**EMPIR Call 2017 – Industry, Fundamental, Normative and Research Potential**

Selected Research Topic number: **SRT-i25**
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# Title: Quality assessment of electric vehicle Li-ion batteries for second use applications


## Abstract

Li-ion batteries lose their capacity with usage and age but are still operational after their first use in electric vehicles (EVs). However, current conventional methods are either time-consuming or inaccurate for the measurement of the residual capacity of aged or second life batteries. Therefore, proposals in response to this SRT should develop an infrastructure for fast and accurate measurements of the residual capacity and the expected residual lifetime of Li-ion batteries of electric vehicles (EVs) in order to support second use applications.



## Keywords

Li-ion batteries, second life batteries, electric vehicles, electrochemical impedance spectroscopy, nonlinear frequency response analysis, distributed relaxation times


## Background to the Metrological Challenges

In order to combat climate change and reduce air pollution the replacement of conventional combustion engines by electric propulsion systems (in conjunction with renewable energy production) is required. However, EVs using Li-ion batteries are considerably more expensive than cars with conventional combustion engines, therefore there is a need to reduce the price of Li-ion batteries. Aging and usage reduces the capacity of Li-ion batteries and the driving range of EVs. When the residual capacity decreases beyond a certain limit e.g. to about 70 % to 80 % of the initial value, batteries in EVs might be replaced but they are still usable for other, less demanding applications, e.g. as energy storage for photovoltaic systems in residential or off-grid applications.

Up to five major Li-ion battery chemistries and variations thereof are currently available, and have different characteristics and aging mechanisms. Currently, the residual capacity of Li-ion batteries can be accurately measured by integrating the measured current of a complete discharging (or charging) process over time, however this procedure takes several hours. Alternatively, the open circuit voltage can be measured against the state of charge and, using look-up tables established during the testing phase of a specific battery type, the residual capacity can be estimated. But although this method is sufficiently fast, it is inaccurate for aged batteries.

Methods based on impedance measurements are widely used to investigate Li-ion batteries in research and development, and are relatively fast and can be automated for practical applications. Moreover, in contrast to some conventional methods, impedance based methods give insight into the internal processes of a battery cell and its history and hence could be used for detecting the premature sudden death of Li-ion batteries.

The current measurement uncertainty of battery cell properties derived from impedance measurements is generally accepted to be in the 10 % range. However, the applicability of impedance measurements to measure the capacity of second life batteries cells with respect to fundamental quality criteria e.g. traceability, comparability, inter-laboratory reproducibility, and measurement uncertainty has not been investigated. In particular, the traceability of low impedance measurement results (mΩ range and below) in the full complex plane has not been realised, due to the lack of standards and calibrations concepts in this challenging impedance range.

Batteries for EVs consist of series and parallel connected cells, but it would be inefficient and prohibitively expensive to disassemble such modules to measure the capacity of individual cells. Consequently, methods


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for measuring the complete module, or a measurement procedure that addresses the individual cells in the module, are needed, i.e. making use of battery management systems already existent in EVs.

## Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on the traceable measurement and characterisation of the residual capacity and the expected residual lifetime of Li-ion batteries of electric vehicles.

The specific objectives are

1. To develop protocols for life cycle testing of different types of Li-ion battery cells and modules in terms of capacity, chemistry and geometry, at different temperatures, currents and cycling patterns. The life cycle tests should include both impedance based methods and conventional methods.
2. To develop validated impedance based methods to measure the residual capacity of Li-ion battery cells with a target relative uncertainty of better than 3 %. In addition, to assess the feasibility of detecting the premature sudden death of Li-ion batteries.
3. To establish traceable impedance measurements in the mΩ and sub-mΩ range in the full complex plane in the frequency range between 10 mHz and 5 kHz, with a target relative uncertainty of 1 %. This should include the development of low impedance standards with arbitrary phase angles and a calibration method for impedance meters.
4. To develop a validated protocol for the application to Li-ion battery modules of the traceable impedance measurements in the mΩ and sub-mΩ range in the full complex plane in the frequency range between 10 mHz and 5 kHz.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (e.g. batteries manufacturers and the automotive industry) standards developing organisations (e.g. IEC-TC21 and input to IEC 62660-1) and end users (e.g. the transport sector).

Proposers shall give priority to work that meets documented industrial needs and include measures to support transfer into industry by cooperation and by standardisation. An active involvement of industrial stakeholders is expected in order to align the project with their needs – both through project steering boards and participation in the research activities.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.5 M€, and has defined an upper limit of 1.8 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 30 % of the total EU Contribution to the project.

Any industrial partners that will receive significant benefit from the results of the proposed project are expected to be unfunded partners.

## Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the automotive sector.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work

## Time-scale

The project should be of up to 3 years duration.