เทคนิคการหักล้างวงจรกรองสำหรับการหาค่าอิมพีแดนซ์
ของเซลล์เชื้อเพลิงชนิดเมมเบรนแลกเปลี่ยนโปรตอน

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บทคัดย่อ

นักวิทยาศาสตร์ทั่วโลกคาดว่าเซลล์เชื้อเพลิงจะเป็นเครื่องมือสำคัญในการก้าวข้ามยุคน้ำมันเชื้อเพลิงจากซาก
ฟอสซิล อย่างไรก็ดีการใช้งานเซลล์เชื้อเพลิงจำเป็นจะต้องมีวงจรแปลงผันกำลังไฟฟ้าเพื่อปรับระดับแรงดันที่ได้จาก
เซลล์เชื้อเพลิงให้สามารถเข้ากันได้กับภาระทางไฟฟ้าที่นำมาต่อ ในการออกแบบวงจรแปลงผันกำลังไฟฟ้าที่เหมาะสม
สำหรับเซลล์เชื้อเพลิงแต่ละตัวจำเป็นจะต้องมีข้อมูลที่สำคัญของเซลล์เชื้อเพลิงนั้น เช่นกราฟความสัมพันธ์ของแรงดัน
และกระแส รวมถึงค่าอิพีแดนซ์ของตัวเซลล์ที่ความถี่ต่าง ๆ อุปกรณ์สำหรับวัดหาค่าอิมพีแดนซ์ของเซลล์เคมีไฟฟ้าที่มี
ใช้ในห้องปฏิบัติในสาขาเคมีหรือวัสดุศาสตร์ ไม่สามารถนำมาใช้ในการหาค่าอิมพีแดนซ์ของระบบเซลล์เชื้อเพลิงขณะทำ
การจ่ายกระแสได้ เนื่องจากมีข้อจำกัดเรื่องกระแสสูงสุดที่เครื่องวัดสามารถวัดได้ ข้อจำกัดนี้ทำให้ผู้ออกแบบวงจรแปลง
ผันกำลังไฟฟ้าต้องทำการวัดหาค่าอิมพีแดนซ์ของเซลล์เชื้อเพลิงเองด้วยวิธีการแบบพื้นฐาน บทความนี้กล่าวถึงข้อควร
ระวังที่ทำให้การวัดได้ค่าอิมพีแดนซ์ที่ผิดเพี้ยนและวิธีการวัดที่ถูกต้อง โดยวิธีการวัดที่นำเสนอในบทความนี้จะทำให้
สามารถวัดค่าอิมพีแดนซ์ของเซลล์เชื้อเพลิงได้อย่างถูกต้องโดยไม่จำเป็นต้องใช้เครื่องมือชั้นสูง

คำสำคัญ: เซลล์เชื้อเพลิง อิมพีแดนซ์ วงจรกรอง

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Filter Cancellation Technique for PEMFC Impedance Evaluation

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Abstract

Scientists around the world regard fuel cells as a promise solution to the fossil fuel mitigation. However, PEMFC needs a proper electric power converter to convert their dc voltage output to match the conventional dc or ac electric load. To design the proper electric power converter, the characteristic of the targeted PEMFC like the characteristic curve or the cell impedance is required. The equipment for measuring the electrochemical impedance, which is usually available in chemical or material science laboratory, is not suited for evaluating the fuel cell system at the rated operating point. The limit is mainly on the current rating of the measuring equipment. This forces the electric converter designers to evaluate the cell impedance manually. This paper presents several pitfalls and solutions in evaluating the cell impedance. With proper measuring configuration presented in this paper the cell impedance can be extracted from the measured signals without using any high-end equipment.

Keywords: Fuel Cell, Impedance, Filter

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1. Introduction

Scientists around the world regard fuel cells as a promise solution to the fossil fuel mitigation. Fuel cells can bridge energy from renewable sources, which are not constant during each day, to the conventional consumption demand by using gas hydrogen as energy carrier [1, 2]. This method is very useful, especially in the transport applications.

Proton exchange membrane fuel cells (PEMFCs) are suited for the transport and residential applications because their operating temperatures are less than 100ºC [3]. However, the PEMFCs are low voltage dc sources. Each PEMFC needs a proper electric power converter to convert their dc voltage output to match the conventional dc or ac electric load. To design the proper electric power converter, the characteristic of the targeted PEMFC like the characteristic curve or the cell impedance is required [4-7].

The equipment for measuring the electrochemical impedance is usually available in chemical or material science laboratory. Although the equipment can test impedance from very low to very high frequency, the testing current is limited at very low level, which is in order of micro to milli-ampere [8]. Moreover, it can test only a small sample of material, which is not suited for testing the impedance of the whole cell simultaneously. These force electric converter designers to evaluate the impedance of the targeted fuel cell by them self.

The simplest way to measure the fuel cell impedance is shown in figure 1. In the figure, the cell is set to operate at the certain operating point. Then a small-signal ac current is added to the dc
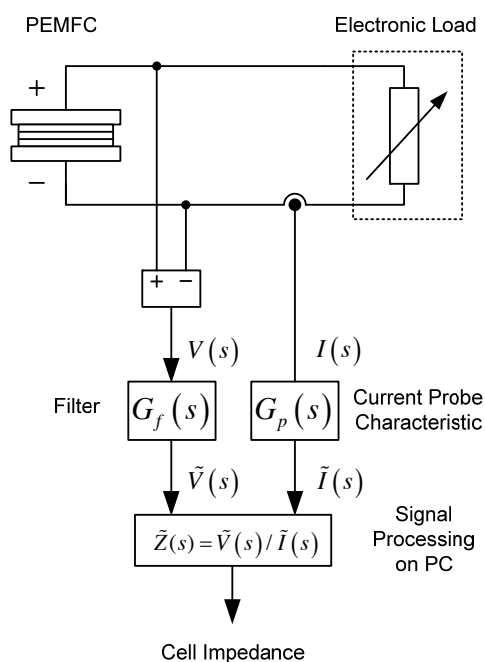

Figure 1 Fuel cell impedance evaluation

operating point. This results in the deviation of the cell voltage at the terminal. The deviation is due to the overall cell impedance. With the help of Fast-Fourier transformation (FFT), the cell impedance can be evaluated from the small-signals of the current and voltage response. The process of using FFT can be done on the personal computer by recording and importing signals from an oscilloscope to the PC.

The mentioned method is quite simple, but in fact, it comes with two hidden problems. The first problem is due to the current probe which used to measuring the cell current. The conventional current probe, which uses the principle of Hall Effect sensor usually have bandwidth about 100kHz [9]. This bandwidth seems to be enough for testing the impedance for the electric converter design where the range of interesting frequency is

lower than the converter switching frequency, which is about 25 kHz. Unfortunately, the problem is due to the phase lag of the measured signal which appears much earlier before the bandwidth limit of the current probe. This is obviously affecting the precision of the impedance testing.

Another problem is the need of proper filter. The current waveform which represents the change of the load can be measured without any filter, but the amplitude of the cell voltage response from the injected ac current perturbation is quite small. The low-pass filter is required to improve the signal/noise ratio of the measured signal and the high-pass is also necessary to eliminate the dc part of the signal. Although the ac coupling is available in every oscilloscope, their cutoff frequency, which is about 3<Hz, is too high. Adding a filter to the voltage measuring path will also decrease the precision of the resulting impedance.

This paper proposes a simple method for measuring the PEMFC impedance correctly.

2. Problem analysis and the proposed solution

According to figure 1, the ac component of the voltage waveform recorded by the oscilloscope is obtained from the filter output. The recorded signal, $\tilde{V}(s)$, can be described as

$$\tilde{V}(s) = G_f(s) \cdot V(s) \tag{1}$$

where $G_f(s)$ is the filter transfer function and $V(s)$ is the real voltage response signal.

The current obtained from the current probe needs no filter. This is because the ac component of current waveform is large enough to be extracted directly from the raw signal in the signal processing stage. However, by the imperfection of the current probe, the measured signal obtained from the current probe without any additional filter is still different from the real current signal. The measured signal, $\tilde{I}(s)$, can be described as

$$\tilde{I}(s) = G_p(s) \cdot I(s) \tag{2}$$

where $G_p(s)$ is the probe characteristic and $I(s)$ is the real current waveform. As a result, the impedance evaluated from the measured signal is

$$\tilde{Z}(s) = \frac{G_f(s) \cdot V(s)}{G_p(s) \cdot I(s)} = \frac{G_f(s)}{G_p(s)} Z(s) \tag{3}$$

which is obviously different from the cell impedance, $Z(s)$.

The simplest way to eliminate the effect of the current probe is to use a resistor as a current sensor. The current through the resistor can be obtained by dividing the voltage across the resistor by its resistance. The measured impedance becomes

$$\tilde{Z}(s) = \frac{G_f(s) \cdot V(s)}{I(s)} = G_f(s) \cdot Z(s) \tag{4}$$

At this point the evaluated impedance is still incorporating the effect of the filter in the voltage path. To eliminate the effect of the filter characteristic we propose to insert the identical filter to the current measuring path. This introduces the same transfer function to the denominator which results in the cancellation of filter transfer function as follows

$$\tilde{Z}(s) = \frac{G_f(s) \cdot V(s)}{G_f(s) \cdot I(s)} = Z(s) \tag{5}$$

By using this method, the real cell impedance can be measured. The diagram of the proposed method is shown in figure 2.
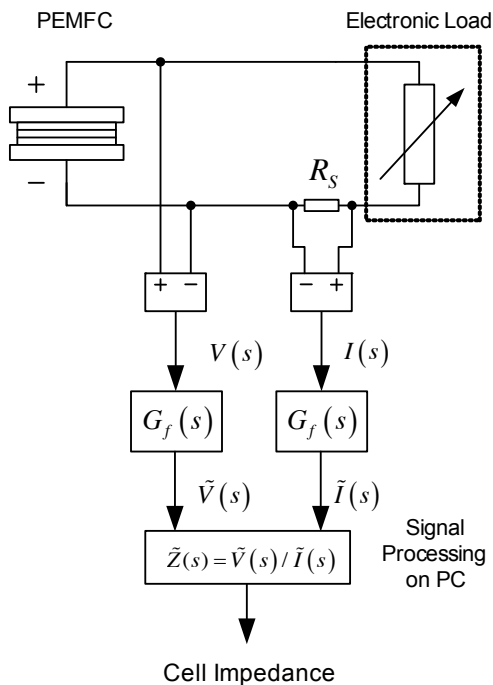
Figure 2 The proposed method

3. Experimental Preparation

The experimental was done on the test bench described in [10]. The fuel cell is single-cell module of PEM type. The dc operating point of the cell was set to 15 A, which resulted in 0.69 V of the cell terminal potential. The ac current of ±3 A were added to the cell current by using the electronic load described in [11].

The band-pass filters which have lower cut-off frequency at 0.1 Hz and upper cut-off frequency at 100 kHz were used. The circuit and component parameters were selected by the software called Filterlab®. This software is dedicated for active filter design and is provided from Microchip with free of charge.
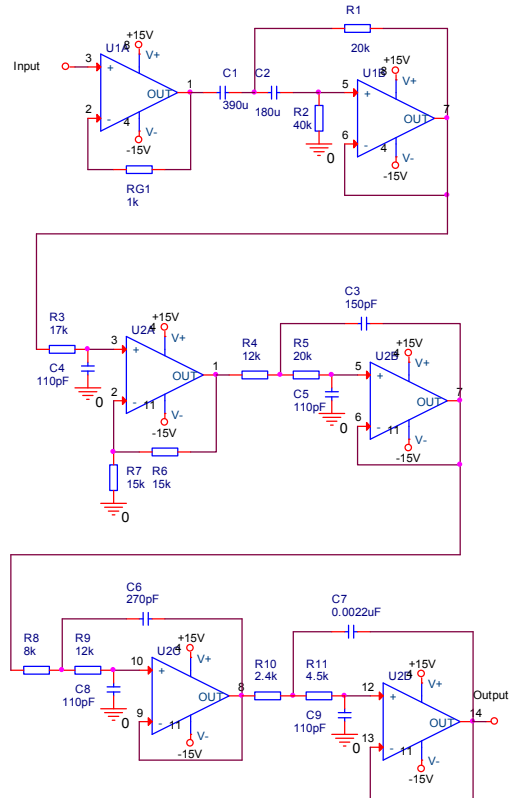

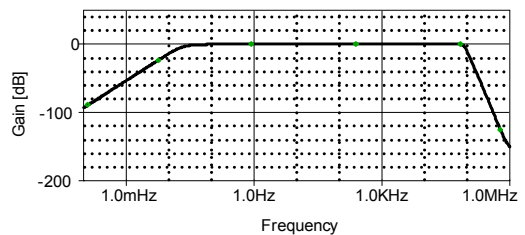Figure 3 The schematic of the designed filter
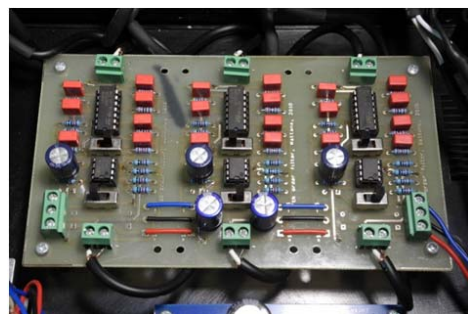

Figure 4 Frequency response of the designed filter
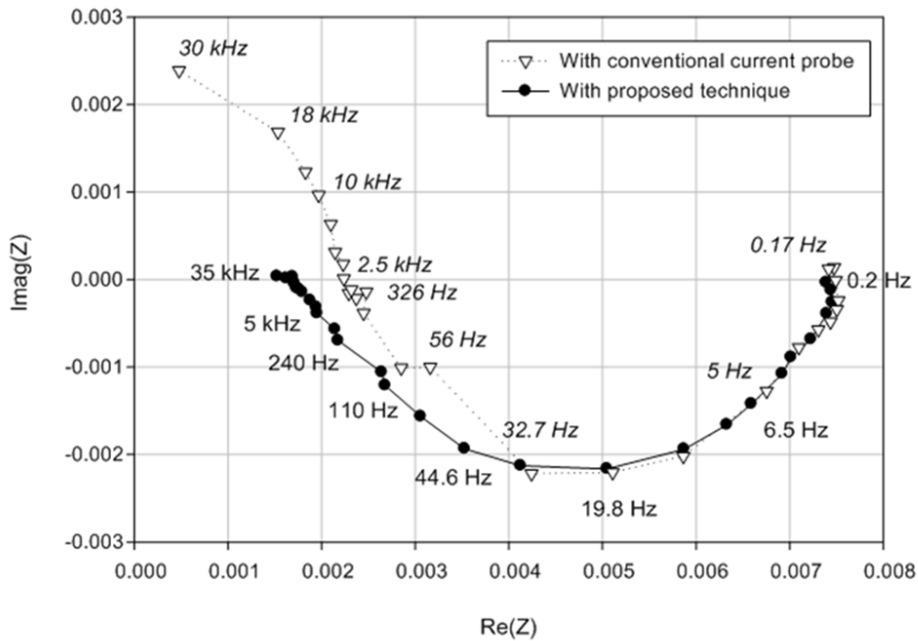

Figure 5 The implemented filter

Figure 6 Comparison of the impedance trajectory

The designed circuit is shown in figure 3 and the frequency response obtained from SPICE simulation is shown in figure 4. The assembled PCB of the filter is shown in figure 5. Please note that there are 3 sets of filter on the PCB and only two were used.

4. Experimental Result and Discussion

The measured fuel cell impedances obtained from the experimental are shown in figure 6. The figure compares two impedances resulted from two different methods. The impedance with white triangle marks is the impedance obtained by using a filter for voltage measurement and using a current probe for current measurement. The impedance with black dot marks is the result of using the proposed method.

It can be seen that the impedance with white triangle have positive complex element at frequency higher than 2.5 kHz. This indicates that there is some inductive element in the system under test. This does not agree with the theory of fuel cell where the equivalent circuit of the cell is compose of only R and C elements [12, 13]. In contrast with the impedance obtained from the proposed method where the trajectory of the impedance is a semi-circle curve. This is much agreeing with the general fuel cell theories.

5. Conclusion

This paper proposed an economical and effective method for evaluating the PEMFC impedance at specified operating point. The method suggested using the a resistance as a current sensing element and uses two identical filters which resulted in a cancellation of filter effect on the measured impedance. The result showed that the measured impedance agreed with the theory of the fuel cell.

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