Intelligent and Integrated Energy Systems

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Control of Power Consumption Using Thermal Inertia (DR)
Energy Systems Integration

Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales

Data Pathway: Information and communication technologies allow a better understanding and control of systems by linking sensor data from multiple locations to control centers.
The **central hypothesis** is that by **intelligently integrating** currently distinct energy flows (heat, power, gas and biomass) using grey-box models we can balance very large shares of renewables, and consequently obtain substantial reductions in CO2 emissions.

**Intelligent integration** will (for instance) enable lossless ‘virtual’ storage on a number of different time scales.
The **Smart-Energy Operating-System (SE-OS)** is used to develop, implement and test of solutions (layers: data, models, optimization, control, communication) for **operating flexible electrical energy systems** at all scales.
Smart-Energy OS
Control and Optimization

Day Ahead:
Stoch. Programming based on eg. Scenarios
Cost: Related to the market (one or two levels)

Direct Control:
Actuator: **Power**
Two-way communication
Models for DERs are needed
Constraints for the DERs (calls for state est.)
Contracts are complicated

Indirect Control:
Actuator: **Price**
Cost: E-MPC at **low (DER) level**, One-way communication
Models for DERs are not needed
Simple 'contracts'

Models for systems of systems

Intelligent systems integration using data and ICT solutions are based on grey-box models for real-time operation of flexible energy systems.
Software solutions

Software for combined physical and statistical modelling

Continuous Time Stochastic Modelling (CTSM) is a software package for modelling and simulation of combined physical and statistical models. You find a technical description and the software at CTSM.info.

Software for Model Predictive Control

HPMPC is a toolbox for High-Performance implementation of solvers for Model Predictive Control (MPC). It contains routines for fast solution of MPC and MHE (Moving Horizon Estimation) problems on embedded hardware. The software is available on GitHub.

MPCR is a toolbox for building Model Predictive Controllers written in R, the free statistical software. It contains several examples for different MPC problems and interfaces to opensource solvers in R. The software is available on GitHub.
Lab testing ....
SE-OS
Control loop design – logical drawing
SN-10 Smart House Prototype
Smart Control of Houses with a Pool

PilotB SN-10 signal overview
revision 1.0 (CITIES add-on)
SE-OS Characteristics

- ‘Bidding – clearing – activation’ at higher levels
- Nested sequence of systems – systems of systems
- Hierarchy of optimization (or control) problems
- Control principles at higher spatial/temporal resolutions
- Cloud or Fog (IoT, IoS) based solutions – eg. for forecasting and control
- Facilitates energy systems integration (power, gas, thermal, ...)
- Allow for new players (specialized aggregators)
- Simple setup for the communication and contracts
- Provides a solution for ancillary services
- Harvest flexibility at all levels
Some DH Related Demo Projects

- Control of WWTP (ED, Kruger, ..)
- Heat pumps (Grundfos, EConGRID, HTF, ..)
- Summerhouses (DC, ENDK, SE, ..)
- Green Houses (NeoGrid, ENFOR, Fj.v. Fyn, ..)
- CHP production opt. (Dong Energy, HOFOR, ..)
- Dynamics Prices in DH systems (EON, EA-E, AVA, Fj.v. Fyn, ..)
- Seasonal Storage Solutions (NREL, Brædstrup,
- Small Area District Heating and Cooling (Rambøll, HOFOR, ..)
- Use of Heat from Supermarkets (Hyllie, HTF, VEKS, ..)
- Use of data from meters (IC-meter, ENFOR, ..)
Case study

Models and Control for DH Systems
Heat Load forecasts – up to 96 h ahead
Models and Controllers
(Highly simplified!)

Diagram showing a simplified model of a system with multiple components labeled as FSC, SC1, SC2, SC3, and OC.
Characteristics
30%, 40%, 50%

Stationary gain of FIR

Stationary gain of ARX

Pole of ARX
Prob. constraints
Controller set-points

Temp at User

Ambient Air Temp.
Observed User Temp.
Supply temperature with/without predictive control
Savings  
*(Reduction of heat loss = 18.3 pct)*

<table>
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<th>Varmekøb</th>
<th>Elkøb</th>
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<tr>
<td></td>
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<td>kWh 1000kr</td>
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<tr>
<td>Med PRESS</td>
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Total besparelse (9 første måneder af normalår): **1,566,000kr**

Besparelse for et normalår:

- $12/9 \times 1,566,000\text{kr} = 2.1 \text{ mill.}$
- Imidlertid står jan.–sept. (75% af året) kun for ca. 65% af graddagen i en normalår.
- $1,566,000\text{kr}/0.65 = 2.4 \text{ mill.}$
Which approach to use?

- **Use simulation based control if:**
  - No access to data from the DH network
  - Want an evaluation of new operational scenarios

- **Use prediction based control if:**
  - Access to network data online
  - Want to use meteorological forecasts automatically
  - Want automated update of models
Control of Temperatures in DH Systems

Lesson learned:

- Control using simulation of temperature gives up to 10 pct reduction of heat loss.
- Control using data and predictions gives up to 20 pct. reduction of heat loss.
Case study

Modelling the thermal characteristics of a small office building
Example

U=0.86 W/m²K

U=0.21 W/m²K
Characterization using Data from Smart Meters

- Energy labelling
- Estimation of UA and gA values
- Estimation of energy signature
- Estimation of dynamic characteristics
- Estimation of time constants
## Results

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<th>$wA_{E\max}^W$</th>
<th>$wA_{S\max}^W$</th>
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Perspectives for using data from Smart Meters

- Reliable Energy Signature.
- Energy Labelling
- Time Constants (e.g., for night setback)
- Proposals for Energy Savings:
  - Replace the windows?
  - Put more insulation on the roof?
  - Is the house too untight?
  - ......
- Optimized Control
- Integration of Solar and Wind Power using DSM
Further Aspects
Live CO2 emissions of the European electricity consumption

This shows in real-time where your electricity comes from and how much CO2 was emitted to produce it.

We take into account electricity imports and exports between countries.

Tip: Click on a country to start exploring →

Wind power potential (m/s) →

Solar power potential (W/m²) 

Like the visualization? We would love to hear your feedback!

Found bugs or have ideas? Report them here.

This project is Open Source: contribute on GitHub.

All data sources and model explanations can be found here.

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Tomorrow

CITIES

Centre for IT Intelligent Energy Systems
(Virtual) Storage Solutions

- Flexibility (or virtual storage) characteristics:
  - Supermarket refrigeration can provide storage 0.5-2 hours ahead
  - Buildings thermal capacity can provide storage up to, say, 5-10 hours ahead
  - Buildings with local water storage can provide storage up to, say, 2-12 hours ahead
  - District heating/cooling systems can provide storage up to 1-3 days ahead
  - DH systems with thermal solar collectors can often provide seasonal storage solutions
  - Gas systems can provide seasonal/long term storage solutions
Summary

- A Smart-Energy OS for harvesting the flexibility of future intelligent and integrated energy systems has been described.
- **Modelling:** Toolbox – CTSM-R - for combined physical and statistical modelling (*grey-box modelling)*
- **Control:** Toolbox – MPC-R - for Model Predictive Control
- Two models for *characterizing the flexibility* have been suggested and demonstrated:
  - **Dynamic models** (used for E-MPC based on prices / indirect control)
  - **Saturation curves** (used for market bidding / direct control)
For more information ...

See for instance

www.smart-cities-centre.org

...or contact

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