Storage Influence in a Combined Biomass/Power-to-Heat Production Plant

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French Energy Context

Domestic Hot Water and Space Heating in France:
→ 35% of total energy consumed (665 sur 1900TWh)


French Energy Planning (PPE 2016):
→ DHS must deliver 5 times more R&R Energy in 2030 (40TWh)


Biomass will have a major role:
→ 50% of the energetic mix of DHS by 2030


BUT Biomass should be considered as a limited resource:
→ Other significant R&R resources must be found


Moreover, increasing amount of renewables on electric grid:
→ Surplus leading to over Voltage


→ Power-to-Heat + Storage
→ Flexibility to Electric Grid + Additional Significant R&R resources for DHN

Production Plant Studied

Outlines

1) Sizing Methodology
2) Sizing Results
3) Operation of the system
1 - Sizing Methodology

**MILP formulation**
\[
\min_{x} c^T \cdot x \\
\text{s.t.} \quad A \cdot x = b \\
D \cdot x \geq e
\]

**Hypothesis**
- No effect of temperature accounted for
- District Heating Operation does not affect costs
- Both sizing and operational optimization

**Decision Variables**

**Operational Variables**
- \( Y_{i}(t) \) : Back Up / Biomass / HP
- \( P_{i}(t) \) : Back Up / Biomass / HP
- \( Y_{st}(t) \) : Storage
- \( P_{ch}(t) \) : Storage
- \( P_{d}(t) \) : Storage
- \( E^{st}(t) \) : Storage

**Sizing Variables**
- \( P_{i}^{max} \) : Back Up / Biomass / HP / Storage
- \( E_{max}^{st} \) : Storage

**MILP and Energy Systems** [7]

1 - Sizing Methodology

Equality Constraints

Overall Energy Balance

\[ \sum P^i(t) + P_{\text{disch}}^i(t) = P_{\text{ch}}^i(t) + P_{\text{load}}(t) \]

Storage Energy Balance

\[ E^i(t) - E^i(t-1) \Delta t = P_{\text{ch}}^i(t) - P_{\text{disch}}^i(t) - K_{\text{loss}} * E^i(t) \]

Boundary Condition Storage

\[ E_{\text{st}}(t = 0) = E_{\text{st}}(t = N) \]

Inequality Constraints

Power Limits

\[ r^i * P_{\text{max}}^i * Y^i(t) \leq P^i(t) \leq P_{\text{max}}^i * Y^i(t) \]

Charging Power Limit

\[ 0 \leq P_{\text{ch}}^i(t) \leq P_{\text{max}}^i * (1 - Y^i(t)) \]

Discharging Power Limit

\[ 0 \leq P_{\text{disch}}^i(t) \leq P_{\text{max}}^i * Y^i(t) \]

Energy Storage Limit

\[ 0 \leq E^i(t) \leq E_{\text{max}}^i \]

Objective

\[ c_{\text{tot}} = c_{\text{invest}} + \sum_{n=1}^{T_{\text{ann}}} \frac{1}{(1 + t_{\text{act}})^{n-1}} (c_{\text{prod}} + c_{\text{start}} + c_{\text{maint}}) \]

Minimum REN ratio

\[ \sum_{i=1}^{N} (P_{\text{bio}}^i(t) + P_{\text{hp}}^i(t) * T_{\text{ren}}^i(t)) \geq T_{\text{ren}} * \sum_{i=1}^{N} P_{\text{load}}(t) \]

Maximum CO2 content

\[ \sum_{i=1}^{N} \sum_{t=1}^{3} C_{\text{O2}}^i * P^i(t) \leq C_{\text{O2}}^{\text{max}} * \sum_{i=1}^{N} P_{\text{load}}(t) \]

Maximum Biomass Available

\[ \sum_{i=1}^{N} P_{\text{bio}}^i(t) * \Delta t \leq m_{\text{max}}^i * P_{\text{C1}}^i \]

Set of \( \varepsilon \)-constraints

Constraints: 120k
2 - Sizing Results

Set of Input Data

- **Weather:** In-Situ measurements from year 2017 in Grenoble
- **Network Load:** 3000 dwelling equivalent [10] + Internal tool CEA for hourly profile
- **Electricity Cost:** Day-Ahead prices (EPEX-SPOT and ENTSO-E)
- **Investment/Operational Costs:** Literature [11, 12, 13, 14]
- **REN Ratio and CO2 Content:** Eco2mix (RTE Database) + CITEPA


**CO2 Content and REN Ratio of Electricity**
2 - Sizing Results

The less renewable is the electricity and the more we need to invest in Biomass (and Storage) to satisfy the REN constraint.

The higher is the CO2 content of the electricity and the more we need to invest in Biomass (and Storage) to satisfy the CO2 constraint.
2 - Sizing Results

Focus on French Context

- Increase of Available Biomass → Increase of the reachable REN Constraint
- Increase of REN Constraint → Increase of LCOE mostly because of Storage size increase

<table>
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S1 $P_{bio_{max}}$ [-] 0.34 0.44
S1 $P_{H_{max}}$ [-] 0.46 0.40
Principles

Control Module (C++)
- Rules Based
- Predictive Control

Prevision Modules (C++)
- Weather
- Network Load
- Costs

Set points

State return

Operational Predictive MILP modifications

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<td>Optimization Horizon</td>
<td>1 year</td>
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<td>Decision Variables</td>
<td>Sizing + Operational</td>
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<td>Objective function</td>
<td>( c_{\text{invest}} + c_{\text{prod}} + c_{\text{dem}} + c_{\text{maint}} )</td>
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3 – MILP Operation

Results – S1

- Receding Horizon of 24h
- Optimization performed every hour
- Time Step of Simulation of 15 minutes
- 5 first months shown

• Biomass as Based Load
• Heat Pump and then Storage used for peaks (due to cost of electricity)

Back-Up Usage of 4.4% only → Validating the design and the Operational MILP
Conclusion and Perspectives

Sizing Methodology

- Traditional Methods limited
- ‘Power fluxes’ type MILP problem
  → Appropriate Physico-Mathematical Approach

MILP based operation required only 4.4% of the back up

Comparison with Rule Based Logic
Control is beneficial to MILP

In France, Power-to-Heat with inter-seasonal storage is necessary only to reach very high REN ratio

Validation through Operation

- Testing Co-simulation Platform PEGASE
- Comparison of different Control strategies
  → Setting up control strategies prior field operation

What to do next?

- Add a cogeneration plant to the studied system
- Multi-Period in Operation (inter-seasonal storage)
- Temperature effect in Operational MILP
THANK YOU
1 - Sizing Methodology

**MILP formulation**

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A \cdot x = b \\
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**Hypothesis**

- No effect of temperature accounted for
- District Heating Operation does not affect costs
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- \( Y^{st}(t) \): Storage
- \( P_{ch}^{st}(t) \): Storage
- \( P_{dissch}^{st}(t) \): Storage
- \( E^{st}(t) \): Storage

**Sizing Variables**

- \( P_{j}^{max} \): Back Up / Biomass / HP / Storage
- \( E_{max}^{st} \): Storage

**Input data**

- Costs (c)
- MILP and Energy Systems [7]
- CPLEX [9]

**Constraints/Objective**

Var Continuous: 35k
Var Integers: 18k

Back Up
1 - Sizing Methodology

Equality Constraints

Overall Energy Balance
\[ \sum P^i(t) + P_{\text{disch}}^{st}(t) = P_{\text{ch}}^{st}(t) + P_{\text{load}}(t) \]

Storage Energy Balance
\[ \frac{E^{st}(t) - E^{st}(t-1)}{\Delta t} = P_{\text{ch}}^{st}(t) - P_{\text{disch}}^{st}(t) - K_{\text{loss}} * E^{st}(t) \]

Boundary Condition Storage
\[ E_{st}(t = 0) = E_{st}(t = N) \]

Biomass Maintenance
\[ Y^{Bio}(t) = 0 \]

Inequality Constraints

Power Limits
\[ r^i * P_{\text{max}}^i * Y^i(t) \leq P^i(t) \leq P_{\text{max}}^i * Y^i(t) \]

Charging Power Limit
\[ 0 \leq P_{\text{ch}}^{st}(t) \leq P_{\text{max}}^{st} * (1 - Y^{st}(t)) \]

Discharging Power Limit
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Energy Storage Limit
\[ 0 \leq E^{st}(t) \leq E_{\text{max}}^{st} \]

Minimum ON Time
\[ T_{\text{on}}^i * X^i(t) \leq \sum_{j=1}^{T_{\text{on}}^i} Y^i(t + j - 1) \]

Minimum REN ratio
\[ \sum_{t=1}^{N} \left( P_{\text{bio}}^i(t) + P_{\text{hp}}^i(t) * T_{\text{ren}}(t) \right) \geq T_{\text{ren}}^{tot} * \sum_{t=1}^{N} P_{\text{load}}(t) \]

Maximum CO2 content
\[ \sum_{t=1}^{N} \sum_{i=1}^{3} CO_2^i * P^i(t) \leq CO_{2\text{tot}} \leq \sum_{t=1}^{N} P_{\text{load}}(t) \]

Maximum Biomass Available
\[ \sum_{t=1}^{N} P_{\text{bio}}^i(t) * \Delta t \leq m_{\text{bio}}^i * PC_{\text{bio}} \]

Objective
\[ c_{\text{tot}} = c_{\text{invest}} + \sum_{n=1}^{T_{\text{am}}} \left( \frac{1}{1 + t_{\text{actu}}}^{n-1} (c_{\text{prod}} + c_{\text{start}} + c_{\text{maint}}) \right) \]

Constraints: 120k

4th International Conference on Smart Energy Systems and 4th Generation District Heating 2018
#SES4DH2018
2 - Sizing Results

Focus on French Context

- No Impact of CO2 in French Case
- Increase of Available Biomass → Increase of the reachable REN Constraint
- Increase of REN Constraint → Increase of LCOE mostly because of Storage size increase

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$P_{max_{load}}$ ~ 18MW

Daily/Weekly Storage

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Inter-Seasonal Storage
3 – MILP Operation

Comparison with usual Rules Based Control

- Reduced Operational Cost
- Optimal use of the synergy between low electricity costs and available storage
3 – MILP Operation

Principles

Control Module (C++)
- Rules Based
- Operational MILP

Prevision Modules (C++)
- Weather
- Network Load
- Costs

Operational MILP modifications

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Detailed Physical Dynamic Model
(Numerical Twin – Fixed Sizing)

Control Module (C++)
- Rules Based
- Operational MILP

Prevision Modules (C++)
- Weather
- Network Load
- Costs

System State Return
No
Every hour