Analysis of energy efficiency of PEM water electrolyzer supplied by an ultrashort pulse wave

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ABSTRACT

Nowadays, energy storage systems require reliable element and equipment. Having rechargeable electric energy source with satisfactory discharge duration becomes a priority in order to supply the mobile electronic devices and the various embarked systems. Best solution for this issue consists to use hydrogen Proton Exchange Membrane (PEM) fuel cell in which hydrogen gas plays the secondary energy source. Gas production from PEM electrolysis depends mainly on characteristic of power supply. In this paper, we focus on energy efficiency study of the PEM water electrolyzer made with Aciplex-501SB membrane and it supplied by 200ns with 100MHz ultrashort pulse wave. As a result, gas produced is extremely pure. Its yield can be calculated by the ratio between the energy output of PEM fuel cell and electric energy consumption during the water electrolysis. It was found that the yield of the designed PEM electrolyzer rises 18.42% that is more efficient compared to PEM electrolyzer supplied by direct current having only 9.36% of energy yield.

Keywords: - *PEM water electrolyzer, PEM fuel cell, ultrashort pulse, energy efficiency*

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1. INTRODUCTION

Today's embedded systems require energy storage devices that guarantee their functioning for a well-defined period. Mobile phones, laptops, cameras, drones, electric cars and all other electronic equipment need a rechargeable electric generator with longest autonomy.

The use of the hydrogen fuel cell partially solves long recharging period problem of the energy storage system. Indeed, recharging gas takes only three to five minutes [1]. Interaction between hydrogen and oxygen gases within cell creates spontaneous combustion and produces electricity. This type of electricity generator rejects only water and heat which is very useful because it contributes to reduce greenhouse effects.

Objective of this paper consists to study and improve the energy efficiency of Proton Exchange Membrane (PEM) electrolyzer. A PEM electrolyzer and a PEM fuel cell were designed to analyze its electric and thermodynamic data, including current intensities, delivered output voltages, gas production flow rate and battery consumption.

2. MATERIALS AND METHOD

2.1. Proton Exchange Membrane water electrolyzer

2.1.1 Ultrashort pulse wave generator

The characteristic of electrolyzer power supply has an important influence on its efficiency. Previous study [2], [3], [4], [5] has shown that the use of an ultrashort pulse signal power supply is more efficient compared to direct current. Thus, an ultrashort pulse voltage generator was chosen as PEM water electrolyzer power supply. Figure 1 shows its electronic circuit and different pulse generator pattern diagrams.

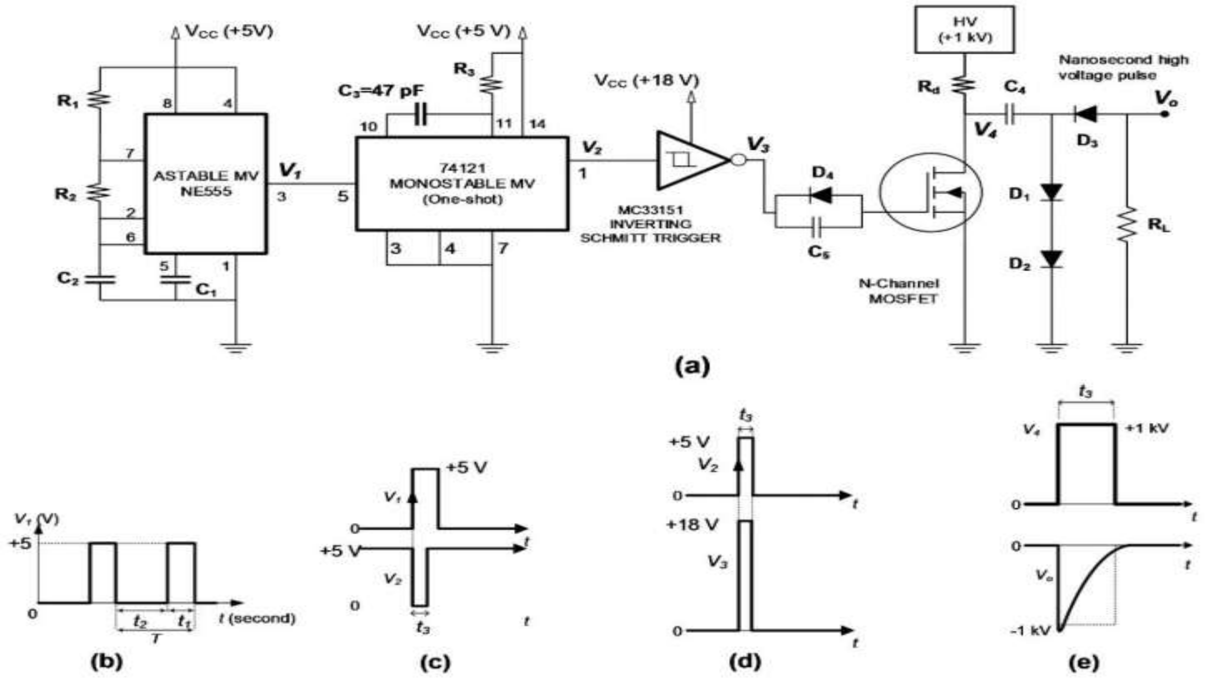
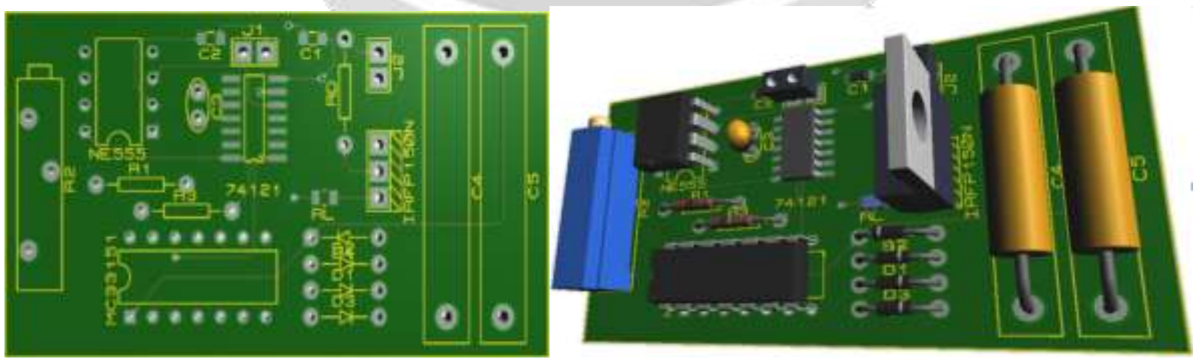


Fig-1: High voltage short pulse generator -(a) Overall electronic circuit, (b) Pulse generated by voltage TTL, (c) Short pulses generator by monostable multivibrator with voltage Schmitt triggering, (d) TTL to non TTL +18 Voltage conversion, (e) Negative short peak high voltage conversion.

Before testing on real implementation, simulation model of circuit (Figure 1 (a)) was run on PROTEUS software with the following values C_1=220nF, C_2=1nF, C_3=47pF, C_4=100nF, R_1=220Ω, R_2=70Ω, R_d=1kΩ and R_L=100kΩ. Using ARES software, the circuit layout of the short pulsation voltage generator and its three-dimensional view is shown in Figure 2.



(a) (b)

Fig-2: (a) Circuit layout of short pulsation voltage generator, (b) Three-dimensional presentation of the short-pulse voltage generator circuit.

Designed generator circuit is powered by 12V direct current from battery supply which is very efficient compared to the use of direct current generators. However, in order to have maximum efficiency, it is necessary to adjust the pulse width and laps time by changing the resistor value by means of potentiometer [6]. To power the PEM water electrolyzer, ultrashort pulse wave generator calibrated at 200ns and 100MHz.

2.1.2 Electrodes

Electrodes ensure liaison between generator and electrolyte. Their choice plays a big role in dihydrogen production rate thanks to electrolysis process [7]. Precious metals such as gold and platinum resist to corrosion caused by the electrolyte and are very efficient electrodes but too expensive use. Therefore, in order to create a large-scale electrolyzer, a cheaper electrode and efficient metal such as carbon steel material was chosen for the electrodes as it is commonly used in an alkaline electrolyzer [8]. Indeed this metal can resist to corrosion compared to others and it costs cheaper than precious metals.

2.1.3 Electrolyte

The electrolyte conducts electricity through the two electrodes of an electrolyzer. Some electrolyte varieties activate more rapidly ion movement towards the targeting electrodes. In the generator, electrolyte made with potassium hydroxide solution KOH was used. This choice is based on fact that it frequently used, it costs lower and its availability on the local market [9].

2.1.4 Proton exchange membrane

In electrolyzer device, a Proton Exchange Membrane (PEM) is located between the electrodes whose conductivity is ensured by the ions present in the side chains of fluoropolymer [10]. Aciplex-501SB having 0.16mm to 0.20mm thick was used as PEM electrolyzer and it has 12 electrolysis cells connected in series, see Figure 4.

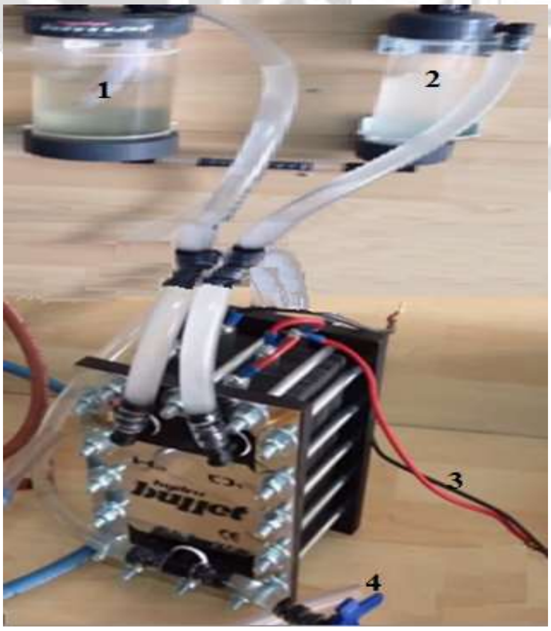
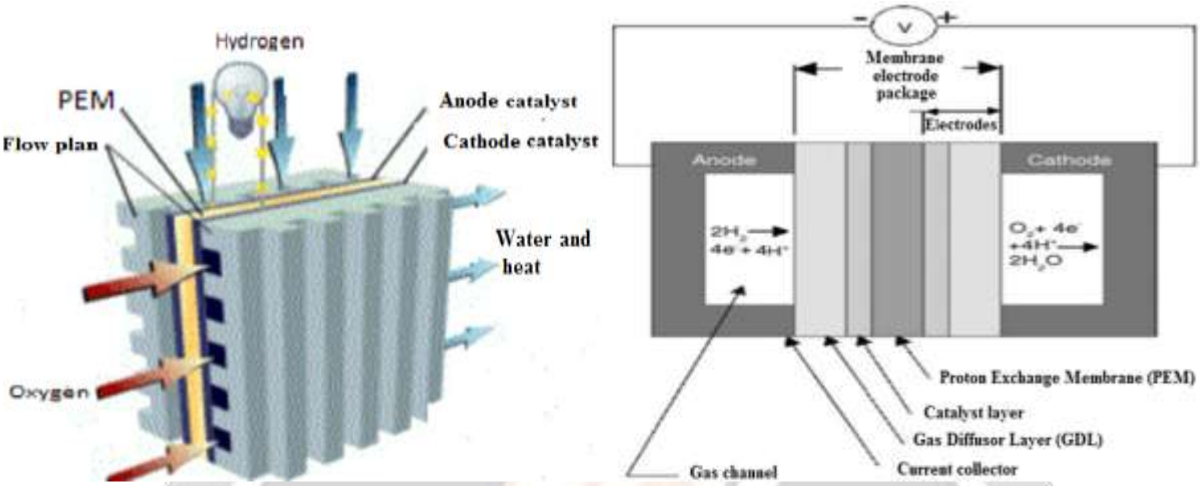


Fig-4: Proton Exchange Membrane electrolyzer

2.2. Proton Exchange Membrane fuel cell

A hydrogen fuel cell was designed that the most important basic elements are composed by electrodes and proton exchange membrane. Figure 5 (a) and (b) shows an overview of PME fuel cell presenting the gas flow through the electrodes formed by a Proton Exchange Membrane located in the middle and two layers which are catalyst layer and Gas Diffusor Layer (GDL) surrounded by current collector components.



(a) (b)

Fig-5: (a) Hydrogen and oxygen flows in PEM fuel cell, (b) Typical diagram of a PEM fuel cell

Furthermore, electrodes efficiency balances correctly the transport processes required for a functional fuel cell. In Figure 6, transport process follows three stages within the membrane:

- Protons removal from the membrane and the catalyst,
- Electrons displacement from the current collector to the catalyst through the Gas Diffusion Layer,
- Water production combined with release of electrons following chemical reactions.

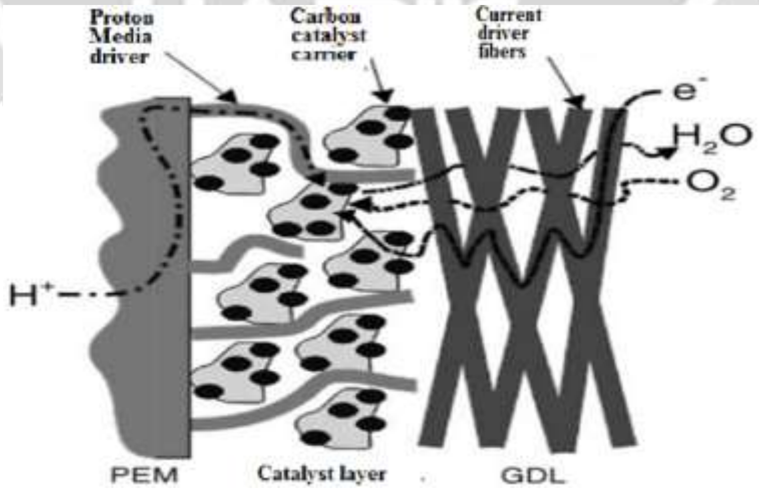


Fig-6: Transport of gases, protons and electrons in an electrode of a PEM fuel cell

Protons, electrons and gases are also called the three phases of a catalyst layer. Optimizing Electrode design consists partially to correctly distribute the elements present in the membrane phase in order to reduce transport losses. In addition, an intimate intersection of these transport processes on the particles of the catalyst layer is important to ensure PEM fuel cell better functioning where each electrode was fixed on both sides of the membrane. Fuel cell membrane used was Aciplex-501SB brand. Figure 7 shows the designed PME fuel cell package. In generator package, dioxygen and dihydrogen injected through input hole partially transform into electricity. Non-transformed gas ejected through the output hole to be reused. PEM configuration has recycling facilities. Input and output holes for dihydrogen are placed nearby positive terminal and for dioxygen nearby negative terminal.

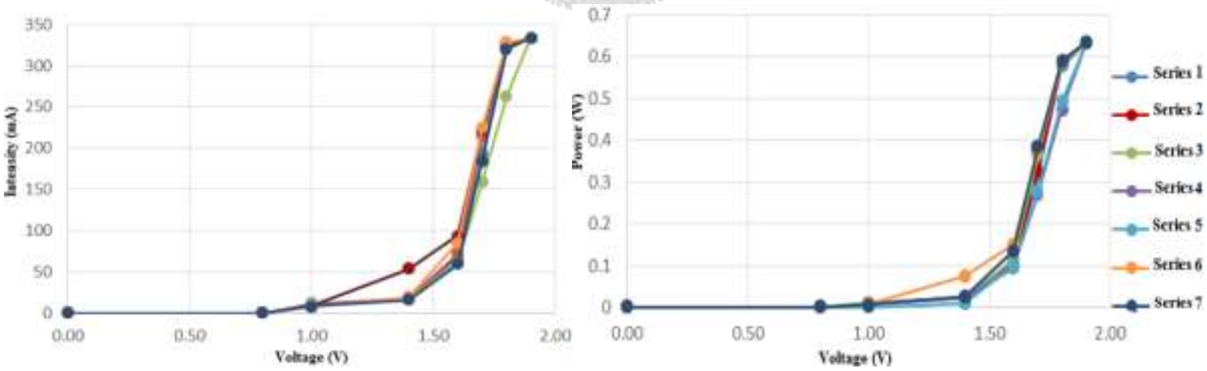
Fig-7: PEM fuel cell package

3. RESULTS

3.1. Electrolyzer power balance

To test PME fuel cell reliability, several measurement series with the same configuration of electrolyzer were adopted. The operating power of an electrolyzer was deduced from measurement. Voltage variation across the electrolyzer creates electricity. The maximum voltage observed at the PEM water electrolyzer output was 1.9V while the current intensity was limited to 1A. For a better understanding the PEM system functioning, seven series of measurements were carried out. Intensity and power diagrams along with voltage values are presented in Figures 8 (a) and (b) respectively.

Regarding the results, the curves have almost the same trend. However, small difference between these curves exists. It is due to existing gas bubbles stuck on the walls of the electrodes. Indeed, gas bubbles slightly modify the resistor value of the electrolysis system. In addition, system capacity charge and discharge conditioned by air bubble might cause these curve difference.



(a) (b)

Fig-8: Voltage variation measurement series on PEM water electrolyzer of (a) Intensity, (b) Power

About gas production within PEM water electrolyzer, gas purity produced is almost extremely pure (99.99%). Figure 9 displays its volume variations and curves show that variations have the same trends in all seven measurement series. In fact, resulting linear curve conform to the following equation:

, $V=0.4E$

where V is the volume of gas (ml) and E the energy required to transform water into gas (J).

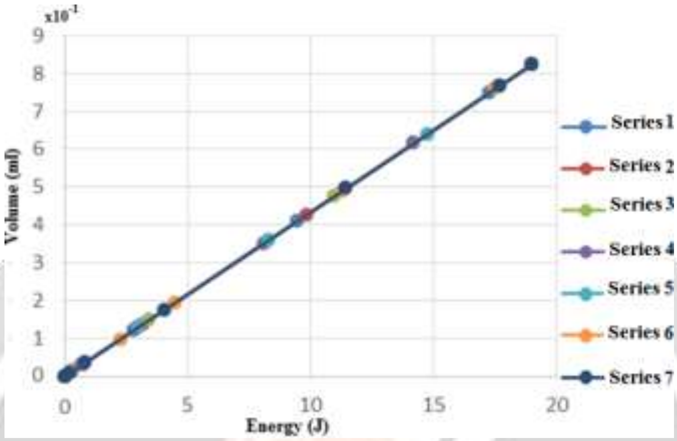
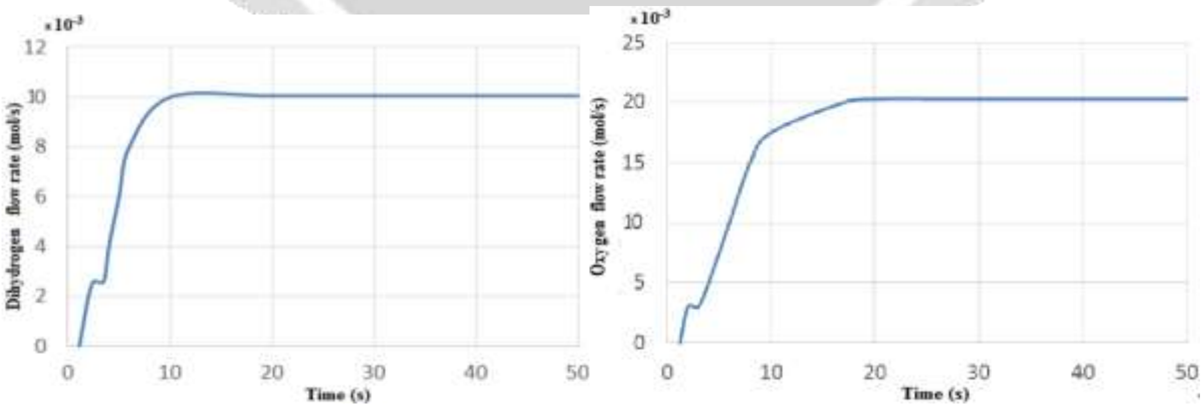


Fig-9: Gas volume production in PEM water electrolyzer

3.2. Hydrogen and oxygen flow rate consumption

The PEM hydrogen fuel cell is supplied by dihydrogen and dioxygen to produce electricity. The pressure of these gases varied in time course. Its consumption caused a pressure diminution in the hydrogen and oxygen tank storage. Thus, the gas flow rate decreased by its own pressure. After running PEM fuel cell, dihydrogen and dioxygen, flow rate variations patterns are recorded and presented in Figures 10 (a) and (b) respectively.



(a) (b)

Fig-10: Time course of gas consumption of PEM hydrogen fuel cell- (a) dihydrogen inlet flow rate, (b) dioxygen inlet flow rate

According to Figure 10, dihydrogen flow rate stabilizes about 10s after running the battery while for dioxygen is about 20s. These two periods result from the quantity proportion of the gas used. In fact, the quantity of dihydrogen used in PEM hydrogen fuel cell is twice than for dioxygen.

4. DISCUSSION

Discussions is based mainly on comparisons, first about the volume of gas produced by the electrolyzer and the gas consumed by PEM fuel cell, then about the energy consumed and the energy produced by the electrolyzer.

Following gas flow rate comparisons (figure 10), assessment of their time production and time consumption for long functioning period of PEM is needed. During 10 hours after running the PEM electrolyzer, it produced 10.4 liters of dihydrogen and 20.8 liters of oxygen under normal conditions temperature (25°C) and pressure (1atm). But the battery which is the PEM fuel cell consumed these quantities of gas produced only for 1h48mn. Moreover, the PEM electrolyzer required energy approximately 76Wh during 10 hours while the battery delivered 14Wh of energy during 1h48mn.

Considering calculation based on these figures, energy yield of electrolyzer for PEM fuel cell gave 18.42%. This percentage represents the electric energy quantity recovered during energy transformation from water cycle by electrolysis of the combustible battery. By contrast, using direct current to run the electrolyzer, yield dropped to 9.36%. Thus, the use of ultrashort pulse wave can save energy up to 96.8% compared to the use of DC power supply. In addition, by combining both designed PEM fuel cell and PEM electrolyzer, this energy generator package has shown more efficient compared to the electrolytic electrolyzer of Kaveh Mazloomi et al., with only 15.51% energy yield [11].

5. CONCLUSION

The study objective was to reuse chemical energy stored in the fuel cell by converting it into electric energy in order to improve the energy efficiency of PEM fuel cell. The performance of the designed PEM electrolyzer using ultrashort pulse gave satisfactory results. In fact, according to the calculations with the data recorded during experimentation, it was found that the energy yield of the electrolyzer of the fuel cell was 18.42%. This yield can be improved by varying some parameters such as temperature and pressure which is among the perspective of the present study.

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