A need- and willingness-based approach for online electric vehicle charging control

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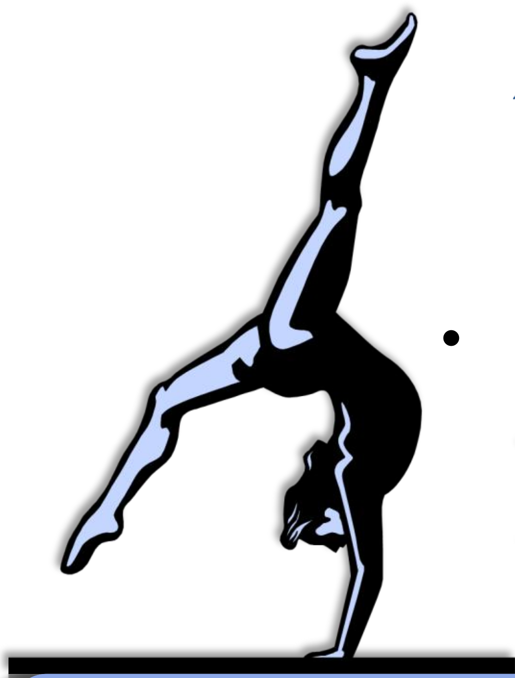
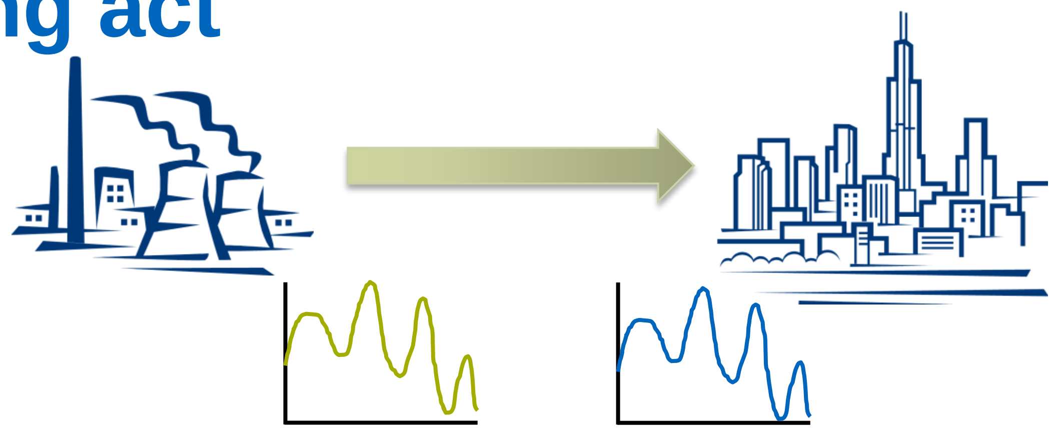
The balancing act





- Challenges
  - ↓ fossil fuels
  - ↓ nuclear power
  - ↑ renewable energies (RE)
  - ↑ energy consumption

Focus on demand

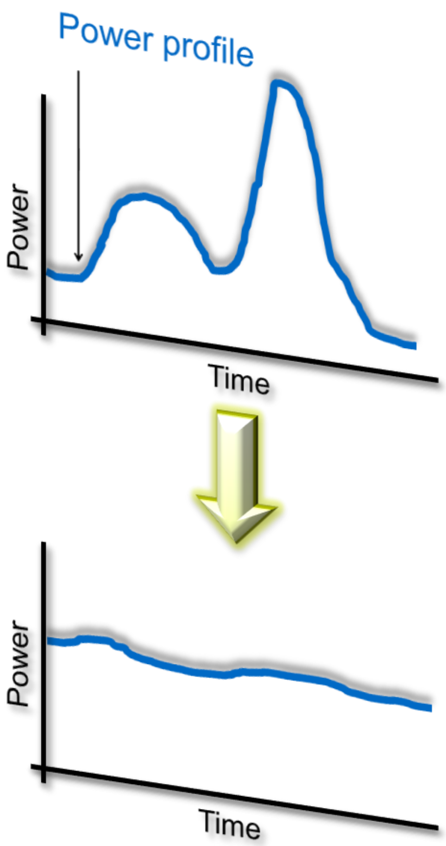
"don't spend more than what you have"

Why electric vehicles and how?

- Variability from renewables and demand
  - regulation and reserve requirements
  - usually inefficient
  - fossil fuels

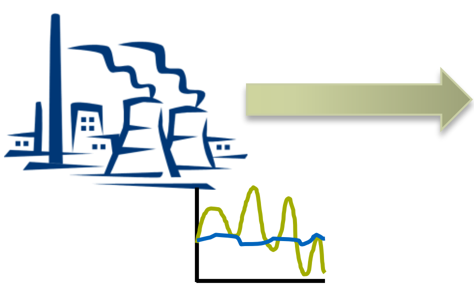
- Use plug-in electric vehicles (PEV) to compensate for this variability

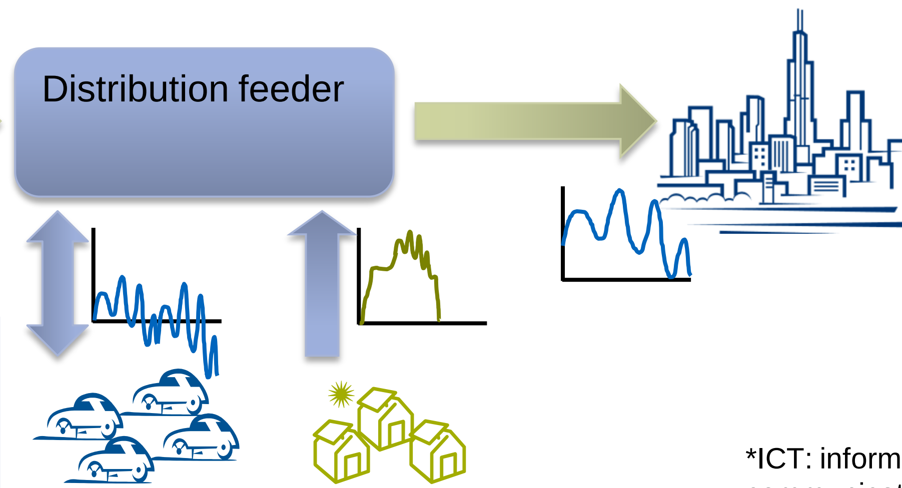
PEVs are flexible loads on power systems



Research problem

- Control PEVs in **real time** to reduce **power variability**
  - within the **distribution network** constraints and distributed **solar** generation
  - low distance to **optimality**
- What is the **tradeoff** between optimality and **ICT*** **requirements** and its main **influencing factors**?

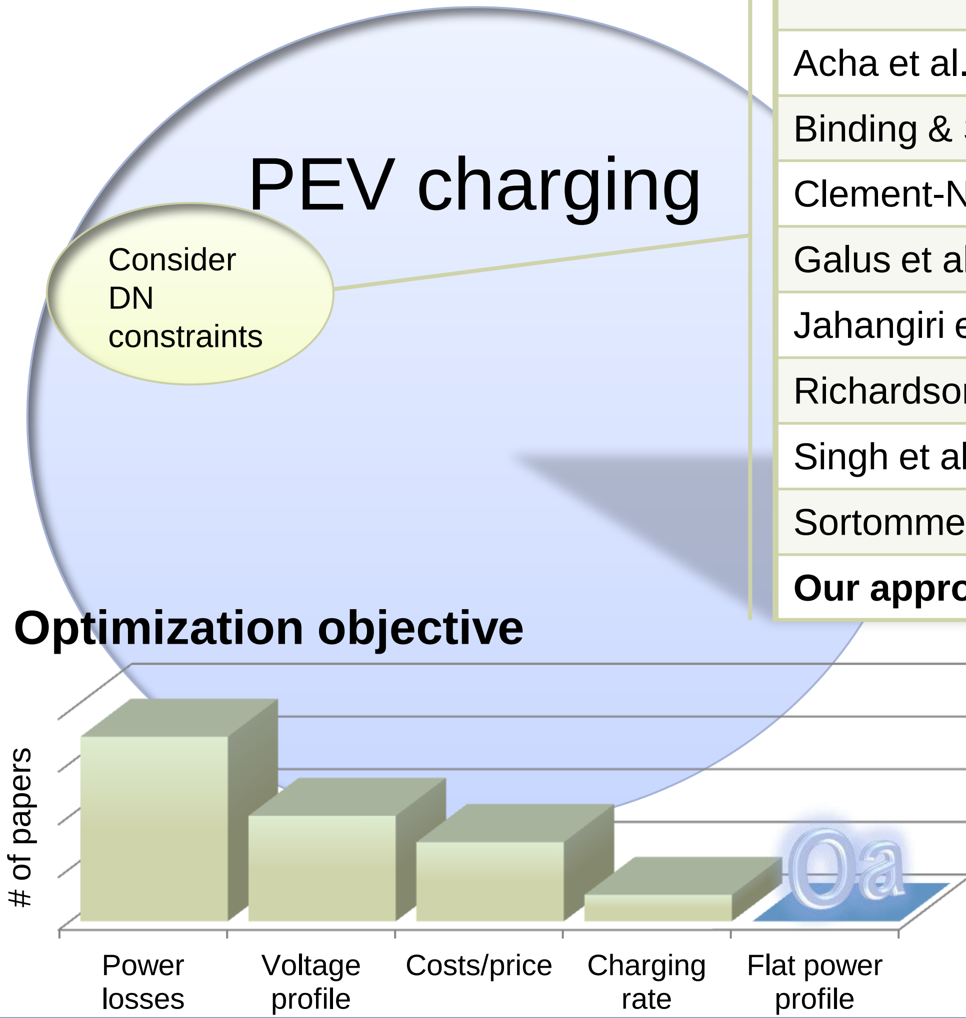




- Privacy
- Dependency on prediction
- Flexibility in constraints and objectives

*ICT: information and communication technologies

Related work



Factors considered	RE	V2G*	Online
Acha et al. 2010	7	6	7
Binding & Sundström 2012	6	7	7
Clement-Nyns et al. 2010	7	7	7
Galus et al. 2011	7	6	7
Jahangiri et al. 2012	6	7	7
Richardson et al. 2012	7	7	7
Singh et al. 2010	7	6	7
Sortomme et al. 2011	7	7	7
Our approach (Oa)	6	6	6

* Vehicle to Grid

Classifying PEV charging optimization

Control method		Optimization approach	
Direct	Incentive-based	Centralized	Decentralized
+ Certainty - Acceptability	+ Acceptability - Uncertainty	+ Simplicity - Scalability	+ Scalability - Complexity

Design principles

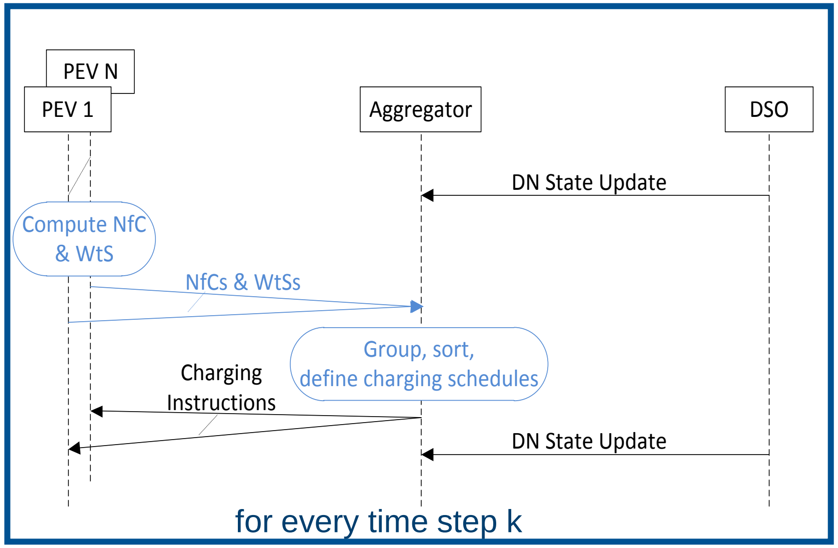
- Decision at aggregator level: **certain & simple**
- Part of the computation on PEVs: **scalable**
- ICT requirements within acceptable bounds
- Low impact in optimality

Benchmark: centralized direct control optimization

Model	
Continuous	- faster - less realistic
Integer	- slower - more realistic

Data	
All known	- strong assumption - absolute best (ref.)
Upon arrival	- realistic - reachable target

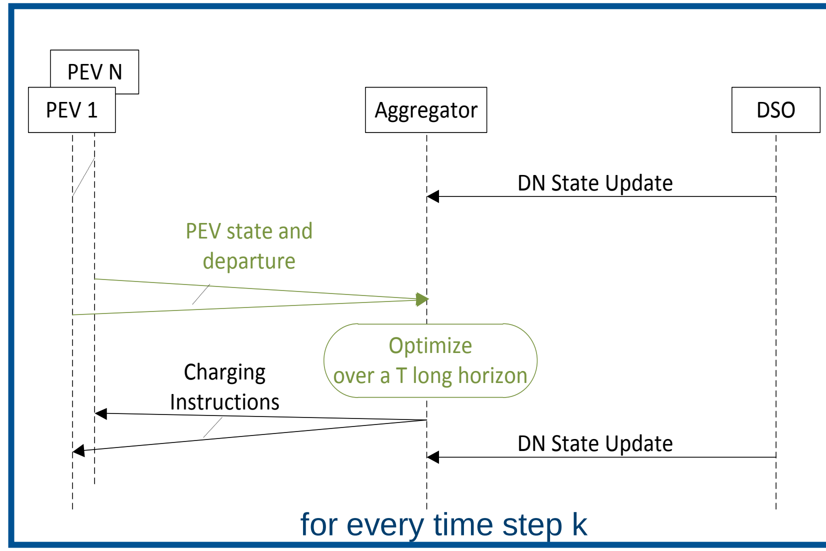
Our approach



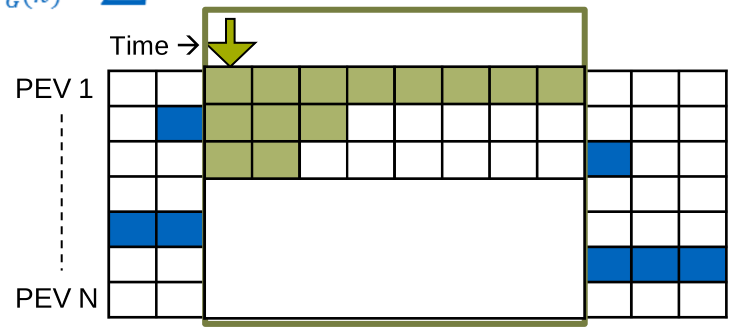
1. Sort NfC and WtS
2. Get current demand
3. Add cars in trouble
4. More charging?
5. V2G?

Benchmark

Quadratic (mixed integer) programming



$$\min_{P_G(k)} \sum \{P_O - P_G(k)\}^2$$



The PEVs

$$NfC \propto \frac{ReqTimeSlots}{AvailTimeSlots}$$

$$WtS \propto \frac{SOC}{DepTime} AvailTimeSlots$$

- With some conditions

$$NfC = C_{tar} \quad for\ C_{noC} < NfC < C_{tar}$$
$$NfC = C_{noC} \quad for\ NfC < C_{noC}$$

- For a full battery → C_{noC}
- If must charge → C_{QoS}

- Below a min. charge → C_{noS}
- If must charge → C_{noS}

For and by every PEV → parallelizable & distributable

SOC: state of charge

The simulation

Constraints

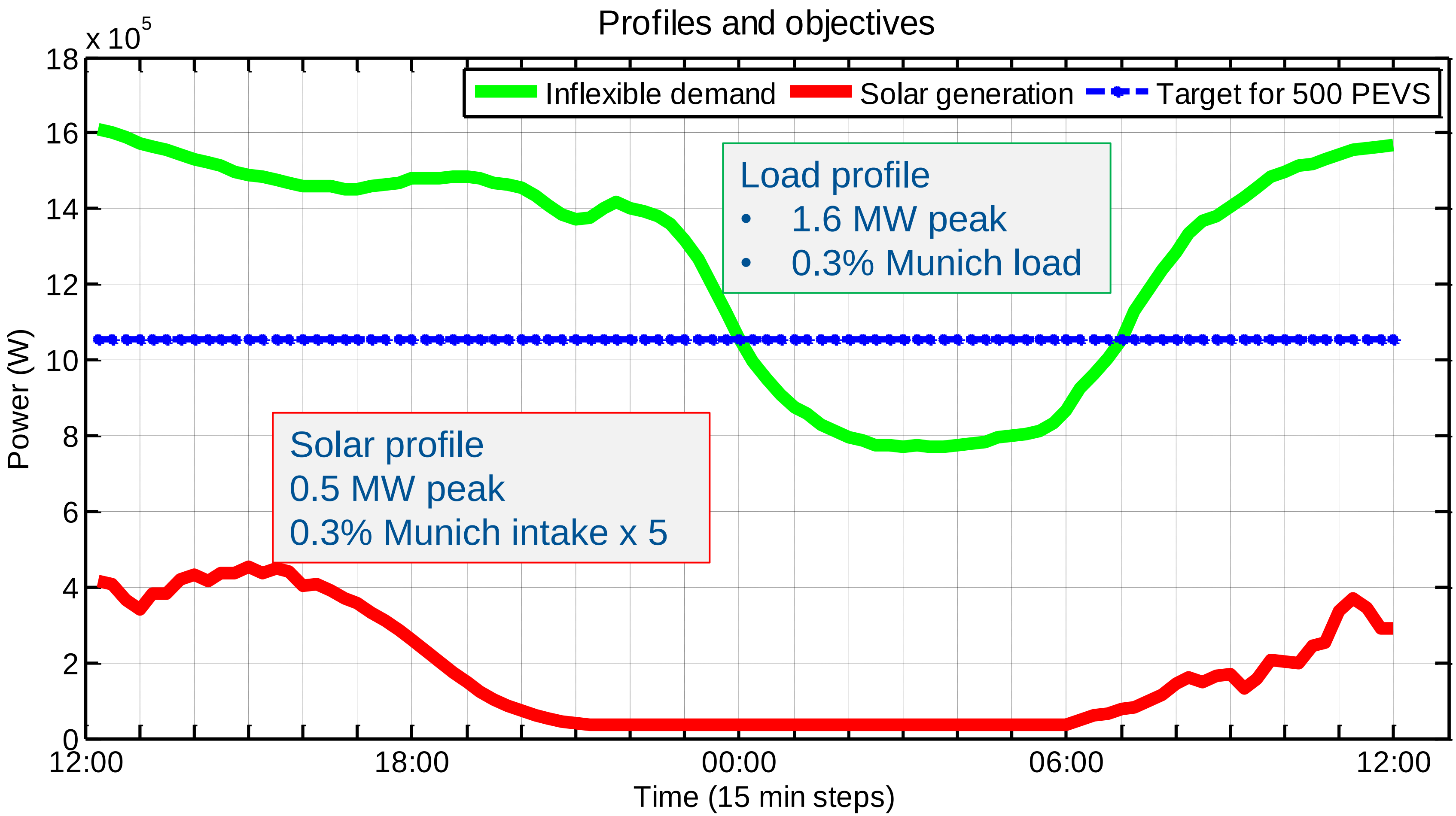
$-P_{lim} < p(t) < P_{lim}$	power limits on every charge
$SOC(end) \geq SOC_{tar}$	final charge
$SOC_{min} \leq SOC(t) \leq SOC_{max}$	battery energy capacity
$0 \leq totalLoad \leq DN\ Capacity$	distribution network capacity

Data

Driving profiles	generated based on latest MiD* survey (100-1000 PEVS)
Load profile	for Munich on a given day from SWM* (scaled)
Solar profile	5 x Munich low voltage intake from SWM* (scaled)

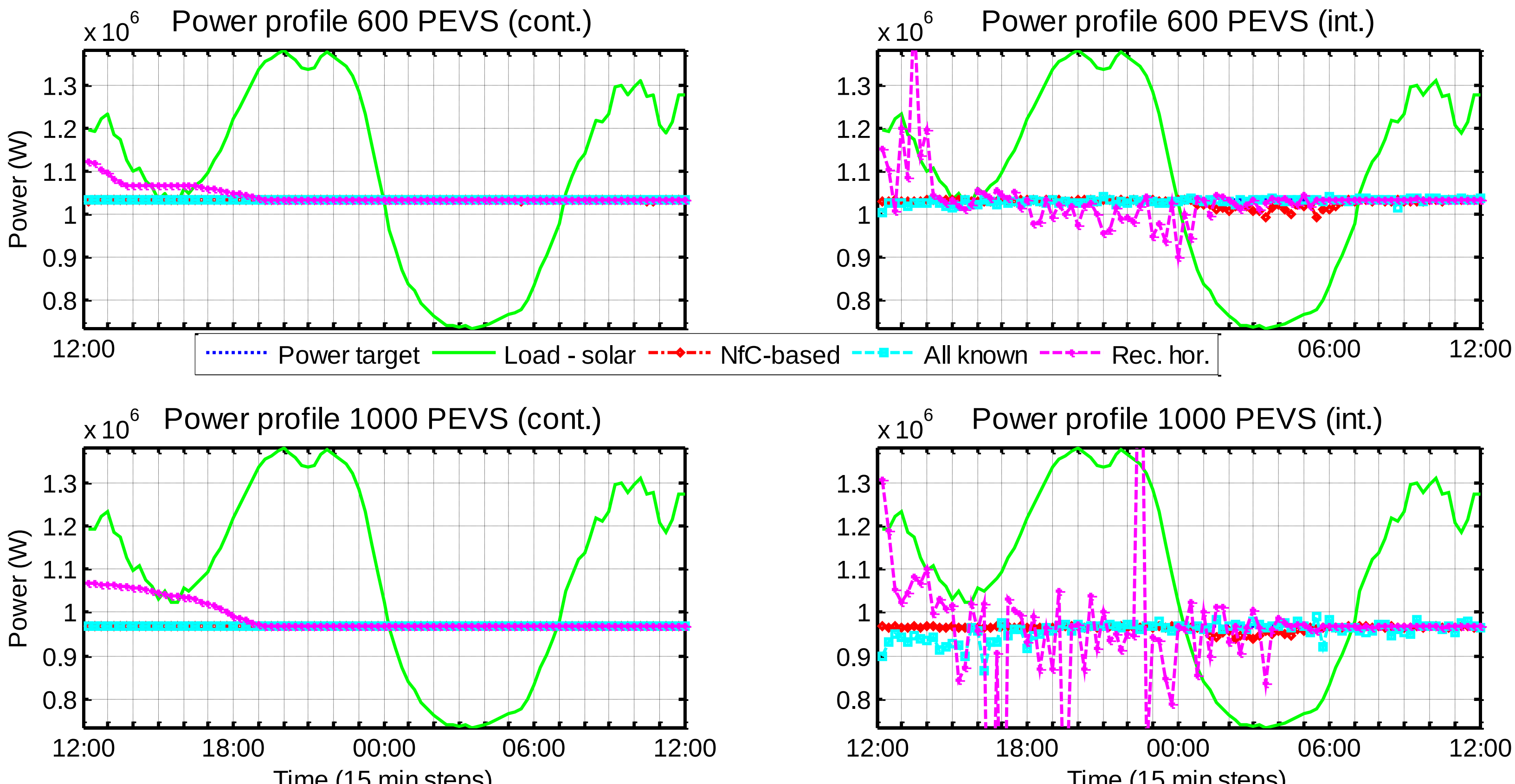
*MiD: Mobility in Deutschland (2008)
SWM: Stadtwerke München

Day-specific Munich curves



Power profile

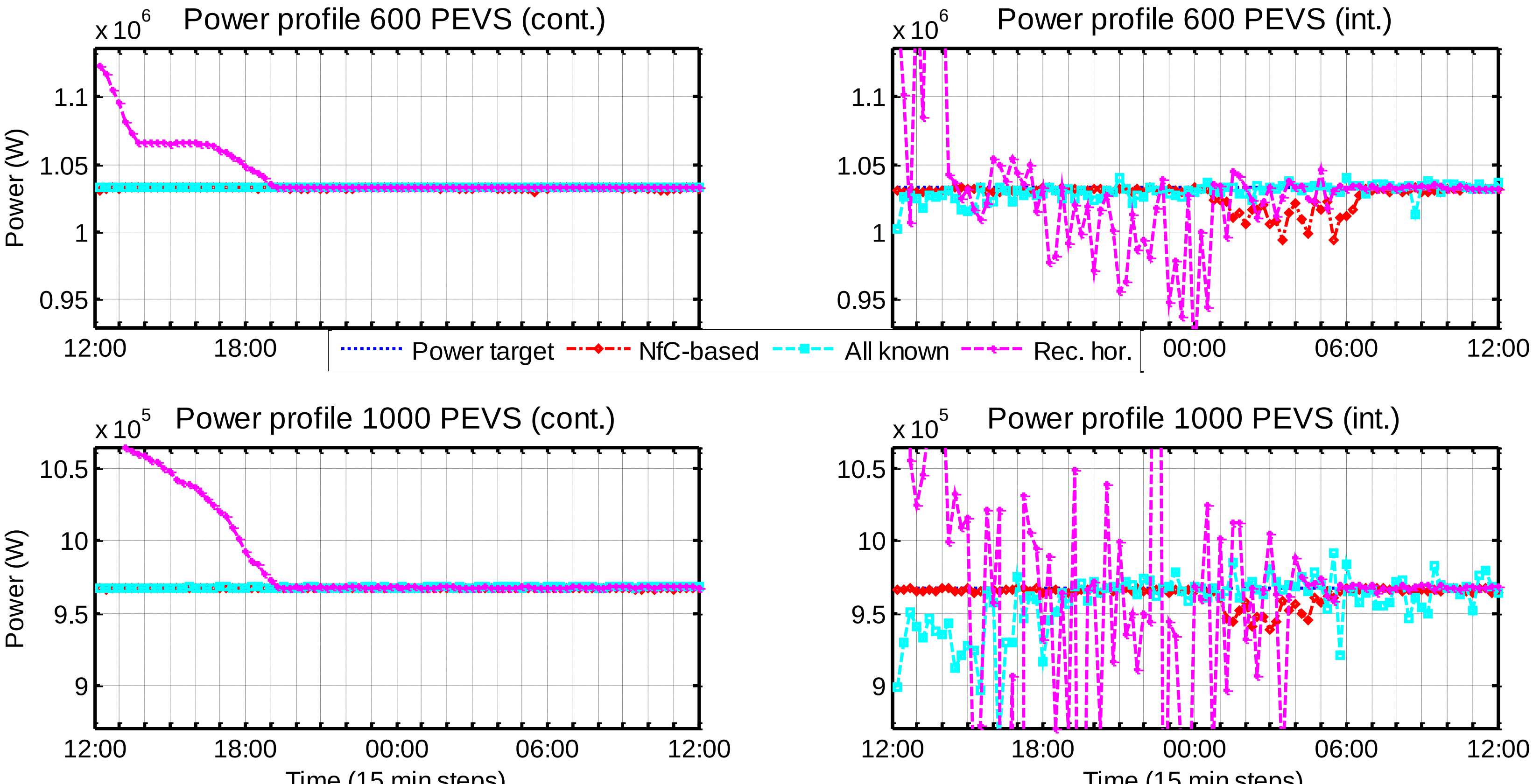
Continuous Integer



Power profile

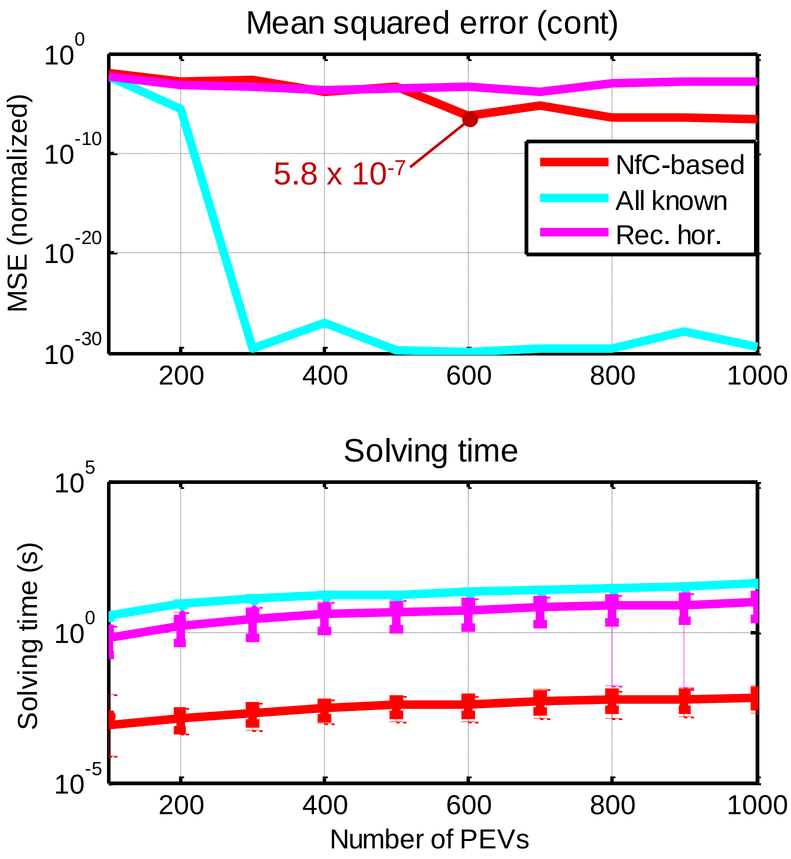
Continuous

Integer

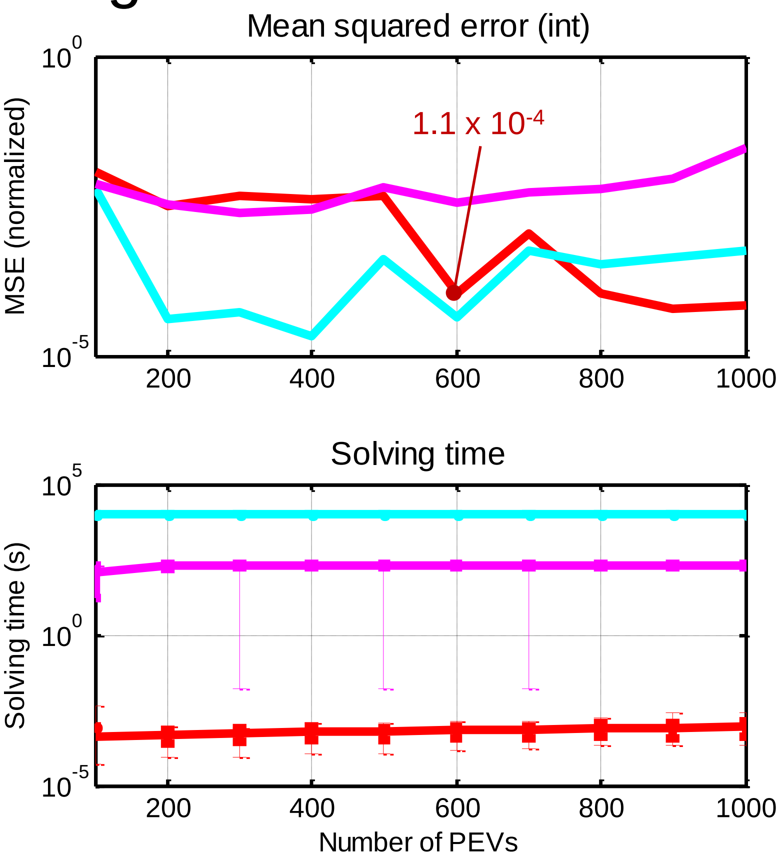


Performance

Continuous



Integer



Conclusions

- NfC-based approach advantages
  - privacy
  - forecast-free
  - naturally distributed & efficient
  - independent complexity of PEV and aggregator
  - extendibility (other flexible loads)
  - significantly faster than optimizing
  - comparable results (under certain conditions)

- Performance depends on the relation between load & fleet size

THANK YOU

- Questions?

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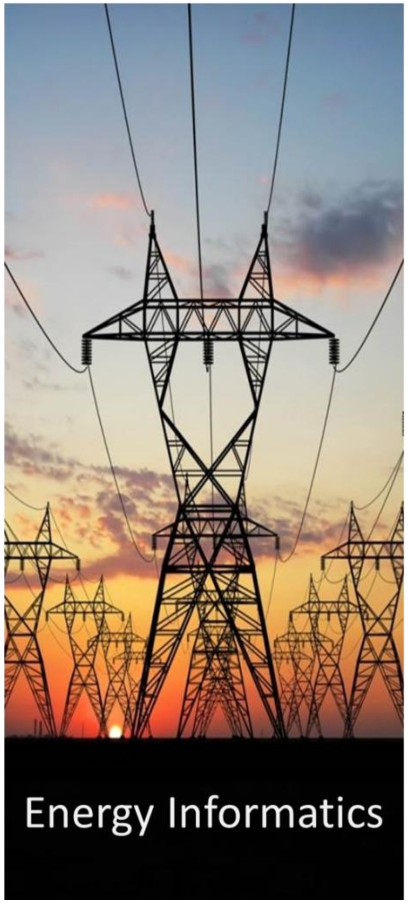

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- Mentioned tools: Matlab(http://www.mathworks.de/products/matlab/) , Yalmip (http://users.isy.liu.se/johanl/yalmip/) , Cplex (http://www-03.ibm.com/software/products/us/en/ibmilogcpleoptistud/), Gurobi (http://www.gurobi.com/)