Integrated Energy Systems
Aggregation, Forecasting and Control

Henrik Madsen, DTU Compute
http://www.henrikmadsen.org
http://www.smart-cities-centre.org
In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK).

In 2014 more than 40 pct of electricity load was covered by wind power.

For several days in 2014 the wind power production was more than 120 pct of the power load.

July 10th, 2015 more than 140 pct of the power load was covered by wind power.
Intelligent Integration and Cities

Cities play an important role – for several reasons ......

Center for IT-Intelligent Energy Systems in Cities (CITIES) is establishing ICT solutions for design and operation of integrated electrical, thermal, fuel pathways in at all scales.

CITIES is the largest Smart Cities and ESI research project in Denmark – see http://www.smart-cities-centre.org .
Future Electric Energy System
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 vs Indirect Control

**Table 3 - Difference between direct (DC) and indirect (IC) control.**

<table>
<thead>
<tr>
<th>Level</th>
<th>Direct Control (DC)</th>
<th>Indirect Control (IC)</th>
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| III   | \[
\min_{x,u} \sum_{k=0}^{N} \sum_{j=1}^{J} \phi_j(x_{j,k},u_{j,k})
\] \[\downarrow u_1 \cdots \downarrow u_J \uparrow x_1 \cdots \uparrow x_J \]
  s.t. \[x_{j,k+1} = f_j(x_{j,k},u_{j,k}) \quad \forall j \in J\] | \[
\min_{\hat{z},p} \sum_{k=0}^{N} \phi(\hat{z}_k,p_k)
\] \[s.t. \quad \hat{z}_{k+1} = f(p_k)\] |
| IV    | \[
\min_{u} \sum_{k=0}^{N} \phi_j(p_k,u_k) \quad \forall j \in J
\] \[s.t. \quad x_{k+1} = f_j(x_k,u_k)\] |
Forecasting is Essential

Tools for Forecasting: (Prob. forecasts)

- Power load
- Heat load
- Gas load
- Prices (power, etc)
- Wind power prod.
- Solar power prod.
- State variables (DER)
Denmark: 48 pct of power load by renewables (> 100 pct for some days)

(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
Price-based Control of Power Load

Figure 12 - Control of aggregated consumption based on a dynamic model (Price-response estimator) for the price-responsive consumption.
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
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
International Alliances on Energy Systems Integration
Proposal (UCD, DTU, KU Leuven): ESI Joint Program in EERA
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!

For more information:

hmad@dtu.dk