Static and dynamic characterization of a supercapacitor

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ABSTRACT

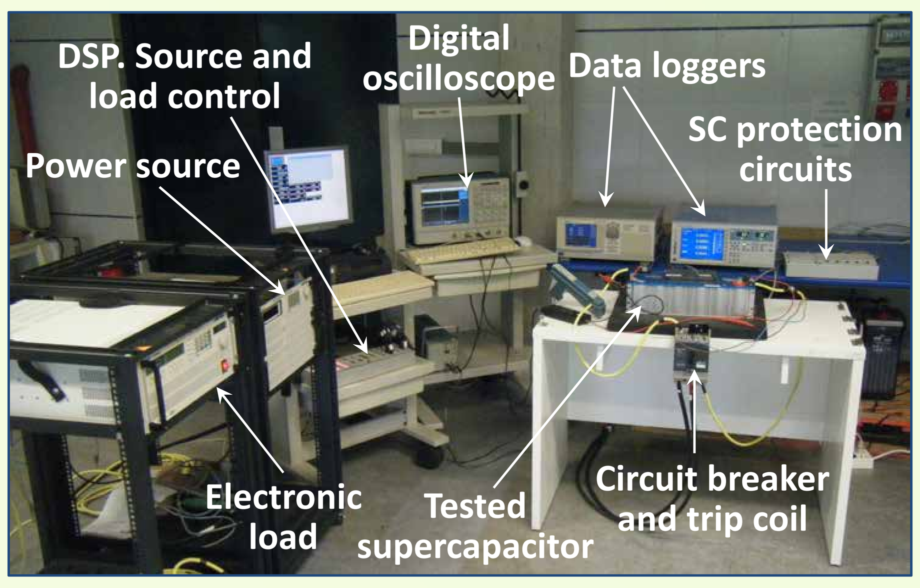
Supercapacitors (SCs) have recently received a major boost as a result of the development of multiple applications, such as the electric vehicle and electric microgrids. Storage systems consisting of SCs combined with batteries or fuel cells have been proposed in multiple applications. Since SCs store energy as an electric field, they are able to efficiently manage high power and high frequency charge-discharge cycles. This ability to handle high power in a wide frequency range grants them a wide advantage against other energy-storage technologies. A static and dynamic characterization of the Maxwell SC BMOD0083 has been accomplished in this study.

EXPERIMENTAL SET-UP

- The Renewable Energies Laboratory of the Public University of Navarre is equipped with the BMOD0083 SC and the power, measurement and protection devices needed to safely and accurately perform the experiments.
- The BMOD0083 SC has a nominal capacitance of 83 F and a nominal voltage of 48 V. It is compound of 18 series-connected cells, each of them with a nominal capacitance of 1500 F and a nominal voltage of 2.7 V.
- The ambient temperature is kept in the range between 22 and 25 ˚C during the experiments.

BMOD0083 SC (Maxwell)

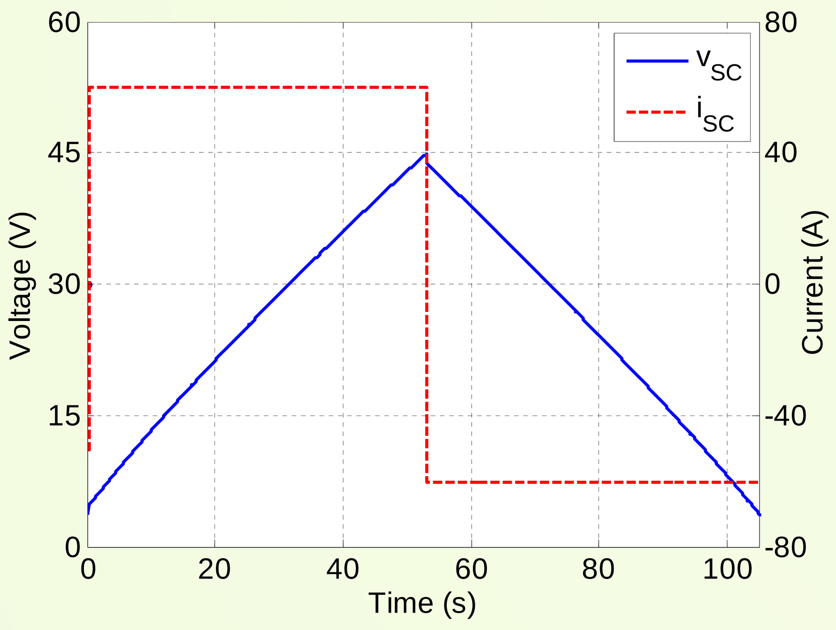
Test bench



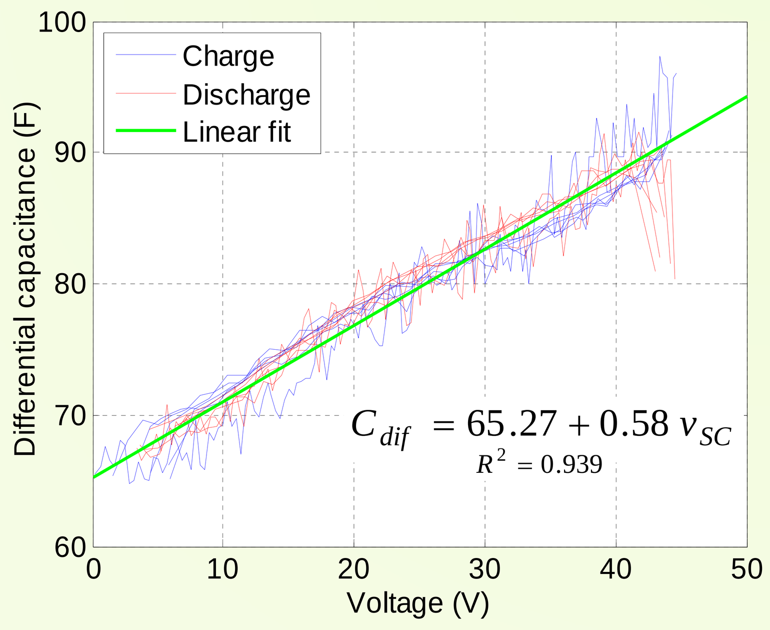
STATIC ANALYSIS

Characterization

60 A charge-discharge cycle



Differential capacitance



- Current: ±10, ±20, ±30, ±40, ±50, ±60 A
- Differential capacitance:

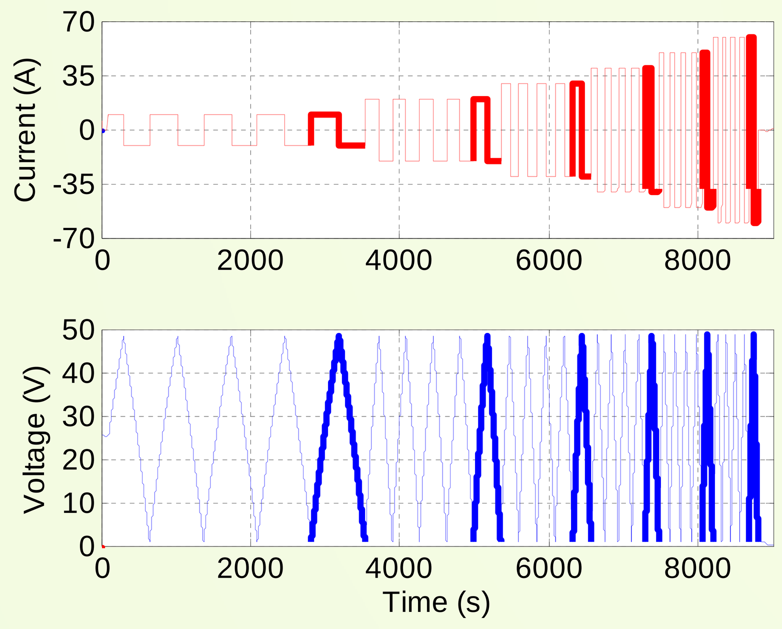
$$i_{SC} = C_{dif} \frac{dv_{SC}}{dt}$$

- Linear relationship between differential capacitance and voltage:

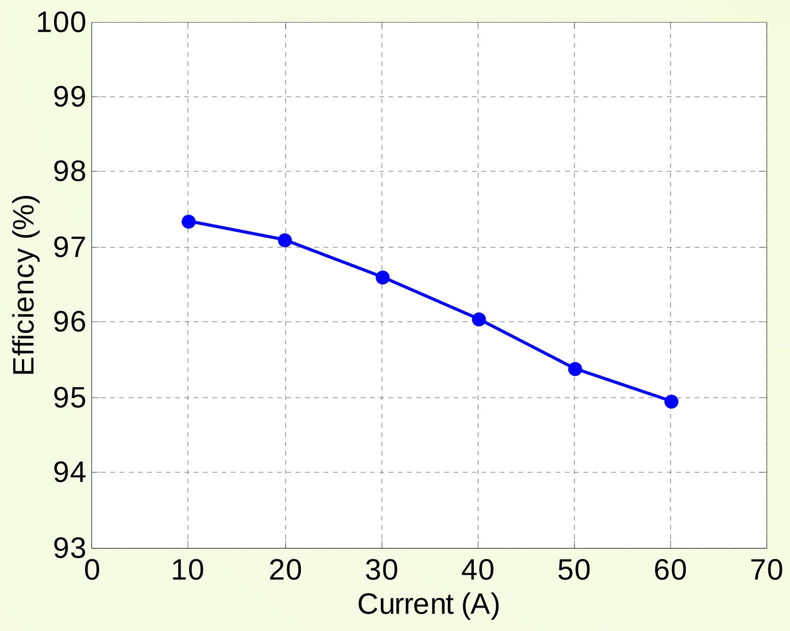
$$C_{dif} \approx i_{SC} \frac{\Delta t}{\Delta v_{SC}} = C_0 + k\, v_{SC}$$

Efficiency

Efficiency test



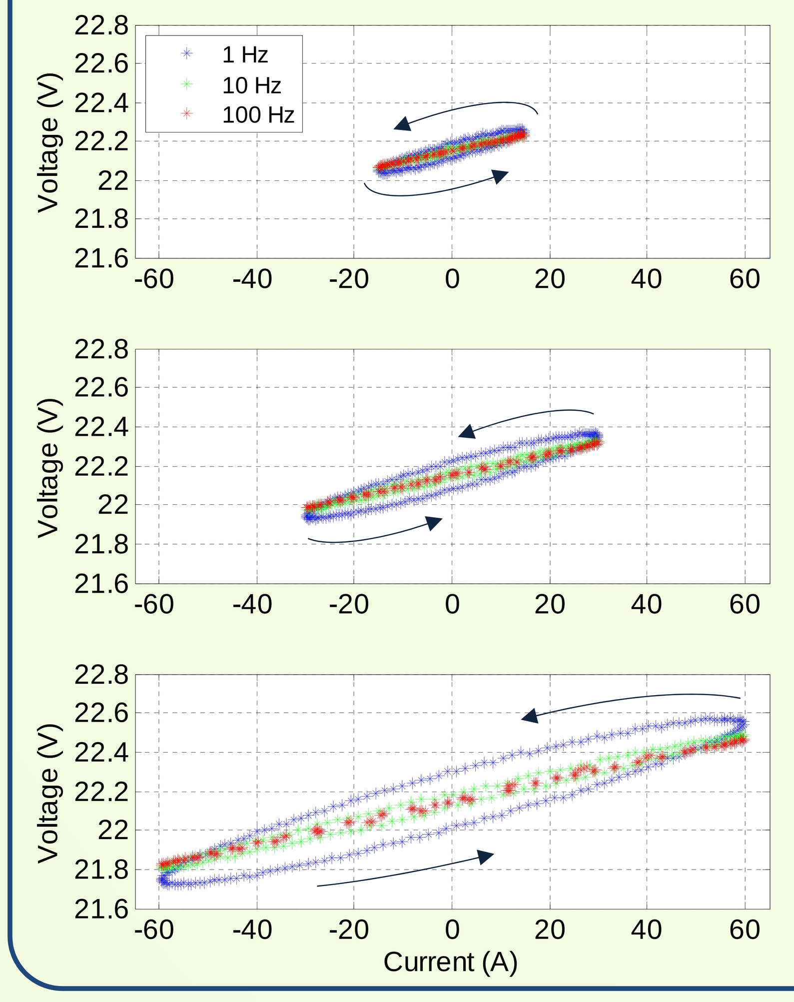
Efficiency vs. current



- Complete charge-discharge cycle:
  - $SOC_{0,C}$=$SOC_{end,D}$
  - Constant temperature
- High efficiency: $$\eta = \frac{\int_{t_{0,D}}^{t_{end,D}} v_{SC}\, i_{SC}\, dt}{\int_{t_{0,C}}^{t_{end,C}} v_{SC}\, i_{SC}\, dt}$$
- Decreasing efficiency with current

DYNAMIC ANALYSIS

High current test



- Sinusoidal charge and discharge cycles:
  - 15, 30, 60 A pk-pk
  - $v_{SC,mean}$=22.15 V
- $\uparrow i_{SC} \Rightarrow \uparrow \Delta v_{SC}$
- The slope of the $i_{SC} - v_{SC}$ curve decreases with frequency:

$$\Delta v_{SC} = \Delta i_{SC}\ Z_{eq}$$

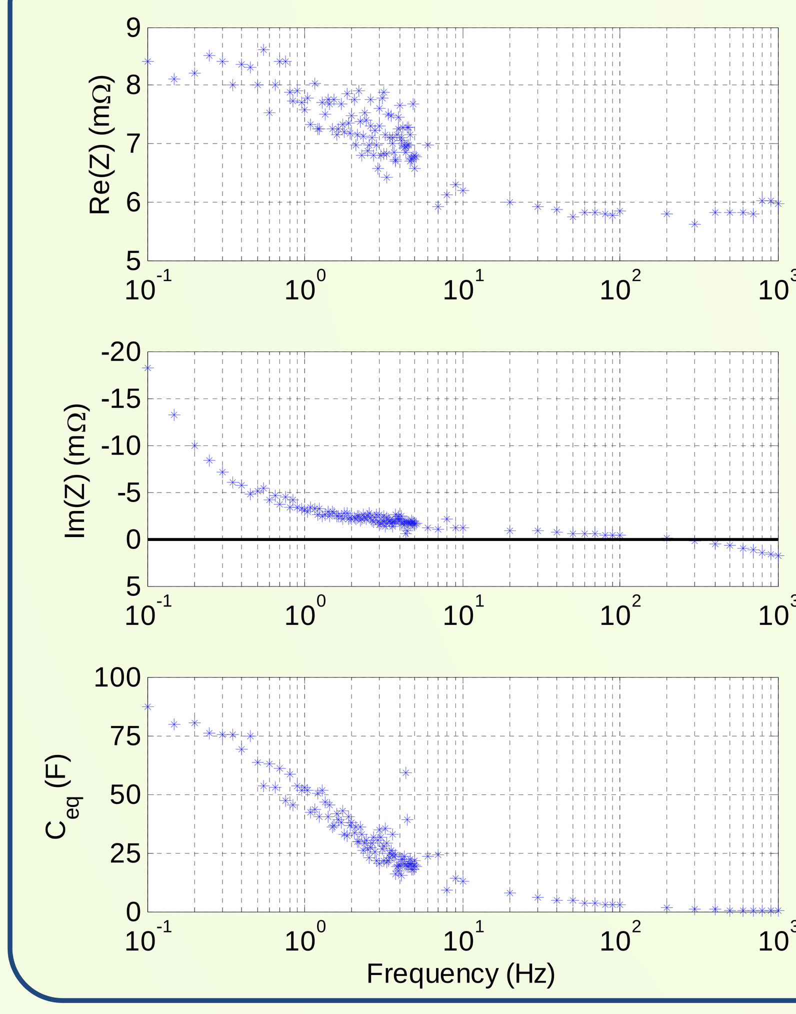
$$\downarrow \Delta v_{SC} \Rightarrow \downarrow Z_{eq}$$

- The area inside the curve decreases with frequency

$$\downarrow Area \Rightarrow \downarrow \varphi$$

$$\varphi = \arctan\left(\frac{\mathrm{Im}(Z_{eq})}{\mathrm{Re}(Z_{eq})}\right)$$

Small current test



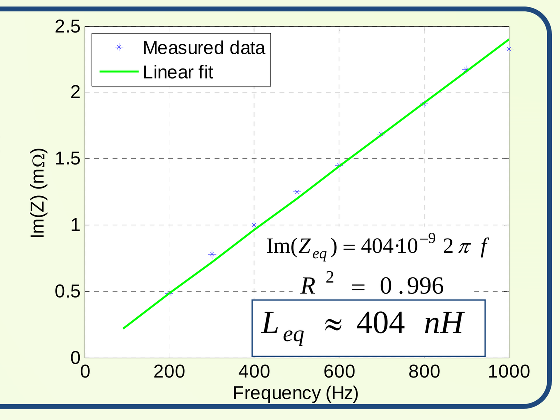
- Test description:
  - Demand of a 2 A DC current and a superimposed sinusoidal component (0.1 A pk-pk)
  - Equivalent impedance from voltage and current measurements
- Impedance: $$Z_{eq} = R_{eq} + j\, X_{eq} = R_{eq} + j\left(\omega L_{eq} - \frac{1}{\omega C_{eq}}\right)$$
- Decreasing capacitance with frequency:

$$C_{eq} \approx \frac{1}{L_{eq}\, \omega^2 - \mathrm{Im}(Z_{eq})\, \omega}$$

Inductance fitting

- High frequency (f≥150 Hz):

$$L_{eq} \approx \frac{\mathrm{Im}(Z_{eq})}{\omega}$$



CONCLUSIONS

- **The static and dynamic behaviour of the BMOD0083 SC (Maxwell) have been characterized.**
- **The differential capacitance is defined as the relationship between current and voltage variation over time. This variable linearly increases with the voltage applied to the SC.**
- **The efficiency is defined as the relationship between the output and the input energy in a complete charge–discharge cycle. This magnitude has been measured in different cycles where the long-term dynamic is stabilized. The measured efficiency is in the range from 95% to 97.2%.**
- **The resistive behaviour of the SC decreases from 8 mΩ in low frequency to 6 mΩ for frequency higher than 5 Hz.**
- **The equivalent capacitance decreases with frequency from the rated (83 F) at frequency lower than 0.5 Hz to a value of 0 F for high frequency (*f*>150 Hz).**
- **Care should be taken with inductive behaviour of the SC for frequency higher than 150 Hz.**

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