

Fractional modelling of supercapacities (SCAPs)

Application to automotive power systems study

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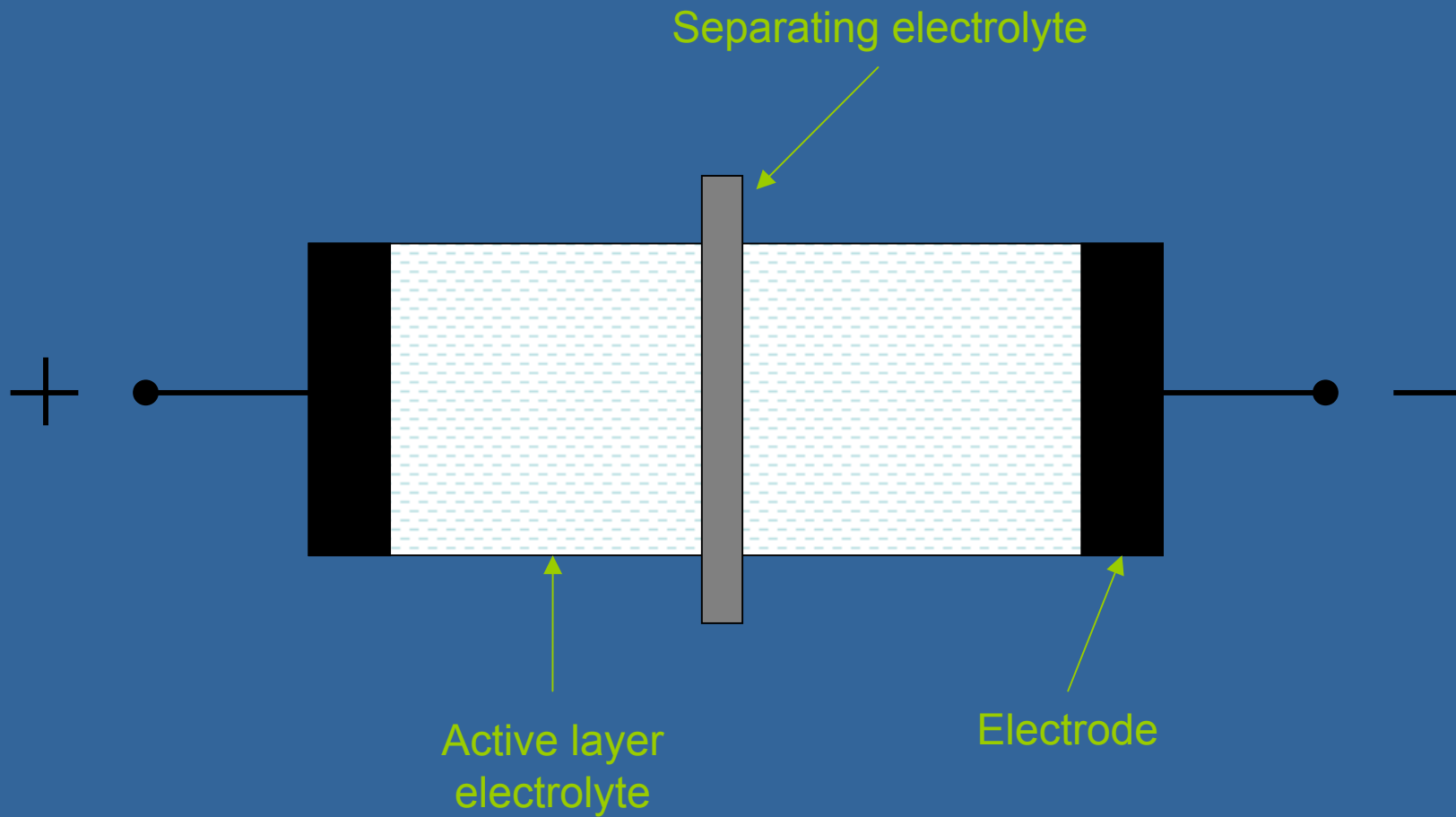
OUTLINE

- Introduction : presentation of supercapacities
- Modelling of supercapacities
- Application : time response study
- Conclusion and prospects

Introduction

Presentation of supercapacities

Principle of the double layer (planar representation)



Principal types of SCAPs : depends on electrolyte technology

- ✓ Activated carbon electrolytes
- ✓ Electrolytes based on metallic oxides
- ✓ Electronic conductive polymers

Mandatory stack utilisation

Technology	Active carbon	Metallic oxydes	Conductive Polymers
Energy density	2 - 40 kJ / kg	10 - 20 kJ / kg	10 - 40 kJ / kg
Power density	0.1 - 2 kW / kg	10 - 100 kW / kg	100 kW / kg
Rated - Surge voltage	2.3 - 3 V	0.8 - 1.2 V	1.3 - 2.5 V
Cycles	> 100 000	> 100 000	10 000 → 100 000
Cost	Relatively low	high	?

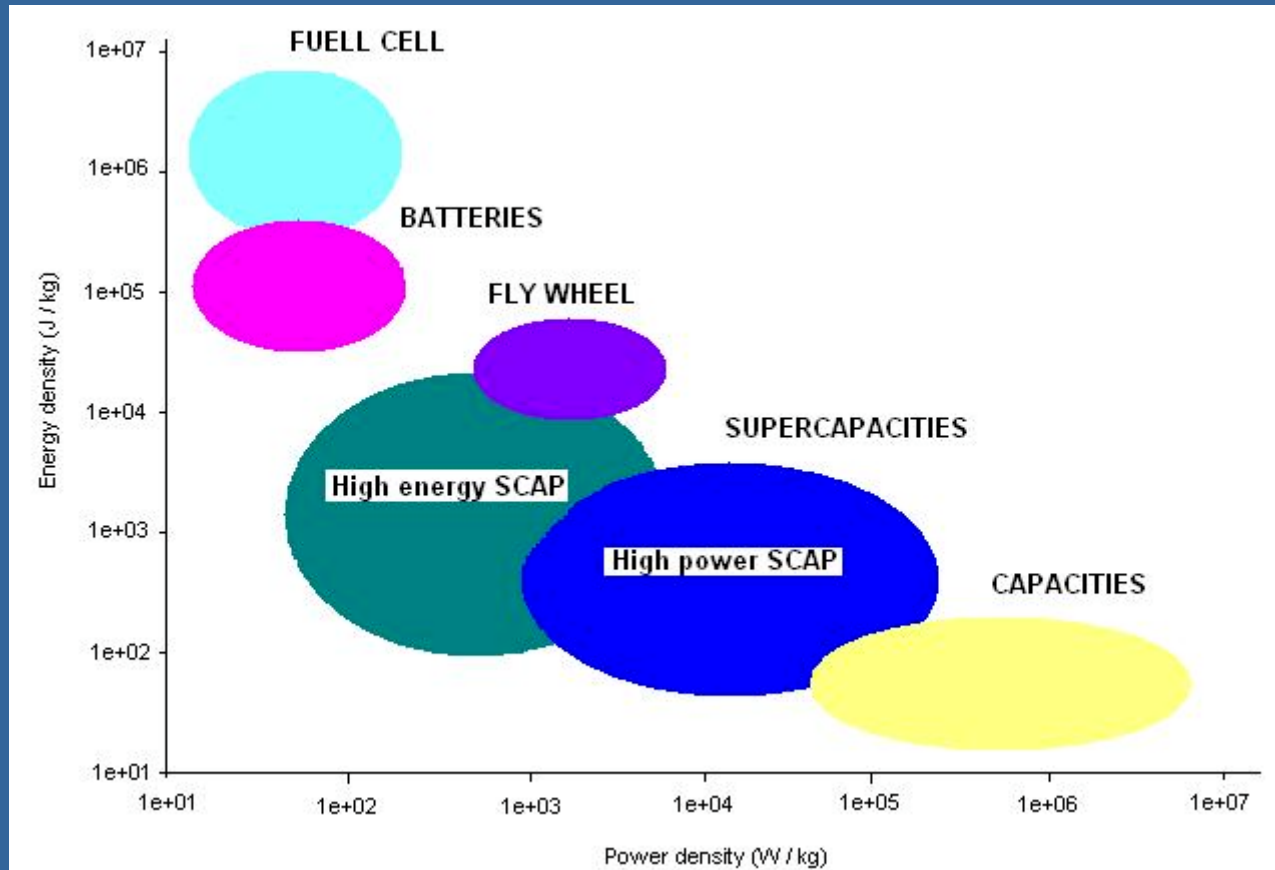
Applications of supercapacities

↳ Utilisation in **automotive vehicles** (hybrid or not)

- ✓ less requests of battery
 - increase its lifespan
- ✓ performances independant of the battery state,
- ✓ under-to dimension the principal source of energy,
- ✓ increase the power available in transient state,
- ✓ recover the braking energy,
- ✓ increase the vehicle autonomy.

↳ Utilisation in **power systems** for power electronics interfaces
(FACTS, wind mill...)

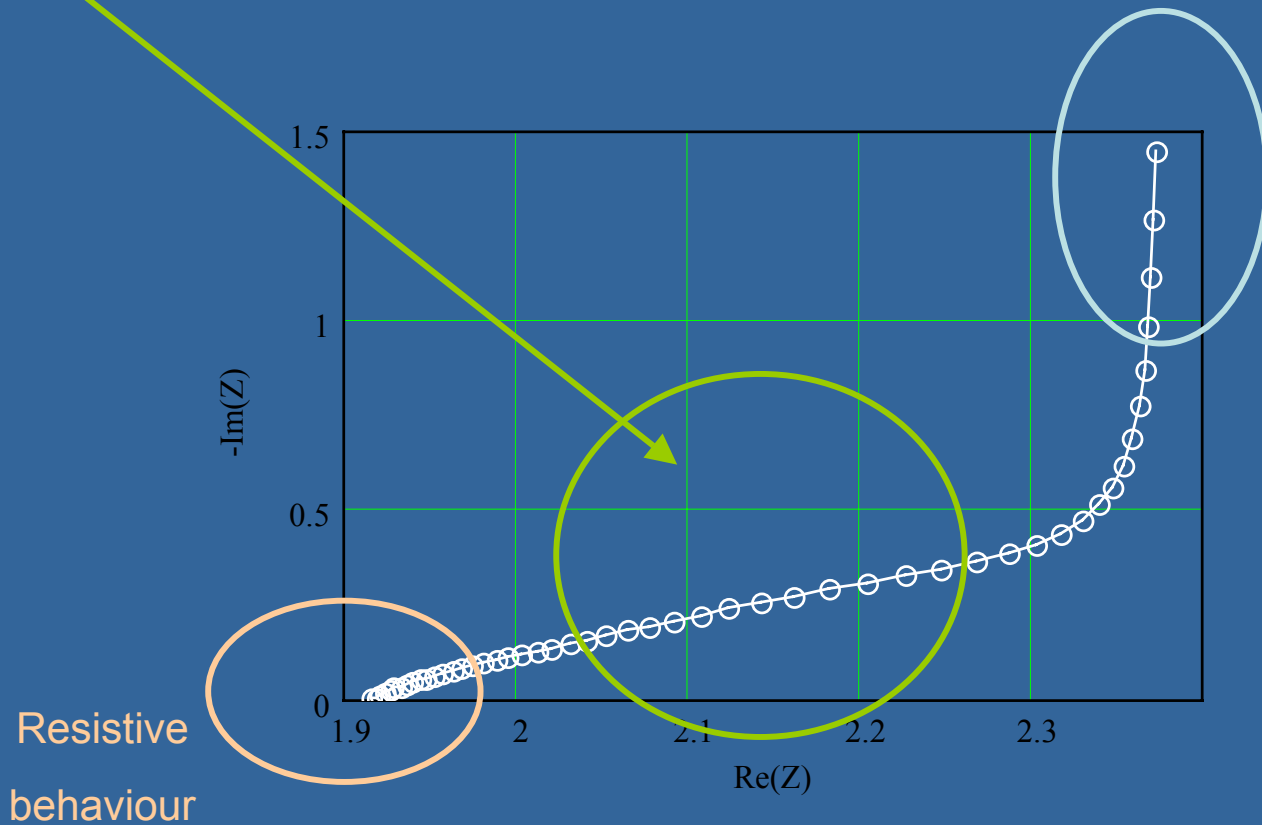
Comparison with other storage devices (Ragone diagram)



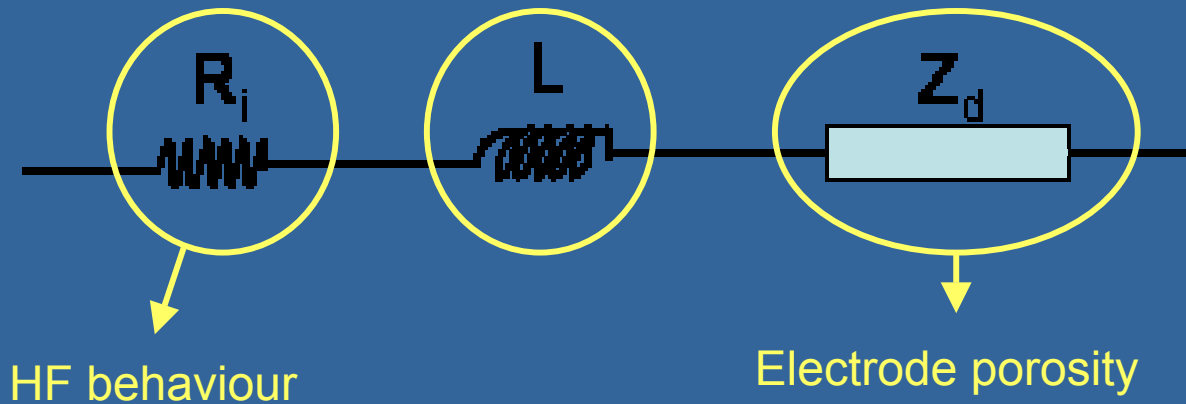
Supercapacities modelling

Impedance of a 1400 F supercapacity (measured with EIS)

Half-order behaviour



Modelling of supercapacity



Analytical modelling of porosity :

$$Z_d(j\omega) = \frac{\tau \cdot \coth(\sqrt{j\omega\tau})}{C \cdot \sqrt{j\omega\tau}}$$



Serial decomposition of coth

Equivalent circuit representation based on (R-C) cells

Half-order modelling of supercapacity

➡ Limited development of $\coth(x)$

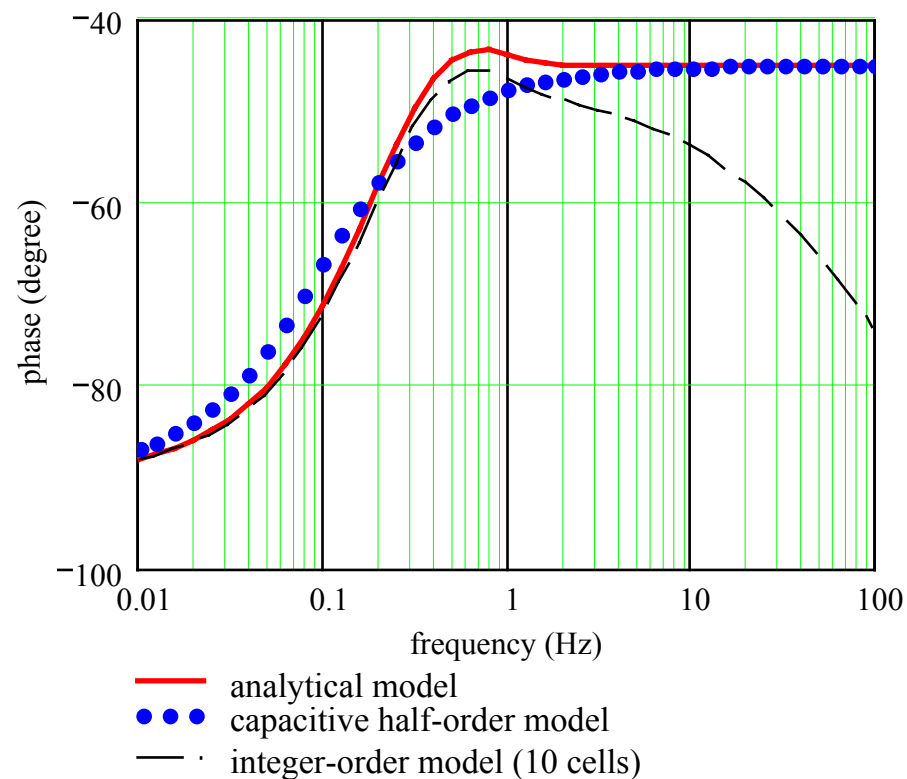
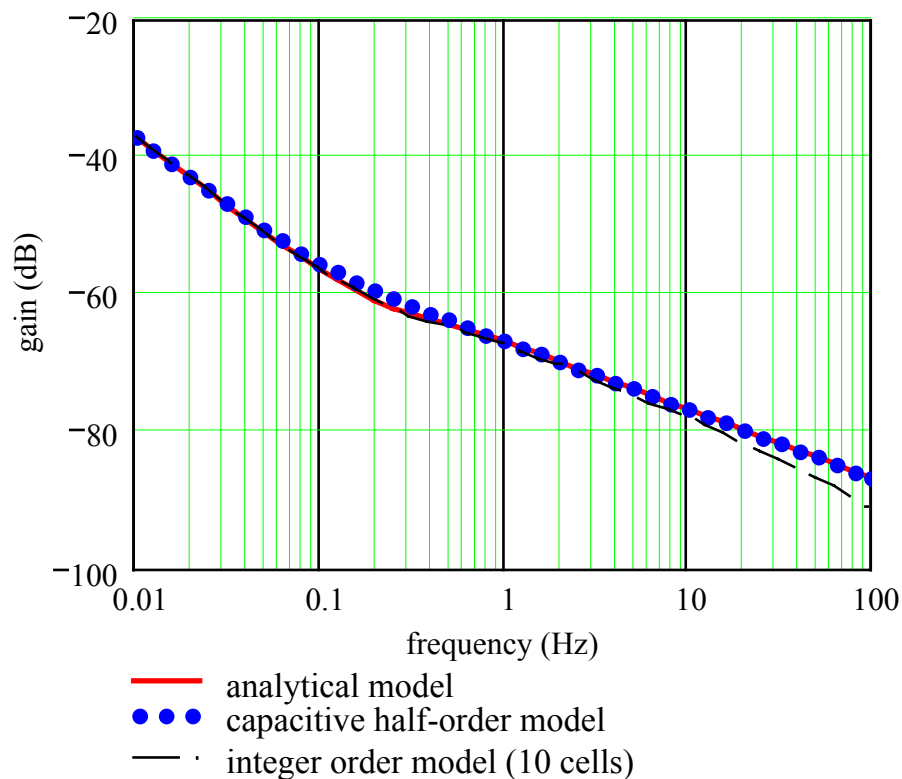
$$\coth(x) = \frac{\cosh(x)}{\sinh(x)} \underset{x \rightarrow 0}{\approx} \frac{1 + x^2/2}{x} \underset{x \rightarrow 0}{\approx} \frac{\sqrt{1 + x^2}}{x}$$

➡ Half-order modelling of porosity

$$Z_d^{1/2} = \frac{\sqrt{1 + j \frac{\omega}{\omega_0}}}{jC_0\omega} \quad \text{with} \quad C_0 = C \quad \text{and} \quad \omega_0 = \frac{1}{\tau}$$

Capacitive implicit half-order system

Comparison between analytical, half-order and integer models



$R_i = 1.883 \text{ m}\Omega$

$L = 50 \text{ nH}$

$t = 1.67 \text{ s}$

$C = 1130 \text{ F}$

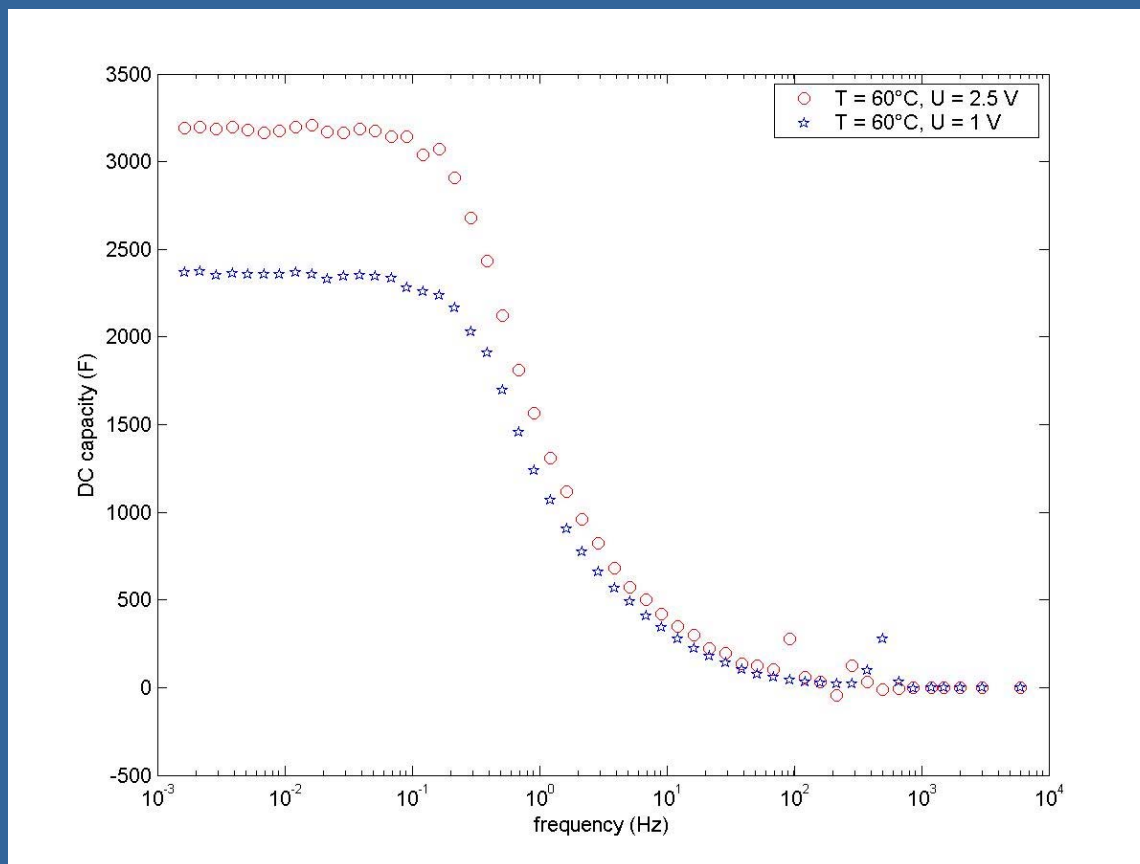
Difficulties of modelling



Non-linear behaviour of capacities

Température

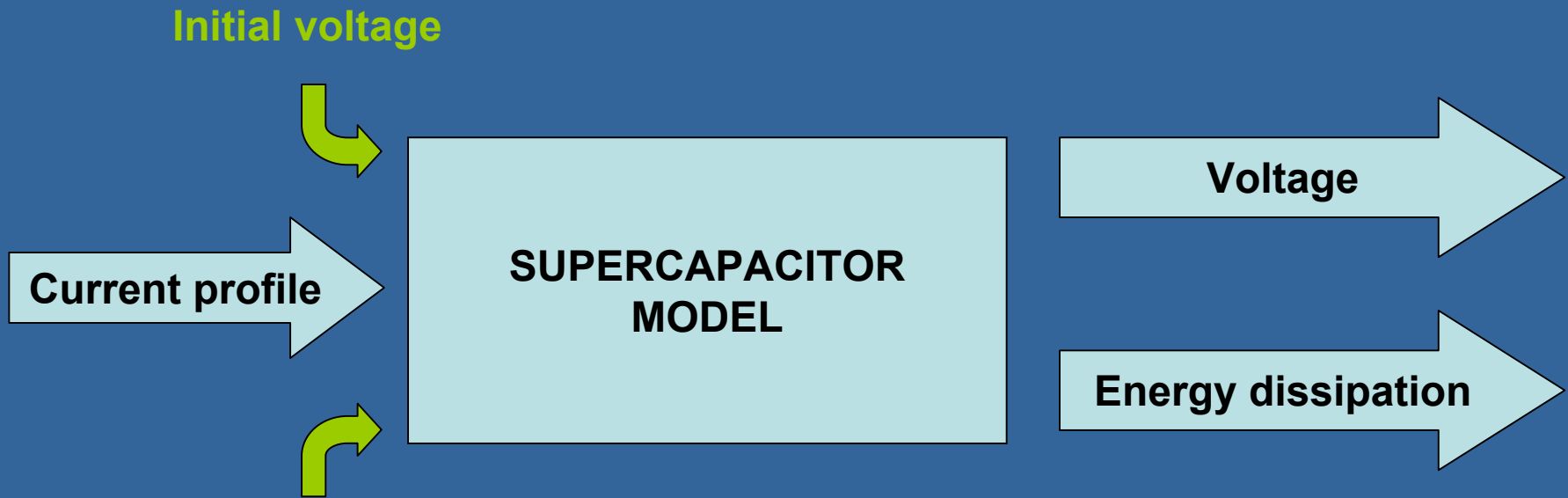
Supply voltage



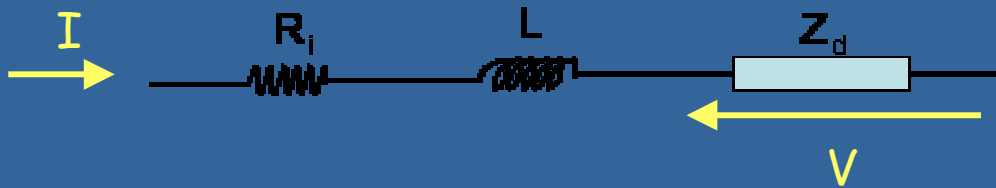
Application

Time response study

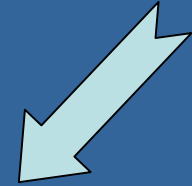
Simulation model :



Current : | - highly dynamic load profile
 | - Deeper discharge and charge



$$V(p) = \frac{1}{C_0 \omega_0^{1/2}} \cdot \frac{(\omega_0 + p)^{1/2}}{p} I(p)$$



$$\frac{ds(t)}{dt} - \omega_0 \cdot s(t) = \frac{1}{C_0 \omega_0} D^{(1/2)} e(t) \quad \left| \quad \begin{array}{l} s(t) = V(t) \cdot \exp(\omega_0 t) \\ e(t) = I(t) \cdot \exp(\omega_0 t) \end{array} \right.$$

$$\begin{cases} s_0 \\ s_m = \frac{1}{h^{-1} - \omega_0} \left[\frac{1}{C_0 \sqrt{\omega_0}} f_m + \frac{1}{h} s_{m-1} \right] \end{cases}$$

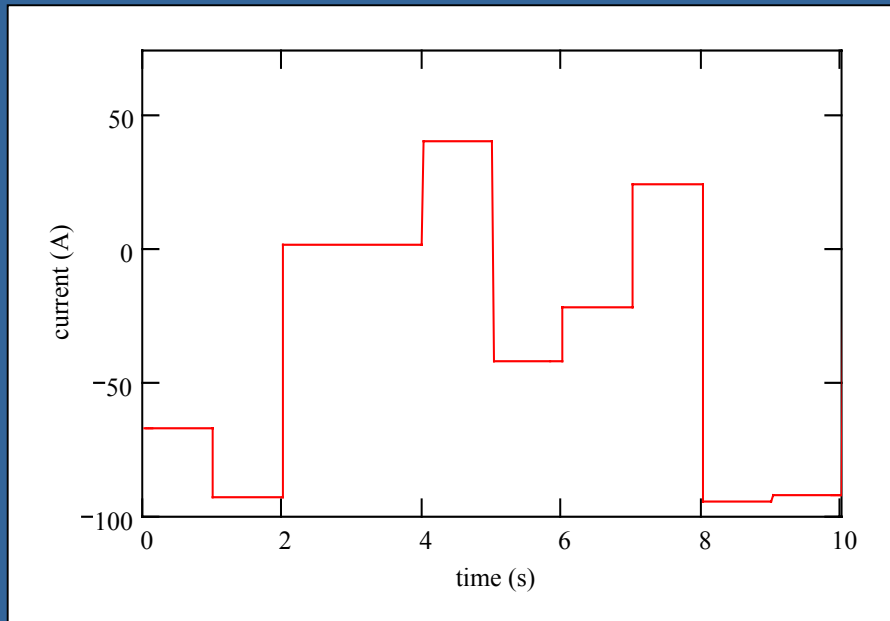
Fractional derivative of $e(t)$ for each step



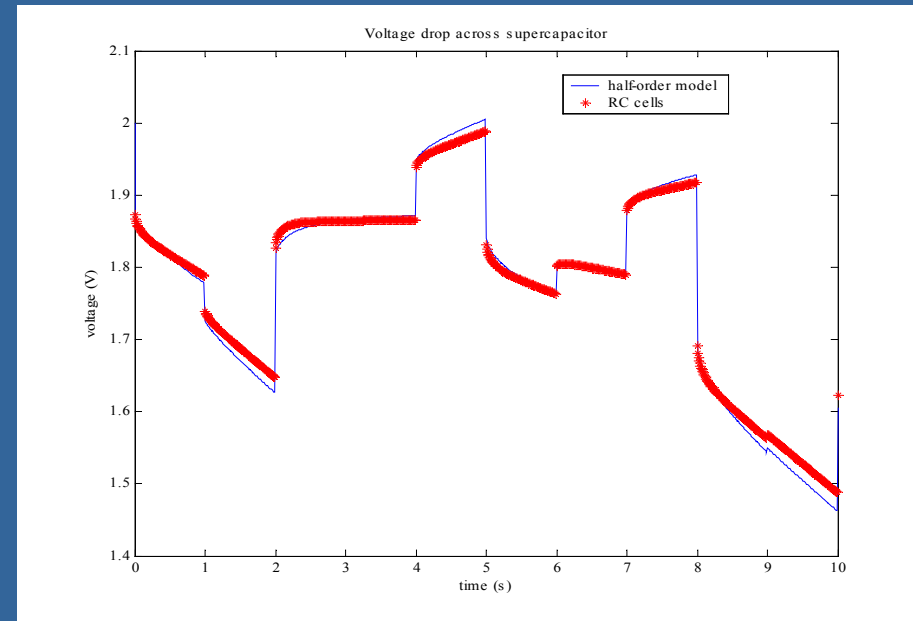
Application : $T = 25\text{ }^{\circ}\text{C}$

$U_{\text{initial}} = 2\text{ V}$

Current profile



Output voltage



*** 10 (R-C) cells

— half-order model



Validation of half-order modelling

Conclusion and prospects

Conclusions :

- ✓ Implicit half-order modelling of porosity
- ✓ Comparison with integer order models
 - ↳ diminution of parameter number
 - ↳ availability on a large frequency range
- ✓ Voltage calculation for any current profile
- ✓ Development of a simulation tool dedicated for impact study of supercapacitor insertion in power systems

Prospects :

- ✓ taking into account of non-linearities
- ✓ insertion of supercapacities in other electric systems