Model Predictive Control for Smart Energy Systems

Rasmus Halvgaard

John B. Jørgensen, Niels K. Poulsen,
Lieven Vandenberghe, Henrik Madsen

CITIES, May 27, 2014
Fossil-fuel free future

Danish Commission on Climate Change Policy, 2010
Agenda

1 Model Predictive Control

2 Model and simulation examples
   - Example 1: EV
   - Example 2: Heat pump and building

3 Aggregator strategies

4 Waste water treatment

5 Conclusions
Economic Model Predictive Control

minimize \[ \sum_{k=0}^{N} c_k u_k \]

subject to \[ x_{k+1} = A x_k + B u_k + E d_k \]
\[ y_k = C x_k \]
\[ u_{\min} \leq u_k \leq u_{\max} \]
\[ y_{\min} \leq y_k \leq y_{\max} \]
Example 1: EV charging

Graph showing the state of charge (SOC) of an electric vehicle over a 24-hour period. The graph includes lines for different charging scenarios and price data. The graphs display charge power in kW and Elspot price in EUR/MWh.
Why MPC?

- Controllable loads (EV, Thermal storage)
- Exploits predictions to react ahead of time (prices, demand, wind)
- Flexible control architecture
- Handles system constraints
- Feedback and disturbance rejection
Heat pump and building

Weather and price forecast

MPC

Heat Pump

Sensors
Heat pump MPC

5 day simulation, 48 h prediction horizon using known inputs. Savings up to 35% compared to MPC with fixed price.
Annual energy consumption and cost

![Graph showing annual energy consumption and costs for different prediction horizons. The graph plots annual power consumption in kWh against the prediction horizon in hours. The x-axis represents the prediction horizon, ranging from 5 to 35 hours, while the y-axis represents annual electricity costs in DKK, ranging from 1200 to 1900. The graph compares different control strategies: EMPCp, EMPC, MPC, and Thermostat. EMPCp shows the highest consumption and costs, while the Thermostat maintains the lowest consumption and costs across all prediction horizons. The MPC and EMPC strategies fall in between, with MPC generally showing slightly lower consumption and costs than EMPC.](image-url)
Aggregator strategies

metered data

Aggregator
Reference
Prices

Smart Grid units

eMPC

EV

Heat Pump

Unit n

Consumption

10 / 19
Decomposition methods

Solve the aggregator problem using

1. Dual decomposition
2. Douglas-Rachford splitting
3. Indirect set point MPC
Dual decomposition

Inputs and outputs $u_j, y_j$

Power $p, q$

Price $c$

Time
Douglas-Rachford splitting

![Graph showing computation time vs. number of units](image)

**Figure:** Convergence for open-loop problem with tuned step sizes $t$. 
Price to temperature set point

\[ f_j(c) = -a_j c + b_j. \]
Indirect set point MPC

- Total power consumption
- Control price
- Power consumption
- Temperature
Waste Water Treatment Plant (WWTP)

Resources

- Electricity
- Waste water

WWTP Energy Hub

- Sewer system
- Treatment Process
- Digester
- Storage tank
- Gas storage
- CHP

Energy service

- Gas
- Electricity
- Heating
Conclusions

- Linear dynamic models of heat pumps in buildings, heat storage tanks, electric vehicles, refrigeration systems, power plants, and wind farms.
- Economic MPC that demonstrates load shifting capabilities of these flexible units.
- Distributed large-scale aggregation methods based on MPC, convex optimization, and decomposition methods.
- Several strategies for controlling the power consumption of a large portfolio of flexible consumers using MPC.
Future work

- Energy management of flexible waste water treatment plants
- Model Predictive Control and forecasts
- Interface to Smart Grid markets
- WWTP aggregation strategies
Questions and Comments

Rasmus Halvgaard
rhal@dtu.dk

www.compute.dtu.dk/~rhal

Department of Applied Mathematics and Computer Science
Technical University of Denmark