

BATTERY LIFETIME IMPROVEMENT USING SUPERCAPACITORS

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2nd EUROREG-PV 2014
Ljubljana, Slovenia
September 1st – 3rd, 2014





OVERVIEW

- Introduction
- Characteristics of energy storage
- Supercapacitor
- Comparison of battery and supercapacitor
 - State of charge
 - State of life
- Hybrid supply
 - Topology
 - Simulation
 - Testing
- Conclusion



INTORDUCTION

Capacitor technology

- Technological advance - supercapacitor

Energy storage system (ESS)

- Basic subsystem in mechatronic system



Hybrid supply → battery and supercapacitor

- Energy
- Power
- Lifetime



CHARACTERISTICS OF ENERGY STORAGE

Basic characteristics

- **Energy density**

SC 2 - 30 Wh/kg
 1 - 20 Wh/L

Li-ion 80 - 200 Wh/kg
 240 - 400 Wh/L

- **Power density**

SC 1 - 10 kW/kg
Li-ion 0,1 - 3 kW/kg

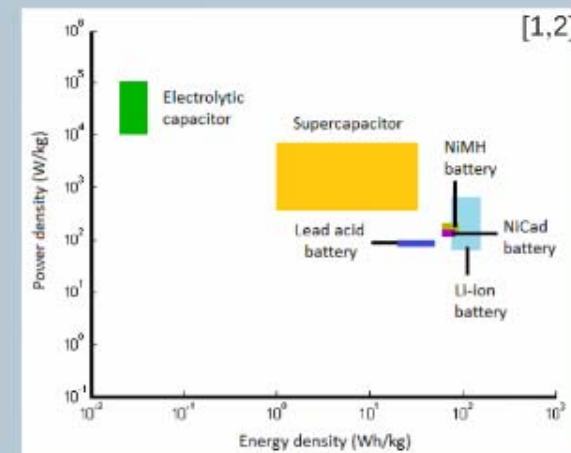


Figure 1: Ragone diagram



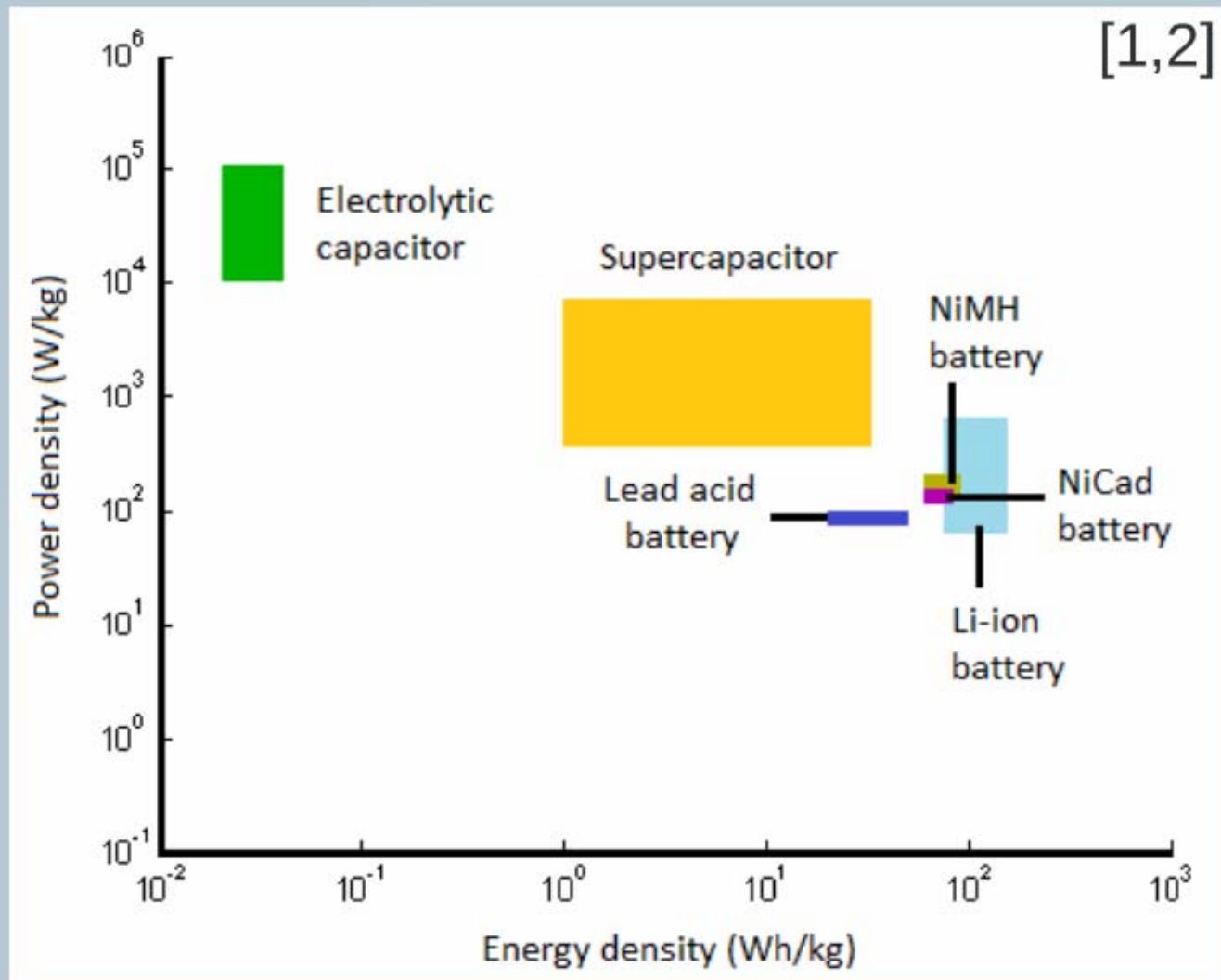


Figure 1: Ragone diagram

SUPERCAPACITOR

Internal structure similar to a battery

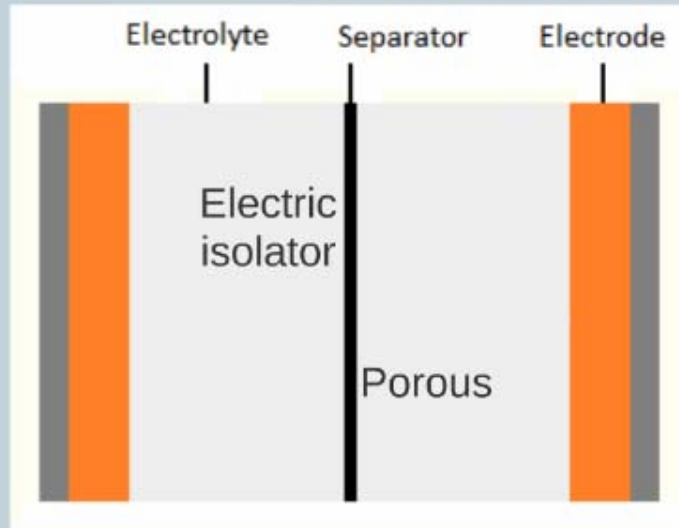


Figure 2: Structure of EDLC

EDLC - Electric Double-Layer Capacitors

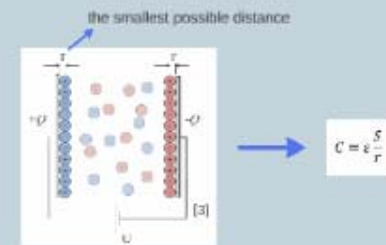
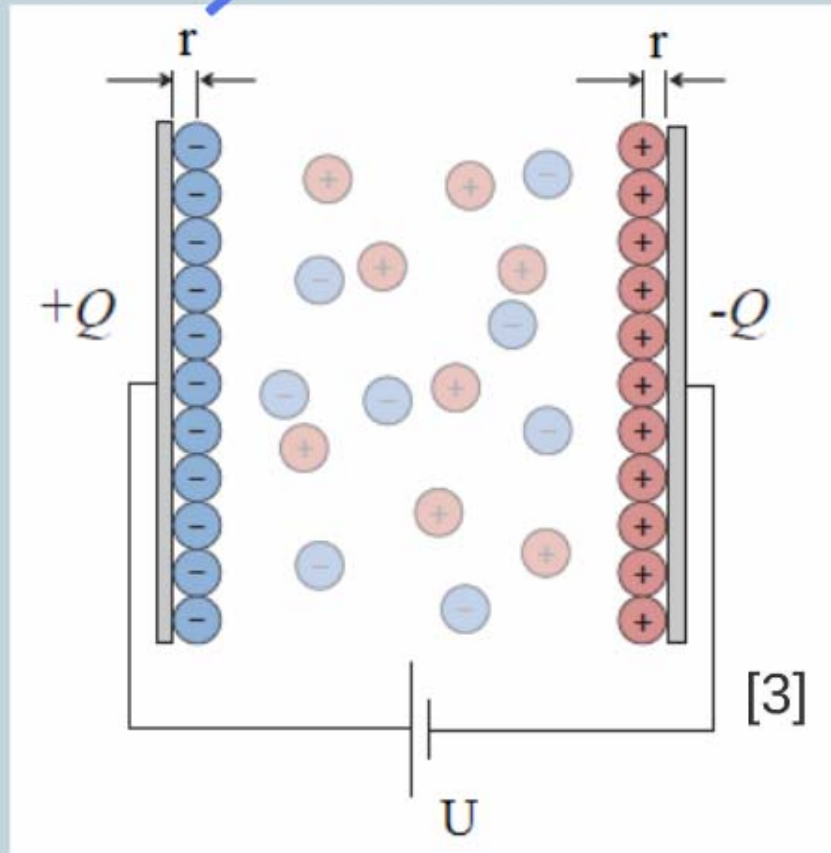


Figure 3: Operational principle of EDLC

the smallest possible distance



$$C = \varepsilon \frac{S}{r}$$

Figure 3: Operational principle of EDLC

COMPARISON OF BATTERY AND SUPERCAPACITOR

The amount of energy

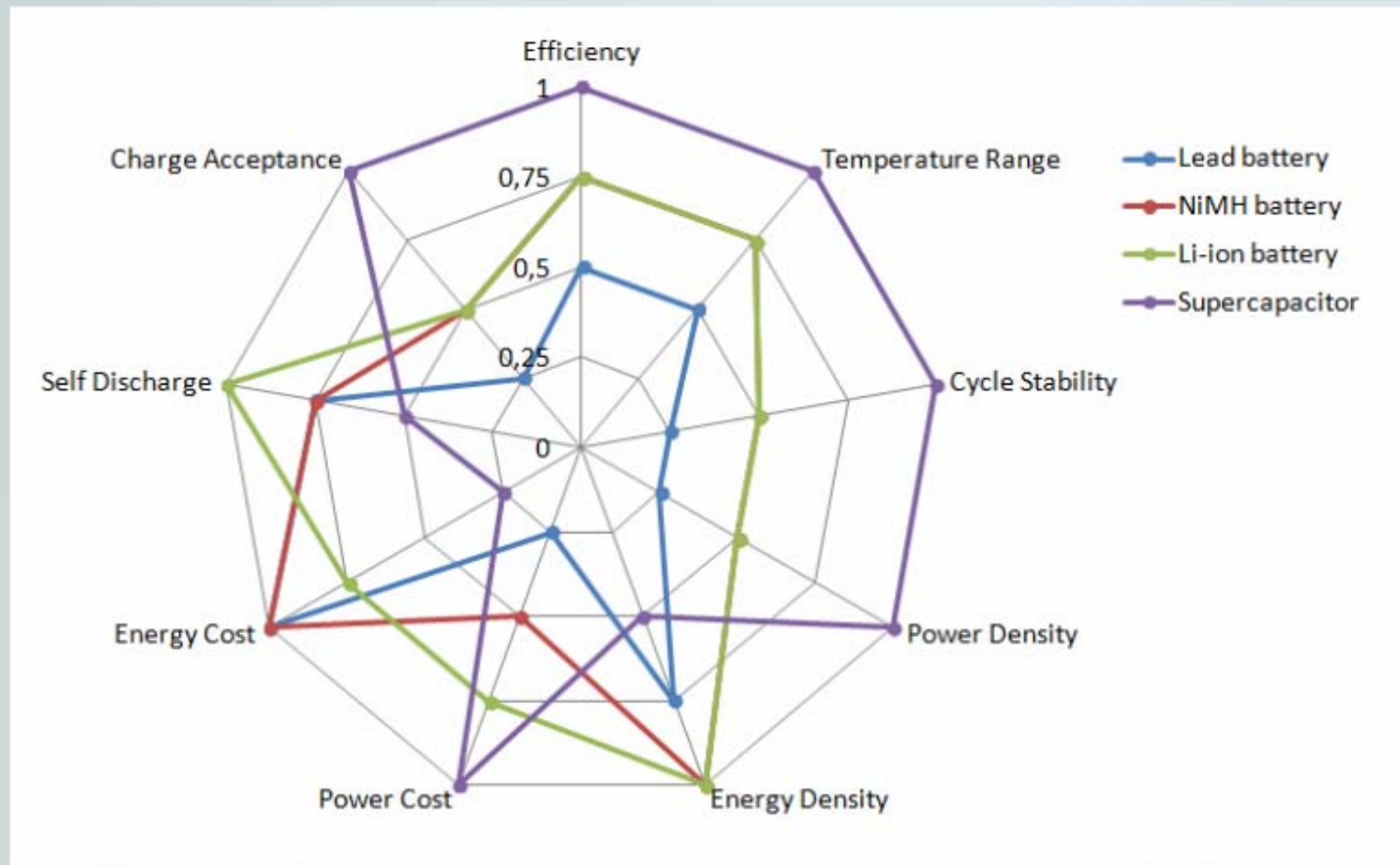


Figure 4: Battery vs Supercapacitor Technologies



STATE OF CHARGE

Indicates how much energy is left in ESS

$$SOC = \frac{E_{ava}}{E_{max}} \cdot 100 [\%]$$

E_{ava} → available energy

E_{max} → maximum energy

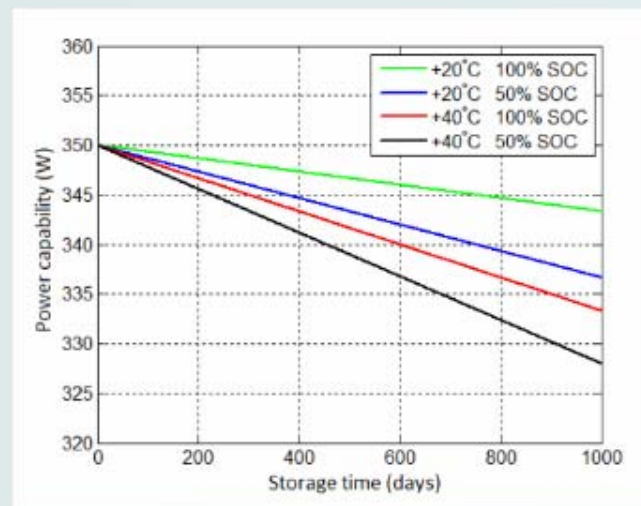


Figure 5: Power capability during storage at different temperatures and SOC

→ Reduce Power capability

→ Reduce lifetime of battery

Supercapacitor

SOC → 100%

Temperature → -40°C – 70°C

STATE OF LIFE

Defining the lifetime

- Internal resistance
- Capacity



Monitoring and defining the boundaries

$$\Delta R = 0.125 \cdot e^{\left(-\frac{1683}{8.315 \cdot (T+273.15)}\right)} \cdot t_m^{(0.7706 \cdot SOC^2 - 0.8238 \cdot SOC + 0.729)} \quad [4]$$

$$\Delta C = -0.078125 \cdot e^{\left(-\frac{1725}{7.615 \cdot (T+273.15)}\right)} \cdot t_m^{(0.7706 \cdot SOC^2 - 0.8238 \cdot SOC + 0.729)}$$

Li-ion

$T = 20^\circ\text{C}$

$SOC = 70\%$

$\Delta R = 100\%$

$\Delta C = 50\%$

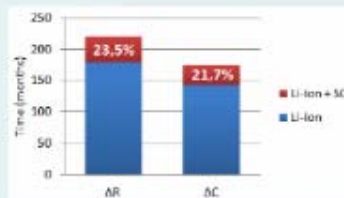


Figure 6: Battery lifetime improvement using supercapacitor

Li-ion + SC

$T = 20^\circ\text{C}$

$SOC = 50\%$

$\Delta R = 100\%$

$\Delta C = 50\%$

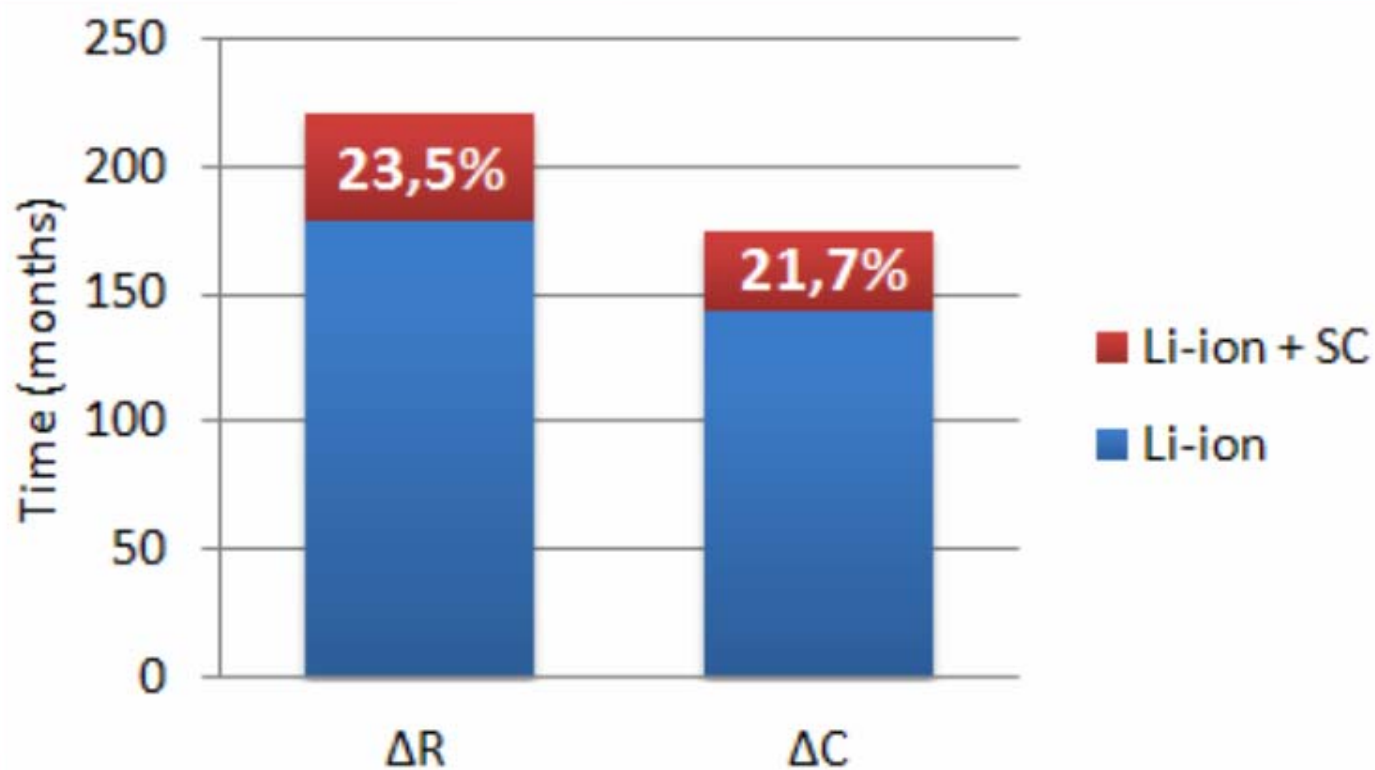


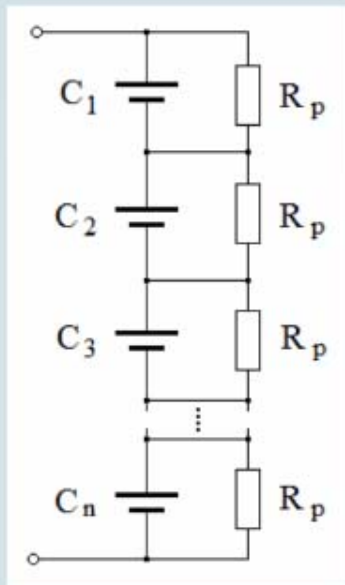
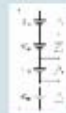
Figure 6: Battery lifetime improvement using supercapacitor

CELL BALANCING

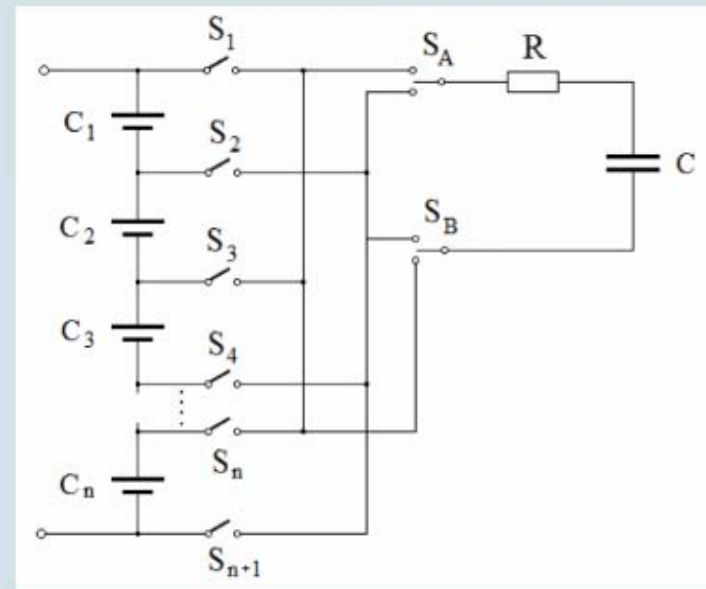
Battery and Supercapacitor

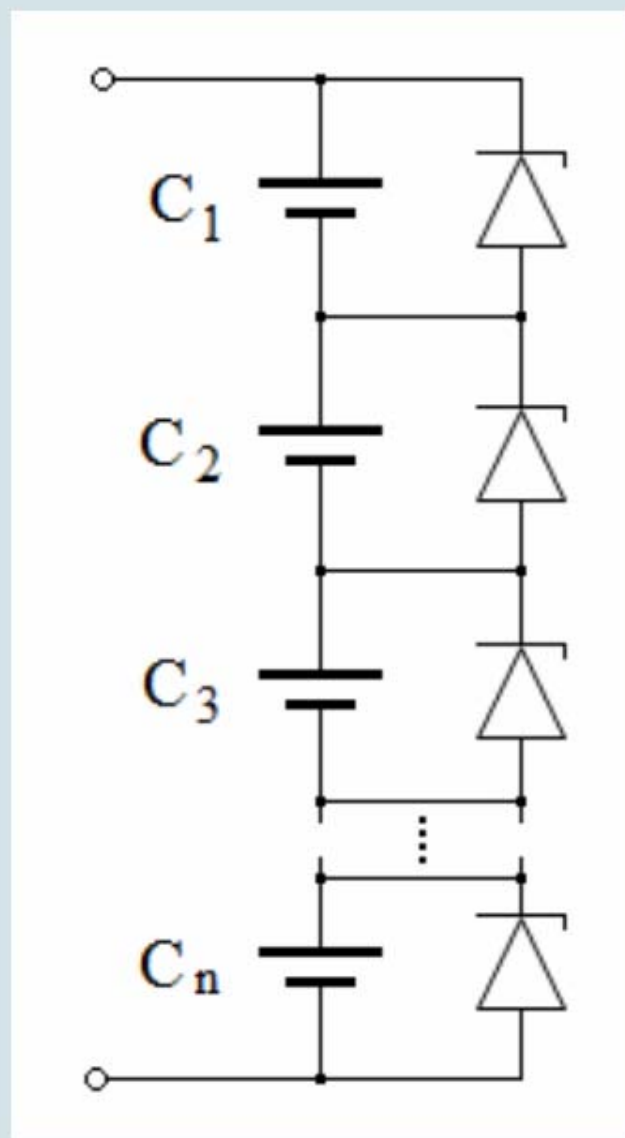
- Low voltage (typically less than 4V)
- Series connection → Charging → Balancing

Passive balancing



Active balancing





HYBRID SUPPLY

Battery - Energy storage

Supercapacitor - Power source



Figure 7: Hybrid supply – battery and supercapacitor

- ➔ Improvement of the lifetime
- ➔ The weight reduction of the ESS



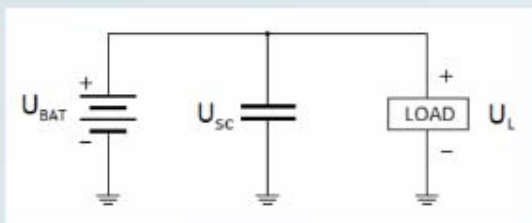
TOPOLOGY

Basic configuration

- Series
- Parallel

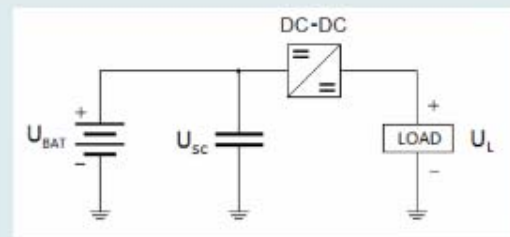
Basic topology

- Directly connecting of Supercapacitor



Other topologies

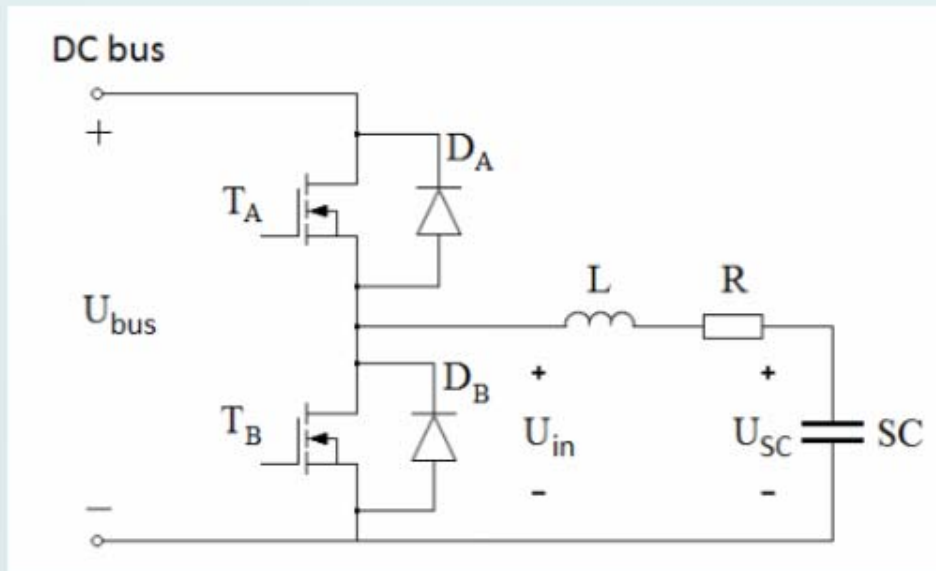
- DC – DC converter





DC-DC converter

Bidirectional DC – DC converter



Bidirectional flow of energy

- Step down (Buck)
- Step up (Boost)



SIMULATION

Hybrid supply
Battery supply
Regenerative braking



Electric machine

Li-ion battery

- Voltage – 14,8 V
- Internal resistance – 400 mΩ

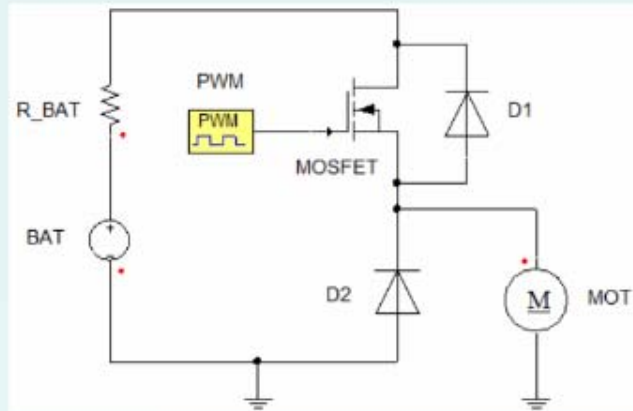
Supercapacitor

- Voltage – 13,5 V
- Capacity – 20 F
- ESR – 75 mΩ

ESR → equivalent series resistance

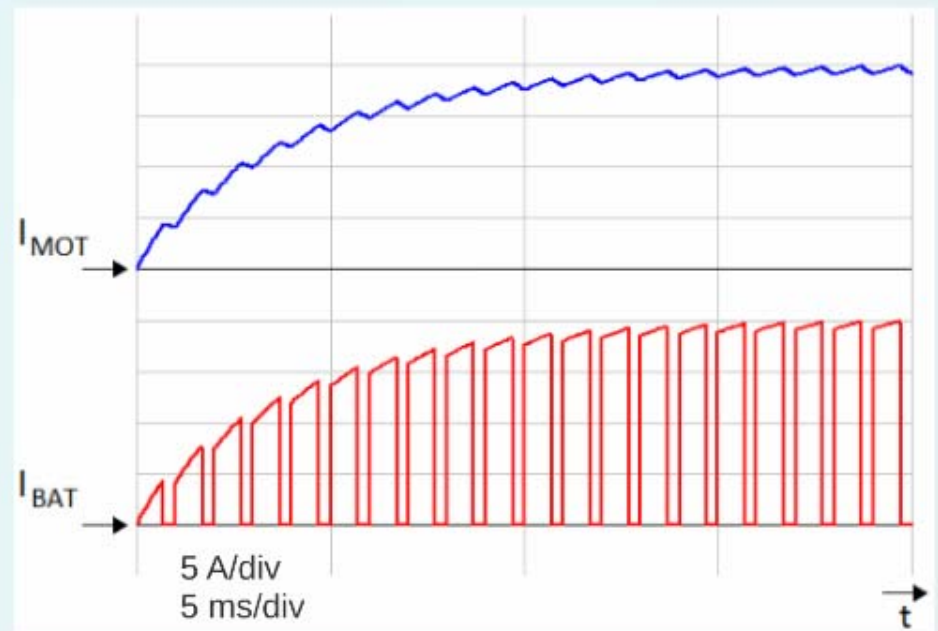
BATTERY SUPPLY

A classic electric motor drive system - PWM



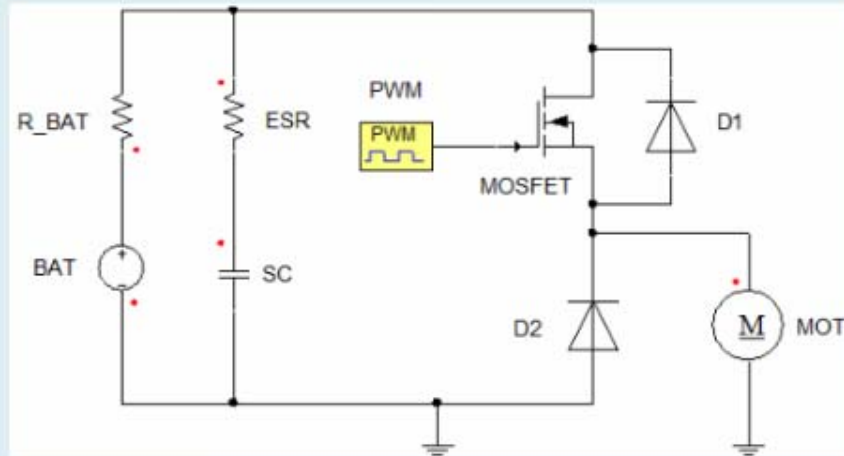
Large pulses of battery current

Battery current

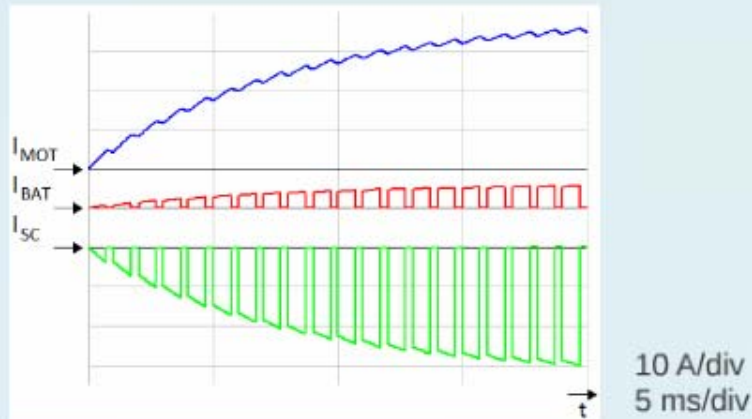


PARALLEL CONNECTION OF SUPERCAPACITOR

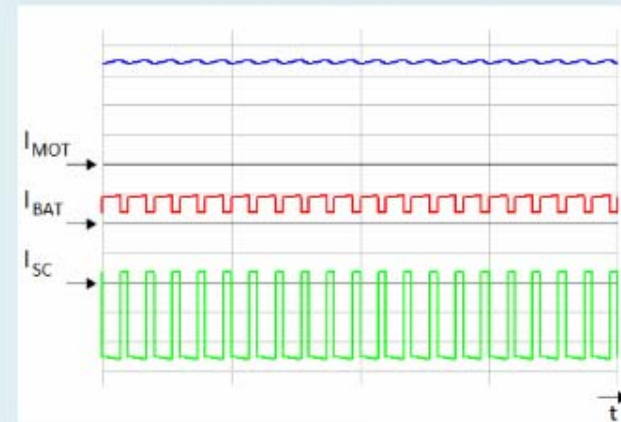
Hybrid supply



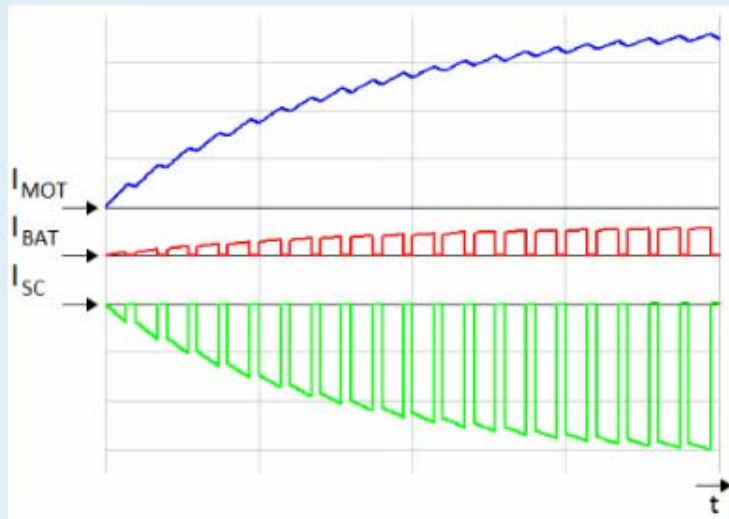
Without initial voltage on SC



With initial voltage on SC (13,5 V)

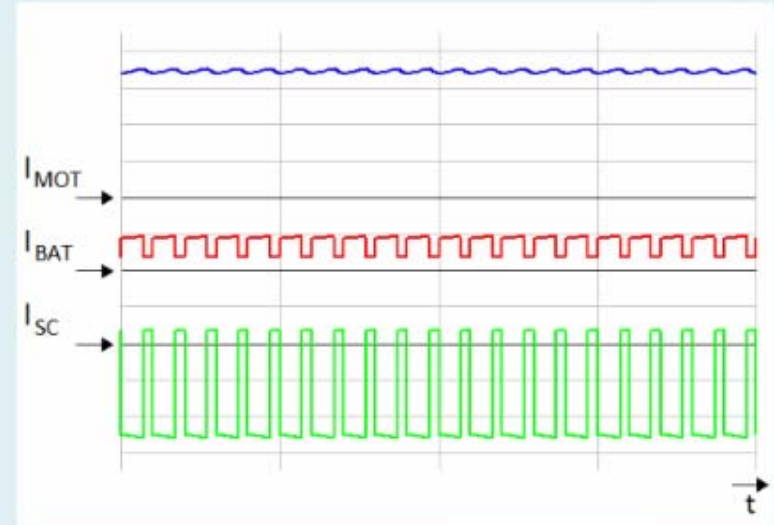


Without initial voltage on SC



10 A/div
5 ms/div

With initial voltage on SC (13,5 V)



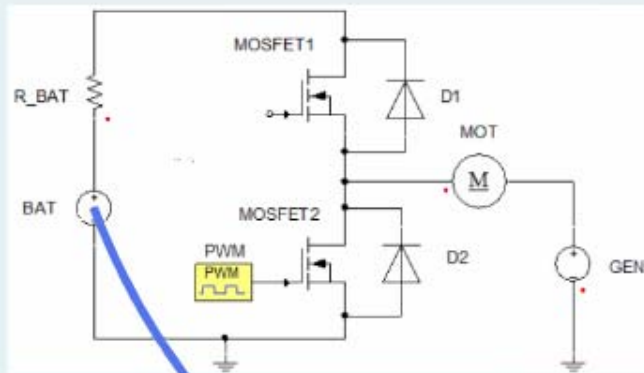
Large pulses of battery current
transferred to supercapacitor

REGENERATIVE BREAKING

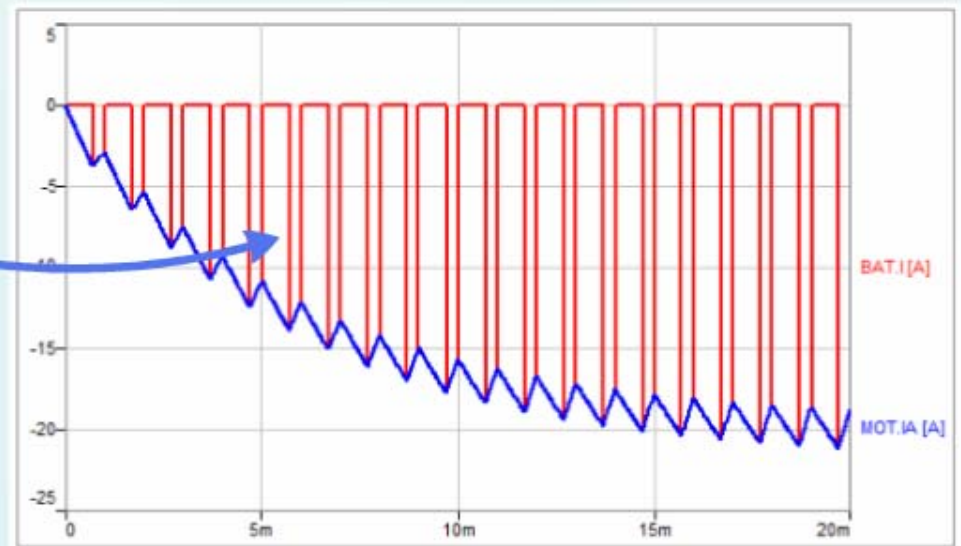
Charging ESS



Bidirectional DC-DC converter

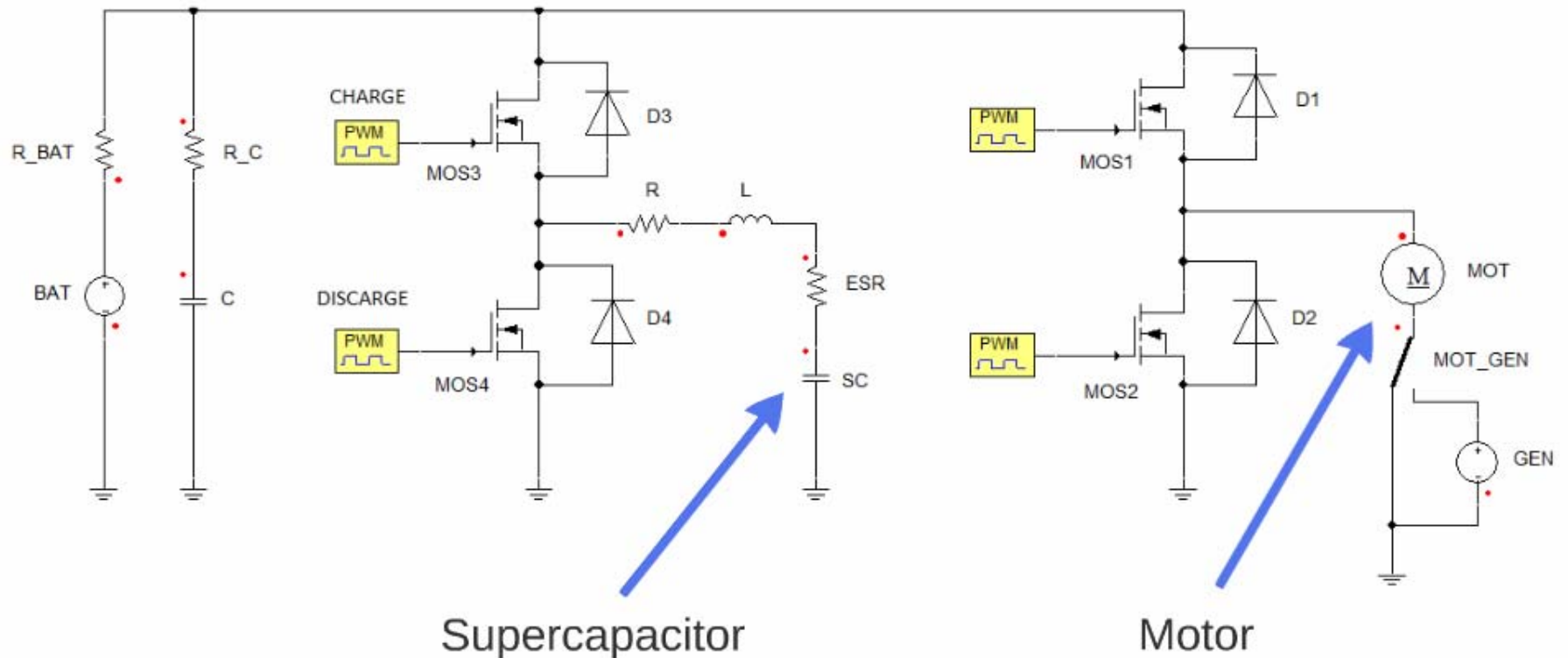


Large pulses current





2 x Bidirectional DC-DC converter



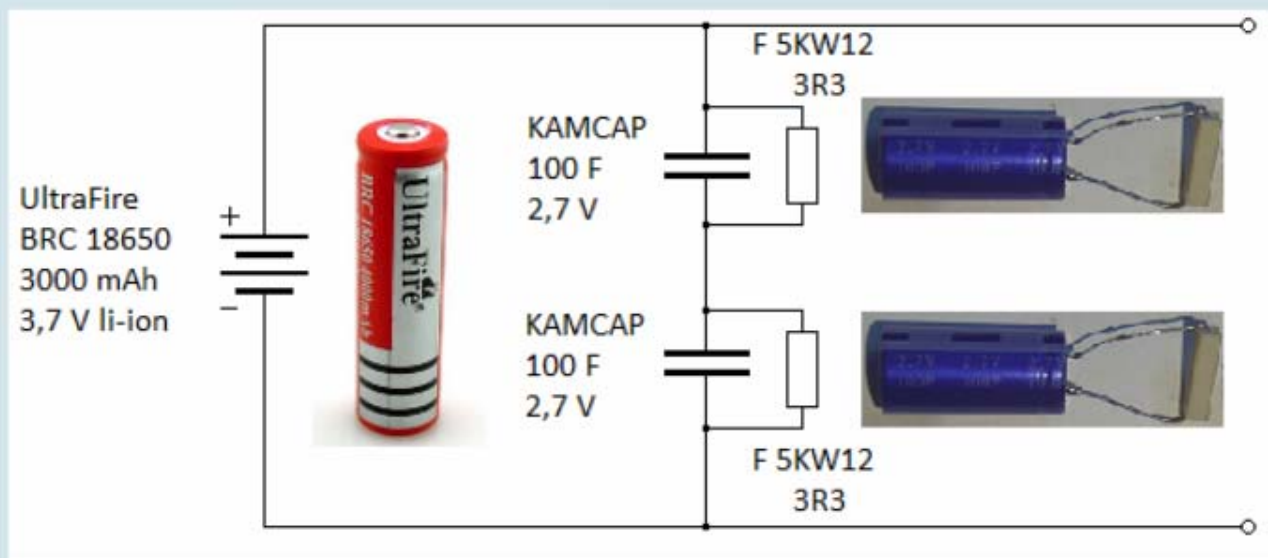
- Regenerative braking
- High power application

TESTING

Supercapacitor KAMCAP

- Constant current charging
- Discharging through a resistor

Li-ion battery UltraFire



CHARGING AND DISCHARGING SUPERCAPACITOR

Constant current - 2A
(Current source)

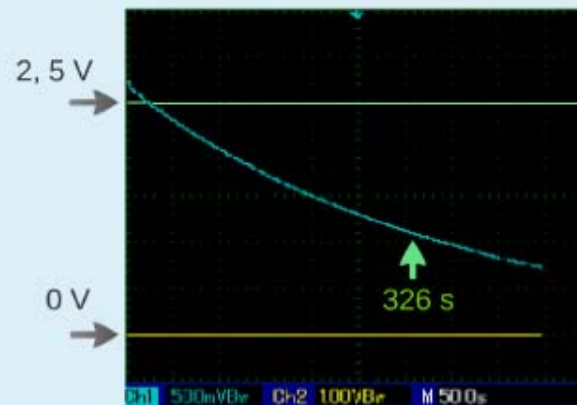


$V = 2,5 \text{ V}$

$t = 128 \text{ s}$

$V \rightarrow$ SC voltage
 $t \rightarrow$ charging time

Discharging



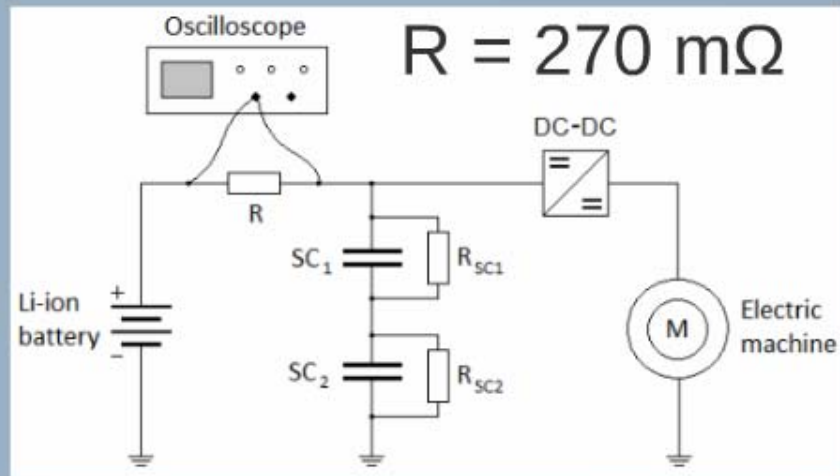
$\tau = 326 \text{ s}$

$R = 3,3 \Omega$

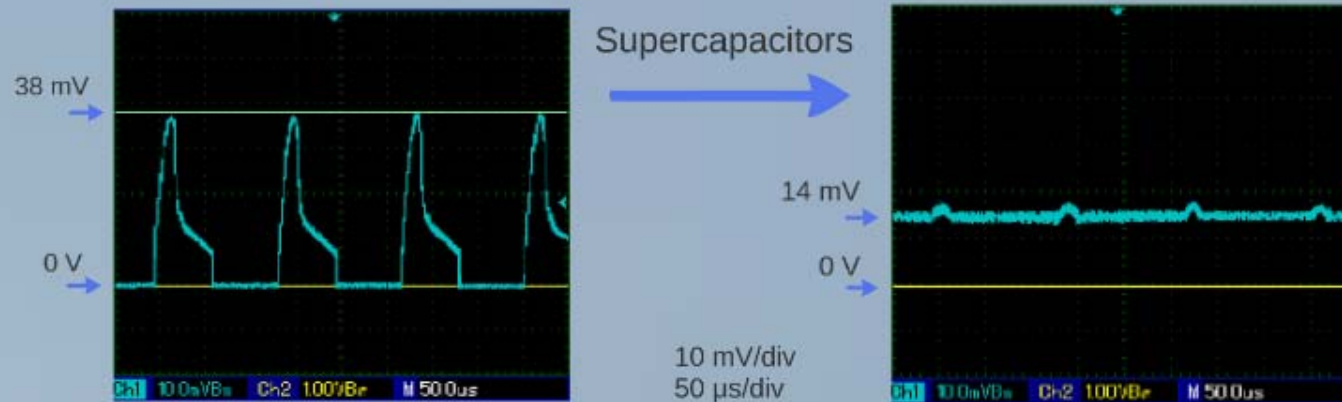
$C = 98,8 \text{ F}$

HYBRID SUPPLY

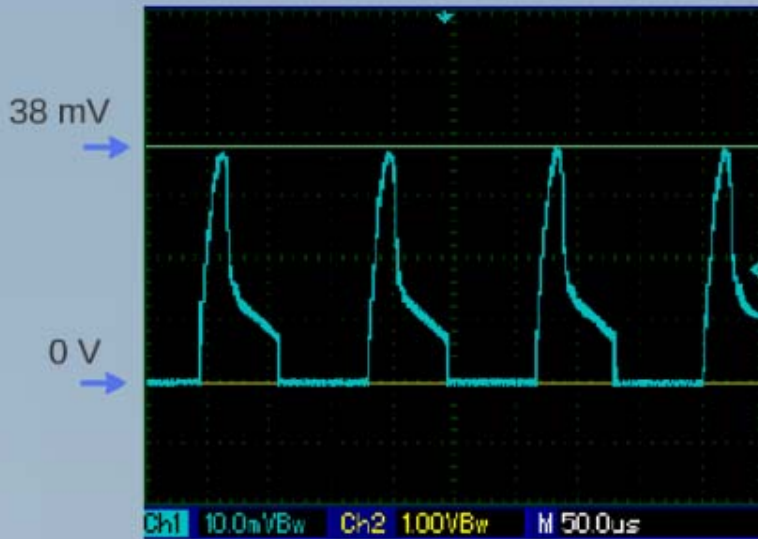
Testing circuit



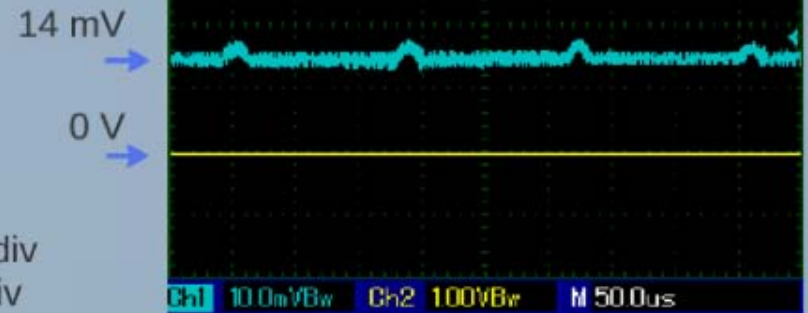
Battery voltage



Battery voltage



Supercapacitors



10 mV/div
50 μ s/div

$$I_{max} = \frac{U_{max}}{R} = \frac{0,038}{0,27} = 141 \text{ mA}$$

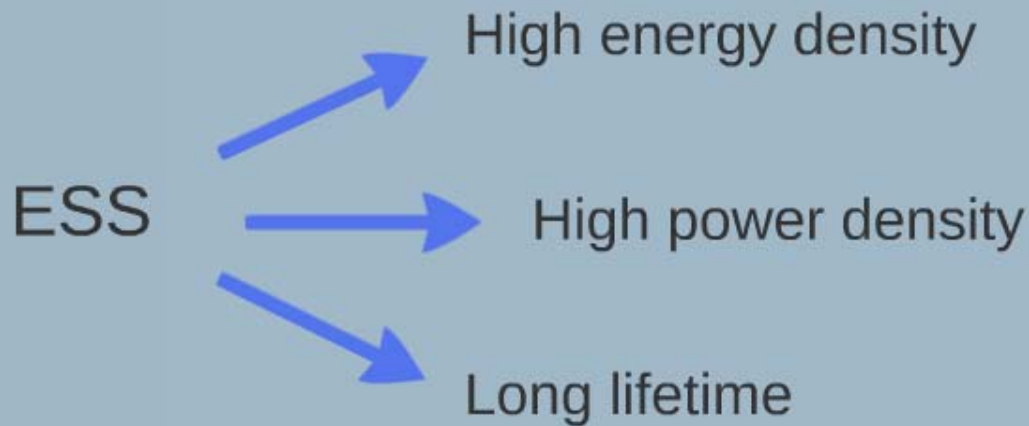
$$I_{const} = \frac{U_{const}}{R} = \frac{0,014}{0,27} = 52 \text{ mA}$$



Battery lifetime



CONCLUSION



Do we have a solution?





Hybrid supply

Reduce weight ✓

Reduce current ✓

Higher current range ✓

Higher efficiency ✓

Longer lifetime ✓

Problem → Cost

Supercapacitors

Li-ion batteries



THANK YOU FOR YOUR ATTENTION



Question?