Traditionnal and new optimisation problems regarding energy management at EDF

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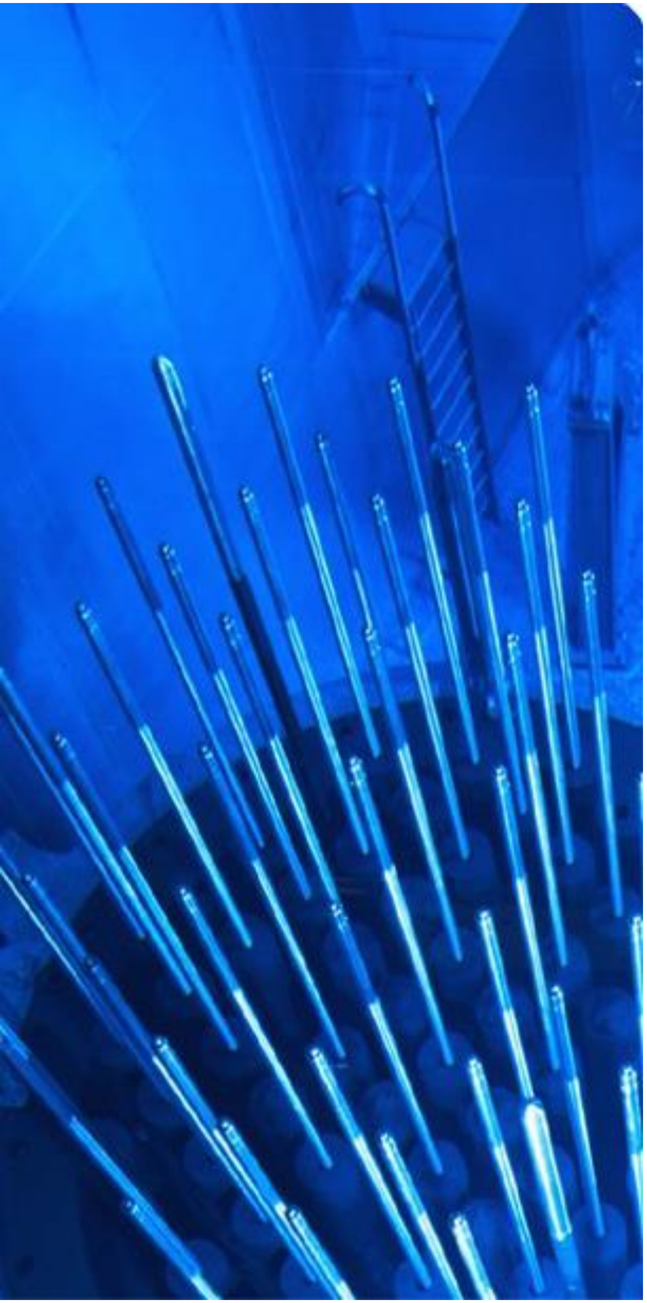
m² c = +e
mathematics × models × computations = more energy
A COST PROJECT

COST
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

EDF
CHANGER L'ÉNERGIE ENSEMBLE



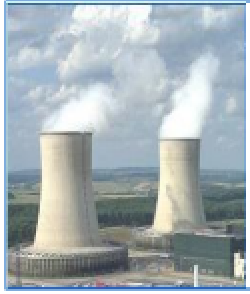
Outline

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

The Generation Management Chain : context and process

Generation Management

Supply



59 nuclear power plants

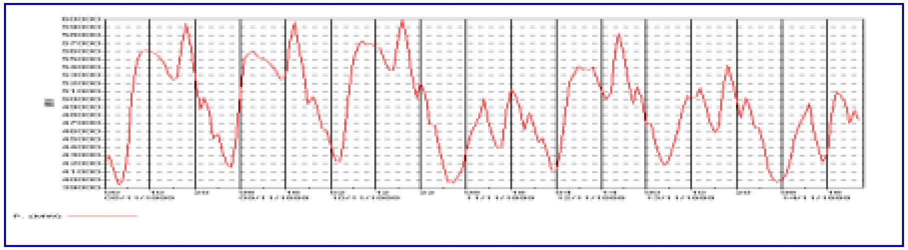
50 classical thermal Plants (coal, fuel, gas)

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

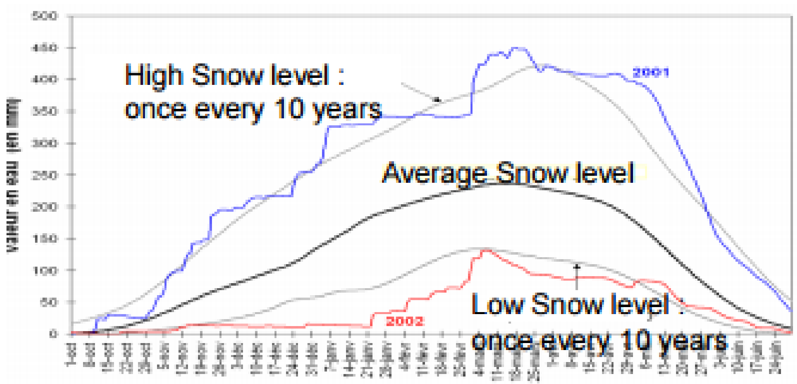
Supply | Uncertainties | Load

On power plants

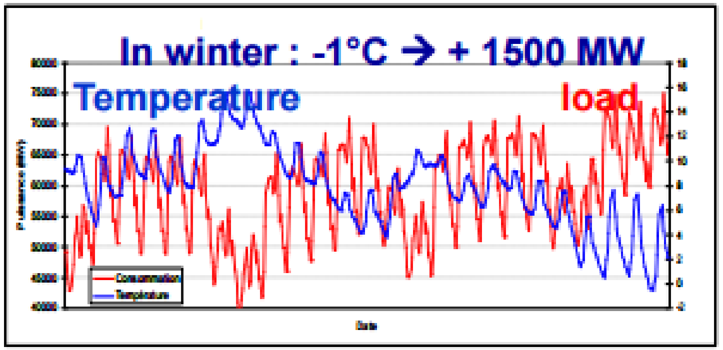
Random outage process
Shut-down duration
Level of nuclear fuel stock

On weather

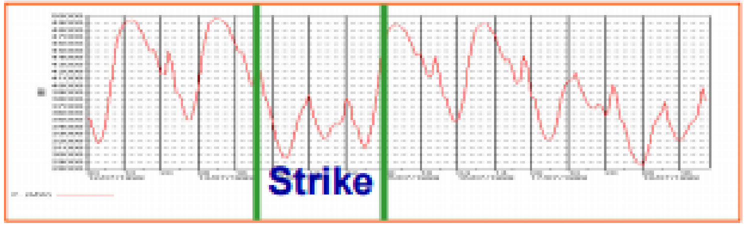
- Temperature of rivers
- Renewables production
- Random inflows



On weather

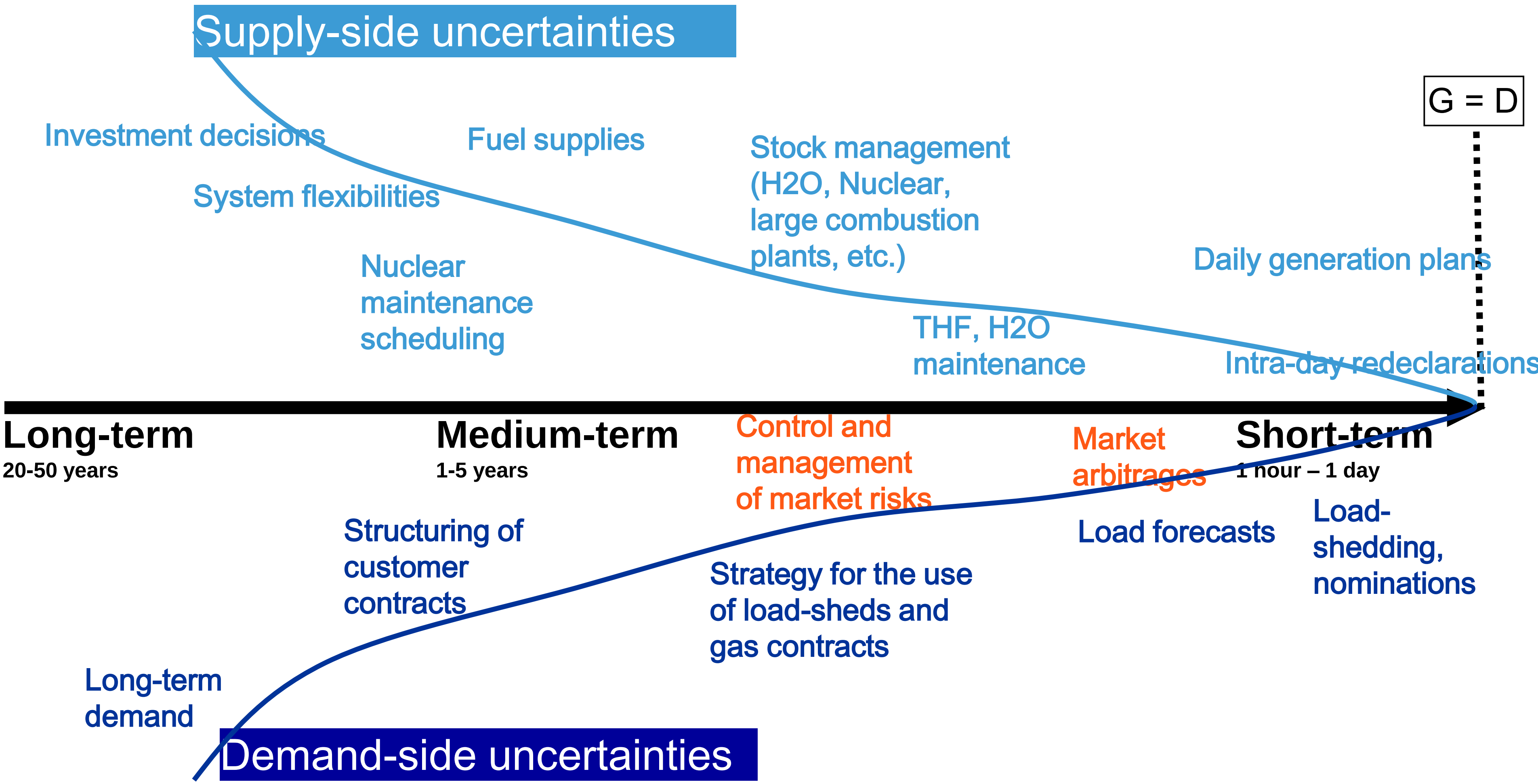


On social events



On economic context
- Industrial activity
- Customers behavior /competitors
- Exchanges with other countries

The decision chain for an Electricity Producer



What about our WIKI?

Electrical Energy Systems

Horizon/Problems:	Planning	Production Management	Network Management	Maintenance Management	Other Problems
Strategic	• Generation Expansion (dismission) Planning (GEP) • Network Expansion Planning (NEP)	• Long term Unit Commitment (UC)	• Transmission and distibution network reinforcements • Energy Storage System (ESS) siting and sizing • Smart grids design	• Power plants long term maintenance • Transmission and Distribution network long term maintenance	• Long Term electricity bilateral contracts
Tactical		• Medium term UC • Medium term hydro reservoirs management		• Power plants medium term maintenance • Transmission and Distribution network medium term maintenance	• Portfolio optimization and derivatives intruments
Operational		• Monopolist:short term UC • Market: max profit short Term UC • Energy markets • Balancing markets and non programmable (renewable) power coordination	• Optimal Power Flow (OPF) • Security Constrained UC (SCUC) • N-k security problems • Optimal Transmission Switching (OTS) • Optimal Network Islanding • Smart grids operations		• Combined gas and power optimization

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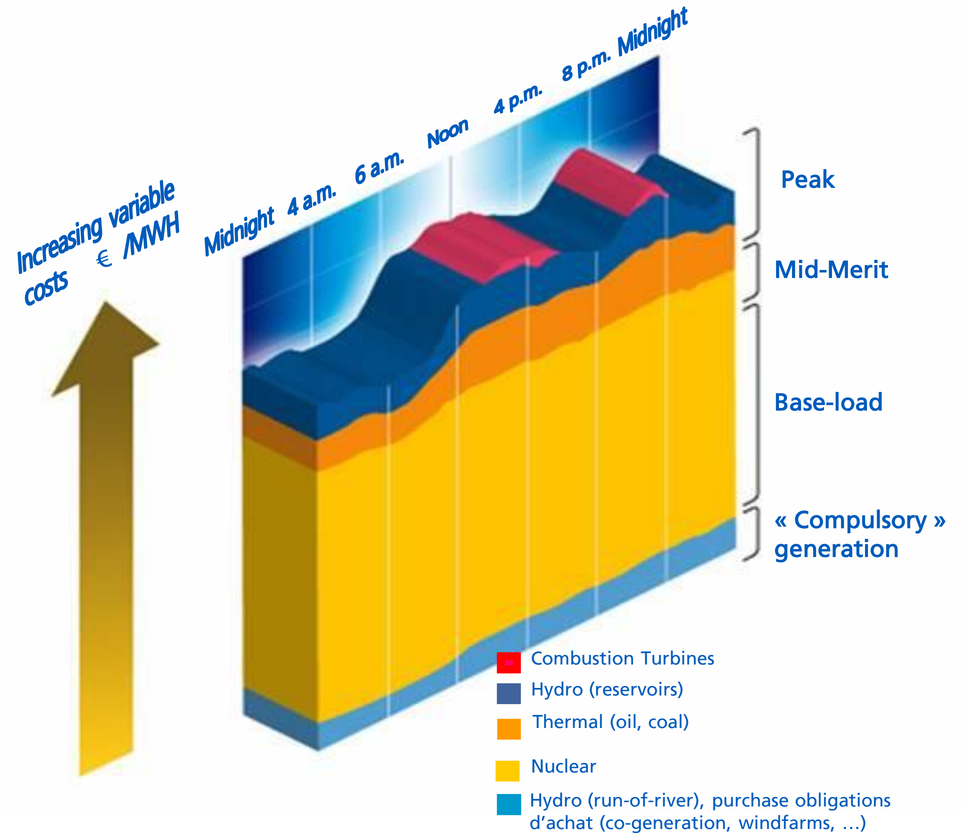
Energy Management – the traditionnal problems

❑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)**

Historical Problems

The classical Problems

Strategic	Planning	Production Management	Network Management	Maintenance Management	Other Problems
Strategic	**Investment (new plants)**	**Simulate Prices (fuels and elec)**		**Nuclear refulling planning**	Long-term contracts
Tactical		**Reservoirs Management (not only hydro)** UC Simulation		Maintenance of other plants	**Portfolio optimization** **Financial Risk Management**
Operational		**Unit Commitment**			

Details are in appendix of this presentation….

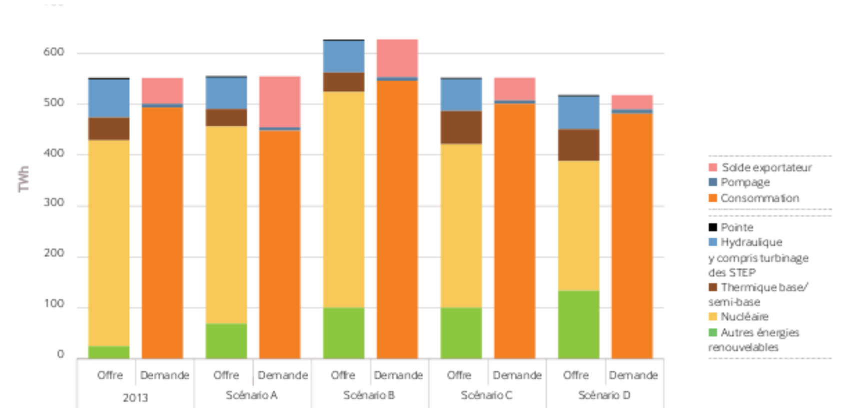
But it is not my purpose to (again) present the historical optimization problems in Energy Management

New Problems

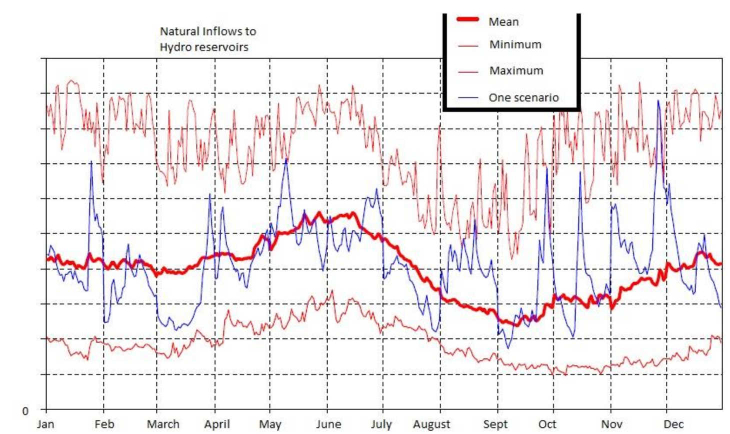
Energy Management – recent evolutions

- 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

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



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



FORUM DE LA R&D

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The new Problems

Strategic	Planning	Production Management	Network Management	Maintenance Management	Other Problems
Strategic			**‘Smart Grids’, design of new systems?**		
Tactical		**UC Simulation in a new context**	**‘Smart Grids’ => new decisions**		
Operational		**Unit Commitment with renewable Balancing Markets?**	**‘Smart Grids’ operation**		

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 - regulation

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

New problems to be modelled :

- New markets
- Local Global Interactions
- New local problems

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

$$\min_{X,Y} \quad c_P^T X + c_D^T Y$$

$$s.t.$$

$$AX = dY + d^0$$

$$F_P X \leq f_P$$

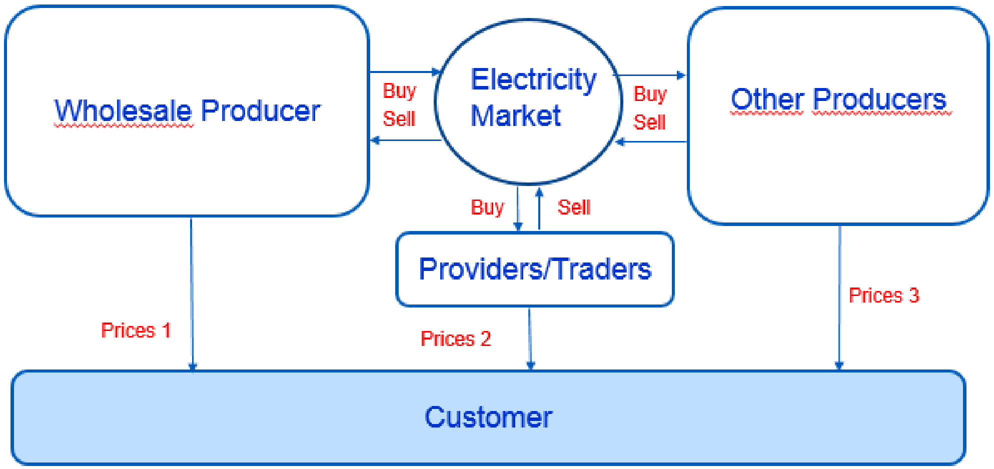
$$F_D Y \leq f_D$$

$$X_R, Y_R \in \mathbb{R}^{N_R}$$

$$X_B, Y_B \in \{0,1\}^{N_B}$$

Local actors

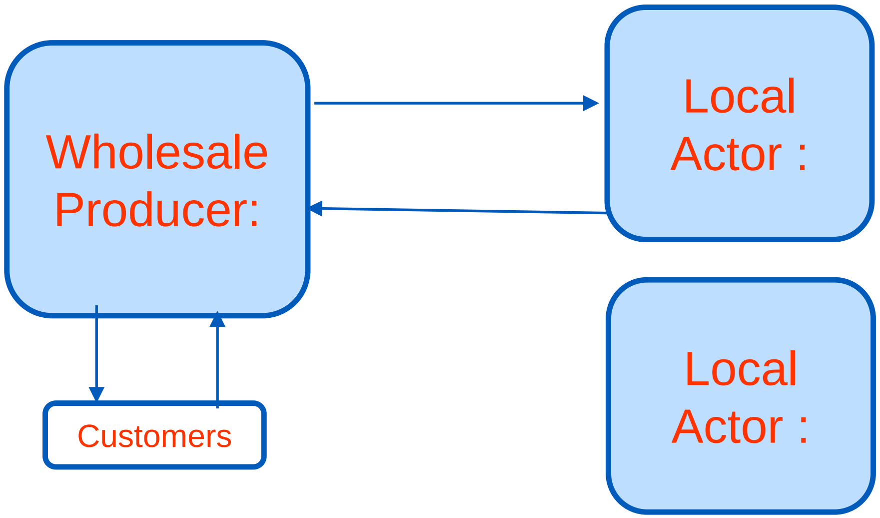
- **How does a consumer will choose his energy provider (objective function : minimizing cost (or other….)**



- This consumer may own generation means (wind farms…), or have levers on its consumption….
  - His problem becomes more difficult with UC, risk management….

Local actors and a centralised wholesale producer

- **How to model ineteractions? How do prices are built?**



- Local actors may be different, independant, not independant…

Optimising at different 'levels' of the grid

- Constraints related to different 'levels'
  - Centralised generation (nuclear, hydro, thermal....)
  - Regional network
    - Industrial consumption
    - Wind power
  - Local network
    - Residential + pro consumtion
- Management of load flexibilities =
  - Move load from one timestep to another
  - Decrease load at some timesteps

=> induce coupling constraints on the network

New objective functions

- Minimize generation cost
- Minimize network 'reinforcement'
  - Reinforcement cost (= future investment cost) depends on the network structure :
    - High cost if the margin is low , low cost if big margin
    - Demand sheddings' can lower the peak
  - Criteria : able to absorb consumtion
    - Max consumption at extreme temperature
    - Max consumtion at normal temperature
    - Max 'medium load curve'
- Maximize 'autoconsumption'

Multi-level problems appear

- Local level – Cost = local network cost (reinforcement)
  - residential+pro consumtion
  - Sun power
  - Local storage
- Regional level - Cost = local network cost (reinforcement)
  - Agregated local consumptions + industrial
  - Agregated local generations + wind power
- National level – Cost = generation cost
  - Agregated regional consumtions
  - Agregated local generations + centralised generation
  - Centralised storage

Appendix

HISTORICAL OPTIMIZATION PROBLEMS IN GENERATION MANAGEMENT

Small focus on main uncertainties

Planning Nuclear Outages

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**

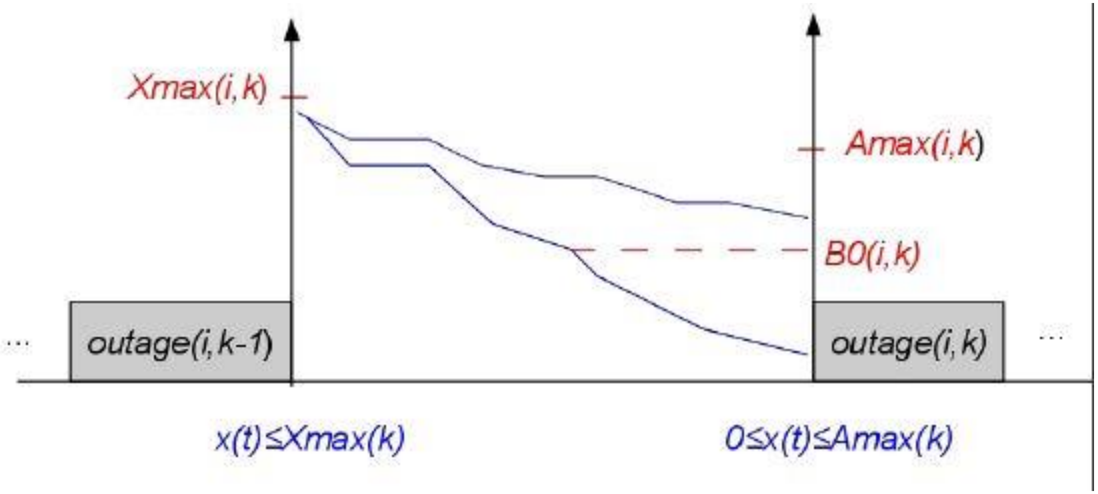
The mathematical problem

A weekly timestep over 5 years

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

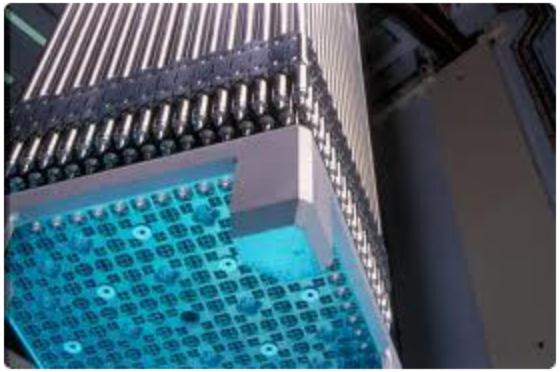
Stochastic problem, strongly combinatorial, non linear, with coupling constraints, to be solved in a short calculation time

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*

$$\underset{a(i,k),r(i,k)p(i,t,\omega),p(j,t,\omega)}{Min} \{\sum_{i,k} C_{i,k} \cdot r(i,k)$$
$$+ \sum_{\omega} \pi(\omega)[\sum_{j,t} C^{\omega}_{j,t} \cdot p(j,t,\omega) \cdot dt - \sum_{i,k} C^{T}_{i} \cdot x(i,T,\omega)]\}$$

$s.t.$

$$\forall t, \omega \sum_{i} p(i,t,\omega) + \sum_{j} p(j,t,\omega) = D^{\omega}_{t}$$

\+ 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

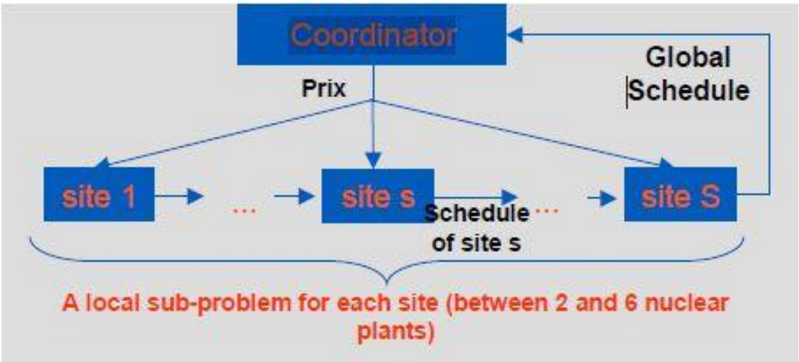
➢i : nucl unit, j : other unit, t : timestep, ω : scenario
➢x(i; t; ω) : Stock level
➢p(i; t; ω) : Production level
➢a(i; k) : Outage date of unit i at cycle k
➢r (i; k) : Refueling of unit i at cycle k (energy)
➢C : cost
➢D : demand

« Solving » the nuclear problem in a deterministic framework

- Operational approaches

Price decomposition : inter-plants constraints are relaxed

- A « Coordinator » calculates the schedule cost and « prices » (linear programmig with continuous variables)
- Each sub-problem computes new refuelling dates within a « timewindow» (mixed integer linear programming)



Local Search (now operational)

iterations between two modules :

- Optimize production knowing outage dates (LP)
- Optimize outages –locally moving- using marginal costs of the production planning (MILP)

MILP frontal solving

But computation time…

EURO/ROADEF Challenge solutions

New difficulties

- The challenge
  - **Taking uncertainties into account**
    - The stock level is not known exactly
    - Demand is (still) very uncertain
  - **Reoptimization and stability**
    - Dates will be re calculated every months (to take into account new datas)
    - The outage dates of the forthcoming months must be stable
    - The others (very far outage date, production level, some refuel level) may be recourses

Mid Term Generation Management

Mid-Term Generation Management

Main Objective

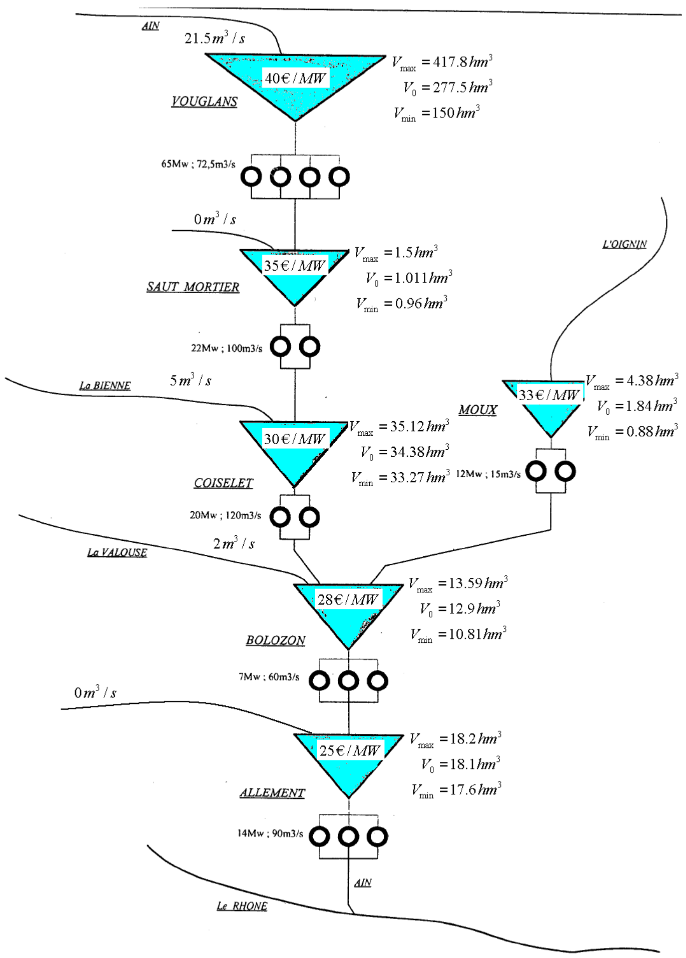
Compute an optimal strategy for stock management

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?

Short-Term Generation Management

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**

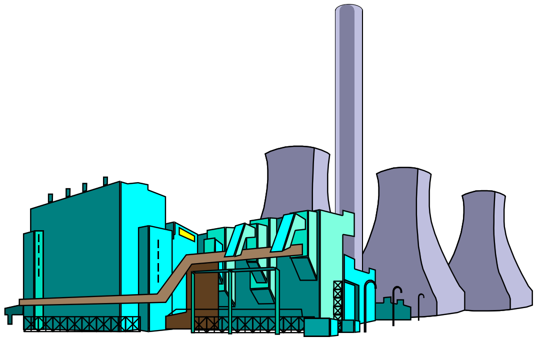
→ **Power and ancillary reserves demand constraints**

- ✓ 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

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

The hydraulic sub-problem

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

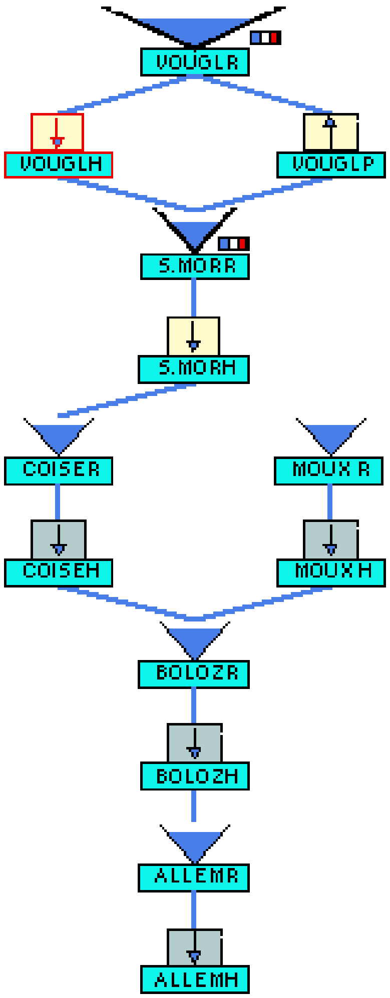
$$\omega_r (V_r^0 - V_r^T)$$

- 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



Conclusion

Thank you for your attention

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