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# Technical evaluation of hybrid super capacitor technologies for local energy communities

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**Abstract.** Renewable energy sources have demonstrated in recent years their ability to reduce the dependence on fossil fuels, contribute to the security of energy supply and play an important role in reducing greenhouse gas emissions. To benefit from the local use of renewable sources and energy efficiency in distributed systems, the concept of local energy communities is established. In local energy communities, new innovative technologies are combined, highlighting the role of energy storage, to provide greater autonomy to communities that adopt this model.
Among energy storage, the use of batteries stands out, while lithium batteries are currently the most widely used for domestic and residential applications, as well as in local energy communities.
This work describes the experimental evaluation of an innovative energy storage system for energy communities based on hybrid supercapacitors (HSC), focused on local energy communities, and its comparison with other well established storage technologies, such as lithium-ion batteries.

**Key words.** Hybrid supercapacitors, local energy communities.

## 1. Introduction

Within the context of an energy transition to a low carbon economy, new roles for local communities are emerging, whereby they are transitioned from being passive consumers to active prosumers with the possibility of local generation, demand response and energy efficiency measures. This indeed proposes the concept of local energy communities (LECs). The energy transition will require significant mainstreaming of social and technical innovations to succeed at the community level.

Thereby, the role of LECs will be key in the energy transition to transform the EU's energy system [1].

LECs emerge as a model for citizen participation in the energy system and its main function is to generate renewable energy through collective generation plants for shared self-consumption. Energy communities are legal entities that empower citizens, small businesses and local authorities to produce, manage and consume their own energy. They can cover various parts of the energy value chain, including production, distribution, supply, consumption, storing or sharing energy. Energy communities may vary depending on their location, involved actors and provided energy services [2]–[5].
Energy communities are built on the concept of local energy self-consumption, that is, the production of energy for own, individual or collective use, and in the same place where it is generated. The idea is not new, but it has gained relevance in recent years after having been granted a certain legal status and its importance for accelerating the transition towards an energy system without CO2 emissions [6].

Energy communities are a key element in the reorganization of energy production and distribution systems. They make it possible to take advantage of renewable resources wherever they are and are an open door for the active participation of citizens in the energy system [7]. Its main advantages can be summarized as:
- Reduction in the use of fossil fuels and the local carbon footprint.
- Greater efficiency in consumption
- Collective investment alternatives for the development of renewable energies.
- Implementation of renewables from the commitment of the community, instead of large projects.
- Favour lower prices for users with fewer resources.
- Development of the local economy.
- Redistribution of benefits, most of which revert to the local community.

In this way, energy communities are a way of approaching the generation and distribution of electricity, as well as other energy services. Developed at the local level, they prioritize the benefit of the community and its environmental, social and economic sustainability.

The AGERAR II project (Storage and Management of Renewable Energies in Local Energy Communities) aims to evaluate technical solutions to promote energy efficiency and sustainability criteria in local communities. To achieve these objectives, one of the main activities of the project performed by INTA in its Energy Laboratory in Huelva is focused on the test and evaluation of different energy storage technologies, such as hybrid supercapacitors, in order to determine their viability for this application, comparing the real performance and potential benefits of these technologies, in terms of efficiency, lifetime, costs, safety, etc.

The objective of this work, which constitutes a study on the performance of hybrid supercapacitors (HSC) in LECs, is to identify and evaluate this new technology as an alternative to combine with lithium-ion batteries, which are the ones that have been used mainly by local energy communities. Hybrid supercapacitors provide higher specific energy than supercapacitors, while still maintaining a high specific power, keeping a balance between capacity and fast charging [8]. Most studies around this technology focus on the materials [9]–[18], as this is still considered as incipient [19], so these researches are indeed needed. This article, following its novel path, focus on the interesting applications that HSC can potentially provide in the context of LECs as part of microgrids and vehicle refuelling stations.

## 2. Testing and evaluation of hybrid supercapacitors for local energy communities at INTA

The Laboratory of the INTA's Renewable Energy Area in El Arenosillo (Huelva) has in their facilities different test benches for the evaluation and demonstration of electrochemical technologies for the storage and generation of electrical energy (batteries, supercapacitors and fuel cells) at cells and modules scale, for stationary and mobile applications. An experimental micro grid, where the most promising technologies are integrated and validated at pilot plant scale, complements these test facilities. The objective of these testing facilities is to support demonstration and evaluation projects in this field, collaborating with companies and other R&D centers in the development and demonstration of their products and systems. For the AGERAR II project, it has been used a battery/supercapacitor test bench, with 4 channels for high voltage (up to 400 A in a range of 0 to 60V, with 6 kW maximum power per channel), and 4 channels of low voltage (up to 40 A in a range of 0 to 5V and a maximum power per channel of 50 W). The HSC has been tested at INTA. First its characterization was carried out, and then it was subjected to successive cycles with different daily charging and load profiles, obtained from real data and simulations, for Spain, specifically to a summer profile.
The hybrid HSC tested at INTA is a prototype of the Chinese brand Toomen based on carbon technology and model 7500F and 48VDC. The technical specifications, according to the manufacturer, are as follow:

- Nominal Capacity: 60 Ah.
- Nominal Electricity: 3000 Wh (Discharge: 1C, 36 V Cut-off).
- Nominal Voltage: 48 V.
- Max. Charging Voltage: 51.4 V.
- Cut off Voltage: 36V.
- Current: Max. Charge cont. 750A Max. discharge cont. 750A.
- Weight: 108.6 kg.
- Dimension: 600x540x212 mm.
- Cycle life: 10000 cycles.

## 3. Results and Discussions

A power profile has been applied to simulate the real summer conditions in southern Spain. Specifically, they deal with the conditions of a house located on the coast of Huelva (Spain), where there is photovoltaic generation during the day. Thus, during daylight hours, power is generated above the consumption of the home. At night, consumption stabilizes, as shown in Figure 1. This charge and discharge profile has already been used experimentally by the authors to validate lithium battery systems in residential applications, analogously to the validation that is objective in the HSC for this work.
This summer profile in Spain has been developed and programmed in a test bench, taking into account the average daily energy consumption, as well as the electricity generation, assuming the contribution of 1 kW of photovoltaic field to the charge of the HSC.

It is enhanced, in the test bench, reducing the period between charging and discharging in such a way that a calendar day is reduced to a period of 12 test hours, taking into account two 30-minute rest periods between charging and discharging, as shown in Figure 1. This profile is repeated for a certain number of charge and discharge cycles, simulating the behaviour of the HSC on successive days.

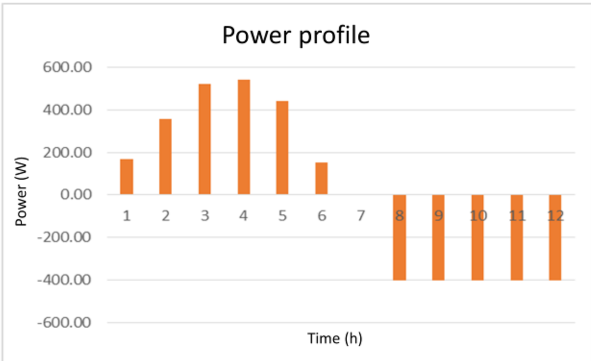


Fig. 1. Simulated power profile in a 12-hour bench for the HSC for summer in Spain.

To obtain the experimental results, the HSC system is connected to the test bench where the power profile is applied, according to Figure 1, while voltage and current are measured during this operation. A diagram of the system is shown in Figure 2.

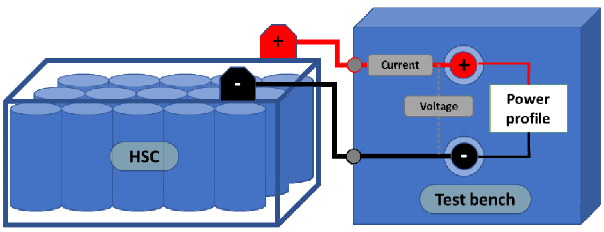


Fig. 2. Diagram of the system in which the hybrid supercapacitor was tested, applying the power profile, while current and voltage were measured.

The voltage and intensity results obtained in the different charge and discharge cycles are shown in the following graph, Figure 3. Blue line represents the HSC voltage while red line is related to the current applied according to the applied profile of Figure 1.

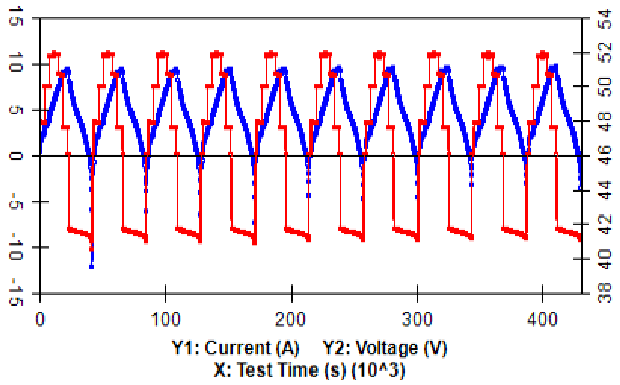


Fig. 3. Representation of voltage and current versus time in the 10 charge and discharge cycles of the HSC for a summer profile in Spain.

From Figure 3, HSC voltage evolution can be seen according to the energy profile applied, keeping the values in range both while charging, during first phases of the profile, and discharging, when the load is applied at later stage. Likewise, the performance (discharge energy divided by the charging energy) is calculated, and an average value of the order of 92% is obtained, with a maximum useful energy extracted of 1.85 kWh.

While for lithium ion 75-200 Wh/kg and 100-360 W/kg are typical values, hybrid supercapacitors operate around 20-30 Wh/kg and 3000-14000 W/kg. In this case, for this specific test, HSC provide 18.5 Wh/kg, that is nearby the typical range limits. Specific power (W/kg) is not tested on limit in this study, as maximum current for this HSC is pretty high. However, it's been verified that system follows the profile's power without any issue.

## 4. Conclusion

HSC systems combine a balance between power and specific energy, reducing the polluting material with respect to batteries.

From the performance point of view, in the case of the HSC the performance is 92%, which is why it is lower than in the case of batteries whose performance reaches 97%. Therefore, the maximum useful energy extracted in the case of HSC is 1.85 kWh, which is slightly less than in the case of batteries, 1.97KWh. The HSC power is also validated within the test limits.

Then, it can be concluded that the HSC can perfectly fit the alternative to combine with the technologies based on lithium-ion batteries.

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