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Development of a New Generation Hybrid System for the Electric Vehicle

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---ABSTRACT---

Today, both environmental concerns and the necessity to find solutions to the world's ever-increasing energy needs force people to find new and clean energy sources and develop environmentally friendly energy conversion systems. In this respect, the 21st century is the period in which 'hydrogen' is used as 'New Energy Technologies' and 'fuel cell' systems are adopted. For this purpose, the change in hydrogen and oxygen consumption in the fuel cell against time was investigated, ranging from 0.86 V to 2.44 V, with the model being repeated each time. The results show that the optimum configuration was found to 2.44 V and 6.88 W of power with the hydrogen flow rate of 0.2 ml/min and the oxygen flow rate of 0.4 ml/min in the polymer electrolyte membrane fuel cell (PEMFC). Our future research in this area will focus on separation of water according to the volume of hydrogen and oxygen gases, as well as determining the efficiency of the solar module and PEM electrolyzer.

KEYWORDS: *Photovoltaic-electrolyzer-fuel cell-battery hybrid system, optimal configuration, electric vehicle*

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I. INTRODUCTION

The process of global urbanization has brought about the rapid economic expansion of all countries in the world. With the continuous the world's energy consumption, and the rapid economic development entailes serious emissions of carbon dioxide [1]. The problem of planet heats up caused by the ongoing emission of greenhouse gases has become a threat to survival and development of humanity, which become a global concern. From the 1960s, environmental degradation have pushed up worldwide, governments aim has been to achieve sustainable economic growth with low-carbon emissions and less energy consumption. The renewable energy generation technologies have shaped the future power grid. Amongst these technologies, wind energy, photovoltaic (PV) power generation technologies, which offer advantages such as superior natural resource endowment, constantly increasing development and readily available, are more mature and more productive than other renewable energy generation technologies [2]. According to statistics, the world's renewable energy capacity additions expanded with almost 50% in 2023, reaching almost 510 gigawatts (GW), with photovoltaic capacity accounted for three-quarters of renewable energy added globally. China commissioned more solar PV in 2023 as the entire world did a year before, while China's wind additions also grew by 66% year-on-year. Alongside China's extraordinary acceleration, the USA, EU, and Brazil also hit all-time highs increases in their renewable energy capacity [3]. To become prevalent PV power generation, which is expected to become the largest source of global electricity production, two major problems have to be solved. One of the problems is the instability of PV power generation which will a massively affect electrical grid. In order to prevent this impact, the grid will not accept unstable electricity, which will cause a waste of power. The second problem is the energy storage challenges. Physical energy storage, electrochemical energy storage, and electromagnetic energy storage technologies, which used in energy storage, will not be able to meet the needs of large energy storage and the empowerment of clean energy in the future. Therefore, many energy storage options, such as pumped hydropower storage, hydrogen storage, compressed air, and batteries, etc. are still at the development stage. Compared with them, hydrogen storage has the characteristics of high energy density, large and easy storage capacity, lower conversion efficiency, and transmission [4]. Hydrogen gas (H_2) produced through water electrolysis using renewable energy sources such as solar, wind or hydroelectric energy can be used in areas such as transport as well as electricity supply for fuel cell vehicles.

The purpose of this work is to develop a model of a hybrid system using PV, Electrolyzer, Fuel Cell and Battery for transport applications. The first step is to construct the circuit simulator and then adding all the elements that is necessary for this system such as a PV system, Electrolyzer, Fuel Cell and Battery. Next, the complete model will be simulated to ensure the circuit will operate as expected. Our goal is to find the optimum design of a new photovoltaic-electrolyzer-fuel cell-battery hybrid system that we model for vehicles.

II. MATERIALS AND METHODS

2.1. Photovoltaic Panel

Photovoltaic solar panels (Figure 3. (a)) are made of semiconductor materials and convert sunlight falling on them directly into electrical energy. Increasing the efficiency of photovoltaic systems is a critical step to maximize the amount of electricity obtained from solar energy. Hybrid energy systems have been developed to increase the efficiency of photovoltaic systems. These systems are integrated with photovoltaic cells along with other renewable energy sources or energy storage systems, achieving higher efficiency.

2.2. Electrolyser

Electrolyzers play a critical role in the production of hydrogen from renewable energy sources. The working principle of electrolyzers is based on the process of separating water into hydrogen (H_2) and oxygen (O_2) gases by applying an electric current between the electrodes. Proton Exchange Membrane (PEM) electrolyzers (Figure 3. (b)) separate water into hydrogen and oxygen using a proton exchange membrane, which is an acidic electrolyte. These electrolyzers are more compact, fast-responding and efficient systems. Increasing the efficiency of electrolyzers is of critical importance in reducing energy consumption, reducing costs and increasing hydrogen production capacity.

2.3. Fuel Cell

The function of a fuel cell is to convert the energy of the fuel reaction into electrical energy. A fuel cell can be modeled as a controlled current source. In this study, the H_2/O_2/Air fuel cell (Fig. 1 (c)) was used. The Fuel Cell is a single cell Proton Exchange Membrane Fuel Cell (PEMFC) for H_2/O_2, hydrogen and oxygen operation. By operating the fuel cell with pure Oxygen instead of Atmospheric Oxygen (Air), it has achieved much higher performance with better results. This Proton Exchange Membrane (PEM) fuel cell produces electricity using hydrogen and oxygen gas. Its by-products are water and heat. When using Fuel Cell H_2/O_2/Air, you also have the option of operating the cell in air-breathing mode simply by removing the stopper. When operating with atmospheric oxygen, the power of the cell is somewhat lower than when operating with pure oxygen.

(a) ***(b)*** ***(c)***

Figure 1. (a) Photovoltaic Panel **(b)** Electrolyser **(c)** H_2/O_2/Air fuel cell

2.4. Electrochemical measurements

For electrochemical tests, a PEM electrolyzer was used for hydrogen and oxygen production. This cell with a surface area of 3.0 cm^2 was used in electrolyzer mode for hydrogen production. Water reacts in the electrolyzer under the influence of electrical energy according to the following formula:

$$2H_2O \longleftrightarrow 2H_2 + O_2 \quad (1)$$

This process takes place in the MEA (membrane electrode assembly). The MEA consists of a cathode, an anode, and a special polymer membrane (PEM) that is permeable to protons but a barrier to electrons. Electrolyzer works according to the PEM principle. The produced gases were stored in storage tanks. The energy stored in the gases in chemical form was converted back into electrical energy in the fuel cell.

Fuel Cell H_2/O_2/Air is a single-cell Proton Exchange Membrane Fuel Cell (PEMFC) for hydrogen and oxygen operation. This Proton Exchange Membrane (PEM) fuel cell produces electricity by using hydrogen and oxygen gas. This cell with a surface area of 3.0 cm^2 was used in fuel cell mode for electric production.

III. RESULT AND DISCUSSION

General view of the studied system is shown in Figure 2.

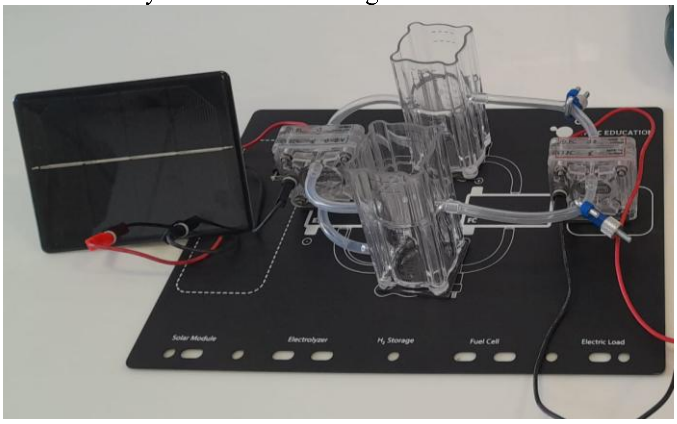
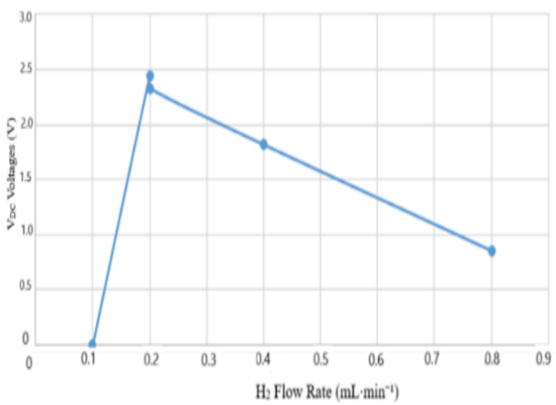


Figure 2. General view of studied system

We oparete the PEMFC system approximately 10 minutes until the system reaches a stable state, after that *hydrogen and* oxygen *fed into* the *system* and the energy parameters of the system are investigated. The load is applied in steps of 2.82 A. Both hydrogen and oxygen flow rates have been allowed to vary from 0.1-1.0 mL·min⁻¹ gradually increased. In this context, a load-following control strategy is used. Additionally, the time evolution of hydrogen and oxygen consumption rates over a range of currents drawn through the cell has been examined.

Table 1. Hydrogen and oxygen flow rates

Component	H_2 Flow Rate (mL.min^{-1})	O_2 Flow Rate (mL.min^{-1})	Voltage of a Cell (V)
PEMFC	0,2	0,4	2,44
PEMFC	0,4	0,6	2,33
PEMFC	0,6	0,8	1,82
PEMFC	0,8	1,0	0,86



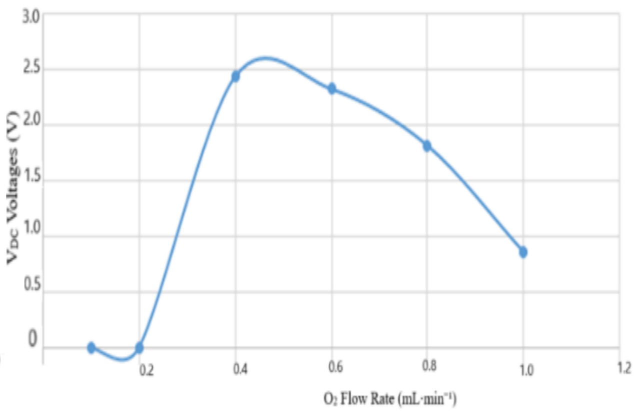
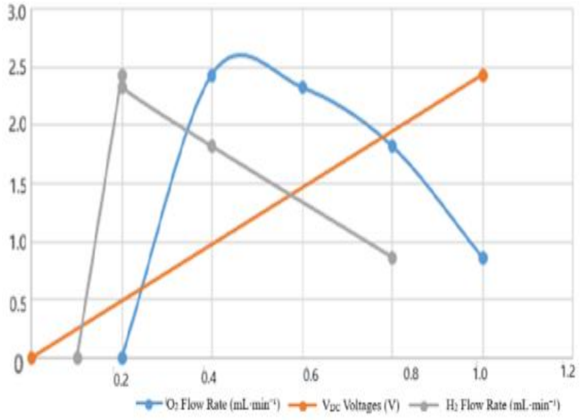


Figure 3. Voltage versus hydrogen flow rate. **Figure 4.** Voltage versus oxygen flow rate.

As shown in Figure 3, with increase in hydrogen flow rate from 0.1 mL·min^{-1} to 1.0 mL·min^{-1}, the voltage increases and then rapidly decreases from 0.2 mL·min^{-1} flow rate. Figure 4 shows that with increase in oxygen flow rate from 0.2 mL·min⁻¹ to 1.2 mL·min⁻¹, the voltage increases rapidly for up to 0.4 mL·min⁻¹, then decreases rapidly. Figure 5 also presents the voltage depending on the flow rate of oxygen and hydrogen.



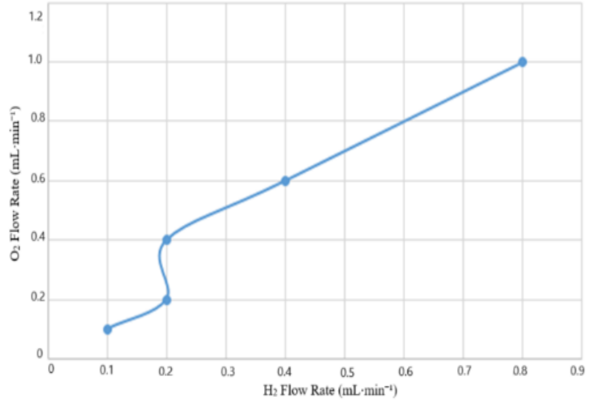


Figure 5. Voltage versus hydrogen and oxygen flow rates. **Figure 6.** H_2 and O_2 flow rates against time

From Figure 6, it can be seen that there was no electricity production below the flow rate of 0.2 mL·min⁻¹ for hydrogen gas and 0.4 mL·min⁻¹ for oxygen gas. The fuel flow variation profile is shown in Table 1 to note the variation of the parameters of interest within the PEMFC and battery.

The available voltage and power from the fuel cell is a main limiting factor in the development of the system. Figure 6 shows the characteristic curve of the power and voltage relationship. When Figure 7 is examined, it is seen that the fuel cell power density increases with increasing voltage density. Figure shows the cell output range from 2.40 W and 6.88 W. The most efficient voltage and cell output are 2.44 V and 6.88 W, respectively, when the hydrogen flow rate is fixed at 0.2 mL·min⁻¹, and the oxygen flow rate is fixed at mL·min⁻¹ of PEMFC cell.

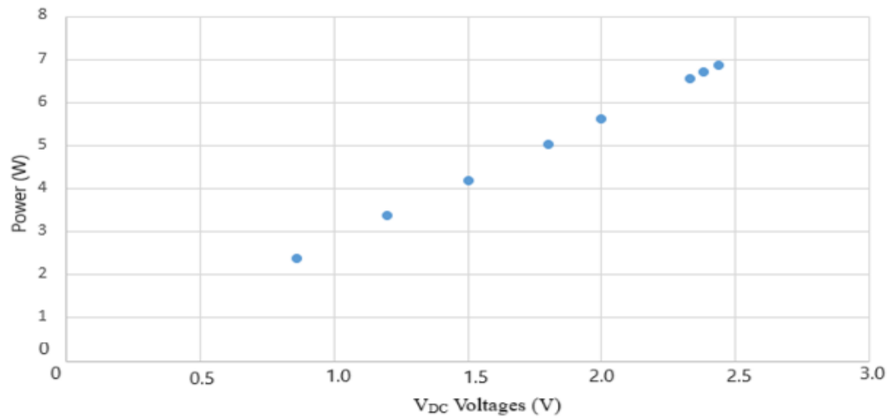


Figure 7. Experimental W-V characteristic of PEMFC cell.

IV. CONCLUSION

This paper presents the optimum power configuration in a new generation hybrid system for fuel cell electric vehicles. The obtained results show that H_2 and O_2 gases were the only products from the electrolyzer with their volume ratio close to 2:1, and the efficiency was determined to be nearly 100% during water electrolysis. For this purpose, the change in hydrogen and oxygen consumption in the fuel cell against time was investigated, ranging from 0.86 V to 2.44 V, with the model being repeated each time. The results show that the optimum configuration was found to 2.44 V and 6.88 W of power with the hydrogen flow rate of 0.2 ml/min and the oxygen flow rate of 0.4 ml/min in the polymer electrolyte membrane fuel cell (PEMFC).

This paper demonstrates also the effectiveness of the proposed hybrid PV/Fuel cell system. By installing this system the total cost of the installed system showed that the system can deliver energy with an acceptable cost.

Our future research in this area will focus on separation of water according to the volume of hydrogen and oxygen gases, as well as determining the efficiency of the solar module and PEM electrolyzer.

A new product will be developed that will compete with the hybrid system, which is one of the elements of electric vehicle technology.

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