Impedance Measurement for Advanced Battery Management Systems

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1. Overview

- We present a fast, low-cost approach to measure impedance in a vehicle at many frequencies (1 Hz to 2 kHz).
- Impedance is an effective non-invasive method of diagnosing the internal state of an electrochemical cell in terms of temperature, ageing, state of charge (SOC) and faults [1, 2].
- We demonstrate that an existing motor drive can be used to excite a battery to measure impedance. Our results are accurate to within a few per cent of measurements from an expensive, bulky commercial system.
- We also explore the variations in cell impedance parameters with SOC, finding that in NMC cells, the charge transfer resistance and SEI layer resistance vary significantly with SOC. In LFP cells the parameter variation is less obvious.

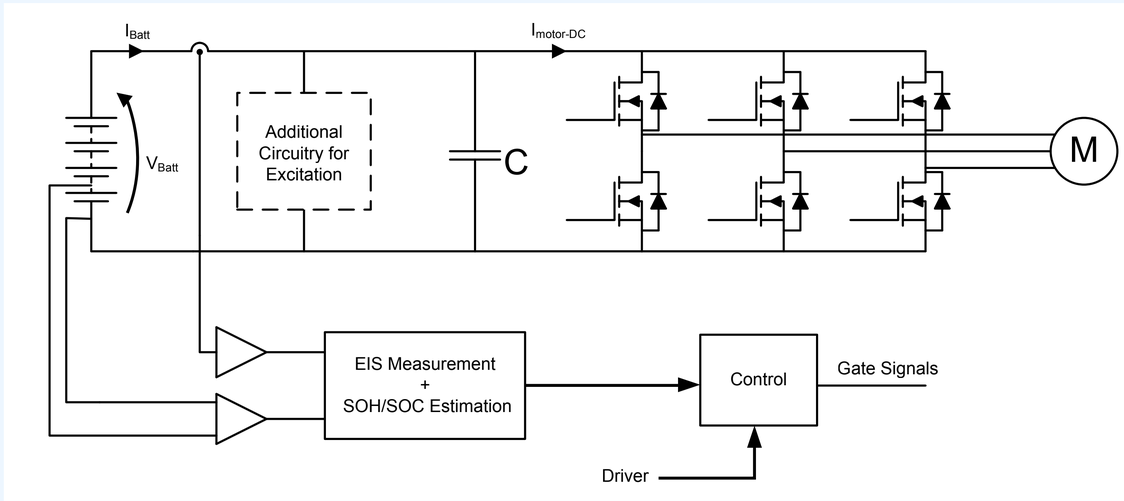

Figure 1: Battery impedance measurement using motor controller excitation integrated into an EV or HEV drivetrain

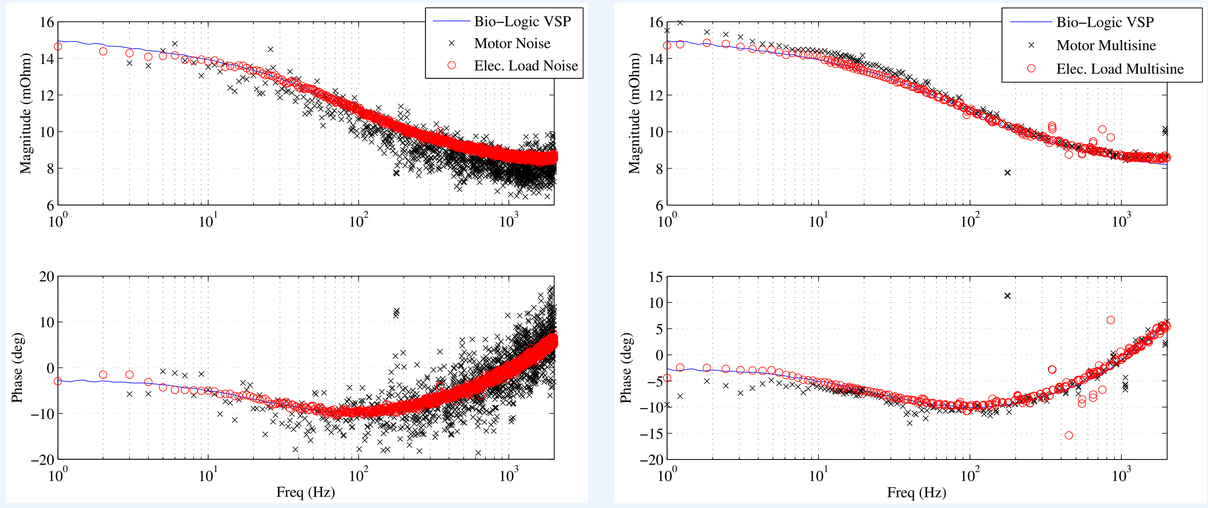

Figure 3: Left – Comparison of results using multisine excitation, Right – Comparison of results using broadband noise excitation.

2. In-Vehicle Impedance Measurement

- Impedance measurement can be incorporated into a drivetrain as shown in Figure 1. The small current perturbation to excite the cells comes either from variations in the main traction current due to driver or controller response, or from an optional additional excitation circuit, or a combination.
- The voltage and current is measured, amplified and processed using a statistical correlation technique we have developed [3] to determine the cell impedances.
- To investigate this, a test rig, Figure 2, was constructed as a scaled-down EV drivetrain with four A123 LFP cells.

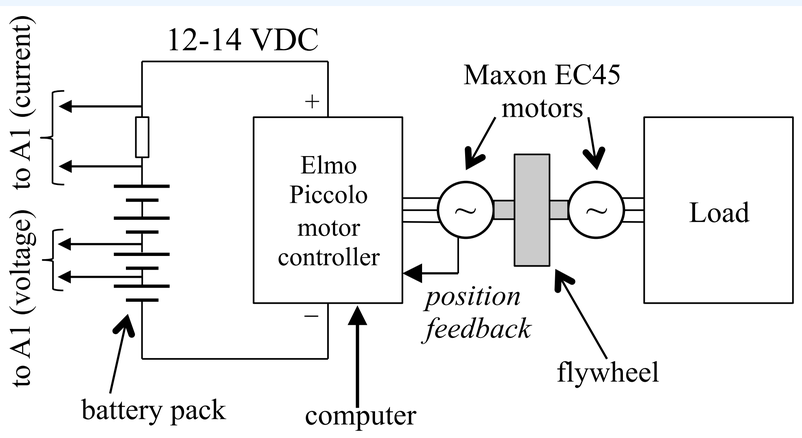

Figure 2: Schematic of motor controller excitation test rig

3. Results with Motor Controller Excitation

- Impedance bode plots for a single A123 LFP cell are shown in Figure 3 which compares measurements made using a commercial potentiostat, electronic load, and motor controller, with two different excitation signal types.
- The comparison is good across all frequencies investigated (1 Hz to 2 kHz) with RMS uncertainties around 5% magnitude and 3° phase. Noise excitation has greater variance but less narrowband interference.

4. Inference of SOC

- We investigated variation in impedance with SOC for two chemistries: lithium-ion nickel manganese cobalt oxide (NMC) and lithium-ion iron phosphate (LFP), Figure 4.
- NMC cells exhibit a clear relationship between impedance and SOC. The charge transfer resistance and SEI layer resistance both give a monotonic change with SOC.
- LFP cells are more challenging, with little variation between impedance and SOC. Double layer capacitance could be a promising parameter.

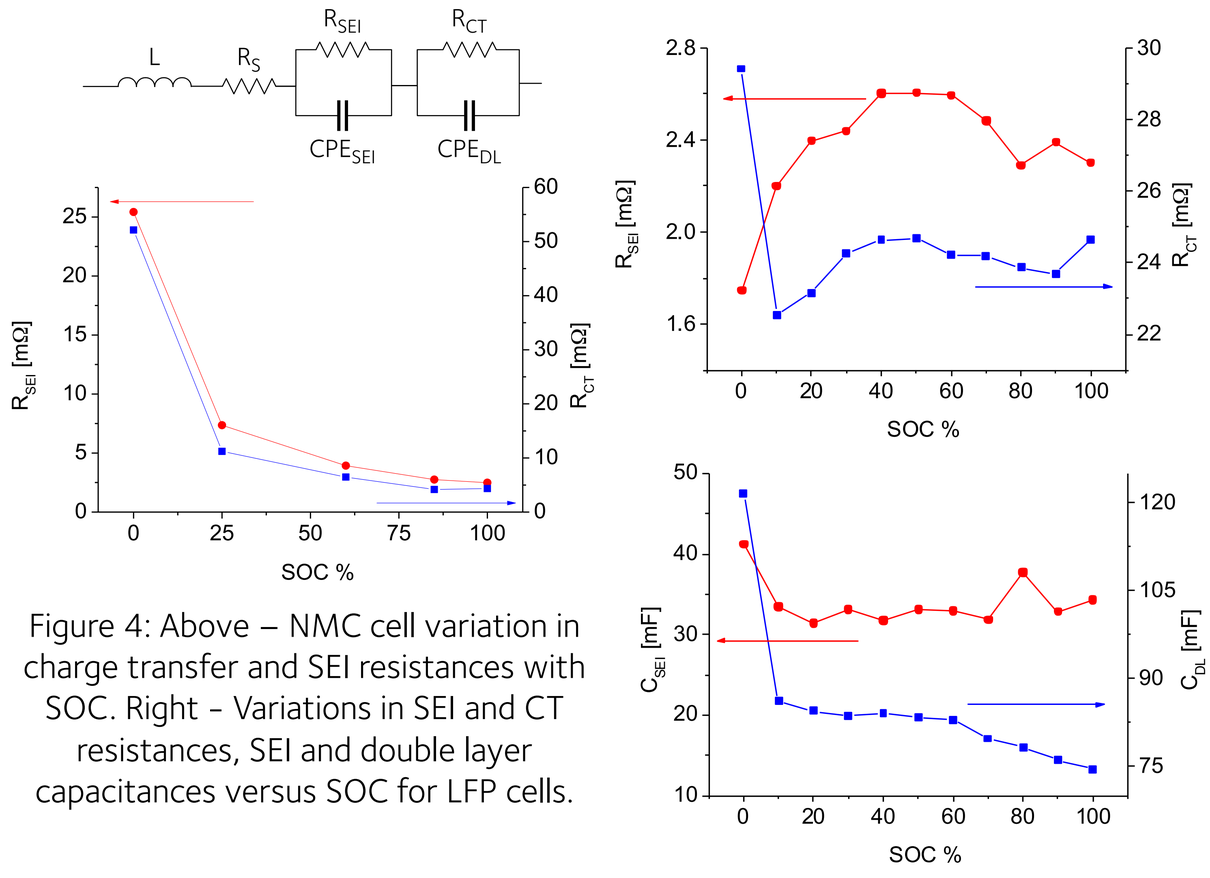

Figure 4: Above – NMC cell variation in charge transfer and SEI resistances with SOC. Right - Variations in SEI and CT resistances, SEI and double layer capacitances versus SOC for LFP cells.

- There is substantial work still to do, but we have demonstrated critical parts of an impedance-based BMS, showing accurate measurements are possible using motor controller excitation.
- The usefulness of impedance for inferring indirect parameters such as SOC depends on the exact relationships between the impedance spectra and the parameters, which varies with chemistry. This is an interesting area for further work.

Acknowledgements

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References

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