The Role of Predictive Models in Energy Efficiency Optimization of Industrial Plants and Buildings

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Outline

• Energy Efficiency Applications
  - Industrial and building segments
  - Energy supply side / demand side

• Decision Making Scenarios
  - Process industries: refining
  - Cogeneration and buildings

• Energy Demand Forecasting Methods
  - Memory-Based Regression
Energy Efficiency

• Terminology
  - Energy efficiency = using less energy to provide the same level of service ... e.g. by using more energy efficient appliances
  - Energy conservation = using less energy to achieve a lesser energy service ... e.g. through behavioral change

• Buildings
  - Energy efficient appliances (refrigerators, freezers, ovens, washers, ...)
  - Monitoring and control of major energy loads (heating, ventilation, air conditioning, lighting, ...)

• Industry
  - Optimized energy conversion – fuel switching, running equipment at its peak efficiency
  - Advanced boilers and furnaces (combustion)
  - Selection of less energy intensive operating modes
Energy Efficiency Applications

- Advanced Control
- Industrial Utilities
- Industrial Process Plants
- Dynamic Energy Targeting and Monitoring
- Homes & Buildings
  - Energy Monitoring
  - HVAC Control
  - Demand-Response
  - Capable Homes
- Smart-grid solutions
- Renewable Energy
- Public Utilities
- Local Poly-generation (CHP)
- Optimal Equipment Scheduling
- Grid
  - Steam, power
  - Electricity, heating, cooling
## Energy Efficiency Optimization

<table>
<thead>
<tr>
<th>Utility Plants CHP</th>
<th>Process Plants Manufacturing</th>
<th>Buildings Homes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Business objective</strong></td>
<td>Generate utilities <em>(power, steam, heating, cooling)</em> to meet customer demands (contracts)</td>
<td>Produce mix of products to meet demands in the downstream industries</td>
</tr>
<tr>
<td><strong>Attitude to energy</strong></td>
<td>Energy directly is the primary business objective</td>
<td>Second largest cost (after cost of raw materials)</td>
</tr>
<tr>
<td><strong>Energy efficiency</strong></td>
<td>Consistently addressed in the plants</td>
<td>Minimize energy use but delivery of products is the first priority</td>
</tr>
<tr>
<td><strong>Approach</strong></td>
<td>Closed-loop control Hierarchical optimization</td>
<td>Dynamic targeting Continuous improvement</td>
</tr>
<tr>
<td><strong>Energy Demand</strong></td>
<td>Dominated by production schedule</td>
<td></td>
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</tbody>
</table>
Operation is mostly determined by the specific crude oil and its properties (e.g. sulfur content)

Minimizing energy use and environmental impact by selecting less energy intensive modes on each process unit

Mix of products to be produced to meet orders

Cooking
Airplanes
Automobiles
Farming
Home heating
Jet Fuel
Railroads
Trucks
Factories
Ships
Sale
Roads
Waxes
Coke
Plant-Wide Optimization Criterion

• **Plant profit** can be formulated as:

\[
\text{Plant Profit} = \sum \left( \text{Product rate} \times \text{Product value} \right) - \sum \left( \text{Raw material usage} \times \text{Raw material cost} \right) - \sum \left( \text{Utility consumption} \times \text{Utility value} \right) - \text{Maintenance costs} - \text{Penalties for GHG emissions} - \text{other costs}
\]

*Utility consumption* can be estimated potentially for each unit based on the previously built model that relates energy consumption with capacity utilization, operating modes, etc.

Closely related to on-site energy generation, types of fuels used, overall energy efficiency, etc.
Predictive Model for Crude Distillation Unit

- Correlates energy consumption on CDU unit with production targets that uniquely define the mode of operation

**Predicted energy consumption**
- Fuel energy (preheat, tower, total)
- Steam energy (tower, side strippers, total)
- Power energy (tower, pump-arounds, total)

**Feed**
- Feed flow rate
- Feed temperature
- API density
- Assay/blend properties

**CDU**

**Products**
- Saturated gas flow rate
- Naphtha flow rate
- Kerosene flow rate
- Diesel flow rate
- AGO flow rate
- Residue flow rate
- Naphtha distillation D86 90% Rec
- Kerosene distillation D86 10% Rec
- Diesel distillation D86 90% Rec
- Diesel sulfur wt%

**Disturbances**
- Weather
CHP and Buildings

Real time pricing

Variable efficiency

Fluctuating demand

• Conversion efficiency of the CHP system is optimized
  - Gas turbines, steam turbines, steam boilers, hot water boilers, compressor chillers, absorption chillers

• Energy demand primarily depends on
  - People’s behavior – How many occupants are in the building? What they are doing?
  - Weather – Do we need cooling or heating? How much is needed to keep the adequate comfort level?
Various Daily Profiles …

- Commerce
- Two-shift manufacturing
- Casino
- Administration

Towards e-Environment, Mar 25 2009, Prague
Structure of the Predictive Model

**Inputs**
- Data age
- Time of day
- Holiday
- Ambient temperature
- *Wind velocity*
- *Humidity*

**Demand Model**

**Predictions**
- Heating demand
- Cooling demand
- Electricity demand
- Steam demand
  ...

*Accuracy of energy demand predictions depends heavily on accuracy of weather forecasts*
Energy Demand Modeling Techniques

- **Heuristics and benchmarks**
  - “Rule of thumb”, benchmarking of similar units

- **First principle models**
  - Based on thermodynamics, mass and energy balances

- **Time series models**
  - ARMA with exogenous variables (e.g. outdoor temperature)

- **Statistical regression**
  - Basic regression functions are determined based on the knowledge how the manufacturing plant is operated
  - Resulting “global” models need to be regularly updated
  - Linear regression, Partial Least Squares (PLS)

- **Local regression**
  - Regression models are built based on understanding of variations and correlations in historical data
  - Local modeling deals well with non-linear dependencies, and with segmentation of data in clusters
  - Also known as: memory-based regression, locally weighted regression (non-parametric statistics)
Local Modeling

Local regression models are built on-the-fly.

Current state and its neighborhood (= past operating points similar to the current one)

... the dependency $Y=f(X_1,X_2)$ is much simpler in the local neighborhood than in global context.
Local Regression

Points in the neighborhood are weighted according to

**Kernel function**

\[ w = \exp\left(\frac{-3\sigma d^2}{2}\right) \]

**Distance function**

\[ d^2 = \sum_{i=1}^{N} \left(\frac{X_i^* - X_i}{h_i}\right)^2 \]

**Query point** $x_0$

**Local neighborhood**

**Independent variable – x**

*(time of day)*

**Forecast – y (load)**

**Bandwidth**

**Polynomial fit**
Thank you for your attention!