



Supercapacitor Integration In EV Powertrains

Power Electronics & Energy Storage Event
Eindhoven, 27 June 2023

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**POWER
ELECTRONICS**

Power Electronics & Energy Storage event
27 juni 2023 | 1931 Congrescentrum 's-Hertogenbosch

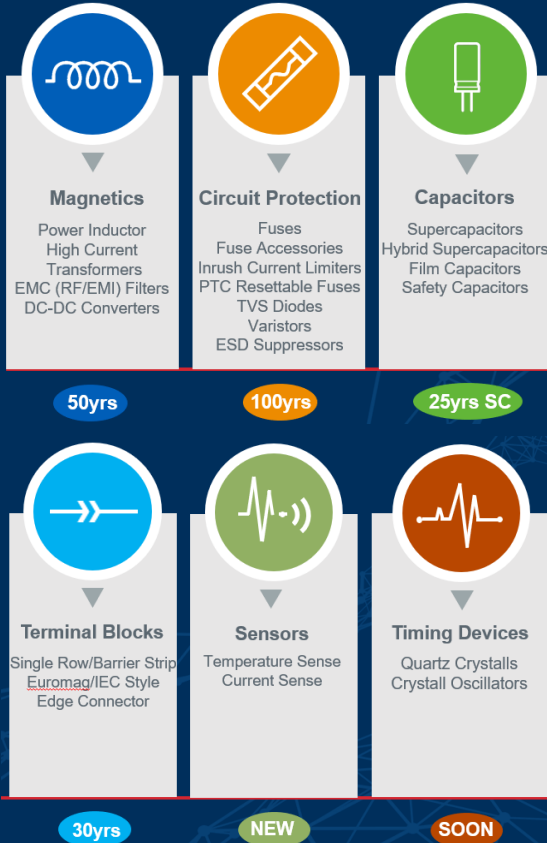
ENERGY STORAGE

1. Supercaps vehicle applications
 - The Ragone Plot
 - Scale of Economy
2. Supercap for hybrid combustion engine
 - Why electrification?
 - Example: Hybrid-CE Excavator
3. Supercap for H2 fuel cell drive
 - Why Energy Storage in FC?
 - Example: 15kW FC drive



Eaton Electronics at a glance

Components for power management



AstrolKWX at a glance

Solutions for DC power electronics challenges

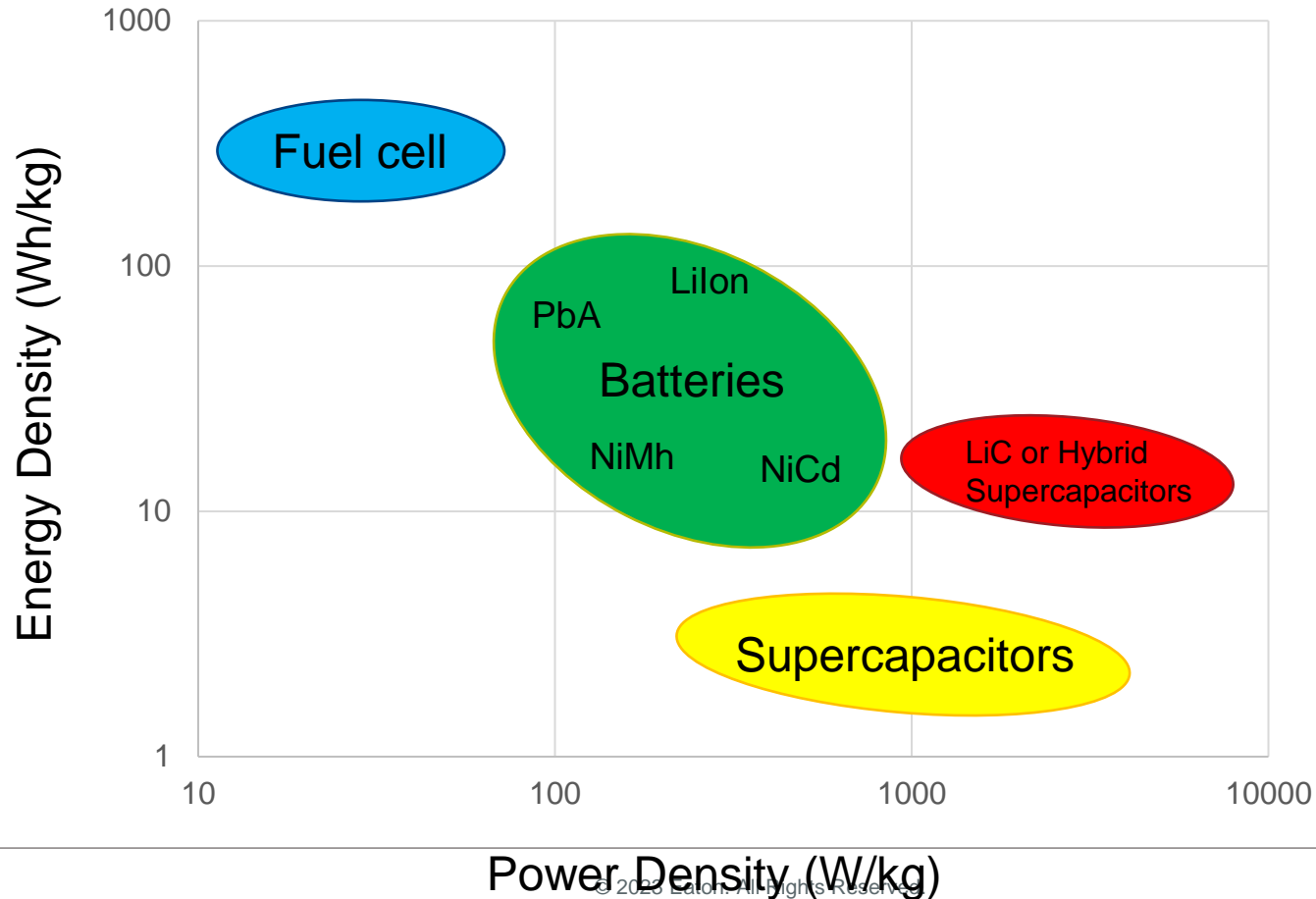
Astrolkwx provides power electronics solutions and supplies A-brand PE components. Our electrotechnical knowledge, application knowledge and support from the brands we represent enable us to advise our customers and provide the best possible solution for any specific application. In addition to standard catalogue products from top suppliers, our strength is in co-creating customer specific solutions. With an extensive range of components for direct and alternating voltage, Astrolkwx provides solutions for power electronics related challenges. We specialize in co-creating customer specific solutions that find their application in DC networks

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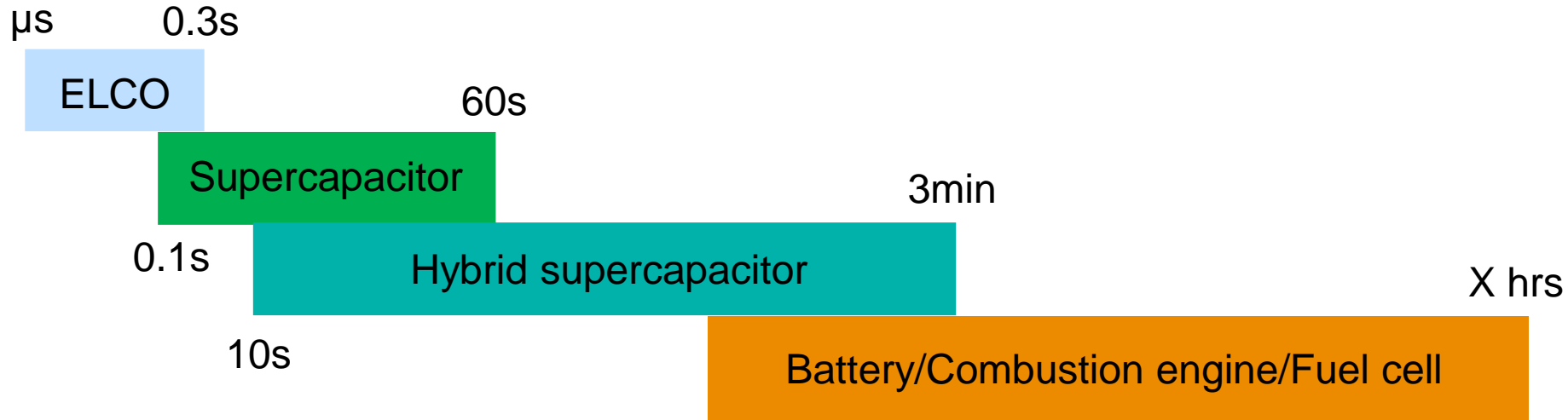
astrolkwx
power electronics solutions

1. Supercaps in Vehicle Applications

Eaton ELX Products On The Ragone-Plot



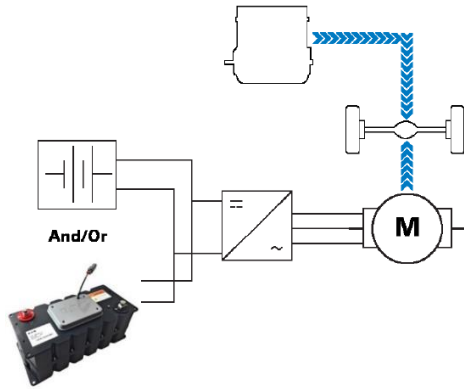
Energy Storage On The Scale Of Economy



The optimal solution depends on: 2min

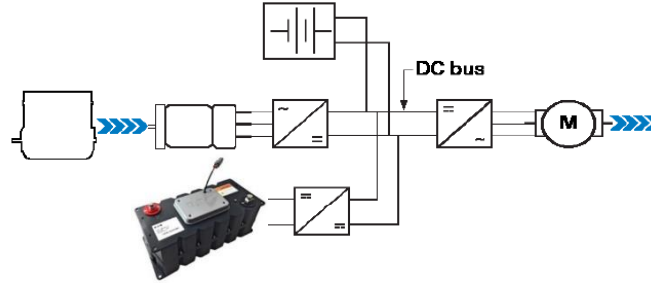
- Duty cycle of charge/discharge
- Number of cycles
- Ambient temperature level
- Discharge current
- Lifetime requirements

Electrified Hybrid Vehicle Powertrain Topologies



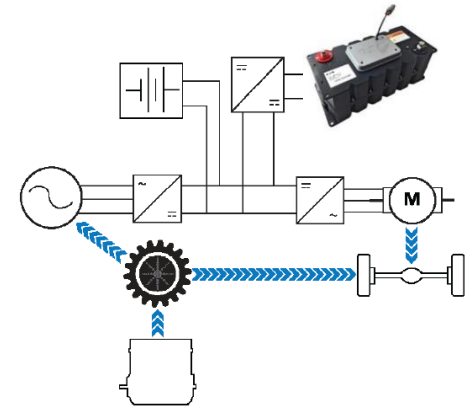
Parallel Hybrid

- 48V normally
- 10-50kW charge/discharge
- Allows combustion engine downsizing
- Fuel efficiency improvement of cca 20%



Series Hybrid (PHEV)

- 400V-800V normally
- 100+kW electric covering part of the drivecycle
- Allows combustion engine downsizing significantly
- Supercap supports battery current shaving (20-30%) to extend range (5-10%) and improve battery life



Power Split Hybrid (full hybrid)

- 400V-800V normally
- 100+kW electric covering part of the drivecycle
- Normally used for passenger cars
- Very complex

Economically Beneficial SC Integrations

1. Combustion engine series hybrids:

- Wheel loaders
- Crushers
- Mining equipments
- Offshore building vessels



2. Fuel cell drives:

- Boats
- HD trucks
- LD trucks/delivery vehicles



2. Combustion engine hybrid example

Motivation For Electrification

- Higher efficiency than hydraulic systems
- Better control on the load side using electric motors
- Less maintenance
- Cleaner solution
- Change for load leveling and energy regeneration

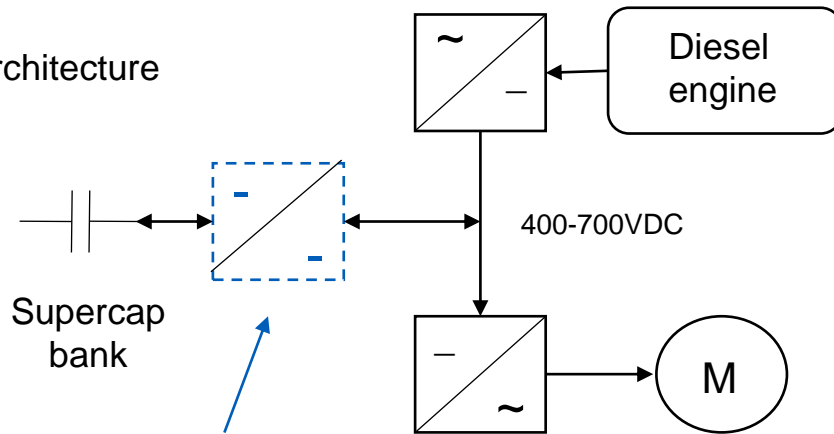
- 25-30% combustion engine downsizing
- 30% fuel efficiency improvement
- xx% SOx, NOx reduction
- Much longer engine lifetime!!!! (normally 2yrs per major maintenance otherwise)

IT
always
SEEMS
IMPOSSIBLE
until IT'S
DONE!

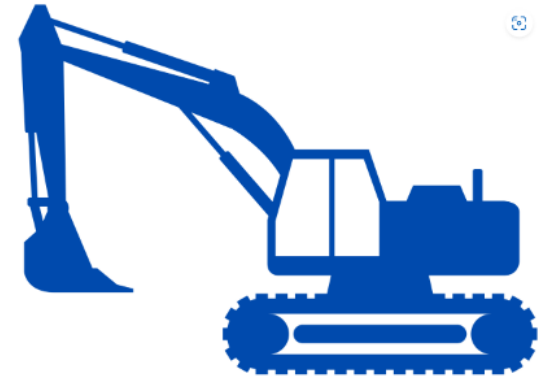
Example: Diesel-Hybrid Excavator

- **Example:** hybrid diesel excavator
 - Engine: 250kW max – goal to downsize to 200kW
 - Powetrain DC-rail: 650V nominal
 - Peak shaving as per load fluctuations using supercapacitors

DC peak shaving Architecture

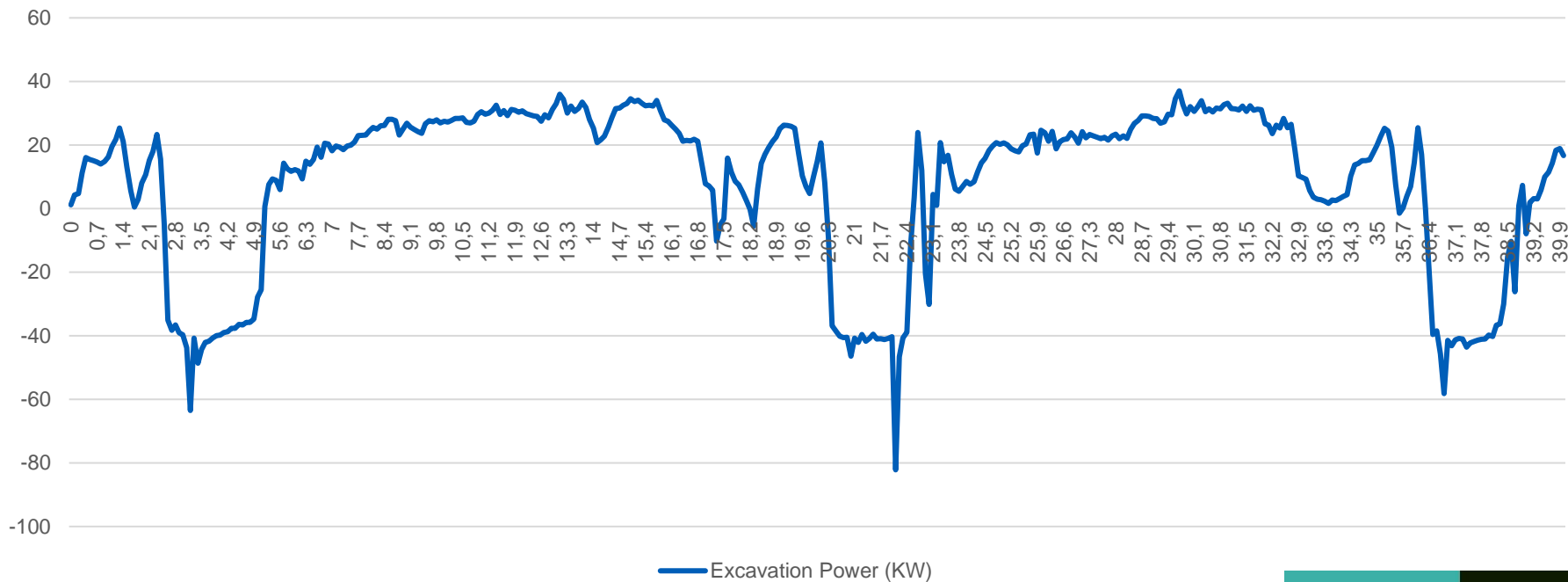


Optional DC/DC converter



Example: Diesel-Hybrid Excavator

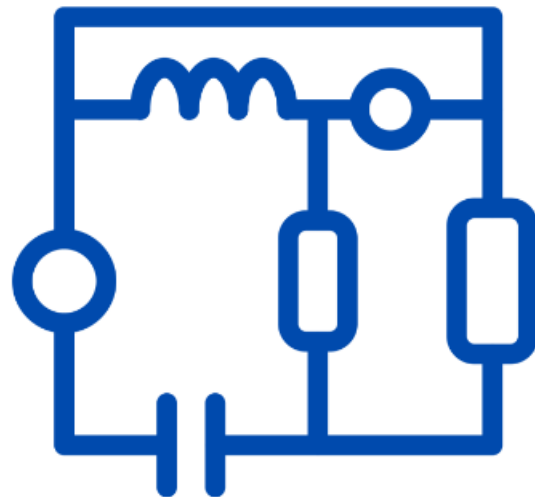
Excavation Power (KW)



Example: Diesel-Hybrid Excavator

Supercap sizing considerations:

- Design lifetime: 10yrs min without maintenance
- Ambient temperature up to +45C => internal temp rise +5C => max allowed supercap temp rise +15C = +65C max supercap temperature
- Ruggedized construction
- Agency certificates preferred: ECE UN R10/R100, UL, CE

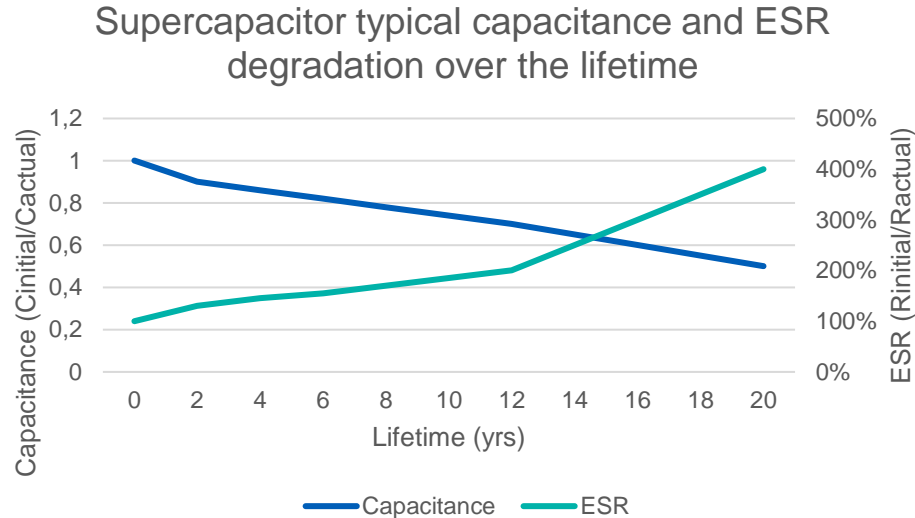


Set The Right Level Of Degradation Over The Lifetime

Supercaps are losing capacitance and elevating ESR during the lifetime. The capacitance needs to be oversized by a certain level of degradation.

Typical degradation allowed per application:

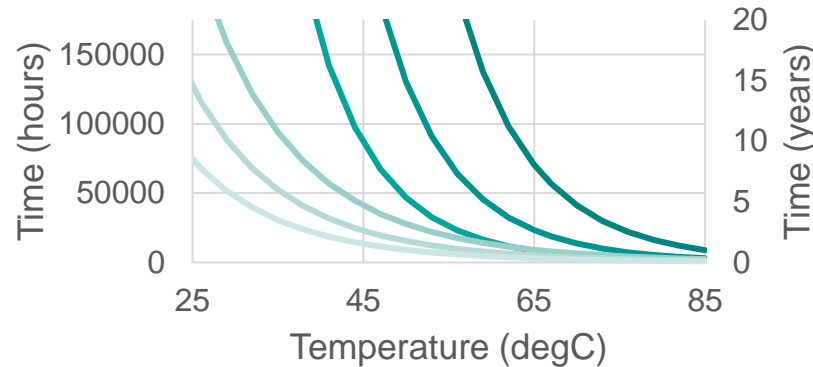
- 20% cap & 1.7xESR – safety critical applications, UPS, medical, aerospace
- 30% cap & 2x ESR – industrial grade applications in general
- 50% cap & 3-4x ESR – automotive or long life and harsh environment applications



Select The Right Charge Voltage Per Cell

Each capacitor type degrades at a different speed - Exceeding the rated voltage and temperature will result in **rapid** degradation

1. Set the max charge voltage according to your application temperature profile
2. Recommended to consult with manufacturer to advise the proper voltage per capacitor as per the allowed degradation level
3. If the application allows (electric vehicles, AGVs etc.) during non-operating times discharge the capacitors...or just not keep it at full charge



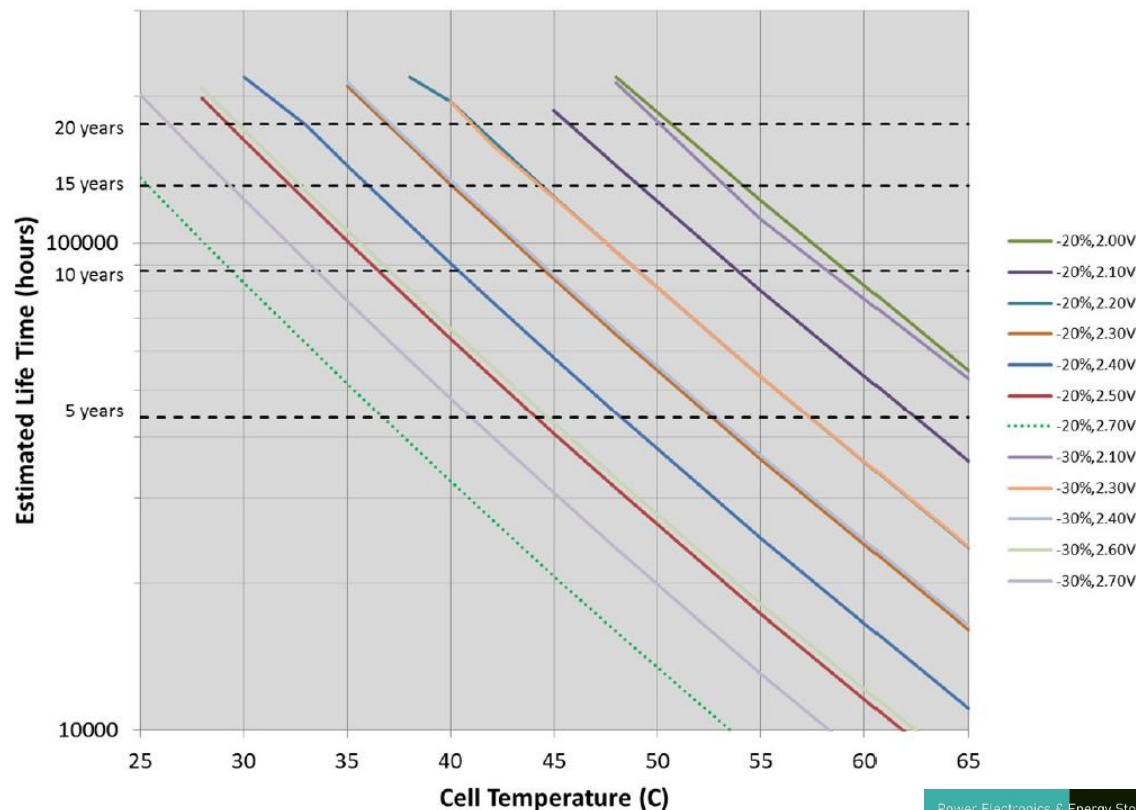
— TV 2.30V — TV 2.50V — TV 2.70V
— HV 2.30V — HV 2.50V — HV 2.70V

Example: Diesel-Hybrid excavator

The supercap sizing for heavy duty cycle vehicles is mostly based on **thermal consideration**

Supercaps lifetime is highly dependant on:

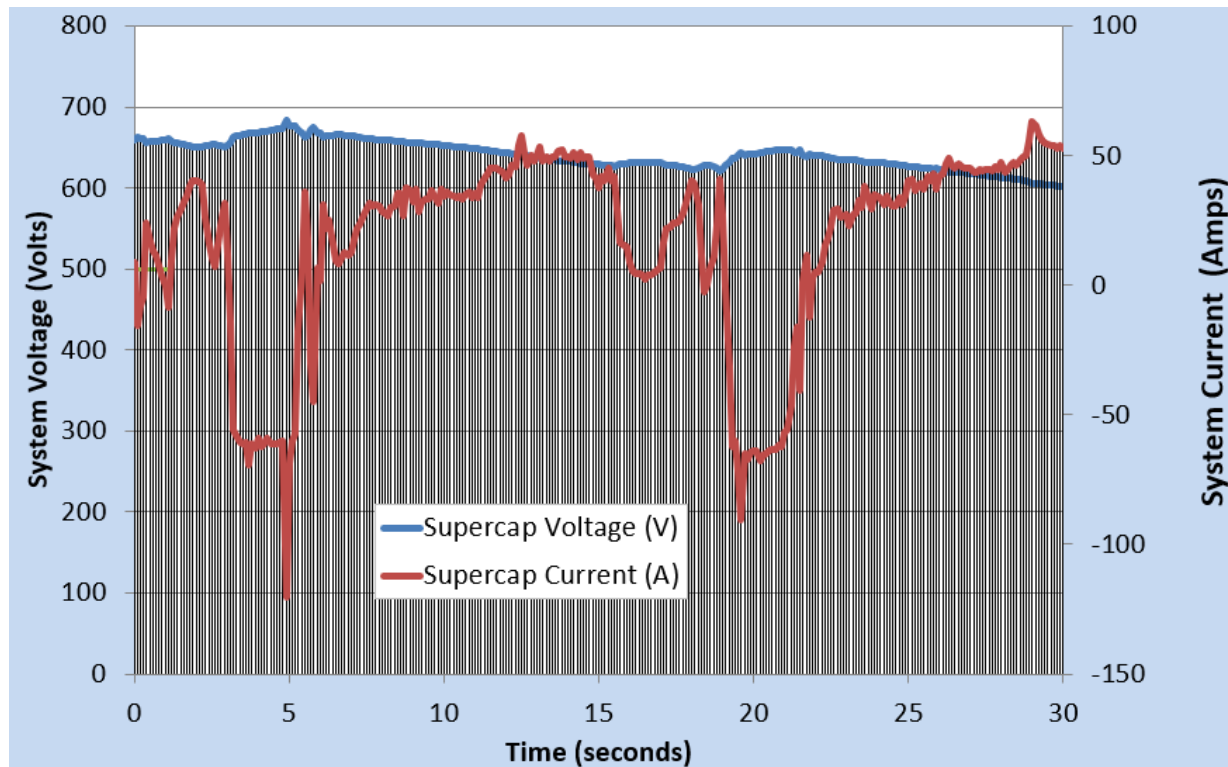
- Ambient temperature – appropriate sizing for **parallel strings/low ESR cells**
- Charge voltage – setting the number of **modules in series** as per DC-rail



Example: Diesel-Hybrid Excavator

Sizing result:

- 15pcs series connected 51V rated supercap modules
- $C = 12.5F$ new/ $10F$ EOL
- $ESR = 75m\Omega/150m\Omega$ EOL
- $I_{rms} = 40A$
- $Trise = 3.5^{\circ}C/7^{\circ}C$ EOL
- Total mas = 225kg
- Total volume = ~250L
- Peak power = 1.9MW



3. H2 fuel cell example

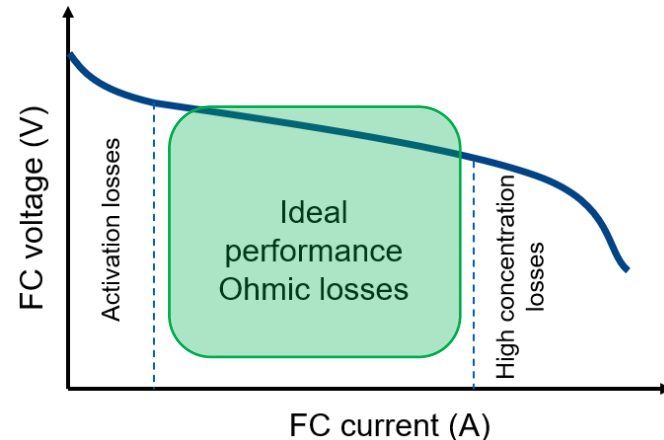
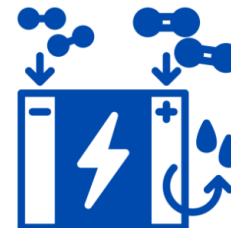
Necessity for supercapacitor/battery in FC drive

1. Fuel cell lifetime improvement:

1. Lifetime is very dependent on load fluctuations => energy storage is a must for load balancing
2. FC membrane is extremely sensitive for air pollution => periodic short circuiting helps to clear pores (x00ms per every x0 seconds => energy storage to provide load backup)

2. Fuel cell performance improvement:

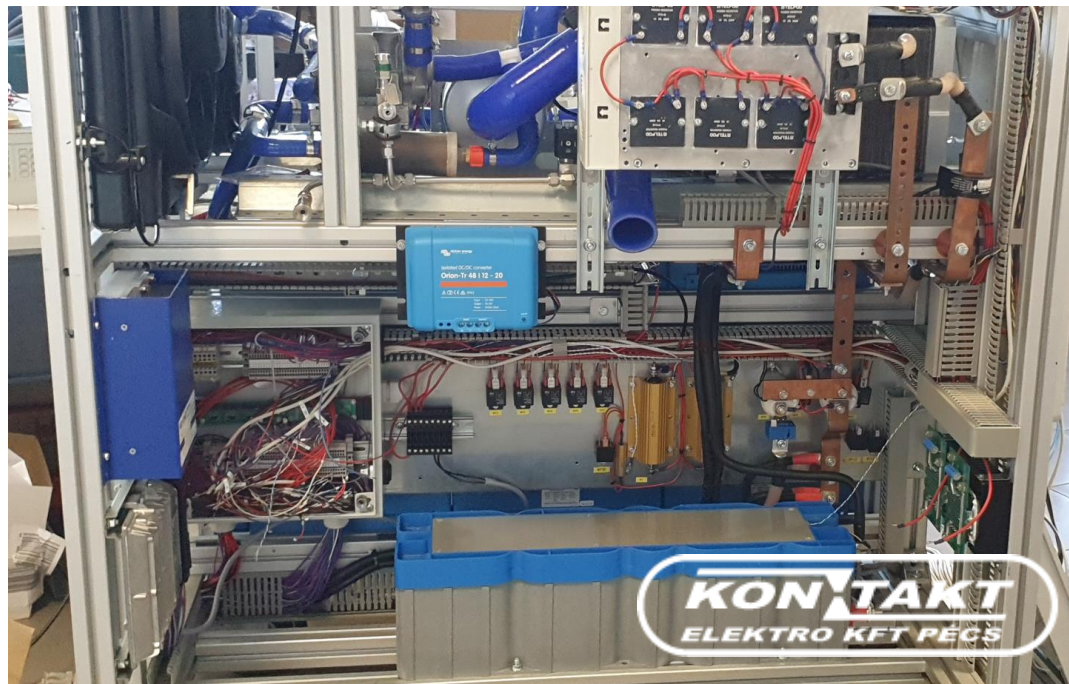
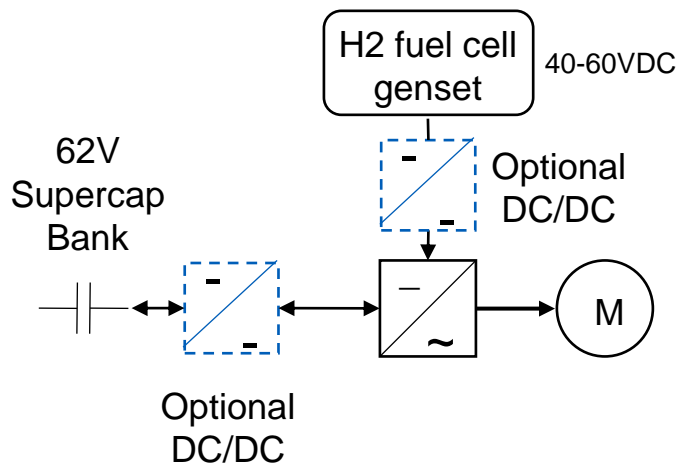
1. **Startup:** fuel cells startup takes time 30-60s, not ready instantly, but supercap can help to speed it up
2. **Energy absorption:** supercap is being charged. It's a must, very critical for safety and lifetime of fuel cell
3. **Power boost:** rapid changes in power can only be followed by an external boost source = supercap or battery



Example – H2 FC Engine

- Fuel cell engine:
 - 15kW max power
 - 60V max output voltage
 - 1kW/s max load fluctuation

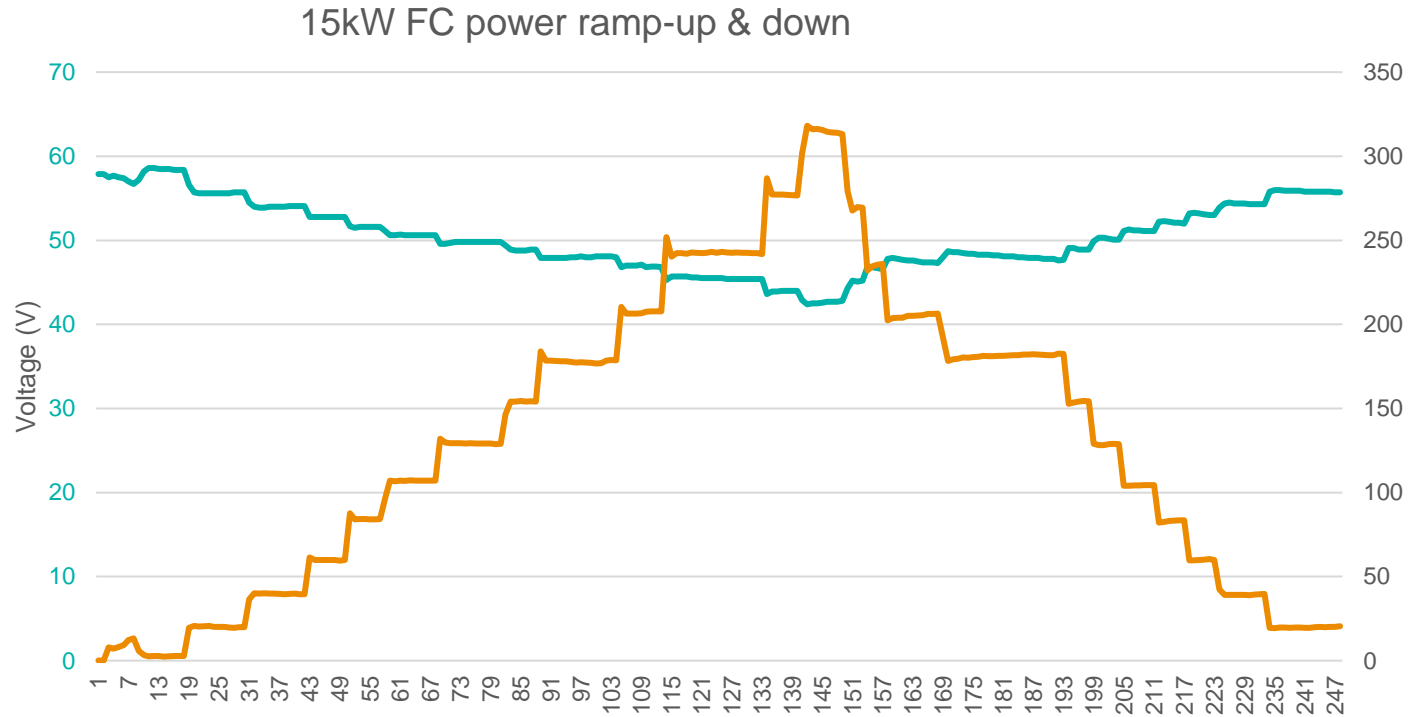
DC peak shaving Architecture



Courtesy of Kontakt-Elektro Kft.

Example – H2 FC Engine

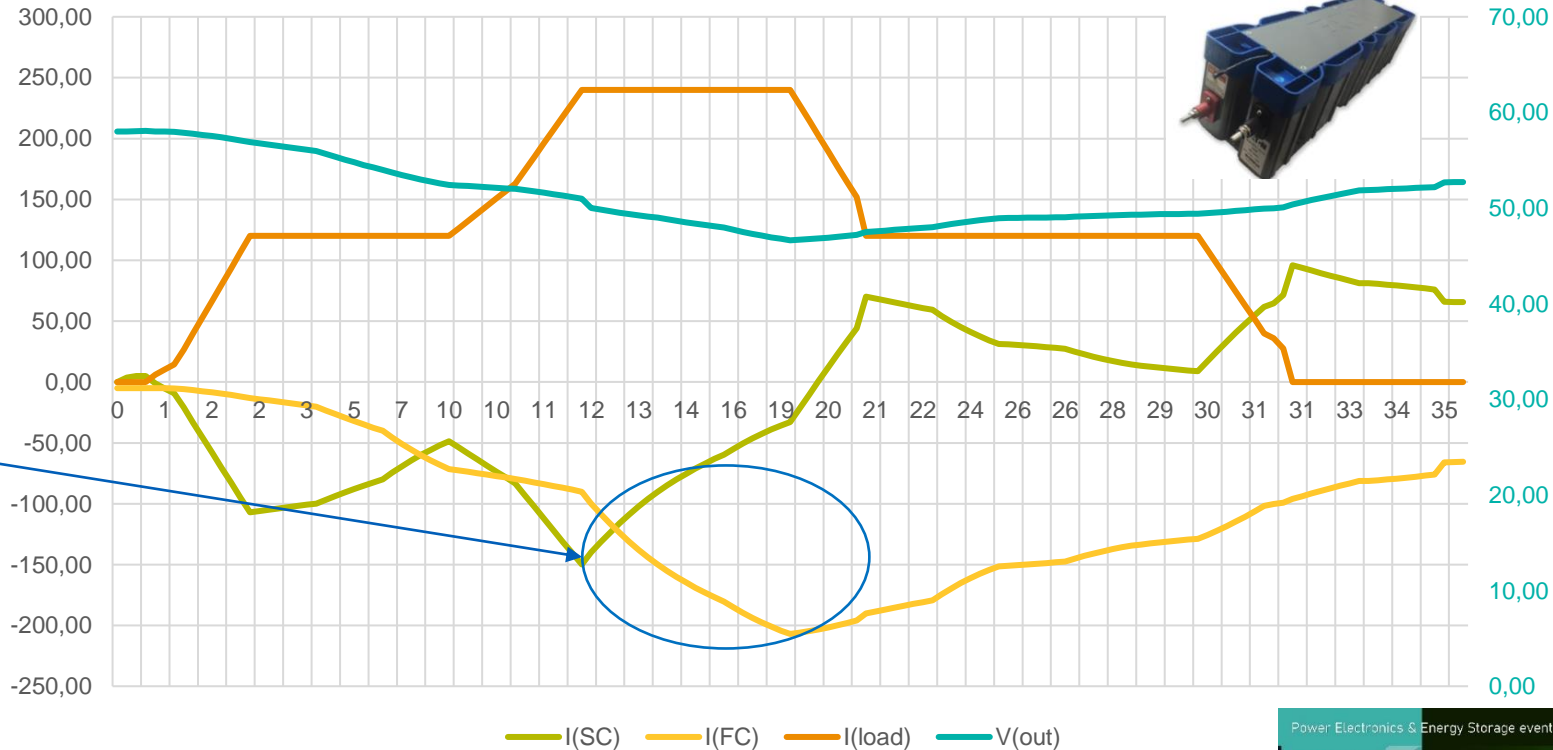
- 1kW/s ramp-up & down rate respected
- Limited performance for load changes especially for vehicles



FC+SC Direct Parallel Connection

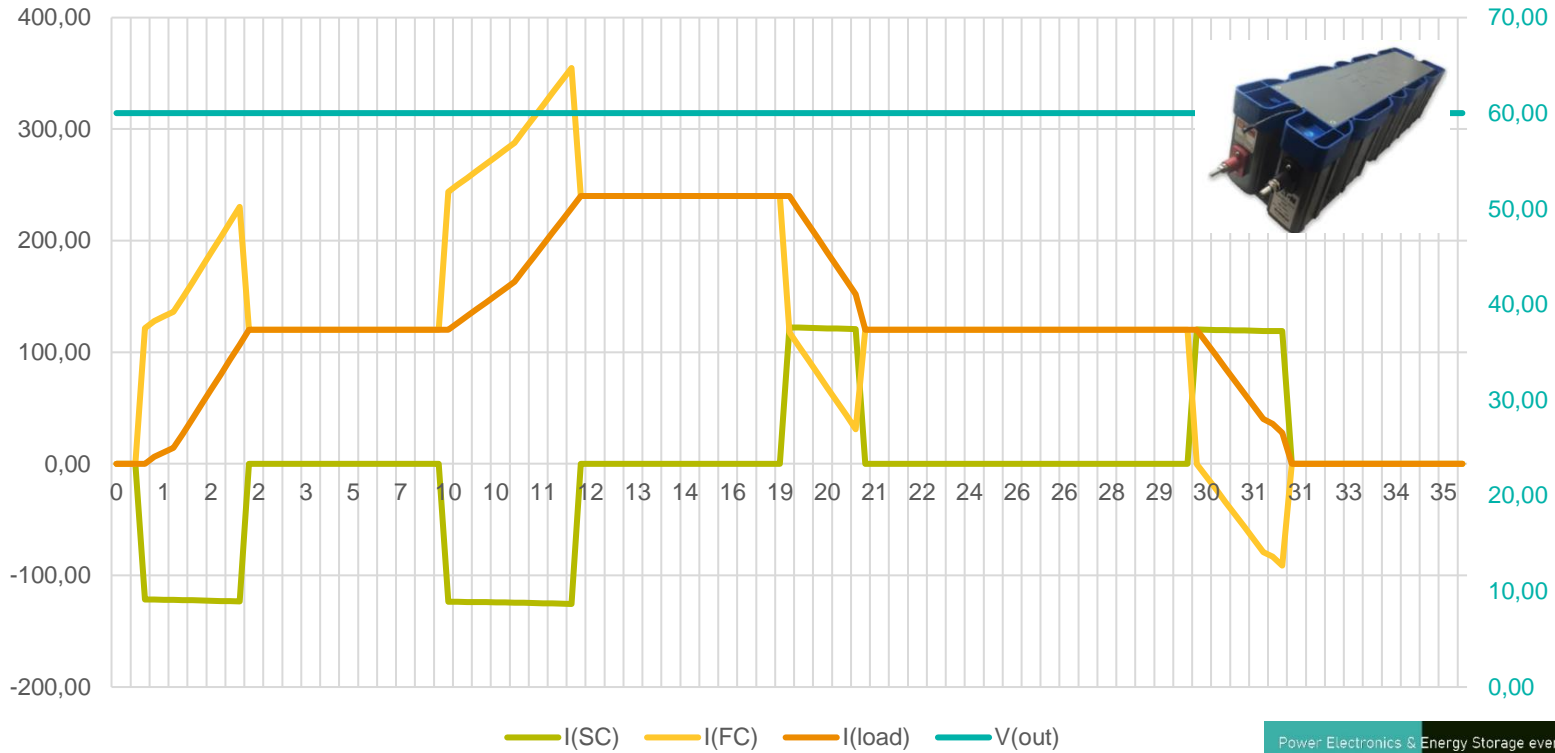
- Straight forward installation
- The FC ramp rate is difficult to control in case the supercap is being discharged too deep
- 130F/62V rated Eaton XLM module connected

0-8-15-8-0kW load on a FC + SC direct parallel drive



FC+SC Connected Through DC/DC Converters

0-8-15-8-0kW load on a FC + SC supplying a 60VDC rail



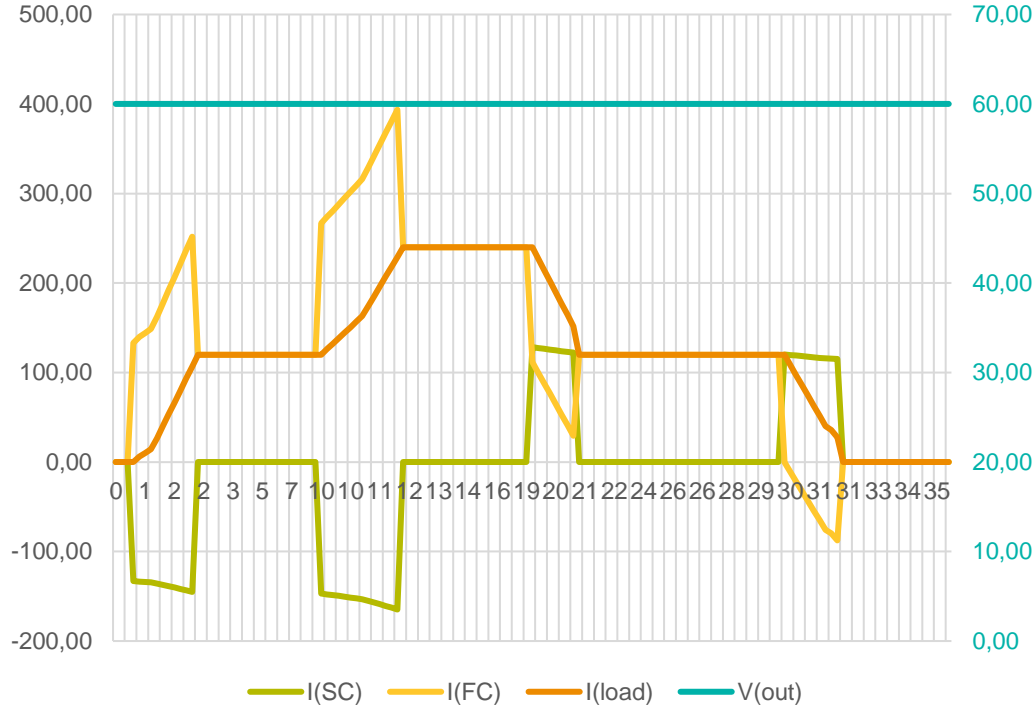
- Need two additional DC/DC (one unidirectional and one bidirectional)
- 130F/62V rated Eaton XLM module connected

FC+SC Connected Through DC/DC Converters

- Need two additional DC/DC (one unidirectional and one bidirectional)
- Optimized supercapacitor size 4sx2p XVM 16V modules (50% size reduction)



0-8-15-8-0kW load on a FC + SC supplying a 60VDC rail



Takeaways

- **Combustion engine Hybridization for Heavy duty vehicles:**
 1. Makes absolutely sense from commercial and technical
 2. supercapacitor sizing for lifetime evaluation focus by thermals
- **H2 Fuel Cell drives:**
 1. mind the load/drive cycle
 2. Direct parallel works with oversized supercap/battery pack, but no DC/DC necessary
 3. Supercap size optimization by using DC/DC converters significantly may reduce the supercap size
 4. Batteries and supercaps may be used in parallel connection for best performance/cost efficiency



Contact us – to update!

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