Electric Vehicle Battery Swapping Station

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About EVBASS

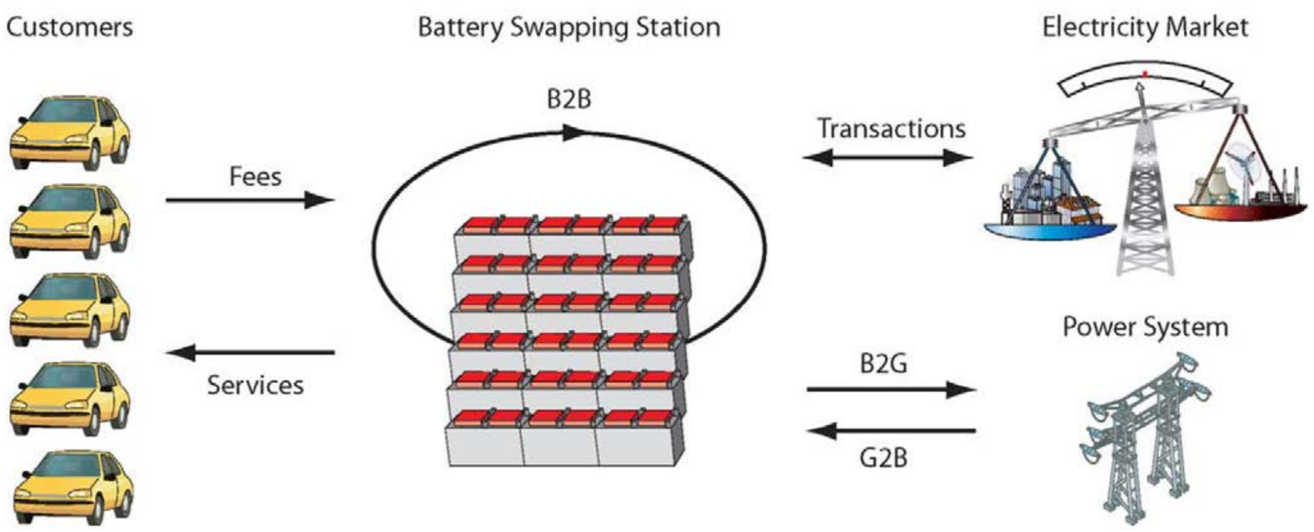
- Funded by the Croatian Science Foundation
- Project budget 100k Eur
- Associate partners:
  - Aalborg University
  - HEP Distribution System Operator
- October 2015 – September 2016

Objectives of EVBASS

- Development of viable business models for a BSS (Battery Swapping Station):
    - Optimization of the BSS operation (interaction with the market)
    - Control and communication within a BSS
- Impact of a BSS on distribution/transmission network
- Deployment of testbed facility

What is a BSS

- Participates in electricity market by performing arbitrage and may provide reserves
- Schedules batteries to perform in three modes:
  - **G2B** (Grid-to-Battery): Charge battery energy **from** the grid
  - **B2G** (Battery-to-Grid): Discharge battery energy **to** the grid
  - **B2B** (Battery-to-Battery): Transfer energy between batteries



Future Transportation System

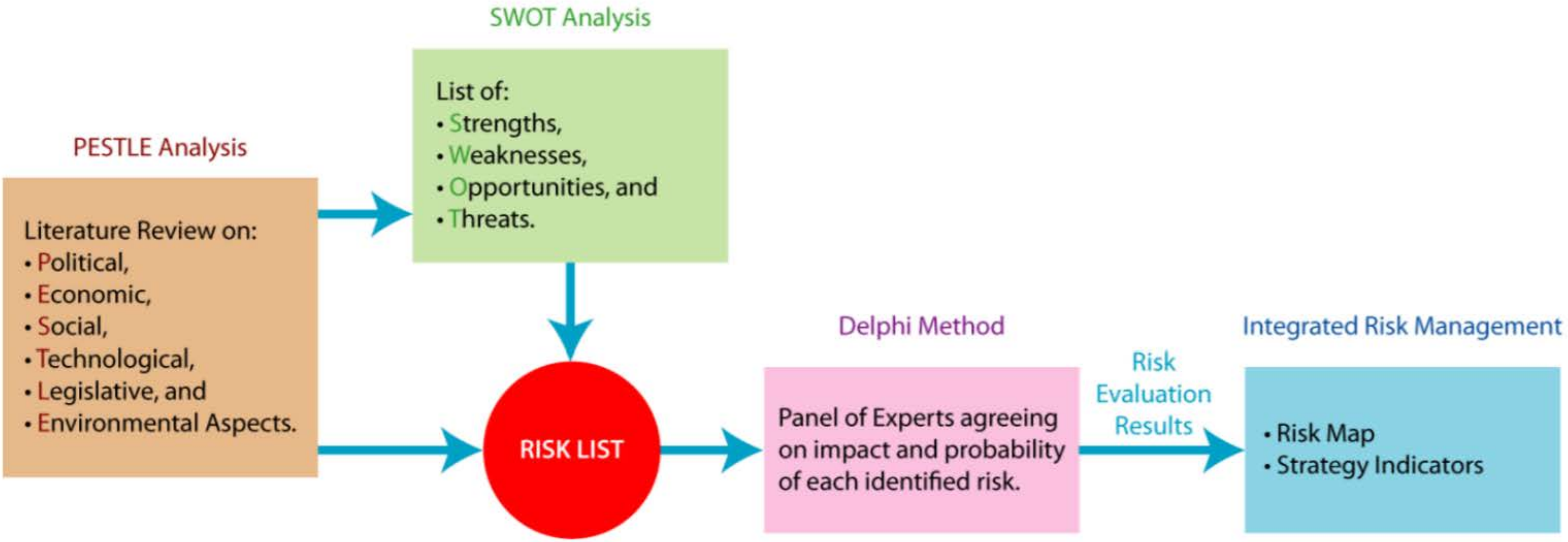
- Political drivers:
  - EU’s 2030 Energy Strategy
  - No fossil fuels goal by 2050 in Denmark
- Economy of electric vehicles:
  - Total cost of ownership
  - Future cost of batteries
  - V2G issue
- Social acceptance:
  - People’s skepticism on the practicality
  - Customers will not choose a new product giving up on their comfort

Future Transportation System

- Technological challenges:
  - High energy density li-ion batteries
  - Battery degradation
  - Charging infrastructure
- Legislative incentives and unresolved barriers:
  - Direct subsidies (one-time bonus) and fiscal incentives, such as reduced taxes
- Environmental impacts:
  - Reduction in global and local pollutants, as well as noise
  - Disposal and recycling issues

Risk Analysis

- The proposed methodology for quantifying the risks of not meeting the 15% EV integration in the next five years



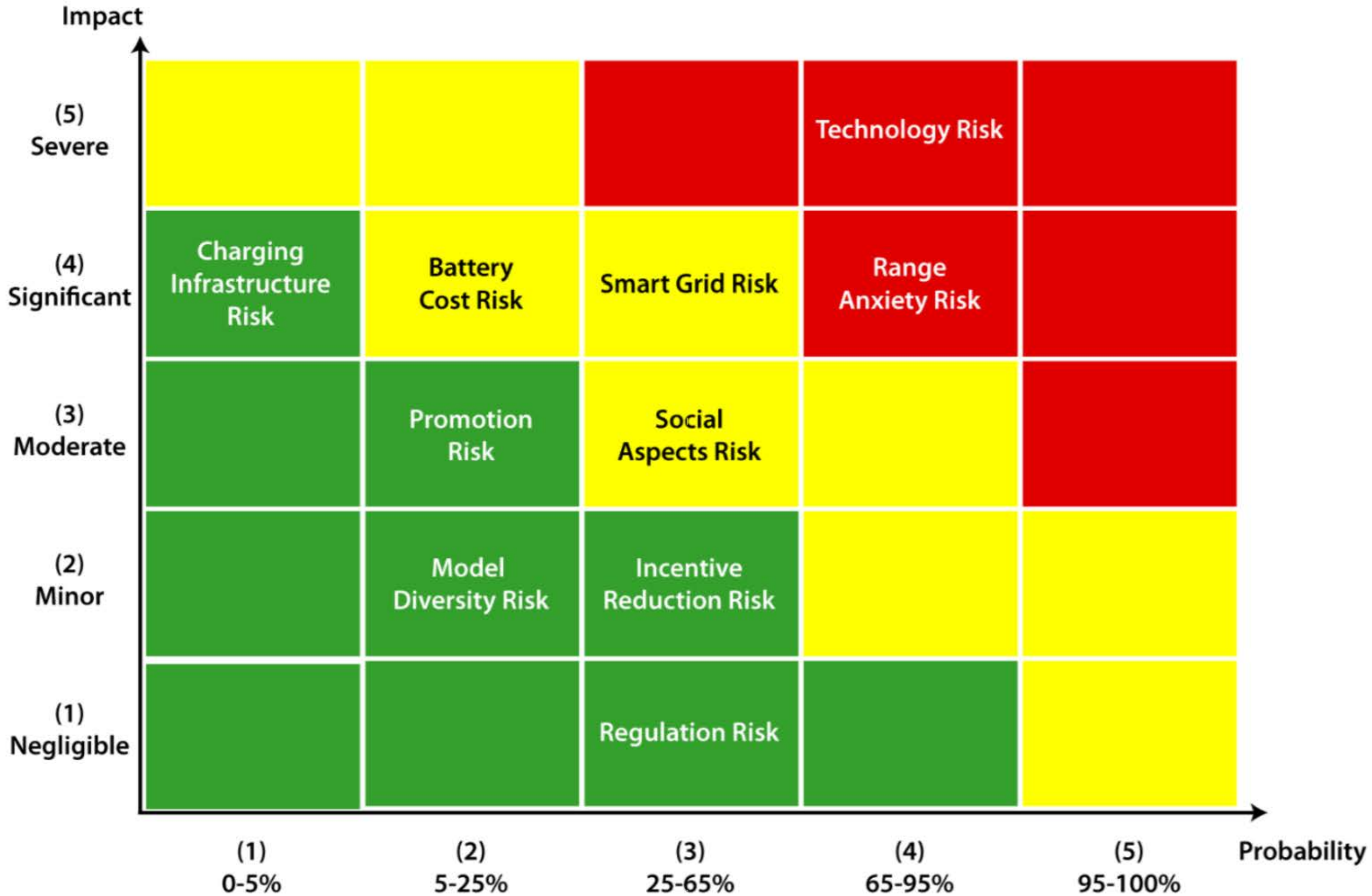
SWOT Anylsis

Strengths	Weaknesses
Safety aspects of EVs are at least as good as that of ICE vehicles	Diversity of EV models (from initial need for standard models to larger model diversity in the future)
Interaction with DSO (coordinated operation with variable and uncertain sources, such as RES)	Potential buyers not aware of the incentives and tax reductions or these do not adequately compensate for new technology - cost savings skepticism
Engine efficiency	High initial cost of EV
Global and local emission impact	Cost of charging infrastructure
Noise pollution reduction	Cost of batteries
	Battery degradation
	Range-anxiety, lower EV range than of CV
	Education and income (limiting the potential EV market)
	Long charging periods (slow chargers at home)
	Standardization of chargers
	Development and standardization of batteries

SWOT Anylsis

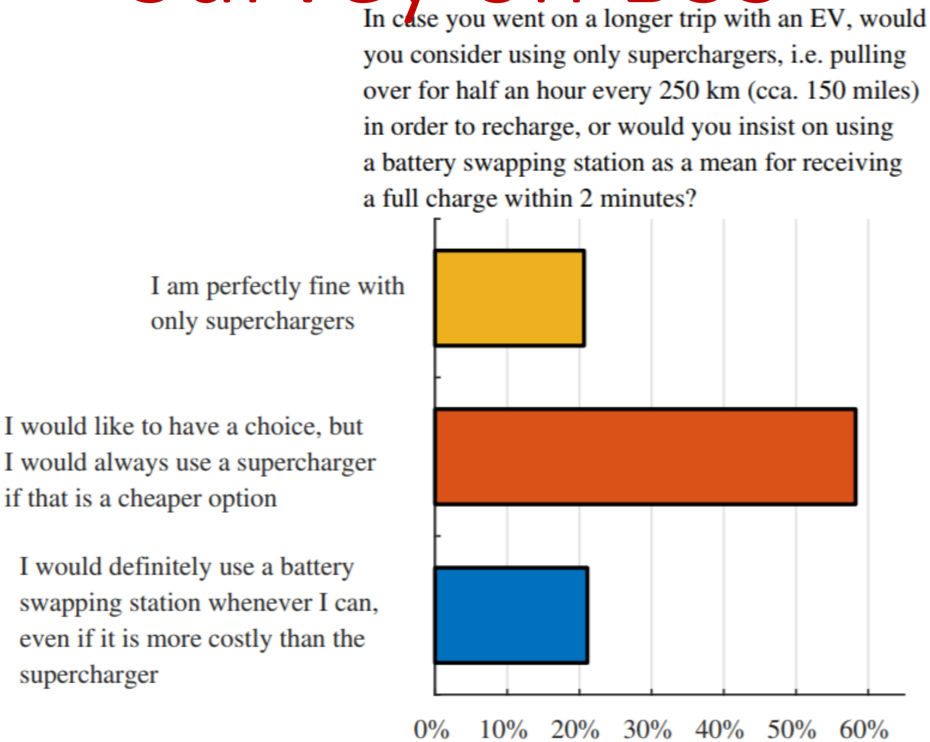
Opportunities	Threats
EU Strategies are promoting EVs	Global financial crisis affects purchase power
EV are reducing fossil fuel dependency	Additional investments into electric grid infrastructure
Integration of EV reduces energy needs	
Integration of EVs supports a strategic goal of CO_2 emissions reduction	
EV as a way of increasing transportation efficiency	
EV as a flexibility tool, increasing the share of RES	
Business case for aggregators	
Lower operation and maintenance cost than of ICE vehicles	
Financial incentives for buying EV	
Corporate social responsibility	

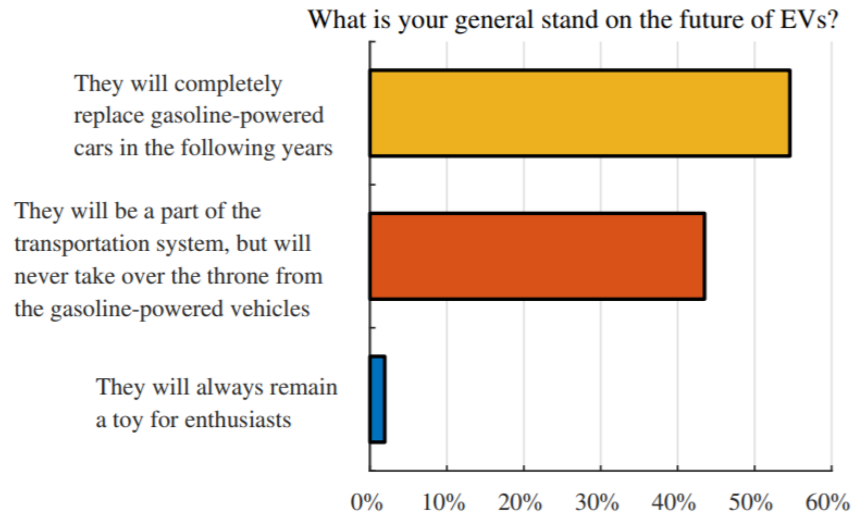
Risk Map

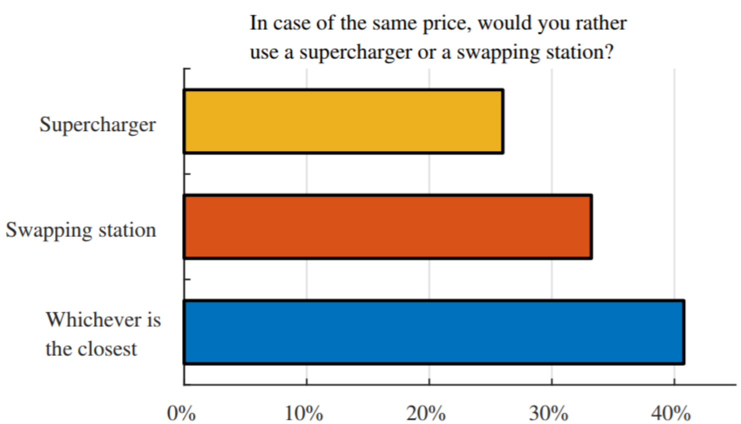


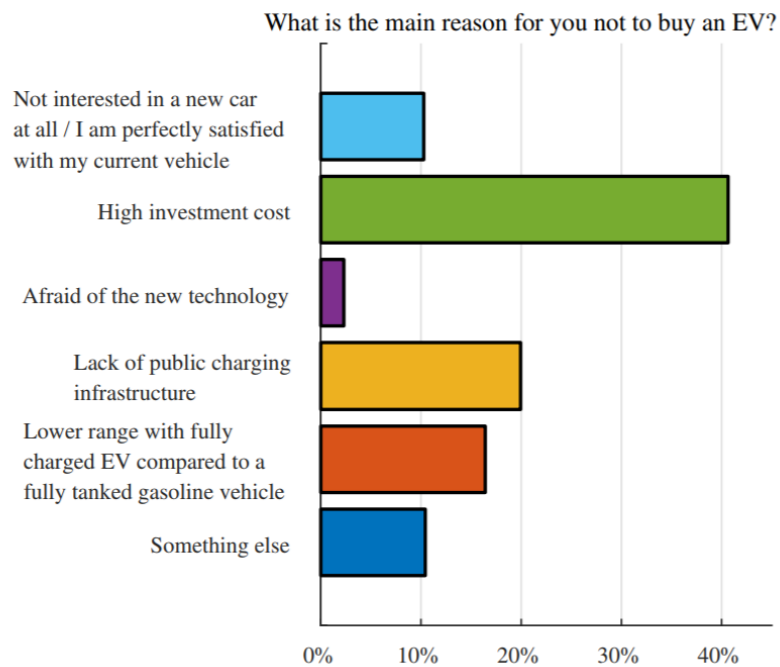
Impact
(5) Severe
(4) Significant
(3) Moderate
(2) Minor
(1) Negligible
Technology Risk
Charging Infrastructure Risk
Battery Cost Risk
Smart Grid Risk
Range Anxiety Risk
Promotion Risk
Social Aspects Risk
Model Diversity Risk
Incentive Reduction Risk
Regulation Risk
(1) 0-5%
(2) 5-25%
(3) 25-65%
(4) 65-95%
(5) 95-100%
Probability

Survey on BSS

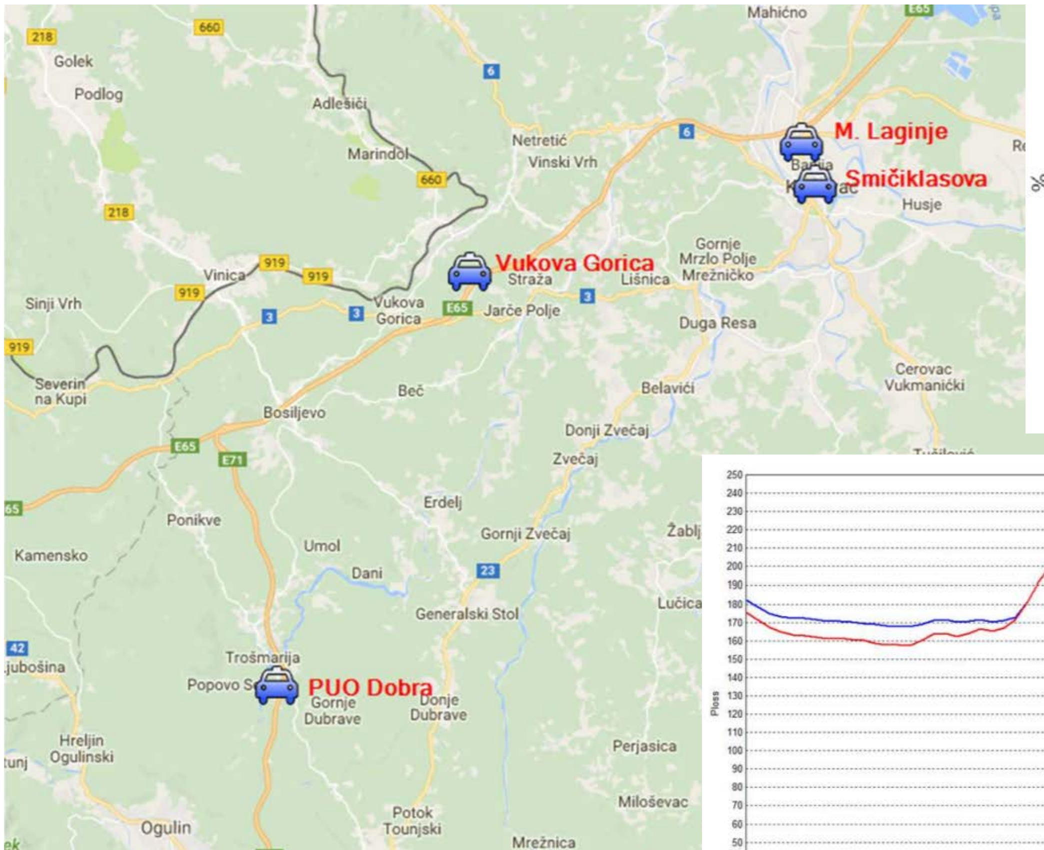


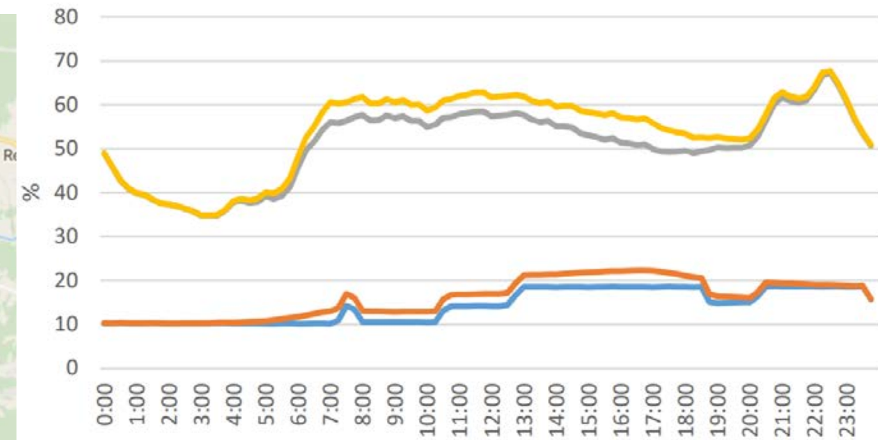




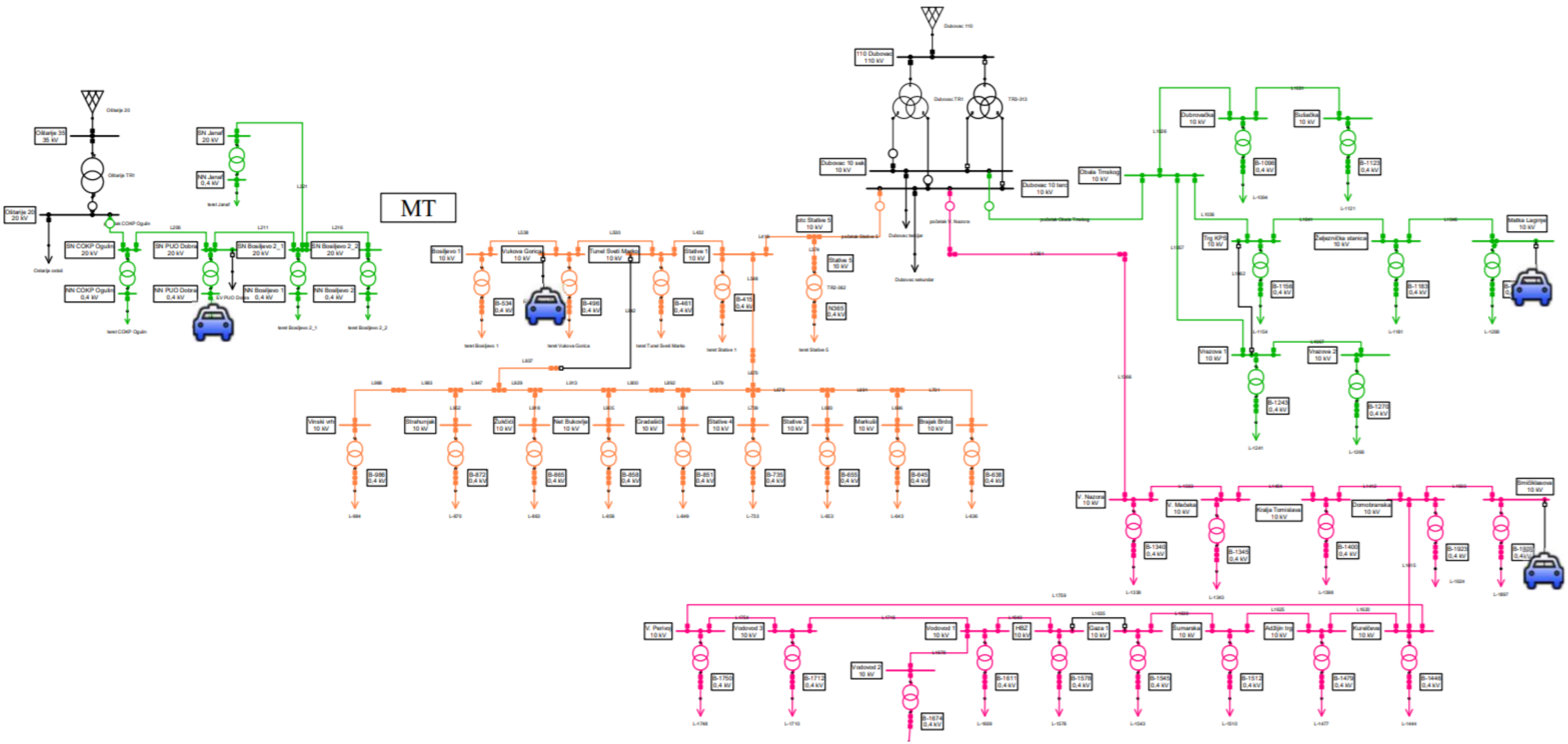


Integration of BSS in Distribution Networks





Integration of BSS in Distribution Networks



BSS Operational Model

- Price taker[1] or price maker?
- Each battery needs to be tracked individually
- Computational tractability
- Acting in reserves market as well

[1] Mushfiqur Sarker, Hrvoje Pandzic, and Miguel Ortega-Vazquez. Optimal Operation and Services Scheduling for an Electric Vehicle Battery Swapping Station, *IEEE Transactions on Power Systems*, vol. 30, no. 2, March 2015, pp. 901-910

BSS Operational Model

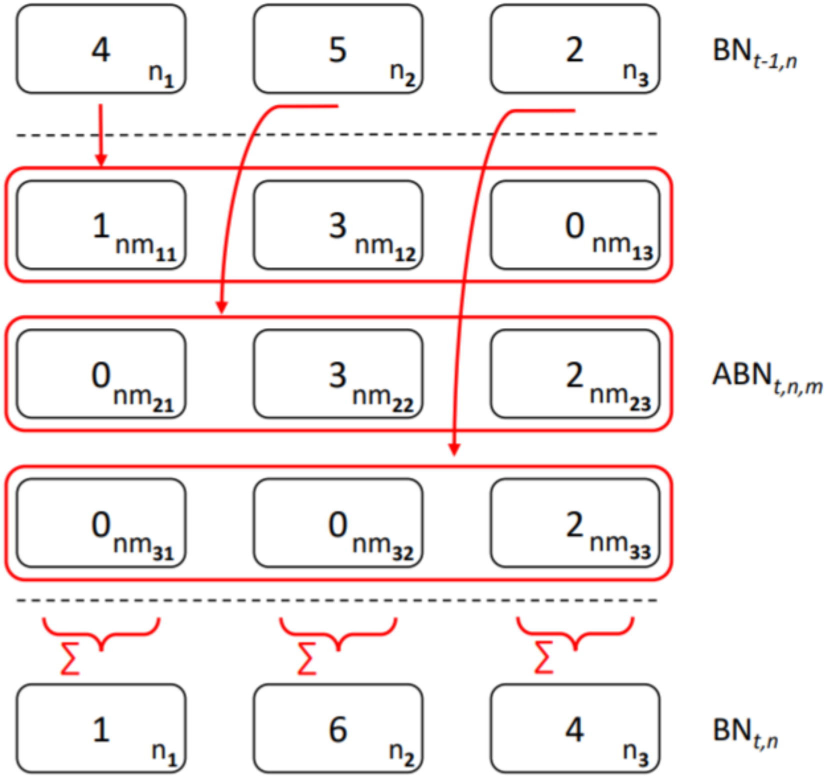
- Price maker model needs to consider the market interactions
- Instead of tracking each battery individually, we use battery clusters depending on the state of energy
- This heavily increased computational tractability
- Reserve capacity is modeled as well, which increases the BSS revenue

BSS Operational Model

- Clustering technique

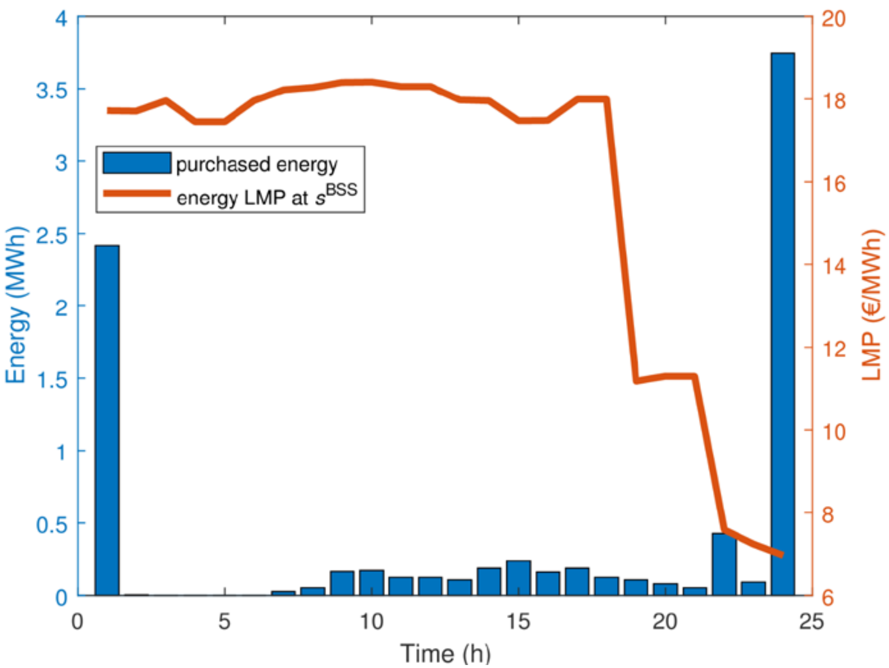
$$\underset{\Xi_{\text{UL}}}{\text{Max}} \sum_{t,n} \pi_n \cdot X_{t,n} - \sum_{t,n} \overline{\pi} \cdot (CN_{t,n} - ACN_{t,n}) - \sum_{t} \delta \cdot b_t^{\text{deg}}$$

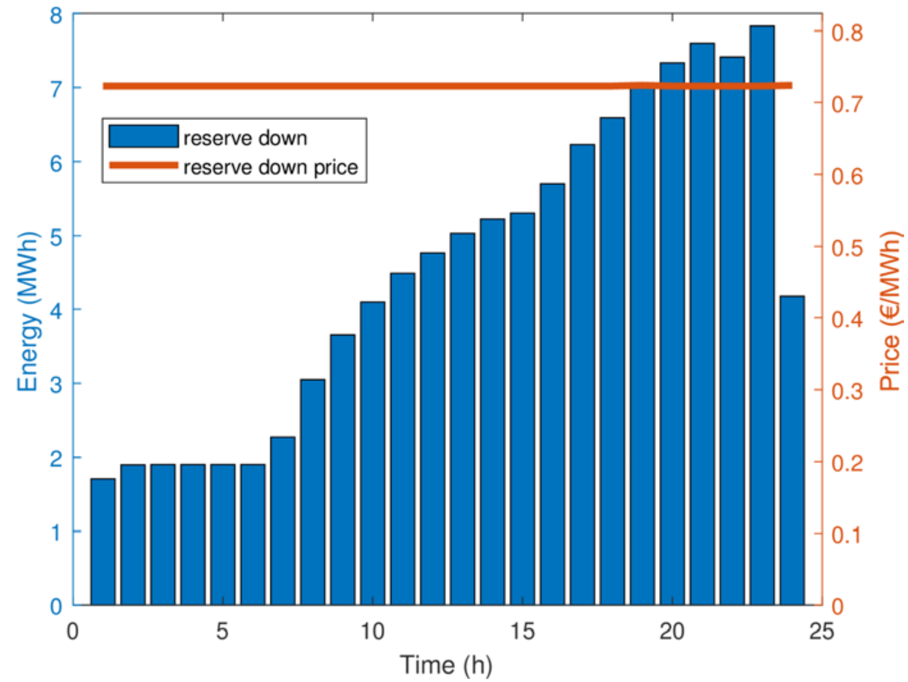
$$- \sum_{t} \lambda_{1,t,s^{\text{BSS}}} \cdot (q_t^{\text{ch}} - q_t^{\text{dis}}) + \sum_{t} r_t^{\text{up}} \cdot \mu_{10,t} + \sum_{t} r_t^{\text{dn}} \cdot \mu_{11,t}$$

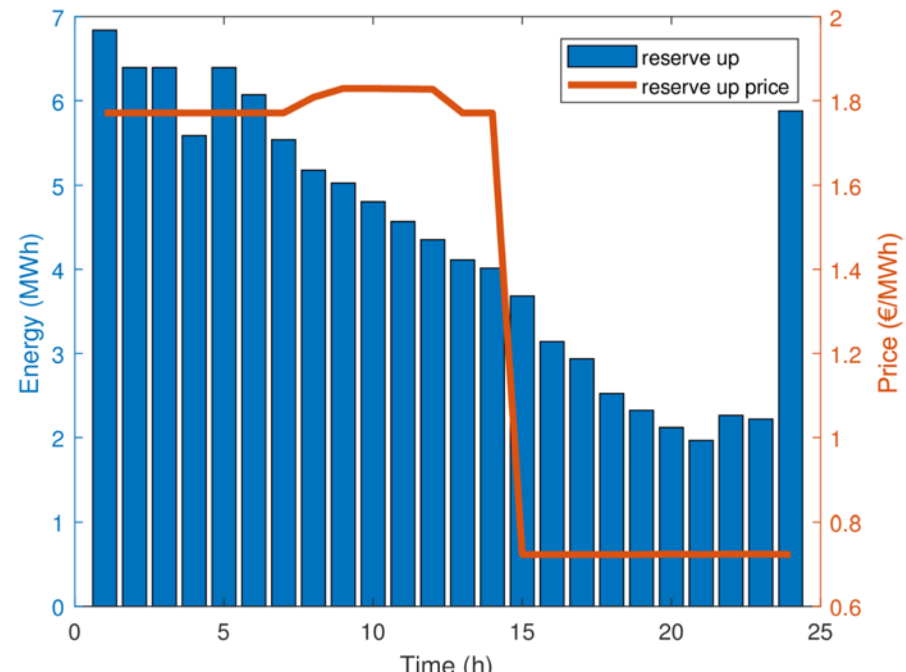


BSS Operational Model

- Results



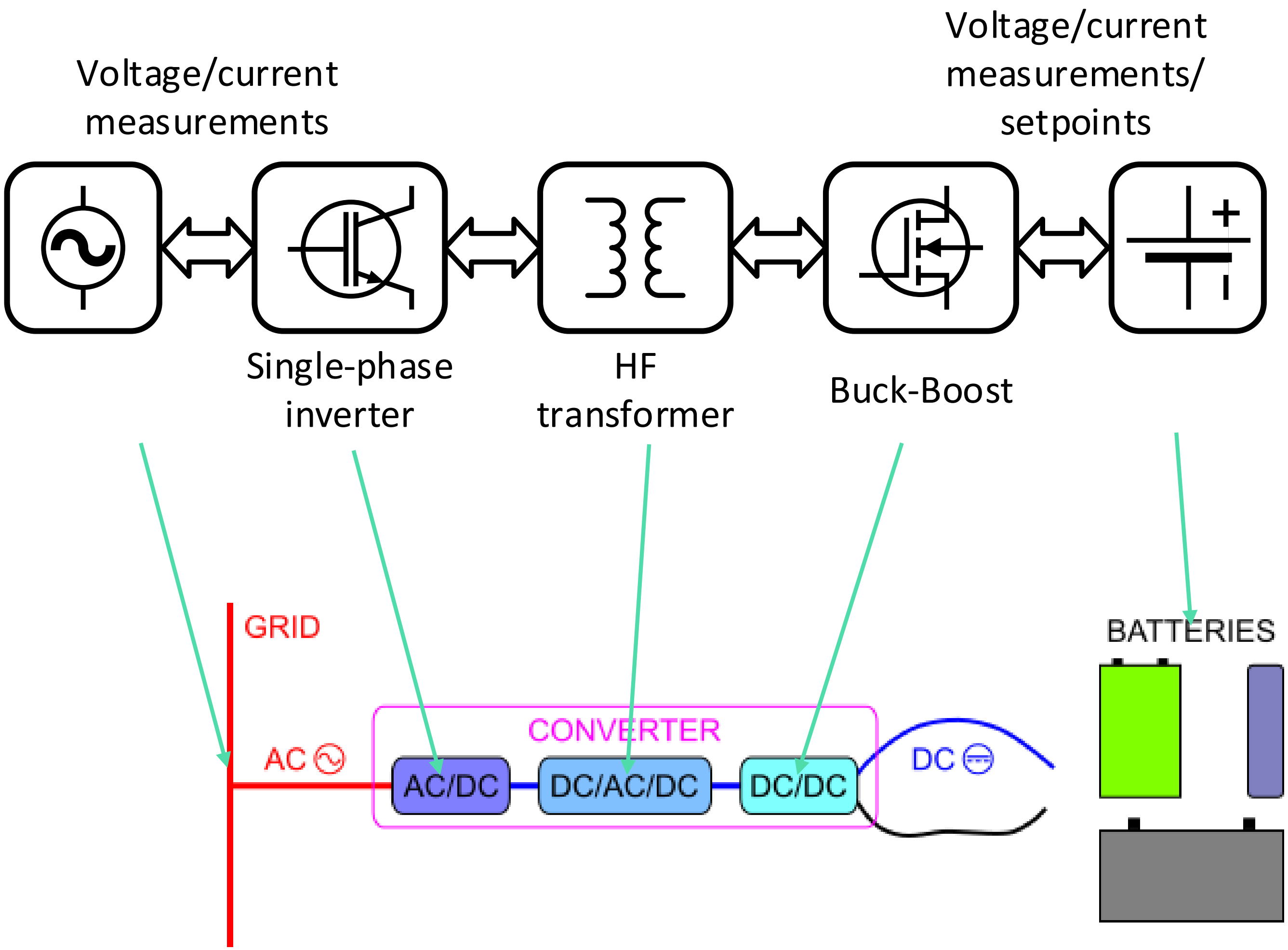




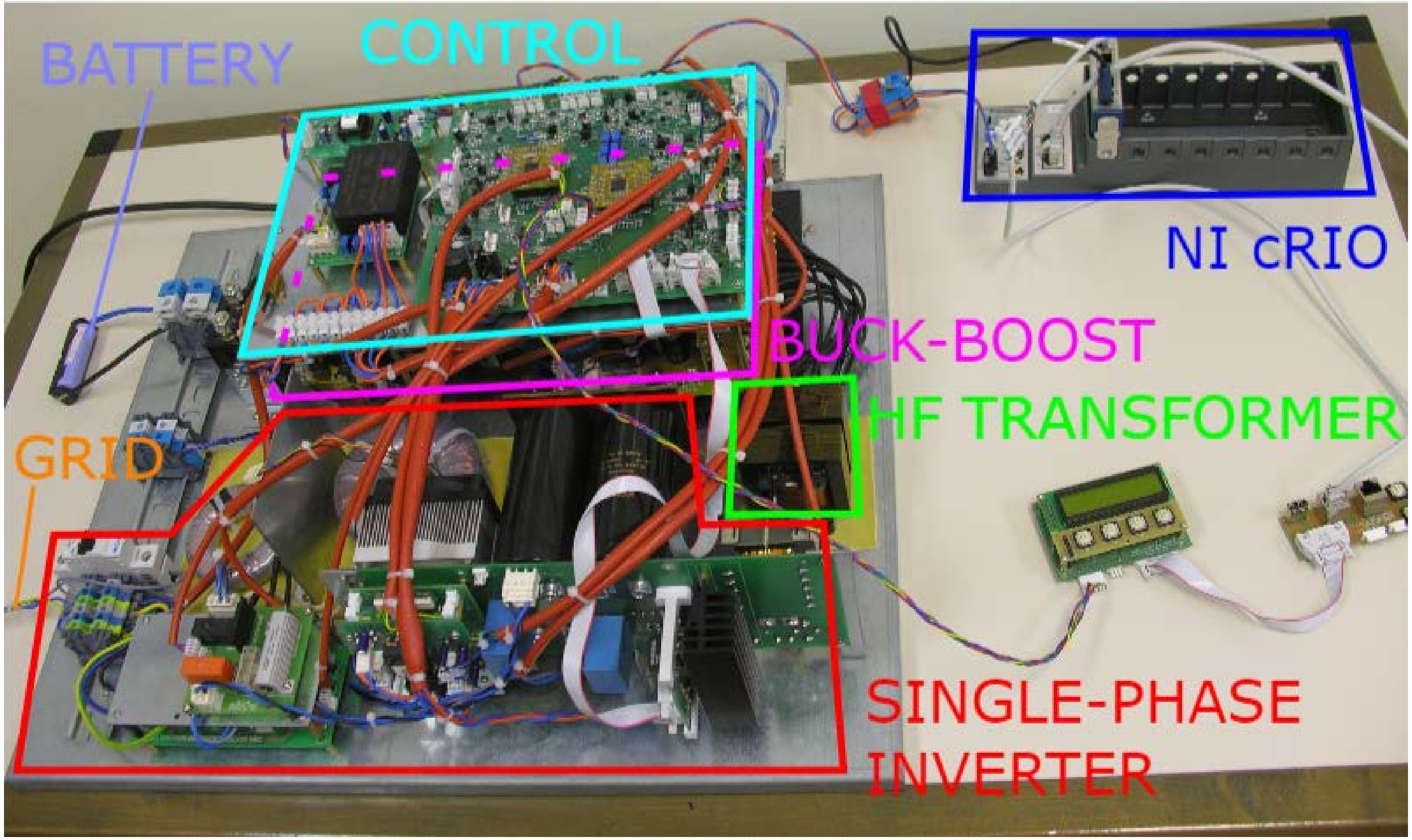
Laboratory Battery Testing

- A dedicated bidirectional AC/DC converter
- Characteristics:
  - Nominal power: 1 kW
  - Output voltage: 0 – 20 VDC
  - Output current: -50 to 50 ADC
  - Input: 50 Hz, 230 VAC
  - Analogue signals 0 – 10 VDC
  - Remote battery voltage sensing
- Control using NI LabVIEW

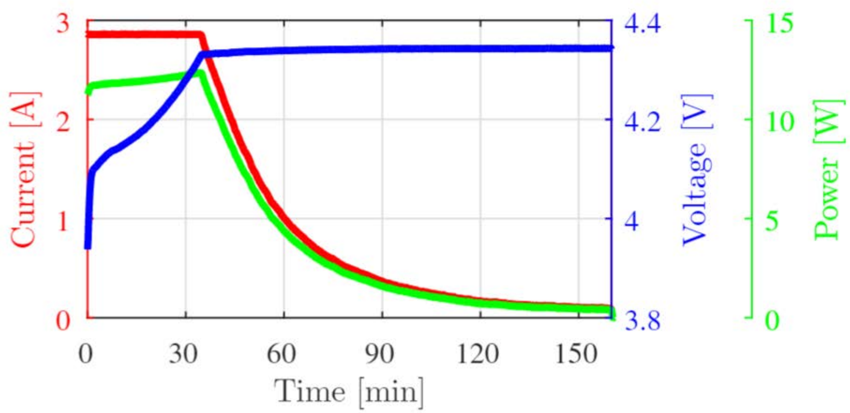
Laboratory Battery Testing



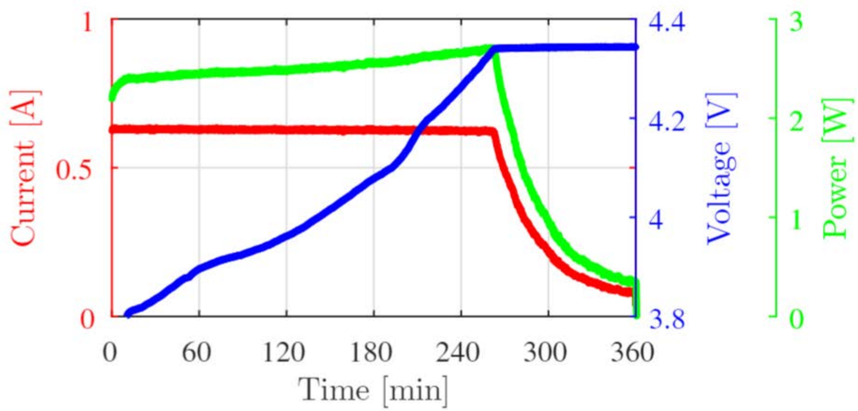
Laboratory Battery Testing



Battery Charging Characteristic



(a) Charging current 2.8 A (1C)



(b) Charging current 0.56 A (0.2C)

?

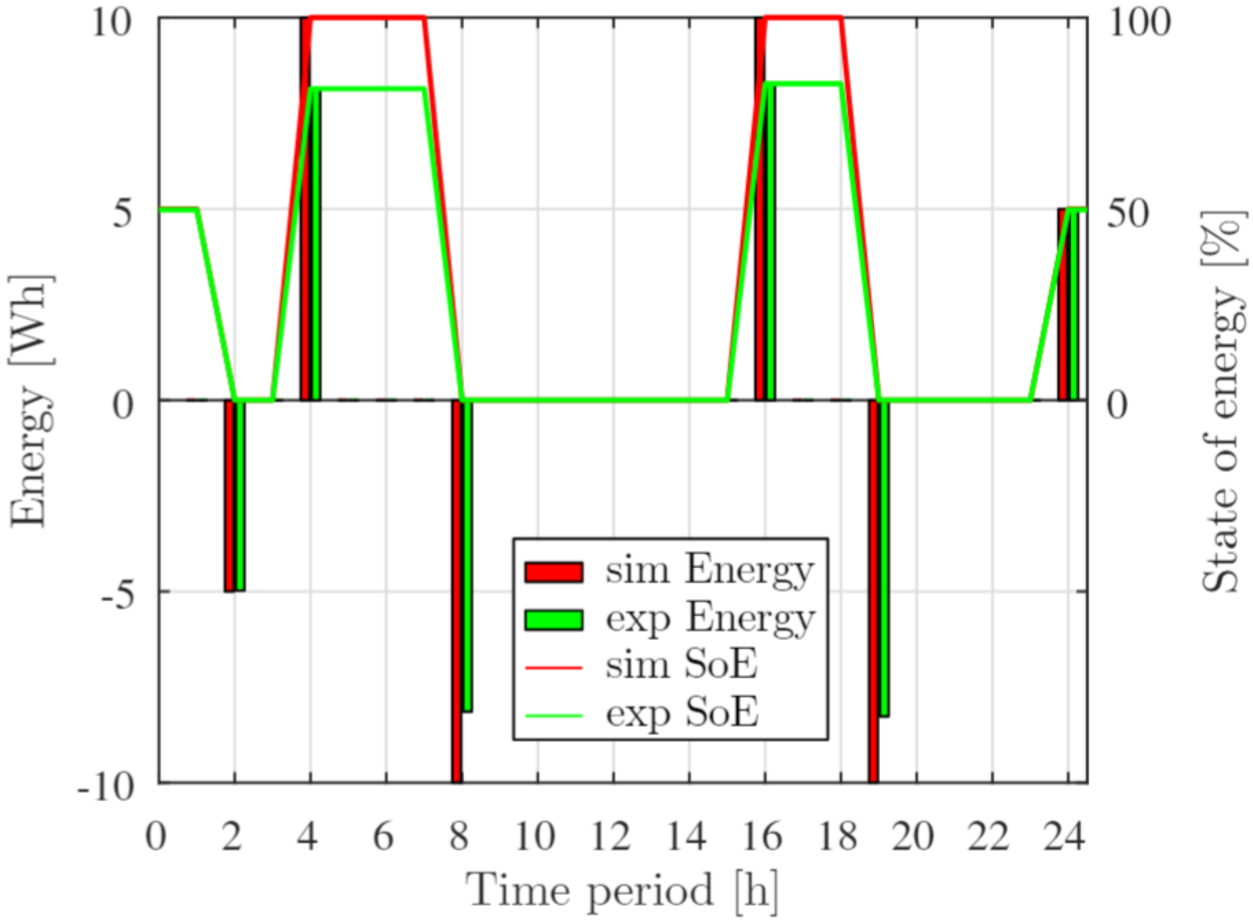
$$s_t = s_{t-1} + p_t^{\mathrm{ch}} \cdot \Delta^{\mathrm{T}} - p_t^{\mathrm{dis}} \cdot \Delta^{\mathrm{T}}, \quad \forall t \in \Omega^{\mathrm{T}}$$

$$s_t \leq SOC^{\mathrm{max}}, \quad \forall t \in \Omega^{\mathrm{T}}$$

$$p_{t,}^{\mathrm{ch}} \leq P^{\mathrm{bat}}, \quad \forall t \in \Omega^{\mathrm{T}}$$

$$p_t^{\mathrm{dis}} \leq P^{\mathrm{bat}}, \quad \forall t \in \Omega^{\mathrm{T}}$$

Consequences



Key Results and Future Needs

- Model of a BSS as price maker
- Development of an accurate battery charging model

- Is there a better way of modeling a price maker player than using bilevel modeling?
- Optimal battery operation models need to acknowledge the dependency of the cycle efficiency degradation on charging speed

Publications

- M. R. Sarker, H. Pandžić, K. Sun and M. A. Ortega-Vazquez. Optimal operation of aggregated electric vehicle charging stations coupled with energy storage. IET Generation, Transmission & Distribution, 2017.
- I. Pavić, T. Capuder, and I. Kuzle. A Comprehensive Approach for Maximizing Flexibility Benefits of Electric Vehicles. IEEE Systems Journal, 2017.
- I. Pavić, T. Capuder, and I. Kuzle. Fast Charging Stations - Power and Ancillary Services Provision. PowerTech 2017.
- I. Pavić, M. Beus, H. Pandžić, T. Capuder, and I. Štritof. Electricity markets overview – market participation possibilities for renewable and distributed energy resources. European Energy Market 2017.
- I. Pavić, N. Holjevac, M. Zidar, I. Kuzle, and A. Nešković. Transportation and Power System Interdependency for Urban Fast Charging and Battery Swapping Stations in Croatia. MIPRO, Opatija, 2017.

Thank you for Your Attention

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