Optimal Scheduling of EV Charging in Distribution Networks

Initial Project Presentation

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Agenda

Impact of Electric Vehicles

Electrification of the transport sector

- additional loads in distribution networks
- voltage drops and overloadings when uncontrolled

For sustainability, decarbonisation of electricity

- variable generation calls for active network management
- EVs for demand side management as storable/deferrable load

Consensus

Existing networks can accommodate substantial penetration levels of electric vehicles if charging is coordinated.

Charging Coordination of Electric Vehicles

Typically, an aggregator acts as intermediary between multiple EV users and wholesale or ancillary service markets.

Vast amount of research was already conducted. Multitude of...

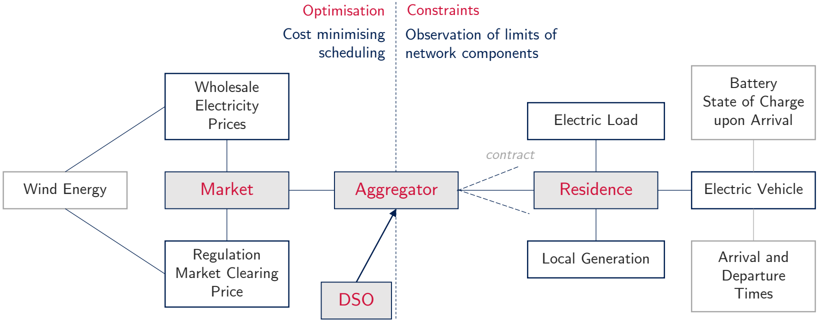
- optimisation objectives
- optimisation techniques
- optimisation hierarchies
- constraints
- scenarios / models
- uncertainty treatment

Market-based and network-based optimisation often disjunct. E.g.

- cost-minimising algorithm disregards network constraints or
- peak-shaving algorithm neglects potential economic benefits.

Uncertainties in Load Scheduling

Consideration of uncertainties about scenarios is more prevalent in academia than recognition of individual uncertainties in mobility patterns, residential demand and market prices.



Research Objectives

Optimisation study based on a developed simulation model

- Develop a robust cost-minimising (bidirectional) scheduling routine for charging EVs while observing network, equipment and demand constraints in a stochastic environment.
- Characterise inherent and conceded uncertainties incurred with the optimal scheduling of EVs. (esp. driving behaviour)
- Compare and assess the performance of multiple optimisation methods under uncertainty and approaches to mitigate their sensitivity to prediction errors.
  - greedy heuristic (benchmark optimisation)
  - metaheuristics (PSO or GA)
  - analytical (linear approximation)

Extract of Problem Formulation

$$
\begin{array}{rrcll}
\min\limits_{\{P_{EV},\omega\}} & C = \sum\limits_{t=1}^{T}\sum\limits_{k=1}^{K}\sum\limits_{d=1}^{D} & \hat{\pi}_t \cdot \Delta t \cdot P_{k,d,t}^{EV} \quad - \quad \rho \cdot \eta \cdot P_{max}^{EV} \cdot \omega_{k,d,t} & & \\
\hline
\text{s.t.} & & \left(1 - \hat{\alpha}_{k,d,t}^{EV}\right) \cdot P_{k,d,t}^{EV} & = & 0 \\
 & 0 \leq & P_{k,d,t}^{EV} & \leq & P_{max}^{EV} \\
 & \beta_{min} \cdot B_{max} \leq & \hat{B}_{k,d}^{arr} + \sum\limits_{t=1}^{T} \eta \cdot P_{k,d,t}^{EV} \cdot \Delta t & \leq & B_{max} \\
 & \gamma_{min} \cdot B_{max} \leq & \omega_{k,d,t} \cdot \left(\hat{B}_{k,d}^{arr} + \sum\limits_{\tau=1}^{t} \eta \cdot P_{k,d,\tau}^{EV} \cdot \Delta t\right) & \leq & B_{max} \\
 & \Delta_{max}^{EV} \leq & \left(\hat{\alpha}_{k,d,t}^{EV} \cdot \hat{\alpha}_{k,d,t-1}^{EV}\right) \cdot \left(P_{k,d,t}^{EV} - P_{k,d,t-1}^{EV}\right) & \leq & \Delta_{max}^{EV} \\
\hline
\text{PF} & V_{min} \leq & V_{k,d,t}^{bus} & \leq & V_{max} \\
 & 0 \leq & S_t^X & \leq & S_{rated}^X \\
 & 0 \leq & I_{\ell,t}^{line} & \leq & I_{\ell}^{max} \\
\hline
\end{array}
$$

$$\forall k \in \{1 \dots K\} \quad \forall d \in \{1 \dots D\} \quad \forall t \in \{1 \dots T\} \quad \forall \ell \in \{1 \dots L\}$$

Example: With 50 vehicles, 24 hour optimisation horizon and 15 minute resolution, the problem has minimum $2 \cdot 50 \cdot 96 = 9600$ decision variables.

Data Acquisition

Price time series

- UKPX Reference Price Data

Demand time series

- CREST demand model

Network topology

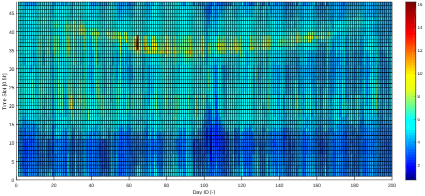
- European LV test feeder

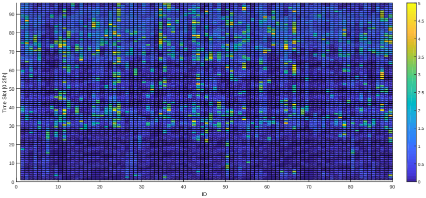
Mobility data

- National Travel Survey

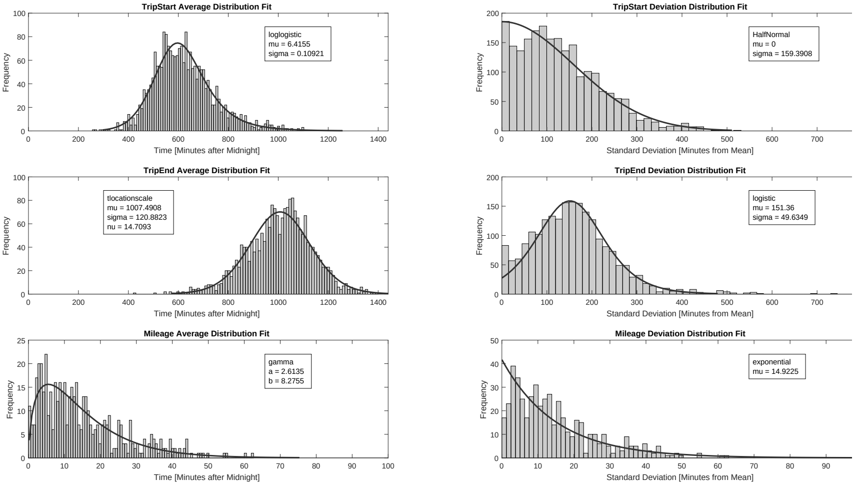
Other parameters

- vehicle specifications
- charging equipment
- ...

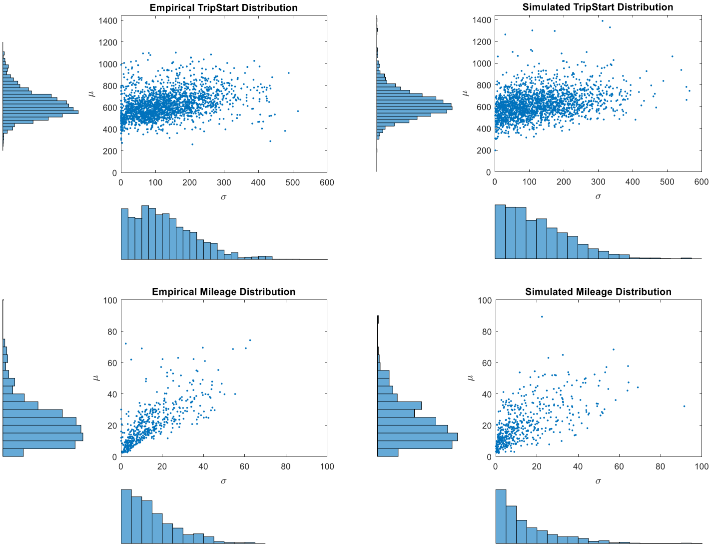




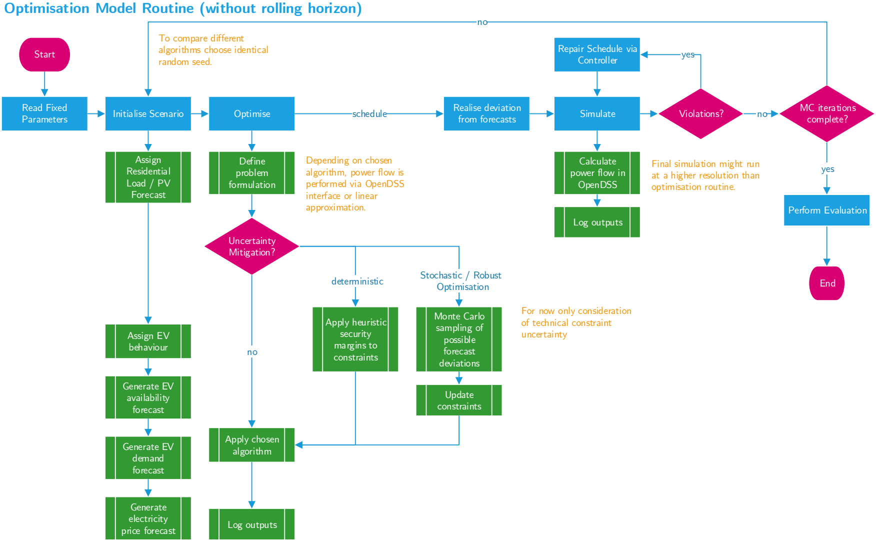
Travel Pattern Analysis



Travel Pattern Analysis



Optimisation Routine



Outlook on Upcoming Research

Implementation of...

- optimisation/model framework (Python, OpenDSS)
- optimisation algorithms
  - greedy heuristic (manual)
  - GA/PSO (DEAP)
  - LP (Gurobi, approximation)
- uncertainty mitigation
  - stochastic programming
  - rolling optimisation horizon
- reparation controller

Anticipated Difficulties

- thermal line limits data
- computational complexity
  - decision variables
  - power flow calculations
- incorporation of ancillary services (market structure)
- uncertainty modeling of demand, PV, and price
- information transfer and modelling forecast accuracy improvements (rolling opt.)
- linear power flow approximation

Summary

Scheduling Problem

- Cost Minimisation
- Physical Constraints
- Uncertainties
- 1-phase Connection
- Stochastic Programming
- Rolling Optimisation

Done

- Data Acquisition
- Travel Patterns
- Network Topology
- Parametrisation
- Power Flow in OpenDSS

To Do

- Framework Implementation
- Optimisation Algorithms
- Uncertainty Mitigation
- Real-time Controller
- Evaluation
- Write-up