De elektrische dubbellaagcondensator als vermogenopslag: een introductie

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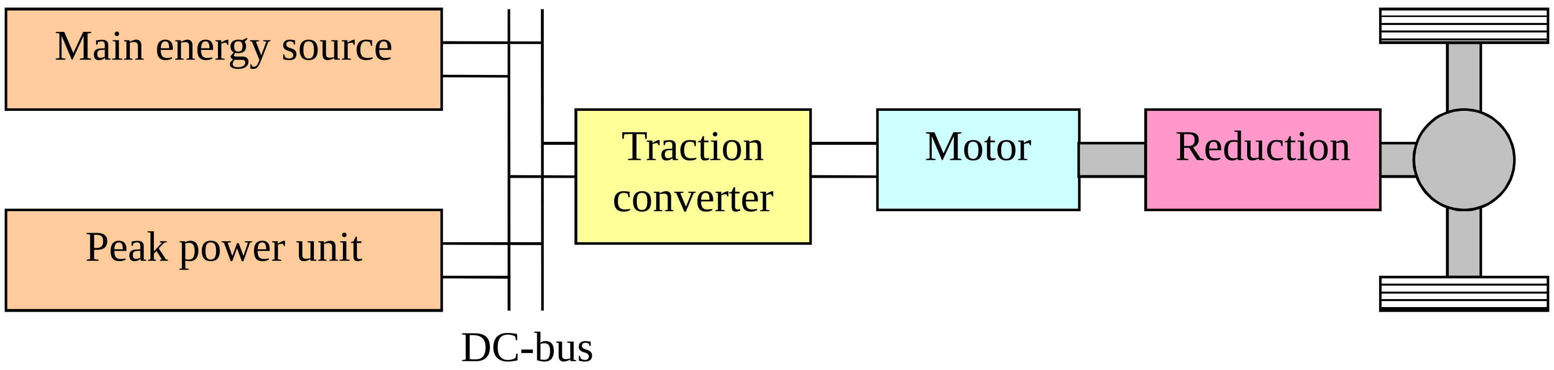
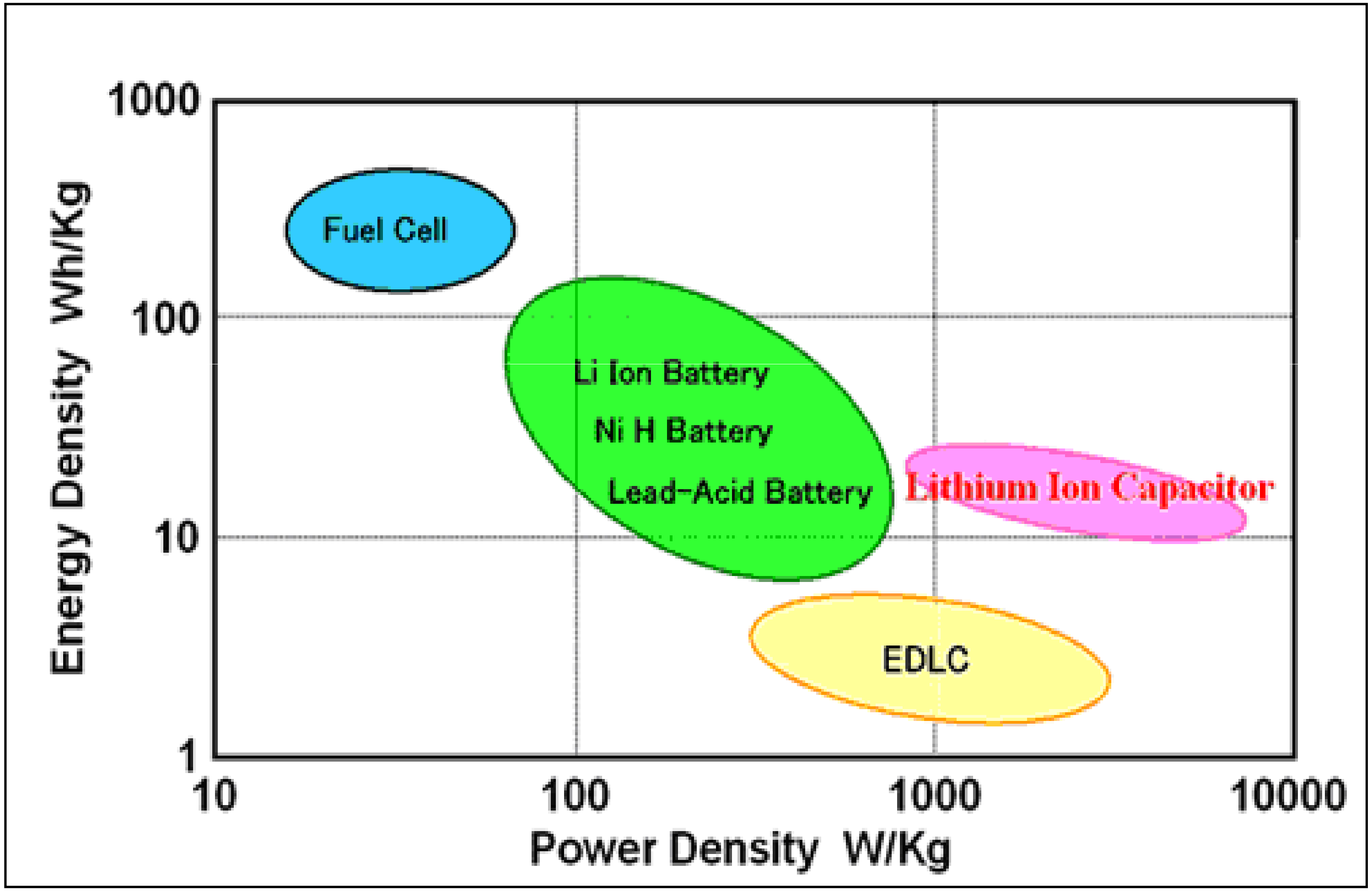
Hybrid electric vehicle propulsion



Battery and Supercapacitor characteristics

		Lead based	Nickel based	Sodium based	Lithium based	EDLC capacitor	LIC capacitor
Cell voltage	V	2	1.2	2 – 2.5	3.5	2.7	3.8
Specific energy	Wh/kg	30 – 35	50 – 80	90 – 130	80 – 200	4 - 7	14
Specific power	W/Kg	70 – 130	175 – 700	100 – 160	300 – 2500	6000 - 7000	
Energy efficiency	%	70 – 85	60 – 85	80 – 90	85 – 95	0.92	
Life cycle		300 – 600	1500 – 2000	600 – 1000	>1000	1.000.000	100000
Working temperature	^{0}C	0 – 45 (-20 – 60)	0 – 50 (-40 – 60)	300 – 350 (250 – 370)	-40 – 70 (charge 0-50)	-35 ~ +65	-20 - 70

Ragone

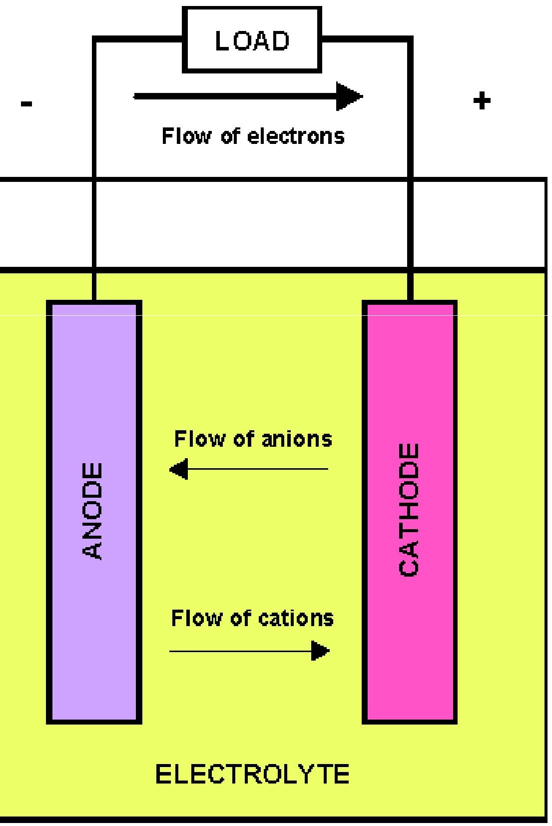


1000
100
10
1
10
100
1000
10000
Energy Density Wh/Kg
Power Density W/Kg
Fuel Cell
Li Ion Battery
Ni H Battery
Lead-Acid Battery
Lithium Ion Capacitor
EDLC

Batterij

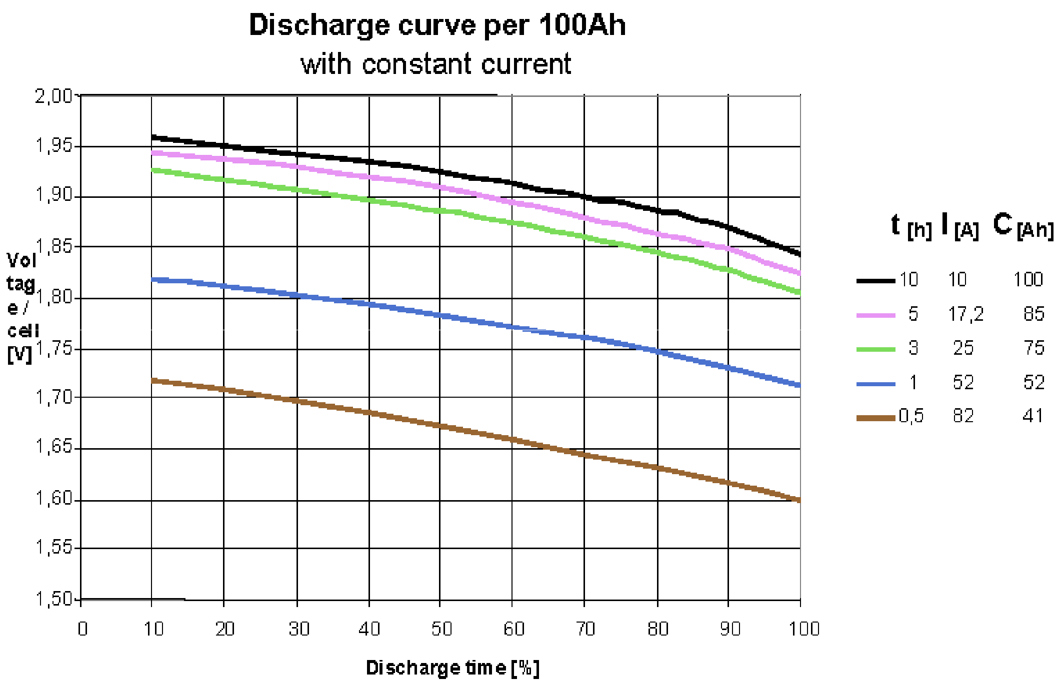
Ontlading

- Beperkte levensduur
- Grote stromen beperken de beschikbare opslagcapaciteit



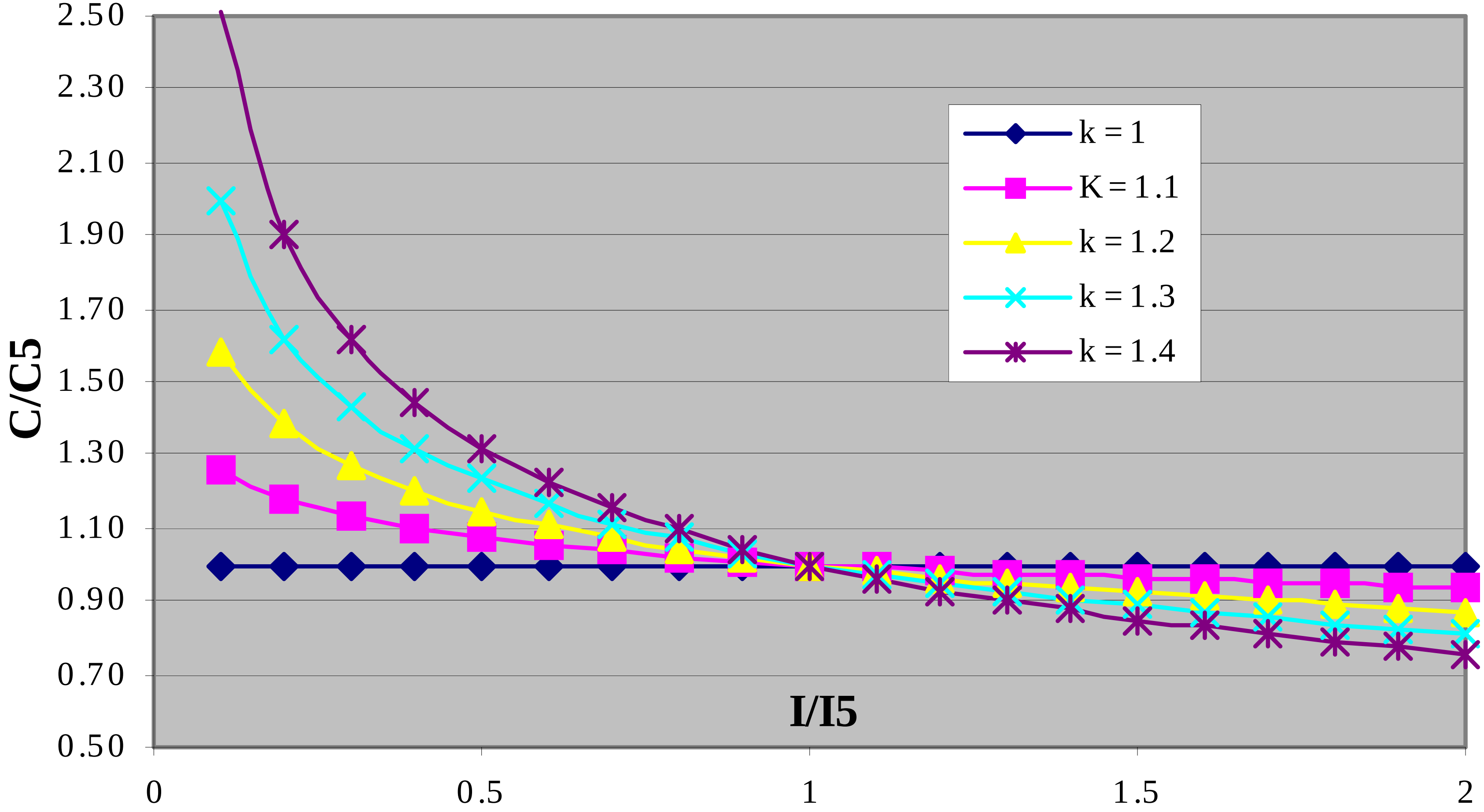
Capaciteit van Batterij

- C_5=100Ah betekent: 20 A x 5 h
- Capaciteit is afhankelijk van de ontlaadstroom!
- Grotere stroom: minder capaciteit
- Typische waarde: k = 1,10 tot 1,20



$$C_p = I^k \times T$$

Battery capacity versus discharge current



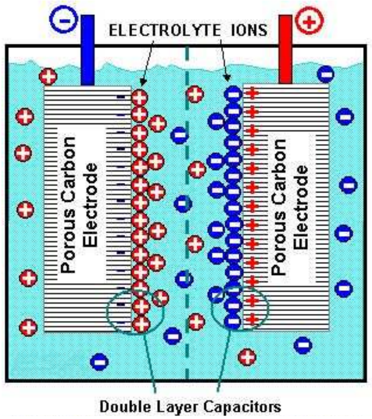
Supercapacitors

Advantages

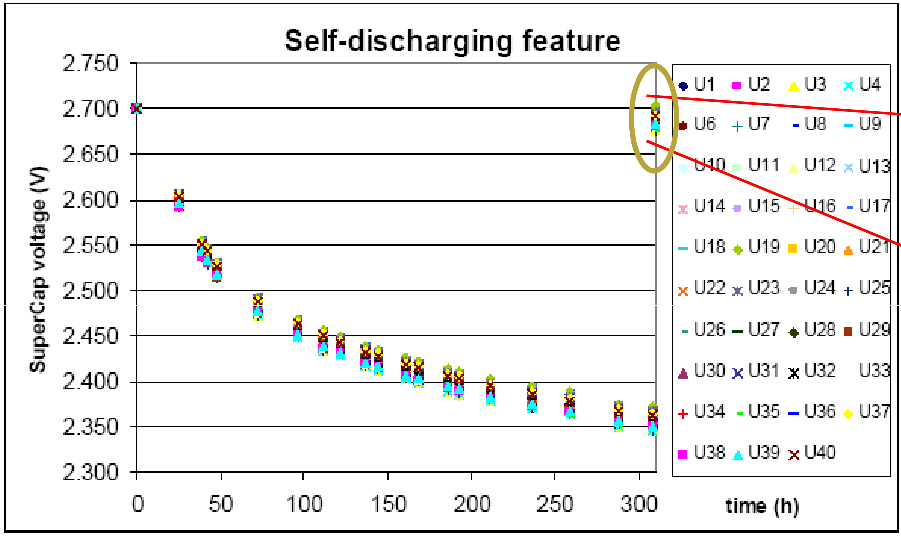
- High power density
- High efficiency
- Low internal resistance
- Long lifetime
- Easy to determine the state of charge by measuring the cell voltage.

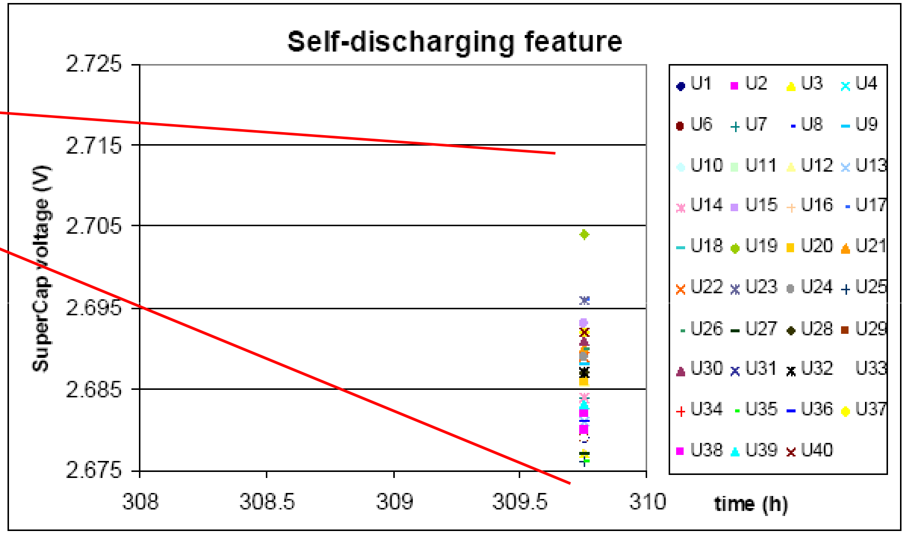
Drawbacks

- Low energy density
- Low cell voltage requires many cells in series for certain applications
- Voltage balancing needed
- Self discharge



Zelfontlading Supercondensatoren



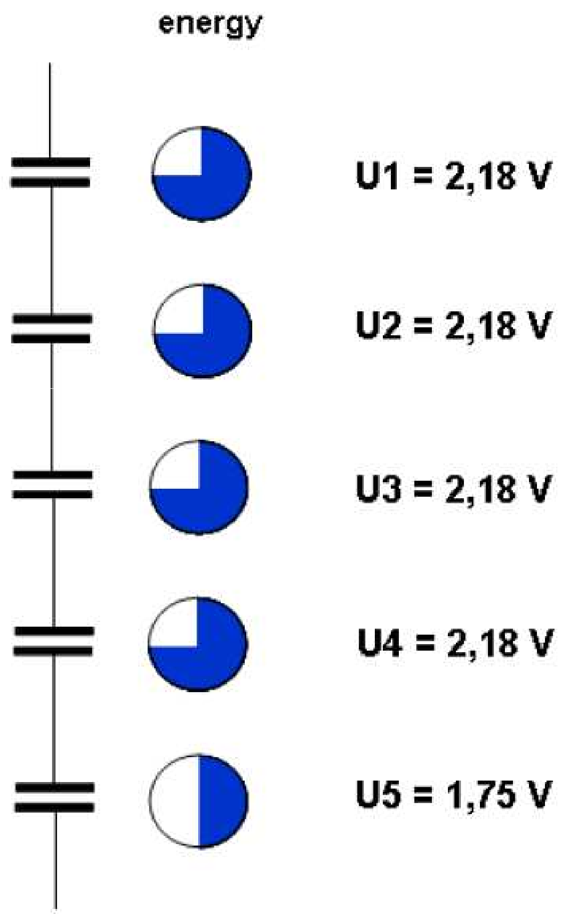


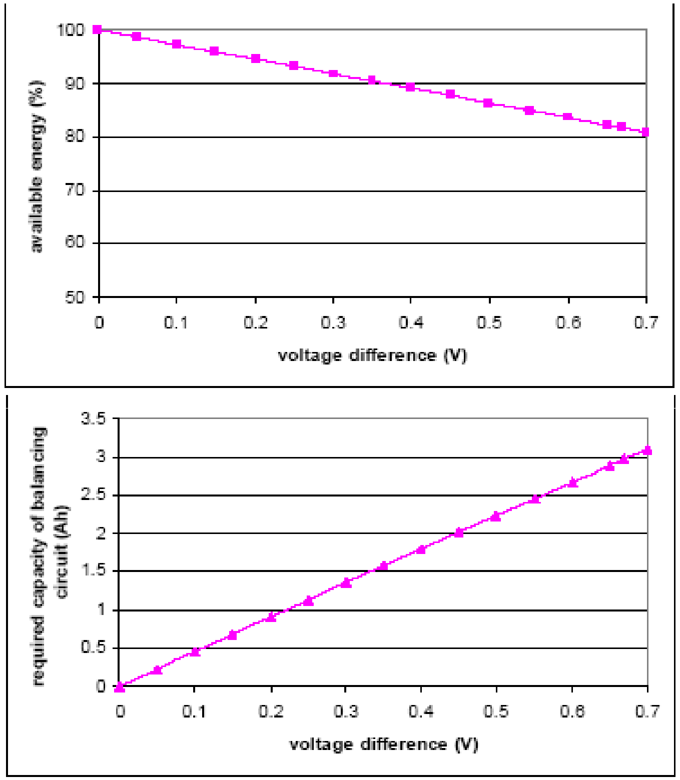
nieuwe type cellen: 0.03 V na 14 dagen rust

Bron: Yonghua C "Methods of Configuring and Managing Super Capacitor Energy Storage as Peak Power Unit", EPE Journal, Reviewing

Onbalance

Voorbeeld





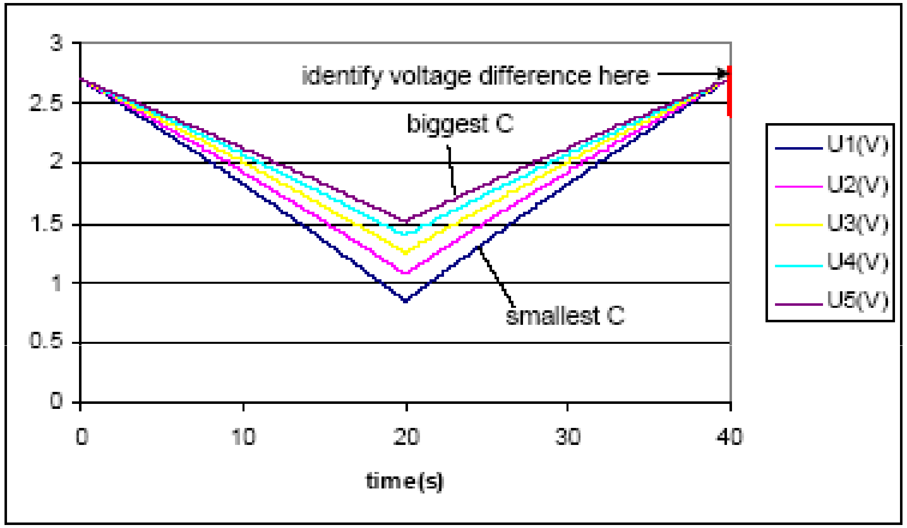
Stel verschil 0.7V => beschikbare energie is 80% (van79kJ)
Vereiste capaciteit van het balancing circuit is 3 Ah

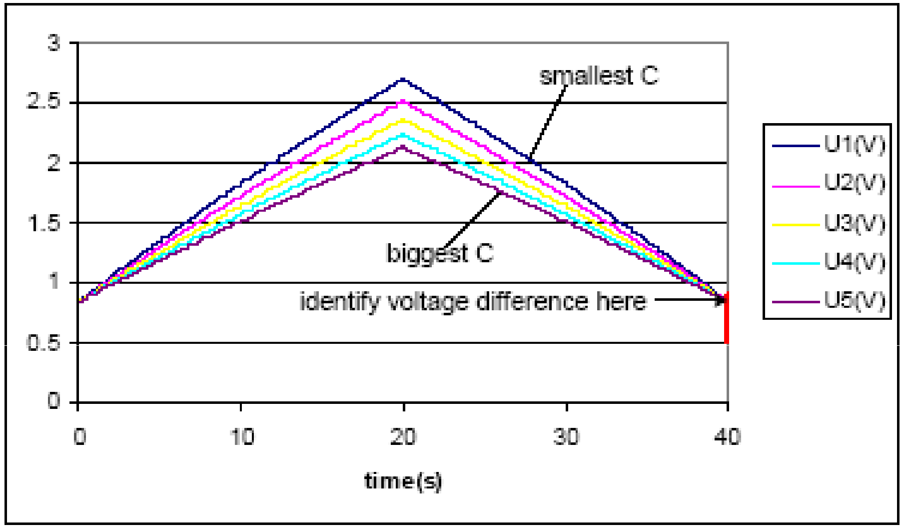
$\Rightarrow$3A in 1u

$\Rightarrow$250mA in 12u

Bron: Yonghua C "Methods of Configuring and Managing Super Capacitor Energy Storage as Peak Power Unit", EPE Journal, Reviewing

Wanneer balancing?





Verschil in karakteristieken (bv capaciteit) per cel

- Links:
  - In 20s: 19836kJ
  - Kan bij stilstand (meer tijd)
- Rechts:
  - In 20s: 16370 kJ
  - Al rijdend

Bron: Yonghua C "Methods of Configuring and Managing Super Capacitor Energy Storage as Peak Power Unit", EPE Journal, Reviewing

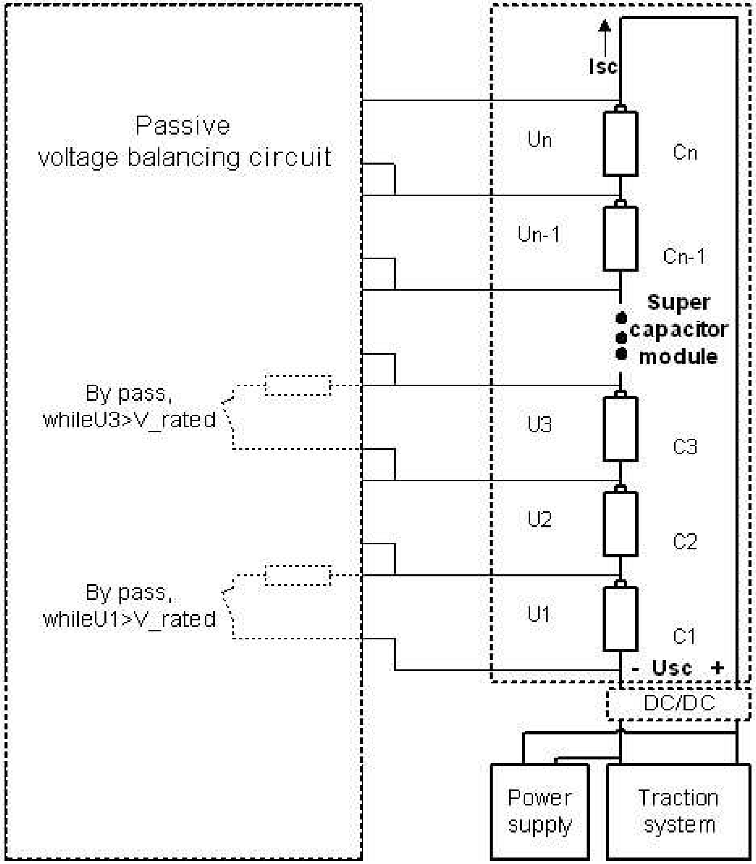
Voltage balancing methodes (1)

Passieve methode

- By pass als
  - cell voltage > V_rated
- Of energie transfer van cellen met hoge spanning naar cellen met lage spanning

Resultaat

- Eenvoudig
- Weinig efficiënt
- Hoofdstroom moet beperkt worden
- Inverse spanning mogelijk



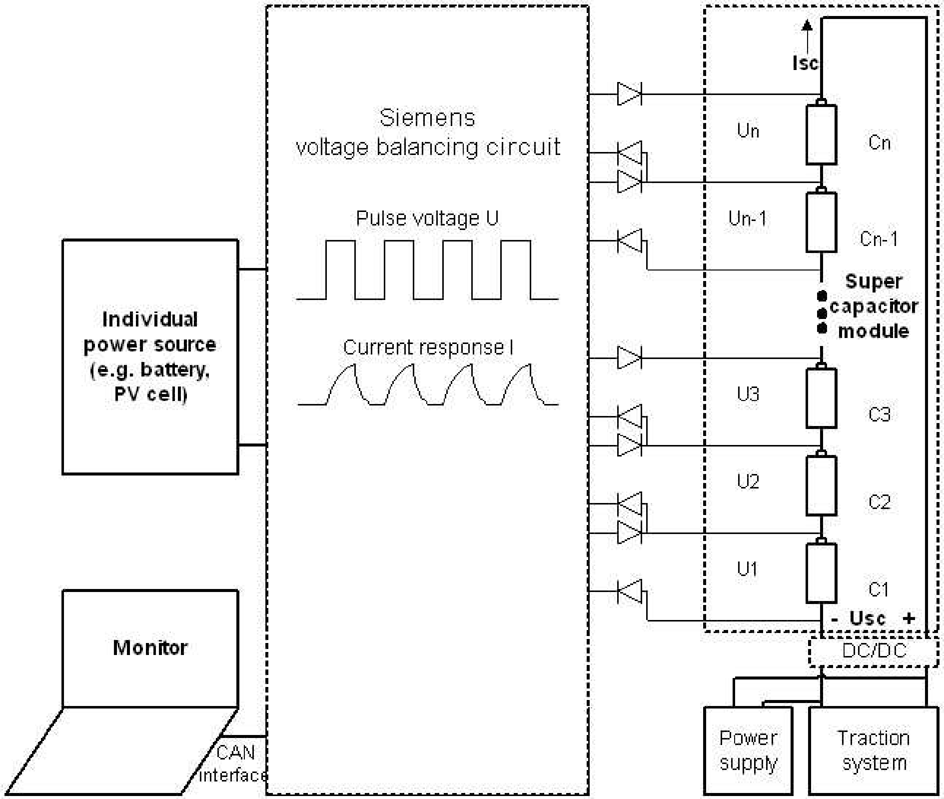
Voltage balancing methodes (2)

Actieve methode

- Puls spanning aan elke cel
- Stroom response ifv celspanning

Resultaat

- Geen inverse stroom
- Geen inverse spanning
- Zeer efficiënt



Power converters and control strategy

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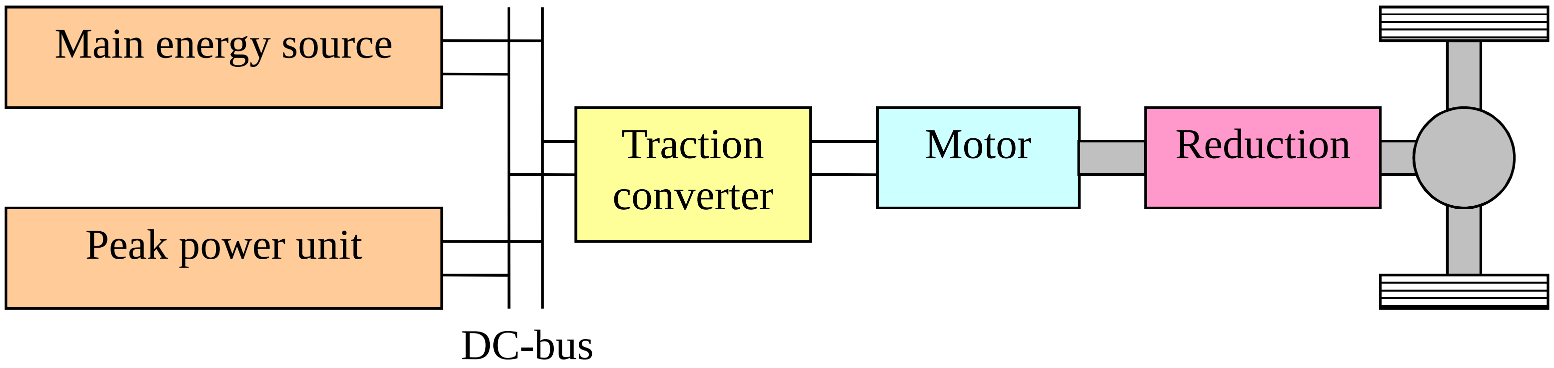


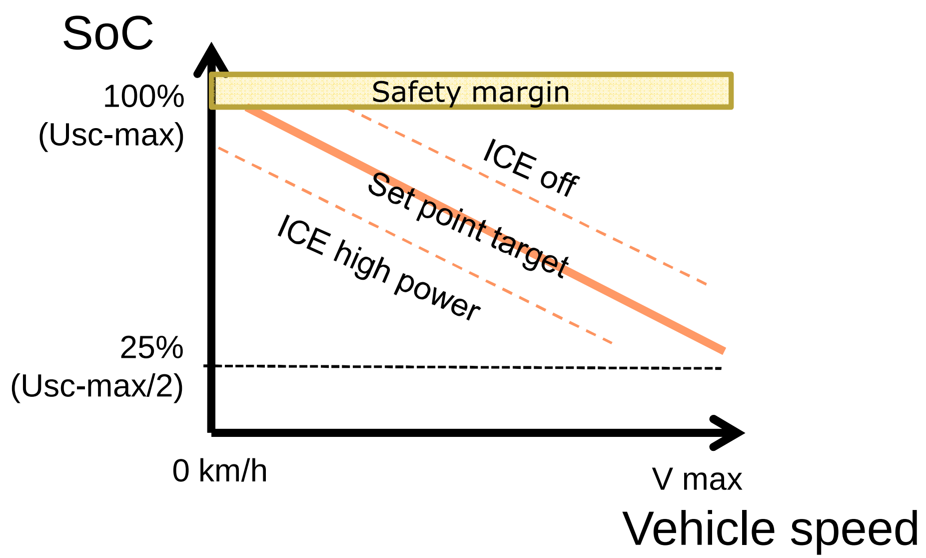
Energie management strategie (Principes)

- Supercaps leveren piekstromen
- Hoofdenergiebron ontlasten
  - Kleinere piekstromen
  - Kleinere stroomvariaties
- Optimalisatie energie-efficiency volledig systeem
- Optimalisatie kost en grootte componenten

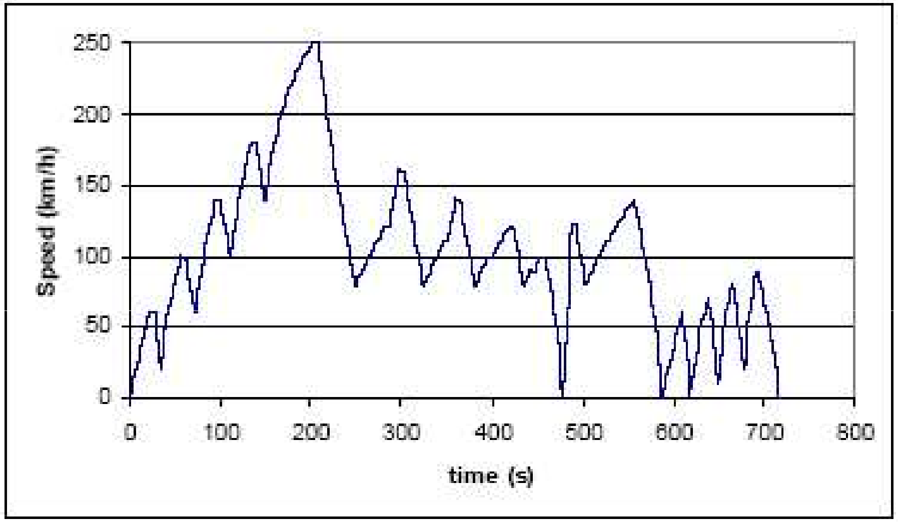
Energie management strategie (Voorbeeld)

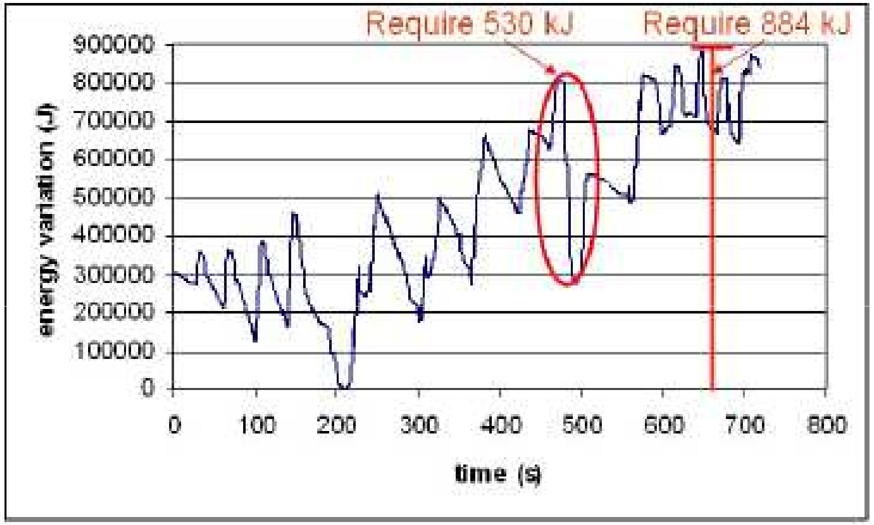
- Hoofd energiebron levert "moving average power" van het gevraagd vermogen
- Supercap levert resterend gedeelte (piek vermogen)

- Bij hoge kinetische of potentiële energie
  - Lage SC spanning (bv 50% van nominale spanning)
- Bij lage kinetische of potentiële energie
  - Hoge SC spanning



Belang van goede energie management strategie

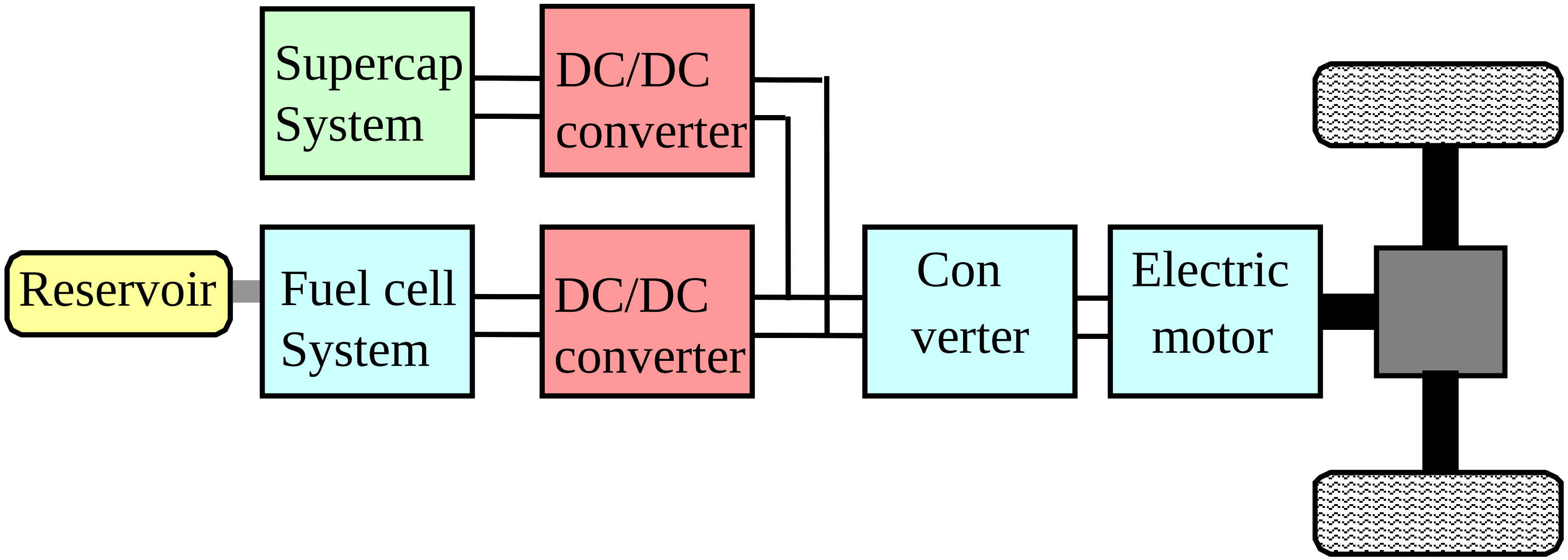




- Grootte van Supercondensator module hang af van energie management strategie

Ref: Yonghua c. et al, “Configuration and verification of the super capacitor based energy storage as peak power unit in hybrid electric vehicles”, EPE2007, Aalborg, Denmark

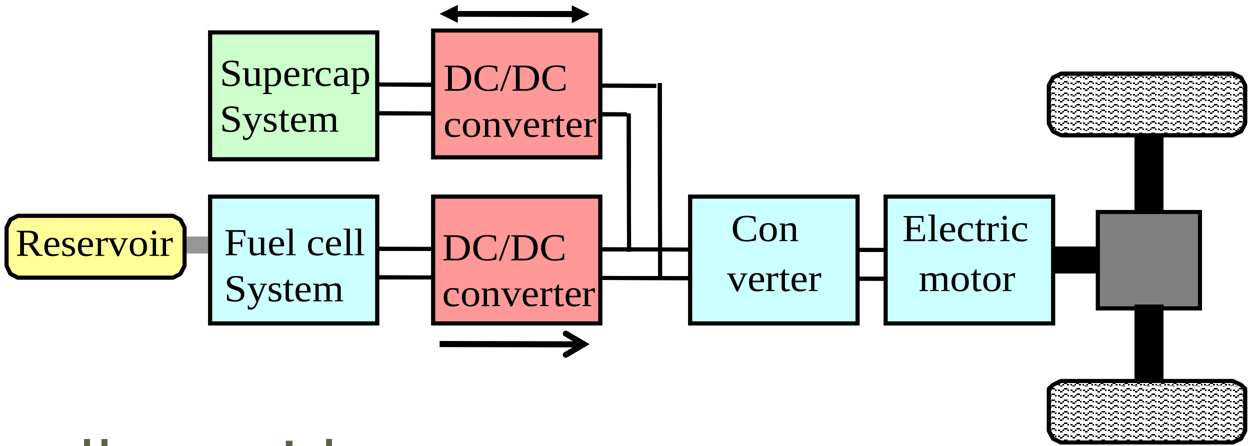
Voorbeeld: Brandstofcel + ELDC



Voorbeeld

- 1.2 ton passenger car
- Fuel cell stack
  - 10kW
  - Maximum power variation 200 W/s
- Super-capacitor
  - 70 series 2.5V cells of 2700 F each
  - Charged at 500W when speed=cte
- ECE-15 drive cycle

Operating principle of a fuel cell hybrid propulsion system with

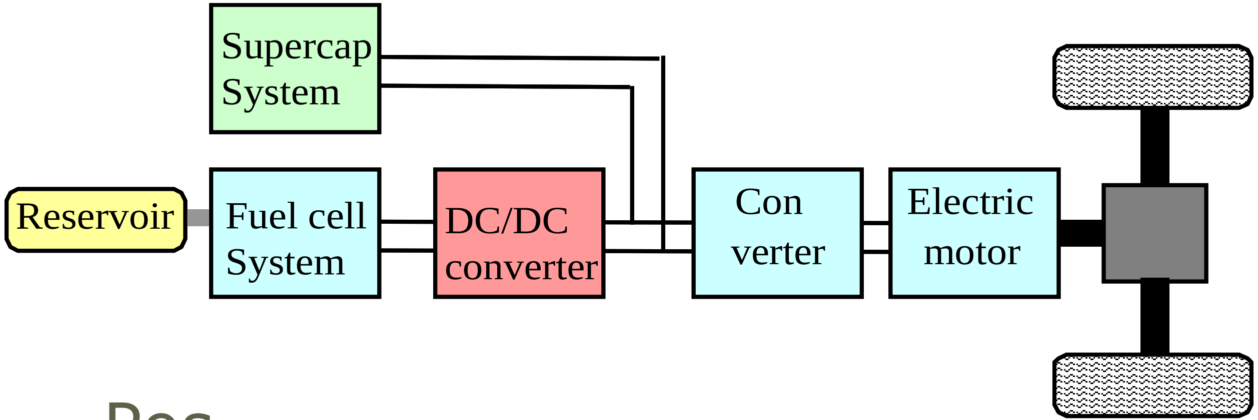


- Fuel cell provides average power
- Super capacitor
  - delivers peak power for accelerating
  - Recuperates braking energy
    - 100 => 0 km/h:

$$E_{kin} = \frac{1}{2}.M.v^2 = 463\,kJ = 129\ Wh$$

$$E_{cap} = \frac{1}{2}.C.U^2_{max} - \frac{1}{2}.C.U^2_{min} = 443kJ = 123\,Wh$$

Other propulsion system topologies



Pos.

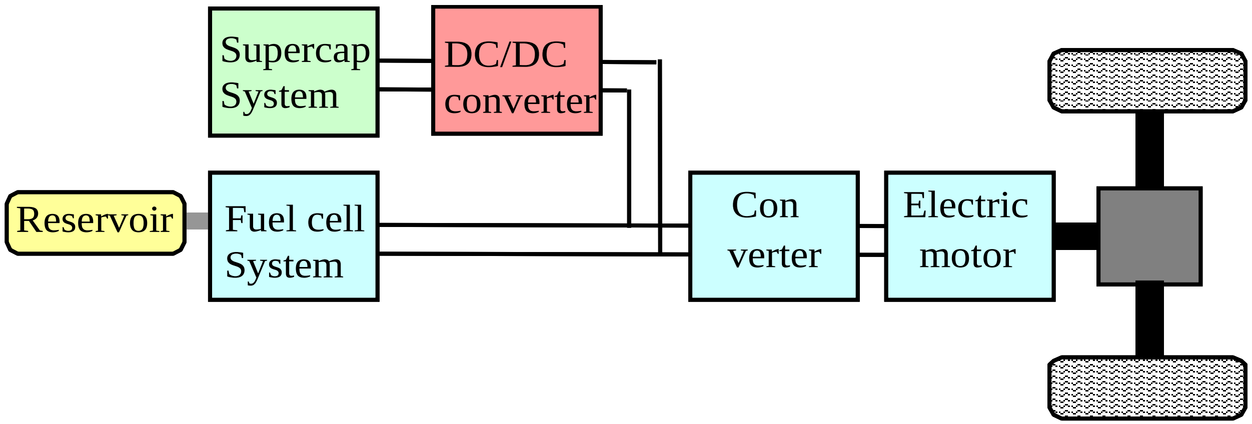
- Cheaper
- Less losses due to DC/DC converter

Neg.

$$E_{cap} = \frac{1}{2}.C.U^2_{max} - \frac{1}{2}.C.U^2_{min}$$

-
- Reduces acceleration performance of vehicle

Other propulsion system topologies

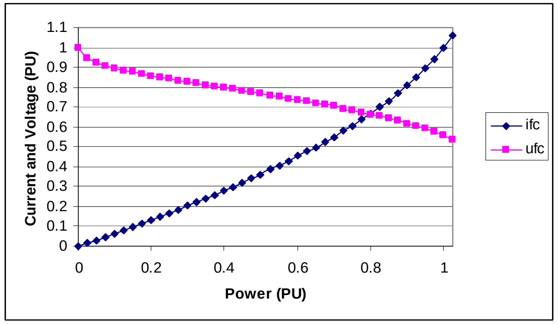


Pos.

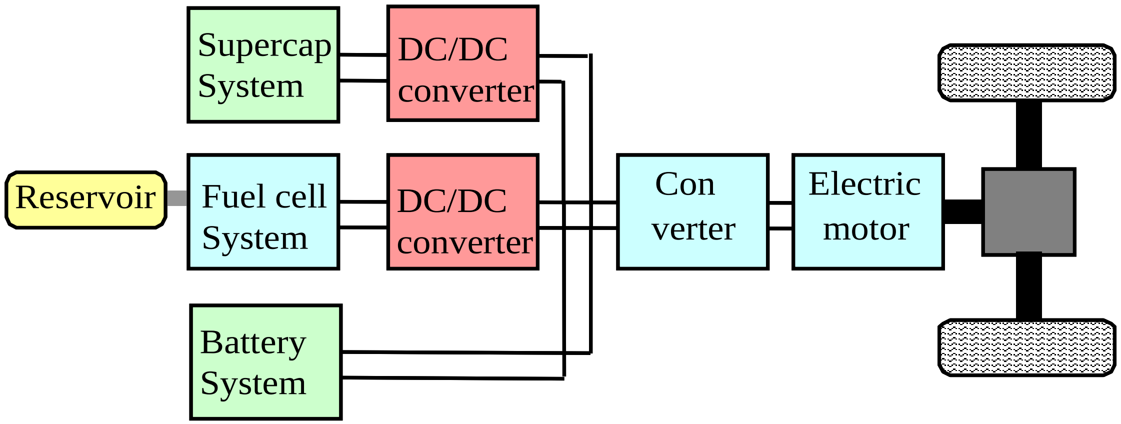
- Cheaper
- Less losses due to DC/DC converter

Neg.

- DC-bus voltage depends on fuel cell voltage



Other propulsion system topologies



Pos.

- Battery can store while driving downhill

Neg.

- More expensive

$$h = \frac{E}{g.M} = 38m$$

Energy consumption Simulation results

	Eff FC conv	Eff SC conv	DPfc/dt	Wh/km	
Two converters	90	95	200	189.5	128%
One FC converter	90		200	174.4	118%
One SC converter		95	200	148.4	100%
Two converters	95	95	200	178.7	120%
One SC converter		95	1250	146.4	99%
One SC converter		80	1250	156.9	106%

=> Primary energy source dynamics versus supercap power converter efficiency

Info?

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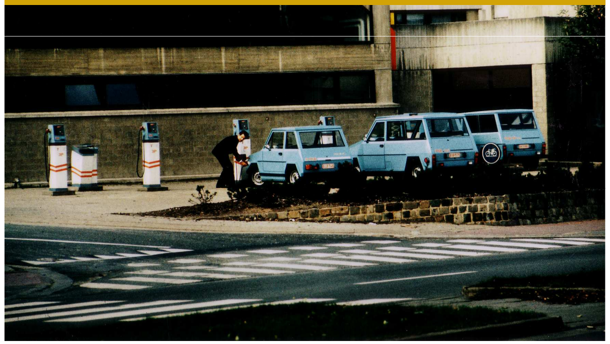

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