Integrated modeling of active demand response with electro-thermal systems

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Conventional & stochastic RES-based electricity generation

Thermal inertia allows decoupling the electrical demand and the thermal demand without loss of comfort
Complex interactions between demand and supply: how do you capture this in an operational model?
Outline

1  Scope & motivation

2  Modeling challenges & issues
   Modeling approaches in the scientific literature
   Integrated model & its added value

3  Applications

4  Conclusion
Modeling challenges & issues

Modeling approaches in the scientific literature
Integrated model & its added value

Based on:
Modeling challenges & issues
Focus on supply side: Simplified representations of the demand side flexibility in a unit commitment and economic dispatch model.
Modeling challenges & issues

**Focus on demand side:**
Simplified representations of the supply side in a detailed thermal building simulation or optimization model.
Integrated model (IM)
Combination of a UC&ED model and a detailed thermal building model
An integrated model

Joint optimization: minimize total operational cost

**UC & ED model**, considering set of power plants, RES-based generation and a fixed demand profile (MILP)

**DR-adherent demand model**: RC network (thermal dynamics building), linear heat pump model, user behavior & external gains (LP)
An integrated model: a first example

- Power system inspired on possible future setting of BE power system;
- 250,000 heat pumps;
- Building properties represented via an ‘average’ building (detached dwelling);
- 52 user behavior profiles.
An integrated model: a first example

- Peak shifting
- Valley filling
- Guaranteed thermal comfort
- Preheating
An integrated model: a second example

Case study:

- Power system inspired on possible future setting of BE power system;
- 250,000 heat pumps;
- Building properties represented via an ‘average’ building (detached dwelling);
- 52 user behavior profiles.
An integrated model: a third example

The residual electricity demand (left) and electricity price (right) in three cases of ADR participation (0%, 50%, 100%).
Output of the committed power plants in case of 0% (left) and 50% (right) ADR participation.
An integrated model: a third example

The thermal and electrical power supplied to one of the dwellings on the two simulated days. Left: Breakdown of the thermal power supplied to a building (50% ADR participation. Right: Electricity demand of the heating system of a single building.
Building indoor temperature (left) and DHW temperature (right) over the two simulated days under different ADR participation.
An integrated model: added value w.r.t to price-elasticity models

The price of electrical energy in hour $k$

The demand for electrical energy in hour $u$

Schematic representation of the partly elastic, partly inelastic demand. The intersection of the demand and supply curves yields the anchor points (index 0) for the elasticity calculation.

$\varepsilon_{u,k} = \frac{\partial d_u}{\partial p_k} \frac{p_{0,k}}{d_{0,u}}$

$p_k$ The price of electrical energy in hour $k$

$d_u$ The demand for electrical energy in hour $u$
The resulting price-demand couples indicate that the price-responsiveness of thermal systems cannot be captured via an own-price elasticity.
An integrated model: added value w.r.t to virtual generator models

- Schedule and dispatch an equivalent generator or energy storage system with a negative output;
- This virtual generator or energy storage system is governed by

\[ E_t = E_{t-1} - \Delta T \cdot \dot{L}_t - \Delta T \cdot \dot{D}_t + \Delta T \cdot \dot{I}_t + \Delta T \cdot \dot{G}_t \]

- Energy content
- Loss term, related to efficiency of storage
- Demand, e.g. for thermal energy services
- Input power for storage
- Gains

- Efficiency, gains and demand for thermal services are difficult to predict ex-ante and highly dependent on user behavior and boundary conditions (e.g. external temperature)
An integrated model: added value w.r.t to price profile representations

Min. operational cost considering fixed electricity demand

Min. building owner energy cost considering fixed electricity price profile
An integrated model: added value w.r.t. to price profile representations

Demand side focus
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CO₂ abatement cost of DR-adherent heat pumps

- Operational cost and CO₂ emission reduction resulting from deployment ADR based on IM
- Alternative use of IM allows estimating avoided investment in additional peak power plant capacity (next slide)

CO₂ abatement cost of DR-adherent heat pumps

Operational cost and CO₂ emission reduction resulting from deployment ADR based on IM

Alternative use of IM allows estimating avoided investment in additional peak power plant capacity (next slide)

CO₂ emission savings of DR-adherent heat pumps

- Operational CO₂ emission reduction resulting from ADR based on IM
- Reference: standard condensing gas boiler

CO$_2$ abatement cost of DR-adherent heat pumps


Attainable without violating thermal comfort requirements of building owners!
Value of DR-based arbitrage and regulation services

Impact of the market penetration on the value of DR

Decrease in operational cost:
- Operational cost decreases as penetration of ADR increases, but average benefit per consumer decreases.

Deferred investment in additional power plant capacity:
- Deferred investment ‘saturates’: additional, ‘similar’ flexibility during critical winter weeks no longer reduces peak demand.

A. Arteconi et al., Active demand response with electric heating systems: impact of market penetration, Applied Energy 177 (2016) 636-648
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Conclusion

1 Integrated modeling framework
   • Operational demand and supply side model formulated using MILP
   • More accurate representation compared to other methods
   • Myriad of applications possible

2 Demand response with heat pumps
   • Could lead to significant environmental and economic advantages: operational cost savings, (additional) peak demand reduction, cost-effective regulation services

3 Future work
   • Impact on heating system design
   • Accounting for limited controllability of DR-adherent heat pumps
   • Heterogeneity of DR-loads, user behavior, building types
   • Conflicting objectives building owner – system operator
Further reading


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Integrated modelling framework (1/3)

Operational MILP combining

• Generation
  • Operational costs
  • Technical constraints

• Demand
  o Traditional (profile)
  o Electrical heating
    • Linear model flexibility

Traditional unit commitment and economic dispatch (MILP)

Explicit model flexible demand (LP)
Integrated modelling framework (2/3)

Demand side model (LP)
• Scaled up demand from x building models
• For each building model:
  o Heat pump
    • Linearized: COP, part-load
  o Domestic hot water tank
    • Fully mixed, DHW demand
  o Building
    • Thermal RC network, solar & internal heat gains
    • User behavior
Case study CO2 abatement cost study

• Set-up
  o Belgium 2030
  o Electricity generation
    • No nuclear; 30% wind; 10% PV; CCGTs and OCGTs
  o Building types
    • 6 age classes; 3 typologies; 2 renovation cases
  o Heating system
    • All DHW tank; 3 heat pump cases

• 250,000 heat pumps with or without ADR
