PV and opportunistic electric vehicle charging in a Swedish distribution grid

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Introduction

What we study

How we do it
Introduction

• 10kV / 400V three-phase power grid
• 5174 grid nodes / end-users
• Only electric vehicles (EV) in the car fleet
• Over- and undervoltage due to
  • High load (mainly winter)
  • High PV generation (mainly summer)

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- 5174 grid nodes / end-users
- Only electric vehicles (EV) in the car fleet
- Over- and undervoltage due to
  - High load (mainly winter)
  - High PV generation (mainly summer)

- PV potential using LiDAR data
- PV penetration 0-100% of yearly load
- Markov-chain EV charging model
- Newton-Raphson power flow solution
PV generation & load data

- Rooftop PV power potential using GIS, LiDAR and irradiance data
PV generation & load data

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- DSO ‘Herrljunga Elektriska’
  - Hourly load for 5174 end-users (2014)
PV generation & load data

- Rooftop PV power potential using GIS, LiDAR and irradiance data
- DSO ‘Herrljunga Elektriska’
  - Hourly load for 5174 end-users (2014)
- Yearly PV penetration with randomly selected rooftops
  - 0%
  - 10%
  - ...
  - 90%
  - 100%
Power grid

- 2 MV grids
- 338 LV grids (rural & city)
- 3891 nodes, 5174 end-uses
Power grid

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- Hourly load data
Power grid

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- Hourly load data
- Allowed end-user voltage
  - Max 1.1 pu
  - Min 0.9 pu
- Always 1.0 pu at the primary substations
Power grid

MV grid
- Total length of feeders: 312 km
- Number of feeders: 638

LV grid
- Total length of feeders: 550 km
- Number of feeders: 7101
EV charging model

- Opportunistic EV charging – charging whenever & wherever parked

For more information: M. Shepero and J. Munkhammar. *Modelling charging of electric vehicles using mixture of user behaviours*. 1\textsuperscript{st} E-Mobility Integration Symposium, October 23\textsuperscript{rd}, Berlin
EV charging model

- Opportunistic EV charging – charging whenever & wherever parked
- Time dependent (time of day, weekend/weekday)

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EV charging model

• Opportunistic EV charging – charging whenever & wherever parked
• Time dependent (time of day, weekend/weekday)
• Markov chain with 3 states
  – Home,
  – Work
  – Other (public parking lots)
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• 2 summer + 2 winter weeks
• Opportunistic EV charging – charging whenever & wherever parked
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• Markov chain with 3 states
  – Home
  – Work
  – Other (public parking lots)
• 2 summer + 2 winter weeks
• Charging power: 3.7 kW
EV charging model

• “Worst-case” scenario: 100% EVs of the total fleet
  – 5295 vehicles in 2016 in the municipality
  – 333 extra EVs in the summer (summer houses)
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• Aggregated 1-minute EV charging data to hourly resolution

\[
E_t^n = \begin{cases} 
E_{t-1}^n + 3.7 \times \Delta t & \text{if charging}, \\
E_{t-1}^n - \eta \times D & \text{if driving}, \\
E_{t-1}^n & \text{else}, 
\end{cases}
\]
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Battery charge per EV at time $t$

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\end{cases}$

3.7 kW charging power $\times$ time

Consumption per km $\times$ driving distance (km)
Results – load and generation

- Small difference in load with EV
  - 18% higher in the summer weeks
  - 9% higher in the winter weeks
Results – load and generation

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• Large seasonal variation in PV generation
  – 100% penetration in the figures on a yearly basis
Results – overvoltage

Number of customers with overvoltage

Aggregated customer-hours

Yearly PV penetration [%]
Results – overvoltage

- Winter
- Summer

With EVs
No EVs

![Graph showing overvoltage with and without EVs in winter and summer](image-url)
Results – undervoltage

Winter

Summer

Winter

Summer
Results – undervoltage

With EVs

No EVs

With EVs

No EVs

With EVs

No EVs

With EVs

No EVs
Discussion & conclusion

- EV charging has a small impact on the voltage in the studied grid
Discussion & conclusion

• EV charging has a small impact on the voltage in the studied grid
• 50% of the customers are affected by overvoltage in a scenario of 100% PV penetration – almost no reduction with EV charging
  – Overvoltage in LV grids far from the distribution substations
  – EV charging during day mainly in the city areas close to substations
Discussion & conclusion

• PV power has a small impact on undervoltage due to EV charging in the winter, in the summer with PV > 50%
Discussion & conclusion

- PV power has a small impact on undervoltage due to EV charging in the winter, in the summer with PV > 50%
- 1.5% of the customers affected by undervoltage in the winter
  - Undervoltage in LV grids far from the distribution substations
  - EV charging mainly in the morning (to work) and in the afternoon (to home)
  - Sun is above the horizon approx. 08:40 – 15:30 in early January
Discussion & conclusion

• Possible solutions to avoid voltage limit violations
  – Grid extension – can be costly for rural grids
  – ‘Smart-grid’, for example real-time measurements with tap-changing transformers
  – Scheduled EV charging or ‘vehicle to grid’ – incentives are needed
Thank you for listening!

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