Quelques évolutions récentes autour des modèles d’optimisation pour le système électrique

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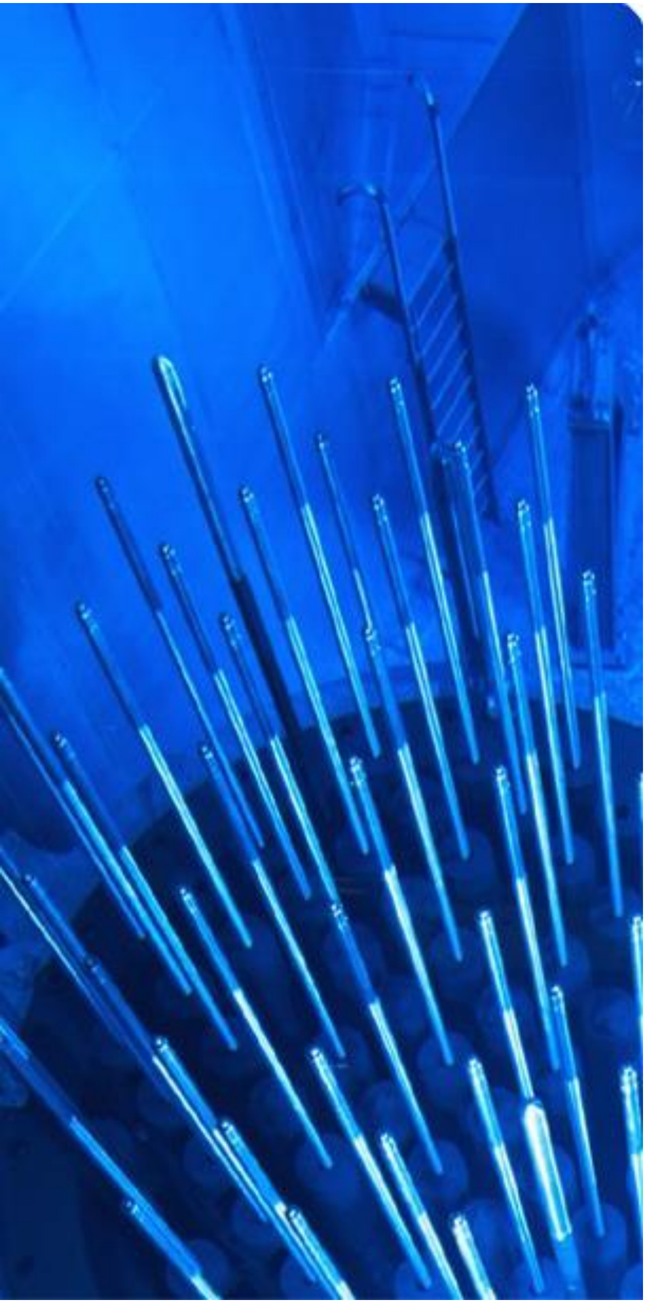


Plan

- Introduction : The Generation Management Chain
- Classical Problems
- New Problems
- Challenges for Optimization

The Generation Management Chain : Context and Process

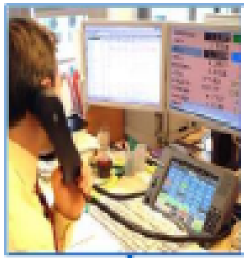
Generation Management

Supply

59 nuclear power plants

50 classical thermal Plants (coal, fuel, gas)

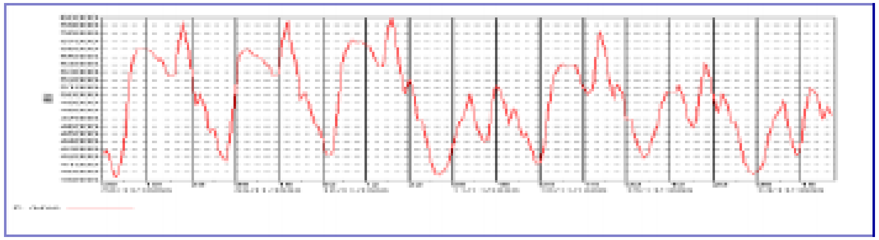
50 hydro valleys



Purchases (markets & producers)

Demand

Time series with yearly, weekly and daily trends :
Profiles consumers, network losses, EDF own consumption, sales



Shedding Contracts

Regulated Transactions

- cogeneration
- Renewable (Wind, PV)

Generation Management

Supply | **Uncertainties** | **Load**

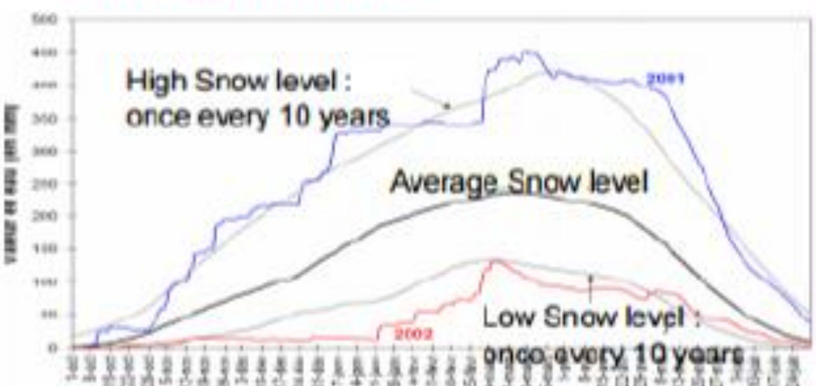
Supply

On power plants

Random outage process
Shut-down duration
Level of nuclear fuel stock

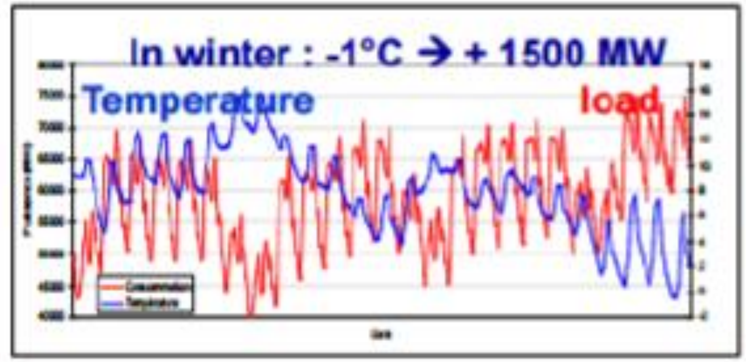
On weather

- Temperature of rivers
- Renewables production
- Random inflows



Load

On weather



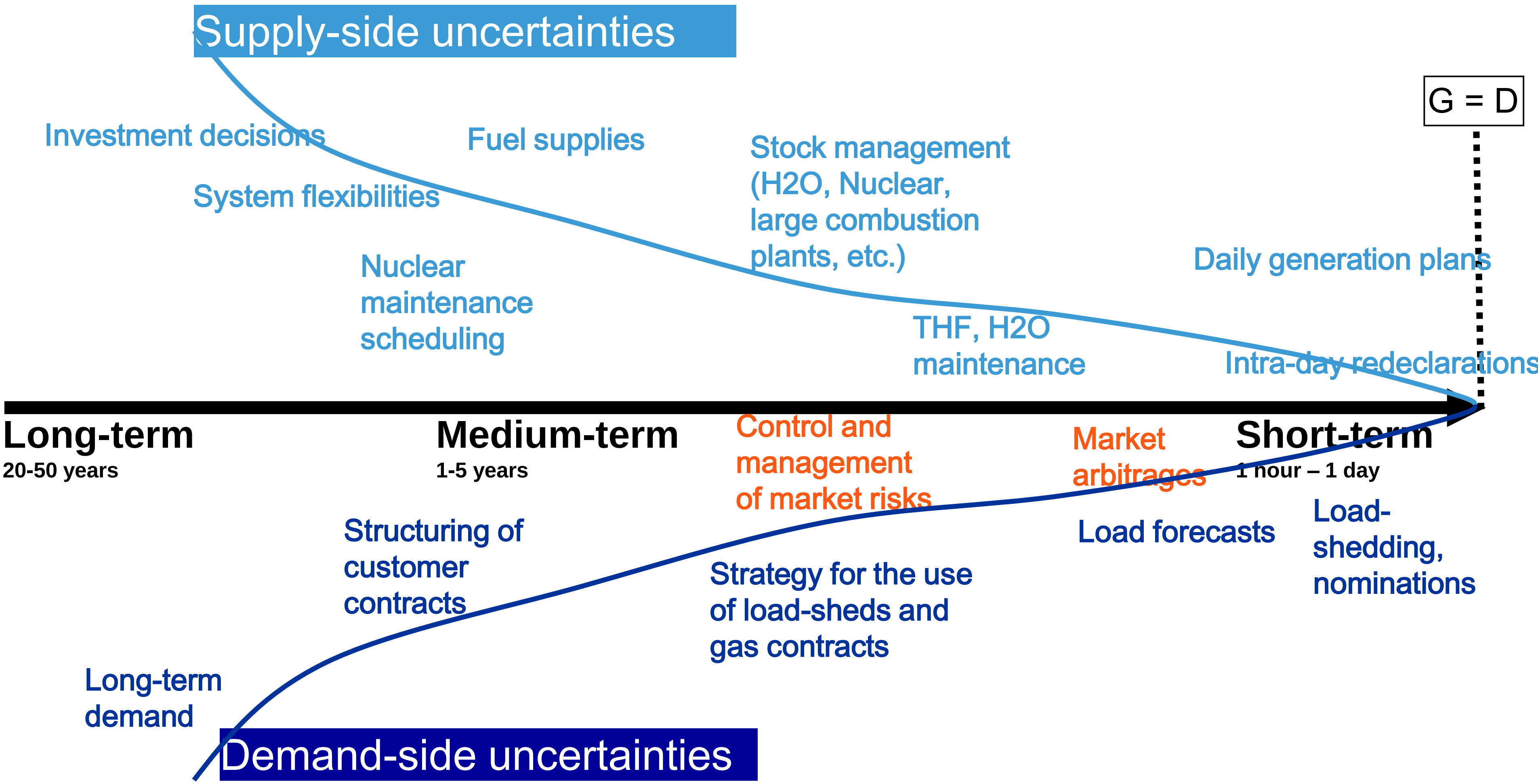
On social events

On economic context

- Industrial activity
- Customers behavior /competitors
- Exchanges with other countries

Classical Problems

Energy management

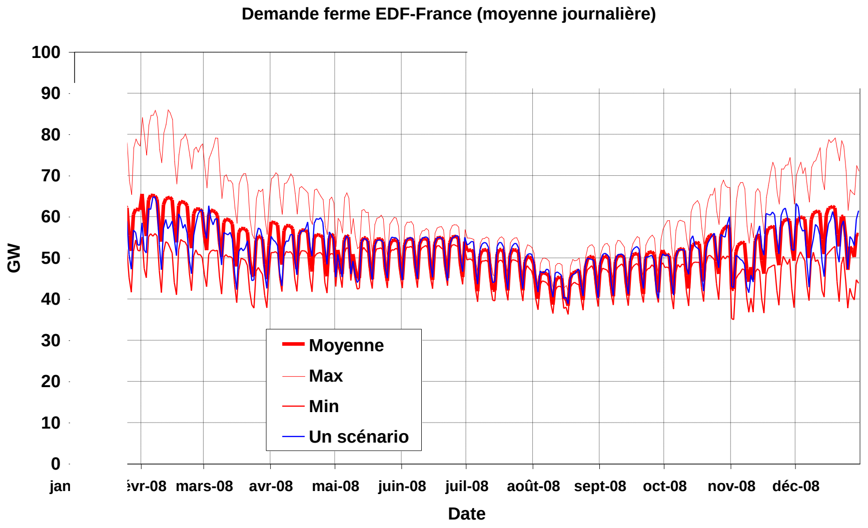


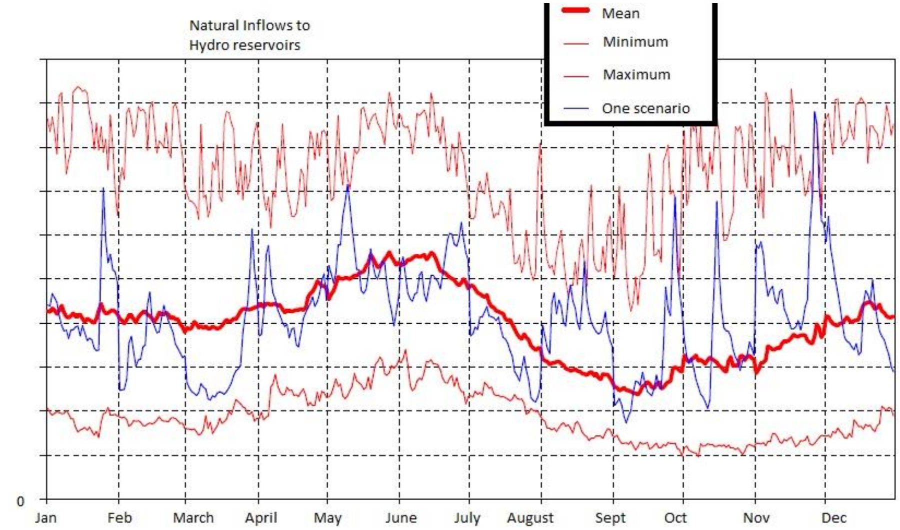
Uncertainties in Energy Management

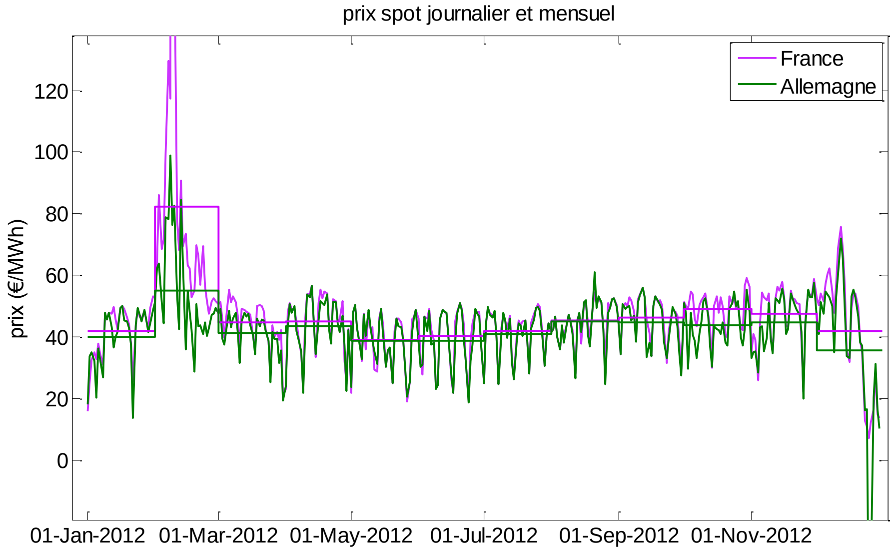
- **Weather**
  - Temperature
  - Wind
  - Sun
  - Snow melting
- **Technical**
  - Failures
  - Duration of plant shutdown
  - Level of fuel (nuclear)
  - …
- **Market**
  - Prices…

And strong correlations between all uncertainties…

Examples


Demande ferme EDF-France (moyenne journalière)
GW
100
90
80
70
60
50
40
30
20
10
0
jan
févr-08 mars-08 avr-08 mai-08 juin-08 juil-08 août-08 sept-08 oct-08 nov-08 déc-08
Date
Moyenne
Max
Min
Un scénario

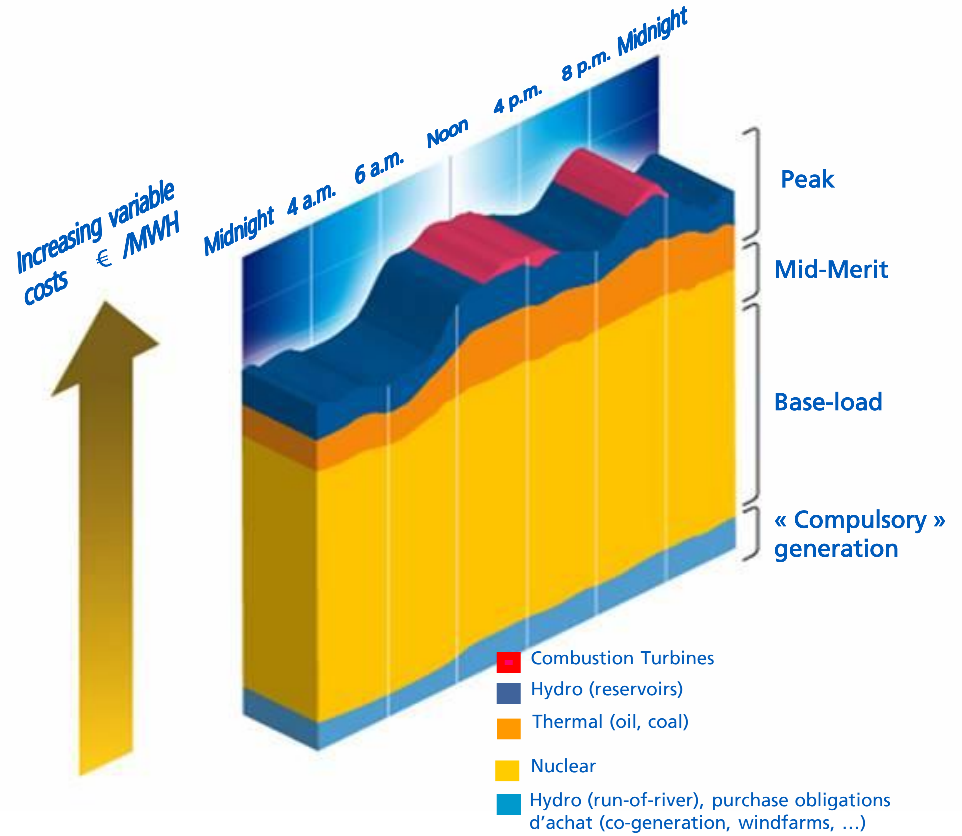

Natural Inflows to Hydro reservoirs
Mean
Minimum
Maximum
One scenario
0
Jan Feb March April May June July August Sept Oct Nov Dec


prix spot journalier et mensuel
prix (€/MWh)
120
100
80
60
40
20
0
01-Jan-2012 01-Mar-2012 01-May-2012 01-Jul-2012 01-Sep-2012 01-Nov-2012
France
Allemagne

Energy Management – the traditionnal problems

❑ Computing optimal schedules for all generating plants :

- ➢ **Satisfying the equilibrium between Generation and Demand**
- ➢ **Minimising generation costs**
- ➢ **Respecting all technical constraints**
- ➢ **Dealing with Uncertainties**

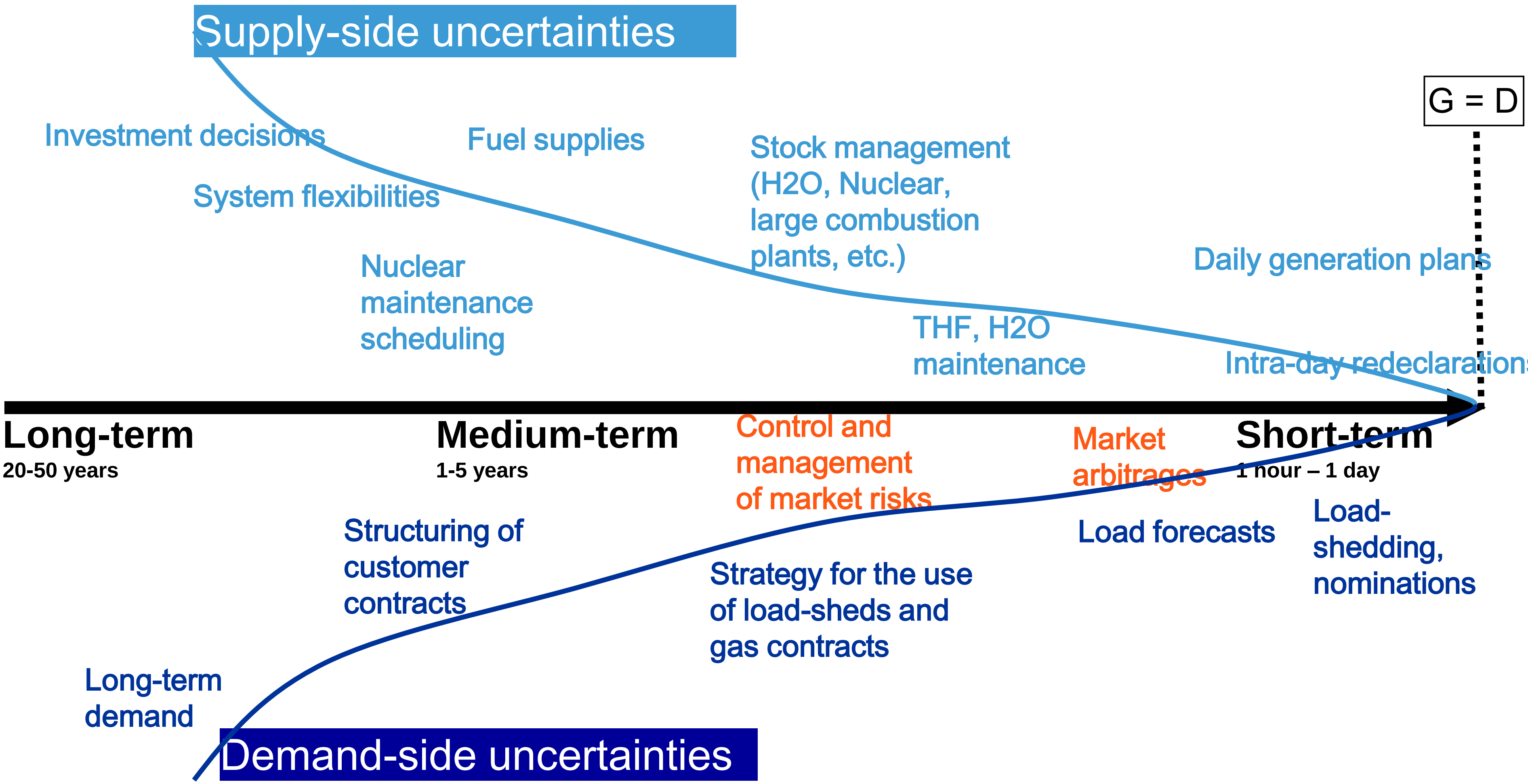


Merit order of generation means
Example of a high consumption on a winter day

Some 'classical' optimisation problems:

- **Planning Nuclear Outages for Refuelling**
- **Computing optimal strategies for stock management**
- **Optimising hourly schedules the day before (Unit Commitment)**

Energy management

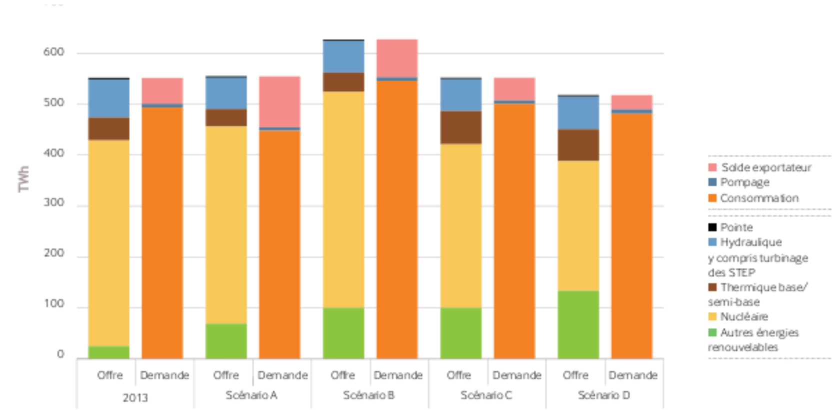


Details in appendix and on the PGMO web site (www.fondation-hadamard.fr/pgmo)

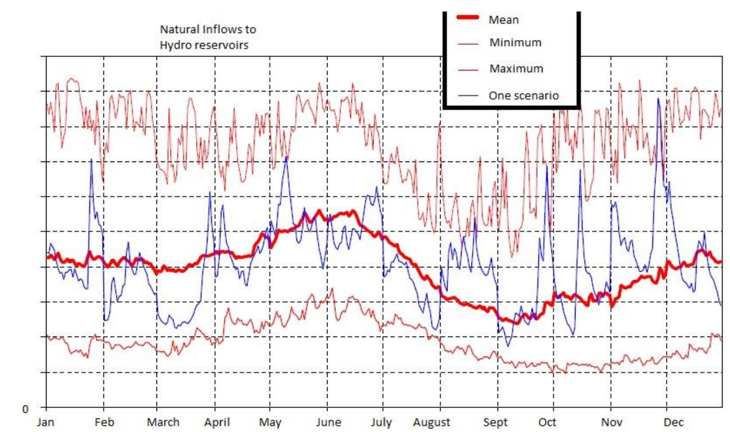
New Problems

Energy Management – recent evolutions

- Strong increase of the share of renewable generation , intermittent and highly unpredictable
- Regulatory evolutions
  - Capacity mechanism,
  - Balancing markets
- Communicating meters (Linky)
  - Load « piloting »
  - Local optimisations



Comparison of the electric mix in 2030 – 4 different prospectve scenario (Annual energy)
Source : Bilan Prévisionnel RTE 2014



→ New problems emerge
The classical problems remain but become more and more difficult

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New Challenges -uncertainties

- Strong increase of the share of renewable generation : Wind power and Photovoltaic Power :
  - The unpredictability of the residual demand facing the traditional maneuvering mix (the non fatal part) increases
  - The uncertainties of the models increase

Huge need of stochastic models, mainly on the short-term

New Challenges -technologies

- Communicating meters:
  - Load Management increases

Optimising together generation and demand

- New controls appear in the typical problems

X : commands on production
Y : commands on demand

$$
\begin{aligned}
\min_{X,Y} \quad & c_P^T X + c_D^T Y \\
s.t. \quad & \\
& AX = dY + d^0 \\
& F_P X \leq f_P \\
& F_D Y \leq f_D \\
& X_R, Y_R \in \mathbb{R}^{N_R} \\
& X_B, Y_B \in \{0,1\}^{N_B}
\end{aligned}
$$

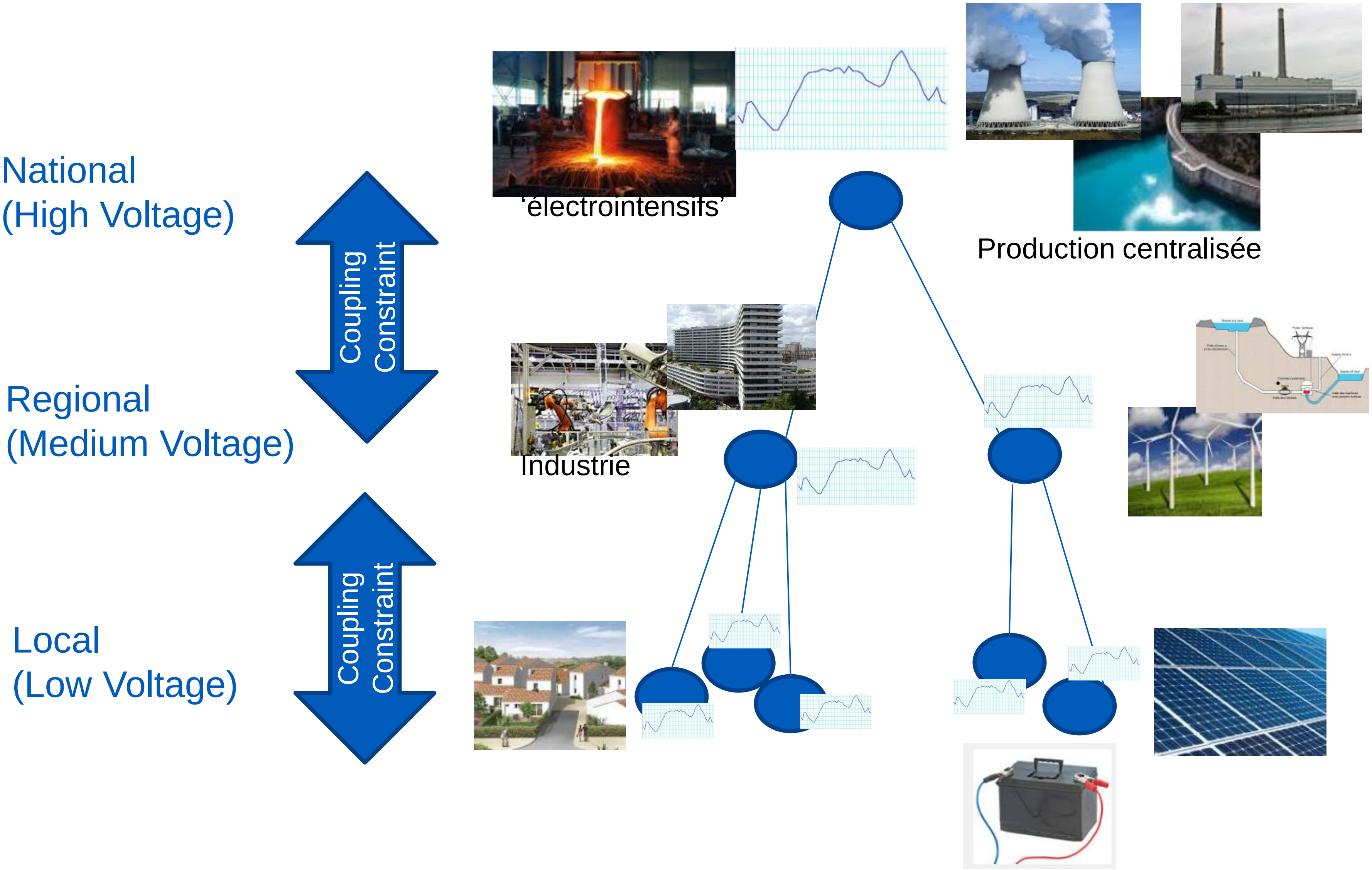
New Challenges -regulation

- Regulatory evolutions :
  - Balancing markets
  - Capacity mechanism
  - Local Actors

New problems to be modelled :

- New markets
- Local Global Interactions
- New local problems

New challenges – Network modelling



New Problems

- New objective functions
  - Decentralised Optimisation => New actors
  - Bilevel (Multilevel) Optimisation
- New decision variables
  - Flexibilities on demand
  - Network
- New constraints
  - Coupling constraints

Merci

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APPENDIX

Planning Nuclear Outages for Refuelling

Planning Nuclear Outages

Main Objective

Compute optimal schedules for outages (minimising costs) for nuclear plants dealing with operationnal constraints and seasonnality of the electricity demand

Outline of the problem

58 plants, between 3 and 5 outages to plan for each plant, over a 5 years period

Numerous operationnal constraints , mainly because of the human resources and machines that are used during a refuelling or maintenance

Costs : intrinsic cost of refuelling and replacing cost for energy (the production of the stopped plant has to be replaced by coal of fuel plants at a higher cost)

Planning Nuclear Outages

Modelling

Costs :
- **Nuclear Fuel cost ,**
- **Other fuel cost**

Decision variables

- **Outages dates** → **integer variables**
- **Amount of fuel at each refuelling** → **integer**
- **Energy produced by each plant at each time step of each scenario** → **continuous/integer**

Constraints

- **Demand : coupling constraint**
- **technical constraints** (constraints on the power level at end of cycle, minimum and maximum power, minimum and maximum levels on fuel stock, maximum number of hours « not at maximum level »,… → **non linear constraints**
- **constraints on the outages schedules**: (early.late dates for some outages, max number of outages at the same time, constraints on ressources, coupling constraints between plants….)

→ **non linear constraints**

The mathematical problem

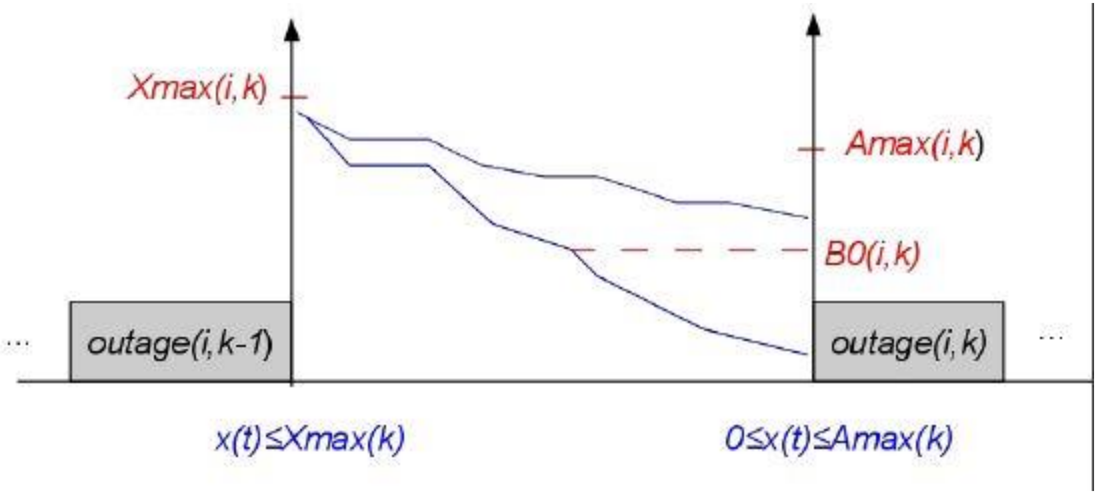
A weekly timestep over 5 years

10000 integer variables, 100000 real variables, 1.7M constraints (deterministic approach)

Stochastic problem, strongly combinatorial, non linear, with coupling constraints, to be solved in a short calculation time

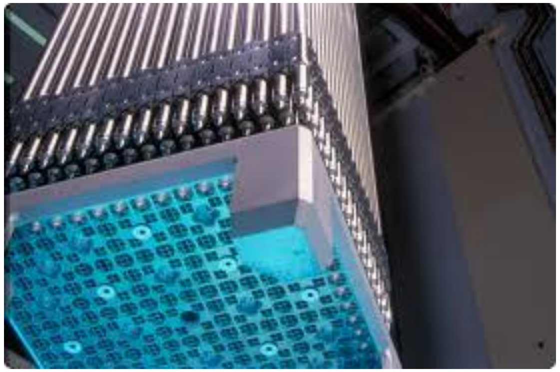
EDF

Constraints on stock level, inducing non linearities



Stock constraints : dynamics , bounds,

Constraints on production, inducing non linearities



Modeling : introducing « state » variables
Discrete and continous variables are coupled…

Modelling the nuclear problem

- Modelled as a recourse problem : *Outage dates and refueling quantities are recomputed monthly (with new hypothesis, mainly on uncertainties) BUT results on the forthcoming month won't be changed*

$$\underset{a(i,k),r(i,k)p(i,t,\omega),p(j,t,\omega)}{Min}\{\sum_{i,k} C_{i,k}\cdot r(i,k)$$
$$+\sum_{\omega}\pi(\omega)[\sum_{j,t} C_{j,t}^{\omega}\cdot p(j,t,\omega)\cdot dt-\sum_{i,k} C_i^T\cdot x(i,T,\omega)]\}$$
$$s.t.$$
$$\forall t,\omega \sum_{i} p(i,t,\omega)+\sum_{j} p(j,t,\omega)=D_t^{\omega}$$

\+ operating constraints of NPP and CTU units

\+ scheduling and ressource constraints on outages of NPP units

- Variables $a(i,k)$ and $r(i,k)$: *Here and now* variables, independent of the scenarios
- Variables $p(i,t,\omega)$ and $p(j,t,\omega)$: *Wait and see* or *recourse* variables depending on the scenarios

- **i : nucl unit, j : other unit, t : timestep, ω : scenario**
- **x(i; t; ω) : Stock level**
- **p(i; t; ω) : Production level**
- **a(i; k) : Outage date of unit i at cycle k**
- **r (i; k) : Refueling of unit i at cycle k (energy)**
- **C : cost**
- **D : demand**

Computing optimal strategies for stock management

Mid-Term Generation Management

Main Objective

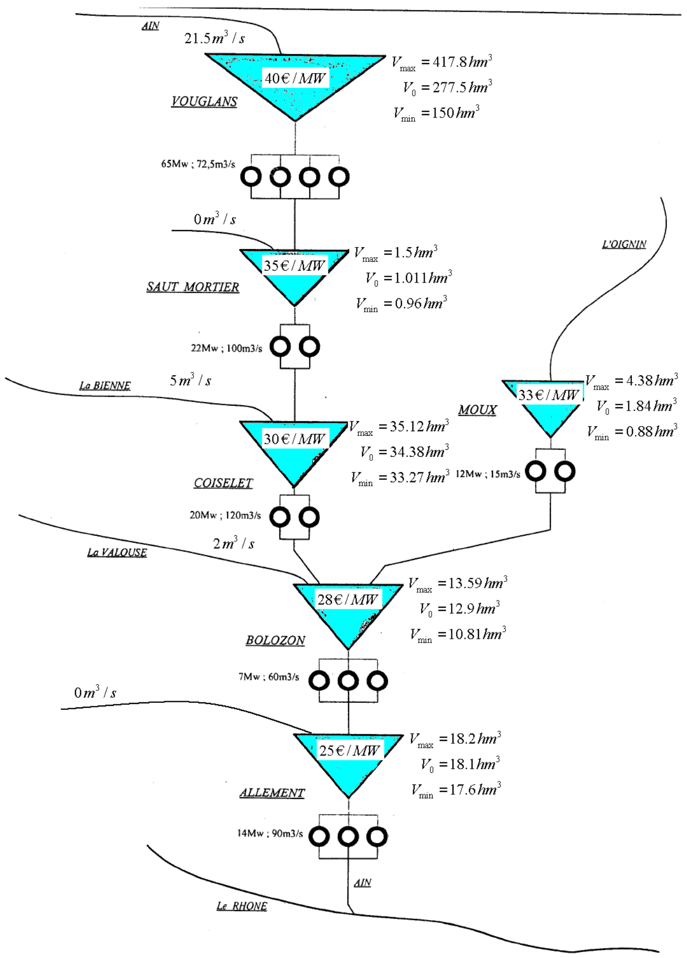
Compute an optimal strategy for stock management

Context

10 to 200 stocks (hydraulic reservoirs, nuclear power, emission –CO_2, Nox…, contracts : demand side managements, long-term fuel contracts)
500 to 10000 scénarios
Daily time-step over 2 to 3 years

Objective : **compute coordinated usage values for each stock.**
(***usage value = what will be earned by not having to use an expensive generation plant in the future)***
⇒**Used to define a strategy** (decision to take facing each possible future scenario, choosing between using the stock now or at a future date , minimizing the global cost

Mid-Term generation management : example of hydro valley



Mi-Term optimisation

Modelling of the problem

Calculate Bellman Values for each stock of energy with :

- Constraints on volumes of stocks
- Constraints on the « power »,(min, max…)
- Non-anticipativity constraint : only the probabilistic distribution of uncertainties can be used
- Coupling constraints on stocks (global demand or flow constraints)

Difficulties

- Objective function and constraints may be non-convex (head effect, runnig ranges…), non differentiable….
- Objective function is non separable problem,
- Big size problem :big number of stocks (up to 50) and scenarios (up to 10000)
- How to take uncertai nties into account?

Optimising hourly schedules the day before (Unit Commitment)

Short-Term Generation Management

Main Objective

Compute schedules for each plant (thermal, hydrau, nuclear) for the next day and adjust them in intra-day

- ❑ Satisfying the equilibrium between Generation and Demand
- ❑ Minimising generation costs
- ❑ Respecting all technical constraints

Short-Term Generation Management

Hydraulic :

- **A hydro-Valley = set of interconnected power plants and reservoirs**
- **~20+ valleys, some composed of more than 50 elements**
- **Cost = global loss of water (water values)**
- **Numerous operational constraints**

Thermal:

- **58 nuclear + (very few) fuel / coal plants + gaz plants**
- **Cost = fuel cost**
- **Numerous operational constraints**

Difficulties

Half-hour time step, 2-days horizon, déterministic

- Between 200 000 and 300 000 variables
- 500 000 constraints, some of them coupling plants
- non convex, non linear, with mixed variables

- Very strong requirements both on optimality (gap of 1% = several millions of euros per year) and feasibility (all schedules have to be technically feasible)
- A problem to solve in a very short time (less than 10 min) due to the constraints on the operational process

Modelling

$$
(P)\begin{cases} Min \sum_{i \in I} c_i(p_i) \\ p_i \in X_i, \forall i \in I \\ p^t \in D^t, \forall t = 1,2,\ldots,T \end{cases}
$$

→ **Minimize the production cost**

→ **Dynamic constraints**

→ **Power and ancillary reserves demand constraints**

- ✓ I production units set (thermal and hydraulic)
- ✓ T number of steps for the time horizon
- ✓ p_i^t production schedule of unit i at time step t
- ✓ $p_i : (p_i^1, p_i^2, \ldots, p_i^T)$ production vector of unit i through the time horizon
- ✓ $p^t : (p_1^t, p_2^t, \ldots, p_{|I|}^t)$ production vector of all units at time step t
- ✓ X_i local dynamic constraints of unit i
- ✓ D^t global demand constraints at time step t (linking)
- ✓ c_i production cost of unit i through the time horizon

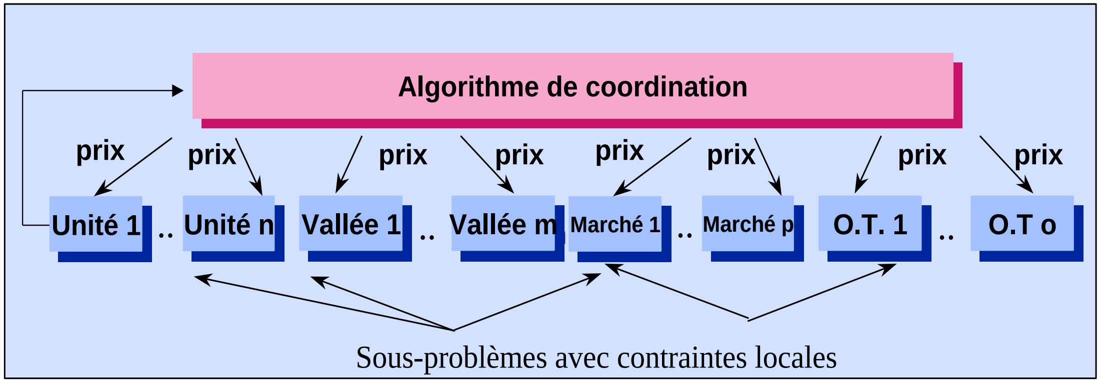
Short-Term Generation Management

Resolution method (deterministic)

A decomposition coordination method, based on lagrangian relaxation : coupling constraints (demand and daily constraints are relaxed)

- Phase 1 : Lagrangian (about 500 iterations) : solved using a bundle algorithm which computes a lower bound of the global cost and marginal costs
- Phase 2 : Augmented Lagrangian (about 500 iterations), solved using Uzawa algorithm which computes feasible schedules (respecting demand constraints)

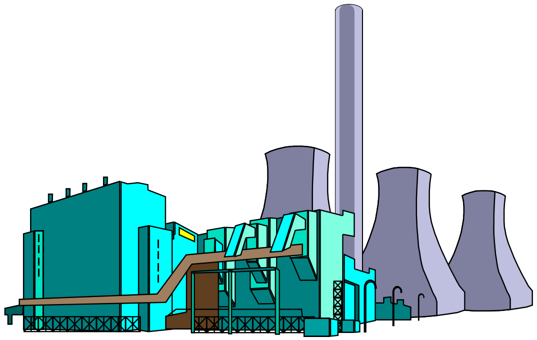
- Thermal sub-problems are solved with a dynamic programming
- Hydro sub-problems are solved with mixed integer linear programming



The thermal sub-problem

- Bound constraints on the delivered power during several time intervals of the time horizon

- Operating technical constraints:
  - Minimal duration of production or halt
  - Start-up and switch off curves
  - Bound constraints on output variation
  - Maximal number of start ups, output variations, and deep output decrease per day



- The operating cost consists of:
  - Start-up costs (depending on the switch-off duration)
  - Power proportional costs
  - Output decrease costs
  - Penalties for the maximal number of start ups, output variations, and deep output decrease per day

Solved using Dynamic Programing or MILP

The hydraulic sub-problem

- A hydro valley = set of interconnected reservoirs and power plants

$$\omega_r (V_r^0 - V_r^T)$$

- Cost = global loss of water

- Constraints
  - Bound constraints
  - Flow constraint :

$$V_r^t = V_r^{t-1} + \sum_{u \in up(r)} T_u^{t-d(u,r)} - \sum_{u \in down(r)} T_u^{t+d(r,u)} + O_r^t$$

- $V(t,r)$ Volume of reservoir r at time step t
- T_u^t Discharge of plant u at time step t
- o_r^t Inflows to reservoir r at time step t
- $d(u,r)$ Travel time of water between unit u and reservoir r