree STEEM

Energy Environment: Science Technology and Management

MAP661D 2018–2019

Stochastic and Decentralized Optimization for the Management of Micro-Grids

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Eligibility/Pre-requisites.

- Mathematical skills. Computer skills.
- Continuous optimization: linear programming, convexity, duality, first-order optimality conditions. [Ber96]
- Probability calculus: probability space, probability, random variables, independence, law of large numbers. [Fel68]
- Software Scicoslab to be installed (else, install software Scilab)

Learning outcomes. After the course the student should be able to

- design mathematical models for energy storage and delivery of renewable energies, especially in micro-grids, and formulate cost-minimization problems,
- use the scientific software Scicoslab and numerically solve small scale problems.

Course main content. The course mixes theoretical sessions, modeling exercises and computer sessions.

In introduction, we present examples of micro-grid and virtual power plant management — where the question of electrical storage is put, due to the need to answer a varying demand and to incorporate intermittent and highly variable renewable energies. During the course, we will present concepts and tools to formulate such problems as stochastic dynamic optimization problems. For this purpose, the first sessions are dedicated to mathematical recalls in probability and optimization, followed by an introduction to the scientific software Scicoslab.

Then, we turn to stochastic optimization. In a deterministic optimization problem, the values of all parameters are supposed known. What happens when this is no longer the case? And when some values are revealed during the stages of decision? We present stochastic optimization, at the same time as a frame to formulate problems under uncertainty, and as methods to solve them according to the formulation. More precisely, we present *two-stage stochastic programming* (and the resolution on scenario tree or by scenarios) and *multi-stage stochastic control* (and the resolution by *stochastic dynamic programming*). We finish with the *Stochastic Dual Dynamic Programming (SDDP)* algorithm (used in commercial software in the world of the energy), which mixes dynamic programming and cutting plane algorithm. Depending on time availability, we will try to shed light on decomposition methods that lead to decentralized optimization (especially adapted to micro-grid management).

Modeling exercises and computer sessions tackle issues like optimal economic dispatch of energy production units, storage/delivery optimization problem to buffer an intermittent and variable source of energy, dam optimal management with stochastic water inflows, battery optimal management with renewable energy inputs.

Examination and requirements for final grade. At the end of each computer session, the student produces a report, which receives a mark after evaluation. Mini-exams, presence and participation also contribute to the final grade.

Contact person. Michel De Lara (Cermics—École des Ponts ParisTech)

Link course.
`http://cermics.enpc.fr/~delara/TEACHING/STEEM2-REST/`

Link master REST.
`http://www.master-renewable-energy.com/`

Link Graduate Degree STEEM.
`https://portail.polytechnique.edu/graduatedegree/steem/`

Program

1 / Tuesday 8, January 2019 (Amphi Gregory)

Scanning the course schedule (14h00–14h30)

Introductory talk (14h30–15h30)

To introduce the course, we present an example of micro-grid management that can be solved using stochastic dynamic optimization.

Work done by François Pacaud (Efficacity and Cermics—École des Ponts ParisTech)
"Optimal Energy Management of a Urban District"

Lecture and exercises (16h00–18h00)

Recalls on probability calculus: probability space, probability, random variables, law of a random variable, mathematical expectation (linearity), indicator function (law, expectation), independence of random variables, almost-sure convergence and law of large numbers. [Fel68]

Exercises on probability calculus. The blood testing problem.

2 / Tuesday 15, January 2019 (Amphi Gregory)

Lecture and exercises (14h00–16h00)

Recalls and exercises on continuous optimization [Ber96].

- Recalls on convexity: convex sets, convex functions, strict and strong convexity (characterization by the Hessian in the smooth case), operations preserving convexity.
- Abstract formulation of a minimization problem: criterion, constraints. Sufficient conditions for the existence of a minimum (continuity and compacity/coercivity). Sufficient condition for the uniqueness of a minimum (strict convexity). Exercises with a quadratic objective function on an interval.

Exercises (16h30–18h00)

We present, under the form of an exercise, an example of optimization problem under uncertainty: "the newsvendor problem".

3 / Tuesday 22, January 2019 (Amphi Gregory)

Computer session

Introduction to the scientific software Scicoslab. [CCN10]

Computer session

The newsvendor problem (only the Section 1, *The newsvendor problem (integer formulation)*)

4 / Tuesday 29, January 2019 (Amphi Gregory)

Modeling session

"Day Ahead Energy Markets"

Computer session

The newsvendor problem (only the Section 1, *The newsvendor problem (integer formulation)*)

You will send the results of the computer project *The newsvendor problem* (only the Section 1, *The newsvendor problem (integer formulation)*)
under the form of a pdf file `TP1_REST_2018_MYNAME.pdf` or `TP1_STEEM_2018_MYNAME.pdf` to `delara@cermics.enpc.fr` before *Monday 4 February 2019, 9 AM.*

- You can choose any software for the computation (but Scicoslab is recommended).
- You can choose any text editor for the report.
- You can insert computer code, but in limited amount.
- The report will display on the first page: title, given name followed by family name, date, mention of *REST 2018–2019*or of *STEEM 2018–2019*.

5 / Tuesday 5, February 2019 (Amphi Gregory)

Lecture

Two-stage stochastic programming on a scenario tree.

Non-anticipativity constraint along scenarios: tree representation.

[SDR09]

Computer session

Sizing of reserves for the balancing on an electric market
(linear and quadratic optimization on a tree)

Exercises

Exercises on probability, optimization and two-stage stochastic programming.

6 / Tuesday 12, February 2019 (Amphi Gregory)

Recalls and exercises on continuous optimization [Ber96].

- Definition of a local minimizer; necessary condition in the differentiable case. Formulation of a minimization problem under explicit equality constraints.
  Necessary first-order optimality conditions in the regular/affine equality constraints case; Lagrangian, duality, multipliers.
  Sufficient first-order optimality conditions in the convex-affine case. Exercises.

Computer session

Sizing of reserves for the balancing on an electric market
(linear and quadratic optimization on a tree)

7 / Tuesday 19, February 2019 (Amphi Gregory)

Lecture

Two-stage stochastic programming on a fan.

Non-anticipativity constraint along scenarios.
Scenario decomposition by Lagrangian relaxation. Progressive Hedging [RW91].

Computer session (16h00–18h00)

Sizing of reserves for the balancing on an electric market
(linear and quadratic optimization on a fan)

You will send the results of the computer project *Sizing of reserves for the balancing on an electric market*
under the form of a pdf file `TP2_REST_2018_MYNAME.pdf` or `TP2_STEEM_2018_MYNAME.pdf` to `delara@cermics.enpc.fr` before *20 February 2019, 18h.*

8 / Tuesday 5, March 2019 (Amphi Gregory)

Correction of the computer project (14h00–14h30)

Exam (14h30–16h00)

Exam on optimization and two-stage stochastic programming.

Correction of the exam (16h30–17h00)

Lecture and exercises

Obtaining the value of a mine by dynamic programming.
Dynamical models of storage (battery models, dam models).
Dynamical sequential systems with control.

9 / Tuesday 12, March 2019 (Amphi Gregory)

Lecture and exercises (14h00–17h00)

Dynamical sequential systems with control and noise.
Optimal control of stochastic dynamical sequential systems. Stochastic dynamic programming. Curse of dimensionality. Exercise on stochastic dynamic programming.

[Ber00, CCCD15]

Computer session (17h00–18h00)

Dam optimal management under uncertainty

10 / Tuesday 19, March 2019 (Amphi Gregory)

Computer session (14h00–18h00)

Dam optimal management under uncertainty

You will send a report of the computer project *Dam optimal management under uncertainty*
(up to Question 8 included) under the form of a pdf file `TP3_REST_2018_MYNAME.pdf` or `TP3_STEEM_2018_MYNAME.pdf` to `delara@cermics.enpc.fr` before *Wednesday 20 March 2019, 15h.*

References

[Ber96] D. P. Bertsekas. *Constrained Optimization and Lagrange Multiplier Methods*. Athena Scientific, Belmont, Massachusetts, 1996.

[Ber00] D. P. Bertsekas. *Dynamic Programming and Optimal Control*. Athena Scientific, Belmont, Massachusetts, second edition, 2000. Volumes 1 and 2.

[CCCD15] P. Carpentier, J.-P. Chancelier, G. Cohen, and M. De Lara. *Stochastic Multi-Stage Optimization. At the Crossroads between Discrete Time Stochastic Control and Stochastic Programming*. Springer-Verlag, Berlin, 2015.

[CCN10] Stephen Campbell, Jean-Philippe Chancelier, and Ramine Nikoukhah. *Modeling and Simulation in Scilab/Scicos with ScicosLab 4.4*. Springer-Verlag, New York, 2 edition, 2010.

[Fel68] W. Feller. *An Introduction to Probability Theory and its Applications*, volume 1. Wiley, New York, third edition, 1968.

[RW91] R.T. Rockafellar and R. J-B. Wets. Scenarios and policy aggregation in optimization under uncertainty. *Mathematics of operations research*, 16(1):119–147, 1991.

[SDR09] A. Shapiro, D. Dentcheva, and A. Ruszczynski. *Lectures on stochastic programming: modeling and theory*. The society for industrial and applied mathematics and the mathematical programming society, Philadelphia, USA, 2009.