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► **To cite this version:**

Denis Candusso, Elisabeth Rullière, Thierry Pascal, Pierre Baurens, Jean-Philippe Poirot-Crouvezier. Impedance Measurement of a Proton Exchange Membrane Fuel Cell. EVS18, Oct 2001, Berlin, Germany. hal-04517822

**HAL Id: hal-04517822**

**<https://hal.science/hal-04517822>**

Submitted on 22 Mar 2024

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# Impedance Measurement of a Proton Exchange Membrane Fuel Cell

Denis Candusso, Elisabeth Rullière, Thierry Pascal, Pierre Baurens, Jean-Philippe Poirot

## Abstract

Proton Exchange Membrane Fuel Cells (PEMFC) are accepted to be one of the best technologies that meets the requirements for in-car application. It is very interesting to monitor the impedance of a FC as it gives information on its physical behaviour; it can allow to know whether the membrane is correctly humidified and it can help to understand the electrochemical behaviour of the FC which is important if one wants the FC to operate at its best. We present the experimental device we developed in order to investigate a 5kW fuel cell operating at its nominal current (500 A); it allows to measure the very small value of the impedance ( $\approx 10^{-3} \Omega$ ) by exciting the FC with a sinusoidal current. We give experimental results showing the evolution of the impedance on the frequency range:  $f_{\min} = 1.6$  Hz,  $f_{\max} = 22$  kHz. We show the significant evolution of the impedance diagram when the operating current is changed. We present the results we got when the FC membrane is getting dry. In the conclusion, we give some possible investigations to be led thanks to our experimental device.

**Keywords:** fuel cell, PEM, optimisation.

## 1 Introduction

The membrane is one of the keys of the PEMFC as it allows the proton exchange. This exchange is optimised by a correct humidification of the gas entering the cell. If there is too much water, the gas cannot diffuse properly and the cell efficiency is bad. If there is not enough water, the diffusion does not occur properly.

As the membrane is assembled together with the electrodes, the impedance of the association "Electrode/Membrane/Electrode" will be measured in order to study the behaviour of the membrane.

Some studies have been carried on for low power PEMFC [1]. Our study is quite original as it reports to a high power one (5kW).

## 2 Impedance measurement device

There are different methods to measure the cell resistance [2] [3] [4]. As the cell is equivalent to a voltage source, the voltage response to a current excitation is generally studied.

At a given operating point, the load circuit can be opened very rapidly; the study of voltage and current curves gives an approximation of the cell resistance. The current has to be interrupted almost instantaneously, which is not easy to realise partly because of the parasitic inductances.

We preferred to use a method without any interruption: the cell operating at a certain point is excited by an alternative current which can be sinusoidal and the voltage response is studied [5].

Because of the small value of the cell resistance ( $10^{-3} \Omega$ ), it is necessary to have a substantial current amplitude in order to have a correct precision for the measurements. For the same reason, we measured the impedance of the whole stack, all the cells being connected in series.

This means that the alternative current amplitude has to be about 20% of the nominal operating current one. We checked that the voltage response was sinusoidal indeed to ensure a linear operation.

Depending on the excitation frequency, the impedance or the resistance can be measured. The frequency range was chosen so that the electrochemical behaviour of the cell is not disturbed; this means that the frequency has to be higher than 0.1 Hz. In order to get a resistive behaviour, the frequency has to be greater than 1 kHz. Because of the very demanding conditions- frequency range and amplitude of the sinusoidal current: 60 A for a current of 300 A delivered by the PEMFC, we chose to realise the current generator thanks to power operational amplifiers (LM 12 components) working in parallel. A schematic view of the generator is given on figure 1. It uses a DC symmetrical voltage source (+/-20 V, 40 A) and needs a water cooler. The maximum amplitude of the provided sinusoidal current is 60 A and the frequency range is 1.6 Hz - 22 kHz.

The general synopsis of the impedance measurement is given on figure 2. The Labview software or an oscilloscope may be used to store the data which can be processed using Excel or Matcad software for example. The impedance measurement can be automated on the whole frequency range.

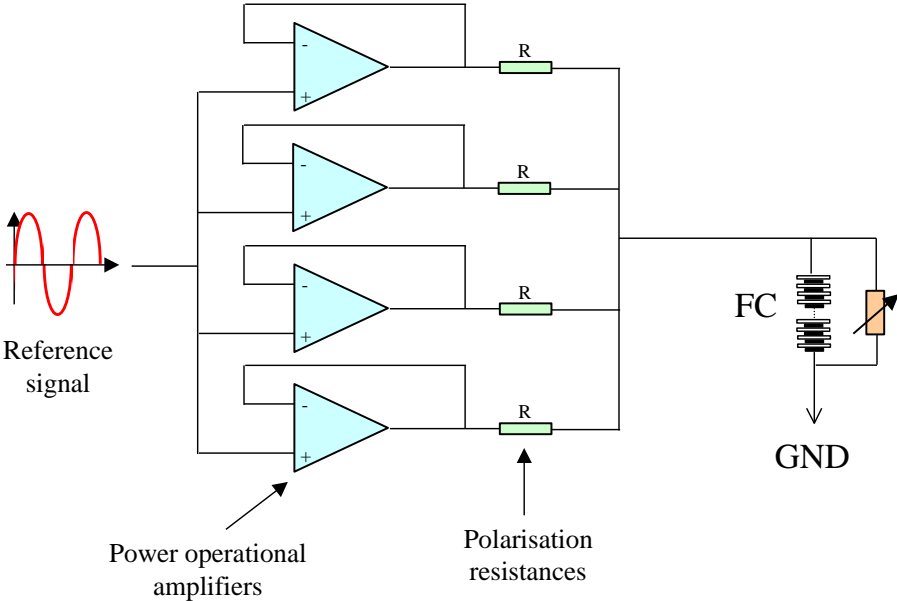
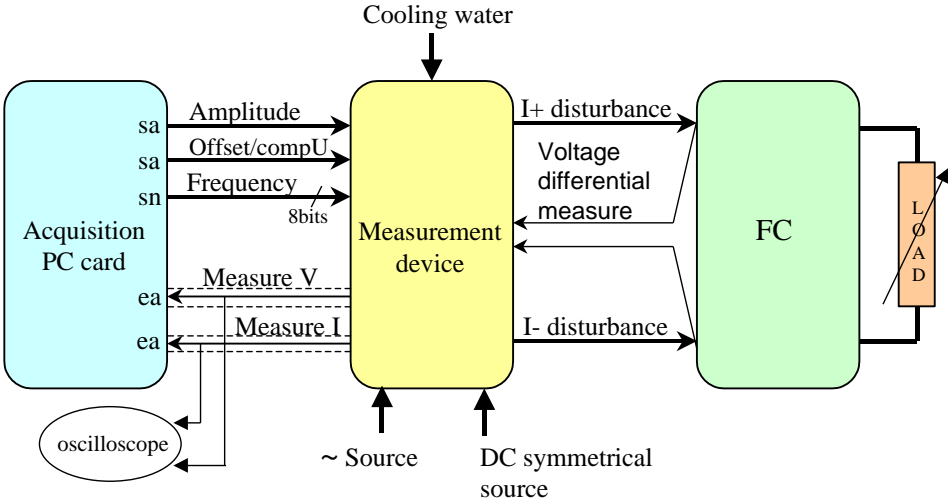


Figure 1: General Schematic View of the Power Generator



sa : analogical output  
 sn : digital output  
 ea : analogical input

Figure 2: Synopsis of the impedance measurement

### 3 Experimental results

#### 3.1 Impedance diagram

Tests were carried out using a 5 kW nominal power FC (nominal current: 500 A and nominal voltage: 10 V) [6].

On figure 3, we show the Nyquist impedance diagram for the PEMFC running through a constant load (the discharge current was 350 A, the amplitude of the sinusoidal signal was 30 A - 10% of the discharge current-). The different frequencies are indicated on the diagram.

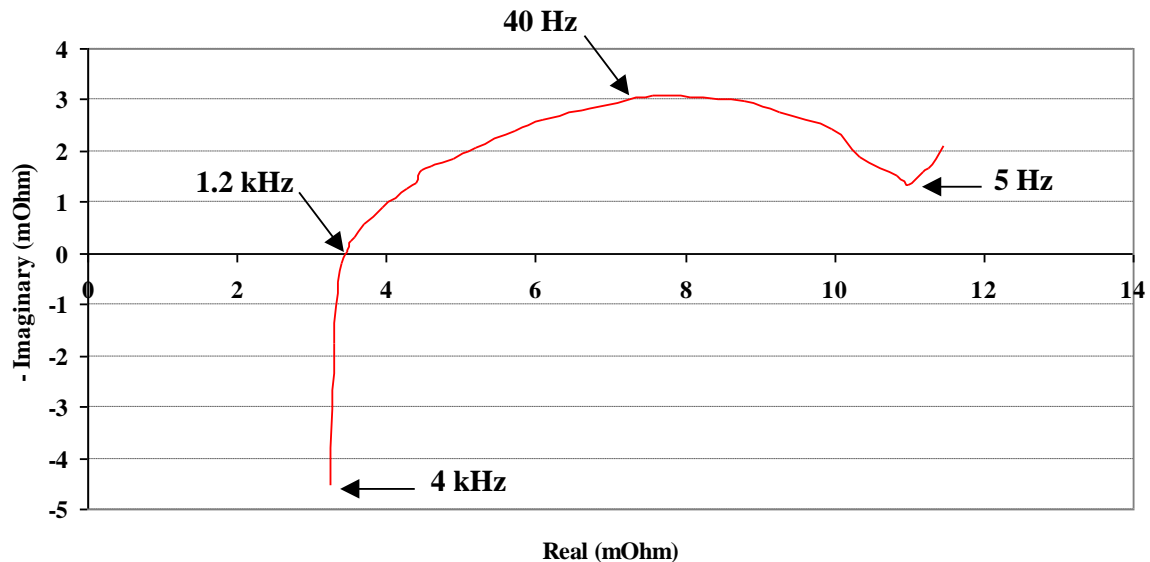


Figure 3: Impedance diagram

It can be noted that for  $f > 1$  kHz, the real part of the impedance is more or less constant, with an increasing inductive part, probably due to connections.

The PEMFC resistance is measured at 1.2 kHz - the imaginary part being null for this frequency. It is about 3.4 m $\Omega$ .

For lower frequencies, ( $f < 5$  Hz), the imaginary part of the impedance decreases first and then increases; it seems that the diagram presents two parts: the first one for  $f > 5$  Hz is an arc and the second for  $f < 5$  Hz may appear as another arc or as an asymptote. Our experimental device cannot measure the FC impedance for  $f < 1.6$  Hz so that the description of the second part is quite imprecise. Anyway, this singularity occurred for all the experiments we carried out (for different discharge currents, different sinusoidal currents as well as for different states of the membrane concerning humidification). It might be due to slow phenomena such as mass transfers occurring for lower frequencies. This observation has to be deepened and interpreted considering the electrochemical behaviour of the PEMFC. This can also lead to an electrical model of the FC.

#### 3.2 Reproducibility

We proved that the impedance diagram was reproducible by making successive experiments with the same operating conditions (same temperature, same current, same gas pressure and flows). Figure 4 shows the impedance diagrams we got for two successive experiments in the following conditions: the discharge current was 88A and the amplitude of the sinusoidal signal was 9 A . They are quite similar.

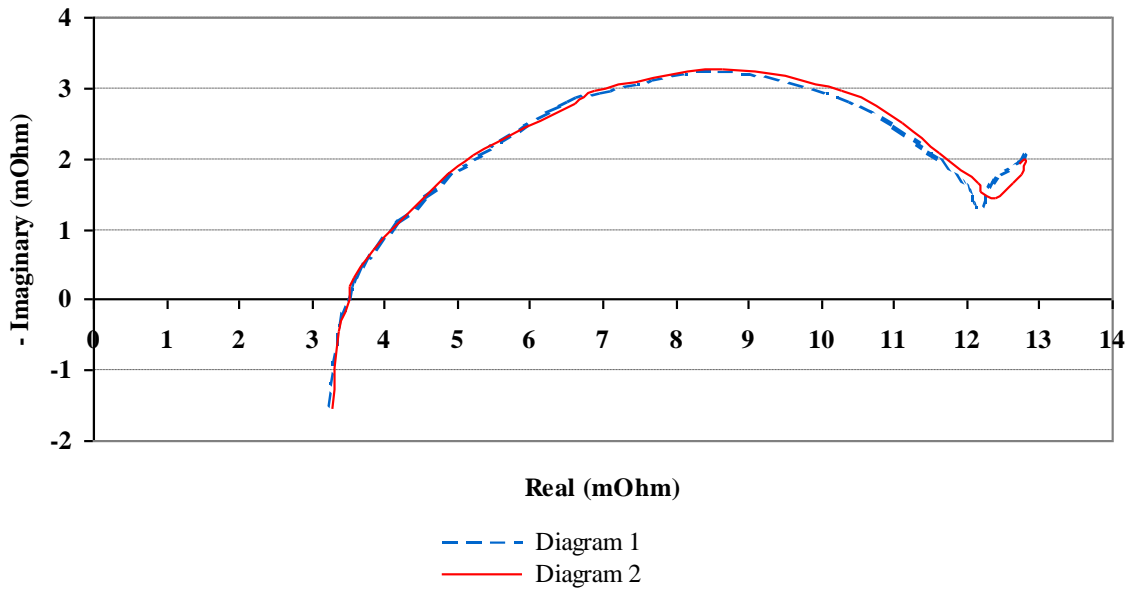


Figure 4: Reproducibility

### 3.3 Evolution of the impedance diagram as a function of the operating current and temperature

Figure 5 shows what happens for two different operating currents: 88 A and 86 A with the same sinusoidal current (8.8 A). Curve n° 2 was drawn with a constant temperature. As for curves n° 1 and 3, the temperature varied as notified.

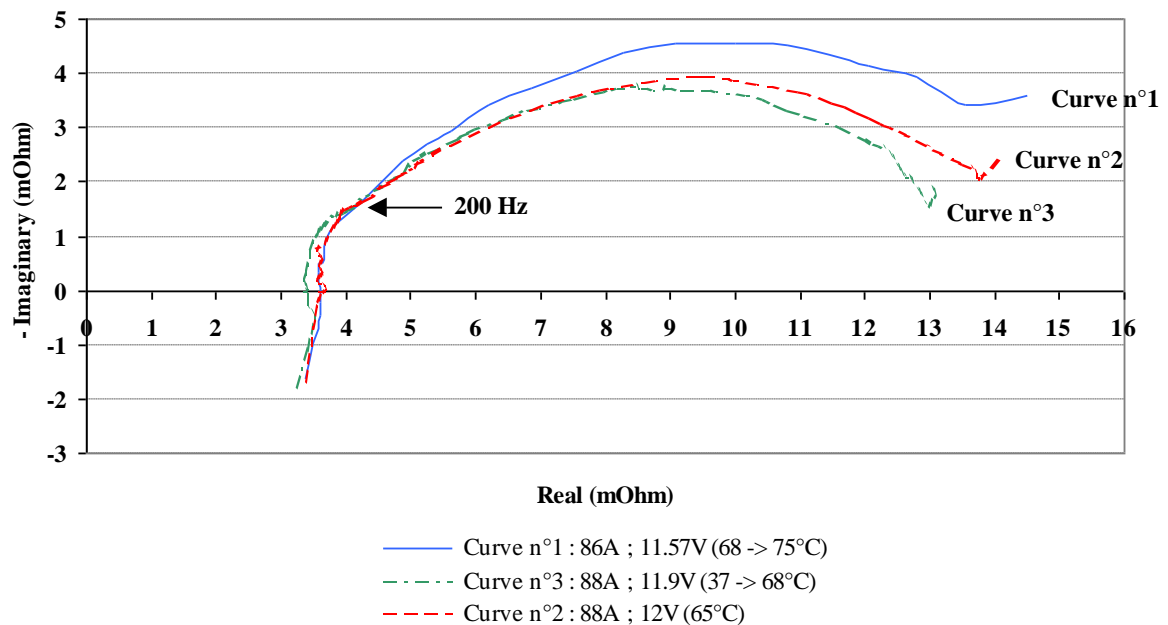


Figure 5: Operating current and temperature influence for I~86A.

We also present the results we got for an operating current equal to 164 A or so; the sinusoidal excitation was 16.5 A (cf. figure 6).

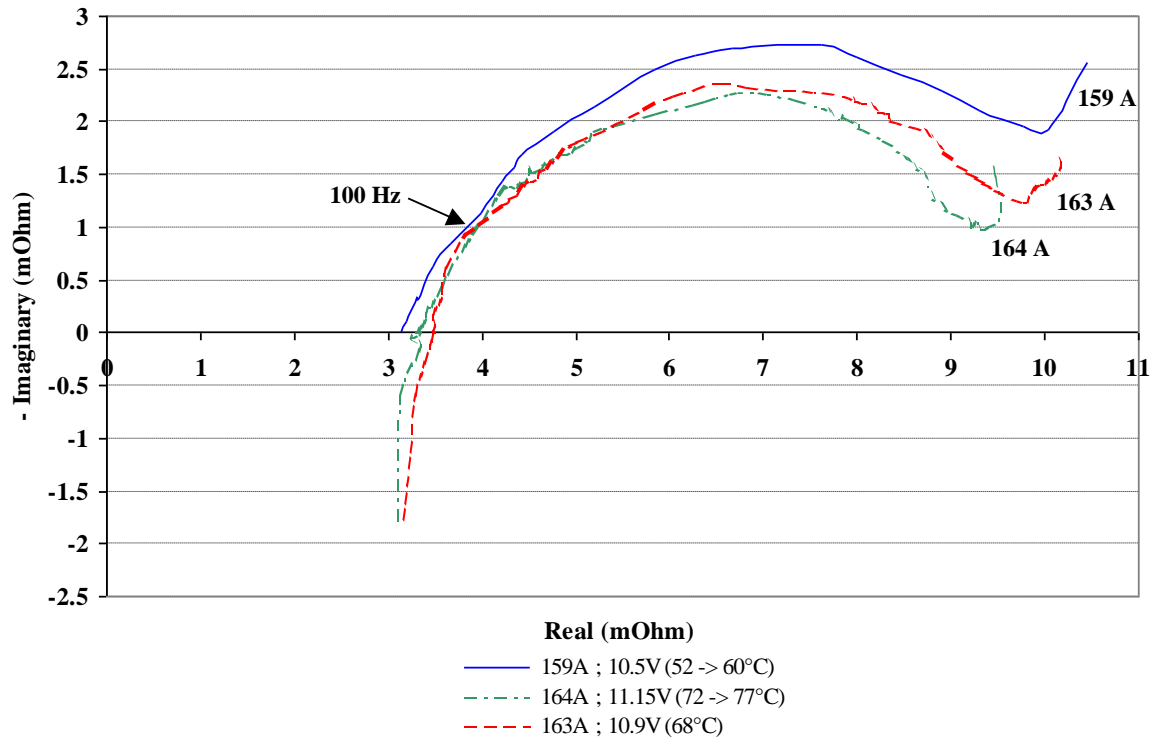


Figure 6: Operating current and temperature influence for I~163A

As in the previous test, one of the experiments was led at a constant temperature; these diagrams show that the operating current has quite a big influence on the results: with a difference of 1 to 5A, the impedance diagrams we got were quite different; with a larger current, the imaginary part decreases, mainly when  $f > 20$  Hz.

The temperature is also to be considered as an influential parameter; the capacitive part is all the more important than the temperature decreases. So is the real part.

Anyway, the polarisation current appears as a more influential parameter than the temperature.

### 3.4 Evolution of the impedance diagram when the membrane gets dry

It is quite interesting to see the evolution of the FC resistance when the membrane is not correctly humidified.

We stopped the water supply for the humidification of the FC and studied its behaviour with no discharge current under a sinusoidal current perturbation of 1 A.

Figure 7 shows the evolution of the resistance during 4 hours.

We noted that the behaviour of the cell was never inductive on the whole frequency range. The frequency for which the phase shift between the current signal and the voltage one is null (resistive behaviour) increased when the cell became drier; at the beginning of the experiments, it was about 3 kHz and at the end it was 22 kHz. The part of the diagram for  $f < f_r$  remains quite similar to what is shown on figure 3. At the end of the tests, the FC resistance was  $2.3 \Omega$  which was approximately 700 times what it was when the FC operated normally.

If the water is provided again, the resistance decreases rapidly; without any discharge current, we measured that the resistance was equal to  $5 \text{ m}\Omega$ . In order for the resistance to go back to the value of

3mΩ, a discharge current has to be sent into the PEMFC. A proper water supply is essential for a good operating of the cell: it induces the electrical conduction and the resistance is lower if there is enough water.

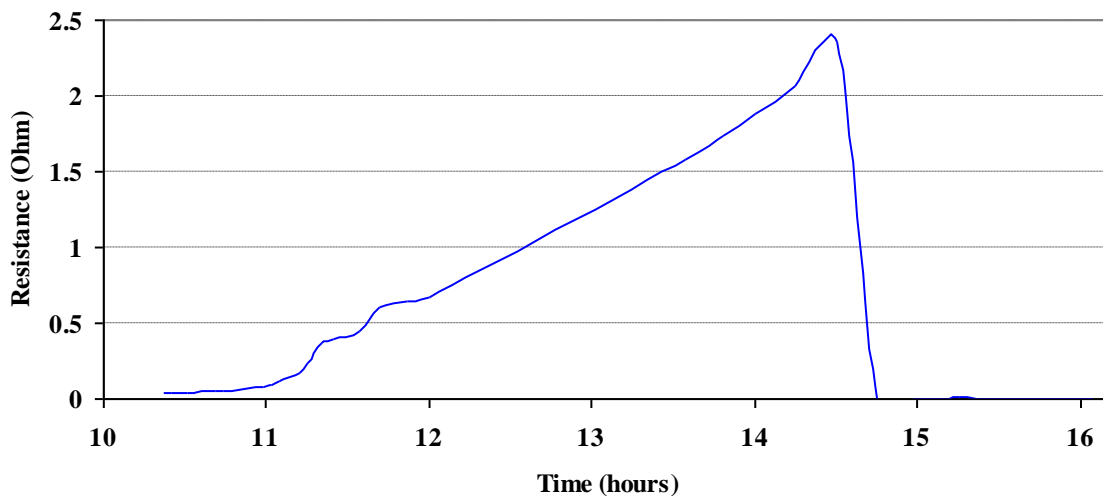


Figure 7: Evolution of the resistance-the cell becoming dry.

## 4 Conclusion

The experimental device we realised is very interesting as it allows to monitor the PEMFC impedance on a large frequency range: 1.6 Hz – 22 kHz. The originality of this device is that it is dedicated to high power fuel cells, especially with large cell area (corresponding to high current).

It can be used to get a deeper understanding of the electromechanical phenomena occurring in the FC depending on parameters such as temperature, operating current. Thanks to these studies, the FC design could be modified in order to improve its operating.

The impedance diagram can also help to get an electrical model of the FC (static or dynamic) in order to simulate and optimise FC systems to be used as power sources.

At last, the membrane could be monitored regarding its water supply thanks to impedancemetry.

In this case, it is not necessary to have a large frequency range, so that it would be interesting to build a simpler, smaller and more efficient power device such as a resonant converter to allow measurements at a given frequency.

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