Strategies of Energy
Flexible Buildings and Districts

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Potentials and Challenges for renewable energy

**Scenario**: We want to cover the world's entire need for power using wind power.

How large an area should be covered by wind turbines?
Potentials and Challenges for renewable energy

Scenario: We want to cover the world’s entire need for power using wind power.

How large an area should be covered by wind turbines?

Conclusion: Use intelligence ....

Calls for IT / Big Data / Smart Energy Solutions / Energy Systems Integration
The Danish Wind Power Case

25% wind energy (West Denmark January 2008)

50% wind energy

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

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

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

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

1980

Today

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

I

Day Ahead Market

TSO

DSO

Balancing Market

BRP

II

Direct Control (DC)

Indirect Control (IC)

III

(a) Sub Aggregator

- Forecast Service
- Opt. and controls services

Aggregator

MET Forecasts
Local Data

(b) Sub Aggregator

- Forecast Service
- Opt. and control services

IV

Actuation

State Info.

Actuation

State Info.

DER

Advanced Controller

DER

Advanced Controller

DER

Advanced Controller

CITIES
Centre for IT Intelligent Energy Systems

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'

Forecasting is Essential

Tools for Forecasting:

- Power load
- Heat load
- Gas load
- Prices (power, etc)
- Wind power produc.
- Solar power produc.
Flexibility Idea

The **central idea** is that by **intelligently integrating** currently distinct energy flows (heat, power, gas and biomass) in we can enable **flexibility** and hence integrate very large shares of renewables, and consequently obtain substantial reductions in CO2 emissions.

**Intelligent integration** will (for instance) enable lossless **virtual** storage on a number of different time scales.
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.

CITIES is the largest Smart Cities and ESI research project in Denmark – see http://www.smart-cities-centre.org. 
Flexibility Concepts

Energy Systems Integration using data and ICT solutions leading to models and methods for planning and operation of future flexible energy systems.
**Denmark (2014)**: 48 pct of power load by renewables (> 100 pct for some days in January)

**(Virtual) storage principles:**
- Buildings 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
CHP gives Energy Flexible Energy Systems
(Paradigmatic example - Denmark)

Gas Turbine

Electricity

Steam Turbine

Heat tank

District heating

Waste incinerators,
Supermarket cooling,
Industrial processes
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
Price responsivity

Flexibility is activated by adjusting the temperature reference (setpoint)

- **Standardized price** is the % of change from a price reference, computed as a mean of past prices with exponentially decaying weights.
- **Occupancy mode** contains a price sensitivity with its related comfort boundaries. 3 different modes of the household are identified (work, home, night).
Aggregation (over 20 houses)
Response on Price Step Change

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

Considerable **reduction in peak consumption**
Case study

Control of Heat Pumps
Grundfos Case Study
Schematic of the heating system
Modeling Heat Pump and Solar Collector

Simplified System
**Formulation**

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

\[
\min_{\{u_k\}_{k=0}^{N-1}} \phi = \sum_{k=0}^{N-1} c^T u_k
\]  

Subject to \( x_{k+1} = Ax_k + Bu_k + Ed_k \) \( k = 0, 1, \ldots, N - 1 \)  
\( y_k = Cx_k \) \( k = 1, 2, \ldots, N \)  
\( u_{min} \leq u_k \leq u_{max} \) \( k = 0, 1, \ldots, N - 1 \)  
\( \Delta u_{min} \leq \Delta u_k \leq \Delta u_{max} \) \( k = 0, 1, \ldots, N - 1 \)  
\( y_{min} \leq y_k \leq y_{max} \) \( k = 0, 1, \ldots, N \)  

\( 4a \) \( 4b \) \( 4c \) \( 4d \) \( 4e \) \( 4f \)
EMPC for heat pump with solar collector (savings 35 pct)
Flexibility in District Heating

- Production
  - Production supply curves
- Distribution
  - Distribution supply curves / price signals
- Consumption
  - Displacement of consumption in buildings

Production heat accumulator
Distribution heat storage in network and accumulator
Proposal (UCD, DTU, KU Leuven): ESI Joint Program as a part of European Research (EERA)
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

Activities 2014
- Feb 18-19 Workshop (Washington)
- May 28-29 Workshop (Copenhagen)
- July 21 - 25, ESI 101 (Denver)
- Nov 17th Workshop (Kyoto)

Activities 2015
- Dublin, Denver, Brussels, Seoul
Energy Systems Integration can provide virtual and lossless storage solutions (so maybe we should put less focus on physical storage solutions)

Flexible Energy Systems might be able to solve many of the problems Europe now is trying to solve by Super Grids (some of these huge investments might not be needed)

Focus on zero emission buildings - and less on zero energy buildings (the same holds supermarkets, wastewater treatment plants, etc.)

District heating (or cooling) provide virtual storage on the essential time scale (up to a few days)

We see a large potential in Demand Side Management. Automatic solutions and end-user focus is important

We see a large potential in coupling cooling (eg. for comfort) and heating systems using DH networks

We see large problems with the tax and tariff structures in many countries (eg Denmark). Coupling to prices for carbon capture could be advantageous.

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)
For more information ...

See for instance

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Some References - Generic

Some References - Heat Dynamics of Buildings