Protective Sets Methodology for Battery Cells of Electric Vehicles

Mario Vašak, Dorijan Leko, Luka Prlenda, Filip Rukavina

University of Zagreb Faculty of Electrical Engineering and Computing

mario.vasak@fer.hr

SCIENTIFIC CONFERENCE ON NEW METHODS AND TECHNOLOGIES OF BATTERY SYSTEMS FOR ELECTRIC VEHICLES

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MLBattProt

Laboratory for Renewable Energy Systems (LARES)

LARES

https://www.lares.fer.hr

- Decision&control based on optimization of dynamic systems
- Minimized combination of operative and investment costs
- Applications to systems for energy transition and climate change adaptation
- Software modules for estimation, decision-making and control:
  - A. Optimal parametrisation (e.g. which PV system capacity and which storage capacity to use?)
  - B. Short-term planning for market participation (e.g. how to shape water pumping profile one day ahead, which flexibility to offer for demand response?)
  - C. Online operation in real time (i.e. how to act now considering all current states, requirements and forecasts?)

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LARES public funded projects

- Smart buildings planning, scheduling, control (Interreg 3Smart, Store4HUC, ERDF PC-ATE Buildings, INUKING, SUPEER, CNSF DECIDE)
- Smart water cycle planning, scheduling, control (H2020 REWAISE, HE RESURGENCE, RRP Dodola)
- Energy hubs sizing and operation scheduling (Interreg DanuP2Gas, Danube Indeet, HyEfRe, I3 NACHIP)
- Data fusion for estimation, prediction & decision support in agriculture (ERDF AgroSPARC)
- Predictive control in smart city lighting (ERDF SmartCityLight)
- BMS add-on for predictive protection of EV battery cells (ERDF EVBattPredtect, RRP MLBattProt)
- Protective predictive add-ons for control systems against excessive loading and fatigue of construction elements in energy and transport systems (ERDF ZaCjel)
- Green Logistics and Management of Vending (ERDF T-Logic, CegLog)
- Advanced Control of Energy Storages and Chargers (ERDF PUELBI)
- Erasmus Mundus Joint Master Programme in Control of Renewable Energy Systems (EMJM EU-CORE)

Dynamical predictive protection of electric vehicle battery health

resurgence

Food MAPP

ZaCjel

REwaise
Resilient Water Innovation for Smart Economy

DECIDE

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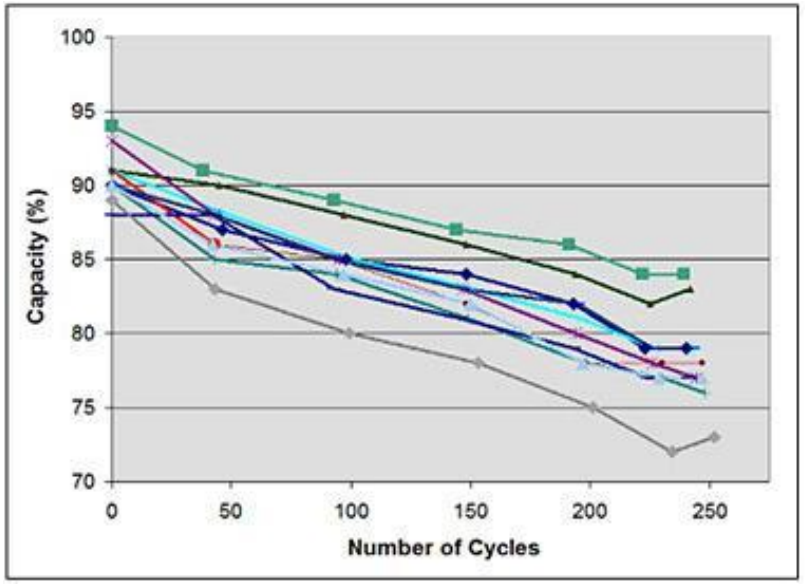
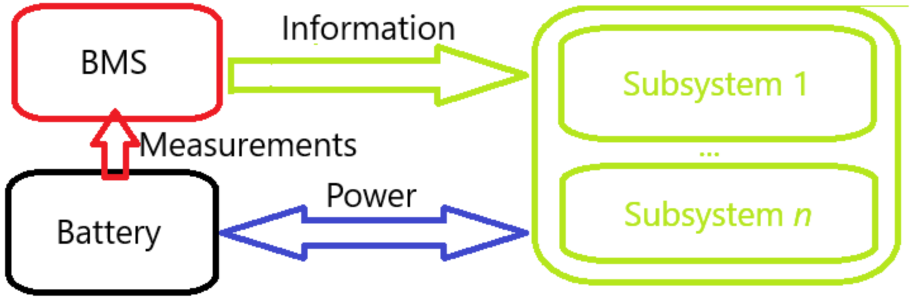
Battery aging and predictive counter-actions

- Electric Vehicle (EV) battery degradation is a major issue
  - It greatly depends on the way how EV battery is exploited: which currents/powers are drawn from the battery or provided to the battery in given battery conditions
    - State of Charge
    - Temperature
    - State of Health



- State-of-the-art Battery Management Systems (BMSs) use on-line inverse of a simple battery model to assess +/- constant power limits and +/- energy limits for several seconds ahead
  - Prevention of base constraints violation



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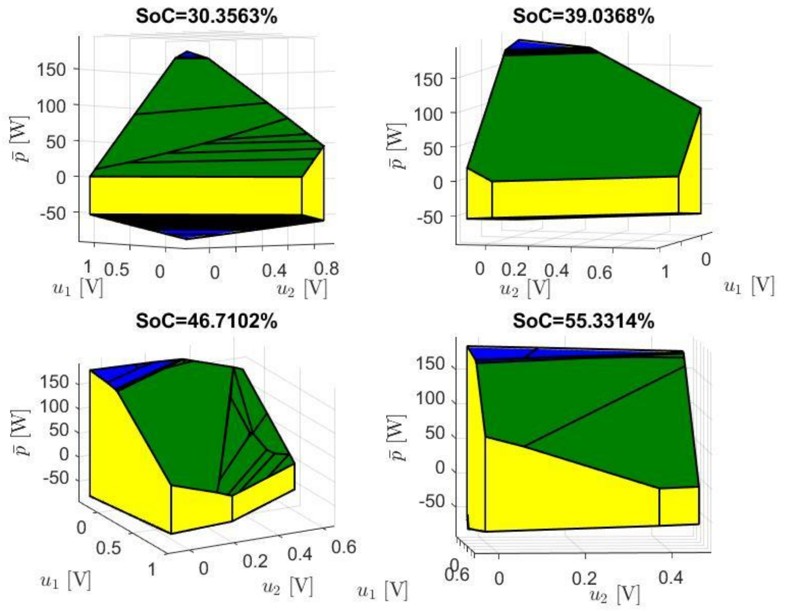
Predictive protective sets in general

$$S \subseteq X_0 \times U^N$$

- **Protective set** for a dynamic system localizes the initial states and corresponding control actions over a future short time horizon with *N* control inputs changes, that are compliant with all constraints posed on the system
- **Computed off-line** based on the system model on its entire domain and **„packed"/sub-approximated** with a set that allows a tractable on-line evaluation
- **On-line implementation**: uses the protective set description in on-board memory for fast computation (multiplications and additions) of admissible bounds of currents/powers for the current system



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Predictive protection of an EV battery cell

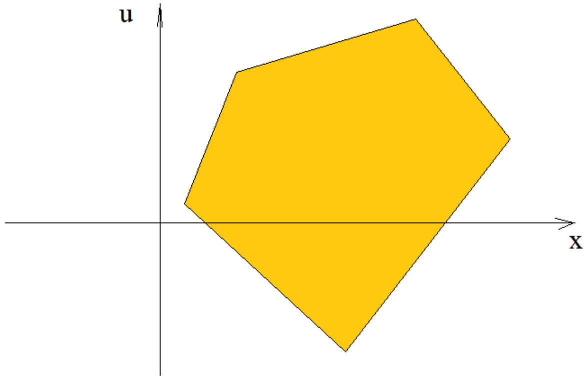
- Off-line (on a desktop computer):

$$\dot{x} = f(x,u)$$

$$g(x,u) \leq c$$

Battery model & constraints

Computation procedure

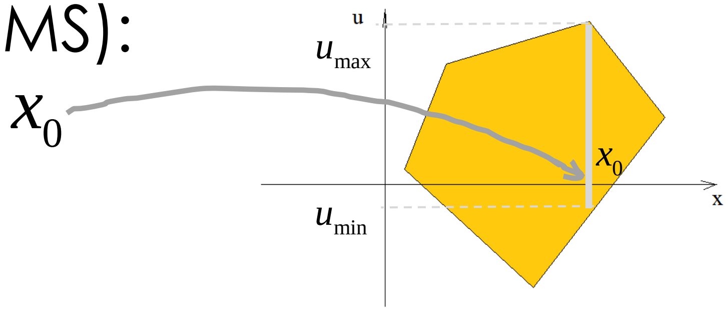


Protective set whose representation is stored in BMS memory

On-line multiply&add

- On-line (in BMS):

Battery state estimation



Constraints on admissible battery currents/powers few seconds ahead

- can be simple upper/lower constant powers for less sophisticated control strategies of EV subsystems,
- can be set-based (allowed profiles) for sophisticated / predictive control strategies of EV subsystems

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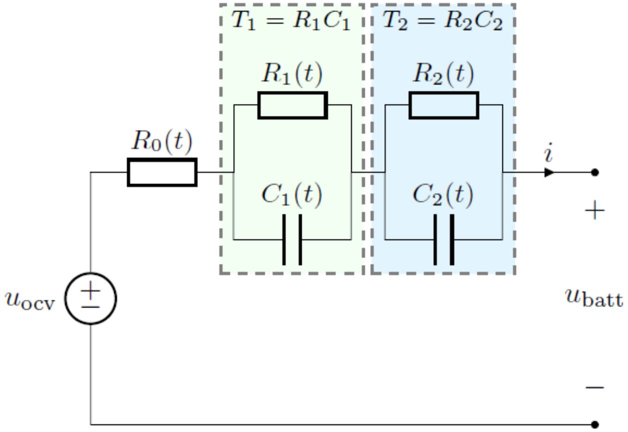
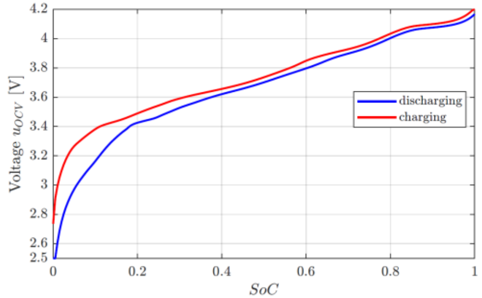
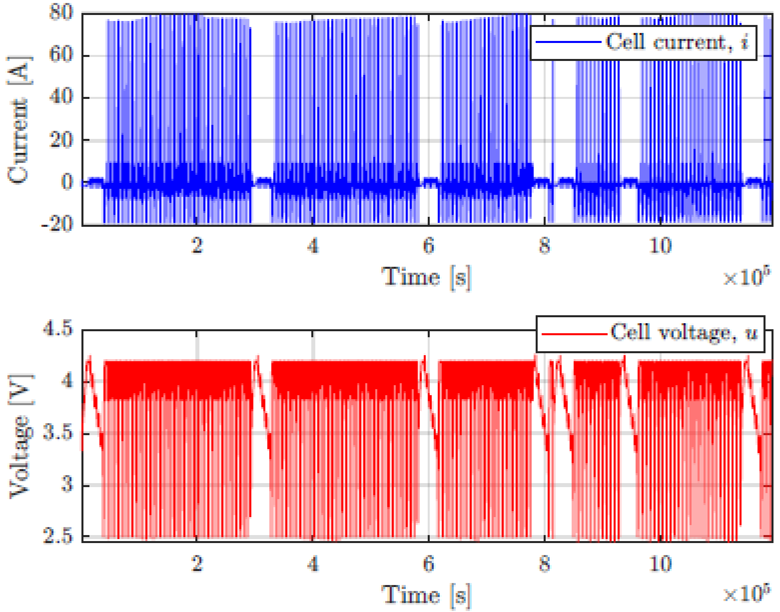
Protection against voltage constraints violation for a battery cell

Grey-box model approach (R2C ECM)

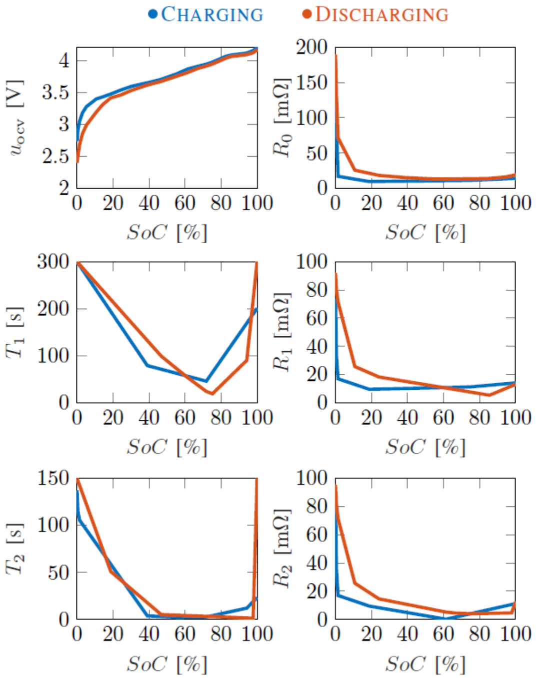




Experimentally obtained identification data



Identified cell parameters



F. Rukavina, D. Leko, M. Matijašić, I. Bralić, J. M. Ugalde and M. Vašak, "Identification of Equivalent Circuit Model Parameters for a Li-ion Battery Cell," 2023 IEEE 11th International Conference on Systems and Control (ICSC), Sousse, Tunisia, 2023, pp. 671-676, https://doi.org/10.1109/ICSC58660.2023.10449745

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Protection against voltage constraints violation for a battery cell

- 10 seconds prediction horizon
- Current, SoC and voltage constraints only
- Fixed temperature, dim(X_0)=3
- Three cases considered:
  - 1: N=1 $\rightarrow$ $\dim(S)=4,\ 351$ halfspaces
  - 2: N=2 $\rightarrow$ $\dim(S)=5,\ 1361$ halfspaces
  - 3: N=5 $\rightarrow$ $\dim(S)=8,\ 102708$ halfspaces

D. Leko, F. Rukavina, M. Matijašić, I. Bralić and M. Vašak, "Computationally Efficient Protective Methodology for Lithium-Ion Battery Cells Based on Safe Sets," 2023 IEEE 11th International Conference on Systems and Control (ICSC), Sousse, Tunisia, 2023, pp. 100-106, https://doi.org/10.1109/ICSC58660.2023.10449773

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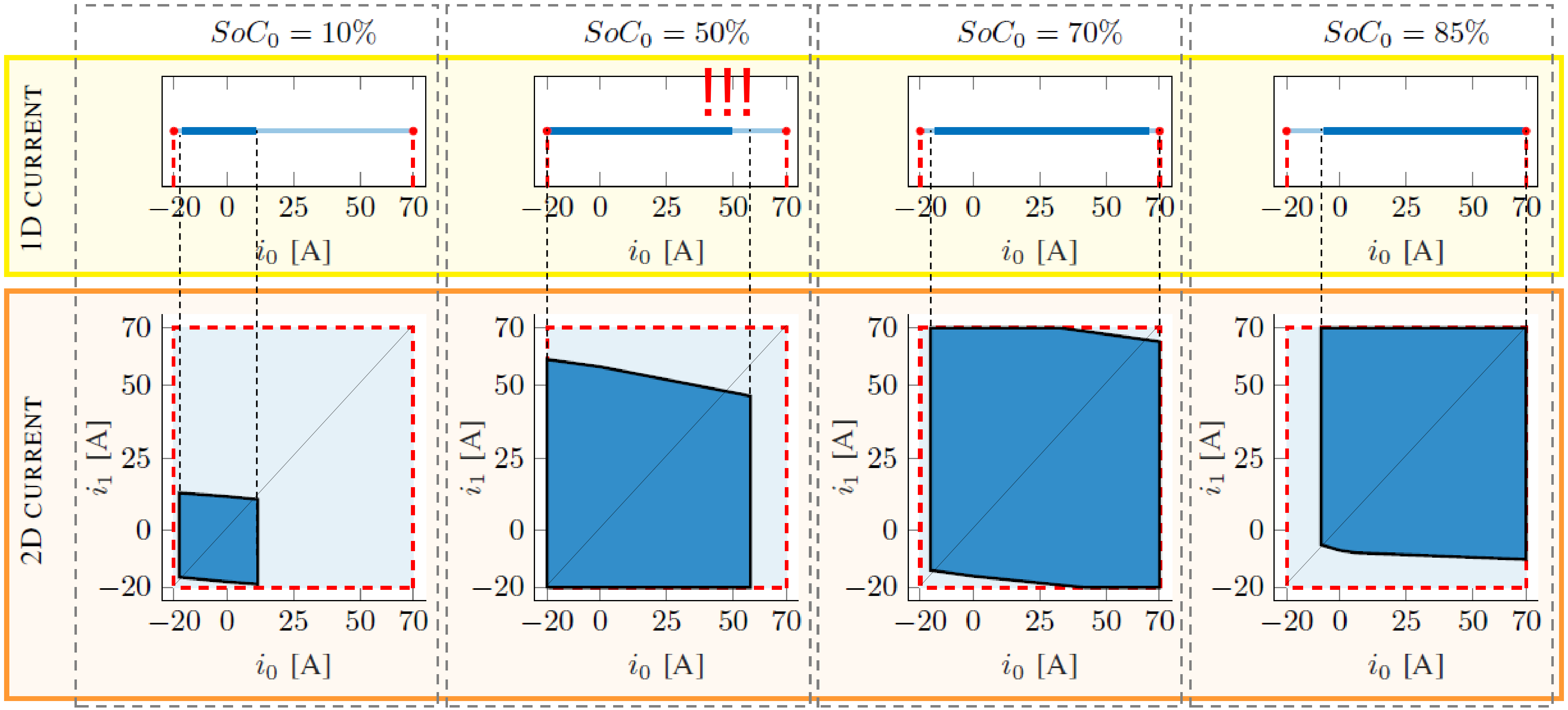
Protection against voltage constraints violation for a battery cell

N=1:

N=2:



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MLBattProt project – extending the approach towards degradation constraints

- Battery aging model
- Varying temperature considered
- Improvement of computation procedure for protective sets
- Robust extension of the protection set from cell to battery pack
- **→Targeted universal design procedure regardless of a specific cell chemistry used**

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MLBattProt project – key methodological steps

- Battery aging model
  - Parameters of the new cell: $\bar{p}$
    - Obtained by identification based on experimental data from samples of new cells
  - Parameters of the aged cell at a particular time instant: $p(t)$
    - Obtained by identification based based on designed aging experiments (time localization problem of parameter change)

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MLBattProt project – key methodological steps

- Battery aging model
  - Machine-learning based representation of aging parameters with a lower-dimensional parameters set η:

$$p(t) = g\left(\bar{p}, \eta(t)\right)$$

  - Machine-learning based search for a dynamic aging model:

$$\dot{\eta} = f\left(\eta, u_1, u_2, SoC, T_{\mathrm{batt}}, i_{\mathrm{batt}}\right)$$

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MLBattProt project – key methodological steps

- Protective set computation
  - Assessment of acceptable degradation box

$$\dot{\mathrm{H}}_{\min} \leq \dot{\eta} \leq \dot{\mathrm{H}}_{\max}$$

$$\Rightarrow \dot{\mathrm{H}}_{\min} \leq f\left(\eta, u_1, u_2, SoC, T_{\mathrm{batt}}, i_{\mathrm{batt}}\right) \leq \dot{\mathrm{H}}_{\max}$$

  - Protective set S computation with the degradation constraints included

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MLBattProt project – key methodological steps

- Protective set „post-processing”:
  - Sub-approximation of S – convexification or piecewise convexification
- Protective set robustification / extension to a family of cells in the battery pack with a specific distribution of states over the cells in the pack – **battery pack protective set**

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