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Autolab Application Note FC04

Impedance Measurements on Fuel Cells and Fuel Cell Stacks at High Currents:
Part 1 – Autolab in Combination with an Electronic Load

Keywords

Fuel cells; High current measurements; Electronic load; Electrochemical impedance spectroscopy

Summary

The use of impedance measurements on fuel cells under load, makes it possible to study the influence of the different fuel cell elements on the behavior and (if present) the degradation of the fuel cell. However, most fuel cells operate at currents far higher than 2 A, while most potentiostat/FRA combinations are limited to 2 A. The maximum current of the Autolab PGSTAT302N with FRA2 module can be extended to 20 A by use of the Booster20A, but even 20 A is not enough to study a Polymer Fuel Cell of reasonable size (50 cm^2 for example). It is therefore desirable to be able to combine the PGSTAT302N with FRA2 module with an electronic load. The load is then capable of drawing the current from the fuel cell, whilst the Autolab is used to do the impedance measurements.

Choice of electronic load

For the experiments presented in this application note we have used the Agilent 6060B load. The experiments described below also can be performed in combination with many other commercially available loads as well.

There are however some important requirements for the load:

1. The load needs to have the possibility for an external input. This is needed to take the frequency signal from the FRA module into the load
2. Output of current as well as potential needs to be present. These are in turn connected to the external inputs of the FRA2 module
3. The bandwidth of the electronic load is the limiting factor in the frequency range that can be used. The Agilent 6060B has a bandwidth of 10 kHz, limiting the frequency range that can be used to 2 kHz. Other loads are available with higher bandwidths

4. The voltage range of the load should preferably start at 0 Volt, especially if measurements are done at single cells. Although the Agilent load is capable of measuring voltages below 3 Volt, the maximum current in that case is no longer 60 A, but decreases rapidly with the voltage (see Figure 1)
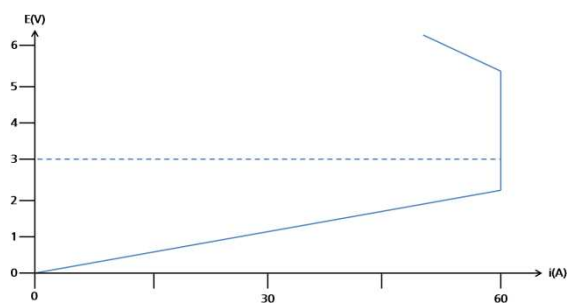

Figure 1 – Contour plot of the Agilent 6060B

Connections between Autolab and the electronic load

The connections described in this section are specific for the Agilent 6060B load. For most other loads however the connections are very similar.

1. The FRA2 DSG output on the front of the FRA2 module is connected to the pin called "Ext Prg" on the back of the load as shown in Figure 2
2. The pin called IM (Current monitor) on the back of the load is connected to "Y" on the front of the FRA2 module
3. The E_{out} (monitor cable of the PGSTAT302N) is connected to the "X" on the front of the FRA2 module

By using the connections described above, the current of the fuel cell is modulated by the frequency signal from the FRA2 module, and the impedance is calculated based on that current and the measured potential response from the differential amplifier.
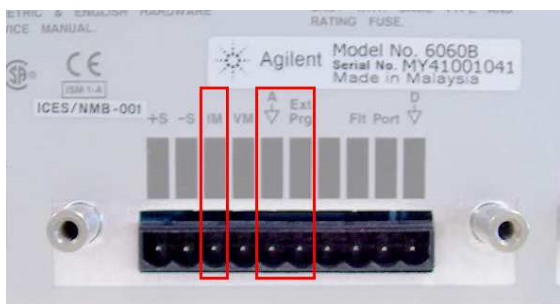
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Figure 2 – Connections to the Agilent 6060B load (back plane)

Experimental conditions

The load used in these experiments has a maximum current of 60 A, and a voltage range of 3-60 Volt.

Measurements were performed on a PEMFC fuel cell (7 cm^2) with Pt catalyst on both anode and cathode side. The fuel cell was operated on humidified H_2/O_2 at 65 ºC. For the impedance measurements an Autolab PGSTAT302N with FRA2 module was used, in combination with the NOVA software.

The load was only used to measure the current. The voltage of the cell was measured by using the differential amplifier of the PGSTAT302N, as we found that this results in less noisy measurements.

The load was operated in constant current mode, whereas the PGSTAT302N was operated in potentiostatic mode. Since the current input (Ext Prg) and the current output (IM) of the load both have a range of 60A/10V, some multiplication factors need to be set in order to obtain the correct impedance values. These values can be specified in the NOVA software directly (see the installation note).

Experimental Results

The initial part of a full i-V curve of the fuel cell is shown in Figure 3.

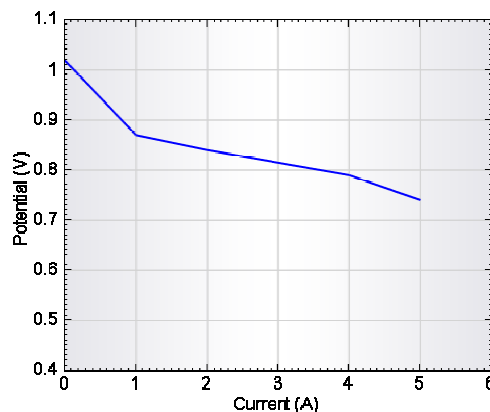

Figure 3 – iV curve of the fuel cell

Impedance measurements were done on several points along this i-V curve in a frequency range from 1 kHz to 100 mHz, with an amplitude of 400 mA in fuel cell current, which resulted in a voltage fluctuation of maximum 10 mV.

Figure 4 shows the results of a measurement at a DC current of 4.6 A, or a fuel cell voltage of 0.76 Volt.
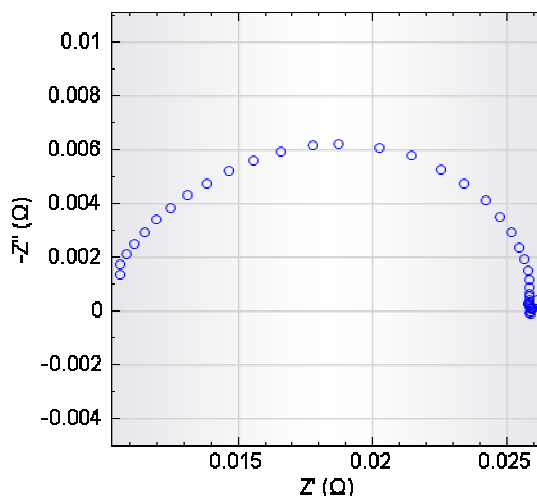

Figure 4 – Nyquist plot obtained at a DC current of 4.6 A

Figure 5 shows a comparison of impedance measurements at different fuel cell currents. As the DC current increases, the total resistance of the cell decreases, as expected.
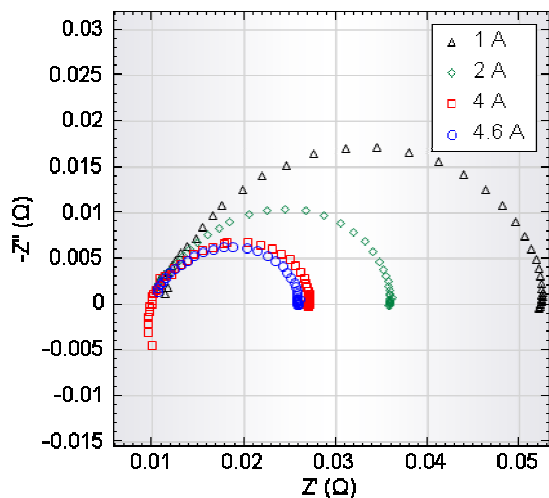
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Figure 5 – Comparison of Nyquist plots obtained at different DC currents

Data Analysis

Choice of equivalent circuit

All data are analyzed using the fit and simulation program in the NOVA software. The equivalent circuit shown in Figure 6 was used to fit the experimental data.
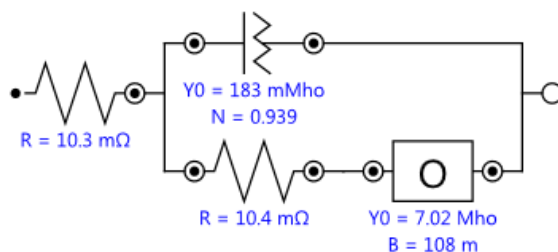

Figure 6 – The equivalent circuit used to fit the data

In which Q represents a so-called constant phase element, O is the cotangent hyperbolic diffusion element. This latter element is used in cases where finite diffusion plays a role. This is the case for example when a RDE is used or in cases where diffusion takes place through a thin film or a coating. The idea is that the concentration of the species involved is constant in the bulk, but is determined by diffusion in the thin film close to the electrode.

The impedance of O is defined by:

$$Z_O = \frac{1}{Y_0} tanh\left(B\sqrt{j\omega}\right)$$

Which upon fitting will result in two values for Y_0 and B, respectively. The value for B depends on the diffusion layer thickness and the diffusion coefficient.

Fitting of the Data

Figure 7 shows a comparison between the measured data obtained at 2 A DC and the fitted data, obtained using the equivalent circuit proposed in this application note.
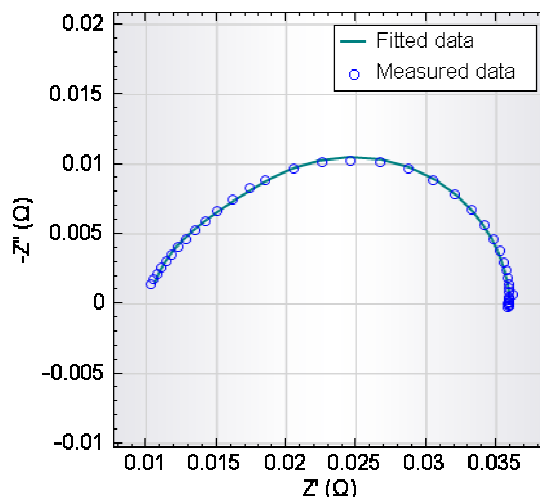

Figure 7 – Comparison of the measured and fitted data obtained at 2 A DC current

The values for the different elements are shown in Figure 8.

Figure 8 – Results from the fitting of the data

Table 1 provides a summary of the values obtained at different DC currents.

	1 A	2 A	4 A	4.6 A
R1 (mΩ)	10.5	10.1	10.1	10.2
R2 (mΩ)	14.4	10.1	8.4	8.8
Q(Y0) Mho	0.247	0.185	0.113	0.156
Q(N)	0.890	0.911	1.000	0.943
O(Y0) Mho	4.33	6.37	11.39	11.86
O(B)	0.12	0.1	0.097	0.082

Table 1 – Overview of the fitting results

It is clearly visible from the table that upon change in current, especially the values for O (or the diffusion behavior) change.

Date

1 July 2011