Smart-Energy Operating-System;
A Framework for Implementing Flexible Electric Energy Systems in Smart Cities

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The Danish Wind Power Case

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.

.... balancing of the power system
The Center for IT-Intelligent Energy Systems (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'

Indirect Control

Control of Heating Systems
Aggregation (over 20 houses)
Flexibility described by Step Response Functions

![Consumption step response graph](image)

- Consumption step response (Olympic Pen.)
- 5 hours

SUSTAIN 2016, DTU, November 2016
Control of Power Consumption

Diagram showing the flow of information from consumption references to a price generator (controller), followed by model parameters to a price-response estimator. The estimator provides prices to a price-responsive consumption block, which eventually leads to aggregated consumption.
Case study

Control of Wastewater Treatment Plants
Kolding WWTP
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

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

- The graph shows the relationship between savings [1000 DKK] and storage volume [m³].
- Savings increase as the storage volume increases.
- There is a notable increase in savings when the storage volume exceeds 10⁴ m³.
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](http://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](http://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](http://GitHub).
Integrated and Flexible Energy Systems
Some Demo Projects in CITIES

- Control of WWTP (ED, Krüger, ..)
- Heat pumps (Grundfos, EconGrid, ENFOR, ..)
- Supermarket cooling (Danfoss, TI, ..)
- Summerhouses (DC, ONE, SE, Energinet.dk, ..)
- Green Houses (NeoGrid, Danfoss, F.Fyn, ....)
- CHP (Dong Energy, F.Fyn, HOFOR, NEAS, ...)
- Industrial production (DI, ...)
- EV (charging) (Eurisco, ENFOR, ...)

.............
(Virtual) Storage Solutions

- 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 implementing flexible and integrated energy systems has been described
- Built on: Big Data Analytics, Cyber Physical systems, Stochastic opt./control, Forecasting, IoT, IoS, Cloud computing, ...
- **Modelling:** Toolbox – CTSM-R - for combined physical and statistical modelling (grey-box modelling)
- **Control:** Toolbox – MPC-R - for Model Predictive Control
- **Forecasting:** Framework (cloud based) for full probabilistic forecasting
- **Simulation:** Framework for simulating flexible power systems
Discussion

- IT-Intelligent Energy Systems Integration can provide virtual storage solutions (so maybe we should put less focus on electrical 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 just 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 (e.g. Denmark).
- Markets and pricing principles need to be reconsidered; we see an advantage of having a physical link to the mechanism (e.g. nodal pricing, capacity markets)