Combined Heat & Power Production: Micro-CHP with Stirling Engine
Activities at Siemens Building Technologies

Conrad Gähler, SBT, Zug (CH)

Smart & Efficient Energy Council, Trento, 2009
Siemens Building Technologies (SBT)
Our key figures

Fiscal year 2008
Oct’07 – Sept’08

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<tr>
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<th>SBT</th>
<th>Total Siemens</th>
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<tr>
<td><strong>Revenue (mio. euros)</strong></td>
<td>6.0 G€</td>
<td></td>
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<tr>
<td><strong>Employees</strong></td>
<td>38,500</td>
<td>ca. 500,000</td>
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**Revenue**
- Europe, CIS, Africa: 60%
- Americas: 33%
- Asia, Australia, Middle East: 7%

**Employees**
- Europe, CIS, Africa: 54%
- Americas: 36%
- Asia, Australia, Middle East: 10%
BT Comfort at a glance...

Energy Efficiency Components for the Smart Building

- Boilers
- Chillers
- Lighting
- BACS
- Wind
- Solar
- Heat Pump
- Heat & Power

Solutions

Services

Value Added Partners

Resellers & Installers

OEMs

Regional companies

Products & Systems

HQ / production sites

Just renamed from "HVAC Products to "Control Products and Systems"

4 Oct 2009 C. Gähler: Micro-CHP with Stirling Engine. SEEC’09 Siemens Building Technologies
Agenda

1. Introduction Siemens Building Technologies
2. Trends in building control (HVAC+)
3. Siemens Micro-CHP Control System (MCS)
4. Micro-CHP: Research
5. ... Questions & Answers
Trends (1)
Alternative energy sources, Renewables

Key trends & findings

- Directives for energy- & emission reduction → less heating needed
- Shift from oil & gas towards renewable energies
- Demand based heating, cooling and ventilation

Trend to fragmentation & renewable in residential buildings

- High Efficiency Wall Hung Boiler
- Wall Hung Boiler
- Floor Standing Boiler

80th and 90th 2008 ≥2020

Heat Pump & Biogas Micro Co Heat
Trends (2)
Integrating more than HVAC
Trends (3)
Energy efficiency

• Laws, regulations, commitments of communities and companies public opinion / image

• Desigo Building Management System: Monitoring, TABS → Low exergy, … Additional functionality in next release

• Better quantification of energetic benefit of control functions → convince planners, owners, operators, and users to ask for the best available technology → need for approved results for standard cases; simulation tools that can cope with innovative technology; norms …

• Mentioned in all printed matters
# Agenda

1. **Introduction Siemens Building Technologies**
2. **Trends in building control (HVAC+)**
3. **Siemens Micro-CHP Control System (MCS)**
4. **Micro-CHP: Research**
5. **… Questions & Answers**
Micro-CHP:
The power plant in the own house
Micro-CHP
Energy flow, principle

- Fuel (gas)
- CHP appliance
- Generator
- Heat exchanger
- Heat
- Electric energy
- Losses
Micro-CHP
Comparison of energy flows

Conventional house

House with m-CHP unit

Primary energy (PE)

Power plant

Production and distribution losses

Energy, CO₂ and cost savings

Gas

El. Power consumption

Losses

El. Power production mCHP

Gas

Heat consumption

Losses

El. Power from power plant

Author

Oct 2009 C. Gähler: Micro-CHP with Stirling Engine. SEEC‘09

Building Technologies / HVAC Products

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Stirling engine: Operating principle and key advantages

Key advantages of SE:

- External combustion → „clean“ exhaust gases
- Frequent start/stopps ok (comparing to fuel cell)
- Linear arrangement:
  - Running at 50Hz → no inverter needed
  - No moving seals → maintenance-free for whole lifetime

The EU considers domestic heat generation with Stirling-based CHP as one of the most promising technologies to save CO2 in a mid timeline → support (Taxes, feed-in tariffs) can be expected
Micro CHP: Stirling Engine & Generator

Stirling engine

Cooling water

Burner flame

Generator
Micro CHP product development: Partners

Microgen Stirling Engine
Consortium MEC:
European boiler manufacturers: Remeha, Baxi, and others

Pel: 1 kW
Pth: 6 kW + 10 .. 30 kW

Large field tests 2009
Market introduction 2010

USPs of Siemens solution
• Complete solution: Automatic firing device (gas valve, ignition ...), control (heat production, consumers), grid supervision
• Homogeneous product range for mCHP, conv. Boilers, heat pumps, solar, wood, ...
Generator running at 50Hz
→ no inverter needed

Up to 3 heating circuits, more with additional controllers

Optional: Buffer storage
micro CHP
Grid supervision

• The electric grid must be supervised
Generator must be disconnected from the grid very quickly in case of
  • Over-/undervoltage
  • Over-/underfrequency
  • Missing grid (→ Islanded operation currently not supported)

• Hardware by Siemens A&D

• Norms are country specific:
  • GB, NL, … G83/1 single measurement
  • D, A, CH, F VDE 0126-1-1 redundant measurement
MCS:
Controller tasks & challenges

Stirling Engine (6kWth, 1kWel), Supp Burner (10..30kW)
2 Gas valves, ignition; Grid connection and supervision; boiler pump, DHW div. valve
Modulate burner power via supply air mass flow
To be controlled: THead (500°C), TBoiler (according to heat demand, e.g. 55°C)

To be optimised
• Minimize SuppBu operation
• Maximize EngBu operation
Without too many starts/stopps!
See next topic (Model Predictive Control)!
MCS: Model-based design with Simulink

Plant model: Stirling + SuppBu + Hydraulics (+ consumers)

Controller (Heat production)

Quant + dead times measurements

Scope
MCS: Simulation results

1: Engine on
2: Generator connected
3: THead controlled very nicely!
4: Fan drives EngBu back
5: TBoiler remains below setp
6: Supp Burner ein
8: Supp Burner off
10a: Supp Burner ein
10: Step of TBoiler setp \( \rightarrow \) 60°C
7: TBoiler overshots due to min heat output of SuppBu
9: Due to overshoot of TBoiler, THeadSp is reduced. Is this reasonable? **Point to discuss!**
11: Modulation of supp Bu is enabled after nach 10 Min
12: ca. 30 Pulses per hour, is ok
Comparison of workflows

Functional specification (requirements)

SW-Spec HVAC

Manual Coding

Model-based design (Simulink)

Simulink-Model = verified SW-Spec: Proof of control quality etc.

Code-Generation

Implementation

Classical:
- Difficult to see what to change in case of problems

Control problems become apparent only here

Integration in appliance, at customer (England)

Module test

Device test (=Test Regelgerät)

Controller design with Simu:
- In case of problems with real HW: Good understanding → targetted improvements possible

Functional specification (requirements)

“Classical“

Integration with engine, at customers (England)

Hardware-in-the-loop test

Device test

Module test

With Code generation: Changes can be made very quickly & reliably in test phase!

Worked at once without changing one single parameter change!
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Optimal control of mCHP building energy system with model predictive control (MPC)
Optimization method:
Performance bound with Model Predictive Control

1. The control must satisfy the requirements for room &DHW temperature
   • PE-optimal control
   • Cost-optimal control

2. We assume perfect a-priori knowledge of
   • System dynamics
   • Future weather, hot-water draws etc.

3. We compute the best theoretically possible operation strategy with
   • Model predictive control (MPC)
   • Linear programming (LP)

4. This result is called performance bound
Focus / Questions

- **Control strategy:**
  What do cost- and PE-optimal operations look like?

- **Performance assessment:**
  Possible cost and PE savings?

- **Impact of different parameters** on optimal control and performance
  - Sizing of Stirling engine
  - Etc.
Optimization constraints; Loads, climate, and tariffs

- Room temperature

- Hot water demand

- Electricity demand

- Climate, Gas & electricity tariffs: Zurich (Switzerland)
## Building types

Three types of buildings (Old, WSV95, EnEV2000):
- 4 apartments, 3 occupants each
- Floor space = 150 m²
- Sizing of SE and SB adapted to building insulation quality

<table>
<thead>
<tr>
<th>Nominal values</th>
<th>Old (poor)</th>
<th>WSV95 (medium)</th>
<th>EnEV2000 (good)</th>
</tr>
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<tbody>
<tr>
<td>Building heat losses [W/K]</td>
<td>446</td>
<td>194</td>
<td>88</td>
</tr>
<tr>
<td>Building time constant [h]</td>
<td>94</td>
<td>162</td>
<td>396</td>
</tr>
<tr>
<td>Stirling Eng. heat output (\eta_{th}=70%) [kW]</td>
<td>19.9</td>
<td>9.4</td>
<td>5</td>
</tr>
<tr>
<td>Stirling Eng. Electr. Power (\eta_{el}=25%) [kW]</td>
<td>7.1</td>
<td>3.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Supp burner heat output (\eta_{th}=95%) [kW]</td>
<td>41</td>
<td>18</td>
<td>8.2</td>
</tr>
</tbody>
</table>
Simulation results: Diurnal progression (base case)

- Building type: Old
- PE optimization

\[ \bar{T}_o = 7^\circ C, \Delta T_o = 6^\circ C \]

DHW tank charged in the evening
Night setback
Engine runs through All night
Supp burner is used for Morning boost
Hot-water draws
Efficiencies

Stirling engine: $\eta_{el, ref} = 25\%$ (as Solo Stirling engine. Microgen has less)
Reference plant: $\eta_{el, ref} = 50\%$
  - Marginal approach, modern CC gas plant with $\eta_{el, ref} = 56\%$
  - 10% grid losses *always* attributed to ref plant
    (import, export, in-house consumption)
Primary energy optimization: Energy flow diagram

Optimization criterion: \[
\min \left( E_{PE,SE} + E_{PE,SB} - E_{el,ref} \right)
\]

Performance assessment: Savings: \(131 - 111 = 20\)

Rel. Savings: \(\frac{20}{87} = 22.9\%\)

Conventional generation

Electricity credit

Condensing boiler

CC power plant (\(\eta_{el}=56\%\), 10% grid losses)

Numbers: MWh, from whole-year simulation WSV95

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Performance assessment: Whole-year simulation results

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<th>Building type</th>
<th>Old</th>
<th>WSV95</th>
<th>EnEV2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional heating (=gas burner alone)</td>
<td>Cost</td>
<td>CHF 15,169.--</td>
<td>CHF 8,512.--</td>
</tr>
<tr>
<td></td>
<td>PE consumption for heating</td>
<td>196.5 MWh</td>
<td>87.4 MWh</td>
</tr>
<tr>
<td>CHP system</td>
<td>Cost-saving</td>
<td>28.5%</td>
<td>28.1%</td>
</tr>
<tr>
<td></td>
<td>PE saving</td>
<td>20.6%</td>
<td>21.9%</td>
</tr>
<tr>
<td>PE-optimal control</td>
<td>Cost-saving</td>
<td>27.5%</td>
<td>25.5%</td>
</tr>
<tr>
<td></td>
<td>PE saving</td>
<td>21.4%</td>
<td>22.9%</td>
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- Equivalent full-load hours: ca. 270d/year
Simulation results: Variation of the sizing of the Stirling Engine

More powerful SE ⇒ less expensive, less PE consumption
⇒ but higher investment costs
⇒ Optimal sizing can be determined by including investment costs
Research
Conclusions

- Method allows to determine possible savings
- CHP saves 20%-30% money and 20%-25% PE (with assumptions used, e.g. 56% el. Ref. plant, in optimal control operation)
- Results give hints and benchmark for simpler control strategies
- Influence of different parameters on optimal control
  - Sizing of Stirling engine, supplementary burner
- Attractive prices for feed-in electricity help to exploit potential