Karlsruher Institut für Technologie

How many electric vehicles can one wind turbine charge?

A study on wind energy generation and electric vehicle demand correlation

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Introduction

Background

- Karlsruhe Institute of Technology (KIT)
- Institute of Industrial Production (IIP)
- Chair of Energy Economics (Prof. Dr. Wolf Fichtner)
- Transport and Energy Group (PD Dr. Patrick Jochem)
- Funded by Helmholtz Research School on Energy Scenarios

Karlsruhe Institute of Technology

iip Institut für Industriebetriebslehre und Industrielle Produktion

HELMHOLTZ ASSOCIATION

energy scenarios school

PhD Thesis

- Topic: **Uncertainties in energy demand of future private households**
- Focus: Charging scheduling of electric vehicles (EVs) under uncertainty; integration of EV into energy system model

Outline

- Research Motivation
- Methodology and Model Design
- Data Input
- Results
- Summary and Future Work

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Research Motivation

- Targets to increase the market share of electric vehicles (EVs) and the integration of renewable energy into power system [1][2]
- The emission of EV depends on the electricity mix for charging
- Load shifting potential of EVs can help integration more renewable energy into power system [3]

Research questions

- How to develop a controlled charging strategy for the integration of renewable energy
- How to study the correlation between a wind turbine and an EV fleet
- How to consider the uncertainties of EV

	Connected EVs	Future EVs
Arrival time	✓	×
Departure time	✓(?)	×
Initial SOC*	✓	×
Target SOC*	✓(?)	×

Table: Information availability of EVs

*SOC: state of charge of battery

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Methodology and Model design

Following charging strategy [4]

- Total EV charging demand scheduled at the level of the wind turbine output
- Utilization of wind energy, alleviation of output volatility, consideration of future EVs

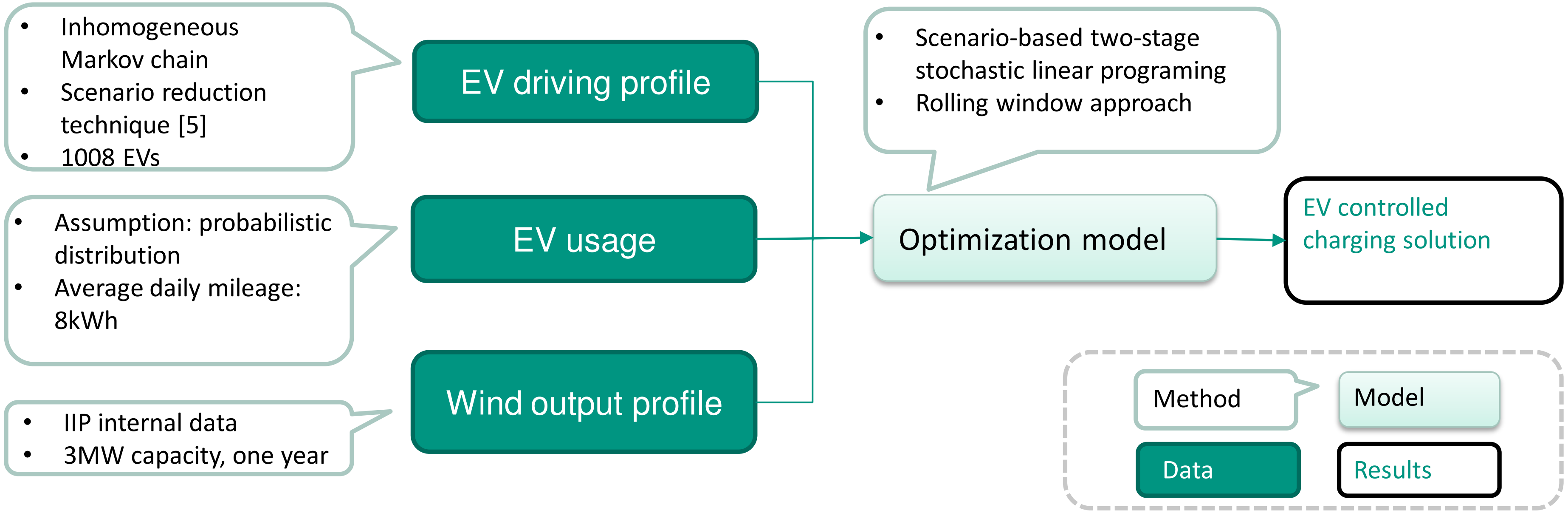

Figure: Model structure

Methodology and Model design

- Objective: min: $\sum_{t=i}^{W^i}(D_t^{grid} + D_t^{cur}) + \sum_{t=i+1}^{W^i}\left|(D_t - G_t^{wind}) - (D_{t-1} - G_{t-1}^{wind})\right|$ (1)

  gap between EV and wind — difference of the gap in two periods

- s.t.: $D_t^{grid} - D_t^{cur} = D_t - G_t^{wind}$ $\quad i \le t \le W^i$ (2)
- s.t.: $D_t = \sum_{m \in EV^i} P_{m,t} + \sum_{s \ge i+1} P'_{s,t}$ $\quad i \le t \le W^i$ (3)

  "connected EVs" "future EVs"

Indices/Sets:

t,s	Time periods
$m(EV^i)$	EV available for charging at period i

Parameters:

i	Starting period of the optimization model
W^i	Ending period of the optimization model
G_t^{wind}	Wind turbine generation in period t [kW]

Variables (non-negative, in italic):

D_t	EV total charging demand in period t [kW]
D_t^{grid}	EV charging demand by the grid in period t [kW]
D_t^{cur}	Curtailed wind generation in period t [kW]
$P_{m,t}$	Charging demand of currently-connected EV [kW]
$P'_{s,t}$	Charging demand in period t of future EV from period s [kW]

Methodology and Model design

Myopic charging strategy

- Only consider currently-connected EVs $P_{m,t}$
- Maximize wind utilization, postpone EV charging when wind output is insufficient

- Objective: min: $\sum_{t=i}^{W^i}\left(D_t^{grid}+D_t^{cur}\right) * c_t + \sum_{t=i+1}^{W^i}\left|\left(D_t - G_t^{wind}\right) - \left(D_{t-1} - G_{t-1}^{wind}\right)\right|$ (1a)
- s.t.: $D_t^{grid} - D_t^{cur} = D_t - G_t^{wind}$ $\quad i \le t \le W^i$ (2a)
- s.t.: $D_t = \sum_{m\in EV^i} P_{m,t} + \sum_{s\ge i+1} P'_{s,t}$ $\quad i \le t \le W^i$ (3a)

Parameters:

c_t Quasi price signal

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Data input

Initial idea

- To describe driving patterns using inhomogeneous Markov Chains [6][7]

Raw data

- From Project izeus (http://www.izeus.de/)
- 28 Daimler Smart EVs for 6 months (2013/10-2014/06)
- 3 recorded states by every minute (driving, charging and only parking)

https://en.wikipedia.org/wiki/File:2013_Smart_Fortwo_Electric_Drive_--_2012_NYIAS.JPG

Specifications:

- Power: peak power output of 55 kW (74 hp)
- Torque: 130 newton meters (96 lbf·ft)
- Top speed of 125 km/h (78 mph)
- 0 to 100 km/h in 11.5 s and 0 to 60 km/h in 5 s
- Battery capacity: 17.6 kW·h lithium-ion battery
- Range: 145 km (90 mi)
- Miles per gallon equivalent: 122 MPGe city, 93 MPGe highway, 107 MPGe combined

- Assumed maximum charging power in the model: 5 kW

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Results

Rolling window approach

- Optimize for the next 24 hours and update in every 15 minutes
- For each optimization, only solution for the first period will be implemented

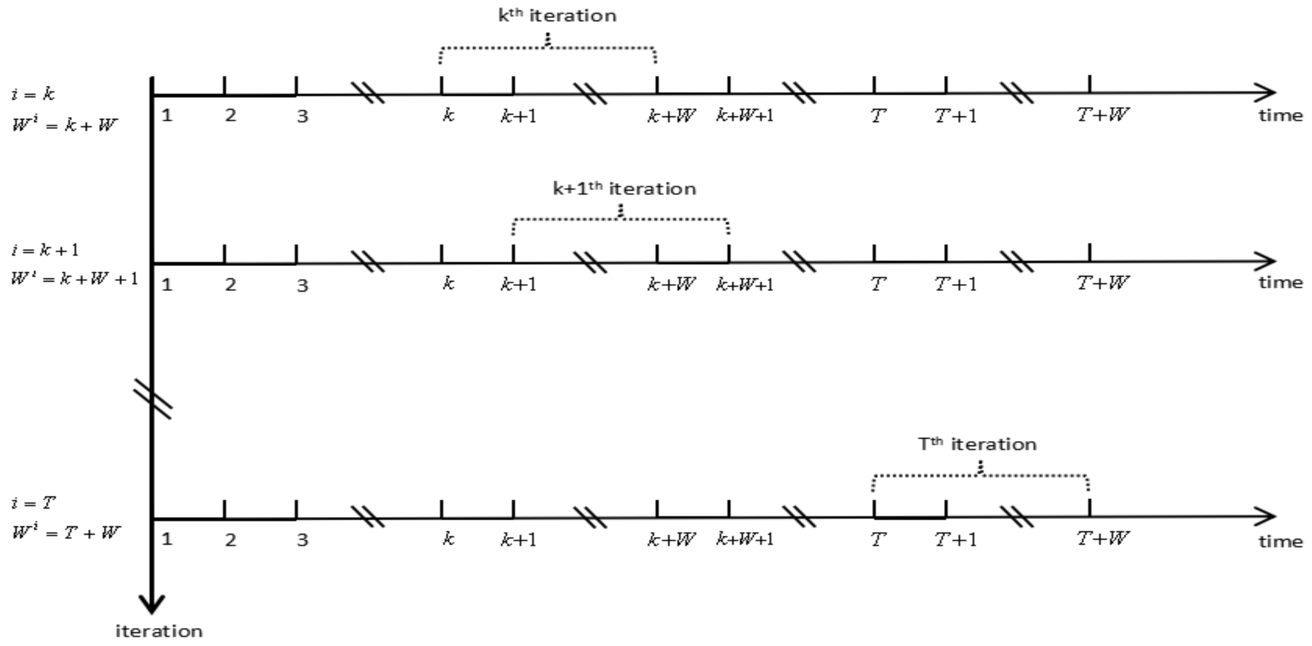

Figure. Illustration of rolling window approach

Results

Integration of wind energy

- Wind turbine output profile: simulation result for 2015, 3 MW capacity
- 4 representative months selected: January, April, July, October
- Instance charging strategy as a reference: to charge with maximum charging power upon arrival until fully charged

	Following	Myopic	Instant
Total charging demand (MWh)	1329.33	1335.68	1424.59
Charging demand by wind (MWh)	1130.14	1132.57	907.26
Charging demand by wind ratio	85.02%	84.79%	63.69%
Unutilized wind ratio	55.00%	54.91%	63.87%
100% wind charging periods ratio	62.65%	73.87%	57.50%

Table: Total charging demand under three charging strategies

Results

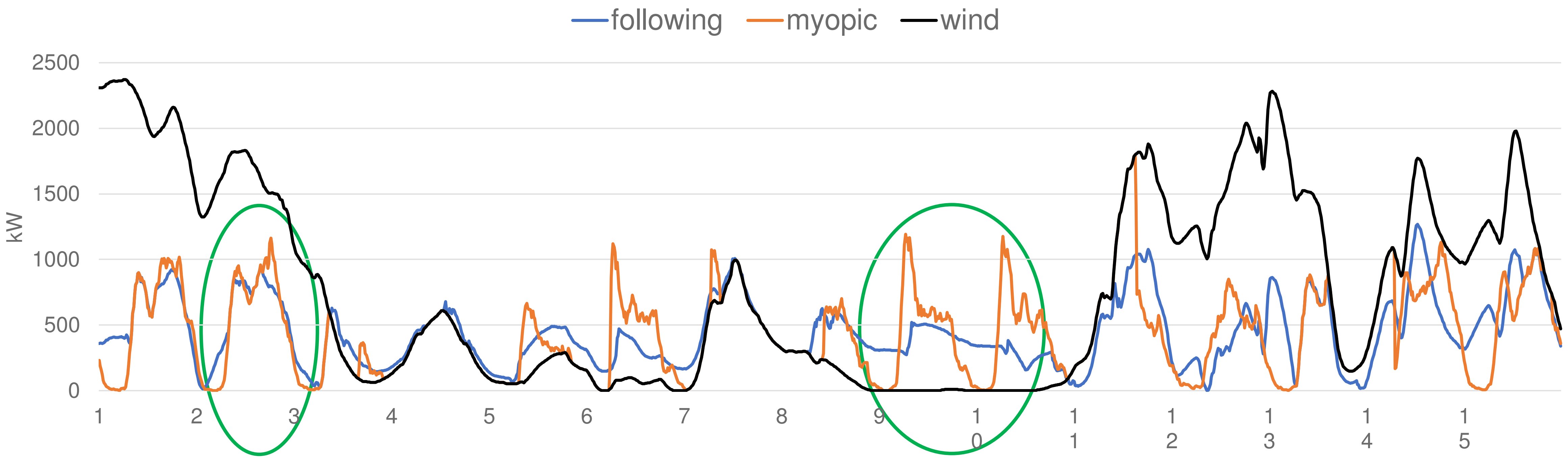

Figure: Time series charging demand under three charging strategies (15 days)

- Day 2: with sufficient wind output, myopic strategy behaves like instant charging strategy
- Day 9&10: with insufficient wind output, demand spike may happen before EV departure under myopic strategy

Results

Alleviation of wind output volatility

- Perfect foresight scenario: objective same with following strategy, but future EV availability known

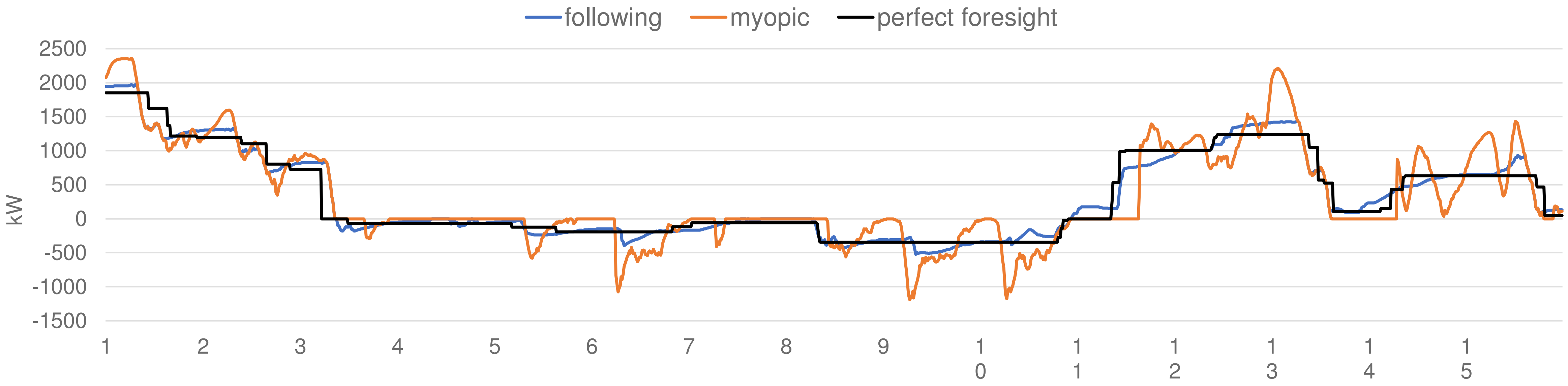

Figure: Curtailed wind energy under two controlled charging strategies (15 days); positive: wind curtailment, negative: grid supply

- Volatility of curtailed (unutilized) wind energy is alleviated for further use
- Peak demand (from grid perspective) decreases

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Summary and future work

Summary

- The optimization model proposed utilizes the load shifting potential of EV for wind energy integration
- With the simulated results, the ratio of EV charging demand by wind increases from 64% to 85% and wind energy volatility is reduced
- The uncertainties from future EVs should be considered in order to alleviate the volatility of wind energy

Future work

- To formulate EV battery degradation cost
- To consider EV discharging (V2G)
- To integrate EV controlled charging into energy system model

References

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Thank you for your attention

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