Poboljšanje modela baterija na temelju laboratorijskih mjerenja

Hrvoje Pandžić
Fakultet elektrotehnike i računarstva (FER)

Završna diseminacija projekta

FER, Zagreb, 27. rujna 2018

O projektu EVBASS

- Financira Hrvatska zaklada za znanost
- Budžet 748 tisuća kn
- Pridruženi partneri:
  - Sveučilište Aalborg
  - HEP Operator distribucijskog sustava
  - Ekonomski fakultet, Zagreb
- Listopad 2015 – rujan 2018

Baterije u elektroenergetici

- Stacionarni spremnik energije:
  - U prijenosnoj mreži
  - U distribucijskoj mreži
  - Kod korisnika (mikromreže)
- Električna vozila

High-level model baterije

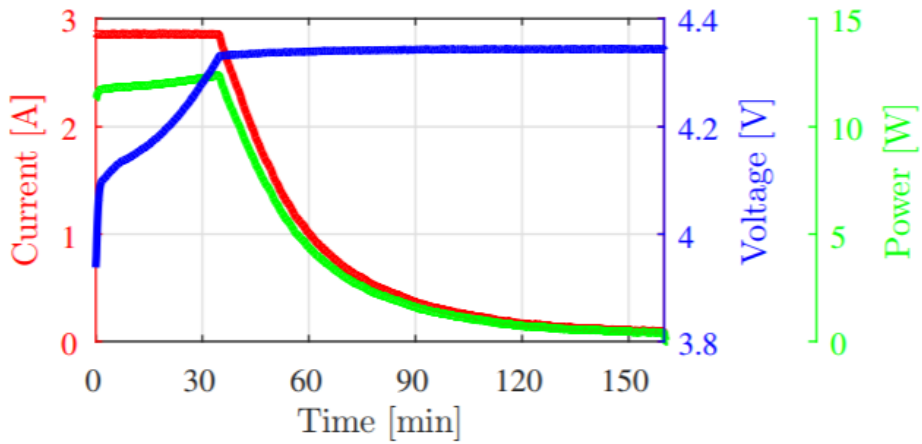
$$ch_t \leq P^{\mathrm{ch}}, \quad \forall t \in T$$

$$dis_t \leq P^{\mathrm{dis}}, \quad \forall t \in T$$

$$soe_t = soe_{t-1} + \Delta t \cdot ch_t \cdot \eta^{\mathrm{E}} - \Delta t \cdot dis_t, \quad \forall t \in T$$

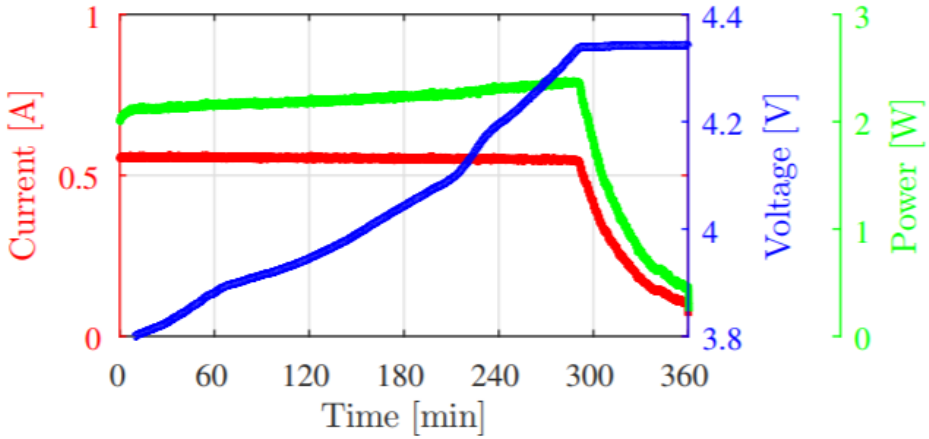
$$soe_t \leq C^{\mathrm{E}}, \quad \forall t \in T$$

Karakteristika punjenja



(a) Charging current 2.8 A (1C)

$$ch_t \leq P^{\text{ch}}, \quad \forall t \in T$$?



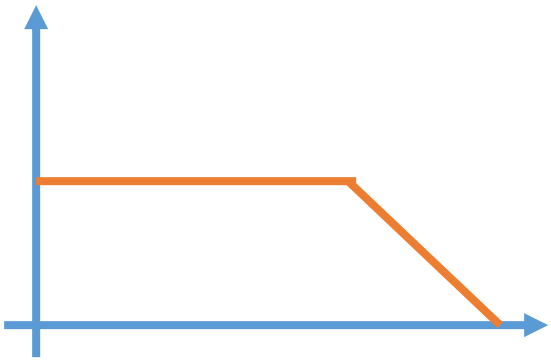
(b) Charging current 0.56 A (0.2C)

Poboljšanje

S. I. Vagropoulos and A. G. Bakirtzis, "Optimal Bidding Strategy for Electric Vehicle Aggregators in Electricity Markets," in *IEEE Transactions on Power Systems*, vol. 28, no. 4, pp. 4031-4041, Nov. 2013.

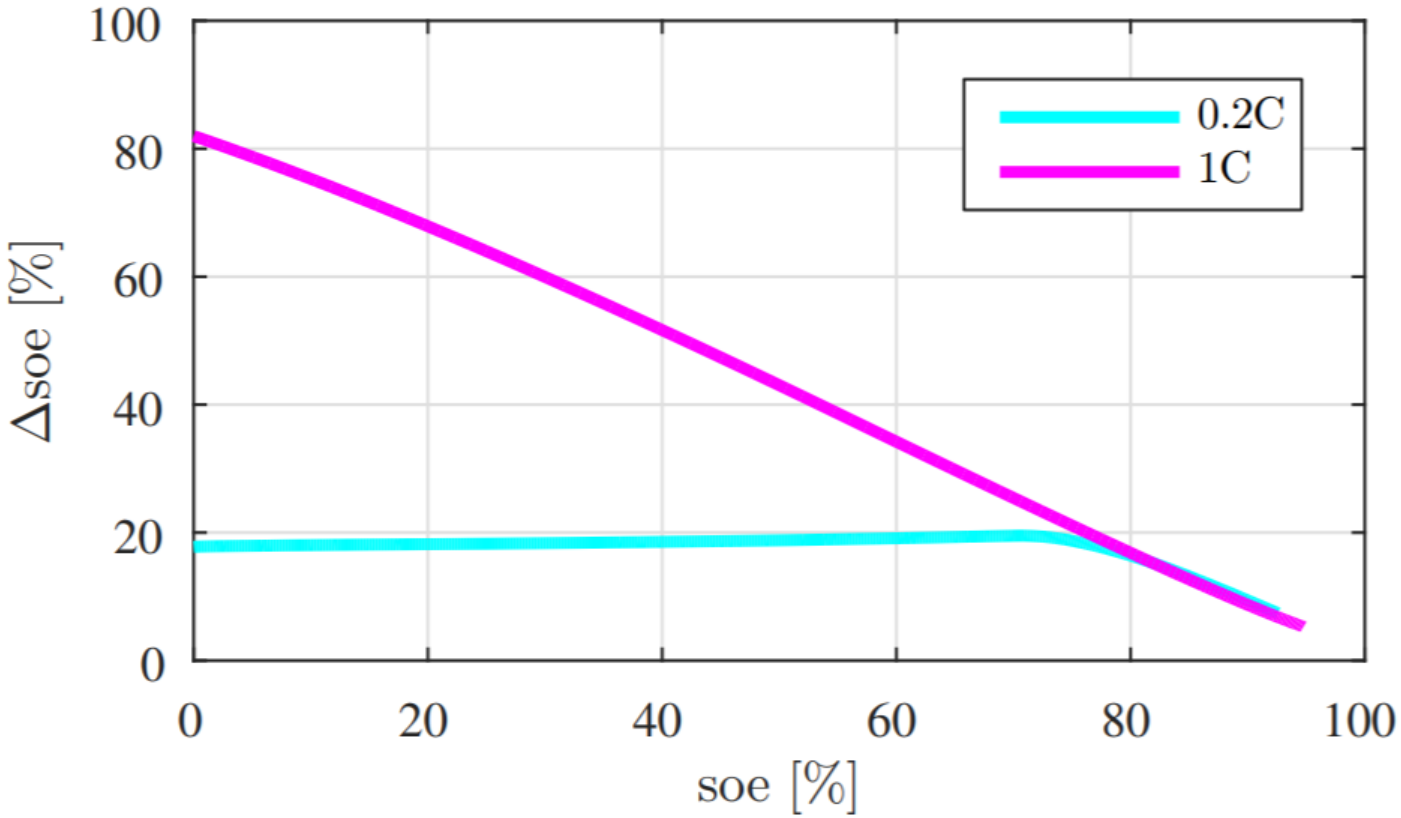
$$ch_t \leq P^{\mathrm{ch}}$$

$$ch_t \leq P^{\mathrm{ch}} \cdot \frac{SOE^{\max} - soe_t}{SOE^{\max} - SOE^{\mathrm{cc,cv}}}$$

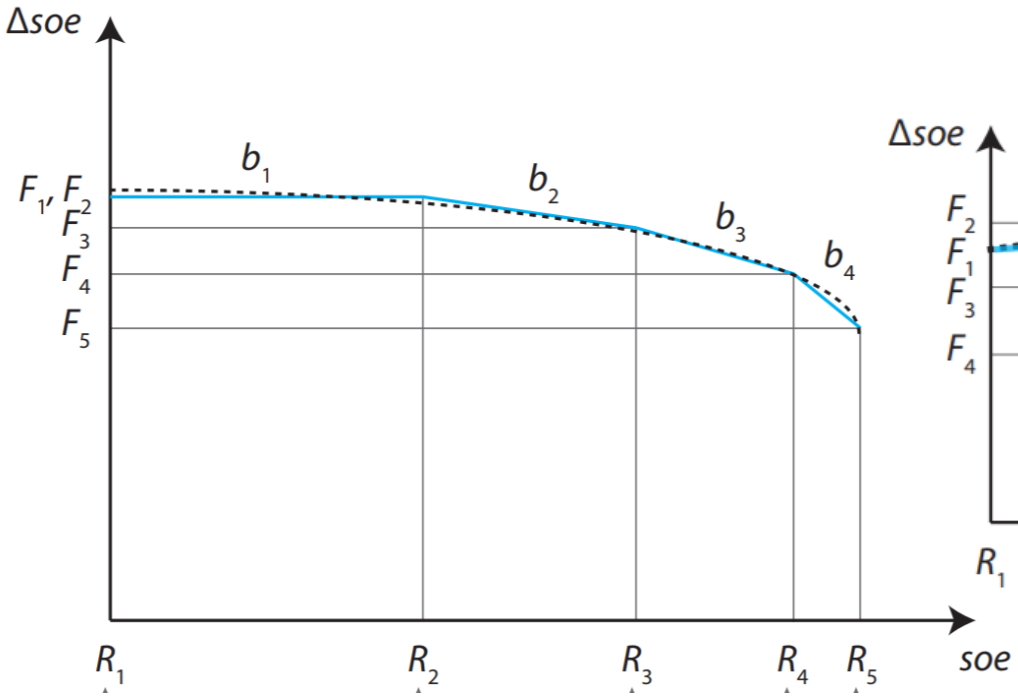


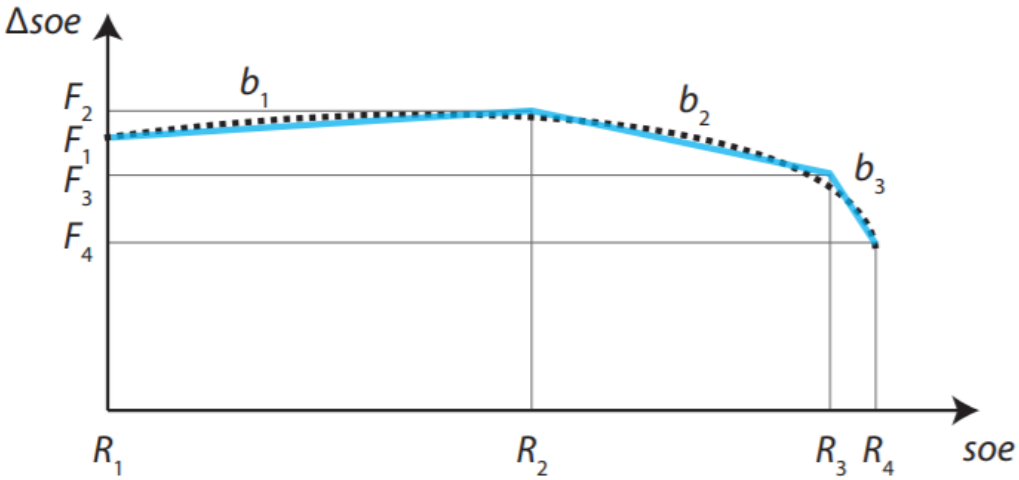
Snaga ili energija?

- Mogućnost povećanja SoE tijekom jednog sata

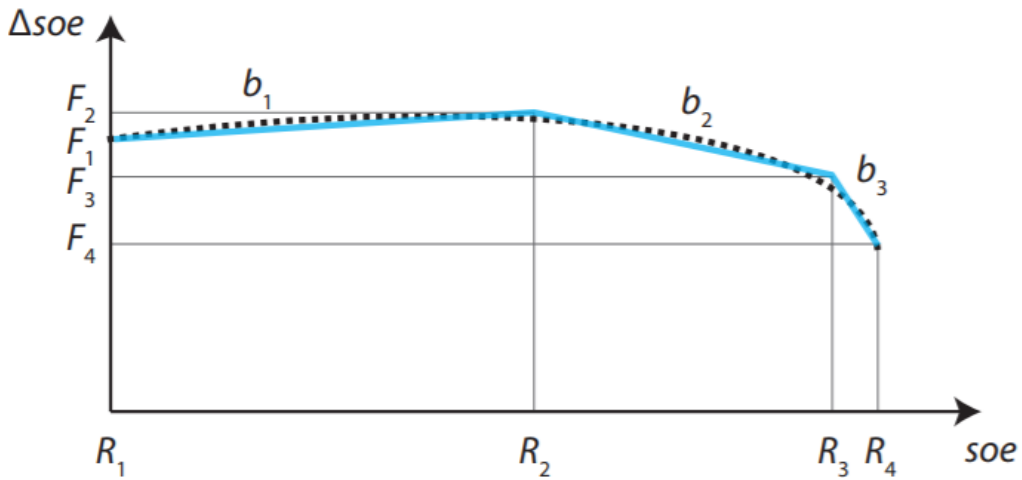


Aproksimacija krivulje punjenja





Linearna aproksimacija



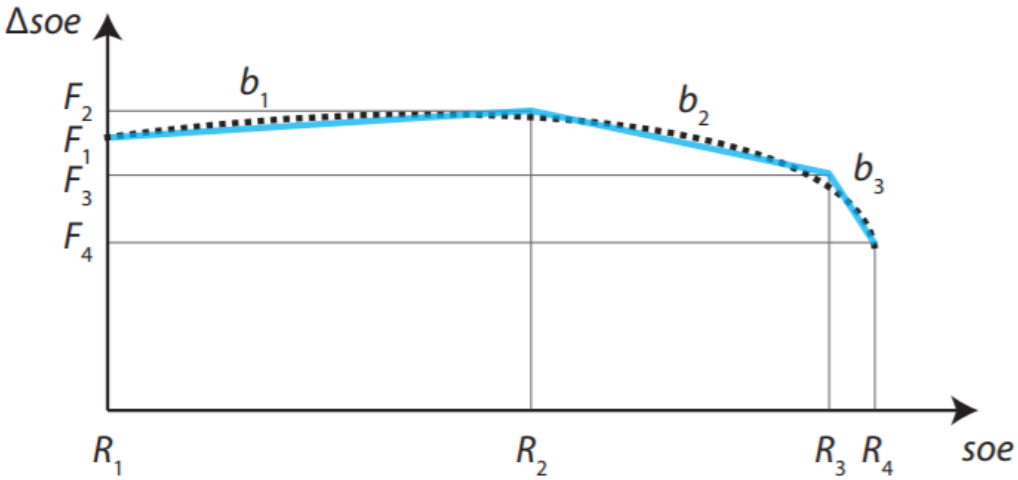
$$soe_t = \sum_{i=1}^{I-1} soe_{t,i}, \quad \forall t \in T$$

$$soe_{t,i} \leq R_{i+1} - R_i, \quad \forall t \in T, i \in I$$

$$\Delta soe_t = F_1 + \sum_{i=1}^{I-1} \frac{F_{i+1} - F_i}{R_{i+1} - R_i} \cdot soe_{t-1,i}, \quad \forall t \in T$$

$$ch_t \leq \frac{\Delta soe_t}{\Delta t \cdot \eta^{\mathrm{E}}}, \quad \forall t \in T$$

Mješovito-cjelobrojna aproksimacija



$$soe_{t-1} = \sum_{i=1}^{I} R_i \cdot y_{t,i}, \quad \forall t \in T$$

$$0 \leq y_{t,i} \leq 1, \quad \forall t \in T, i \in I$$

$$\sum_{i=1}^{I} y_{t,i} = 1, \quad \forall t \in T$$

$$\begin{bmatrix} y_{t,1} \\ y_{t,2} \\ \vdots \\ y_{t,I} \end{bmatrix} \leq [\mathbf{H}] \begin{bmatrix} b_{t,1} \\ b_{t,2} \\ \vdots \\ b_{t,I-1} \end{bmatrix}$$

$$\sum_{i=1}^{I-1} b_{t,i} = 1, \quad \forall t \in T$$

$$\Delta soe_t = \sum_{i=1}^{I} F_i \cdot y_{t,i}, \quad \forall t \in T$$

$$ch_t \leq \frac{\Delta soe_t}{\Delta t \cdot \eta^{\mathrm{E}}}, \quad \forall t \in T$$

Usporedba modela

- Tri modela
  - Osnovni (Baseline)

$$ch_t \leq P^{\mathrm{ch}}, \quad \forall t \in T$$

  - Linear CC-CV

$$ch_t \leq P^{\mathrm{ch}}, \quad \forall t \in T$$

$$ch_t \leq P^{\mathrm{ch}} \cdot \frac{SOE^{\max} - soe_t}{SOE^{\max} - SOE^{\mathrm{cc,cv}}}$$

  - Predloženi (Energy charging model)

$$soe_t = \sum_{i=1}^{I-1} soe_{t,i}, \quad \forall t \in T$$

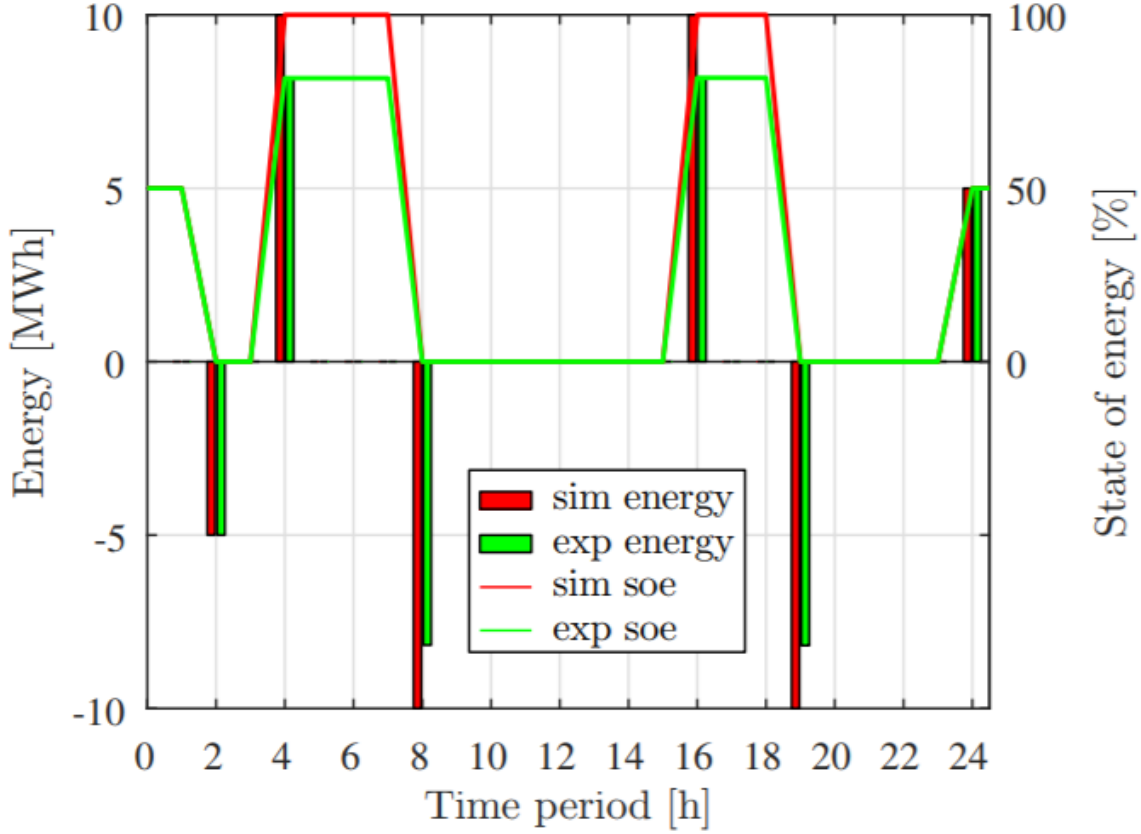
$$soe_{t,i} \leq R_{i+1} - R_i, \quad \forall t \in T, i \in I$$

$$\Delta soe_t = F_1 + \sum_{i=1}^{I-1} \frac{F_{i+1} - F_i}{R_{i+1} - R_i} \cdot soe_{t-1,i}, \quad \forall t \in T$$

$$ch_t \leq \frac{\Delta soe_t}{\Delta t \cdot \eta^{\mathrm{E}}}, \quad \forall t \in T$$

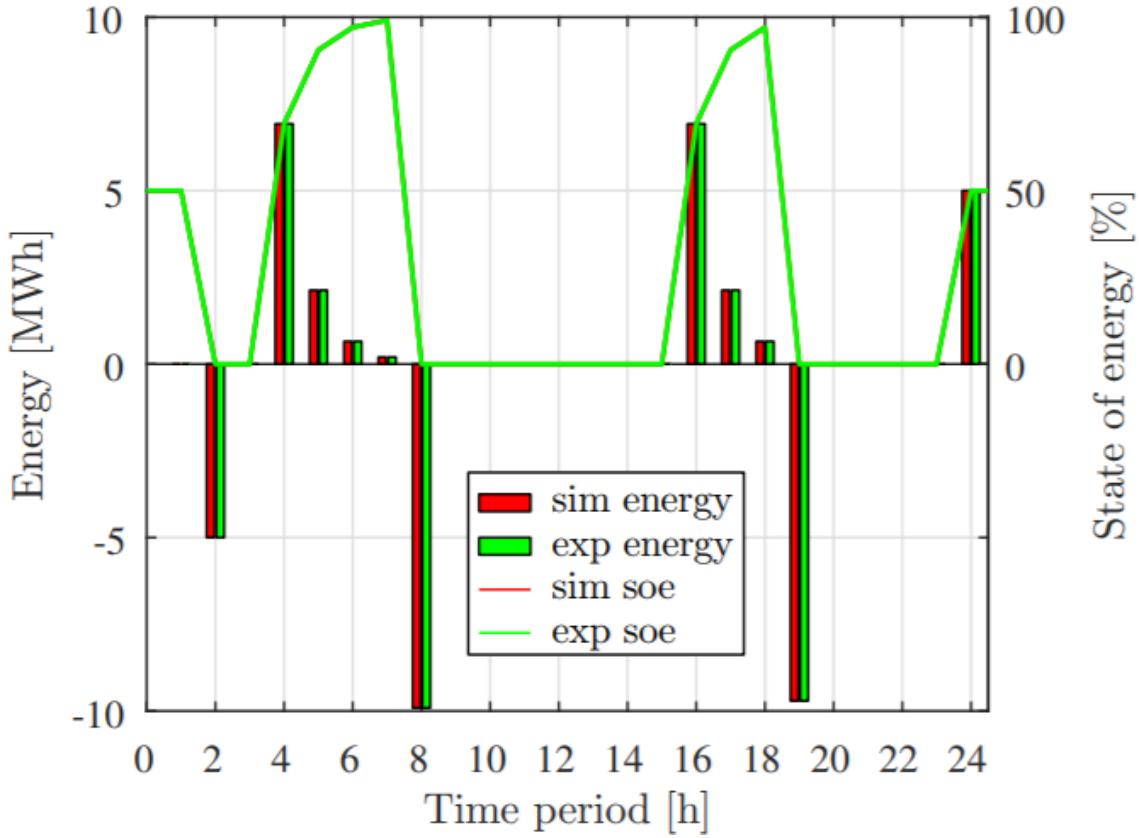
Rezultati (1C)

- Baseline model



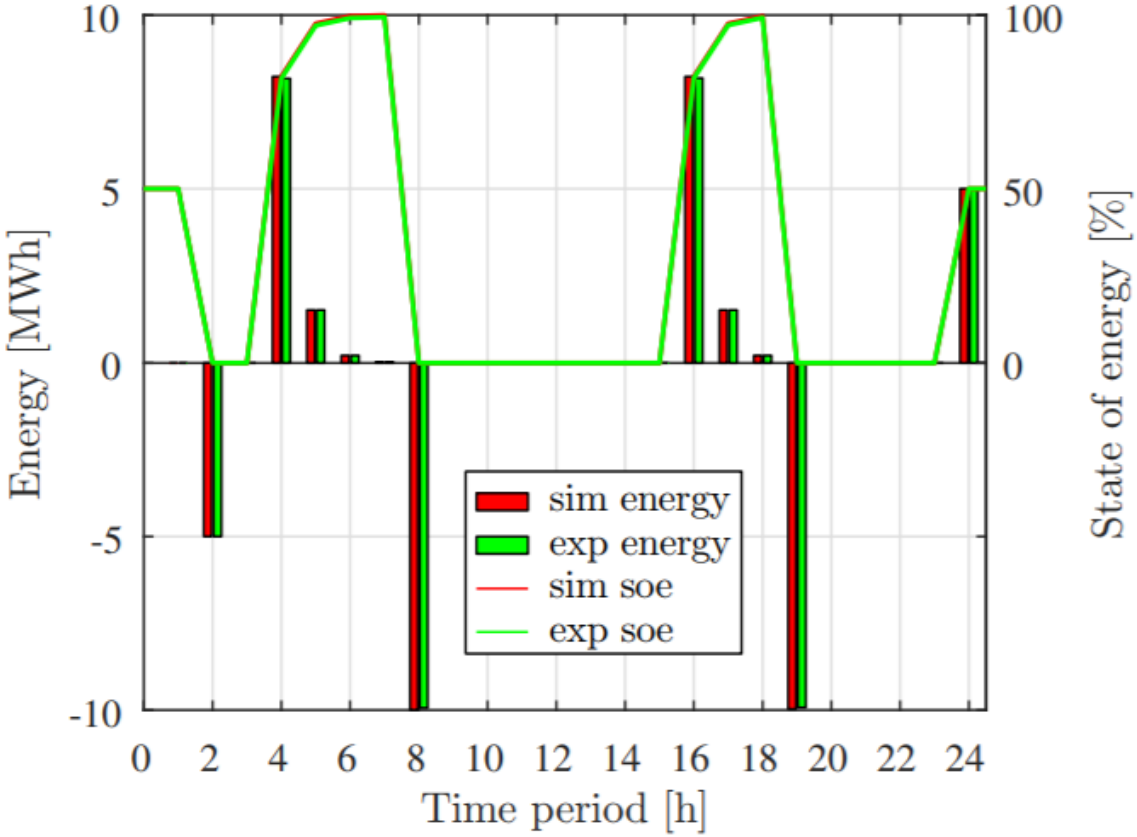
Rezultati (1C)

- Linear CC-CV model



Rezultati (1C)

- Energy charging model



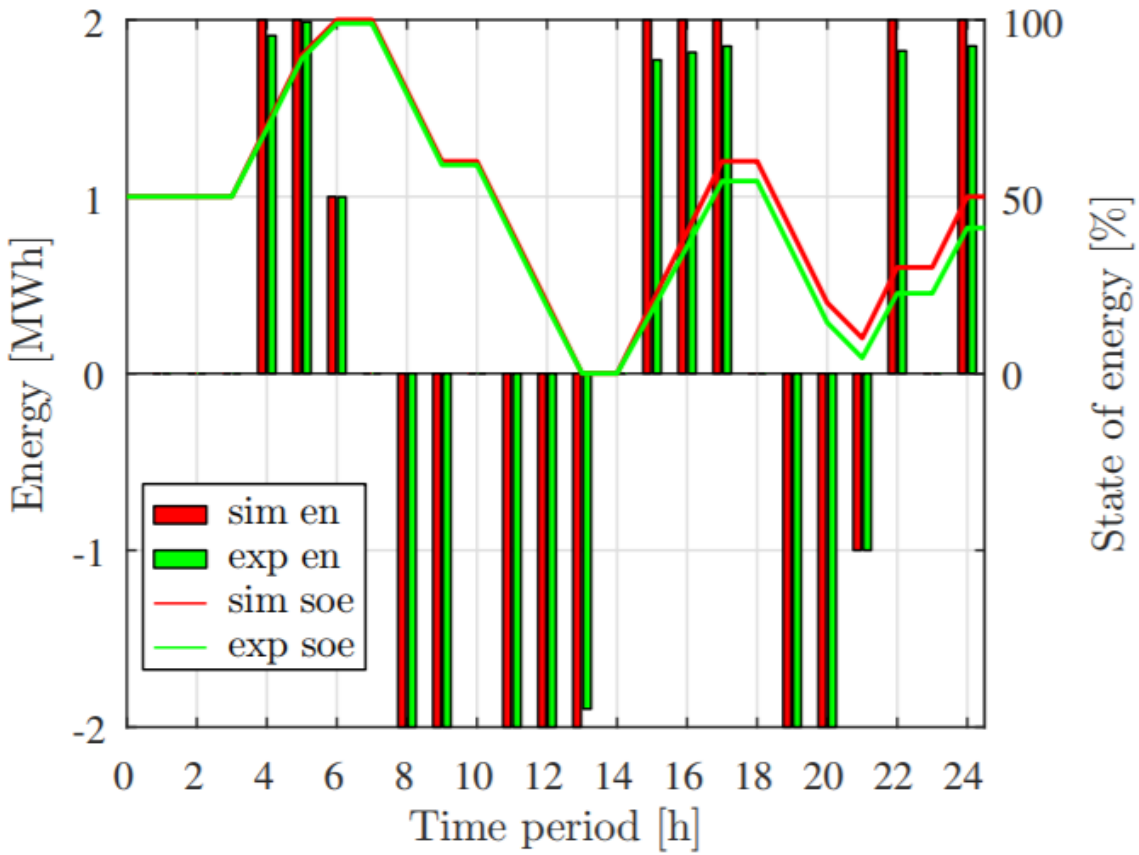
Rezultati (1C)

Sumarno:

Model		Baseline	Linear CC-CV	Energy Charging
Delivered energy (MWh)	Simulation	25.00	24.62	24.97
	Experiment	21.36	24.62	24.87
Charged energy (MWh)	Experiment	21.36	24.62	24.87
Resulting profit (€)	Simulation	272.04	249.51	264.71
	Experiment	91.02	249.51	259.64

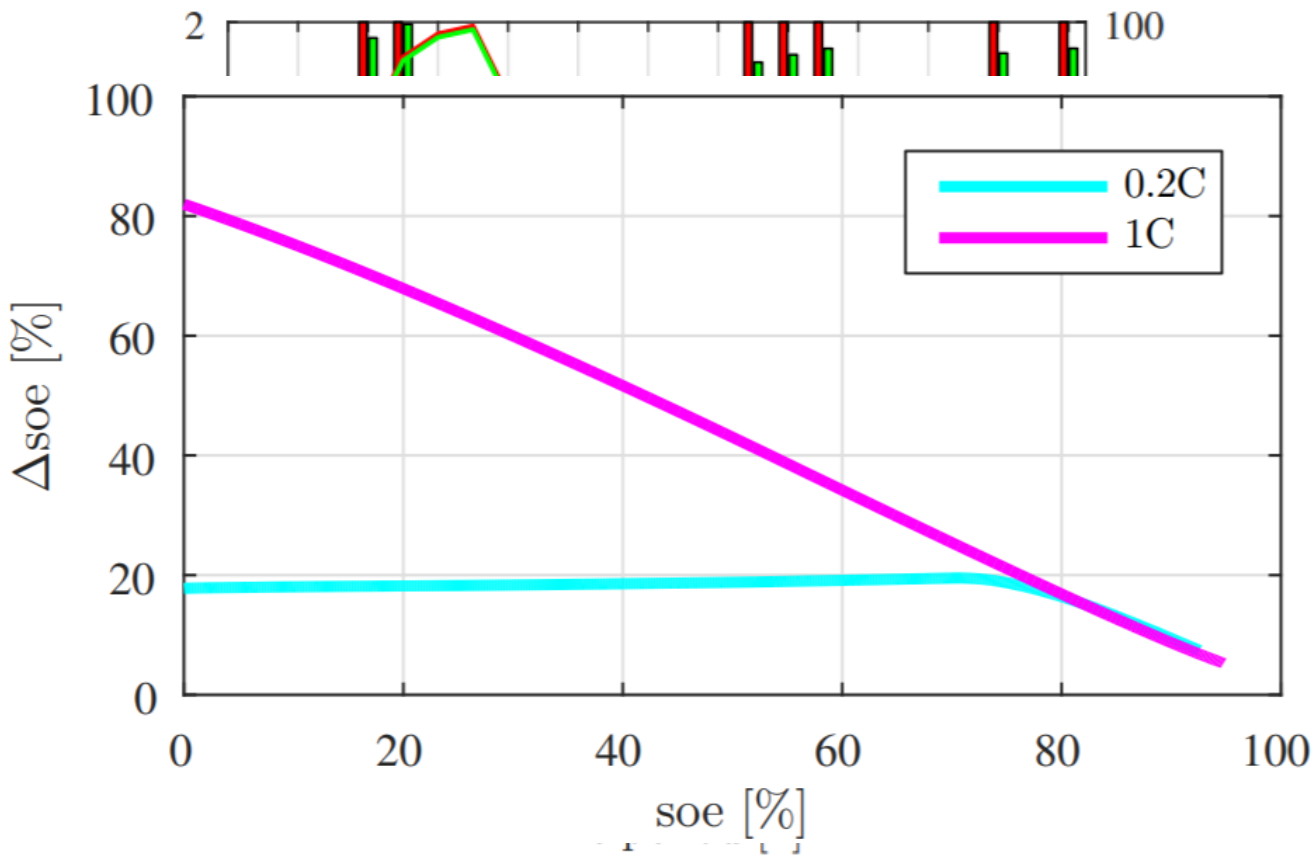
Rezultati (0,2C)

- Baseline model



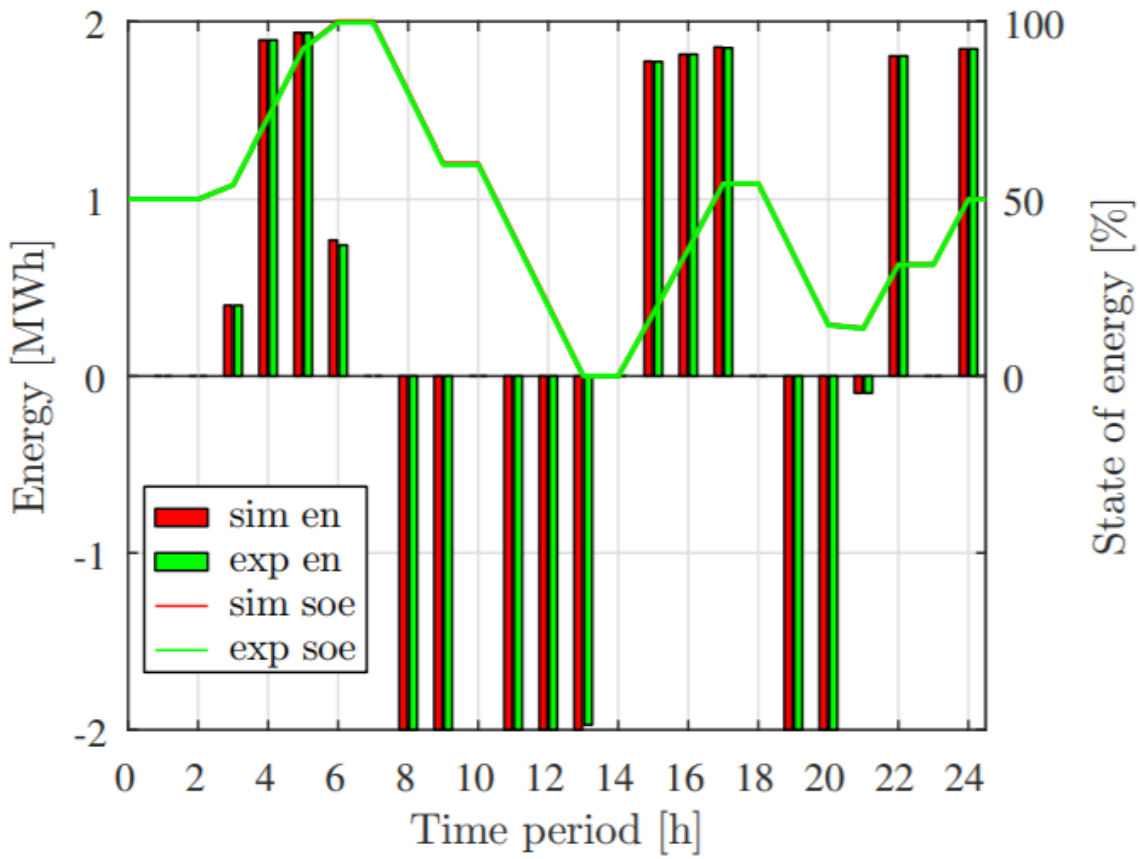
Rezultati (0,2C)

- Linear CC-CV model



Rezultati (0,2C)

- Energy charging model



Rezultati (0,2C)

Sumarno:

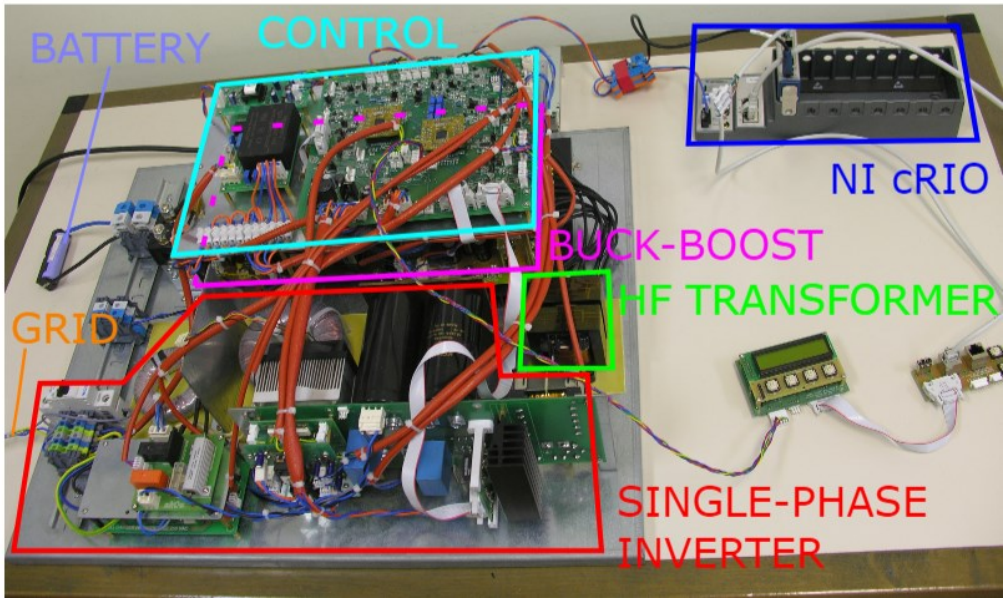
Model		Baseline	Linear CC-CV	Energy Charging
Delivered energy (MWh)	Simulation	15.00	14.89	14.10
	Experiment	14.90	14.79	14.07
Charged energy (MWh)	Experiment	14.01	13.91	14.06
Resulting profit (€)	Simulation	202.39	196.79	198.44
	Experiment	165.05	159.59	196.87

Zaključno

- Adresirali smo sociološko-političko-poslovno-tehničko-pravno-okolišni problem
- Poslovni model stanice za zamjenu baterija EV
- Utjecaj na elektroenergetski sustav (distribucija i prijenos)
- Laboratorijski postav

Zaključno

- Testiranje baterija



Hvala na pažnji

Evbass.fer.hr

EV BASS

HRZZ
Croatian Science Foundation

FER
UNIVERSITY OF ZAGREB
FACULTY OF ELECTRICAL ENGINEERING AND COMPUTING

AALBORG UNIVERSITET

HEP OPERATOR DISTRIBUCIJSKOG SUSTAVA d.o.o.