

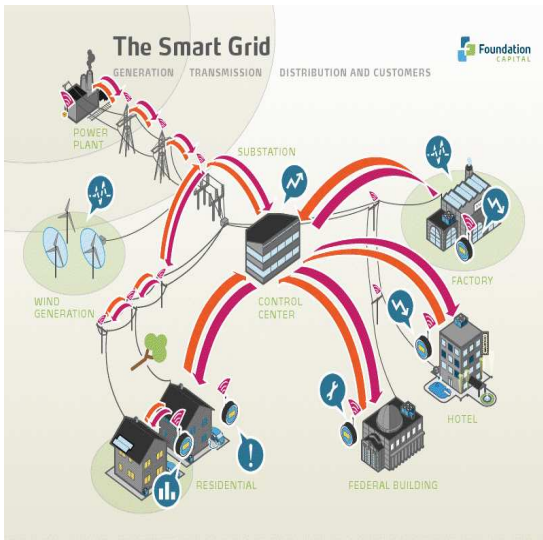
# Cooperating between academy and industry for the optimization of smart grids

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CERMICS, École des Ponts ParisTech, France

CERMICS, France

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# Challenges ahead for optimization in energy



*Optimizing is  
obtaining the best compromise  
between needs and resources*

Marcel Boiteux  
(président d'honneur  
d'Électricité de France)

# Outline of the talk

- ✎ In 2000, the *Optimization and Systems* group was created at École des Ponts ParisTech and, since then, we have *trained PhD students* in stochastic optimization, mostly with Électricité de France Research and Development
- ✎ Since 2011, we witness a growing demand from energy firms for stochastic optimization, fueled by a *deep and fast transformation of power systems*
- ✎ We will sketch *how we cooperate with the industry* on *smart grid optimization* issues

# Outline of the presentation

- 1 École des Ponts ParisTech–Cermics–Optimization and Systems
- 2 What is happening to power systems?
- 3 How we cooperate between academy and industry
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# L'École nationale des ponts et chaussées



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

## University Paris-Est

### ✎ École des Ponts ParisTech

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 and Systems Group

is one of the three groups harbored by the Cermics

# Here is the flesh and blood of the Optimization and Systems Group

## Senior researchers

- ▷ Jean-Philippe CHANCELIER
- ▷ Michel DE LARA
- ▷ Vincent LECLÈRE
- ▷ Frédéric MEUNIER

## Associated researcher

- ▷ Pierre CARPENTIER (ENSTA ParisTech)

## Students

- ▷ engineering schools, master, PhD, post-doc

# The Optimization and Systems Group specializes in... optimization!

## ☞ Methods

- ▷ Stochastic optimal control (discrete-time)
  - Large-scale systems
  - Discretization and numerical methods
  - Probability constraints
- ▷ System control theory, viability and stochastic viability
- ▷ Discrete mathematics; combinatorial optimization; operations research

## ☞ Applications

- ▷ Optimized management of energy systems under uncertainty (production scheduling, power grid operations, risk management)
- ▷ Transport modelling and management
- ▷ Natural resources management (fisheries, mining, epidemiology)

## ☞ Softwares

- ▷ Scicoslab, NSP
- ▷ Oadlibsim

# We teach at master and engineering levels

## Masters

- ▷ Master Parisien de Recherche Opérationnelle
- ▷ Optimisation & Théorie des Jeux. Modélisation en Economie
- ▷ Mathématiques, Informatique et Applications
- ▷ Économie du Développement Durable, de l'Environnement et de l'Énergie
- ▷ Renewable Energy Science and Technology Master ParisTech

## École des Ponts ParisTech

- ▷ Introduction à la recherche opérationnelle (F. MEUNIER)
- ▷ Optimisation et contrôle (J.-P. CHANCELIER)
- ▷ Modéliser l'aléa (J.-P. CHANCELIER)
- ▷ Modélisation pour la gestion durable des ressources naturelles (M. DE LARA)

Our industrial contracts mostly deal with energy issues, whereas the public ones touch on biodiversity management

### Industrial contracts

- ▷ Conseil français de l'énergie (CFE)
- ▷ SETEC Energy Solutions
- ▷ Électricité de France (EDF R&D)
- ▷ Thales
- ▷ Institut français de l'énergie (IFE)
- ▷ Gaz de France (GDF)
- ▷ PSA

### Public contracts

- ▷ STIC-AmSud (CNRS-INRIA-Affaires étrangères)
- ▷ Centre d'étude des tunnels
- ▷ CNRS ACI Écologie quantitative
- ▷ RTP CNRS

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# Three key drivers are remolding power systems



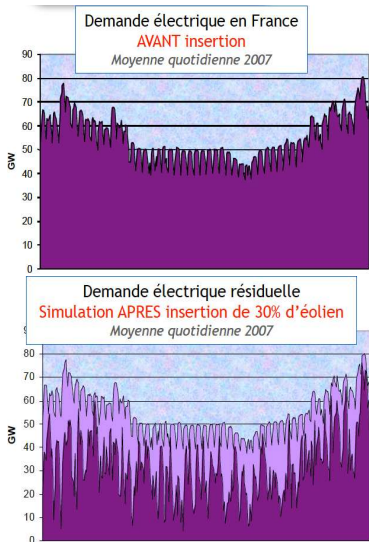
- Environment
- Markets
- Technology



Multiple levels of integration – interoperability  
Distributed Generation Renewable Generation Storage Demand Response



# Key driver: environmental concern



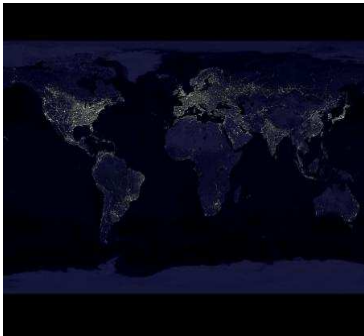
The European Union climate and energy package materializes an environmental concern with three 20-20-20 objectives for 2020

- ☞ a 20% improvement in the EU's energy efficiency
- ☞ a 20% **reduction** in EU **greenhouse gas emissions** from 1990 levels
- ☞ raising the **share** of EU energy consumption produced from **renewable resources** to 20%



Successfully **integrating renewable energy sources** has become critical, and made especially difficult because they are **unpredictable** and **highly variable**, hence triggering the use of local storage

# 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 public authorities  
(autonomy, efficiency)
- ✎ with a **network in horizontal expansion**
- ✎ with more and more exchanges  
(trade of commodities)



A **change of paradigm for management**  
from **centralized** to more and more **decentralized**

# Key driver: telecommunication technology



Linky

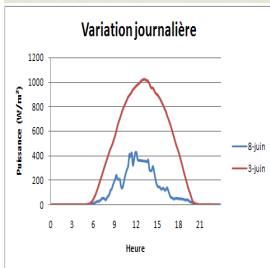
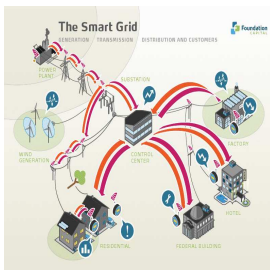
A power system with **more and more technology** due to evolutions in the fields of metering, computing and telecoms

- ☞ smart meters
- ☞ sensors
- ☞ controllers
- ☞ grid communication devices. . .



A **huge amount of data** which, one day, will be a new **potential for optimized management**

# The “smart grid”? An infrastructure project with promises to be fulfilled by a “smart power system”



## Hardware / infrastructures / smart technologies

- ▶ Renewable energies technologies
- ▶ Smart metering
- ▶ Storage

## Promises

- ▶ Quality, tariffs
- ▶ More safety
- ▶ More renewables (environmentally friendly)

## Software / smart management (energy supply being less flexible, make the demand more flexible)

smart management, smart operation, smart meter management, smart distributed generation, load management, advanced distribution management systems, active demand management, diffuse effacement, distribution management systems, storage management, smart home, demand side management...

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# We cooperate with industry partners, looking for longlasting research relations through training and capacity building

- ☞ As academics, we cooperate with industry partners,  
looking for longlasting close relations
- ☞ We are not consultants working for clients,  
but focus en 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

# Électricité de France R & D / Département OSIRIS

## ✎ Électricité de France is the French electricity main producer

- ▷ 159 000 collaborateurs dans le monde
- ▷ 37 millions de clients dans le monde
- ▷ 65,2 milliards d'euros de chiffre d'affaire
- ▷ 630,4 TWh produits dans le monde

## ✎ Électricité de France Research & Development

- ▷ 486 millions d'euros de budget
- ▷ 2 000 personnes

## ✎ Département OSIRIS

Optimisation, simulation, risques et statistiques pour les marchés de l'énergie  
 Optimization, simulation, risks and statistics for the energy markets

- ▷ 145 salariés (dont 10 doctorants)
- ▷ 25 millions d'euros de budget



## We have trained 10 PhD from 2004 to 2014, most of them now related with EDF and energy management

- \* Laetitia ANDRIEU, former PhD student at EDF, now at EDF R & D
- \* Kengy BARTY, former PhD student at EDF, now at EDF R & D
- \* Anes DALLAGI, former PhD student at EDF, now at EDF R & D
- \* Laurent GILOTTE, former PhD student with IFE, now at ERDF
- \* Pierre GIRARDEAU, former PhD student at EDF, now at ARTELYS
- \* Eugénie LIORIS, former PhD student, now post-doc at Berkeley
- \* Babacar SECK, former PhD student at EDF, now at University of Calgary
- \* Cyrille STRUGAREK, former PhD student at EDF, now at Munich-Ré
- \* Jean-Christophe ALAIS, former PhD student at EDF, now at ARTELYS
- \* Vincent LECLERE, former PhD student (partly at EDF), now at CERMICS

# Recently, contacts have expanded

## with small companies

- ▷ ARTELYS
- ▷ SETEC Energy Solutions
- ▷ SUN'R Smart Energy

## with large companies

- ▷ French Energy Council (CFE), member of the World Energy Council
- ▷ institute for energy transition Efficacity
- ▷ Total Énergies Renouvelables

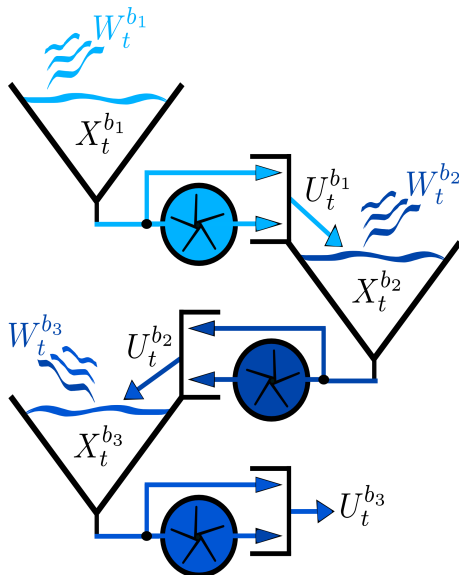
# ARTELYS

- ➡ ARTELYS is a company specializing in optimization, decision-making and modeling
- ➡ Relying on their high level of expertise in quantitative methods, the consultants deliver efficient solutions to complex business problems
- ➡ They provide services to diversified industries: Energy & Environment, Logistics & Transportation, Telecommunications, Finance and Defense
- ➡ We have trained master and PhD students that now work for ARTELYS

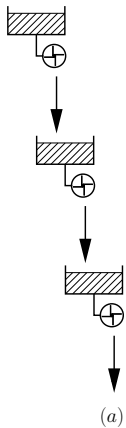
# SETEC Energy Solutions

- ➡ Créée en 2011, **SETEC Energy Solutions** est la filiale du groupe SETEC spécialisée dans les domaines de la **production** et de la **maîtrise de l'énergie** en France et à l'étranger
- ➡ SETEC Energy Solutions apporte à ses clients la maîtrise des principaux process énergétiques pour la mise en œuvre de solutions innovantes depuis les phases initiales de définition d'un projet jusqu'à son exploitation
- ➡ We worked on the **optimization of a dam valley**, to assess the **opportunity** to **invest in a dam concession**

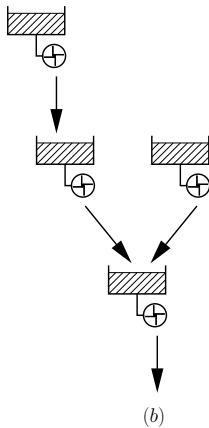
# Complexity increases with interconnected dams



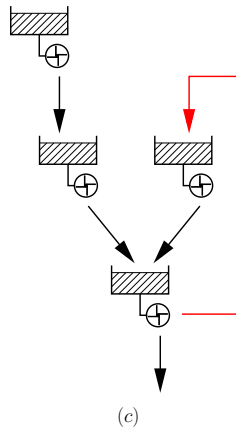
# Typology of hydro-valleys



dams in cascade

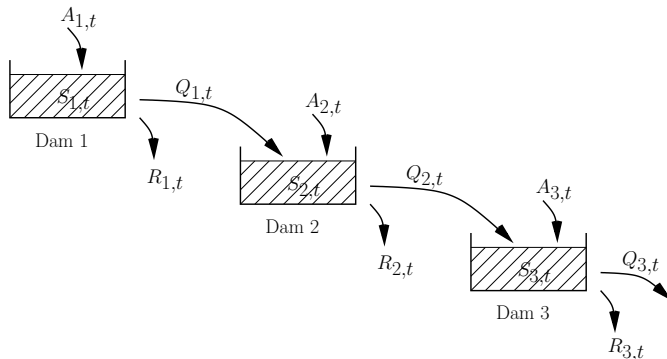


converging valleys



pumping

# Sketch of a cascade model with dams $i = 1, \dots, N$



$a_i(t)$  : inflow into dam  $i$  at time  $t$  (rain, run off water)

$S_i(t)$  : volume in dam  $i$  at time  $t$  (water volume)

$q_i(t)$  : turbinéd from dam  $i$  at time  $t$  (valued at price  $p_i(t)$ )

$r_i(t)$  : spilled volume from dam  $i$  at time  $t$  (irrigation...)

# The SUN'R Smart Energy company

- ☞ **SUN'R Smart Energy** is a Paris based company with
  - ▷ a focus on building smarter solutions for **distributed energy resources** in the context of emerging deregulated energy markets
  - ▷ and a solid political will towards the development of both **renewables** and energy **storage**
- ☞ In 2011, we started a collaboration that led us to be part of the **R & D SunHydrO project**



# What is the R & D SunHydrO project?



- ☛ 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
- ☛ ENSTA and ENPC are advisors for the optimization part
  - supervision of a post-doctorate recruited by SUN'R Smart Energy
  - in cooperation with an Operations Research specialist, especially recruited by SUN'R Smart Energy

# What contains the R & D SunHydrO project?

- ☞ A simulation/assessment model, that describes the functioning of
  - ▷ a pumping station for energy transfer, with detailed models of the turbines
  - ▷ the electricity market, with different types of reserves (short, medium, long term) and their costs
- ☞ An optimization model that represents
  - ▷ time at discrete steps
  - ▷ control and state variables
  - ▷ uncertainty in renewable energy production
  - ▷ dynamical equations for storage
  - ▷ information structure,  
or how control variables are allowed to depend on past events
  - ▷ constraints and criterion
  - ▷ risk attitude of the decision-maker

# French Energy Council, member of the World Energy Council, contracted the Cermics to report on Optimization methods for smart grids

- ✚ Formed in 1923, the **World Energy Council** (WEC) is the UN-accredited global energy body, representing the entire energy spectrum
- ✚ WEC informs global, regional and national energy strategies
- ✚ In 2012, the **French Energy Council** contracted the Optimization and Systems group to produce a report on **Optimization methods for smart grids**, freely available on October 2014
  - ▷ Power Systems Undergo a Deep Remolding
  - ▷ Energy Actors Express Renewed Demands towards Optimization
  - ▷ Uncertainty in Decision-Making Can Be Handled in Many Ways
  - ▷ Displaying Stochastic Optimization Resolution Methods
  - ▷ Relating Ongoing Works and Practices

# We work with the institute for energy transition Efficacy

- ✚ Both France and Europe are committed to a 20% reduction in energy consumption and greenhouse gas (GHG) emissions by 2020, and longer-term objectives, so-called Factor 4 commitments for 2050, set even higher targets
- ✚ If these targets are to be met, major efforts will be required from **cities** (housing, offices, shops, urban transport, etc.), which alone account for two thirds of energy consumption and around 50% of GHG emissions
- ✚ To meet this challenge, the French government has decided to set up an **institute for urban energy transition, Efficacy**
- ✚ This research and development institute is of a new kind, based on an action research approach and bringing together France's cutting-edge skills from both public and private sector
- ✚ Michel De Lara is member of the **Efficacy scientific committee**
- ✚ The Optimization and Systems group **advises Efficacy** on **optimization** issues in **microgrid** management

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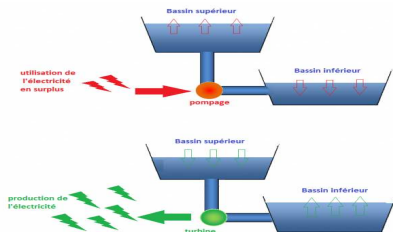
# The electricity grid is becoming more and more complex



● Multiple levels of integration – interoperability  
● Distributed Generation    ● Renewable Generation    ● Storage    ● Demand Response

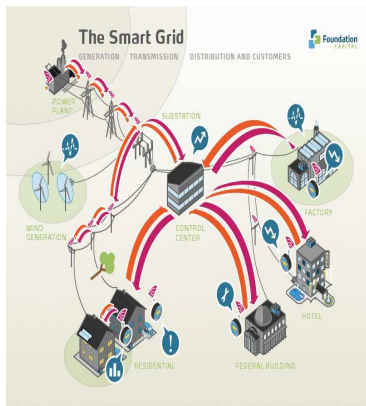
- ☞ Multiple energy resources: photovoltaic, solar heating, heatpumps, wind, hydraulic power, combined heat and power
- ☞ Spatially distributed energy resources (onshore and offshore windpower, solarfarms), producers, consumers
- ☞ Strongly variable production: wind, solar
- ☞ Intermittent demand: electrical vehicles
- ☞ Two-ways flows in the electrical network
- ☞ Environmental and risk constraints (CO<sub>2</sub>, nuclear risk, land use)

# Current trends in the electric grid foster the use of decentralized and stochastic optimization



- ✎ More telecom technology  
 ↳ more data
- ✎ More data and more unpredictability  
 ↳ more statistics
- ✎ More unpredictability  
 ↳ more storage  
 ↳ more dynamic optimization
- ✎ More unpredictability  
 ↳ more stochastic dynamic optimization
- ✎ More telecom technology and more decision centers  
 ↳ more decentralized optimization

# Decentralized and stochastic optimization must cope with challenges induced by the electric grid transformation



- ✎ tackling **large scale** stochastic optimization problems:  
design algorithms that use spatial, temporal and random structures to decompose problems in solvable subproblems
- ✎ handling **risk** issues by proper mathematical formulations, and design adapted algorithms
- ✎ coping with team problems, with **decentralized and private information**
- ✎ deal with **multiple actors** with their own objectives: game theory, stochastic equilibrium, market design



# We propose to launch a Club LORI

## Logiciels pour l'Optimisation des Réseaux Intelligents

### ☞ Goal of the Club LORI

- ▷ Making academics and companies closer in working together
- ▷ On algorithms and **softwares**:  
dedicated toolboxes, including modelers and solvers
- ▷ For **smart grid optimization**: demand-side management, peak shaving, wind/solar energy insertion and battery usage, combined heat-power generation, energy control of buildings, micro-grid management

### ☞ Working method of the Club LORI

- ▷ Semester/annual orientation council
- ▷ Weekly/monthly meetings
- ▷ Recruitment of a **software engineer**

### ☞ Funding of the Club LORI

- ▷ 15 kEUR per year (during five years)
- ▷ EDF/PGMO, Artelys, Sun'R Smart Energy
- ▷ within the newly created Association REI smartgrids France (Summer 2015)