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Performance Parameters of Direct Coupling Advanced Alkaline Electrolysis and PEMFC System

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Abstract: The proton exchange membrane fuel cell (PEMFC) is regarded as the most competitive candidate to replace the traditional forms of power conversion due to its prominent advantages. The hydrogen gas is used as a main fuel in the fuel cells. The hydrogen gas can be produced through the use of solar energy which is connected to alkaline electrolysis cell (AEC) by water splitting process known as electrolysis. In this paper, a thermodynamic model is presented to design and optimize a direct coupling system (DCS) that has two cells, an alkaline electrolysis cell (AEC) and a proton exchange membrane fuel cell (PEMFC). Moreover, the performances of the direct coupling system (DCS) are evaluated using numerical model that are built in Engineering Equations solver software. So several parameters concerning the direct coupling system (DCS) such as the voltage of system, the hydrogen rate production from electrolysis which injects to fuel cell and producing power of the full system. The simulations result show that, the voltage of alkaline electrolysis is higher than the fuel cell. The water management process in the whole system is considered satisfactory due to the low value of the losses in the amount of water. The water which is generated from the fuel cell is injected to electrolysis cell, so the electrolysis cell does not need to inject large quantities of water. The efficiency of the system is about 34.85% and this efficiency is satisfactory compared to other systems of power generation as this percentage is due to clean, renewable and environmentally friendly fuel.

معاملات أداء المنظومة المقترنة مباشرة من المحلل الكهربائي القلوي وخلية الوقود ذات غشاء الفصل البوليمري

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ملخص: ان خلية وقود غشاء تبادل البروتون هي المرشح الأكثر قدرة على المنافسة ليحل محل المنظومات التقليدية لتحويل الطاقة وذلك نظرًا لمزاياها البارزة . يستخدم غاز الهيدروجين كوقود رئيسي في خلايا الوقود وبالإمكان إنتاجه من خلال توصيل الألواح

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الشمسية بالمحلل الكهربائي القلوي الذي بدوره يقوم بفصل الماء الى غاز الهيدروجين وغاز الأكسجين اي ما يسمى بعملية التحليل الكهربائي . في هذه الورقة تم عرض نموذج ديناميكي حراري لتصميم وتحسين منظومة اقتران مباشر يحتوي على خليتين ، خلية المحلل الكهربائي القلوي وخلية وقود نوع غشاء تبادل البروتون . بالاضافه الى ذلك فلقد تم تقييم أداء منظومة الاقتران المباشر باستخدام النموذج العددي الذي تم انشاؤه في برنامج المحاكاة (برنامج حل المعادلات الهندسية) . تمت دراسة العديد من معاملات الأداء المتعلقة بمنظومة الاقتران المباشر مثل جهد المنظومة، و معدل غاز الهيدروجين المنتج من المحلل الكهربائي والذي يتم حقنه في خلية الوقود كما تمت دراسة كمية الطاقة الكلية المنتجة من خلية الوقود. أظهرت نتائج المحاكاة أن جهد المحلل الكهربائي القلوي أعلى من جهد خلية الوقود. في المنظومة يتم حقن الماء المتولد من خلية الوقود في خلية المحلل الكهربائي ، وأظهرت النتائج ان خلية المحلل الكهربائي لا تحتاج إلى المزيد من الماء المحقون من خارج المنظومة ، لذلك تعتبر عملية إدارة المياه في المنظومة بأكملها جيده. ان كفاءة المنظومة حوالي 35% ، ويرجى ملاحظة أن هذه الكفاءة مرضية لأنها ناتجة عن وقود نظيف ومتجدد وصديق للبيئة.

Keywords: ***Renewable energy, alkaline electrolysis cell (AEC), the proton exchange membrane fuel cell (PEMFC), power generation.***

1. INTRODUCTION

The continued use of hydrocarbon fuels to generate heat and power has caused environmental problems such as air pollution and global climate change. In this regard, fuel cells are attracting much research attention these days as promising alternative power sources. The fuel cells generate electricity power by direct electrochemical combination of hydrogen and oxygen. Fuel cells have higher efficiencies and less environmental impacts compared to the conventional heat engines. Currently, fuel cells are researched in various applications such as portable electronic devices, heat and power generation and electrical vehicles. A proton exchange membrane fuel cell (PEMFC) is one of

the most advanced fuel cell technologies, and can operate at relatively low temperatures below 100 °C due to the high ionic conductivities of polymer membranes electrolytes (PEMs) [1].

The hydrogen gas is used as a main fuel in the fuel cells, but is not freely available in nature. Thus, the hydrogen gas is produced from fossil fuels or water. The splitting process which is known as electrolysis of a water molecule to produce hydrogen gas is one of the most common methods of producing hydrogen gas. The water splitting process requires a power electricity to flow through electrode and water to break their molecule into hydrogen and oxygen. The electrical power is provided from solar energy through solar panels, to make this system more environmentally friendly and does not emit pollutants or harmful gases and is renewable. During the past decade, several methods have utilized to producing the hydrogen. However, the only state-of-the-art technique is the water electrolysis. The application of hydrogen using as fuel had been made practical, because the water splitting by electrolysis is a mature and commercially available technology which is widely being used for generating hydrogen capacities ranging from few cm3/min to thousands m3/h [2].

The research and development of fuel cell systems for various applications have increased dramatically in recent years. In this work, a thermodynamic model is presented to design and optimize a direct coupling system (DCS) that has two cells, an alkaline electrolysis cell (AEC) and a proton exchange membrane fuel cell (PEMFC). Therefore, the performances of the direct coupling system (DCS) are evaluated using numerical model that are built in Engineering Equations solver software. So several parameters concerning the direct coupling system (DCS) such as the current density and temperature are studied to determine their effect on hydrogen and water production rate.

2. LITERATURE REVIEW

Renewable energy is one of the most important research focus in the field of energy production due to pollution and fumes in the atmosphere that are produced from conventional energy. There was many research focus in renewable energies in terms of production, consumption and use.

The researcher Rabbani conducted research to study the dynamic behavior of the proton exchange membrane fuel cell (PEMFC) in order to understand the dynamic and operational behavior of the cell to improve the efficiency and performance of the cell, and to determine the components of the cell in terms of response at operation and the development of the cell model. One of the most prominent results was a correlation between the polarization curve of the innovative model and the operating data of the cell. The efficiency of fuel cells can also be increased by increasing the temperature, and it was deduced that stack start–up at high current densities reduces exegetic efficiency in the initial instances. [17], and some other studies discussed the provision of hydrogen fuel used in fuel cells. One of the aims of this study was to know how to generate hydrogen gas from water by the electrolysis process by preparing a mathematical model of the advanced alkaline electrolyte by (Mathlab software) based on the laws of thermodynamics and chemical reactions to understand and predict its behavior, mode of operation and performance and show the (I-V) curve which is one of the most important curves of these devices. And some main parameters such as ohm voltage and activation voltage (anode and cathode) affect the performance of the alkaline electrolysis. Identify appropriate and improved conditions for the operation of the electrolysis cell. The study showing that the cell's voltage increases by increasing the current density and the hydrogen and oxygen atoms which is separated increases with current density increase. The difference in operating temperatures affects its voltage, there is no difference in the flow rate of hydrogen produced at different temperatures, the rate of hydrogen production increases with current density increase [19]. And many studies have tried to combine renewable energy generation systems with systems that provide renewable fuels such as hydrogen. Researcher Dewangan prepared a paper titled Hybrid System Consisting of a Solar Panel and a Fuel Cell, where his study focused on modeling and analyzing the hybrid system. This research aims to discuss hybrid systems in the future, especially from the environmental point of view (low noise and zero emissions), Also in terms of operating costs. Design modeling of hybrid system optimization, also create a system model for accurate simulation to predict the real performance of the hybrid system (PVFC), and then undertaking detailed analysis of the effect of changes in system configurations, power conditioning units, and sites to choose the optimal design of the system. This paper aims to proper data collecting and/or data synthesizing that describe the system operation and load profile and visualize the dynamics analysis of the system. Using long-term power flows. The results also show that the system's operational performance depends not only on the efficiency of the components but also on system design and consumption behavior [18].

3. MATERIALS AND METHODS

The integrated power supply system contains several devices that are connected to each other, as these devices complement each other. The layout in Figure. 1 illustrates the generation path of this system. The source of electricity is a renewable energy source (solar energy) that provides electrical energy (DC current) to feed alkaline electrolysis, the amount of electrical energy which is derived from the renewable source is determined according to the need of alkaline electrolysis. Alkaline electrolysis that device producing hydrogen gas which is a main fuel of fuel cell. The hydrogen gas storage is a storage unit by cylinder, these cylinders store hydrogen gas at a particular pressure to be used as needed and at different times where renewable energy in the source of electricity is not available as a result of the disadvantages of renewable energies such the interruption or weather state for several days. The Hydrogen gas is discharged from storage cylinders and used to generate electric power and reparation for lost energy production. The proton exchange membrane fuel cell (PEMFC) a device uses hydrogen gas as a main fuel to electric power generation and produce a water and heat by chemical reactions.

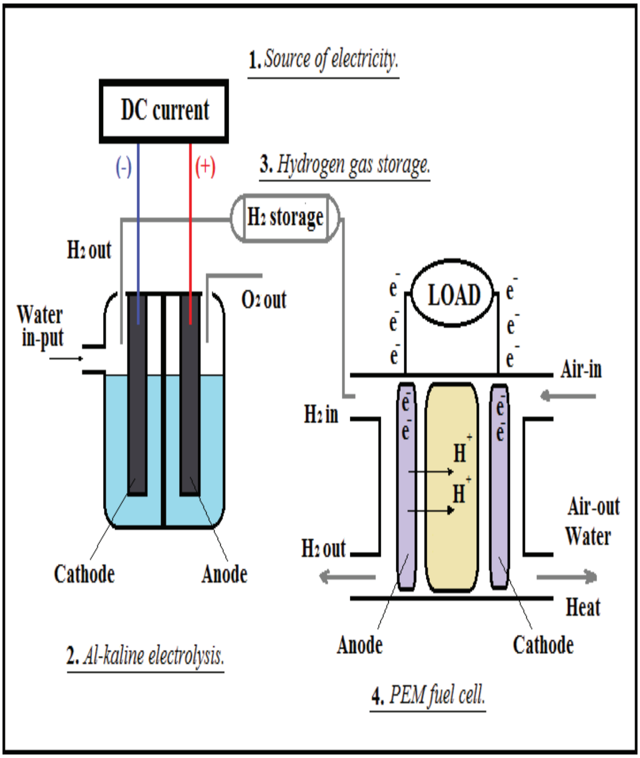

Figure (1). Layout for DCS system.

3.1 Alkaline electrolysis

A device that splitting a water molecule to hydrogen gas (H_2) and oxygen gas (O_2) by passing (DC) current. The electrolysis consists of two electrodes (anode and cathode), electrolyte and separating diaphragm [1]. The electrodes are metal sheets on both sides of the alkaline electrolysis, those electrodes is responsible for splitting process of hydrogen and oxygen gases formation from water, these metal panels provide a suitable area for the flow of electrical charges on their surface. The metal which is used to manufacture the cathode can be divided into three class: high overpotentials type (Cd, Ti, Hg, Pd etc.), middle overpotentials type (Fe, Co, Ni, Cu, Au, etc.) and low overpotentials type (Pt, Pd, etc.). The common metals for the anode manufacture is nickel (Ni), nickel-plated steels or alloys. The electrolyte is a water solution used in an electrolysis to provide good electrical conductivity due to poor electrical conductivity of pure water, this solution contains either potassium hydroxide (KOH) or sodium hydroxide (NaOH) with a typical concentration (20-40 wt%), to increase efficiency of gas production (NaCl) is added to the electrolyte solution [2]. The diaphragm works to keep the produced gases which split in each chamber, and do not mix the gases which is produces, because that could allow reformation gases or contamination in the electrolysis. The most important factors when choosing a diaphragm are:

1. Allow the passage of hydroxide ions and water not allow the passage of gases.
2. Do not allow gases to pass.

3. Mechanical resistance to corrosion.
4. Resistance to chemical damage that results from chemical reactions.
5. The ohmic resistance is low [3].

When (DC) current passing into electrodes of electrolysis the electrical energy splitting water molecule. The hydrogen gas bubbles are formed on the negative electrode (Cathode), and the oxygen gas bubbles are formed on the positive electrode (Anode) [4].

3.2 Proton exchange membrane fuel cell

An electrochemical device that generates electrical power by chemical reactions of hydrogen and oxygen and produces heat and pure water. The fuel cell block consists two electrodes (anode & cathode) and electrolyte layer [6]. The electrodes are on both sides of the fuel cell. Anode is the negative electrode of the fuel cell. The function of the anode is to connect the portable electrons by the hydrogen molecule to the electric circuit of fuel cell (electrical load), also providing a path for the diffusion of hydrogen gas over the catalyst surface. The cathode is the positive electrode of the cell and provides a path for the oxygen gas diffusion on the catalyst surface, also the function of this electrode receives electrons from the electric load to combine with oxygen molecules and hydrogen ions to form water [7]. The electrolyte is a material that allows the positively charged ions which is separated from the hydrogen gas to pass from the anode to the cathode to combine with the oxygen to form water, and electrolyte does not allow the transfer of electrons. [8]. When hydrogen gas is pumped into the fuel cell is oxidized at the anode into protons and electrons, the protons pass through the proton exchange membrane to the cathode. The electrons pass to the electric load because the proton exchange membrane is not conductive [9].

4. THEORY AND CALCULATION

The mathematical model describes the system in terms of many variables (internal and external). The mathematical model helps to predict how the system works and behaves in several ways, including the state of thermodynamics and electrochemically, and the effect of operating parameters on system [10].

4.1 Mathematical Expressions and Symbols

4.1.1 Alkaline electrolysis cell (AEC) model description

The process of mathematically describing the behavior of a system depends on describing the processes occurring in the system including the electrochemical side. The following chemical reactions show the chemical process that occurs at the electrolysis [4]:

- The general electrochemical reaction of electrolysis:

$$H_2O_{(liquid)} + \text{DC current} \rightarrow H_{2(g)} + \frac{1}{2}O_{2(g)} \quad \text{......} \quad (1)$$

- Hydrogen evolution reaction (HER):

$$H_2O_{(liquid)} + 2e^- \rightarrow H_{2(g)} + 2OH^- \quad \text{......} \quad (2)$$

- Oxygen evolution reaction (OER)
- The reverse voltage can be said the maximum possible amount of useful work for electrolysis, also known as the reversible work [12], and can be calculated using the following law [11].

Where the reverse voltage as a function of electrolysis cell temperature in Kelvin (K) and can be determined by following equation:

$$V_{rev} + V_{rev}(T) + \frac{RT}{zF}\ln\frac{\left(P - P_{KOH}\right)^{1.5\,P_w}}{P_{KOH}} \quad \text{.......} \quad (4)$$

$$V_{rev}(T) = 1.5184 - 1.5421e^{-3}T + 9.523e^{-5}T\ln T + 9.84e^{-8}T^2 \quad \text{.......} \quad (5)$$

Where the universal gas constant (J/mol), the faraday's constant in (C/mol), the Number of electrons transferred during electrochemical reaction, The operating pressure of the electrolysis cell in (bar), the

$$2OH^- \rightarrow +\frac{1}{2}O_{2(g)} + H_2O + 2e^- \quad \text{.......} \quad (3)$$

vapour pressure of a purified water, the vapour pressure of the electrolyte solution in the (atm) unit.

The voltage of alkaline water electrolysis cell can be expressed in the following relationship [11]:

$$V_{cell} = V_{rev} + V_{act} + V_{ohm} \quad \text{.......} \quad (6)$$

Where the activation voltage in (volt) which is establishing due the activation losses of the electrochemical reaction, also measure the extent of the electrode activity in the electrolysis cell [13], can be calculated by the following formula:

$$V_{act} = 2.3026\frac{RT}{zF\alpha_{a/c}}\log\left(\frac{i}{i_o}\right) \quad \text{.......} \quad (7)$$

Where the charge transfer coefficient, the exchange current density in [A/c].

The ohm voltage corresponds to the ohm losses, ohm losses are produced in cell elements, such as the resistance generated by the electrodes of an electrolysis cell and electrical connections [2]. The ohm voltage value is estimated by the following law:

$$V_{ohm} = ri \quad \text{.......} \quad (8)$$

Where the specific area of ionic resistance in (cm^2/S), its value can be estimated using the following formula

$$r = \frac{\delta}{\sigma_\varepsilon} \quad \text{.......} \quad (9)$$

$$\sigma_\varepsilon = \sigma_o(1-\varepsilon)^{1.5} \quad \text{.......} \quad (10)$$

Where the electrolyte thickness (cm), the conductivity of KOH solution (S/cm), the electrical conductivity in the presence of bubbles and the void fraction of the electrolyte which is calculating by following law:

$$\varepsilon = 0.0153\left(\frac{i}{i_{lim}}\right)^{0.3} \quad \text{.......} \quad (11)$$

The limiting current density (A/cm^2).

The rate of hydrogen gas production is related to the (DC) current (I) and number of cells, divided by Faradays constant (F) multiplied by the number of electrons (z), as shown in the following equation [1]:

$$n_{H_2} = n_f \frac{n_c I}{zF} \quad (12)$$

Where the Faraday's efficiency.

The rate of oxygen gas production and water consumption can be calculated using the following law:

$$n_{H_2O} = n_{H_2} = 2n_{O_2} \quad (13)$$

4.1.2 The proton exchange membrane fuel cell (PEMFC) model description:

The mathematical model of the fuel cell describes the mechanism of cell work and the chemical reactions that are formed in the cell, also shows the behavior and performance of the cell, it is very important to apply mathematical equations correctly and clearly to prepare an accurate thermodynamic approach. [7]. The proton exchange membrane fuel cell (PEMFC) process can be expressed chemically in the following reactions [5]:

The general electrochemical reaction of fuel cell:

$$H_{2(g)} + \tfrac{1}{2}O_{2(g)} \rightarrow \text{Electrical power} + H_2O_{(liquid)} + \text{Heat} \quad (14)$$

Anode side:

$$H_2 \rightarrow 2H^+ + 2e^- \quad (15)$$

CATHODE SIDE:

$$\tfrac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O \quad (16)$$

The voltage in the fuel cell is divided into two parts, the first part is the reversible voltage (E) in (volt) and can be predicted by thermodynamics approach, because this reversible volt (E) depends on Gibbs's free function of chemical reactions that are affected by the operating temperature and pressure of cell. The other part is a several of losses, these losses reduce the voltage of cell such (Activation voltage, ohm voltage and concentration voltage) the cell voltage can be calculated by the following relationship [15]:

$$V_{cell} = E + V_{act} + V_{ohmic} + V_{conc} \quad (17)$$

The reversible voltage can be estimated by linear equation as a function of the temperature in (K) and partial pressure in (bar) for the reaction gases.

$$E = 1.229 - 8.5e^{-4}\left(T_{cell} - 298.15\right) + 4.308e^{-5}\left(\ln P_{H_2} + \tfrac{1}{2}\ln P_{O_2}\right) \quad (18)$$

$$P_{H_2} = 0.5P_{H_2O}^{sat}\left[\exp\left(-\frac{1.635J}{T_{cell}^{1.334}}\right)\left(\frac{P_a}{P_{H_2O}^{sat}}\right) - 1\right] \quad (19)$$

$$P_{O_2} = P^{sat}_{H_2O}\left[\exp\left(-\frac{4.192J}{T^{1.334}_{cell}}\right)\left(\frac{P_c}{P^{sat}_{H_2O}}\right)-1\right] \quad (20)$$

$$\log_{10} P^{sat}_{H_2O} = -2.18 + 2.95e^{-2}T_C - 9.18e^{-5}T^2_C + 1.44e^{-7}T^3_C \quad (21)$$

Where:

J = Current density in (A/cm[2]).

$P_{a,c}$ = partial pressure of electrodes.

$P^{sat}_{H_2O}$ = Saturation pressure of water.

The activating voltage occurs as a result of the activation losses due to resistance which is established on the electrodes of the fuel cell and can be calculated by the following mathematical expression in (volt) [15]:

$$V_{act} = -0.9514 + 3.12e^{-3}T_{cell} - 1.87e^{-4}T_{cell}\ln I + 7.4e^{-5}T_{cell}\ln C_{O2} \quad (22)$$

Where concentration of oxygen gas is can be found in the following equation [15]:

$$C_{O_2} = \frac{P_{O_2}}{8.08\, e^{\left(\frac{-498}{T_{cell}}\right)}} \quad (23)$$

The ohm voltage represents the ohm losses that occur as a result of the resistance to transfer electrons on surface of the electrodes and the transfer of protons through the membrane and can be expressed in the following relationship [16]:

$$V_{ohmic} = -I\,R_{int} \quad (24)$$

The internal resistance of cell in (ohm) can be calculated by following formula:

$$R_{int} = 1.605e^{-2} - 3.5e^{-5}\,T_{cell} + 8e^{-5}\,I \quad (25)$$

The concentration voltage of the cell occurs as a result of the excess reactant concentration near the catalyst surfaces and determined using the following law [16].

$$V_{conc} = \frac{RT}{2F}\ln\left(1 - \frac{I}{I_{lim}}\right) \quad (26)$$

The power is one of the most important outputs of the cell, as the primary goal of designing this system is the generation and production of power. The output power of this system is the electrical current which is produced by cell multiplied by the voltage differences of the cell. Thus we evaluate the power of this cell by the following simple formula:

$$POWER_{cell} = IV_{cell} \quad (27)$$

4.2 The constants and confidents

After presenting the mathematical laws related to preparing the mathematical model of the system, there are some important constants and confidents such as operating temperature and some of the constants related cell design and type that are listed in Table 1 and 2.

Table (1). Setting parameters of alkaline electrolysis.

Constant parameter	Symbol	Value
Area of electrodes	A	50 cm^2
Faraday's constant	F	96485 C/mole
Number of cells		36
Number of electrons		2
Gas constant	R	8.314 J/mole*K
exchange current density		30 A/cm^2

Table (2). Setting parameters of the PEM fuel cell.

Constant parameter	Symbol	Value
Area of cell	A	50 cm^2
Faraday's constant	B	0.016V
Number of cells		36
Number of electrons		2
Current limit		25 A

5. RESULTS AND DISCUSSION

When the direct coupling system (DCS) system is operated by solar energy with different values for the current densities. Several different results are observed for the system parameters which affects of the system.

5.1 The (I-V) characteristics of whole system

The (I-V) characteristics curve is one of the most important curves for studying and predicting the behavior of system, also shows the stability of the system and its performance during operation at different loads of current density. The (I-V) characteristics is considered one of the most important results that must be focused upon when analyzing the state of the system, because the voltage difference of the two cells is affected by any difference that occurs in several variables, including (the partial pressure and the molar fraction of the reactants and products for the chemical reaction). The current density and the voltage differences of the system are mathematically related to several variables including (the flow rate of the produced hydrogen gas and the produced power) so any change in the value of the current density works on a change in the operating behavior of the system and the results which is obtained.

There is a big difference between the voltage difference generated from the alkaline electrolysis cell and the fuel cell, the voltage difference of the electrolysis is higher than the fuel cell. As in figure 2. the value of voltage difference increases with the current density increase as a result of the energy consumed in the alkaline electrolysis, because the process of water splitting requires a high amount of energy. While the difference in voltage of the fuel cell decreases with increasing current density in the system as a result of the losses in the fuel cell, including activation and ohmic voltage.

5.2 Activation voltage

The chemical reactions within the system whether dissociation and formation reactions requires an amount of energy when they occur. This energy is called the activation energy, an amount of activation energy is generated when a chemical reaction begins. This energy produces a voltage difference called the activation voltage. The effect of this voltage is negative or positive value depending on the type of chemical reaction (dissociation or formation reaction).

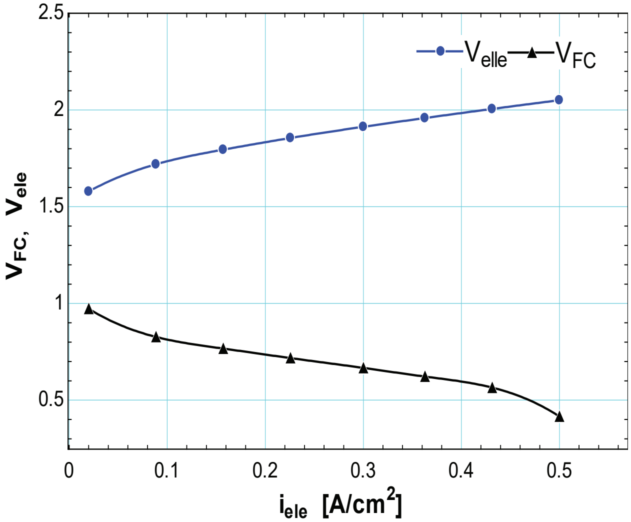

Figure (2). The change in the voltage of alkaline electrolysis and PEM fuel cell by changing in current density.

As noted in figure. 3 the relationship between the current density and the activation voltage of the system is direct, the activation energy increases with the current density increase. The results show that the alkaline electrolysis cell activation voltage is higher than the fuel cell due to the difference in the chemical reaction between the two cells, as the process of water split needs a high activating energy to break the covalent bond unlike the energy which is require to form the water atom in fuel cell.

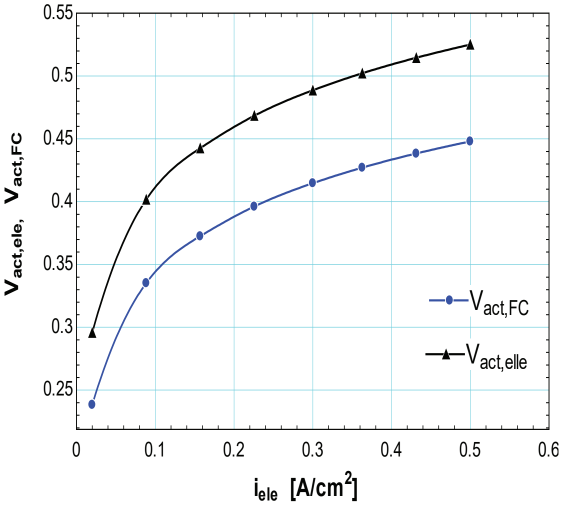

Figure (3). The change in the activation voltage with change in current density.

5.3 Ohmic voltage

The ohmic voltage is formed due the passage of electric current in a path based on Ohm's law, the relationship between the current density and the ohmic voltage is a direct relationship. The ohmic resistance in the system is a result of several factors. These factors are common between the two cells, including (ion conduction as a result of the passage of ions through the electrolyte, the thickness of the electrodes in the two cells, the distance between the electrodes as this gap works on establishing ohmic resistance and electrical connections in the two cells). Therefore the materials involved in the manufacture of electrical connections must be carefully selected and with appropriate specifications in order to reduce the value of ohmic resistance.

As can be seen from the figure. 4 the values of the Ohm's voltage in the two cells are close at the start operation of the system. And then the values of the ohmic voltage in the electrolysis increase at high current densities, the Ohm's voltage value of electrolysis is higher than the fuel cell due to the increase in the hydrogen gas generation process, because hydrogen gas generating process increase the amount of bubbles on the surface of the electrodes.

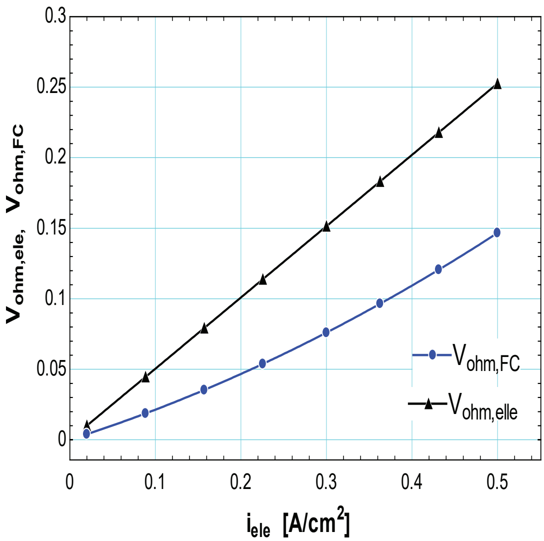

Figure (4). The change in the Ohm's voltage with change in current density.

5.4 The quantity of hydrogen gas produced and consumed in the system

The amount of hydrogen production is one of the most important parameters to evaluate the performance of alkaline electrolysis cell (AEC), to evaluate the produced gas there are several points that are taken into account, including:

- The amount of gas produced relative to the current density.
- Quality of produced gas.
- The purity degree of produced gas.
- Efficiency of the generation process.

The curve in Figure 5 shows that the relationship between the current density and the produced hydrogen gas is a direct. The rate of hydrogen production increases as result of more electrons pass, the electrons are responsible for breaking the covalent bond of the water molecule. The rate of hydrogen production is affected by Faraday's efficiency.

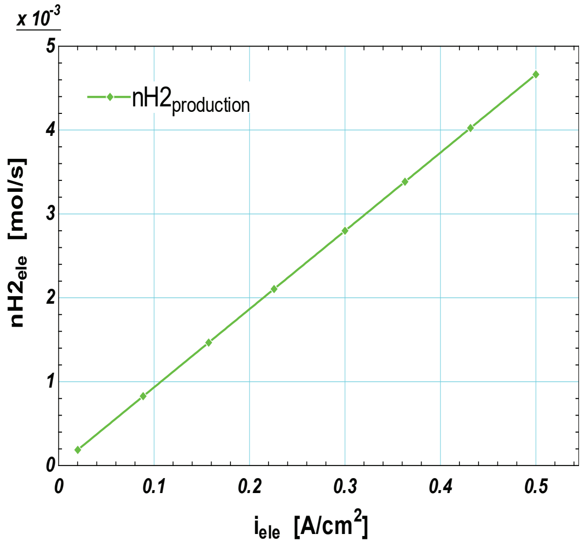

Figure (5). The amount of hydrogen gas production.

The electric current value generated by the fuel cell depends on hydrogen amount injected into the cell. As each hydrogen atom carries two electrons, the amount of the electric current increases with hydrogen amount increase as shown in figure .6.

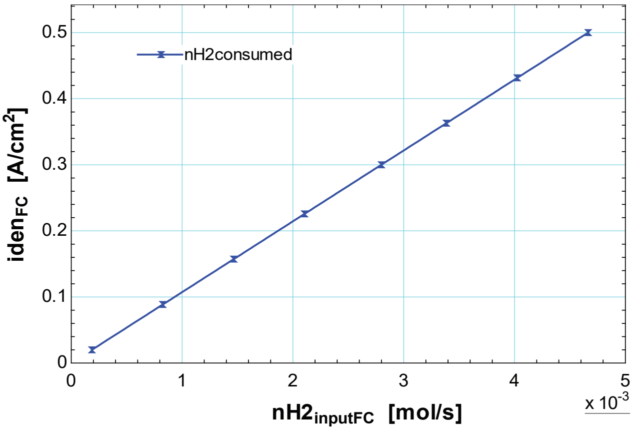

Figure (6). The amount of hydrogen gas consumed.

The electric current generated is affected by the change in generating efficiency within the cell and the fuel consumption rate. The fuel consumption rate is defined as the amount of useful fuel divided by the amount of fuel consumed. The residual values of generation efficiency and fuel consumption rate are losses, including losses within the pipes of the fuel cell during the injection process, also the process of diffusion fuel on the surfaces of the electrodes. These losses effect on the electrical current value.

5.5 The quantity of oxygen gas produced and consumed in the system

The operation process of the fuel cell depends on quantity of hydrogen and oxygen gases. The amount of hydrogen is generated and stored in cylinders, about oxygen gas a quantity of air is injected which is containing 21% of the oxygen gas and 79% of the nitrogen gas, but the ratio of nitrogen gas is large, which effects on the storage area of the gas, and this is considered one of the disadvantages of the system, because such a quantity needs an increase in the storage space and the number and size of tubes within the system. That will increase the cost of design and construction process.

Therefore, the amount of pure oxygen gas that is generated from the alkaline electrolysis cell must be used to inject it into the cell. The amount of oxygen gas generated is stored in the storage cylinders and then injected into the fuel cell. In this way, the space which is the nitrogen gas is needed in the system was removed.

The curve in figure 7. the amount of oxygen generated in the electrolysis cell. The value of oxygen generated increases with the electric current increase, due to the compatibility of chemical equations between the electrolysis cell and the fuel cell, the amount of oxygen needed by the fuel cell equals the amount of oxygen generated in the electrolysis cell, as shown in Figure 8.

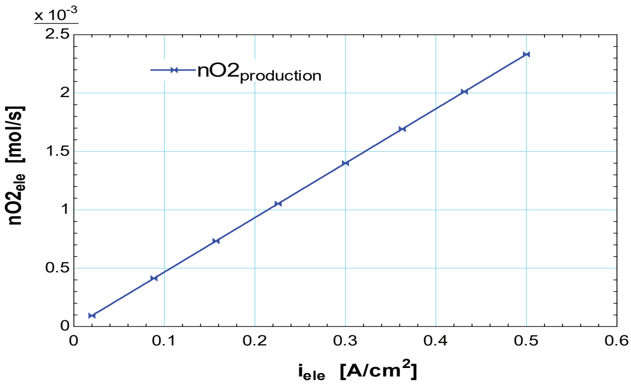

Figure (7). The amount of oxygen gas production.

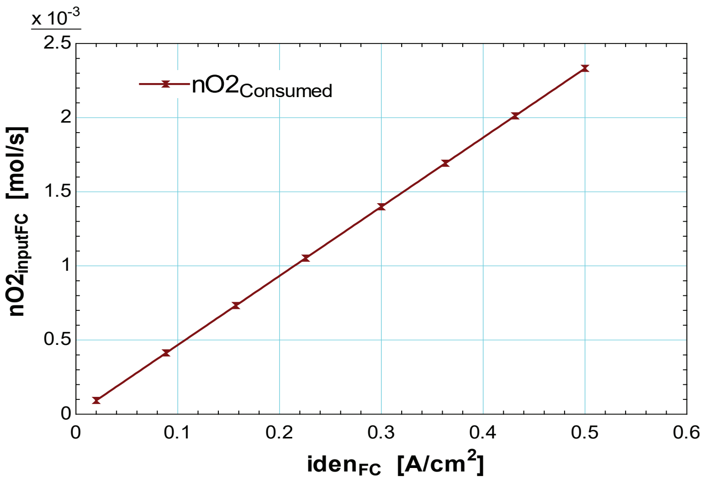

Figure (8). The amount of oxygen gas consumed.

5.6 The quantity of water produced and consumed in the system

The pure water is one of the products by the fuel cell, the amount of water produced increases with the hydrogen gas increase. One of the most saving techniques in this system is to use the amount of pure water from the fuel cell and inject it for electrolysis cell.

Hence, the amount of water required by the electrolysis cell is supplied inside the system, and this system becomes a closed circuit system. However, at continuous operation of this system there will be losses in the amount of water. The curves in figure.9, 10 shows that the amount of water produced from the fuel cell is close to the amount of water consumed in the alkaline electrolysis cell.

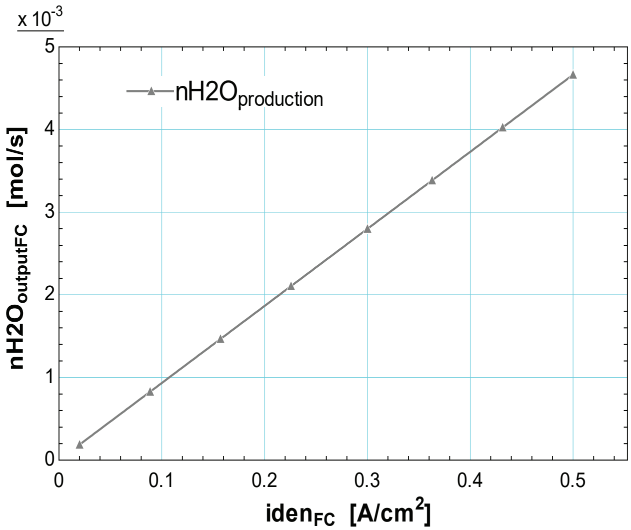

Figure (9). The amount of water production.

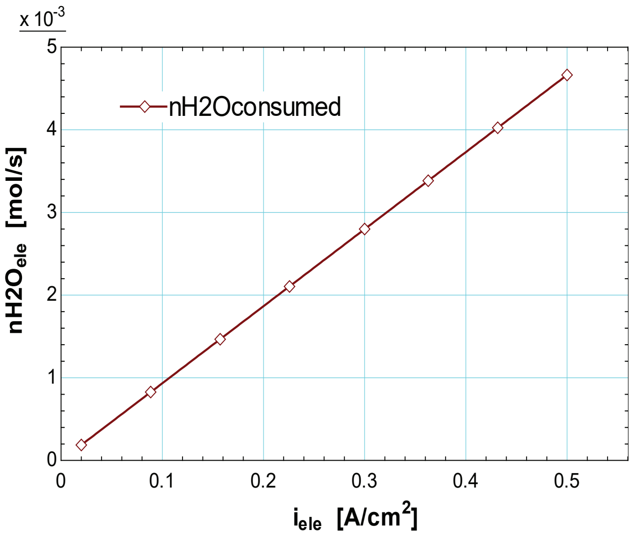

Figure (10). The amount of water consumed.

5.7 The amount of power produced in the system

The amount of power produced from the fuel cell and consumed by the electrolysis is one of the most important parameter for assessing and predicting the behavior of the system, and how to control the operation process. As can be seen from the curve in figure .11 the power relationship with current density whether produced or consumed power is considered a direct relationship. The power value increases with current density increase.

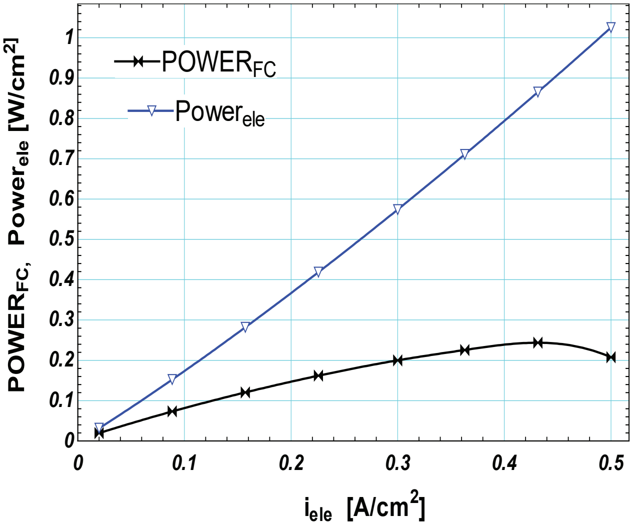

Figure (11). The power of whole system.

However, the power consumed in the electrolysis cell is higher than the fuel cell due the process of breaking the covalent bond of the water atoms needs a large amount of energy, so the value of the voltage in the cell increases. Consequently, the power consumption is high due to an increase in the value of the voltage and electric current.

The power of the fuel cell is related to the fuel flowing to the cell, the power produced from the fuel cell increases with the hydrogen fuel increase. The value of power in the cell increases until it reaches the highest point in the power curve. The value of production power decreases due the losses forming in the cell, which in turn affect the value of the voltages within the cell. The operation of the fuel cell at the highest power point is very difficult because this affects the operational life of the cell, then the process of controlling the cell becomes difficult.

One of the advantages of this system is that it can exploit the largest amount of energy generated through the renewable source. For example, if using a solar panel, as it is known solar generation is a variable of value according to weather and time conditions. Especially at peak times, the value of solar radiation increases and therefore the value of the generated power increases. It is possible to use this amount of power and divide it into two parts: the first is used to power the alkaline electrolysis, and the other part is used to power other electrical loads and in this way the loss between the two powers in the system will be compensating.

6. CONCLUSION

Fuel cells are useful devices, more efficiency with less environmental pollution compared to the conventional heat engines. Proton exchange membrane fuel cell (PEMFC) is regarded as the most competitive candidate to replace the traditional forms of power conversion because of its prominent advantages than other types. This paper shows the working behavior for the full system by building a mathematical model in order to assess several parameters such device voltage including (activation and ohmic), the hydrogen gas which is produced from electrolysis and then injected to fuel cell as a fuel to produce electrical power, pure water and heat. In this work, a thermodynamic model for design and optimization of direct coupling advanced alkaline electrolyzer and PEMFC system (DCS) is presented. Moreover, the performance of the direct coupling system (DCS) are evaluated using numerical model that is built in Engineering Equations solver software.

The simulations result show that, the voltage of electrolysis cell is higher than fuel cell.

The water flow rate production from the fuel cell is the same as that of electrolyser cell. This makes the whole system in mass balance case.

The solar power consumed in the electrolysis and the power production by fuel cell at 0.3 of current density. This means that the whole system efficiency equal . If this is compared with other generation sources such as (steam cycle & gas cycle) power plants or conventional heat engines (diesel engine & electrical generator). This efficiency is very close to the other generation technologies, but the advantages of this efficiency is pure efficiency of power generation. Because it was obtained from clean fuel.

7. ACKNOWLEDGMENT

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