Methodologies for Operating Future Intelligent and Integrated Energy Systems

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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% of electricity load was covered by wind power.

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

July 10th, 2015 more than 140% of the power load was covered by wind power.
Flexible Solutions and CITIES

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.
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'

Direct and Indirect Control
For DC info about individual states and constraints are needed

(a) Indirect control
(b) Direct control
SE-OS Characteristics

- Bidding – clearing – activation at higher levels
- Control principles at lower levels
- Cloud based solution for forecasting and control
- Facilitates energy systems integration (power, gas, thermal, ...)
- Allow for new players (specialized aggregators)
- Simple setup for the communication
- Simple (or no) contracts
- Rather simple to implement
- Harvest flexibility at all levels
Forecast requirements

Day Ahead:
- Forecasts of loads
- Forecast of Grid Capacity (using eg. DLR)
- Forecasts of production (eg. Wind and Solar)

Direct Control:
- Forecasts of states of DERs
- Forecasts of load

Indirect Control:
- Forecasts of prices
- Forecasts of load
Which type of forecast?

- Point forecasts
- Conditional mean and covariances
- Conditional quantiles (Prob. forecasts)
- Conditional scenarios
- Conditional densities
- Stochastic differential equations
Grey-box modelling are used to establish models and methods for real-time operation of future electric 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 Wastewater Treatment Plants
Kolding WWTP

CITIES
Centre for IT Intelligent Energy Systems

NTU-DTU Smart Cities Workshop, Oct. 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

Diagram showing the flow from the Elspot price forecast, through the Sewer system, to the WWTP, and the impact on the STAR system, which includes sensor filtering and time delay, CTSM-R model parameter estimation, and closed loop prediction.
WWTP Control goal

\[
\text{minimize} \quad p_{fee} Q^T S_N + p_{elspot}^T u
\]
Sewer System Control Goal

\[
\text{minimize overflow} + p^{T}_{\text{elspot}}f(Q)
\]
Sewer System Annual Elspot Savings
Energy Flexibility
Some Demo Projects in CITIES

- 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, ...)

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(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
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 (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)
Summary

- A Smart-Energy OS for implementing flexible and intelligent energy systems in smart cities 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
- **Simulation**: Framework for simulating flexible power systems.