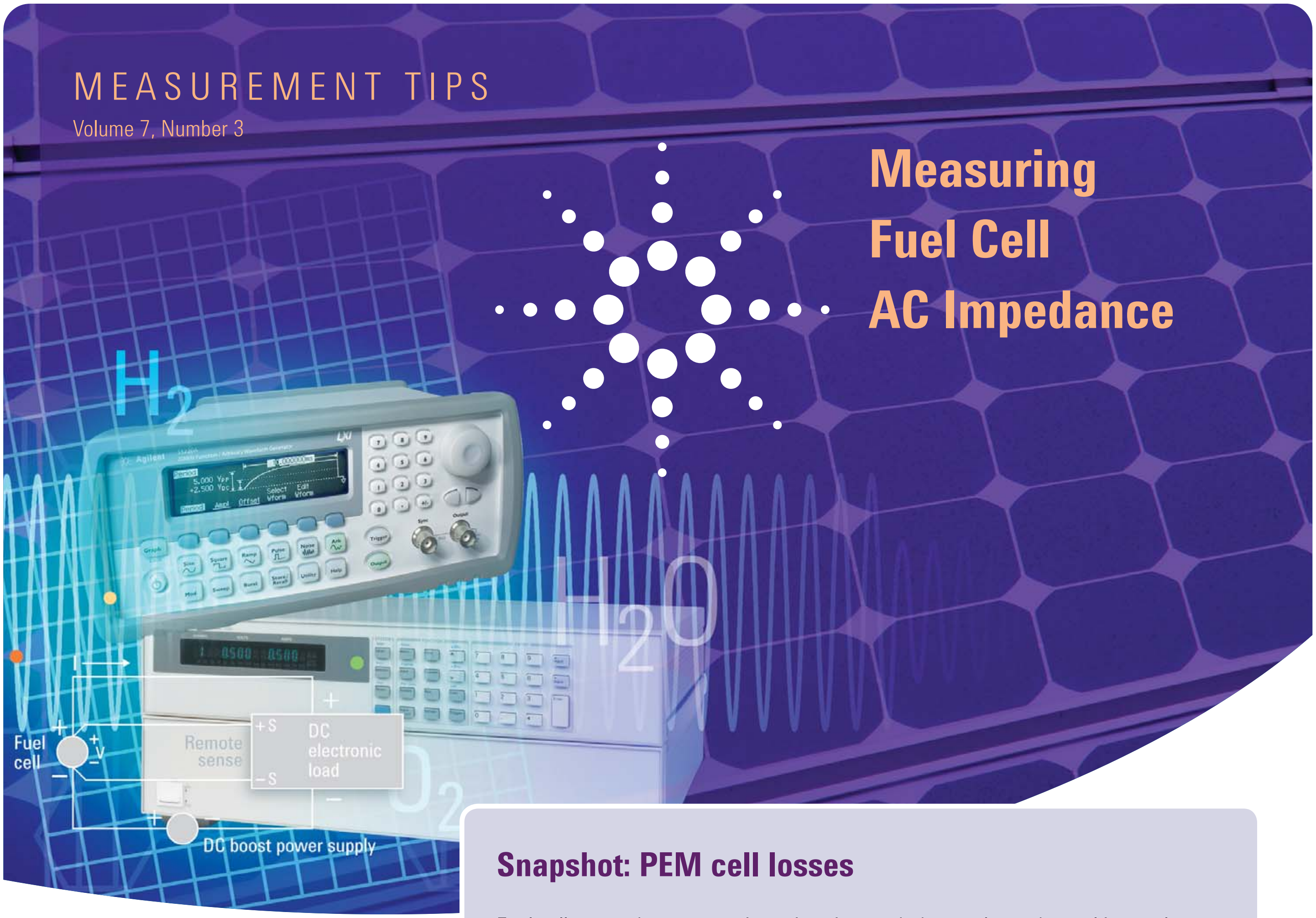
MEASUREMENT TIPS
Volume 7, Number 3

Measuring Fuel Cell AC Impedance



A fuel cell is an electrochemical device used to create electricity through a reaction between a fuel (such as hydrogen) and an oxidant (such as oxygen) in the presence of an electrolyte. In addition to producing electricity, the reaction generates by-products, which typically are only water and heat. Therefore, using fuel cells is an environmentally friendly way to produce electricity.

If you are involved in any of the various stages of developing fuel cells, you need to draw current from your fuel cell or fuel cell stack. In addition, measuring the AC impedance of your fuel cell can help you identify the kinetic and ohmic resistances, which can uncover efficiency issues by revealing internal cell losses. Measuring impedance across a range of frequencies (electrochemical impedance spectroscopy or EIS) can help you identify problems with the fuel cell components or deviations in the fuel cell assembly process.

Snapshot: PEM cell losses

Fuel cell researchers at a major university needed to evaluate the real internal power losses of a PEM (proton exchange membrane) fuel cell over a wide range of operating conditions, including various current densities and temperatures. With the cells operating in a temperature-controlled chamber, they used the Agilent Technologies N3300A DC electronic loads to draw DC current from several cells at one time. The N3300A loads allowed the researchers to vary the DC current drawn from the cells. The loads also enabled them to make complex impedance measurements on the cells by driving the loads with a sine wave from an Agilent 33220A function generator and using the loads to directly make simultaneous voltage and current waveform measurements from which the impedance could be calculated. These impedance measurements led the researchers to the internal PEM cell losses they sought.

PEM photo courtesy of the *National Research Council of Canada*

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Electronic loads draw DC and AC current

Fuel cells are non-linear devices because internal fuel cell impedance changes with operating conditions such as temperature and current density. As a result, you need to evaluate your fuel cell under a variety of operating conditions, including many different current levels. Electronic loads are available to draw power from a fuel cell. Many of these loads can operate in constant voltage mode, which controls a fixed voltage across the cell, or constant current mode, which controls a fixed current drawn from the cell. A typical fuel cell polarization curve (a plot of the fuel cell steady-state voltage vs. current) shows the voltage decreasing little as current increases over a range of operating currents (especially in the ohmic region), so using a load in constant current mode instead of constant voltage mode makes sense. The fuel cell will determine or "control" the voltage and the load will control the current. There are many electronic loads available in various power and current levels. Obviously, to test fuel cell stacks, you need a higher-power load.

To measure fuel cell AC impedance, you can choose an electronic load that has the ability to generate a small sine wave of current superimposed upon the larger DC current that it is drawing from the fuel cell. This low-level current stimulus will produce a corresponding sinusoidal voltage as a response to the internal fuel cell impedances. You can then use measurement instrumentation to acquire both the AC current and voltage waveforms, and from the data representing these waveforms you can calculate the fuel cell AC impedance. See **Figure 1**.

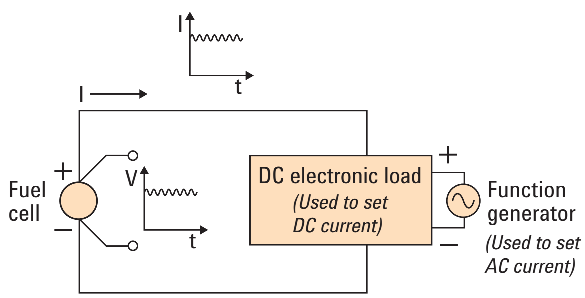

FIGURE 1. ***Stimulate your fuel cell with a sinusoidal current and then calculate impedance from the measured current and resultant voltage waveforms.***

Electronic loads facilitate impedance measurements

Six key features of electronic loads help make precision AC impedance measurements:

1. **Constant current mode:** As we mentioned earlier, this feature is important because it allows the load to control the current in the fuel cell. This feature enables you to easily change the current operating point of the fuel cell to explore how the impedances are affected by current density changes.
2. **External programming input:** This feature is a set of input terminals on the load that will allow an externally generated voltage to modulate the electronic load input current. The current drawn by the load from the fuel cell can be controlled by a voltage signal on the load's external programming input port. This feature enables you to use an external function generator to produce a voltage sine wave and thereby superimpose a current sine wave on the DC current already being drawn by the load.
3. **Built-in synchronized voltage and current digitization capability:** This feature makes it possible for the electronic load to digitize its own input voltage and input current waveforms. To calculate the fuel cell AC impedance, you will need the sinusoidal voltage and current data. While you can use external instrumentation such as oscilloscopes and current probes or current shunts, these instruments may not have sufficient accuracy. Having waveform measurement capability built into the load itself is a benefit. Being able to simply measure a steady-state voltage and current is not enough. To calculate complex AC impedances, you need synchronized waveform data, including phase information.
4. **Low-voltage operation:** This feature gives the electronic load the ability to draw current even when a low voltage is applied to its input terminals. Most electronic loads are designed with some type of semiconductor devices (such as FETs) that are used to draw current from the source connected to the load input. To draw current, these semiconductors require some voltage across them. A single fuel cell typically produces 1 V or less, so choose a load that can draw the current you need at the voltage you expect or add a boost supply (see measurement tip for more information).

MEASUREMENT TIP

Add a boost supply to increase load low-voltage operation

When you are drawing a lot of current from a single fuel cell, the fuel cell voltage will often drop well below 1 V. Depending on the ratings of your electronic load, it is possible that the load will not be able to draw the current you want at these low input voltages (your load documentation should specify this behavior). For example, Agilent N3300A loads can draw full current down to 2 V; at lower voltages, the current is linearly derated from full current at 2 V to zero current at zero volts. If the load cannot draw enough current at your low operating voltage, a DC power supply can be added in series with your fuel cell voltage to boost the voltage seen at the load input terminals. The DC power supply can be a fixed output supply or a programmable supply, and it should produce about 3 V and must be able to handle the maximum current you expect to draw from your fuel cell. Note that the power drawn by the load will increase. See **Figure 2**.

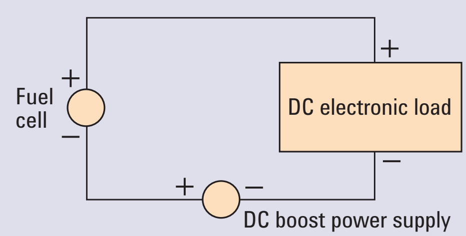

FIGURE 2. ***Add a DC boost power supply in series with a fuel cell to increase the voltage at the load enabling the load to draw more current at low fuel cell voltages.***

5. **Remote voltage sensing:** This gives the electronic load the ability to measure the voltage across two terminals that are located a distance away from the load input terminals. The current measured by the load is the exact same current that flows through your fuel cell, but to get an accurate impedance measurement, it is important to measure the voltage right at the terminals of interest. This feature enables you to get accurate AC impedance measurements that do not include unwanted load lead impedances or connector impedances.

MEASUREMENT TIP

Use load remote sense leads for accuracy

To get an accurate fuel cell impedance measurement, you must avoid measuring the impedance of load leads and connectors used in your setup. Agilent N3300A loads have remote voltage sensing terminals that allow the load to measure the voltage right at the desired measurement points for a single cell, a group of cells, or the entire stack. An accurate voltage measurement is necessary to produce an accurate calculated impedance result. Note that N3300A loads allow up to a 5 V difference between the sense terminals and the load input terminals, which allows them to easily accommodate a 3-V boost supply, if needed. See **Figure 3**.

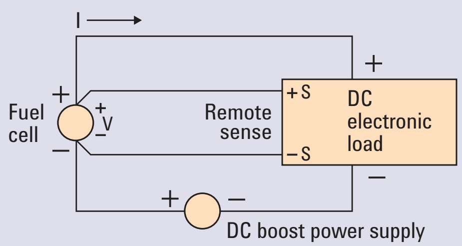

FIGURE 3. ***Use remote voltage sense terminals to measure the voltage at the exact points where you want to calculate impedance.***

6. **Parallel operation:** If you need more current (or power) than a single load can handle, an electronic load that is capable of parallel operation can solve the problem. Fuel cell stacks can produce large amounts of power that could exceed the power rating of a single load. With this paralleling capability, you can test higher-power fuel cell stacks.

EIS measurement from load data

Agilent N3300A DC electronic loads have all of the features mentioned above, which makes them ideal for measuring fuel cell AC impedance. You can use an Agilent 33220A function generator to drive the load's external programming input and stimulate the fuel cell with a low-level sinusoidal AC current. Then you can use the load to measure both the AC current and resultant AC voltage waveforms. Next, you need a computer to read back the voltage and current waveform data; you can use any suitable math package to perform a fast Fourier transform (FFT) on the data. Finally, complex math functions can be used to divide the transformed voltage by the transformed current to obtain the fuel cell complex impedance (both magnitude and phase). You can repeat this process at any frequency within the capabilities of the equipment to get a full spectrum of impedance measurements or an EIS measurement. You can also use this instrumentation to generate a fuel cell polarization curve. For a more thorough discussion of this AC impedance measurement technique, please refer to the Agilent product note, *"Making Fuel Cell AC Impedance Measurements Utilizing Agilent N3300A Series Electronic Loads"* (publication number 5988-5358EN).

Summary

Performing AC impedance measurements on your fuel cells can reveal problems with your fuel cell components or deviations in your assembly process. Whether you are working on individual cells or a fuel cell stack, electronic instrumentation is available to facilitate these AC impedance measurements. Agilent N3300A DC electronic loads are well qualified to draw DC current as well as stimulate your cells with an AC waveform. Additionally, these loads can make waveform measurements facilitating the calculation of the cell's complex impedance across a frequency band to give you an EIS measurement.

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