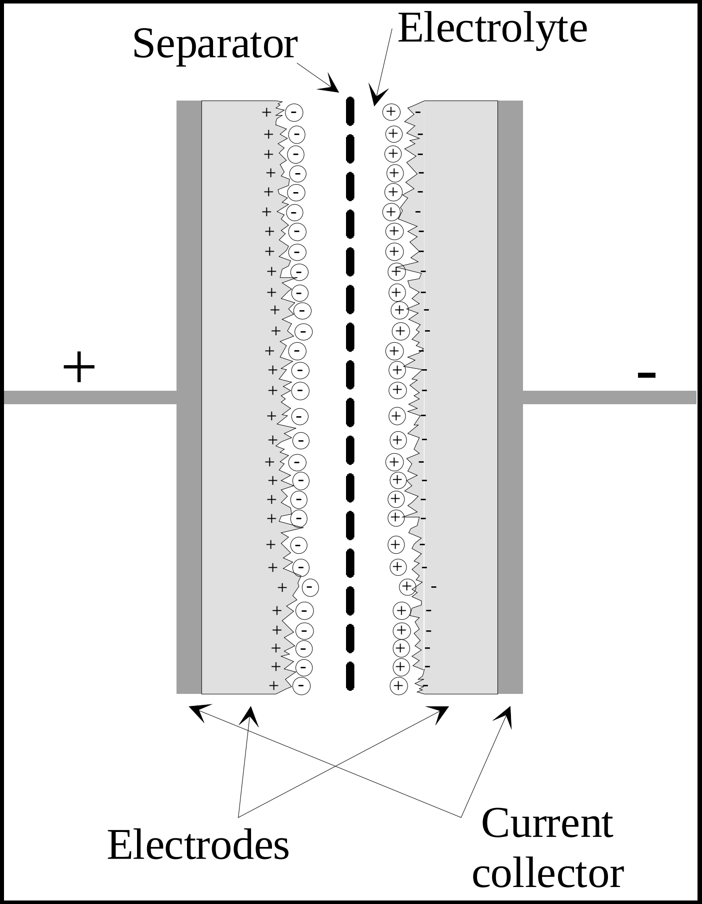
Laboratoire d'électronique industrielle
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

# Supercapacitors: Summary

- Generalities on Supercapacitors
  - Principle
  - Model of a supercapacitor
  - Series connection of supercapacitors
- Sizing of a supercapacitive tank
  - Sizing method
  - Energy efficiency and power availability
- Applications and converters
  - Voltage drop compensation for weak distribution networks
  - Energy buffers for elevators
  - Uninterruptible power supplies
- Conclusion

# Generalities on Supercapacitors

- Principle
  - Supercapacitors: electrochemical double layer capacitor
  - High energy density, together with a high power density
  - Energy stored by charge transfer at the boundary between electrodes and electrolyte
  - Amount of stored energy is a function of :
    - Electrode surface,
    - size of ions,
    - level of electrolyte decomposition voltage



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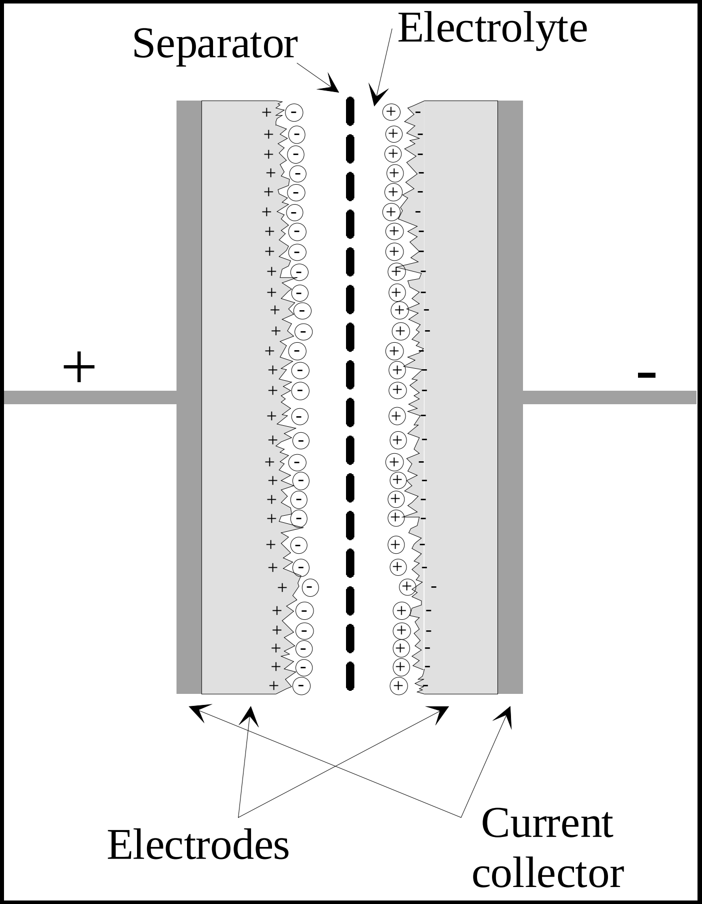
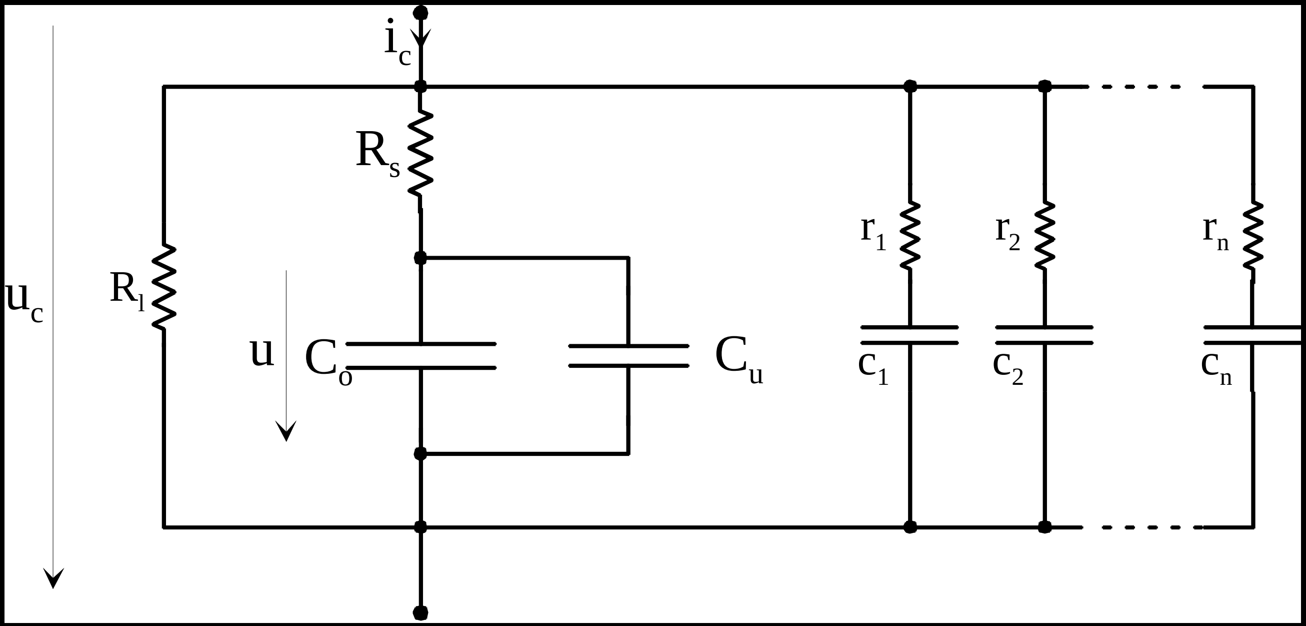
# Generalities on Supercapacitors

- Principle : technology
  - Electrodes: activated carbon
    - High surface area part
    - Define the energy density
  - Current collectors
    - High conducting part
  - Membrane
    - Avoids electronic contacts between the electrodes
    - Allows the mobility of the charged ions
  - Electrolyte
    - Supplies and conducts ions
    - Dissociation voltage of organic electrolytes less than 3V
    - Organic electrolytes have a lower ionic conductivity (reduced power capability)



# Generalities on Supercapacitors

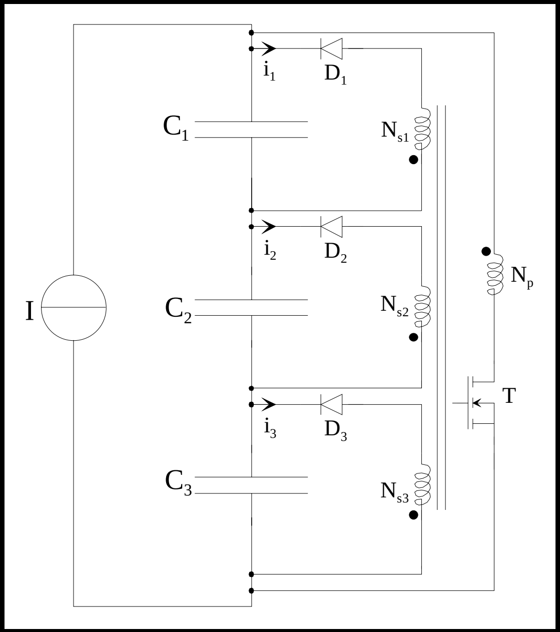
- Model of supercapacitors




  - Voltage dependant capacitance
  - Series resistor
  - Leakage resistor
  - rc sub-circuits (relaxation phenomena)

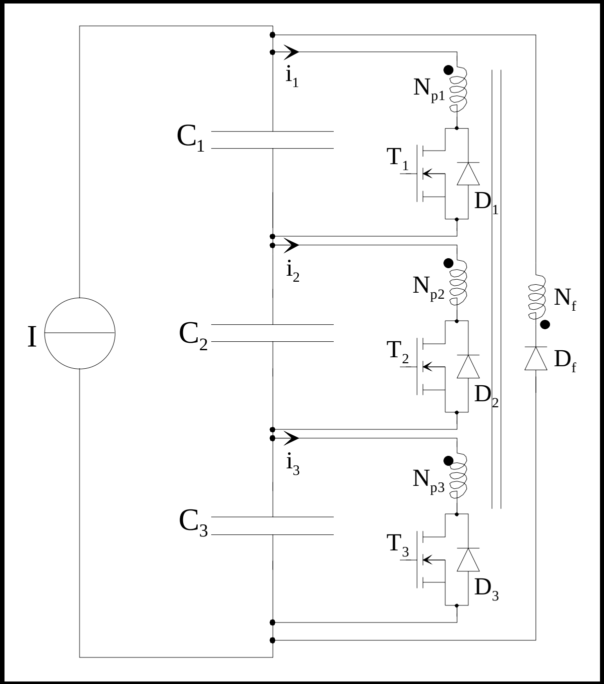
# Generalities on Supercapacitors

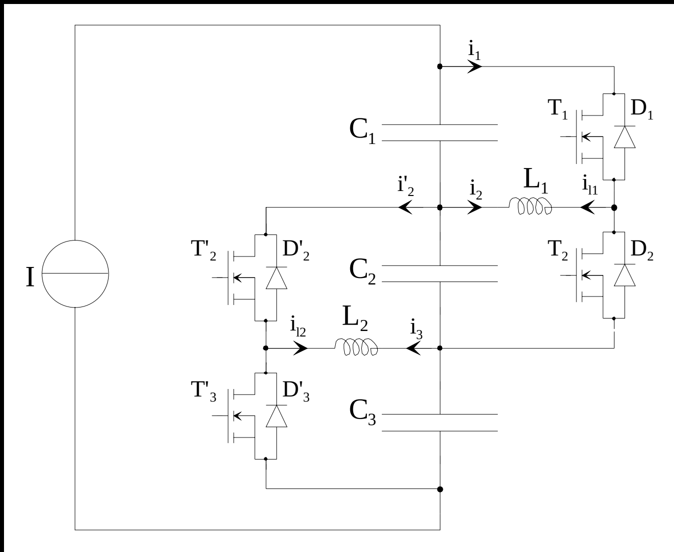
- Series connection of supercapacitors
  - Voltage sharing solution, using power electronics solutions to offer a high efficiency.




Centralized flyback dc-dc converter with distributed secondary

forward dc-dc converter with distributed primary




association of buck-boost dc-dc converters

# Sizing of a supercapacitive tank

- Sizing method
  - Energy stored in a supercapacitor

$$W_M = \frac{1}{2} C U_M^2$$

  - Voltage discharge ratio: the minimum voltage during the discharge has to be limited for efficiency reasons

$$d = \frac{U_m}{U_M} 100$$

  - The usable energy is then only part of the maximum stored energy

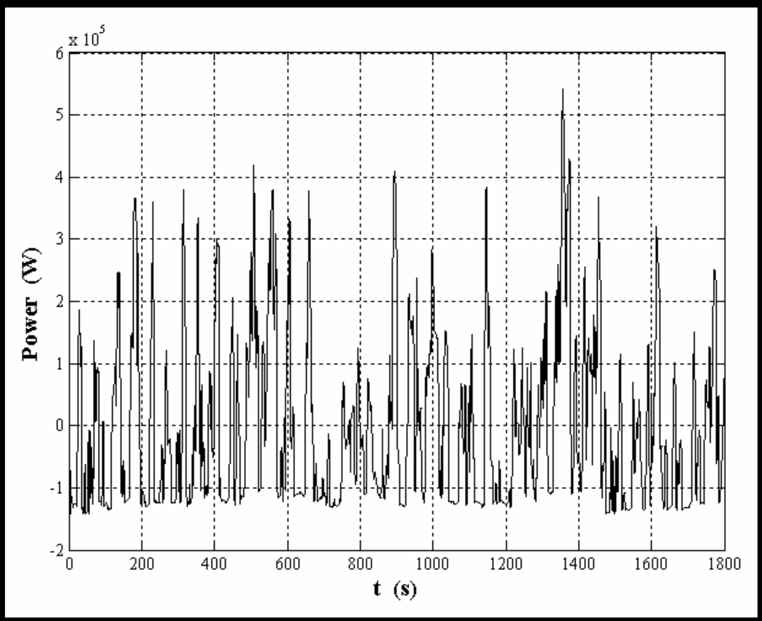
$$W_u = W_M \left( 1 - \left( \frac{d}{100} \right)^2 \right)$$

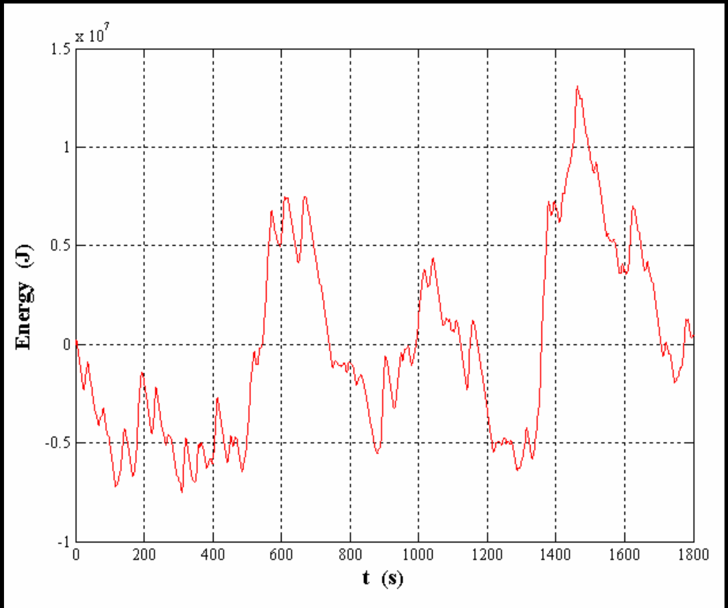
  - Number of supercapacitors for a given usable energy

$$N_s = \frac{2 W_u}{C U_M^2 \left[ 1 - \left( \frac{d}{100} \right)^2 \right]}$$

# Sizing of a supercapacitive tank

- Sizing method
  - Example



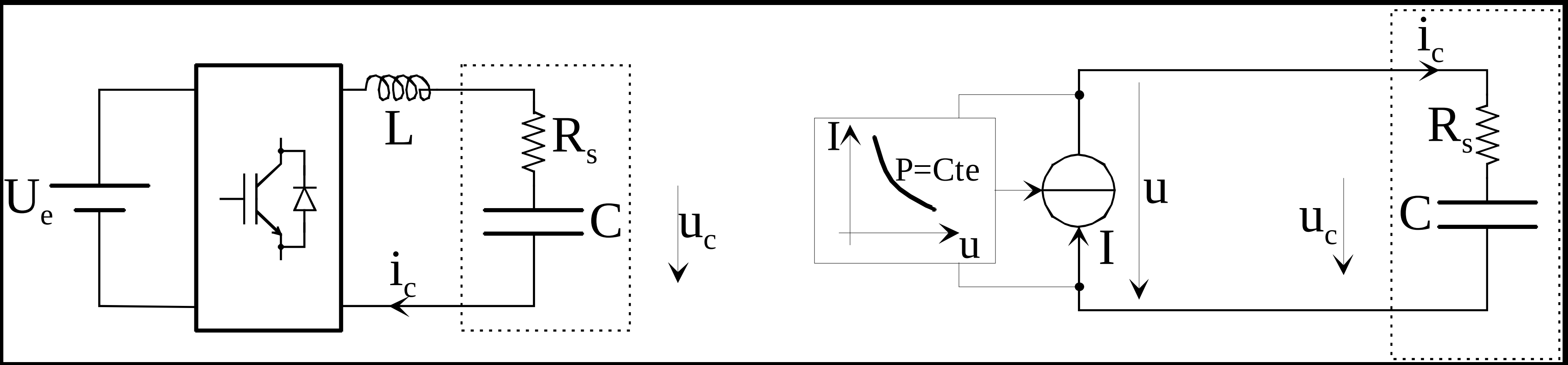

**The needed energy is $E_u$=20.55MJ(5.7kWh)**

$W_u$=0.55MJ (5.7kW.h)
C=1800F, $U_M$=2.5V, $I_M$=200A

| $N_s$ | d (%) | Volume ($m^3$) | Weight (kg) | E (kw.h) |
|---|---|---|---|---|
| 4872 | 50 | 1.46 | 1948 | 7.6 |
| 5709 | 60 | 1.71 | 2283 | 8.92 |
| 7164 | 70 | 2.15 | 2865 | 11.2 |

# Sizing of a supercapacitive tank

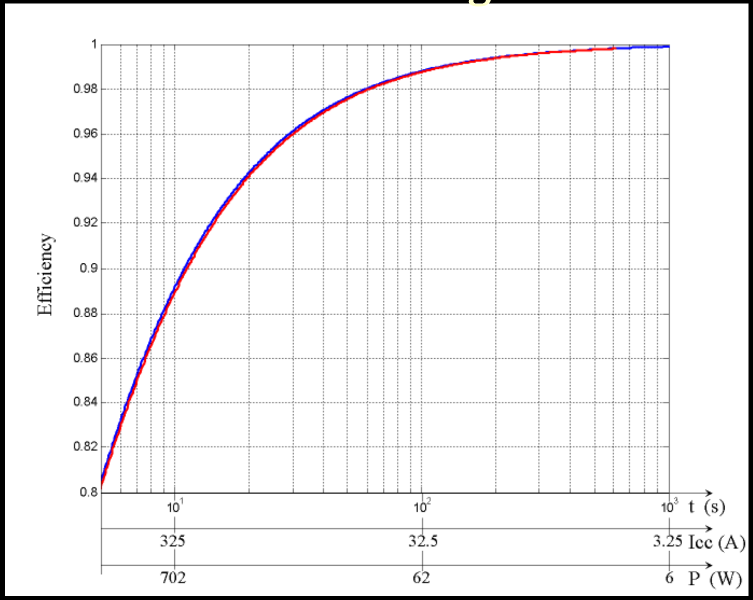
- Energy efficiency and power availability
  - Due to the series resistor, energy efficiency of supercapacitors has to be taken into account during the sizing of the supercapacitive tank
  - Energy efficiency has also an influence on the power availability
  - Two cases have to be investigated:
    - Energy efficiency for a constant current charge/discharge
    - Energy efficiency for a constant power charge/discharge



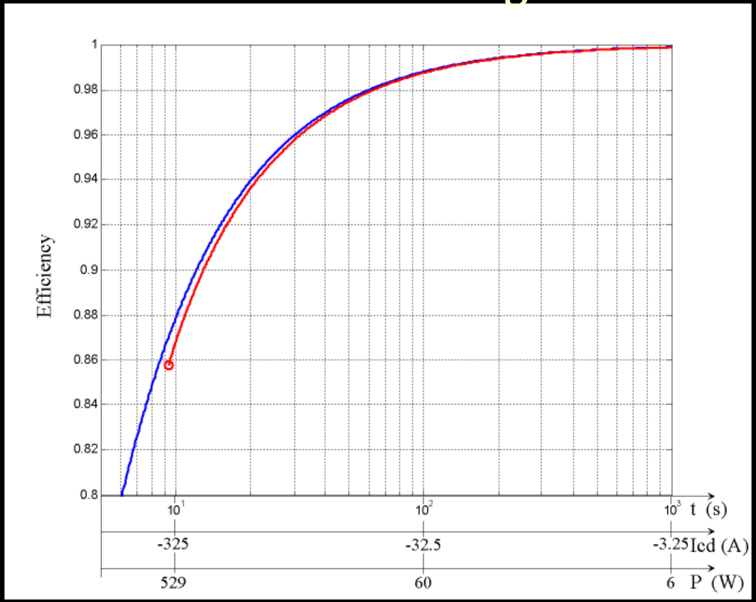
# Sizing of a supercapacitive tank

- Energy efficiency and power availability : Example of a 2600F/2.5V/0.7mΩ Scap

**Charge**



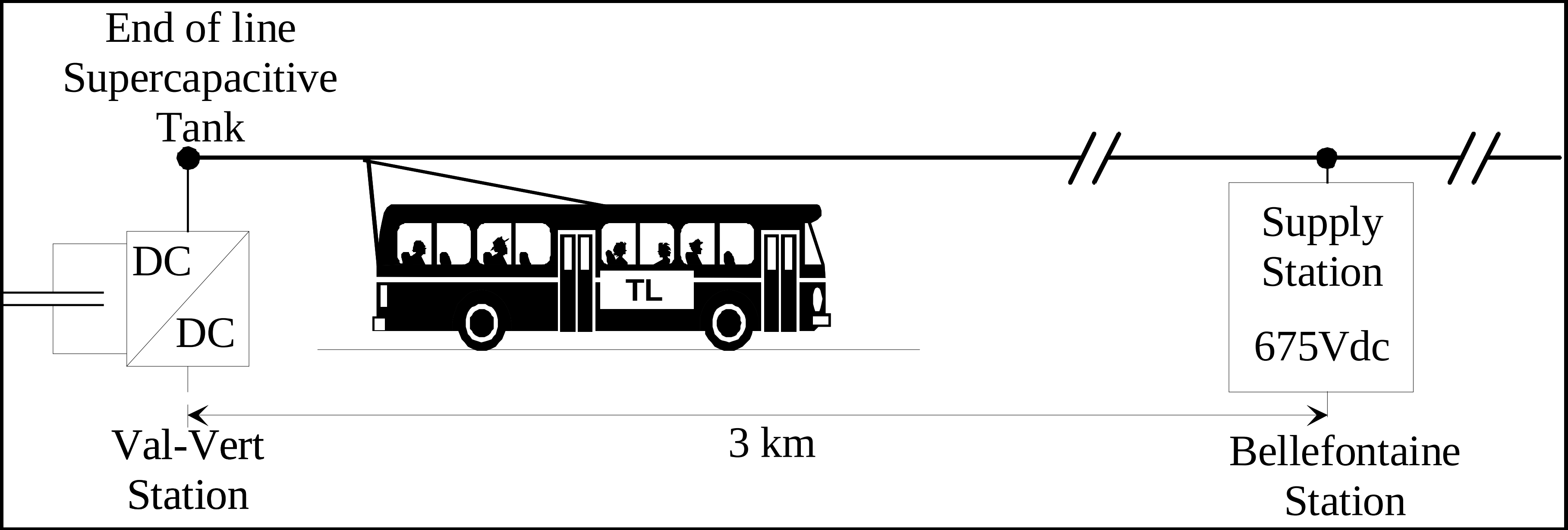

**Discharge**




  - Time for loading energy has to be kept up to 10s for a 90% energy efficiency (Ic<320A or P<700W)
  - Time for unloading energy has to be kept up to 10s for a 90% energy efficiency (Ic<320A or P<400W)
  - Taking into account the necessity of 90% of energy efficiency, the current or the power for charging/discharging have to be limited: the power density is only 806W/kg (instead of 4300W/kg)

# Applications and converters

- Voltage drop compensation for weak distribution networks
  - Using supercapacitors to provide/absorb the energy needed to maintain at a constant level the end-of-line voltage.



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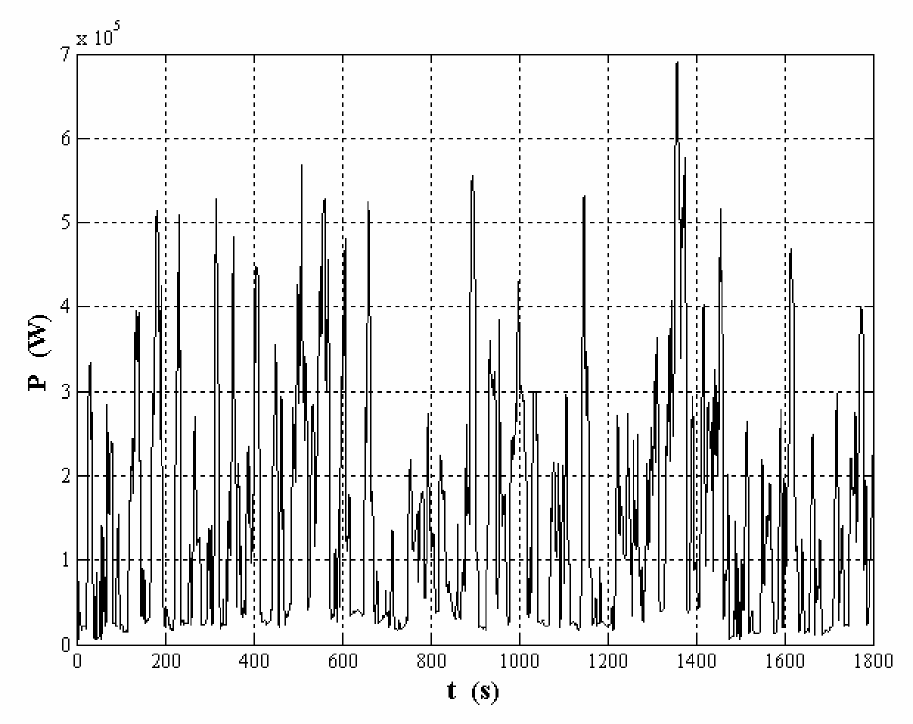
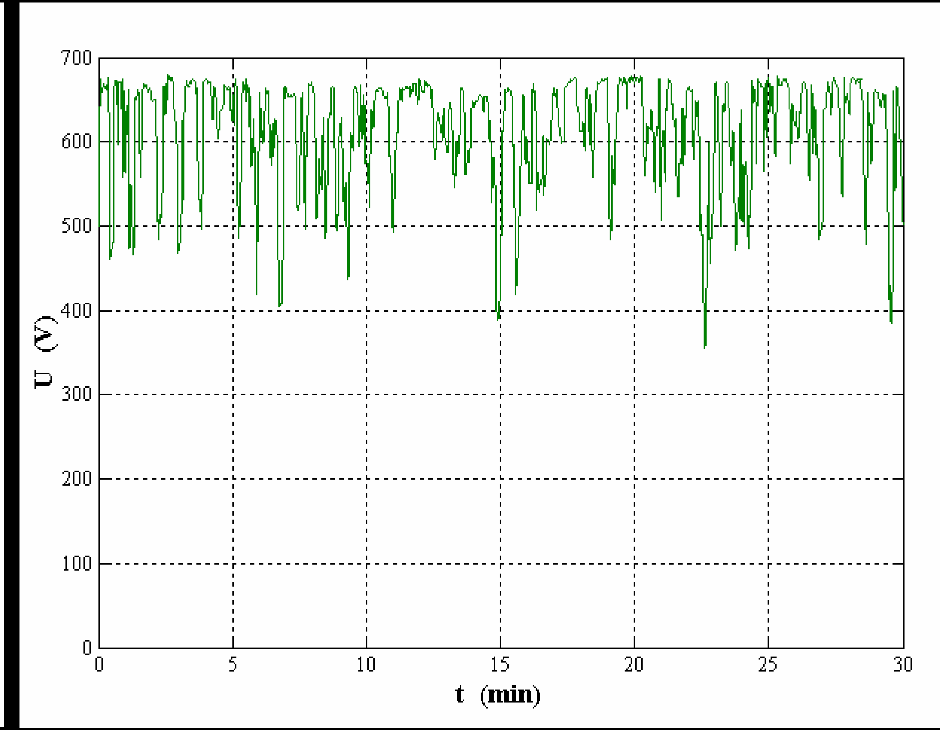
# Applications and converters

- Voltage drop compensation for weak distribution networks
  - Typical waveforms on the line N°7 (Lausanne, CH)



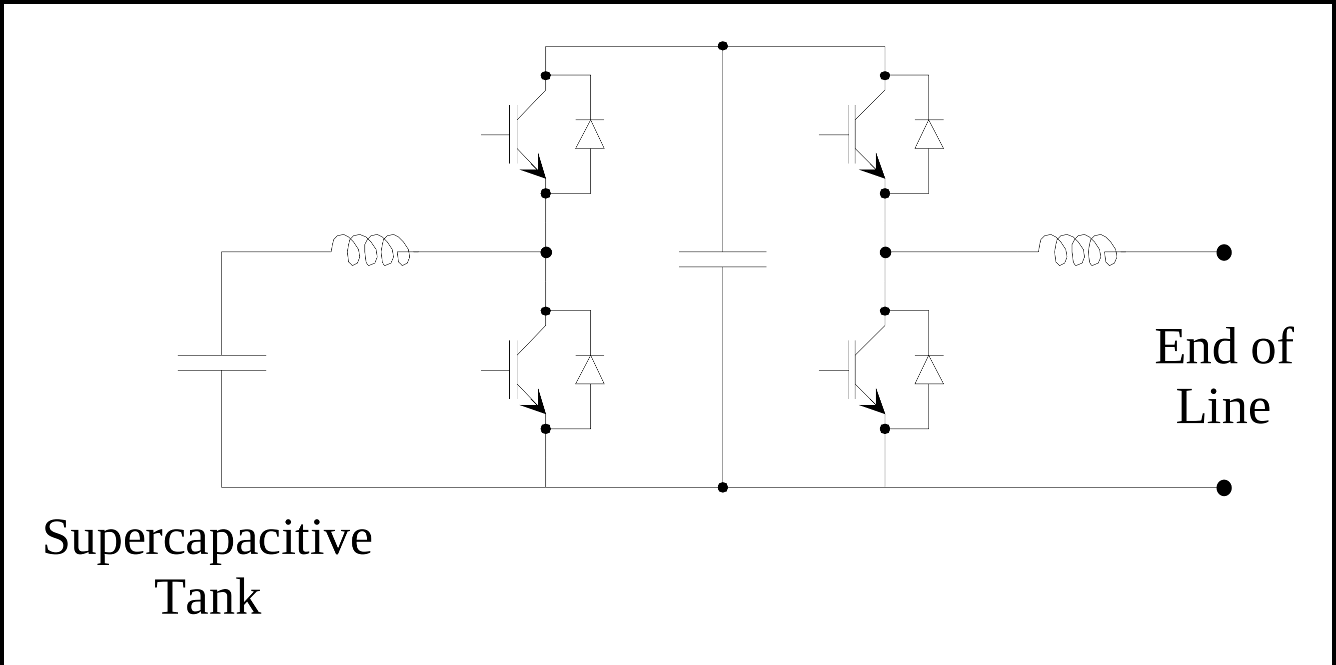

Power Profile
At the "Bellefontaine" station




Voltage at the end of line
"Val-Vert" Station

# Applications and converters

- Voltage drop compensation for weak distribution networks
  - It is necessary to use a double stage power converter to interface the supercapacitive tank to the end of the line.



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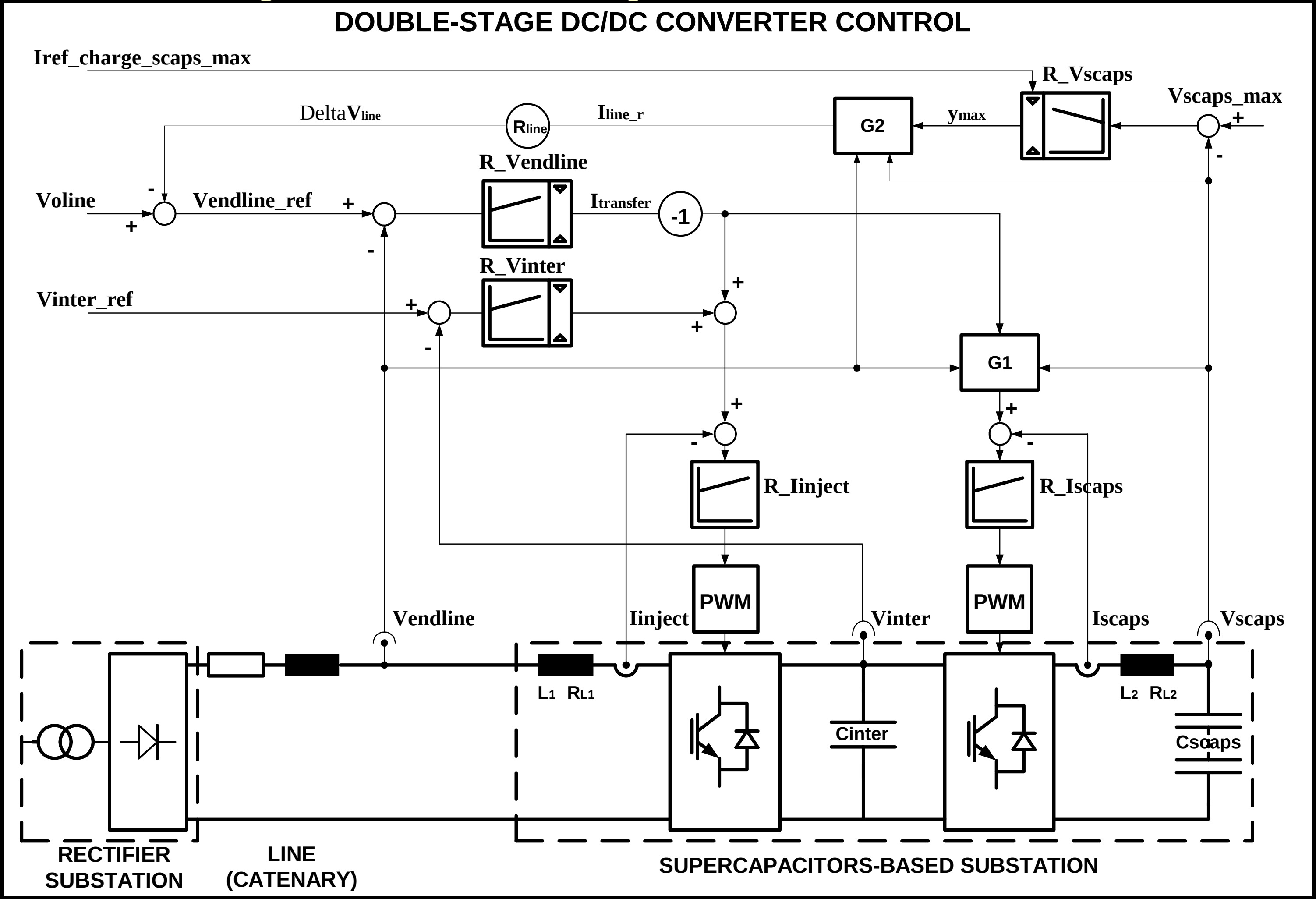
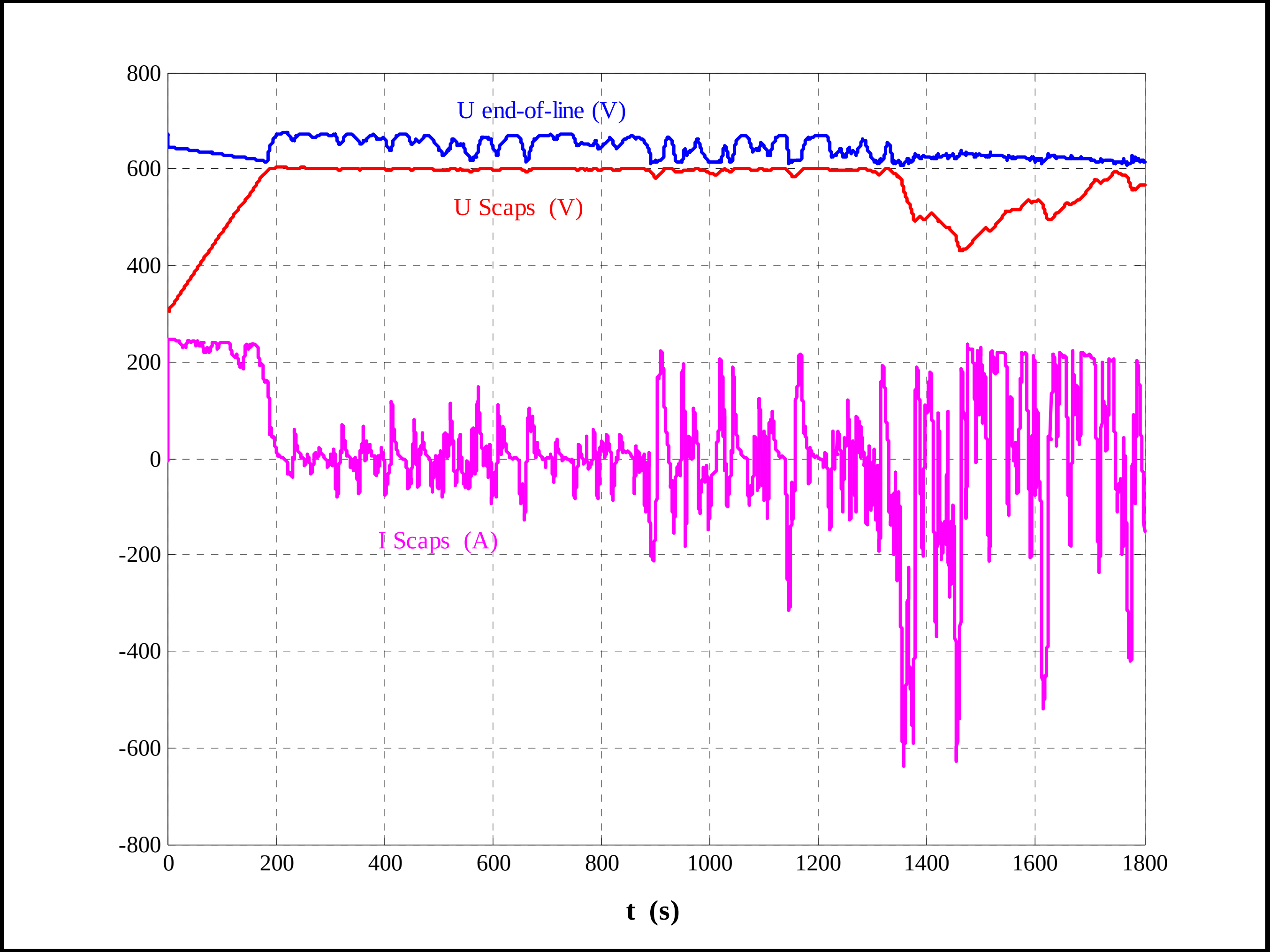
# Applications and converters

- Voltage drop compensation for weak distribution networks
  - Special control algorithm have to be implemented



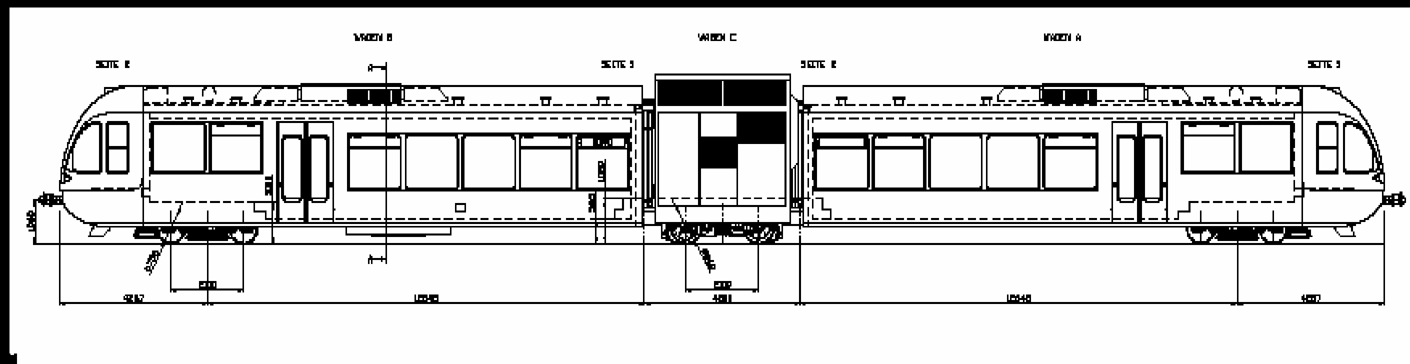
# Applications and converters

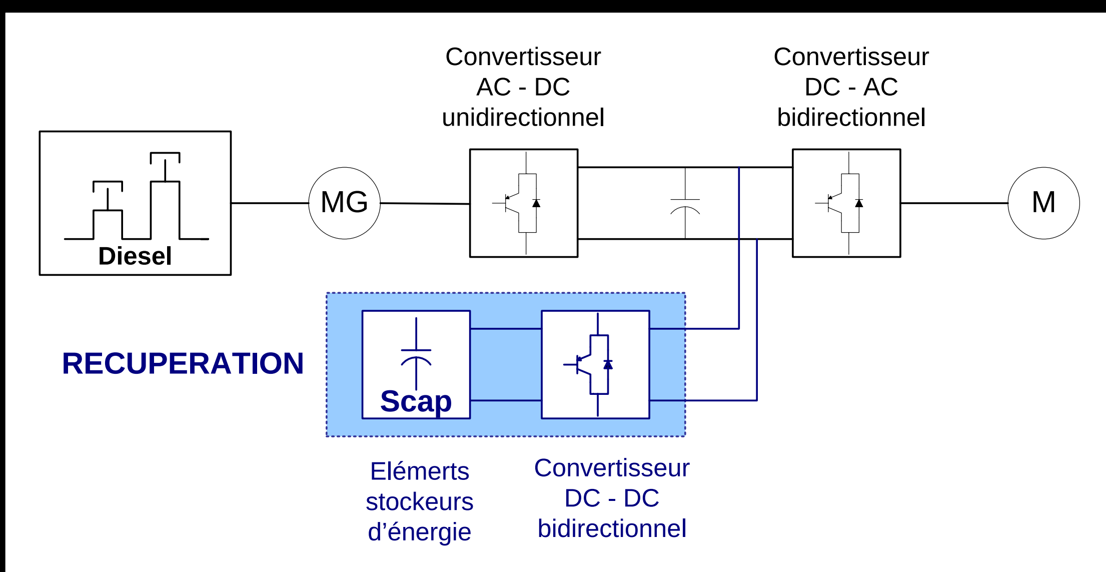
- Voltage drop compensation for weak distribution networks
  - Simulation results



# Applications and converters

- Application in transportation : reduction of emissions and energy savings
  - Diesel-electric trains: reduction of emissions and energy savings
  - Partner : Stadler Rail/ ABB






Principle of operation

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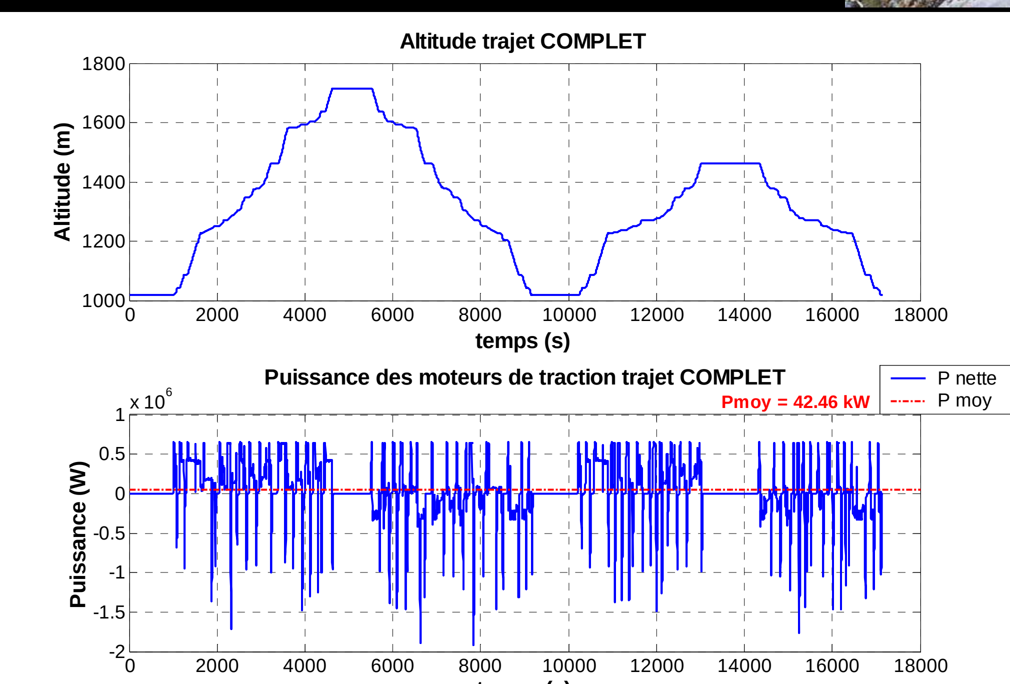
# Applications and converters

- Application in transportation : reduction of emissions and energy savings

The track

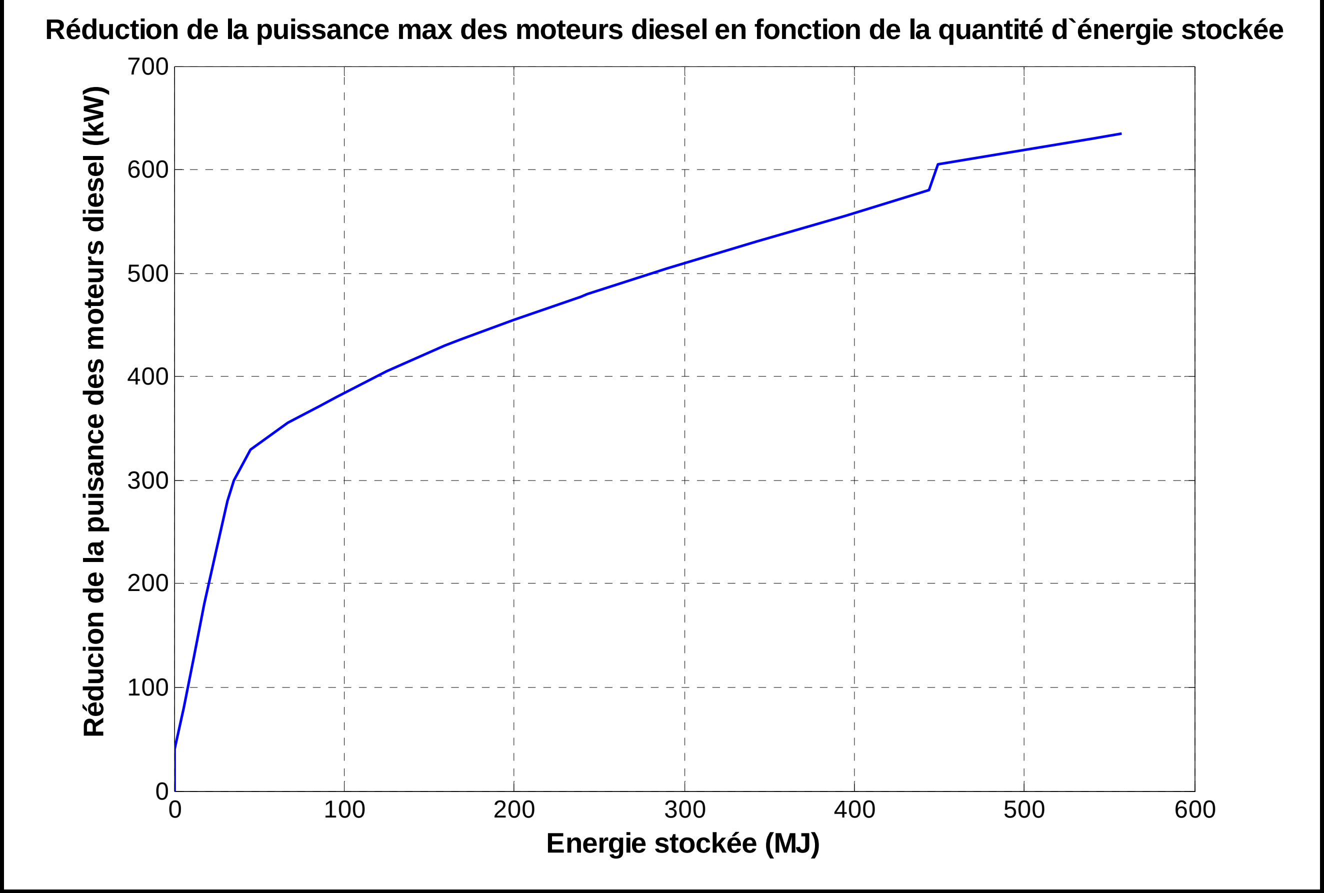




Altitude

Instantanous value of power

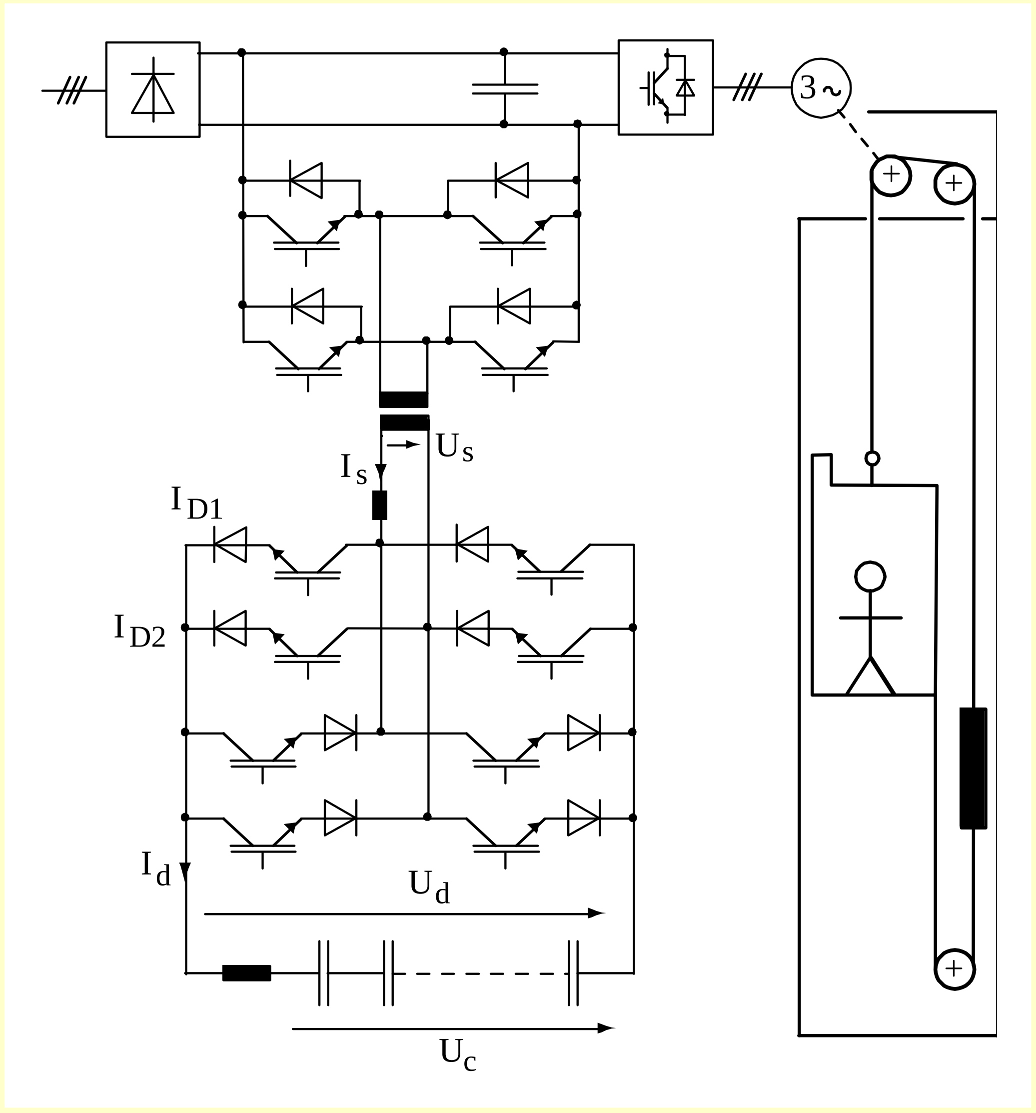
# Applications and converters

- Application in transportation : reduction of emissions and energy savings
  - Reduction of the maximal delivered power of diesel motors in dependency of the amount of stored energy



# Applications and converters

- Energy buffers for elevators

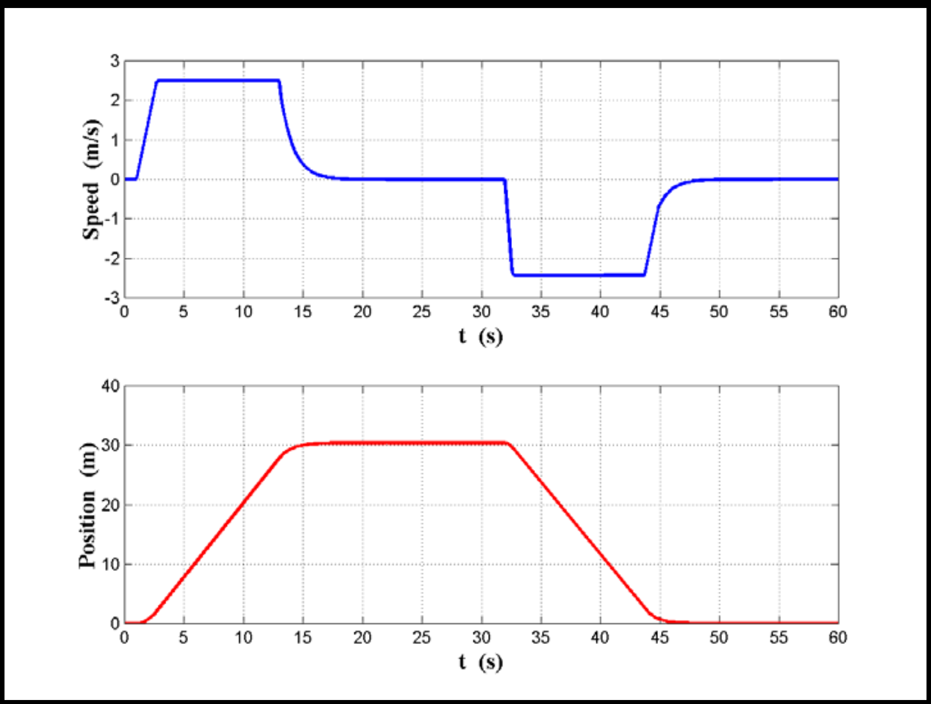


# Applications and converters

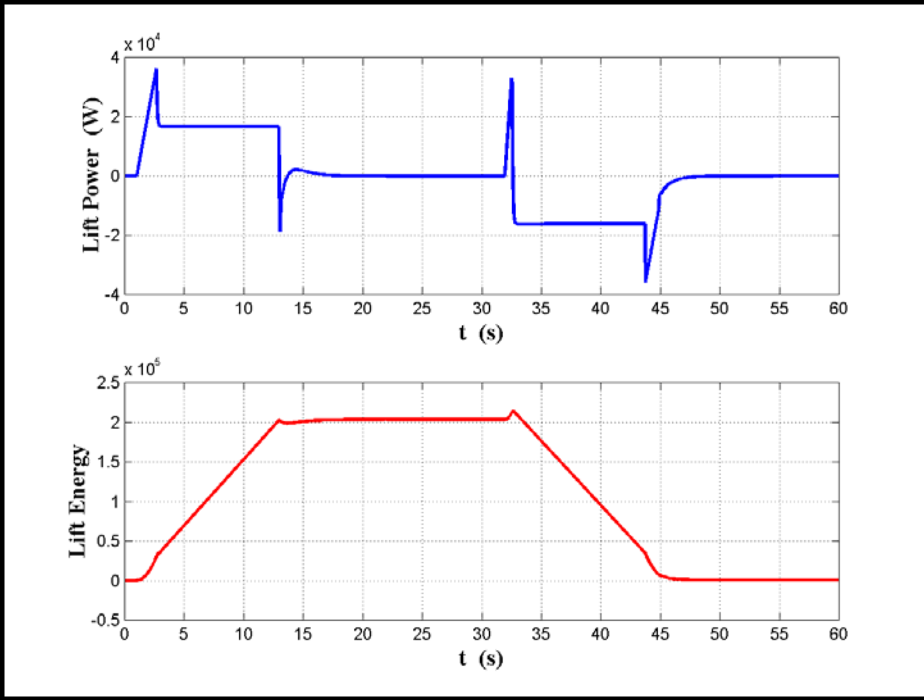
- Energy buffers for elevators :
  - simulations regarding a real system

⇒car weight : 720kg, counter weight : 1440kg, load : 1400kg

**Speed, Position for a 10-floors up/down run**




**Power and Energy for a 10-floors up/down run**




**The needed energy is 220kJ (61Wh)**

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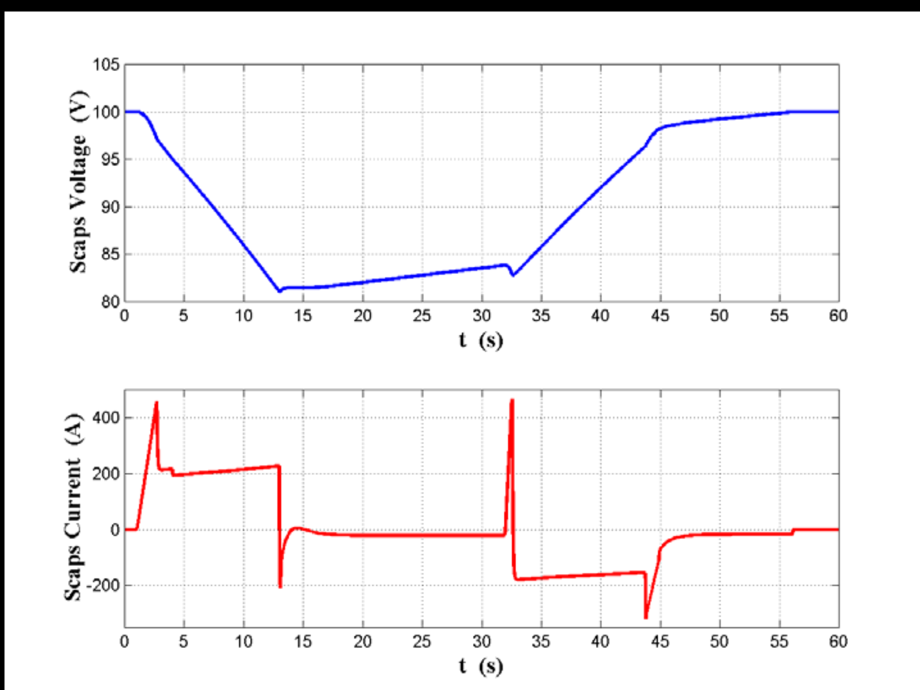
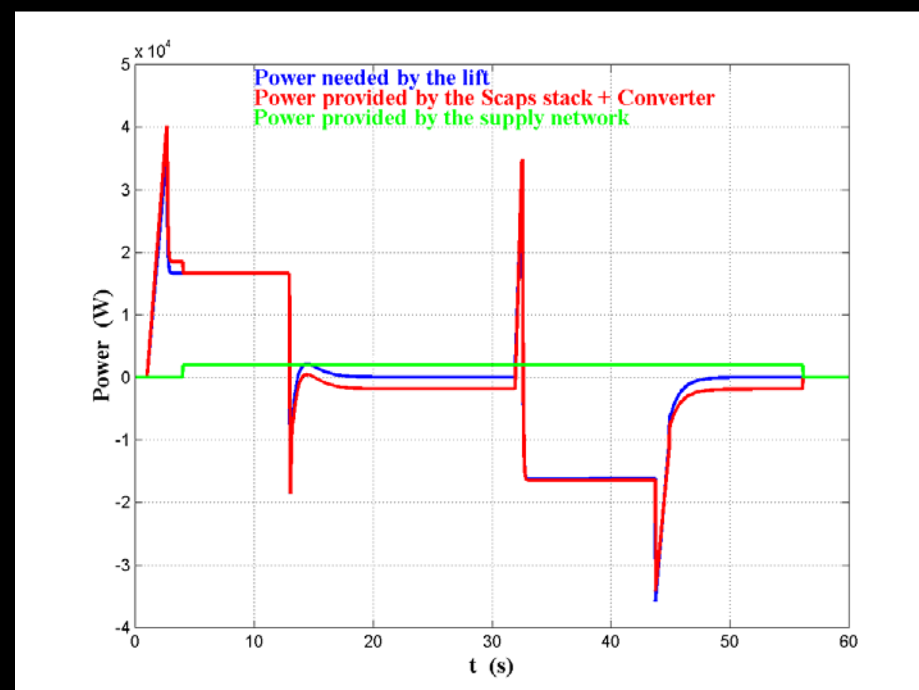
# Applications and converters

- Energy buffers for elevators
  - Simulations regarding a real system
    - The power provided by the network has only to compensate the losses of the lift drive

**Scaps voltage/current (10-floors up/down run)**




**Powers for a 10-floors up/down run**



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# Conclusion

- Supercapacitors are new components for energy storage
  - High energy density (even if lower than batteries)
  - High power density
- Model of supercapacitors have to take into account
  - The voltage dependence of the capacitance
  - The series/leakage resistors
  - Relaxation phenomenon
- Energy efficiency
  - Power availability of supercapacitors is affected by their energy efficiency
- Applications
  - Main applications use supercapacitors as energy buffers
  - In applications where supercapacitors are used as main energy source (UPS), the reduced energy density is compensate by their high power density, combined with an increased lifetime compared to batteries.