CITIES

Center for IT-Intelligent Energy Systems in Cities

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The Danish Wind Power Case

.... balancing of the power system

In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK)

In 2015 more than 42 pct of electricity load was covered by wind power.

For several days the wind power production was more than 100 pct of the power load.

July 10th, 2015 more than 140 pct of the power load was covered by wind power
From large central plants to Combined Heat and Power (CHP) production

1980

From a few big power plants to many small combined heat and power plants – however most of them based on coal

Today
Energy Systems Integration

Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales
The **Center for IT-Intelligent Energy Systems in Cities (CITIES)** is aiming at establishing methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways 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 Integration

Energy Systems Integration using data leading to grey box models for operation of future 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.
Case study

Control of Power Consumption (DSM) using the Thermal Mass of Buildings
Data from BPA

Olympic Pensinsula project

- 27 houses during one year
- Flexible appliances: HVAC, cloth dryers and water boilers
- 5-min prices, 15-min consumption
- Objective: limit max consumption
Aggregation (over 20 houses)
Response on Price Step Change

![Graph showing consumption step response (Olympic Pen.) with a 5-hour delay.]
Control of Power Consumption
Case study

Heat Pumps and Local Storage
Modeling Heat Pump and Solar Collector

Simplified System
Advanced Controller
Economic Model Predictive Control

Formulation

The Economic MPC problem, with the constraints and the model, can be summarized into the following formal formulation:

$$\min_{\{u_k\}_{k=0}^{N-1}} \phi = \sum_{k=0}^{N-1} c^t u_k$$  \hspace{1cm} (4a)$$

Subject to

$$x_{k+1} = Ax_k + Bu_k + Ed_k \hspace{1cm} k = 0, 1, \ldots, N - 1$$  \hspace{1cm} (4b)$$

$$y_k = Cx_k \hspace{1cm} k = 1, 2, \ldots, N$$ \hspace{1cm} (4c)$$

$$u_{min} \leq u_k \leq u_{max} \hspace{1cm} k = 0, 1, \ldots, N - 1$$ \hspace{1cm} (4d)$$

$$\Delta u_{min} \leq \Delta u_k \leq \Delta u_{max} \hspace{1cm} k = 0, 1, \ldots, N - 1$$ \hspace{1cm} (4e)$$

$$y_{min} \leq y_k \leq y_{max} \hspace{1cm} k = 0, 1, \ldots, N$$ \hspace{1cm} (4f)$$
Heat pump with thermal solar collector and storage (savings up to 35 pct)
Case study

Control of Wastewater Treatment Plants
Waste-2-Energy

Resources

- Electricity
- Waste water

WWTP Energy Hub

- Treatment Process
- Digester
- Storage tank
- Gas storage
- CHP

Energy service

- Gas
- Electricity
- Heating

Greater Copenhagen Smart Solutions, Gate21, June 2016
Energy Flexibility in Wastewater Treatment

- Sludge -> Biogas -> Gas turbine -> Electricity
- Power management of the aeration process
- Pumps and storage in sewer system

Overall goals:
- Cost reduction
- Minimize effluent concentration
- Minimize overflow risk
Energy Flexibility in Wastewater Treatment

Sewer system → WWTP

Elspot price forecast → STAR

R

Sensor filtering and time delay

CTSM-R
Model parameter estimation

Closed loop prediction
Sewer System Control Goal

minimize overflow + \( p_{elspot}^T f(Q) \)
Sewer System Annual Elspot Savings

![Graph showing the relationship between Savings [1000 DKK] and Storage Volume [m^3].]
IT-Intelligent Energy Systems
Some Examples from the CITIES project

- Control of WWTP (ED, Krüger, ..)
- Heat pumps (Grundfos, ENFOR, ..)
- Supermarket cooling (Danfoss, TI, ..)
- Summerhouses (DC, SE, Energinet.dk, ..)
- Green Houses (NeoGrid, Danfoss, F.Fyn, ....)
- CHP (Dong Energy, FjernvarmeFyn, HOFOR, NEAS, ...)
- Industrial production (DI, ...)
- EV (charging) (Eurisco, ED, ...)
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
- Gas systems can provide seasonal storage
Discussion

- IT-Intelligent Energy Systems Integration can provide virtual storage solutions (so maybe we should put less focus on physical storage solutions)
- District heating (or cooling) systems can provide flexibility on the essential time scale (up to a few days)
- Gas systems can provide seasonal virtual storage solutions
- Smart Cities are smart elements of a Smart Society
- We see a large potential in Demand Response. Automatic solutions, price based control, and end-user focus are important
- We see large problems with the tax and tariff structures in many countries (eg. Denmark).
- Markets and pricing principles need to be reconsidered; we see an advantage of having a physical link to the mechanism (eg. nodal pricing, capacity markets)