EUROPEAN
HEAT PUMP
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Industrial | Commercial | Residential
Heating & Cooling | Components & Equipment

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Flexible operation of heat pumps in district heating systems to unlock synergies between the heating & power sector

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2015-2019, Budget 19 M€, Danish public funding 11 M€
Transition towards renewable energy supply

Source: https://windeurope.org/about-wind/daily-wind/top-countries

~ 67 % of households supplied by district heating
Sector coupling heat/power using large-scale heat pumps

Renewable power generation

Renewable heat sources

Heat pump

Heat demand

Storage capacity

District heating

Renewable heat sources
How can large-scale HPs support the integration of energy sectors? - Strategies

- Operation according to heat demand
- Cost-optimal operation schedule
- Ancillary services TSO / DSO level
- Combination of flexible assets

Helping the integration of energy sectors

Fast regulation necessary
Frequency regulation services in Denmark

Ancillary services in Western Denmark

Ancillary services in Eastern Denmark

Primary reserve
Secondary reserve
Manual reserve

0.3 MW up and down
1 MW symmetric
5 MW up and down

0.3 MW symmetric
1 MW symmetric
5 MW up and down

Frequency reserve (disturbance reserve)
Frequency reserve (normal reserve)
Secondary reserve
Manual reserve

5 sec
30 sec
150 sec
5 min
order
order + 15 min
Market potential

Daily average regulation prices DK1

Daily average of regulation prices DK2
Fast regulation of ammonia heat pump
The demonstration case – FlexHeat Nordhavn
The demonstration case – FlexHeat Nordhavn

- 2-stage ammonia heat pump
- Low-stage compressor
- High-stage compressor
- Open flash intercooler
- Desuperheater
- Condenser
- Subcooler
- Heat storage
- separator
- Evaporator
- Groundwater
- To the sea
- Electric heaters
- Secondary pump
- Primary pump
- To customers
- From customers
- 800 kW thermal
- DH supply: 60-82 °C
- Part-load: 20-100 %
Delivery of frequency regulation

Start-up and shut-down times of FlexHeat heat pump compared to required regulation times in Eastern Denmark

- Primary reserve (FCR-N)
- Secondary reserve (planned service)
- Tertiary reserve

Legend:
- Start-Up 70 °C
- Shut-down 70 °C forward
- Start-up 60 °C forward
- Shut-down 60 °C forward
- Start-up 80 °C forward
- Shut-down 80 °C forward
Heat pump control does not allow for faster regulation
Limiting factor: Risk of condensation in the suction line during ramp-down
Behaviour during fast ramp-up and ramp down
Different possible solutions

2-stage ammonia heat pump

- Low-stage compressor
- High-stage compressor
- Desuperheater
- Condenser
- Subcooler
- 2-stage ammonia heat pump
- DH forward
- DH return
- To the sea

Electric preheating

Direct expansion evaporator

To the sea

2-stage ammonia heat pump

- Low-stage compressor
- High-stage compressor
- Desuperheater
- Condenser
- Subcooler
- 2-stage ammonia heat pump
- DH forward
- DH return
- To the sea

To the sea
Recommendations for design of dynamically operated large-scale ammonia heat pumps

Control

• Control structure influences the ramping times and the dynamic behaviour strongly -> optimization needed
• Indirect capacity control may cause oscillating response

Cycle design

• No significant difference in ramping times could be observed for one-stage and two-stage heat pump
• Fast load changes resulted in less oscillations in the one-stage cycle compared to the two-stage cycle
Recommendations for design of dynamically operated large-scale ammonia heat pumps

Avoiding condensation in the suction line during fast ramp-down

• Crucial for dynamically operated ammonia heat pumps -> other fluids/cycles should be investigated

• Change of superheat control or electric preheating for existing plants

• Optional superheating through IHX or by using the source for preheating for newly installed systems
Delivering primary frequency regulation from combined flexible units
Alternative: Combination of flexible assets

Alternative: Combination of flexible assets
Alternative: Combination of flexible assets

Daily power uptake profiles for 1st week in January

- Day 1
- Day 2
- Day 3
- Day 4
- Day 5
- Day 6
- Day 7

Power uptake [kW]
Hour of the day

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
**Alternative: Combination of flexible assets**

<table>
<thead>
<tr>
<th>Heat cost [€/MWh]</th>
<th>Average FCR-N price [€/MWh]</th>
<th>Resulting total heat cost [€/MWh]</th>
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<td>50</td>
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<td>50</td>
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</tbody>
</table>

**Base case - total heat cost**: 22.82 €/MWh

**Weighted average FCR-N price for HP operation in 2018 (87.5% bidding strategy)**: 29.06 €/MWh

**Weighted average FCR-N price for HP operation in 2018 (perfect foresight bidding strategy)**: 34.02 €/MWh

**Break even total heat cost**: 22.82 €/MWh

**Total cost difference (2018)** [€/a]

- **Offset - Optimal (w/o FCR-N income)**: 2961 €/a
- **Offset - Optimal (FCR-N income, 87.5 € bidding strategy)**: -805 €/a
- **Offset - Optimal (FCR-N income, perfect foresight bidding strategy)**: -1779 €/a
Conclusion

Frequency regulation
- Tertiary reserve is possible
- Secondary reserve is possible with optimized control structure
- Primary regulation needs additional measures that allow for fast regulation of the HP

Combination of flexible assets
- HP can support fast regulating unit
- Economic synergy effects

Design of fast regulating HPs
- Prevent condensation in the suction line during fast ramp-down
- Control strategy
- Fluctuating operation conditions need to be considered
Thank you for your attention!

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