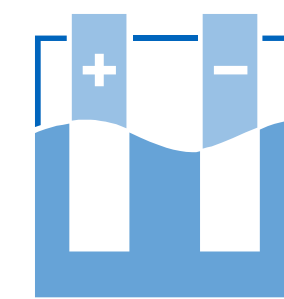




Realizing Serial Hybrid Energy Storage Systems (sHESS) by implementing Switching Circuits on Battery Cell Level

Max F. Horsche, Michael Sturm and Andreas Jossen
Chair of Electrical Energy Storage Technology (EES),
Technical University of Munich (TUM),
Arcisstr. 21, 80333 Munich, Germany

Technical University of Munich



EES
Chair of
Electrical Energy Storage Technology



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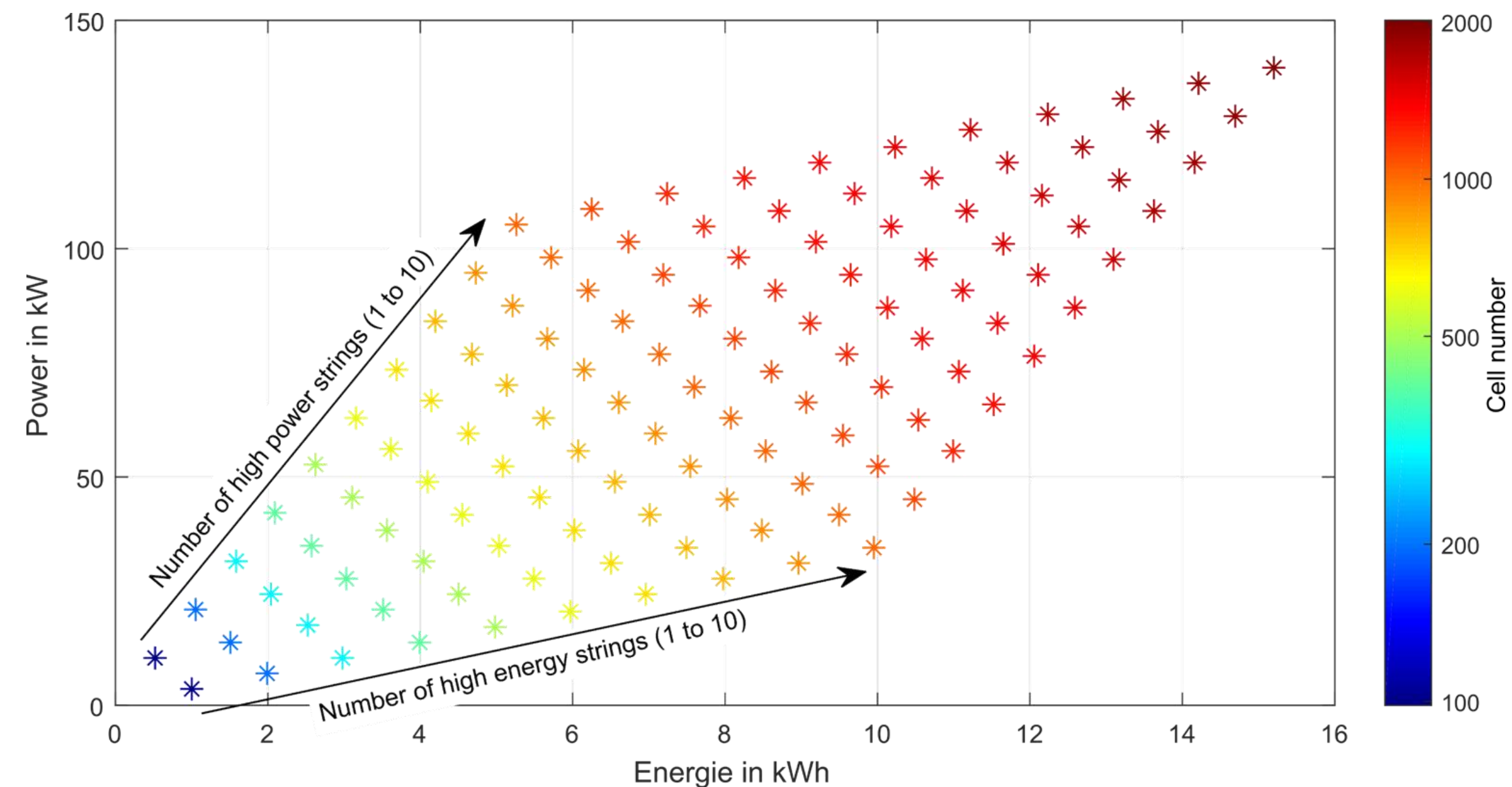
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Outline:

1. Motivation
2. Switching Circuits
3. Load Management
4. Dynamic Output Voltage
5. Serial Hybrid Energy Storage Systems

Motivation and Existing Problems

- Moderate level of Modularity and Scalability
- Active or Passive Cell Balancing due to unequal Cell Parameters
- Nonlinear Voltage Level which follows the Open-Circuit-Voltage (OCV)
- Suboptimal Power and Energy Ratio for many Applications
- Hybrid Energy Storage Systems (HESS) often need an expensive DC/DC converter





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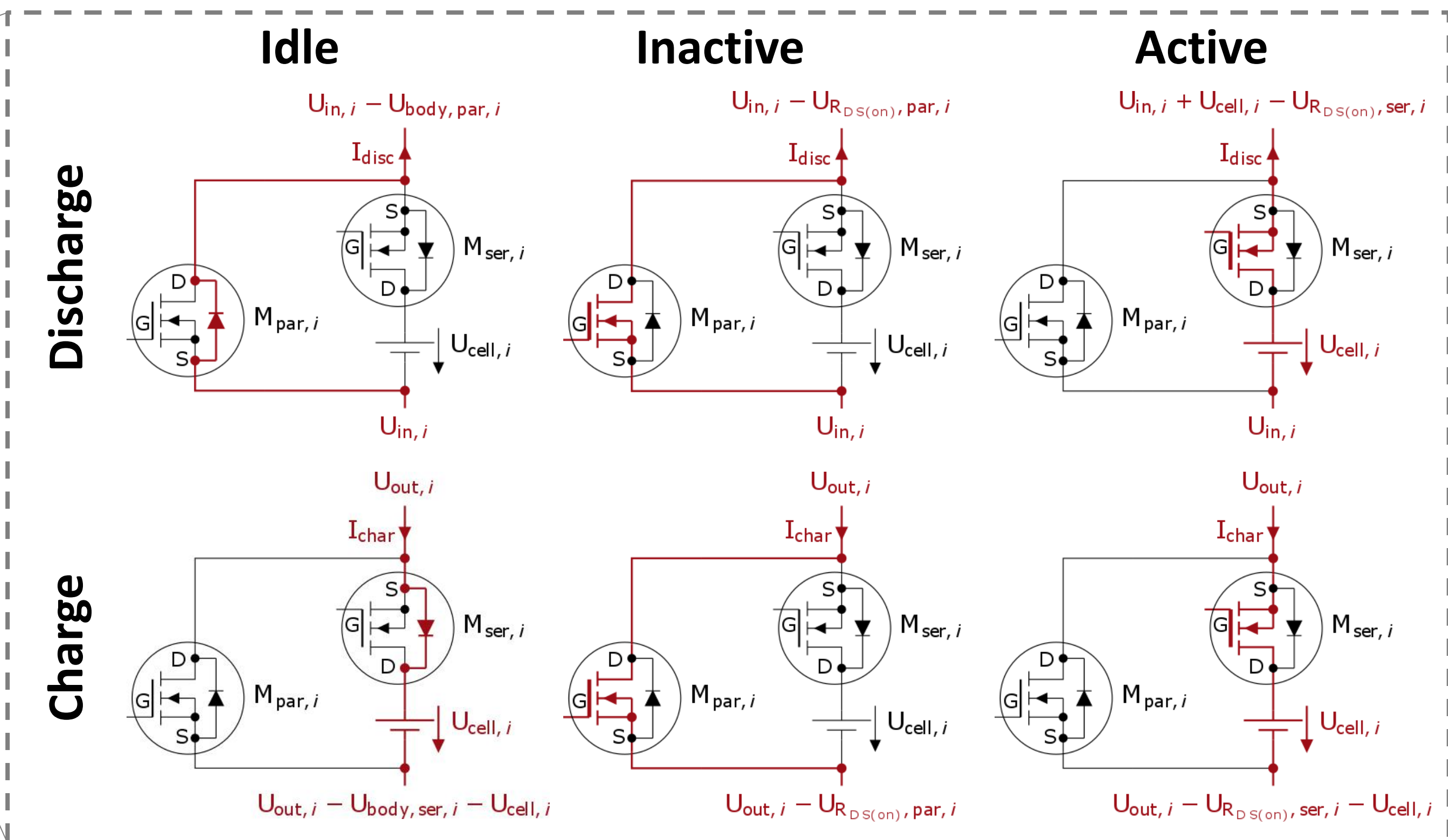
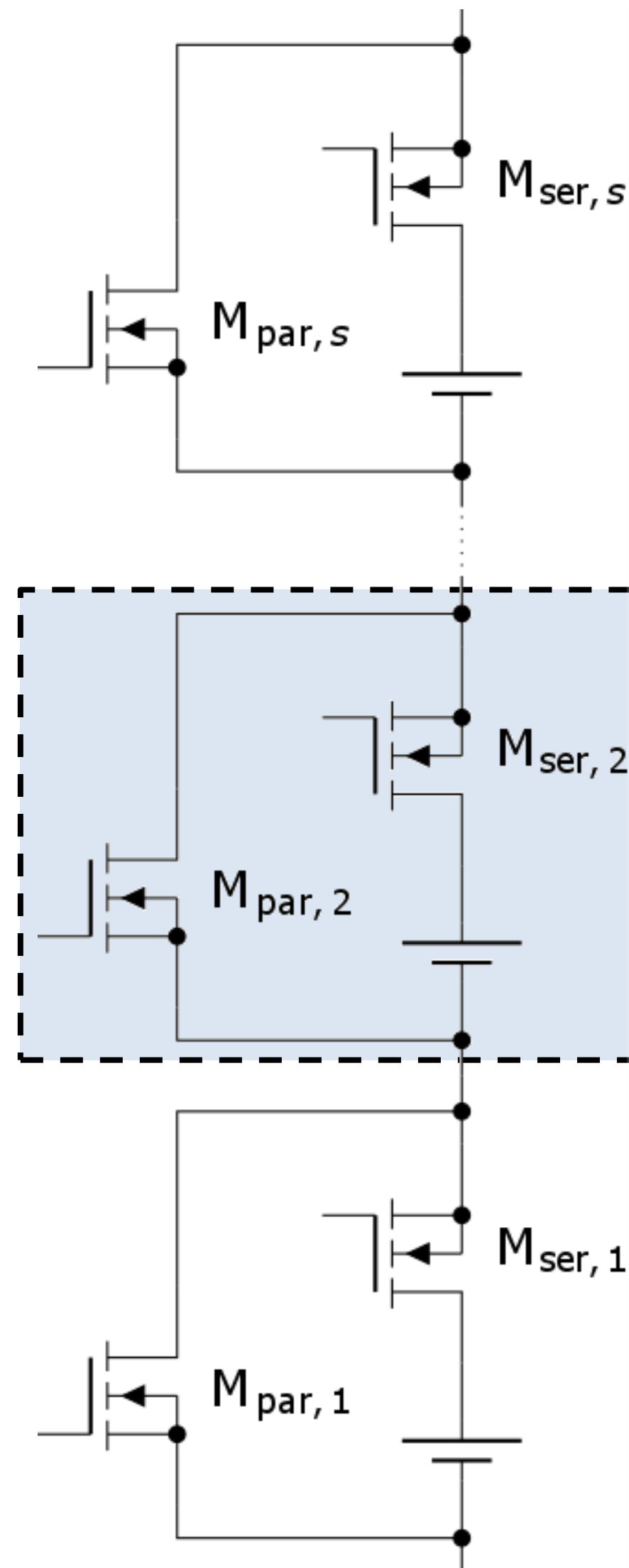
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Switching Circuits on Battery Cell Level

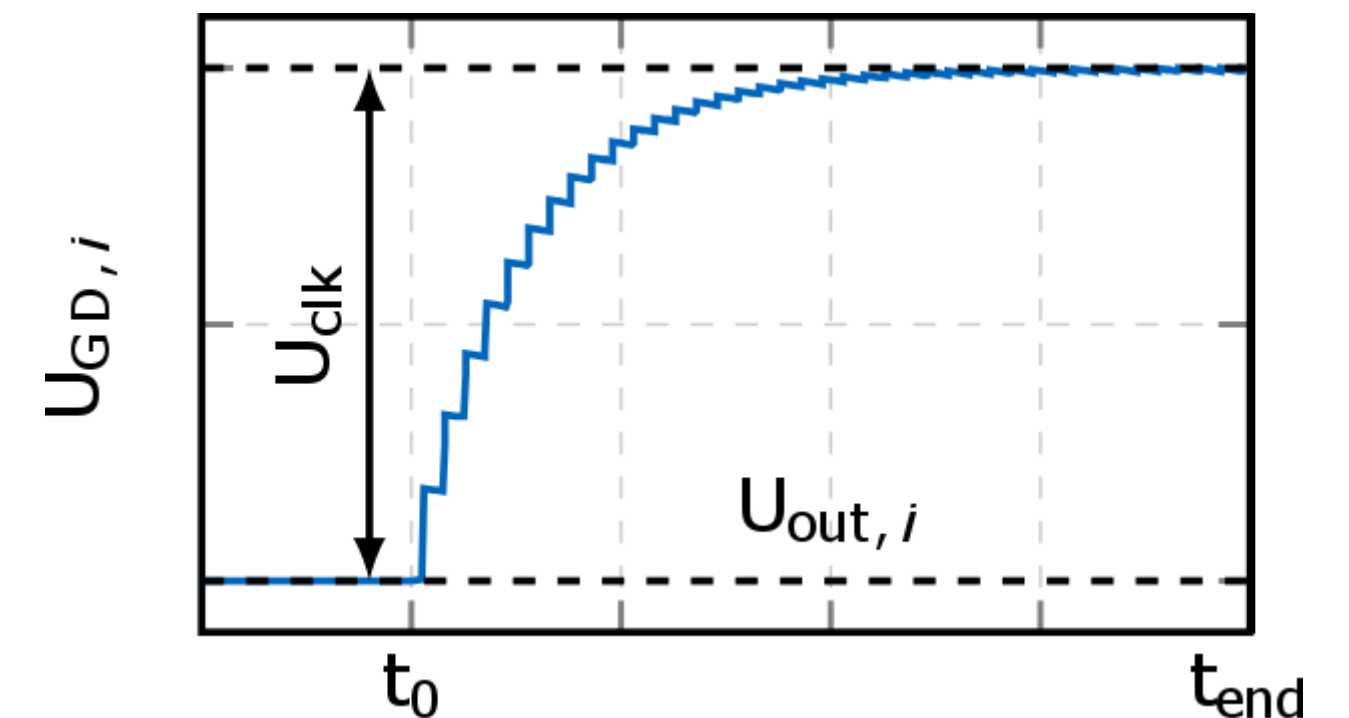
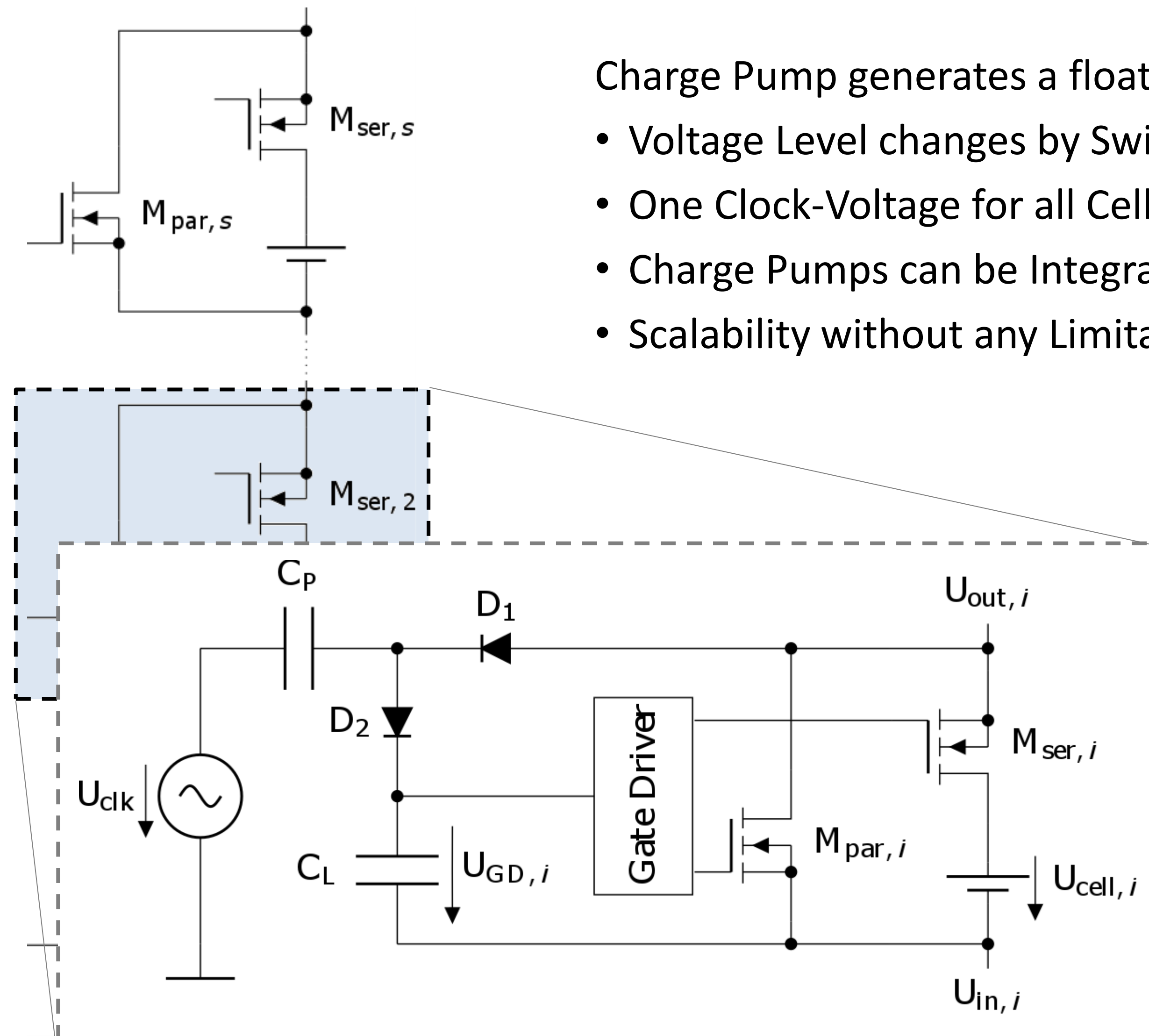
- Two Switches (MOSFETs) for each Cell
- Modularity and Scalability by using Charge Pumps
- Discrete States for each Cell-Stage:
Idle, Inactive, Active, Shorted (forbidden)



Realization of a single Cell-Stages

Charge Pump generates a floating Gate-Driver Potential:

- Voltage Level changes by Switching underlying Cell-Stages
- One Clock-Voltage for all Cell-Stages
- Charge Pumps can be Integrated on Chip easily
- Scalability without any Limitations



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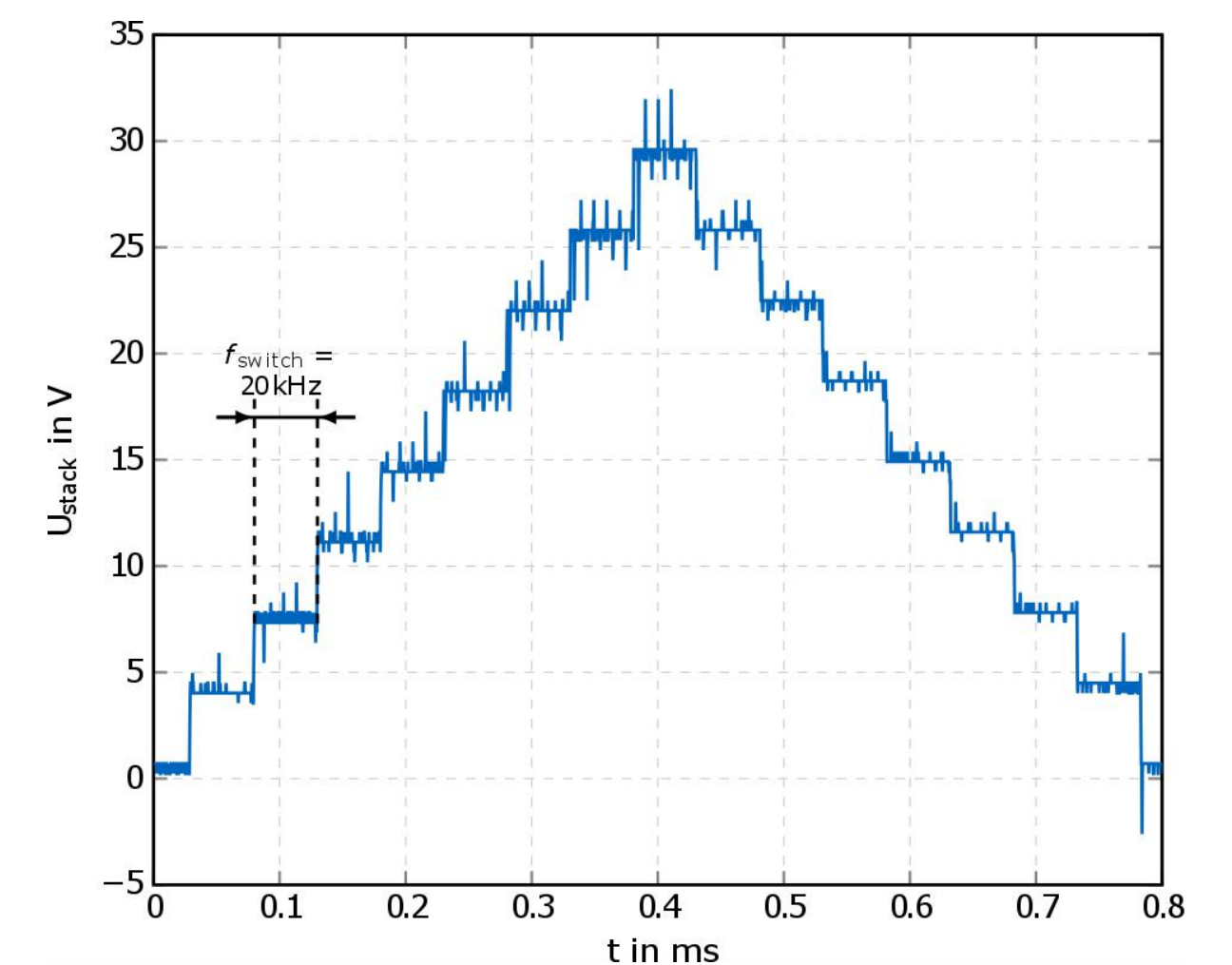
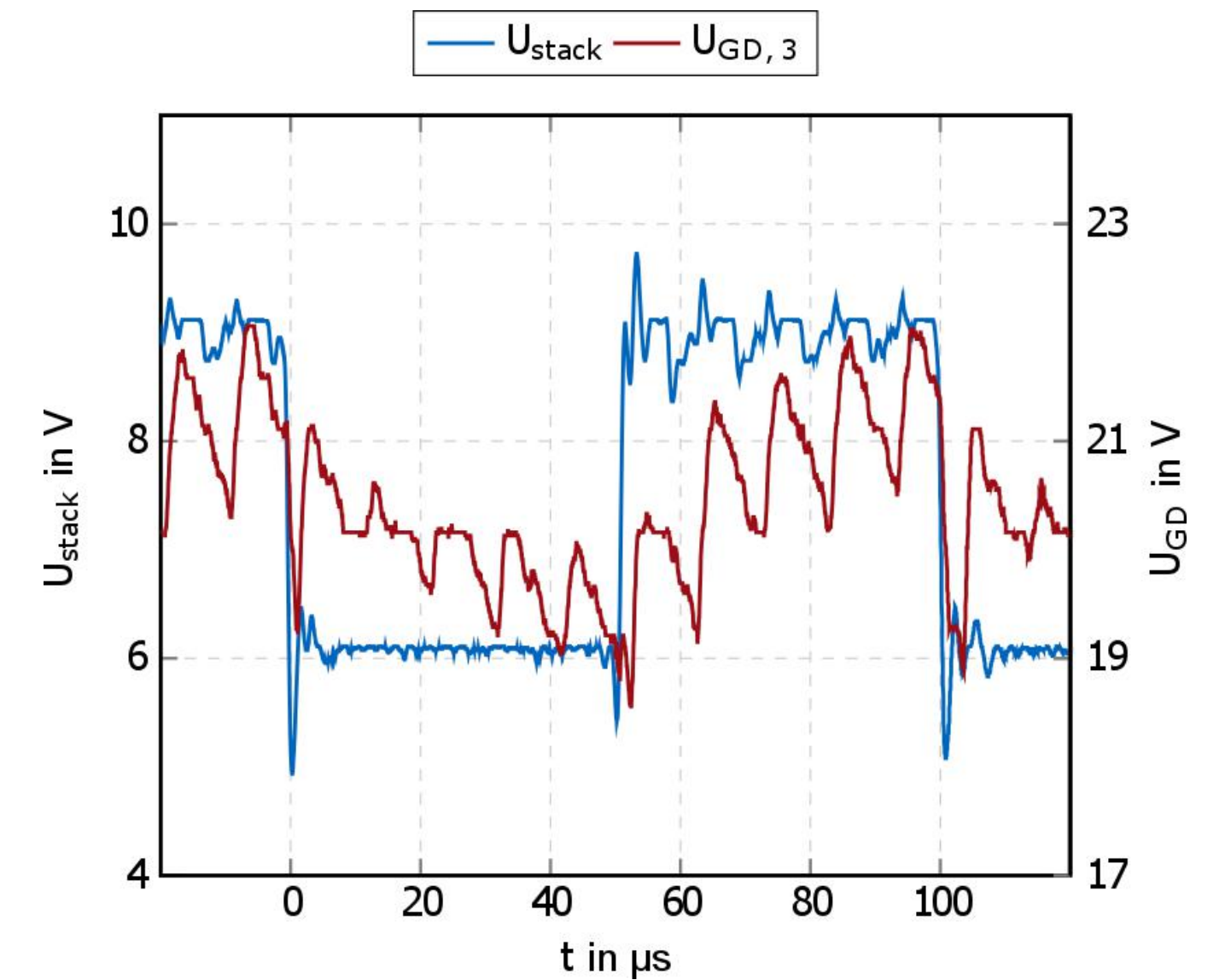
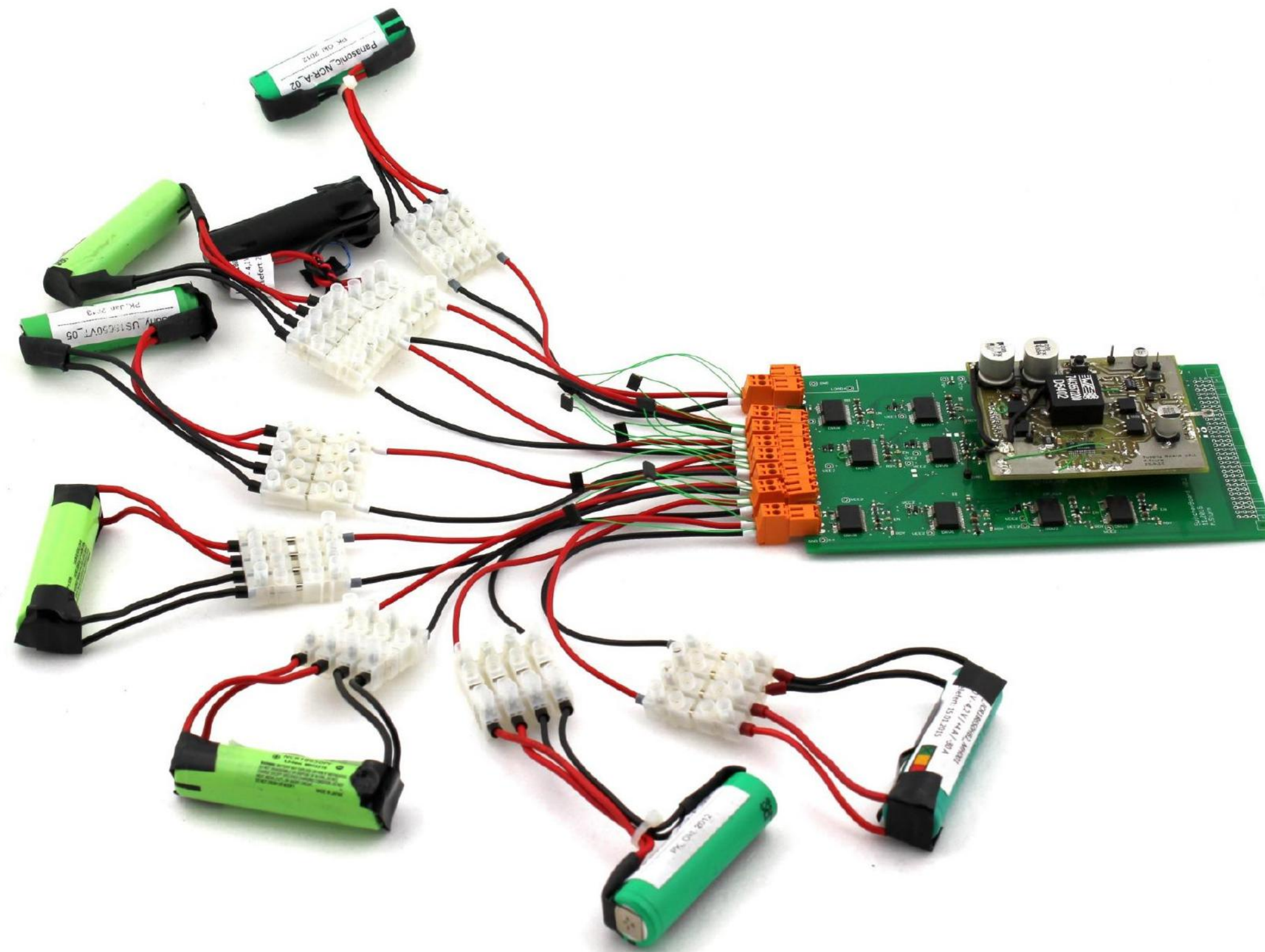
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Laboratory Prototype proves Concept and Load Management

Laboratory Prototype with up to eight Cell-Stages:

- Self-Sustaining Power Supply to generate Floating Potentials
- Possibility to activate/inactivate each Cell independently and in random Order



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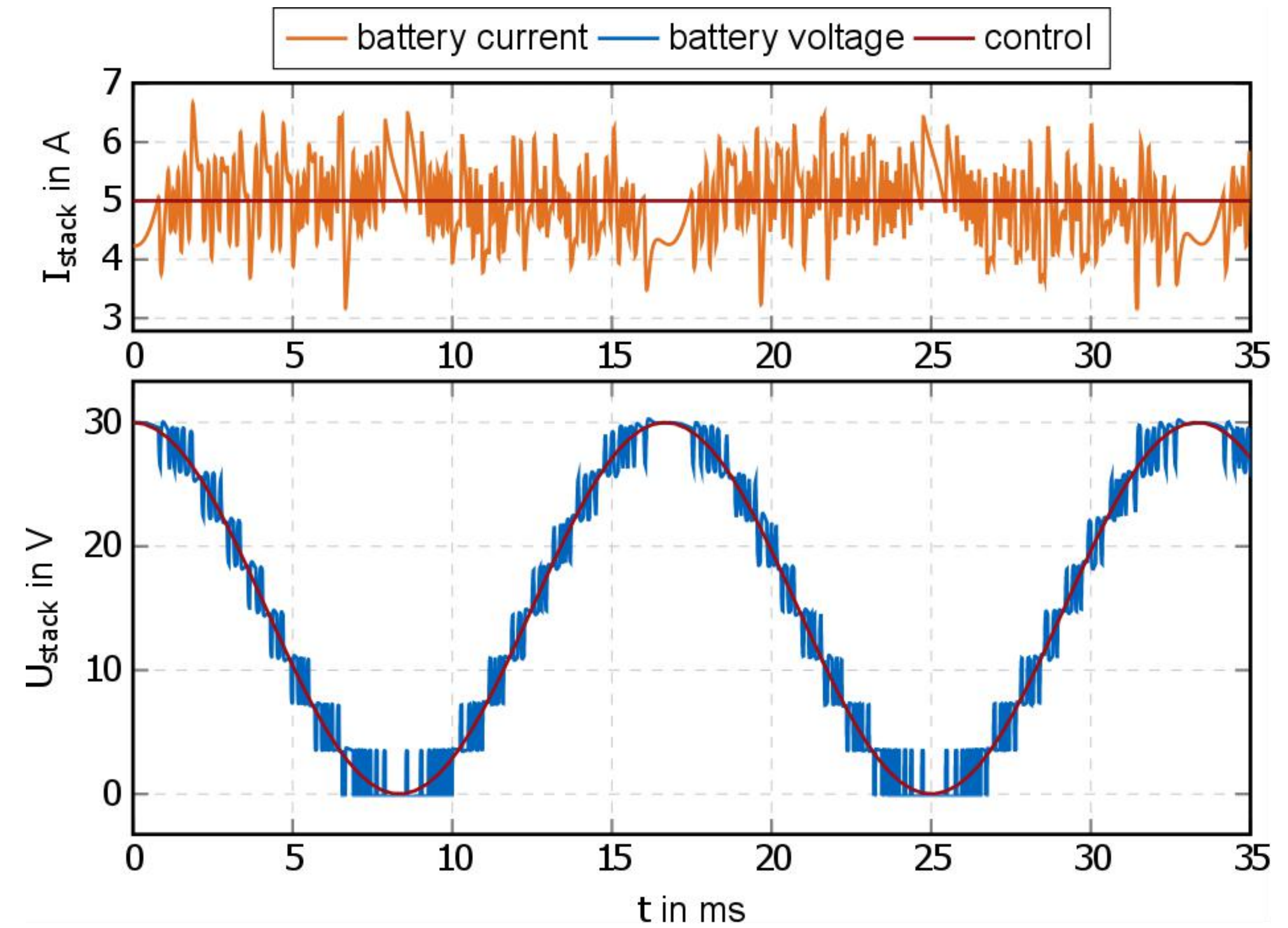
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Dynamic Output Voltages

Simulating eight Cell-Stages:

- Direct-Coupled to Grid (60 Hz)
- Voltage Level can be enlarged with the amount of Cell-Stages
- Negative Output Voltage possible with “Midpoint Tap”
- Combination of three DC/AC-Batteries to generate Three-Phase Sine-Waves
- Current or Voltage Control



Average Discharge Current $I_{\text{stack}} = 5 \text{ A}$

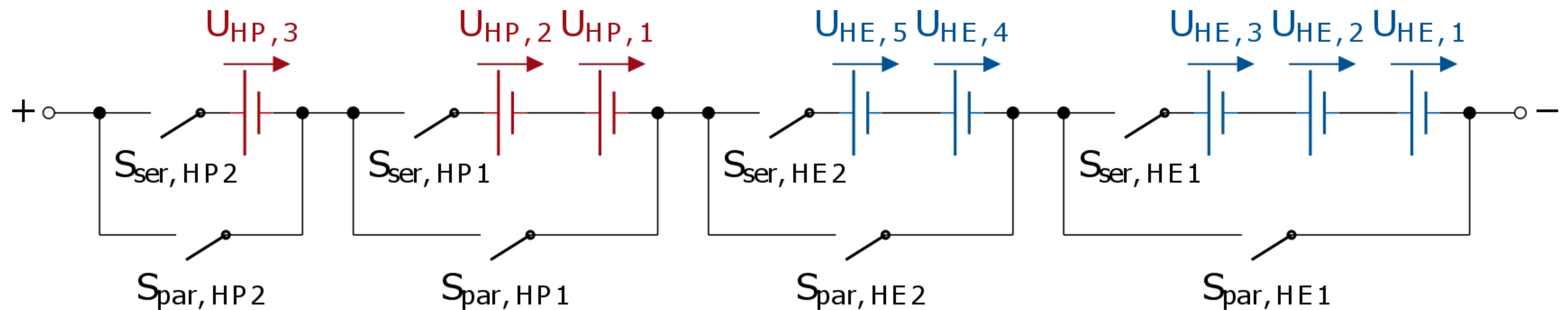
Maximum Switching Frequency $f_{\text{Switch}} = 20 \text{ kHz}$



Realizing Serial Hybrid Energy Storage Systems (sHESS)

Combination of different Cell Types High Power (HP) + High Energy (HE):

- Full utilisation due to independent Load Management
- Precisely tailored Battery Packs (HP/HE-Ratio)
 - HE-Part operates as Base-Load Supply
 - HP-Part operates as Booster or Peak-Load Supply
- Cluster of several serial Batteries to minimise amount of Switches



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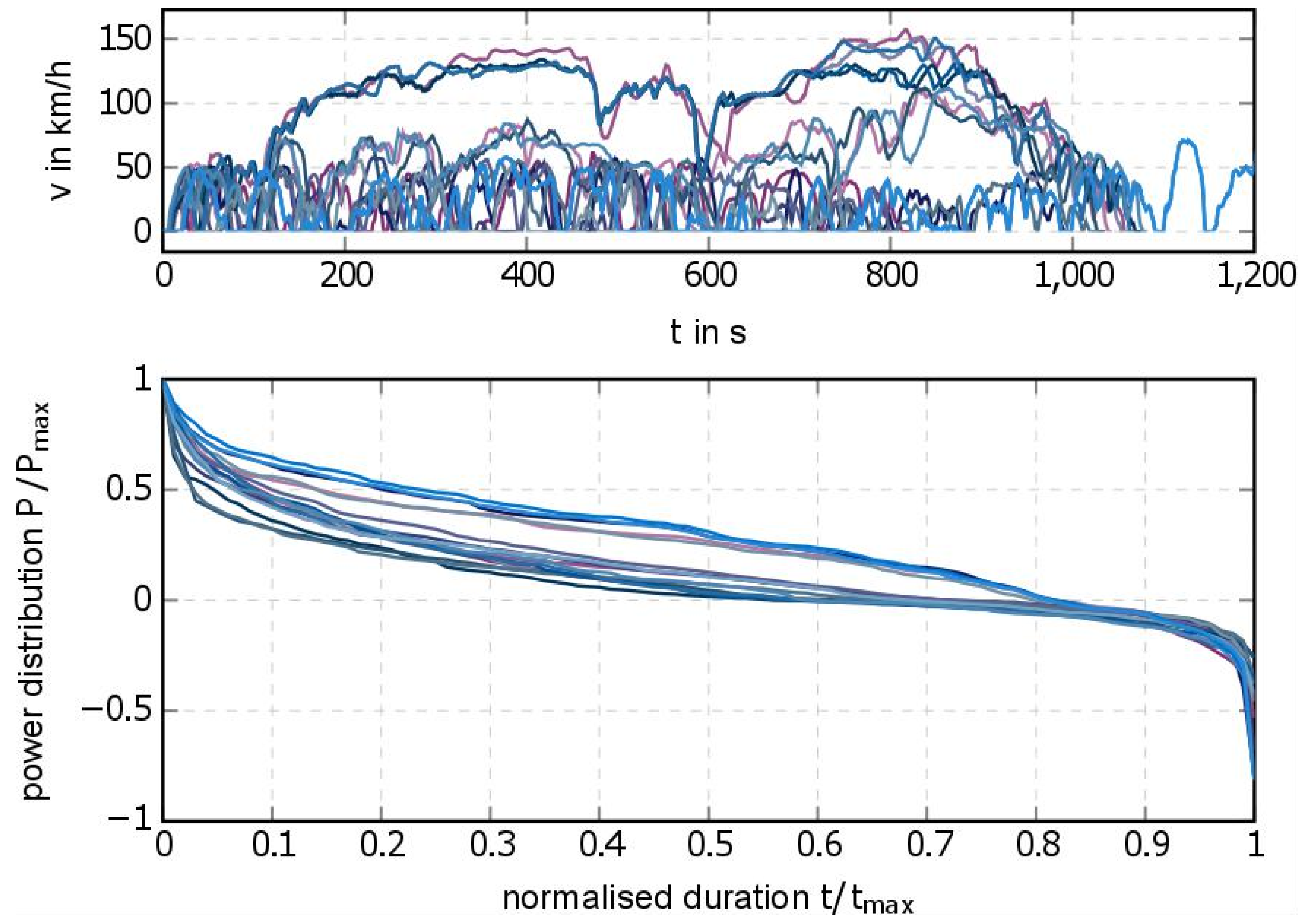
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Analyzing standardized Driving Cycles to extract the Average Load Duration Curve

Analysing 149 standardised Driving Cycles:

- Calculate Load Profile with a common EV Modell
- Normalise Power and Time (without standstill)
- Rearrange in descending order to get the Load Duration Curve
- Building the Average of all 149 Load Duration Curves

ARTEMIS Driving Cycles (17 out of 149)

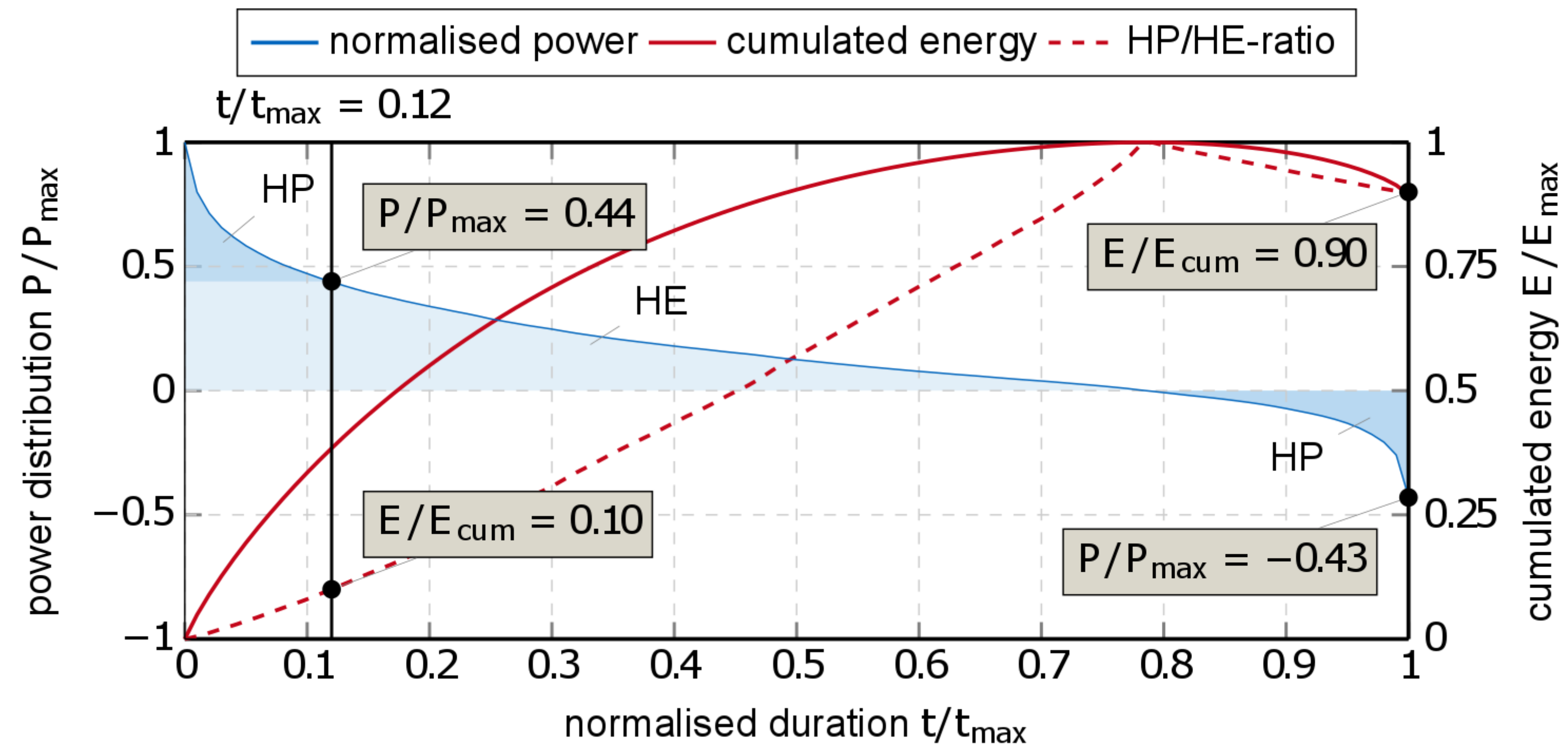




Optimal Dimensioning of Electrical Energy Storage Systems for EVs

Exemplarily the High-Power (HP) part is used to fully utilise the Recuperation:

- 10 % of Total Energy E_{cum} can be Recuperated at a Peak Charging Power of 43 % P_{max}
- This amount of Energy is equal to the Discharge Power above 44 % P_{max}
- Around 90 % of the time the necessary Power is below 50 % P_{max}



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Simulation Results of a “Peak Shaving” Strategy

8s3p High Energy (HE) with Panasonic NCR18650PB

4s1p High Power (HP) with LG ICR18650HB2

- Equal Current Capabilities

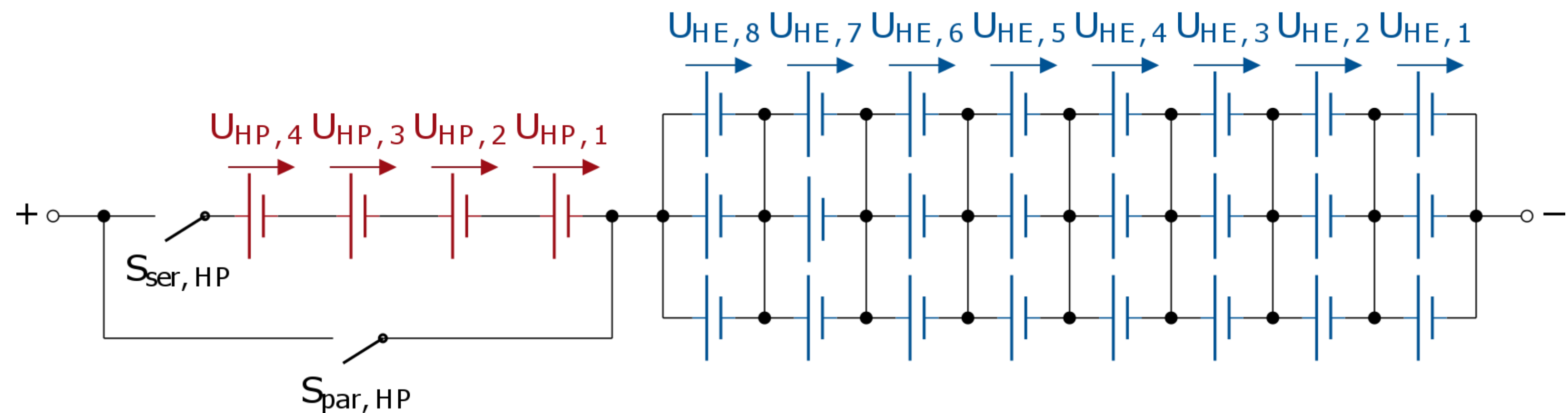
$$1p \text{ HE: } I_{\text{disc}} = 10 \text{ A} \quad I_{\text{char}} = 1.365 \text{ A}$$

$$1p \text{ HP: } I_{\text{disc}} = 30 \text{ A} \quad I_{\text{char}} = 4 \text{ A}$$

- 5.8 × higher Capacity and 11 × higher Energy

$$8s3p \text{ HE: } C_N = 2.88 \text{ Ah} \quad E_{\text{sum}} = 249 \text{ Wh}$$

$$4s1p \text{ HP: } C_N = 1.50 \text{ Ah} \quad E_{\text{sum}} = 22 \text{ Wh}$$



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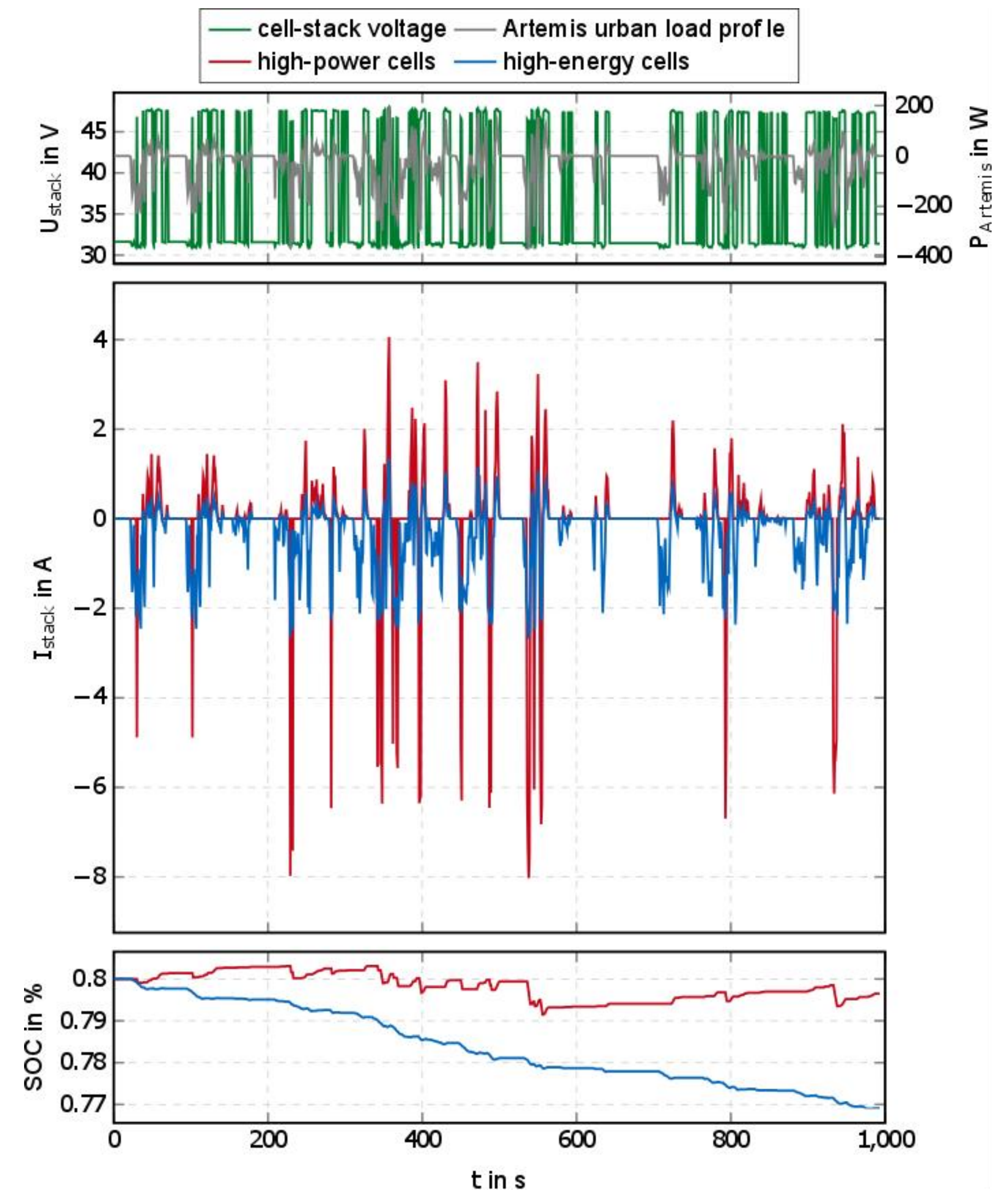
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- HP-part as additional “Boost” during Acceleration and Recuperation
- Higher Battery Voltage results in Lower Current for constant Power. Thus reducing stress for the HE-part
- State-of-Charge (SOC) for the HP-part keeps roughly the same



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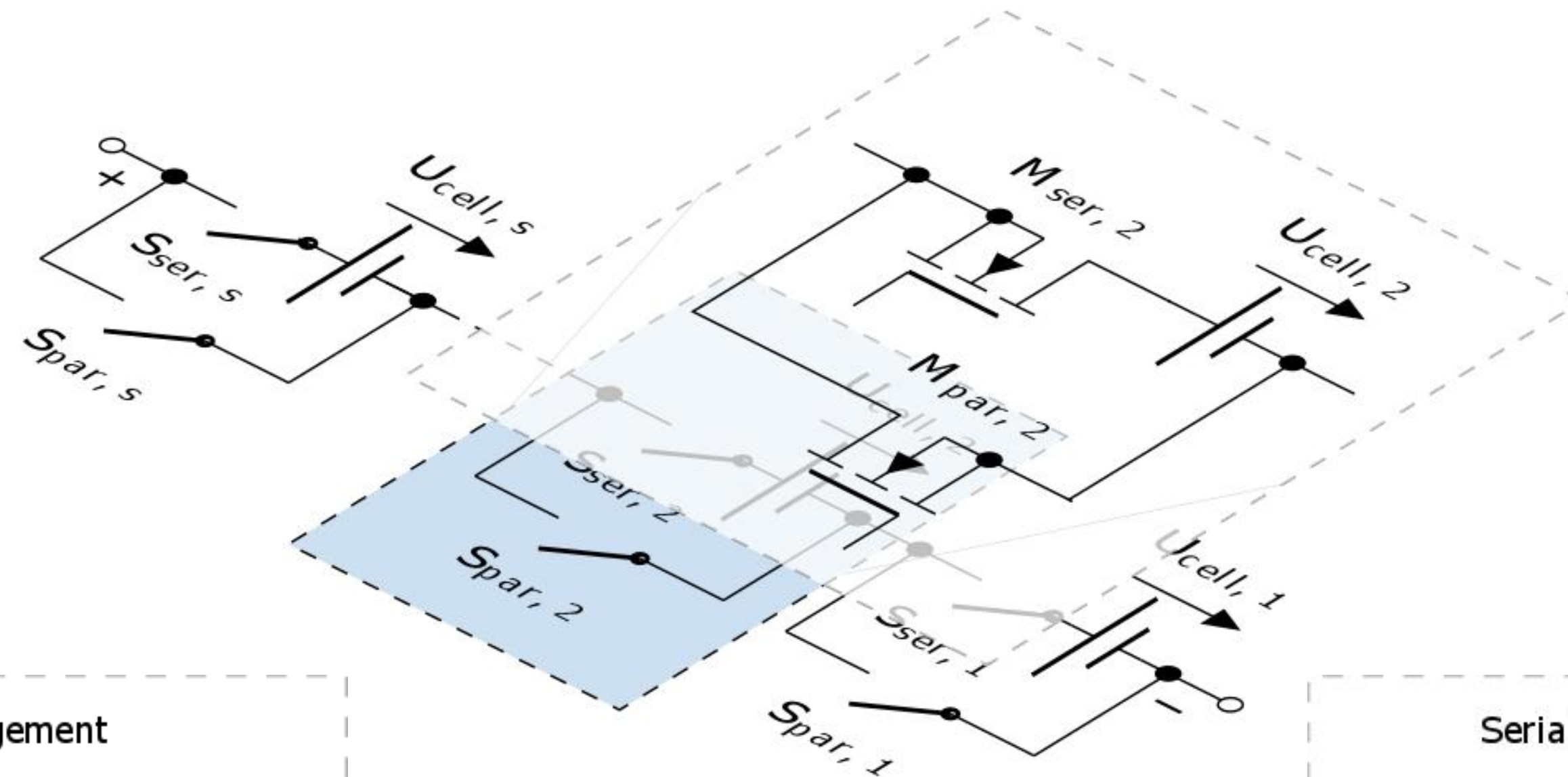
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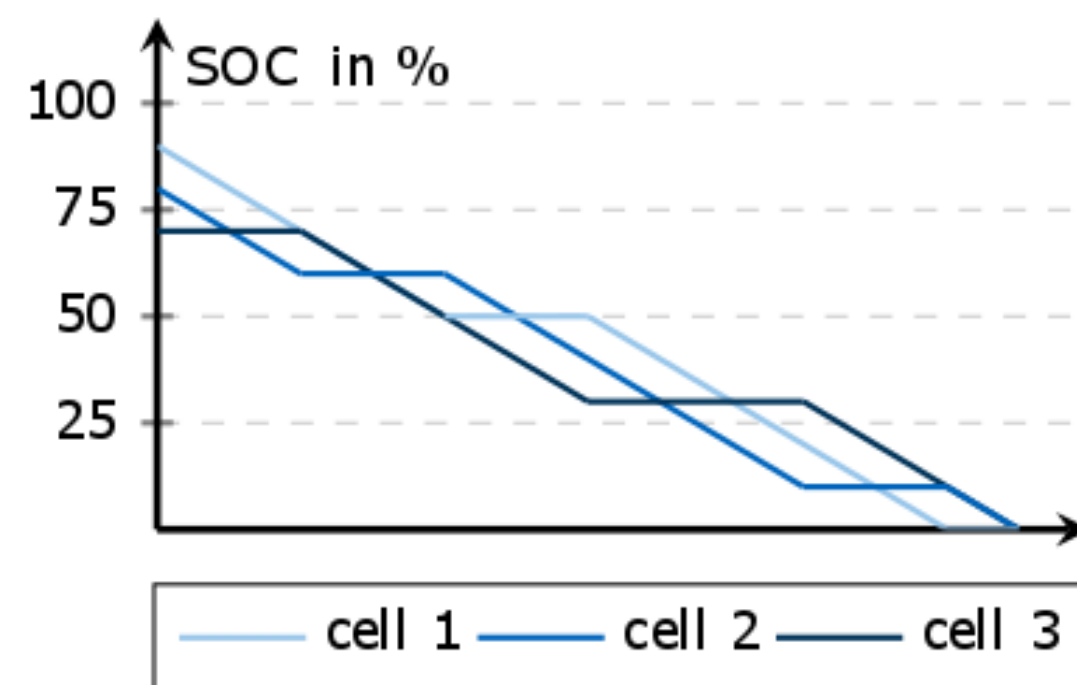
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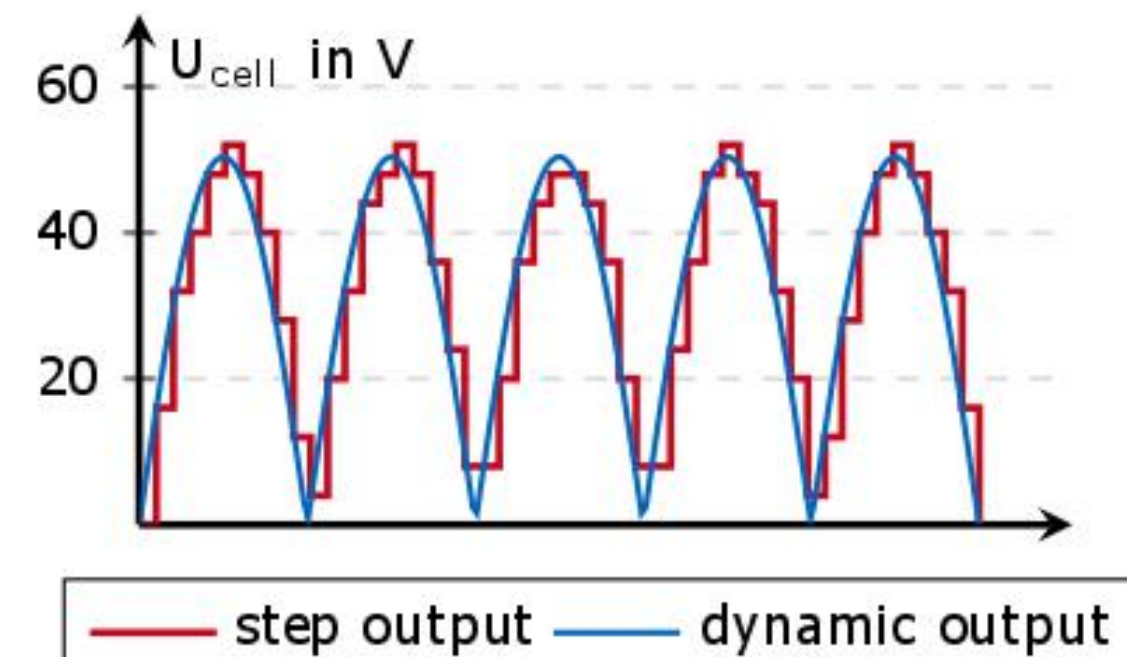
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Load Management



Dynamic Output Voltage



Serial Hybrid el. Energy Storage

