ModuLab®
electrochemistry

Application Guide

EIS cell analysis techniques
Comparison of single sine correlation and multi-sine / FFT

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Application Guide: AGML04

Introduction

The Solartron ModuLab System offers the capability of measuring cell impedance using multi-sine / Fast Fourier Transform (FFT) or single sine correlation (SSC) techniques. Both techniques have advantages and disadvantages and therefore it is for the end-user to decide which is appropriate for their applications.

i) Single sine correlation is widely regarded as the most accurate and repeatable method for measuring the impedance of a cell. With suitable choice of integration period, the noise rejection capabilities of the technique are unparalleled. However, since the cell under investigation is stimulated sequentially at different frequencies over the range of interest, experiments can take in excess of one hour (particularly if low frequency analysis is required). This may not be an issue if the cell chemistry is constant during the measurement. However, there are applications where this may not be the case and interpretation of low frequency results must therefore be treated with care.

ii) The multi-sine / FFT technique simultaneously applies multiple sine wave frequencies to the cell. For example, three frequency decades may be selected with a base frequency of 1 mHz providing simultaneous impedance results for 1 Hz to 1 mHz in a single measurement. This takes 16 minutes to complete, compared to a similar SSC analysis which takes around 80 minutes, (five times as long). The major disadvantage of the multi-sine technique is that rejection of noise and distortion is not as effective as for SSC. However, this may be a small price to pay when fast measurement capability is needed particularly at low frequencies and when the test cell may not be stable for prolonged periods of time.

Key system capabilities used in this demonstration

- Single sine correlation and multi-sine / FFT impedance measurement techniques

Equipment required for this demonstration

- ModuLab electrochemical test system with Booster 2A and HV options (experiment may be run at lower current if ModuLab potentiostat only is available)
- Sealed lead acid battery - e.g. 6 V or 12 V (for example 2.5 Ah). Lower power rechargeable batteries may be used if required (but the experiment levels must be modified to suit the battery that is in use)

Connections

- Connect the potentiostat to the battery using the connection diagram shown in the following experiment.

Experiment setup

Select "AGML04 Single Sine vs Multisine FFT" in the "ModuLab Application Guide" project

Step #	Purpose
Step 1	Charge the cell while capturing data at low rate
Step 2	Allow the cell to rest after charge while capturing data at slow rate
Step 3	Measure cell impedance using SSC, 100 kHz to 1 Hz, gstat mode (0 DC current - no charge / discharge)
Step 4	Allow the cell to rest while capturing data at slow rate
Step 5	Measure cell impedance using multi-sine / FFT, 100 kHz to 1 Hz, gstat mode (0 DC current as step 3).

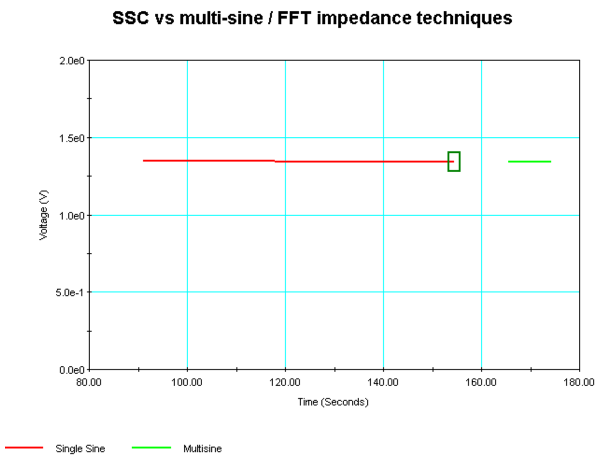
Additional test possibilities:
- Loops could be used to repeat the entire sequence for cell lifetime tests
- Analyse anode / cathode performance using auxiliary channels (voltage drop and impedance)

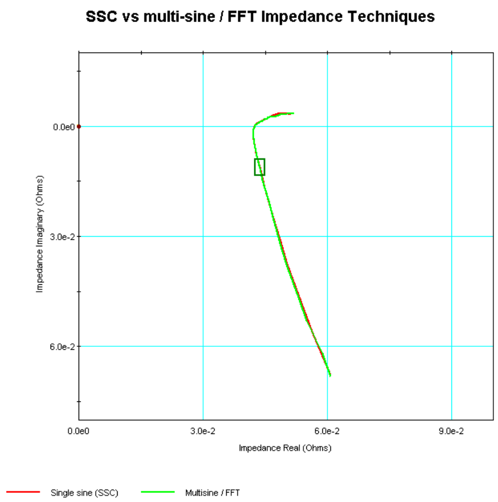
Notes on setup

Using the experimental setup described in the table above, it is simple to demonstrate the use of both single sine correlation and multi-sine / FFT techniques to measure the impedance of a battery. The battery was charged once prior to the two impedance measurements so that it was in the same state of charge in both cases.
The impedance techniques can be run in current (gstat) or voltage (pstat) control mode as preferred. The AC stimulus level was chosen to be well within the linear regime of the battery (100 mA AC produced less than 10 mV AC voltage excursion on the cell). By examining the results in tabular format, it can be seen that the voltage stimulus level per frequency in the multi-sine / FFT analysis was much lower than the single sine stimulus and, with care, could have been increased to further reduce noise.

Data presentation and analysis

The single sine measurement is presented in red, multi-sine / FFT in green on the plots shown below. The impedance results are very similar although possibly with a little more noise associated with the multi-sine / FFT measurement, which is to be expected. The speed of multi-sine / FFT when compared with single sine is clearly shown on the time graph. Indeed, the measurement time was less than one fifth of that of the equivalent SSC measurement with similar data quality. When operating at low frequency as in this case, the time difference may be of critical importance for stability of results or for increased throughput of tests.





Conclusions

Each technique has its relative merits. If the speed of measurement is critical then the use of multi-sine / FFT technique is recommended. If however, the user requires the highest quality, noise free results then it is more appropriate to use single sine correlation. The flexibility of the ModuLab system allows users to try both techniques and by analysis of data select the one that is most appropriate for each cell under test. ModuLab is a unique system that allows all of the impedance measurement technique to be used across the whole frequency range from 10 µHz to 1 MHz if required.

Application Guide

Solartron Analytical's Quality System is approved to BS EN ISO 9001:1994

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