Smart Water and Intelligent Energy Systems

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• Energy Flexibility and Wastewater
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• New large H2020 project – SmartNet
• Other international activities
Energy Systems Integration

Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales
Center for IT-Intelligent Energy Systems (CITIES) is establishing ICT solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales.

CITIES is the largest Smart Cities and ESI research project in Denmark – see http://www.smart-cities-centre.org.
Energy-System OS
Optimization in ES-OS

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 vs Indirect Control

<table>
<thead>
<tr>
<th>Level</th>
<th>Direct Control (DC)</th>
<th>Indirect Control (IC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>III</td>
<td>$\min_{x,u} \sum_{k=0}^{N} \sum_{j=1}^{J} \phi_j(x_{j,k},u_{j,k})$</td>
<td>$\min_{\hat{z},p} \sum_{k=0}^{N} \phi(\hat{z}_k,p_k)$</td>
</tr>
<tr>
<td></td>
<td>$\downarrow u_1 \ldots \downarrow u_J$</td>
<td>s.t. $\hat{z}_{k+1} = f(p_k)$</td>
</tr>
<tr>
<td></td>
<td>$\uparrow x_1 \ldots \uparrow x_J$</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>s.t. $x_{j,k+1} = f_j(x_{j,k},u_{j,k})$ $\forall j \in J$</td>
<td>$\min_u \sum_{k=0}^{N} \phi_j(p_k,u_k)$ $\forall j \in J$</td>
</tr>
<tr>
<td></td>
<td>s.t. $x_{k+1} = f_j(x_k,u_k)$</td>
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Table 3 - Difference between direct (DC) and indirect (IC) control.
Grey-box Modelling and Virtual Storage Principles

Grey-box modelling is an essential tool for implementing energy flexible solutions.

(Virtual) storage principles:
- Buildings (thermal mass) can provide storage up to, say, 5-12 hours ahead
- District heating/cooling systems can provide storage up to 1-3 days ahead
- Gas systems can provide seasonal storage
Price-based Control of Power Load
Case study

Control of Wastewater Treatment Plants
Kolding WWTP
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
WWTP Control goal

minimize $p_{fee} Q^T S_N + p_{elspot}^T u$
Activated Sludge Model (ASM) No. 1

\[
\begin{align*}
\dot{S}_{NH} &= -i_{XB} (\rho_1 + \rho_2) - \left( i_{XB} + \frac{1}{Y_A} \right) \rho_3 + k_a S_{ND} X_{B,H} \\
\dot{S}_{NO} &= -\frac{1 - Y_H}{2.68 Y_H} \rho_2 + \frac{1}{Y_A} \rho_3 \\
\dot{S}_O &= -\frac{1 - Y_H}{Y_H} \rho_1 - \frac{4.57 - Y_A}{Y_A} \rho_3 \\
\dot{S}_S &= \rho_7 - \frac{1}{Y_H} (\rho_1 + \rho_2) \\
\dot{X}_S &= (1 - f_p) (b_H X_{B,H} + b_A X_{B,A}) - \rho_7 \\
\dot{X}_{B,H} &= \rho_1 + \rho_2 - b_H X_{B,H} \\
\dot{X}_{B,A} &= \rho_3 - b_A X_{B,A} \\
\dot{S}_{ND} &= \rho_8 - k_a S_{ND} X_{B,H} \\
\dot{X}_{ND} &= (i_{XB} - f_p i_{XP}) (b_H X_{B,H} + b_A X_{B,A}) - \rho_8
\end{align*}
\]

\((S_I, X_I, X_P, \text{and } S_{ALK})\)
Reactions Rates in ASM No. 1

\[
\rho_1 = \hat{\mu}_H \frac{S_S}{K_S + S_S} \frac{S_O}{K_{O,H} + S_O} X_{B,H}
\]

\[
\rho_2 = \hat{\mu}_H \frac{S_S}{K_S + S_S} \frac{K_{O,H}}{K_{O,H} + S_O} \frac{S_{NO}}{K_{NO} + S_{NO}} \eta_g X_{B,H}
\]

\[
\rho_3 = \hat{\mu}_A \frac{S_{NH}}{K_{NH} + S_{NH}} \frac{S_O}{K_{O,A} + S_O} X_{B,A}
\]

\[
\rho_7 = k_h \frac{X_S/X_{B,H}}{K_X + X_S/X_{B,H}} \left( \frac{S_O}{K_{O,H} + S_O} + \frac{K_{O,H}}{K_{O,H} + S_O} \frac{S_{NO}}{K_{NO} + S_{NO}} \right) X_{B,H}
\]

\[
\rho_8 = \rho_7 \left( X_{ND}/X_S \right)
\]
Aeration Control
Sewer System Control Goal

minimize overflow + $p_{el spot}^T f(Q)$
Sewer System Annual Elspot Savings
Some Energy Flexibility Sub-Projects in CITIES
Energy Flexibility
Some Demo Projects in CITIES

- Control of WWTP (ED, Kruger, ..)
- Heat pumps (Grundfos, ENFOR, ..)
- Supermarket cooling (Danfoss, TI, ..)
- Summerhouses (DC, Nyfors, ..)
- Green Houses (NeoGrid, ENFOR, ....)
- CHP (Dong Energy, EnergiFyn, ...)
- Industrial production
- VE (charging)

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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 at GitHub.
International Alliances on Energy Systems Integration
News (DTU Compute is leading):
ESI Joint Program in EERA

- Modelling
- Forecasting & Control
- Technology
- The Customer
- Finance & Regulation

CITIES
Centre for IT Intelligent Energy Systems

Singapore visit at DTU, March 2016
Foster a Global Community

Vision
A global community of scholars and practitioners from leading institutes engaged in efforts to enable highly integrated, flexible, clean, and efficient energy systems

Objectives
- Share ESI knowledge and Experience
- Coordination of R&D activities
- Education and Training Resources

Recent Activities
- 2013 – IEEE P&E Issue on ESI
- 2014 – Four workshops on ESI
- 2015 – ESI 101 and 102 Courses
Thanks for your attention!

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