An Operational Model for Optimal Non-Dispatchable Demand Response for Continuous Power-intensive Processes

or

An Operational Model for Optimal Production Scheduling under Hourly-varying electricity prices for Continuous Power-intensive Processes

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EWO Meeting, 03/09/2011
Main challenge: balance supply and demand
→ This is the motivation for “smart grids”!

High Observability enabled by increased communication capabilities

Source: U.S.-Canada Power System Outage Task Force

This slide is based on a presentation slide by Prof. Gabriela Hug, Department of Electrical Engineering, Carnegie Mellon University, ESI seminar, January 13 2011
Demand Response (DR): Overview and recent work for industrial processes

Basic idea: To balance supply and demand of a power system, one can manipulate both: supply and demand → demand response (DR).

Utility provider perspective: distinguish dispatchable and non-dispatchable DR

Source:
- Former BOC, Rutgers (2002)
- UBuffalo (2007) (Air separation)
- Goal of our current research: Develop a generic model for non-dispatchable DR

Other power-intensive processes:
- Chlor-alkali synthesis
- Paper production
Industrial customer’s perspective: Problem Statement for an Air Separation Plant

Due to compressors!

Electricity costs

Price forecast

Operational Decisions
- When to produce and amounts?
- Inventory levels?

Strategic Decisions
- Additional equipment?
- Additional tanks?
- Equipment upgrade?

Liquid Oxygen
Liquid Nitrogen
Liquid Argon
Gaseous Oxygen
Gaseous Nitrogen

Demand forecast

Investment Costs
Overview: Research Methodology

**Step 1**
Obtain an efficient model for the short-term scheduling

**Step 2**
Model investment decisions: additional equipment, upgrade equipment, add. storage tanks; (retrofit, multi-period)

**Step 3**
Develop a suitable algorithm to solve the large-scale optimization problem

**Step 4a (projected)**
Model uncertainty in electricity prices

**Step 4b (projected)**
Multiple plants

Focus of this talk

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data

stochastic

deterministic

Single plant

operational

strategic

decisions

modeling

solution method

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## Operational Model

<table>
<thead>
<tr>
<th>Objective function</th>
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</table>
| \[
\sum_{i} y_{i} \leq \sum_{j} h_{j} \quad \forall j \in J \\
\quad \quad \quad \quad \quad Pr = S \quad \forall h, q \in \text{Nonstorable} \quad h
\] |

### Feasible region

\[
\sum_{i} x_{i} \geq x_{0} \quad y, p, q \quad \{ \}
\]

### Mass balances

\[
h < k < \infty \quad \{ \}
\]

### Logic constraints for transitions
**Operational Model**

**Feasible region**: projection in product space

**Modes**: different ways of operating a plant

**Energy consumption**: requires correlation with production levels

**Mass balances**: differences for products with and without inventory
Modeling of transitions

Immediate [1]: Minimum uptime
Immediate [2]: Minimum downtime

State diagram for transitions

Logic constraints for transitions

**Modes**: different ways of operating a plant

**Transitions**: between modes to enforce e.g. min. uptime/downtime
Result: Comparison of production schedules

Electricity consumption profiles for test case B

Inventory profiles for test case B
### Case studies: Air separation plants

#### Problem sizes

<table>
<thead>
<tr>
<th>plant</th>
<th>type of schedule</th>
<th># constraints</th>
<th># variables</th>
<th># binary</th>
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<td>21838</td>
<td>16129</td>
<td>1512</td>
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<td>cyclic</td>
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**cyclic is the harder problem**

For the same demand, P2 can produce cheaper due to higher flexibility

<table>
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<th>case</th>
<th>cyc/ncyc</th>
<th>RMIP</th>
<th>MIP CPLEX</th>
<th>MIP XPRESS</th>
<th>CPU CPLEX</th>
<th>times (s)</th>
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</table>

**Computational results**

Decreasing demand = harder to solve due to higher operational flexibility

**Savings compared to constant operation**

<table>
<thead>
<tr>
<th>case</th>
<th>demand/capacity</th>
<th>savings</th>
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<tbody>
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<td>P1A</td>
<td>82%</td>
<td>4.58%</td>
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<tr>
<td>P1B</td>
<td>74%</td>
<td>12.02%</td>
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<tr>
<td>P2B</td>
<td>51%</td>
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<td>P2C</td>
<td>72%</td>
<td>7.44%</td>
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<tr>
<td>P2D</td>
<td>85%</td>
<td>4.90%</td>
</tr>
<tr>
<td>P2E</td>
<td>95%</td>
<td>3.76%</td>
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Operational flexibility is key to achieve economic savings with demand response.