

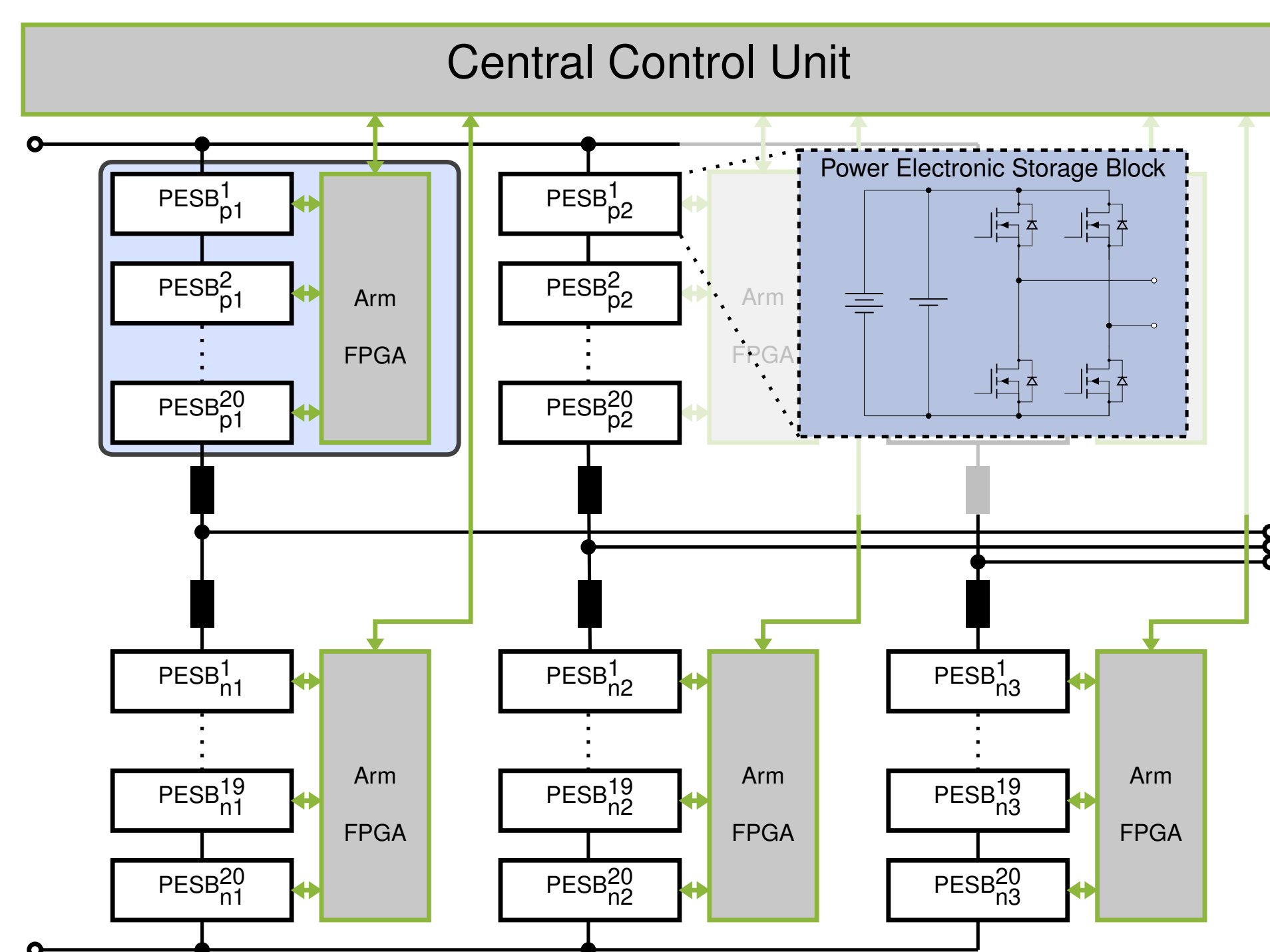
Faster than Real-Time Electro-Thermal-Aging Emulation of Multiple Batteries in a Modular Multilevel Converter

Lars Leister | Niklas Katzenburg | Kai Kuhlmann | Lukas Stefanski | Marc Hiller

Overview and Topology

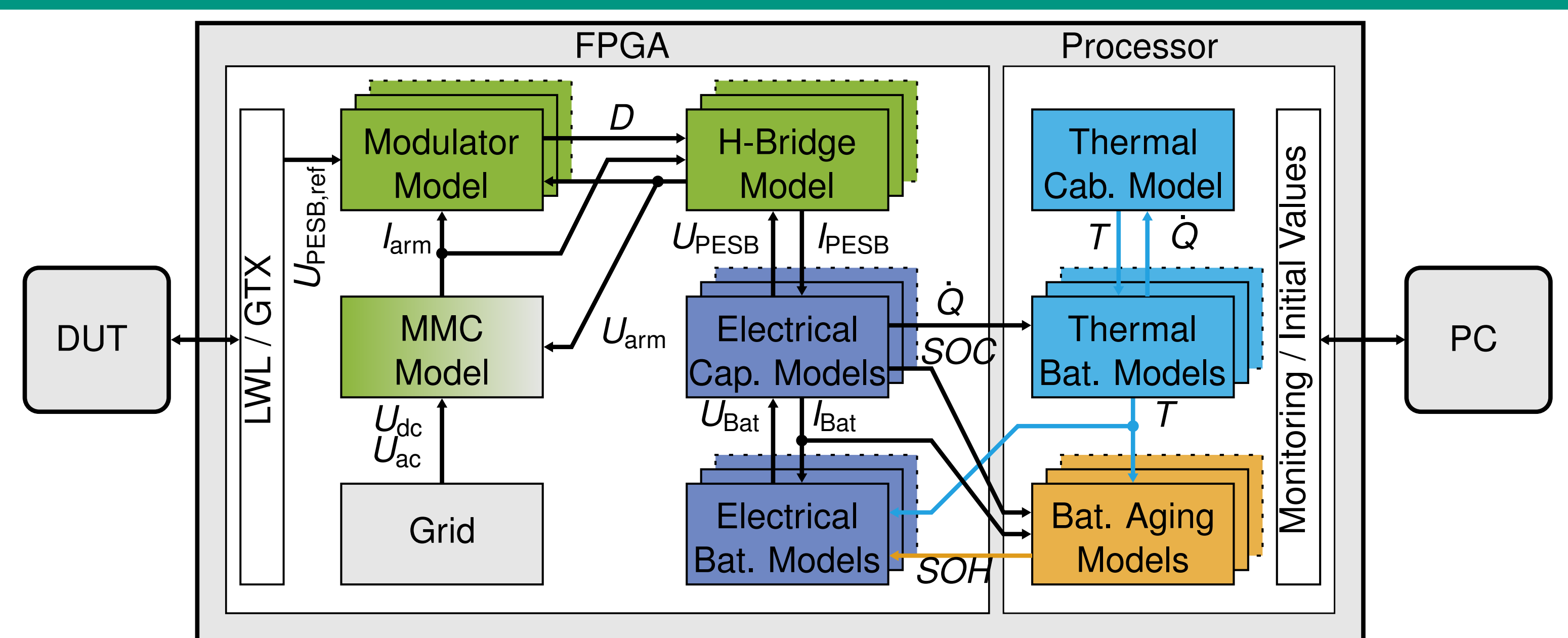
Modular Multilevel Converter (MMC) with Batteries

- Combination of different batteries, e.g., second-life
- Online lifetime estimation and optimization
- Integration of DC sources, e.g., PV into the grid



Schematic of the Battery Integrated MMC and its Control Structure

Emulated Components

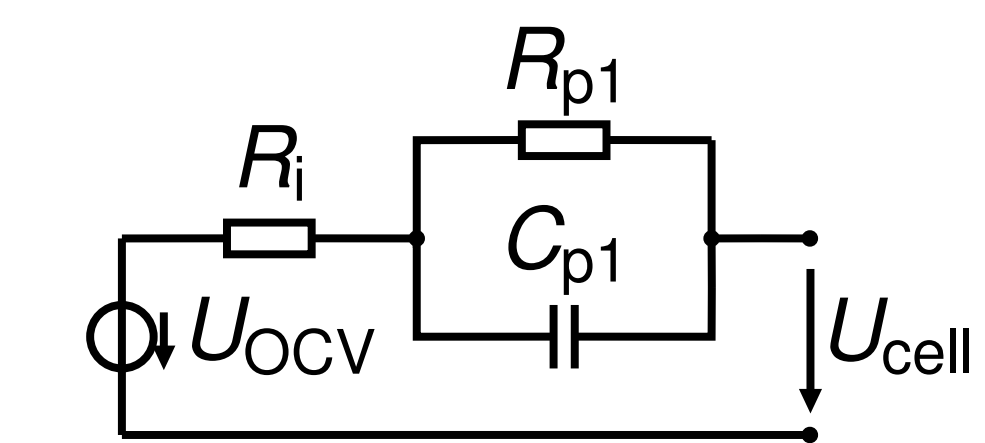


Schematic of the Emulator Running on the ETI SoC-Platform (Zynq-Z7030)

Hardware

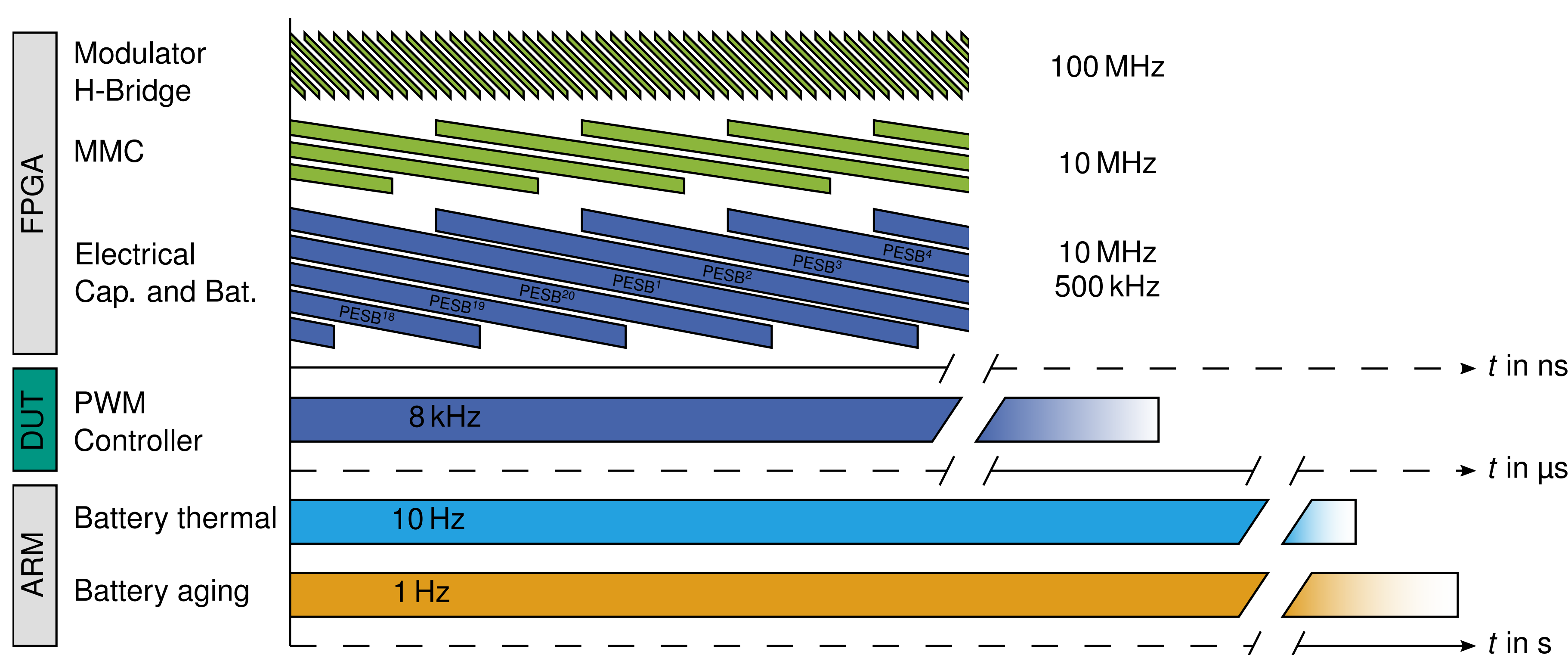


Electrical Cell Model



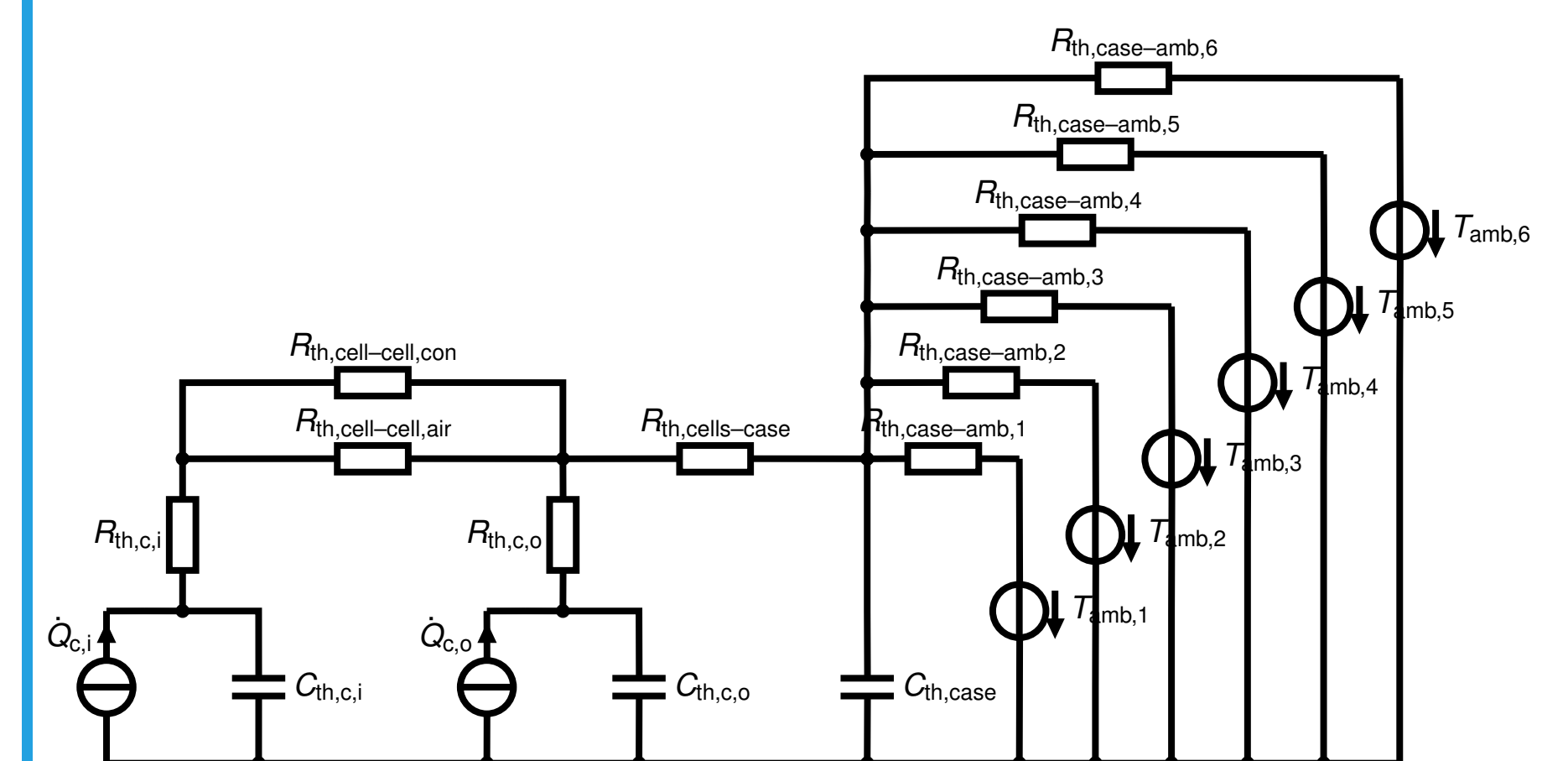
Equivalent Circuit Model (ECM) using 3-D LUTs

Timing



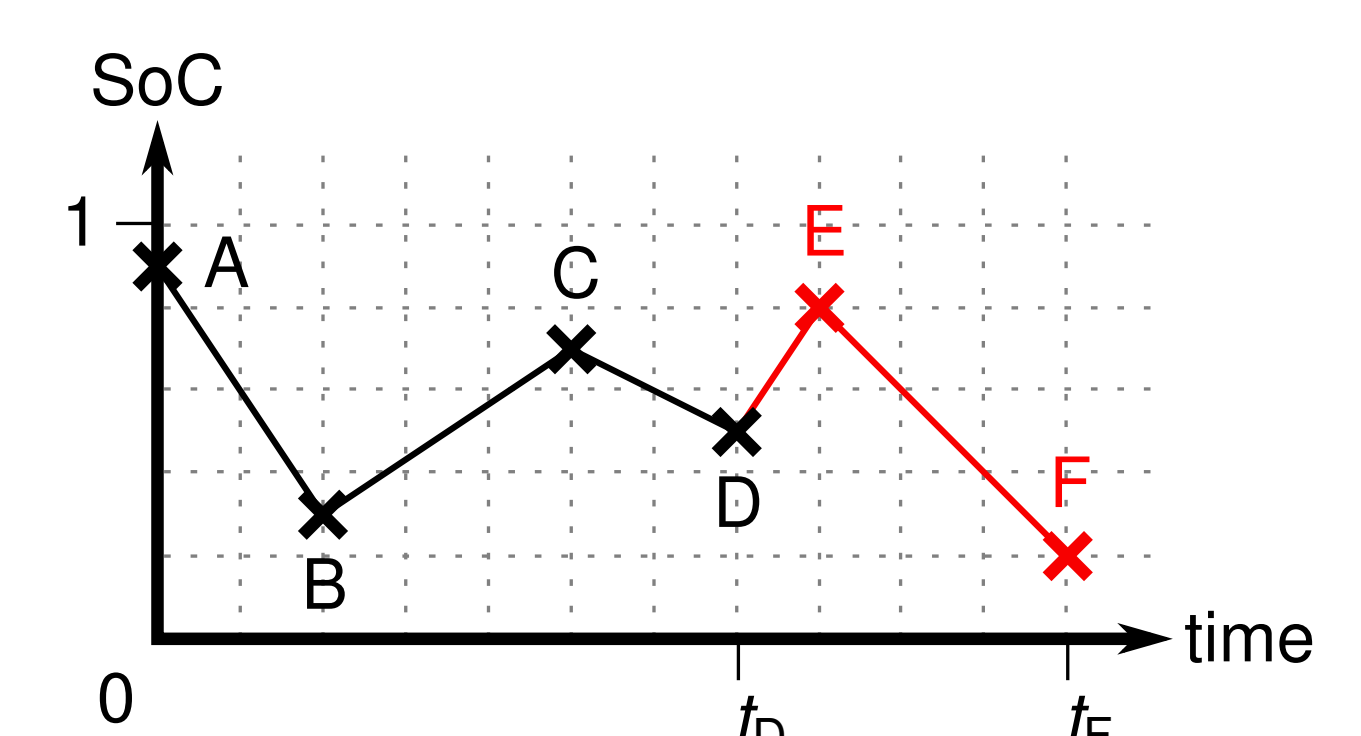
Overview of Timing Relations Between the Model Components

Thermal Module Model



Thermal ECM of a Battery Module

Aging Model

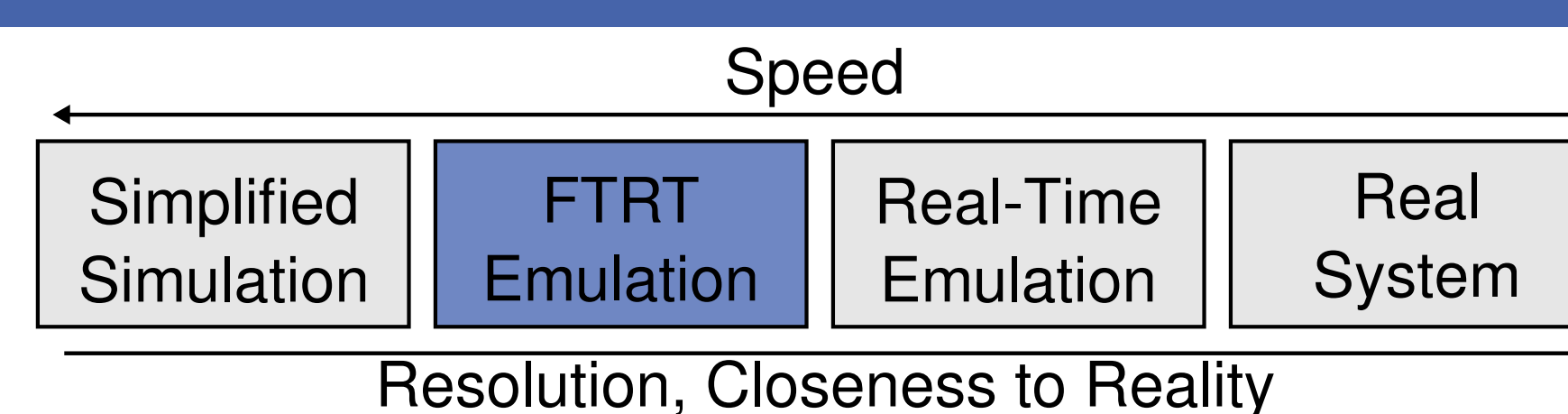


Evaluation at t_D	Evaluation at t_F
A-B: Half Cycle	A-F: Half Cycle
B-C: Half Cycle	B-E: Full Cycle
C-D: Half Cycle	C-D: Full Cycle

Demonstration of the Rainflow Algorithm

Key Points

- Scalable, fast, realistic modelling
 - Enabling energy management evaluation
- ⇒ Closing the gap between simulation and real-time emulation



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2023 European Conference on Power Electronics and Applications (EPE'23 ECCE Europe) in Aalborg, Denmark

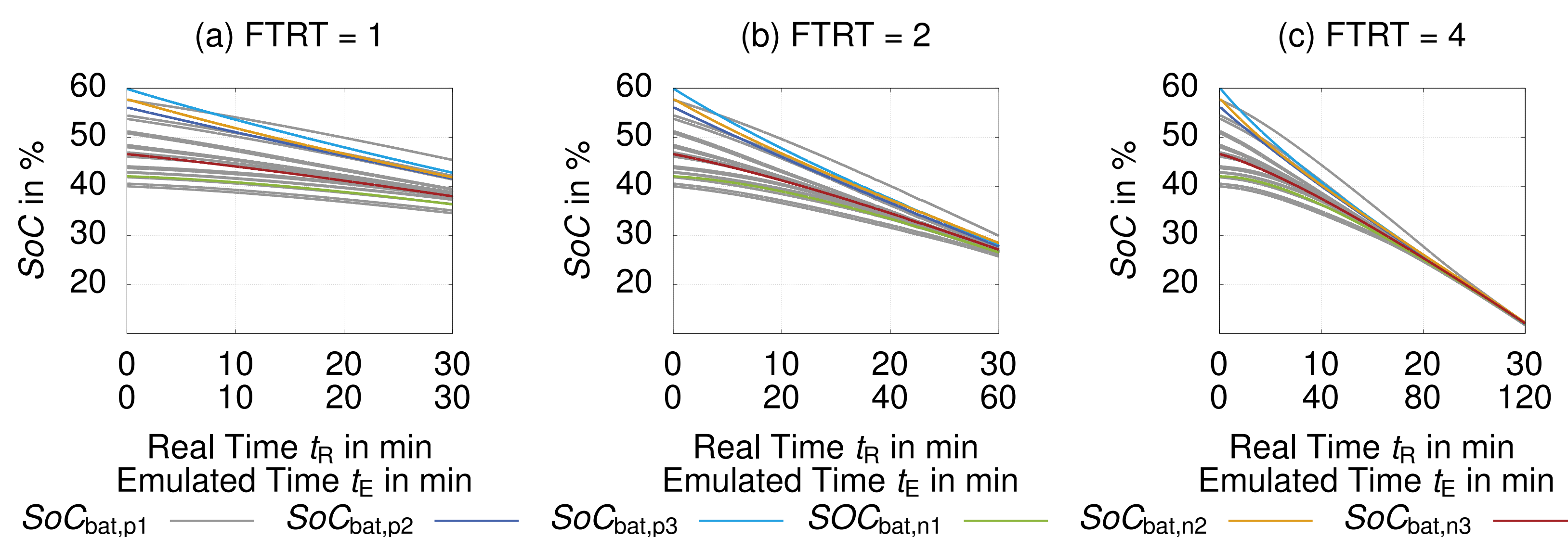
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Long-Term Evaluation of Faster than Real-Time

- Exemplary control algorithm: Balance SoC within and between the arms
- Accelerated emulation gives identical results faster



Exemplary Initial SoC

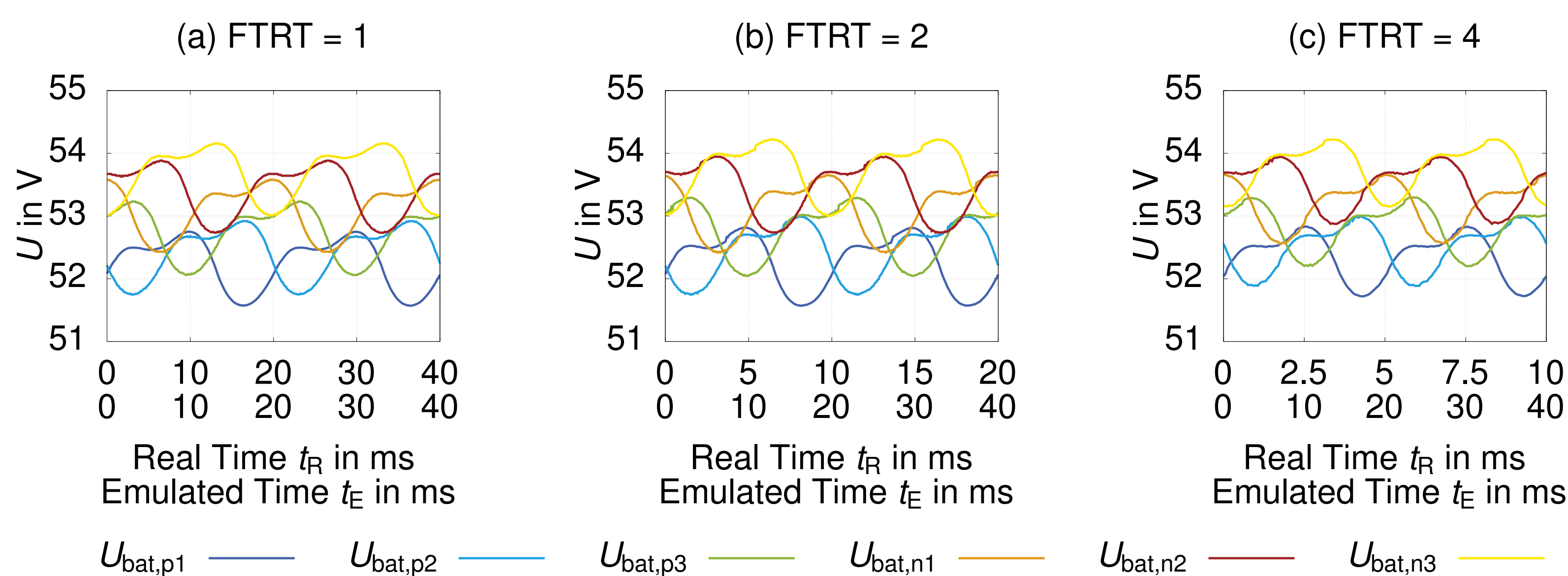
$p_{1,01}$: 48% $p_{1,02}$: 54% $p_{1,03}$: 40% $p_{1,04}$: 46%
 $p_{1,05}$: 43% $p_{1,06}$: 42% $p_{1,07}$: 44% $p_{1,08}$: 47%
 $p_{1,09}$: 48% $p_{1,10}$: 51% $p_{1,11}$: 48% $p_{1,12}$: 54%
 $p_{1,13}$: 44% $p_{1,14}$: 58% $p_{1,15}$: 41% $p_{1,16}$: 53%
 $p_{1,17}$: 48% $p_{1,18}$: 51% $p_{1,19}$: 43% $p_{1,20}$: 44%

p_2 : 56% p_3 : 60%
 n_1 : 42% n_2 : 58% n_3 : 47%

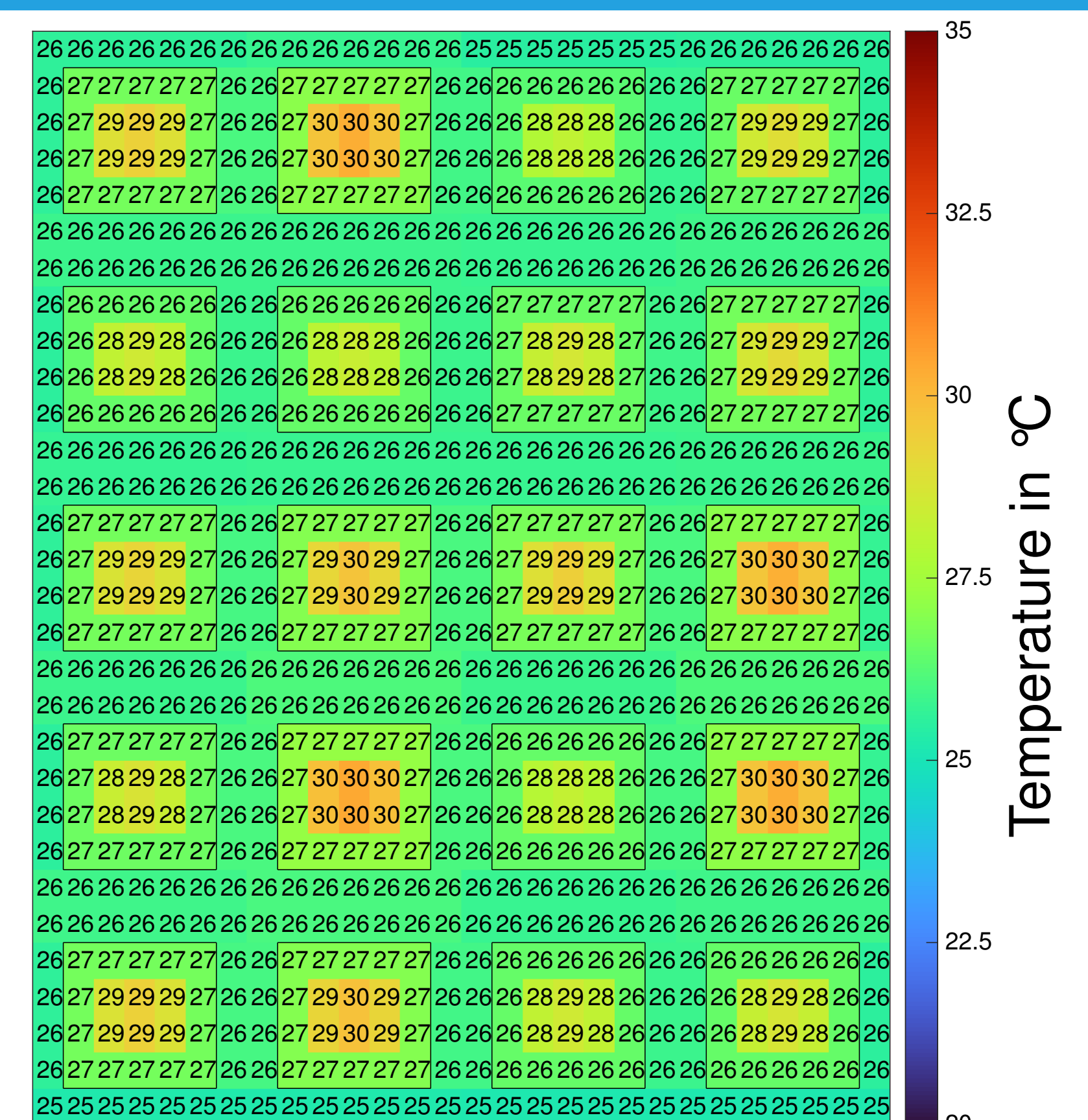
Initial SoCs for all Evaluations

Short-Term Evaluation of Faster than Real-Time

- Reduced resolution for FTRT results only in minor deviations

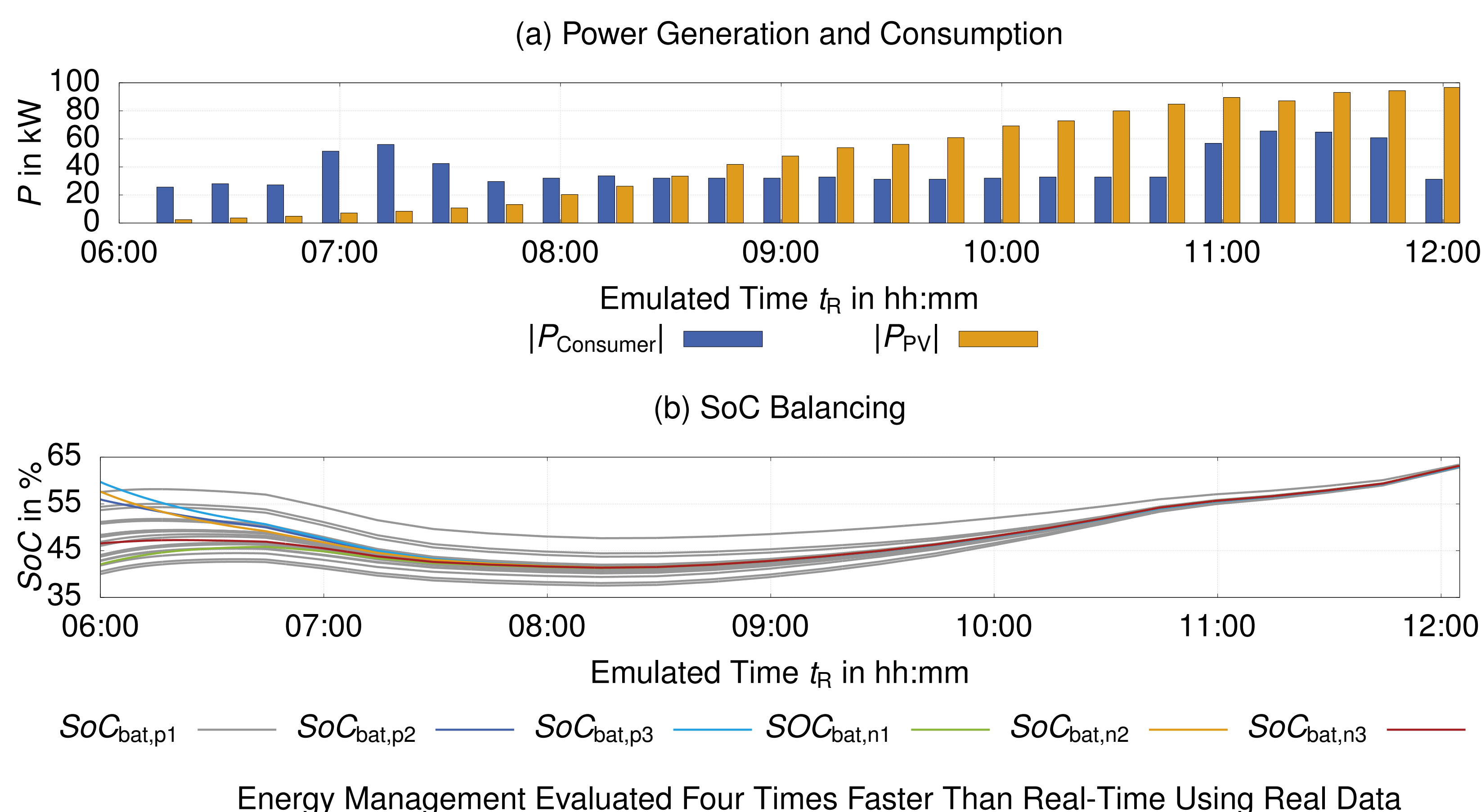


Thermal Interaction



Temperatures in the Cabinet after 1 h

Energy Management Evaluation



One Arm of the Emulated Prototype



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