Application of sensitivity analysis for energy power management

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July 8, 2011
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5. EDF electricity management consists in minimizing the production cost safely;

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Figure: Electicity load: source `http://www.rte-france.com/fr/`

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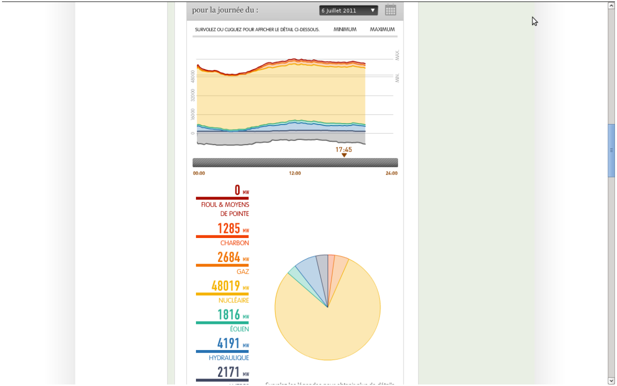

Figure: Energy mix: source http://www.rte-france.com/fr/

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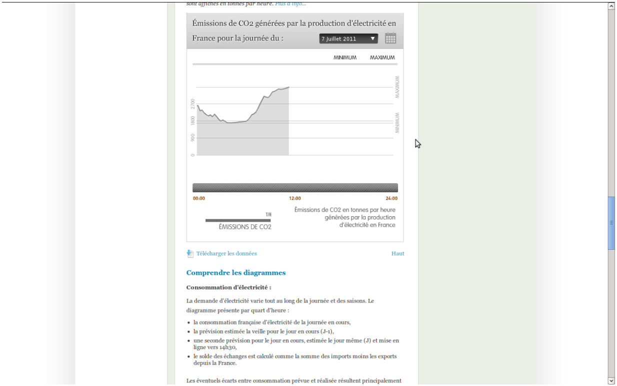

Figure: CO2 Emmission: source `http://www.rte-france.com/fr/`

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- Schedule power-stations shut-down for maintenance and refuelling (stochastic, multi-year);
- Objectify the values of stocks of reserves (stochastic, multi-year);

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- Take market positions;
- Objectify appeals of all power stations for supplying demand (sample based, dayly);
- Perform automatic and/or manuel re-declarations, for matching more tightly the load curve with generation curve (real-time, intra-day);

Introduction

Main focus of this talk

Studying some different formulations for the problem of scheduling power station shut-down.

Outline

Problem formulation
- Current formulation of the problem
- Weakness of the current formulation

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Current formulation of the problem

Weakness of the current formulation

First proposal

Continuous time re-formulation

Advantages and limits

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Current formulation of the problem

Problem description

- 58 reservoirs representing 80% of the generation capacity must be stopped periodically about $4-5$ weeks in order to perform maintenance operations and to refuel;
- The number of parallel shut-downs is limited and a delay must be observed between two consecutive operations of a maintenance team;
- Of course EDF must still supply demand of its clients;

Current formulation of the problem

Decision variables

- $s(t)$ energy in the stock;
- $u(t)$ power generated during one time-step;
- $a(t)$ 0 if stop and 1 otherwise;

Parameters

- $c(x, t)$ cost of amount x of energy generated (convex, increasing);
- $d(t)$ demand at time t;
- $\psi(x, T)$ value of the stock at the end of the study period;
- $\mathbb{S}$ set of power plants which need maintenance;

Current formulation of the problem

Brief sketch of the current formulation :

$$\min \mathbb{E}\left[\sum_{t=1}^{T-1} c(d(t) - \sum_{i \in \mathbb{S}} u^i(t) a^i(t), t) + \psi(s(T), T)\right]$$

$$s^i(t+1) = s^i(t) - u^i(t)$$

$$s^i(t) \in [0, \overline{s}^i(t)]$$

$$u^i(t) \in [0, \overline{u}^i(t)]$$

$$a^i(t) \in \{0, 1\}$$

$$a \in \{\text{constraints of the planning}\}$$

$u^i(t)$random variable that observes the noise trajectory causally

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Uncertainty arises from demand and from the duration of the maintenance which could vary between more or less 2 weeks

Weaknesses of the current formulation

Independently of the computational burden, this problem has some structural weaknesses:

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Independently of the computational burden, this problem has some structural weaknesses:

Weaknesses

1. one weakness of this formulation is due to the decision variable $a^i(t)$ which is open-loop;
2. second weakness is due to the lack of information allowing to perform local search based sensitivity of objectif function with respect to the date of stop;

In practice even if the first campaign (period between the end of a stop and the end of subsequent stop) is fixed the second campaign may vary a lot according to noise trajectory.

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Continuous time-reformulation

Point of view of the continuous formulation

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Point of view of the continuous formulation

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- The idea is to introduce date of beginning of the stop and the stop duration in order to reformulate the problem;

Continuous time-reformulation

Continuous time-reformulation

Given a feasible planning its valorization $\Psi(\tau)$ then reads:

$$\begin{aligned}\min_{u(\cdot),s(\cdot)} \quad & \int_0^T c\left(d(t) - \sum_{i\in\mathbb{S}} u^i(t)\left(1 - \mathbb{I}_{[\tau^i,\tau^i+\Delta^i]}(t)\right), t\right) dt + \psi(s(T),T) \\ \text{u.c.} \quad & \dot{s}^i(t) = -u^i(t) + r^i(t)\mathbb{I}_{[\tau^i,\tau^i+\Delta^i]}(t), \quad \forall i\in\mathbb{S}, \\ & s^i(\tau^i) \geq 0, \quad \forall i \in \mathbb{S} \\ & 0 \leq u^i(t) \leq \overline{u}^i(t) \quad \forall i \in \mathbb{S}\end{aligned}$$

The objective is only to compute directionnal derivative of $\Psi(\tau)$ in order to locally improve this planning.

Continuous time-reformulation

Lets consider the following problem :

$$\varphi(x) = \min_{y \in F} \{ f(x,y) \mid g(x,y) = 0 \}$$

- How to compute φ' :

$$\varphi'(x) = f'_x(x, y(x)) + \langle f'_y(x, y(x)), y'(x) \rangle$$

- Lets p be the optimal multiplier of the constraint then, under mild assumptions see [BS00] we have :

$$\varphi'(x) = f'_x(x, y^*) + \langle p, g'_x(x, y^*) \rangle$$

Continuous time-reformulation

- Let $A(j)$ the set of power stations which are stopped when power station j starts its stop ;

$$A(j) = \left\{ i \mid \tau^j \in [\tau^i, \tau^i + \Delta^i] \right\} \setminus \{j\}$$

- Let $B(j)$ the set of power stations which are stopped when power station j ends its stop ;

$$B(j) = \left\{ i \mid \tau^j + \Delta^j \in [\tau^i, \tau^i + \Delta^i] \right\} \setminus \{j\}$$

Formal result (hand made)

$$\Psi'_{\tau^j}(\tau) \sim c\left(d(\tau^j) - u^j(\tau^j) + \sum_{i \in {}^c A(j)} u^i(\tau^j), \tau^j \right) + c\left(d(\tau^j + \Delta^j) + \sum_{i \in {}^c B(j)} u^i(\tau^j + \Delta^j), \tau^j + \Delta^j \right)$$
$$-c\left(d(\tau^j) + \sum_{i \in {}^c A(j)} u^i(\tau^j), \tau^j \right) - c\left(d(\tau^j + \Delta^j) - u^j(\tau^j + \Delta^j) + \sum_{i \in {}^c B(j)} u^i(\tau^j + \Delta^j), \tau^j + \Delta^j \right)$$
$$- p^j(\tau^j + \Delta^j) \times r^j(\tau^j + \Delta^j) + p^j(\tau^j) \times r^j(\tau^j)$$

Advantages and limits

1. For theoretical justification of this hand-made interpretation see [PBB11];
2. The problem has been investigated in a the deterministic framework;
3. This analysis gives an idea about how the issue related to the displacement of a stop reads;

Outline

Dynamic programming re-formulation (discrete-time)

Point of view of the Dynamic programming re-formulation

- The date of stops are stopping-time for the cost process induced by the energy management of all the reserves;
- We solve the Bellman equation;

Dynamic programming re-formulation (discrete-time)

For sake of simplicity we consider the following deterministic discrete time model with only one stop to manage:

$$\min \sum_{t=0}^{T-1} c(d(t)-u(t),t)\mathbb{I}_{[0,\tau]\cup[\tau+\Delta,T]}(t) + c(d(t),t)\mathbb{I}_{[\tau,\tau+\Delta]}(t) + \psi(s(T),T)$$

$$\begin{aligned} u.s. \quad & s(t+1) = s(t) - u(t) \\ & s(\tau+\Delta) = s(\tau) + R \\ & s(\tau) \in I \\ & u(t) \in [0,\overline{u}] \end{aligned}$$

Dynamic programming re-formulation (discrete-time)

The continuation cost $\Gamma(s,\theta)$ is the value of the following problem:

$$\min \sum_{t=0}^{T-1} c(d(t)-u(t),t)\mathbb{I}_{[\theta+\Delta,T]}(t) + c(d(t),t)\mathbb{I}_{[\theta,\theta+\Delta]}(t) + \psi(s(T),T)$$

$$u.c. \quad s(t+1) = s(t) - u(t)$$

$$s(\theta+\Delta) = s$$

Lets $W(s,\theta)$ denotes the optimal value starting from state s at time θ:

$$W(s,\theta) = \min_{u,\tau} \sum_{t=\theta}^{\tau} c(d(t)-u(t),t) + \Gamma(s(\tau)+R,\tau)$$

$$s(t+1) = s(t) - u(t)$$

$$s(\tau) \in I$$

$$s(\theta) = s$$

Dynamic programming re-formulation (discrete-time)

Γ and W are solutions of the backward recursions:

$$\Gamma(s,\theta) = \min_u \{c(d(\theta+\Delta)-u,\theta+\Delta)+\Gamma(s-u,\theta+1)\} + c(d(\theta),\theta) - c(d(\theta+\Delta),\theta+\Delta)$$
$$\Gamma(s,T) = \psi(s,T)$$

$$W(s,\theta) = \min\left\{\min_u c(d(\theta)-u,\theta)+\Gamma(s+R,\theta), \min_u c(d(\theta)-u,\theta)+W(s-u,\theta+1)\right\}$$

And $\tau^*(s,\theta)$ is the first time β such:

$$\Gamma(s^*(\beta)+R,\beta)+\min_u c(d(\beta)-u,\beta) = W(s^*(\beta),\beta) \text{ with } s^*(\theta)=s$$

Advantages and limits of dynamic programming

- Dynamic programming provides feedback decisions;
- It is relatively easy to consider the markovian case;
- Dimensionality is still the main weakness of dynamic programming;

Dynamic programming re-formulation (continous time)

Point of view of the Dynamic programming re-formulation

- The date of stops are stopping-time for the cost process induced by the energy management of all the reserves;
- We solve the HJB equation;

Dynamic programming re-formulation (continous time)

For sake of simplicity we consider the following model with only one stop to manage:

$$
\begin{aligned}
\min_{u,\tau} \int_0^{\tau} c(d(t)-u(t),t)dt &+ \int_{\tau}^{\tau+\Delta} c(d(t),t)dt + \int_{\tau+\Delta}^{T} c(d(t)-u(t),t)dt \\
&+ \psi(s(T),T) \\
u.c. \quad & \dot{s}(t) = -u(t) \\
& s(\tau) \in I \\
& s(\tau+\Delta) = s(\tau) + R \\
& u(t) \in [0, \bar{(}u)(t)]
\end{aligned}
$$

Dynamic programming re-formulation (continous time)

Γ denotes the continuation cost after τ:

$$\forall s \in I + R, \quad \Gamma(s,\theta) = \min_{u(t)} \left\{ \int_{\theta+\Delta}^{T} c(d(t) - u(t), t)dt + \psi(s(T), T) \right.$$
$$\left. + \int_{\theta}^{\theta+\Delta} c(d(t), t)dt + \psi(s(T), T) \right\}$$
$$u.c. \quad \dot{s}(t) = -u(t)$$
$$s(\tau + \Delta) = s$$
$$u(t) \in [0, \bar(u)(t)]$$

Dynamic programming re-formulation (continous time)

The Bellman function $W(x, z, \beta)$ satisfies the HJB equation:

$$\frac{\partial W}{\partial \beta}(x, z, \beta) + \min_{v} \left\{ c(d(\beta z) - v, \beta z) - \frac{\partial W}{\partial x}(x, z, \beta) v z \right\} = 0$$
$$W(x, z, 1) = \Gamma(x + R, z)$$

Then the optimal time is to stop is:

$$\tau^*(s, t) \in \arg\min_{z} W(s, z, t) \tag{1}$$

Outline

Conclusion

Each approach has raised a difficulty. Next step will consist in combining these two methodologies as in [BCG10].

K. Barty, P. Carpentier, and P. Girardeau.
Decomposition of large-scale stochastic optimal control problem.
RAIRO Operation Research, 2010.

J.F. Bonnans and A. Shapiro.
Perturbation analysis of optimization problems.
Springer Verlag, Berlin Heidelberg, 2000.

L. Pfeiffer, F. Bonnans, and K. Barty.
Sensitivity analysis for the outages of nuclear power plants.
Presentation of the paper at the next COPI 2011 conference, FRANCE, 2011.