Visite de EDF Renouvelables du Mardi 15 octobre 2024

L'optimisation mathématique au service des EnR

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Energy companies have been using optimization for long

Optimizing is obtaining the best compromise between needs and resources

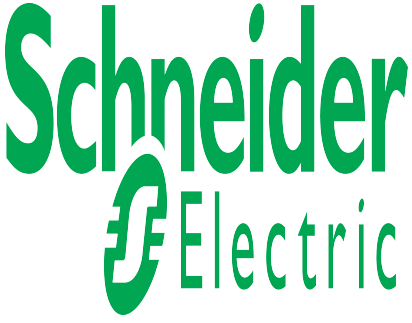
Marcel Boiteux

- Resources: portfolio of assets
  - production units
    - high cost/low cost: thermal/hydropower
    - stock/flow, predictable/less predictable, intermittent: thermal/wind, sun
  - tariffs options, contracts
- Needs: energy, safety, environment
  - energy uses, demand decentralized and less predictable
  - safety, quality, resilience (breakdowns, blackout)
  - environment protection (pollution) and alternative uses (dam water)
- Best compromise: minimize socio-economic costs (including externalities)

Context: optimization, ENPC, EDF R& D

- In 2000, the Optimization and Systems team was created at École nationale des ponts et chaussées
- We were encouraged and supported by Électricité de France Research and Development (EDF R& D / OSIRIS: René Aïd, Yannick Jacquemart) to develop a research activity in stochastic optimization,
- Between 2010 and 2013, we have trained several PhD students with continuous support (financial, scientific) from EDF R& D
- Since 2011, we have been witnessing a growing demand from small and large energy firms for stochastic optimization, fueled by a deep and fast transformation of power systems

Our industrial partners

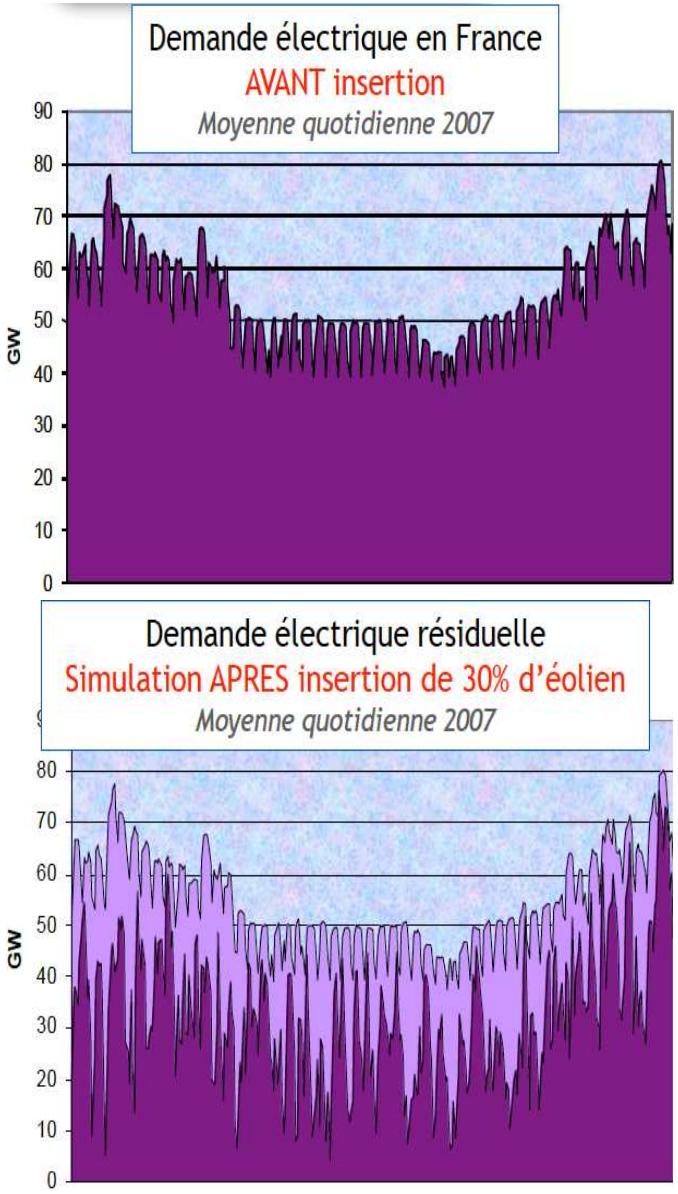


Outline of the presentation

Three key drivers are remolding power systems

- Penetration of renewable energies
- Expansion of markets
- Penetration of Information Technology (IT)

Key driver: penetration of renewable energies

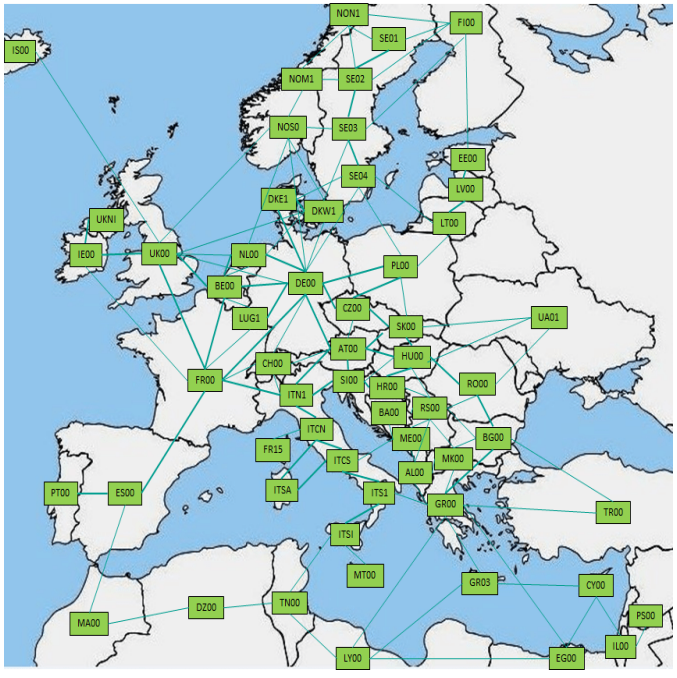


- Costs of wind and sun energies have dropped down
- Successfully integrating renewable energy sources has become critical
- But wind and sun energies are highly variable (unpredictable) and intermittent
- This triggers the use of local storage

$\Downarrow$

multistage stochastic optimization

Key driver: economic deregulation



- A power system (generation/ transmission/distribution)
  - less and less vertical (deregulation of energy markets)
  - hence with many players with their own goals
- with some new players
  - industry (electric vehicle)
  - regional authorities (autonomy, efficiency)
- with an electrical network in horizontal expansion

$$\Downarrow$$

A change of paradigm for management
from centralized to more and more decentralized:
decentralized optimization, large-scale systems, game theory

Key driver: telecommunication technology

Linky

A power system
with more and more technology
due to evolutions in the fields of
metering, computing and telecoms

- smart meters
- sensors
- controllers
- grid communication devices

$\Downarrow$

A huge amount of data,
a potential for optimized management:
demand response, principal-agent models, bilevel optimization

Outline of the presentation

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More than 24 years of cooperation with industry partners

- As academics, we cooperate with industry partners, looking for longlasting close relations
- We are not consultants working for clients, but focus on capacity building
- Our job consists mainly in
  - training Master and PhD students, working within the company and interacting with us, on subjects designed jointly
  - developing methods, algorithms
  - contributing to computer codes developed within the company
  - training professional engineers in the company

Let's open the Russian dolls. . . one by one

- École nationale des ponts et chaussées
  is one of the world's oldest engineering institutes
  and hosts a substantial research activity
  - CERMICS
    is the applied mathematics
    and scientific computing research center
    - The Optimization Group
      is one of the three groups harbored by the Cermics

and it comprises a subgroup specialized in stochastic optimization

Jean-Philippe Chancelier, Michel De Lara, Vincent Leclère
and Pierre Carpentier (part time)

Outline of the presentation


eDF

Électricité de France R & D / Département OSIRIS

- *Contributions to the Discretization of Measurability Constraints for Stochastic Optimization Problems*, Kengy Barty 2004
- *Optimization under Probability Constraint*, Laetitia Andrieu 2004
- *Variational Approaches and other Contributions in Stochastic Optimization*, Cyrille Strugarek 2006
- *Particular Methods in Stochastic Optimal Control*, Anes Dallagi 2007
- *From Risk Constraints in Stochastic Optimization Problems to Utility Functions*, Babacar Seck 2008
- *Resolution of Large Size Problems in Dynamic Stochastic Optimization and Synthesis of Control Laws*, Pierre Girardeau 2010
- *Risk and Optimization for Energies Management*, Jean-Christophe Alais 2013

Programme Gaspard Monge pour l'Optimisation, la recherche opérationnelle et leurs interactions avec les sciences des données (PGMO: EDF and FMJH)

- PGMO/IROE project 2024
  Leader-Follower Problems in Energy with Witsenhausen Model
- PGMO/IROE project 2023
  Optimal Operation and Valuation of Electricity Storage
- PGMO/IROE project 2016-1749H OGRE
  Optimization, Games and Renewable Energy
- PGMO/IROE project 2014-1604H LASON2
  Centralized versus Decentralized Energy Management in a Stochastic Setting
- PGMO project 2014-1605H STORY
  Scientific network on Stochastic and Robust Optimization and Applications

French Energy Council, member of the World Energy Council

- *Uncertainty, Inertia and Optimal Decision. Optimal Control Models Applied to Greenhouse Gas Abatment Policies Selection*, Laurent Gilotte 2004
- 2012 report on *Optimization Methods for Smart Grids*

SETEC Energy Solutions

Dam Optimal Management Under Uncertainties
(to assess the economic value of a hydro-valley), 2012

- Private course on
  stochastic optimization for the management of energies
- Supervision of a student

The collaboration has led to the development of the
SETEC Energy Solutions *software Hydroptim*®

Sun'R Smart Energy company

R & D SunHydrO project
(FUI, public and private funding)

- *Design and build a pumping station for energy transfer (10–12 MW) with profit-making business model*
- Supervision of a post-doctorate recruited by SUN'R Smart Energy, Ariel Waserhole 2016

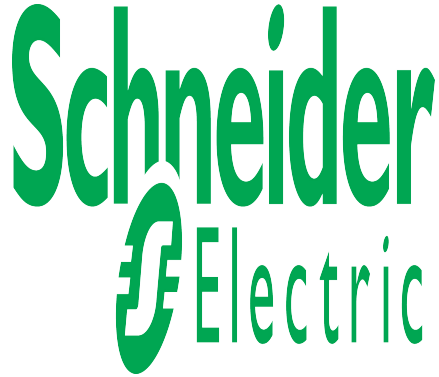
TotalEnergies

- *Stochastic Optimization for the Procurement of Crude Oil in Refineries*,
  Thomas Martin 2021
- *Design and operation management of oil-fields taking into account partially observed uncertainties*,
  Cyrille Vessaire 2021

Institute for energy transition Efficacity

- *Decentralized Optimization Methods for Energy Efficiency Management under Stochasticity*,
  François Pacaud 2018
- *Time Decomposition Methods for Optimal Management of Energy Storage under Stochasticity*,
  Tristan Rigaut 2019

Schneider Electric and Efficacity



- *Subdifferentiability in Convex and Stochastic Optimization Applied to Renewable Power Systems*,
  Adrien Le Franc 2021

Pers-ee company

- *Design and Operation of Hydrogen Supply Chains under Renewable Production and Demand Uncertainties*, Raian Lefgoum

RTE, France's Transmission System Operator

- Private course on stochastic optimization and risk handling for the management of energies
- *Dynamic Programming and Decomposition Methods for Prospective Studies in Energy Systems*,
  Camila Martínez Parra

Outline of the presentation

- More renewable energy
  - $\Longrightarrow$ more randomness in production
  - $\Longrightarrow$ more flexibility needed (production and demand)
  - $\Longrightarrow$ more storage capacity and management
- How do you manage decentralized production, demand and storage?
  - to satisfy production=demand when both are random
  - at least cost
- Our answer:
  solving large-scale multistage stochastic optimization problems by mixing multiple decomposition methods
  - time blocks + prices/resources
    - dynamic programming across time blocks
      + prices/resources decomposition by time block
      (application to two time scales battery management)
  - time + space
    - nodal decomposition by prices or by resources
      + dynamic programming within node
      (application to large scale microgrid management)

Training and events organization

- SESO Smart Energy and Stochastic Optimization
  International Thematic Weeks and Winter Schools
  2014–2019, 2023
- SESO and CIRM-Interface 2019 Winter Course,
  Stochastic Optimization for Large-Scale Systems
  4-8 November 2019
- BIRS-CMO workshop
  Multi-Stage Stochastic Optimization for Clean Energy Transition
  22-27 September 2019

Publications in energy journals

François Pacaud, Pierre Carpentier, Jean-Philippe Chancelier, and Michel De Lara.

Optimization of a domestic microgrid equipped with solar panel and battery: Model predictive control and stochastic dual dynamic programming approaches.
Energy Systems, 15:115–139, 2024.

Adrien Le Franc, Pierre Carpentier, Jean-Philippe Chancelier, and Michel De Lara.

EMSx: A numerical benchmark for energy management systems.
Energy Systems, 14:817–843, 2023.

François Pacaud, Michel De Lara, Jean-Philippe Chancelier, and Pierre Carpentier.

Distributed multistage optimization of large-scale microgrids under stochasticity.
IEEE Transactions on Power Systems, 37(1):204–211, 2022.

Tristan Rigaut, Pierre Carpentier, Jean-Philippe Chancelier, Michel De Lara, and Julien Waeytens.

Stochastic Optimization of Braking Energy Storage and Ventilation in a Subway Station.
IEEE Transactions on Power Systems, 34(2):1256–1263, March 2019.

Jean-Christophe Alais, Pierre Carpentier, and Michel De Lara.

Multi-usage hydropower single dam management: chance-constrained optimization and stochastic viability.
Energy Systems, 8(1):7–30, February 2017.

Laetitia Andrieu, Michel De Lara, and Babacar Seck.

Taking risk into account in electricity portfolio management.
In Mario V.F. Pereira Steffen Rebennack, Panos M. Pardalos and Niko A. Iliadis, editors, *Handbook of Power Systems 1*. Springer Verlag, 2009.

A more detailed example of our research

Excerpts from the slides
Large Scale Smart Grid Optimal Management

`http://cermics.enpc.fr/~delara/exposes/slides_Princeton-SantaBarbara_2021.pdf`