Publishable Summary for 23IND04 MetSuperCap
Metrology for static and dynamic characterisation of supercapacitors

Overview

Supercapacitors (SCs), an environmentally friendly technology, are being used as energy-storage devices across an increasing number of fields, including as a replacement for batteries in higher-power density applications. This electrochemical energy storage device has an operating principle and charge storage mechanism which is more closely associated with those of rechargeable batteries than electrostatic capacitors. However, as the behaviour of SCs differs from both, and in order to support the growing use of SCs, accurate characterisation is required for SCs and SCs banks, both in the laboratory and under operating conditions. In addition to this, validated software is needed to identify the equivalent electrical model of SCs for dynamic applications. Quick, traceable, and effective measurement techniques are also required to evaluate the State of Charge (SoC) and State of Health (SoH) of SCs and to promote the uptake of SCs in industrial and energy applications.

Need

The EU's Batteries Directive 2006/66/EC aims at improving the protection, preservation, and quality of the environment by, for example, imposing maximum quantities for certain types of metals and chemicals contained in batteries. SCs, an environmentally friendly technology, strongly reduce the presence of certain chemicals and metals, which is unavoidable in many types of batteries. In addition, the life cycle of SCs is very long (a hundred times longer than batteries), their charging and discharging limits are not critical, unlike for batteries, and they pose zero thermal runaway risk over a wide temperature range. These devices can be used, amongst others, in industrial and energy applications but their uptake and future commercialisation is currently hampered due to technical problems and a lack of established electrical parameter models, consistency in testing, and industrial standards.

SCs metrics are only partially defined by manufacturer guidelines and standards and these furthermore lack the appropriate accuracy analysis. Therefore, guidelines on the methods for accurate characterisation of SCs and banks are needed. To implement SCs and SC banks into applications, reliable tools for the accurate determination of a multiparametric equivalent circuit model (ECM) are needed. A clear measurement and identification tool is not within the knowhow of many companies. A reliable and recognised tool would allow designers and manufacturers to easily implement SCs into a wide range of applications. Applications require frequent monitoring of the SoH and SoC of the supercapacitive components to provide correct feedback to the users and to ensure a sufficient maintenance schedule is in place. Therefore, developing rapid and reliable methods of measurement and diagnosis is of great interest for many applications. In specific applications, for example, the coexistence of batteries and SCs may lead to complex charging management systems. New models and methods developed for SCs have to be verified in the presence of distorted waveforms (low power quality) and the limits of their validity 'in operation' must be defined. Finally, it should be noted that to date almost all the studies, standards and guidelines mainly concern Electric Double Layer Capacitors (EDLCs) while new guidelines for the characterisation of SCs also need to take into account hybrid SCs and pseudo-SCs.

Objectives

The overall objective of the project is to establish a traceable, consistent and sound measurement and characterisation framework for both SCs and SC banks. This includes the development of rapid techniques for

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the determination of SoC/SoH of SCs, for the determination and assessment of ECM parameters, the verification of the proposed techniques in real conditions and the processing of inputs for standards developing organisations.

The specific objectives of the project are:

1. To develop metrologically traceable methods, including the assessment of uncertainty, for characterising the capacitance, resistance, specific power and energy for SCs of different sizes (from 1 farad to 3000 farads, for discharge currents up to 500 A and voltages up to 60 V) and at least two different types and brands. The developed methods should be suitable for the characterisation of SCs banks with maximum instantaneous discharge power up to 25 kW (e.g., 420 A at 60 V).
2. To develop software/models for identifying relevant parameters for the static and dynamic characterisation of SC and SC bank models. The target error of the developed software/models will be lower than 5 % (for voltages greater than 200 mV). In addition, to define optimised voltage/current waveforms, based on representative SC charging and discharging cycles, for characterising SCs and for validating models by measurement.
3. To develop rapid techniques, including the assessment of uncertainty, for accurately measuring the SoC and SoH of SCs. Additionally, to test and verify the developed techniques on at least two different types of SCs.
4. To design and produce two test benches fitted with a measurement system and a measurement procedure to evaluate the actual behaviour of SCs under operating conditions, including battery/emulator-SCs hybrid systems. The test benches will also be used for the validation of the outputs of Objectives 1 3 and for the evaluation of at least two applications of SCs in energy systems, (e.g., photovoltaics (PV), uninterrupted power supplies (UPS), electric vehicles (EVs)).
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain, standards developing organisations (those associated with the EU's Batteries Directive 2006/66/EC), and end users (e.g., EMN for Smart Electricity Grids, the aerospace, automotive and energy sectors).

Progress beyond the state of the art and results

SCs and banks of SCs require time-demanding testing, and research laboratories often provide tests which are limited in terms of physical conditions and the SCs sample analysed. This project will go beyond the state of the art, by providing a large database of electrical parameters of SCs and SC banks of various and sizes and brands made available to the public via Open Access (OA).

Measurement of the parameters of SCs and SC banks

The approach suggested by the standards is sometimes relaxed in terms of accuracy of the SC parameters determination. For instance, the standard EN IEC 62391-1:2022 details that current and voltage measurement accuracy should be about ±1 % or less. Relaxed accuracy limits for the instrumentation result in equally large uncertainties on the SC parameters. The project will go beyond the state of the art by developing a guide that provides a clear relationship between the instrumentation, the measurement method, and the expected uncertainty on the SC parameters.

Equivalent Circuit Models of Super Capacitors

Multiple approaches for modelling SCs have been presented in the literature. These ECM models are quite promising due to their strong application value, as they allow the equivalent circuit of the SC to be directly implemented into complex control systems which can include charge control and the load. This project will go beyond the state of the art by improving the target error of ECM models and software to 5 % and extending the use to a wide variety of SCs sizes and types, testing the validity of such models also with real waveforms.

State of Health and State of Charge determination

The determination of SoC and SoH allows systems to increase reliability, predictive maintenance and real time condition monitoring. Rapid methods are not common but are of great applicative interest and the determination of the SoC/SoH requires the use of complex techniques or the use of complex algorithms combined with the device's ECM. This project will progress the state of the art by exploring the possibility of

using rapid (e.g. impulsive) measurement techniques and other approaches linked to ECM parameters, in order to obtain a reliable SoC/SoH assessment.

Real applications with hybrid "SC plus battery" systems

The use of SCs in conjunction with batteries provides undoubted advantages in terms of absorption and return of power peaks which, managed by SCs, improve efficiency, and extend the life of the batteries. Applications for such hybrid devices, e.g. electric vehicles, require the development of hybrid charge control systems, which are beyond the state of the art and go beyond a common battery management system. Furthermore, the operation of SCs in real conditions requires further studies and validations. This project will provide a clear picture of how laboratory determinations can be applied in real conditions.

Outcomes and impact

Outcomes for industrial and other user communities

The good practice guide for evaluating the uncertainty of electrical parameters (e.g. capacitance, resistance, specific power and energy) in SC testing and characterisation, covering a wide range of SC sizes (1 – 3000 F) developed within the project will enable SCs users, designers and SC manufacturers to simplify the characterisation of SCs and SC banks. A widely-recognised standard procedure associated with a metrological infrastructure providing the traceability for such assessment will provide higher trust to both the customer and the manufacturer.

The methodologies and procedures for the accurate determination of the characteristics of the SCs will improve the reliability and accuracy of these parameters which are crucial for designers and users, especially for more demanding applications, such as space, e-mobility and energy applications. The validation of the methodologies for the use of SCs in real conditions, verified for different types and sizes of SCs, will allow manufacturers of systems using SCs (e.g., for renewables, automotive applications, e-mobility in general) to design more robust technical solutions and better plan predictive maintenance.

An ECM validated and verified on a large sample of SCs, for real-time applications, will provide a useful reference for SC manufacturers and provide an additional design parameter. Instrument and SC manufacturers will use the advanced hardware for the characterisation of SCs in pilot lines to improve the accuracy and reliability in parameter assessment, providing better specifications for their products, with consequent benefits also for users and designers.

The rapid techniques for determining the SoC/SoH of SCs can be used by manufacturers of electronic systems that use SCs as power supply units, increasing the reliability of the systems and allowing the successful implementation of predictive maintenance techniques. These techniques are also important for manufacturers of aerospace and e-mobility storage systems. The availability of two large databases, one regarding the characterisation and characteristics of SCs and a second developed regarding the SoC/SoH of SCs could constitute a benchmarking for manufacturers for the development of new products.

Outcomes for the metrology and scientific communities

The project will provide the scientific community with traceable measurements for the characterisation of SCs and banks of SCs. The validity of the proposed measurement techniques will also be verified in operation (i.e., with ripple and harmonics) and consider new types of hybrid SCs. The guidelines for these measurements can be used by other metrologists to meet the measurement needs of the national industries producing and using SCs. The project will provide scientific and technical knowledge on such precision measurement systems to electrical metrologists, researchers in the field of storage and its applications in e-mobility, energy and power electronics from related academic fields for further development. The consortium will provide an overview of the measurement accuracy obtainable with the most well-known DC measurement techniques and Electrochemical Impedance Spectroscopy (EIS) techniques, that currently does not exist either for manufacturers or in scientific publications, except for individual analyses under controlled conditions and generally on a few types or sizes of SCs.

NMIs will deliver a report containing the CMCs concerning the characterisation of SCs, compliant with those published in the KCDB website, which will be ready for use in NMIs depending on market demand in the various countries. These CMCs will be of high relevance to the metrology community, as at the moment no NMIs deal with high capacitance measurements, especially in the 10 F – 3000 F range, which is the one that is receiving great interest in SC applications.

The two large open access databases that group together a significant amount of relevant data on different types of SCs, will enable academic communities (both metrological and non-metrological with limited or no capabilities to perform measurements and characterisations on SCs) to undertake further research activities including analysis of data and information about SCs' variability versus charging conditions, versus charging patterns, versus SoC/SoH and related aging.

The development of rapid techniques for the definition of SoC/SoH also requires the development of both analysis and measurement techniques. These developments will benefit both the metrology and scientific community since they can improve and speed up the assessment of these parameters.

Outcomes for relevant standards

The project will support the EU's Batteries Directive 2006/66/EC which aims at improving the protection, preservation, and quality of the environment by, for example, imposing maximum quantities for certain types of metals and chemicals contained in batteries. The project, by promoting the use of SCs combined with batteries, allows, for the same power supplied, to reduce the part borne by the battery and also significantly reduces the amount of energy borne by the battery. This indirectly leads to a reduction in the metal-pollutants embedded in the battery, reducing the related risk associated with disposal.

In addition, the consortium will promote the results of the project within the standardisation community and will provide input into the standardisation process (such as IEC TC40 and IEC TC113). The participants who are in contact or are members of corresponding technical committees will inform them about the results of this project and will endeavour to ensure they are incorporated in any updates to the standards or guidelines.

Longer-term economic, social and environmental impacts

The contribution to SoC/SoH assessment provided by the project has a significant impact on predictive maintenance techniques, which is a key factor boosting the growth of this technology, whose market is already expected to double in the next 5 years. Promoting the diffusion of SCs in electrical systems by design, and their adoption, also means meeting the needs of the European Strategic Energy Technology (SET) Plan, which provides a roadmap to enable the transition towards a climate neutral energy system through the development of low-carbon technologies. SCs, differently from the batteries, do not require the use of rare or polluting materials and, on the contrary, can also implement organic materials, constituting an environmentally friendly component. To promote the diffusion of SCs also responds to the social demand for high-capacity portable power supply that is becoming more and more crucial.

List of publications

n/a

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:		June 2024, 36 months
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Internal Beneficiaries: 1. INRIM, Italy 2. CMI, Czechia 3. LNE, France 4. RISE, Sweden 5. VSL, Netherlands	External Beneficiaries: 6. CRF, Italy 7. Keysight AT, Austria 8. Novac, Italy 9. Pleione, Germany 10. POLITO, Italy 11. UNIGE, Italy 12. UTwente, Netherlands	Unfunded Beneficiaries: n/a