Hybrid Power Generation System of Solar Energy, Electrolysis and PEM Fuel Cells

Abdullatif Musa[1*], Khaled Abuojlida [2] , Khalid Abdelkader [3], Hamza Ahmed [4]

[1] Abdullatif_musa@yahoo.com, [2] Sakhar1979@Gmail.com, [3] Abdelkader.khalid@hist.edu.ly,

[1] Department of Marine Engineering, Faculty of Engineering, University of Tripoli, Tripoli, Libya
[3] Higher Institute of Science and Technology, Ghadames, Libya

ABSTRACT

A polymer electrolyte membrane fuel cell (PEMFC) is one of the most advanced fuel cell technologies due to its prominent advantages. Hydrogen gas is used as a fuel in the fuel cells, and it can be produced by water splitting process or known as electrolysis. In this study, three models are developed and used: photovoltaic (PV) solar panel, alkaline electrolysis cell (AE) and a proton exchange membrane fuel cell (PEMFC). These three models are integrated together to consist a model system, called Nour generation system (NS). As it is known, designing of the PV solar panel system need information about the solar radiation being intercepted in the site, for this reason, two cities of Libya (Tripoli and Ghadames) were selected as a case study. In this work, the impact of the Libyan cities position on the performance of Nour generation system is evaluated and compared. Moreover, the effect of operating pressure on the performance of Nour generation system is studied. The simulation results show that, there is an extra in the production of the actual power of PV solar panel, especially in summer, that could be reach 37% in July. The advantage of this extra energy is the potential to exploit the excess actual power of PV solar panel through fueling the public electricity grid or used in other applications. Furthermore, Nour generation system does not need any pumps or compressors, which means less devices in the system.

Keywords: Solar energy, PEMFC, Power generation system, Performance parameters.

1. Introduction

It has become clear that, if humans have to fully enjoy the benefits of energy in a sustainable way without jeopardizing the environment, it is imperative to reconsider the kind of energy that is produced and the ways that they are used [1]. In fact, hydrogen can operate as storage and carrying medium of the primary sources [2]. 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 PEMFC [3]. Hydrogen gas can be produced from fossil fuels or water. 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. New components models are described and the system is optimised to minimise entropy generation. The entire system is designed to meet the environmental conditions and demand of Misurata a city in Libya for which the necessary data has been obtained [4] . Several studies have tried to combine renewable energy generation systems with systems that provide renewable fuels such as hydrogen [2–9] .

In Ref [10], three validated models are developed and used: PV, AE and PEMFC. All the models are integrated together to consist a model system, which called Nour generation system (NS). The simulations results show that, the advantage of Nour system makes the energy available at night and when the sun is not providing enough radiation, it can be used the PV solar panel and PEMFC together at the same time . In fact, this study is an extension to the study in paper [10] and is aimed to study and evaluate the effect of the global solar radiation and operating pressure on the performance of Nour generation system. Therefore, meteorological data for the period of January 1995 to December 2010 for two cities

of Libya (Tripoli and Ghadames), is collected from Libyan National Meteorological Center Climate and Climate Change [11].

2. Nour Generation System Description

Nour generation system (NS) consists of PV solar panel, Alkaline electrolysis, two tanks, PEM fuel cell, control system and inverter. As it can be seen from Figure (1), the main energy source in Nour generation system is the sun. The energy transported through the sun rays is harnessed via PV panel in electricity and thermal heat forms.

The electricity is sent to the electrolysis, which is generated hydrogen (fuel) and oxygen. The generated fuel and oxygen are stored in the tanks and then sent to the Proton Exchange Membrane (PEM) fuel cell. The PEMFC block consists two electrodes (anode & cathode) and electrolyte layer. Anode is the negative electrode of the fuel cell while the cathode is the positive electrode. The control system is sent DC output to the inverter. This Inverter converts DC output of PEMFC or PV solar panel into a clean AC current for AC load.

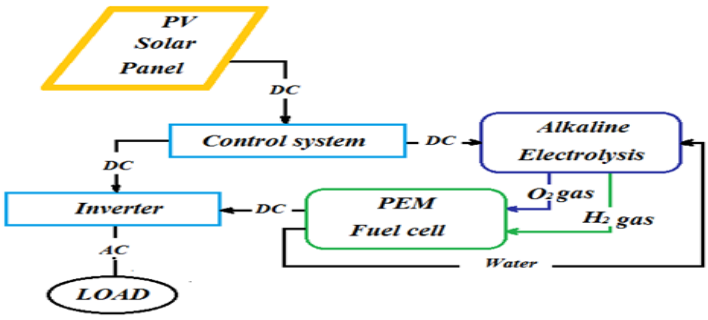

Figure 1. The layout of Nour generation system

3. Results and Discussion

In fact, this study is an extension to the study in Ref [10] and is aimed to study and evaluate the effect of the global solar radiation and operating pressure on the performance of Nour generation system. So the impact of the city's position in Libya on the performance of the system is investigated. Meteorological data (the global solar radiation) for two cities of Libya (Tripoli and Ghadames), are selected

as a case study. The measured global radiation in Tripoli varies from 2.744 KWh/m^2 in December, to 7.484 KWh/m^2 in July. While the measured global radiation in Ghadames varies from 4.03 KWh/m^2 in December, to 8.001 KWh/m^2 in July. Figure. 2 shows the effect of the global solar radiation in Tripoli on the performance of Nour generation system, and this is one of the most important curves for predicting the minimum and maximum actual power generation from PV solar panel in each month during the year. As noted from (Figure. 2) the relationship between demand power and actual power of PV solar panel, that the values of actual power of PV solar panel in July are high compared to those produced in December and the difference increases with the increasing in the demand power. This means that there was a saving in the production of the actual power of PV solar panel, especially in summer, which could reach 37% in July. The advantage of this saving energy, gives the potential to exploit the excess actual power of PV solar panel through electricity fueling the public grid or using it as fuel that can be used in other applications. The design of the solar panel system depends on the choice of the lowest solar radiation value in calculations, which in turn show a number of solar panels required, this is the main reason of the extra power of PV solar panel in summer season. It can be observed that as the demand power increases, the actual power of PV solar panel and peak power of the PV panel also increase. This means an increase in the number of the PV solar panel is used (Fig. 3), that explains why the difference in extra power of PV solar panel (Fig. 2) and fuel production (Fig.4) varies between minimum and maximum demand power. Figure .4 shows relation between demand power and fuel and oxygen flow rates from the electrolysis cell . Please note that, these hydrogen and oxygen productions are injected to the PEMFC. As it can be shown from Figure. 4 the amount of hydrogen input to PEMFC is identical to the amount of water which is generated from the PEMFC. In such a system, it's best to use oxygen instead of air, in order to reduce a system volume. As it can be noted, the hydrogen

production rate increases linearly with the increasing demand power , and the highest hydrogen production rate is observed 80 L/day at the maximum demand power (33000 Wh/day). Figure. 5 represents the impact of the city's position in Libya on the performance of the system. Two cities Tripoli and Ghadames, Libya as a site study is selected in this work. The minimum global radiation in Ghadames is 4.03 KWh/m^2 in December, while it is 2.744 KWh/m^2 in Tripoli. This explains why the actual power of PV solar panel in Ghadams is high compared to Tripoli in the same month in December, especially when the demand power is high, so the number of PV solar panel of Nour generation system used in Ghadames will be less, this also means that, the cost will be less. Figure. 6 shows the simulation result of the cell voltage of alkaline electrolysis as a function of operating pressure. The operating pressure increased, the partial pressure and reversible voltage are increased, as a result of that the cell voltage of the alkaline electrolysis goes up. This means that, the power needed to produce fuel and Oxygen in the alkaline electrolysis is increasing, resulting in a drop in Nour generation system efficiency (Figure 7). The advantage of this result is the system does not need any pumps or compressors. This means less devices in the system , which will positively affect the system cost.

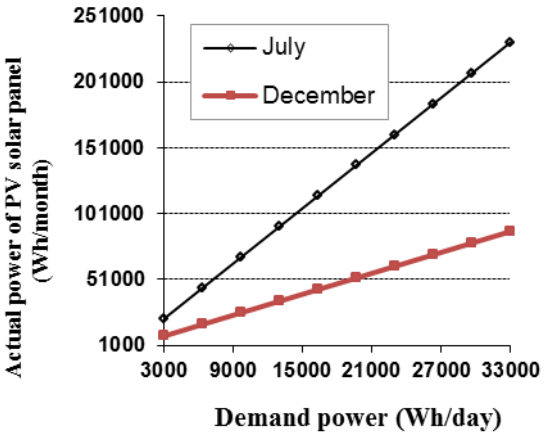

Figure 2: The effect of the global solar radiation in Tripoli on the system performance.

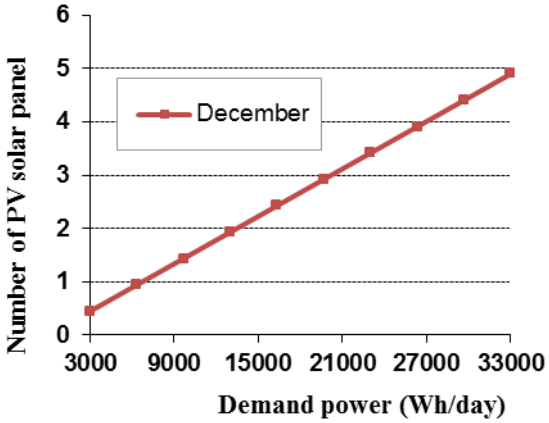

Figure 3: Number of PV solar panel as a function of the demand power.

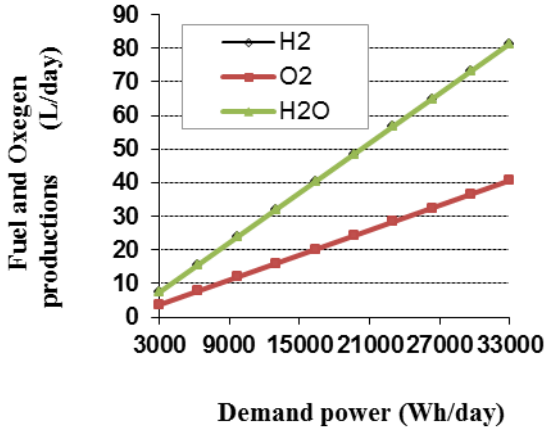

Figure 4: Fuel and Oxygen productions as a function of the demand power.

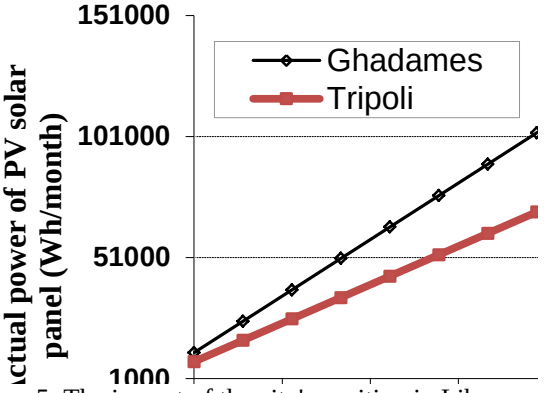

Figure 5: The impact of the city's position in Libya on the system performance.

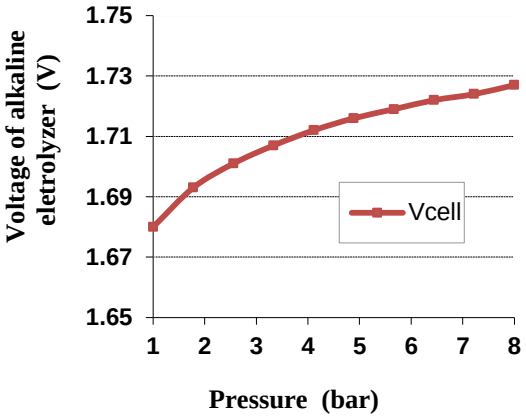

Figure 6: Cell voltage as a function of pressure.

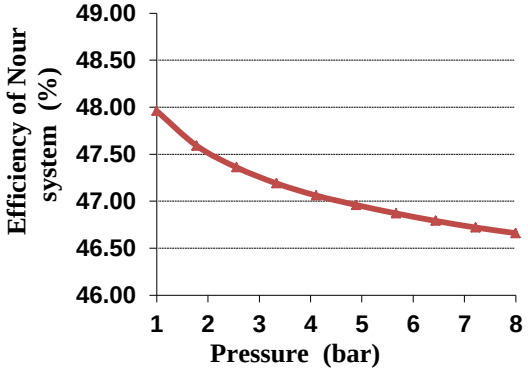

Figure 7: The effect of operating pressure on Nour generation efficiency.

4. Conclusions

In this paper, three validated models are developed and used, PV, AE and PEMFC models .

so a method to integrate the solar energy and fuel cells power generation (Nour generation system) has been introduced. The impact of the Libyan cities position on the performance of Nour generation system is evaluated and compared. It can be concluded, that the higher global radiation of the city means , the lower the cost of the system. In other words, the site of the city is impact to the performance of Nour generation system. It is so an important to focus on reducing the power needed to produce fuel and Oxygen in the alkaline electrolysis for higher system efficiency. The simulation result show that, the system does not need any pumps or

compressors. This means less devices in the system , which will positively affect the system cost.

References

[1] A. Tijani, N. Yusup, and A. Abdol Rahim, "Mathematical modelling and simulation analysis of advanced alkaline electrolyzer system for hydrogen production", ScienceDirect Procedia Technology 15 798 – 806, 2014

[2] Y. De Silva, "Design of an Alkaline Electrolysis Stack", University of Agder, 2017.

[3] H. Ahmed, A. Musa, "Design of Direct Coupling Advanced Alkaline lectrolysis and Fuel Cells System", CEST 2 conference, Sebratha, Libya 2019.

[4] A. El-sharif "Simulation Model of Solar-Hydrogen Generation System", university of Newcastel, Newcastel, UK. 2017.

[5] M. Rashid, M. Al Mesfer, H. Naseem, and M. Danish, "Hydrogen Production by Water Electrolysis: A Review of Alkaline Water Electrolysis, PEM Water Electrolysis and High Temperature Water Electrolysis", International Journal of Engineering and Advanced Technology (IJEAT), ISSN: 2249 – 8958, Volume-4 Issue-3, February 2015.

[6] A. Ates, S. Zendehdel and E. Canil, " Solar energy supported hydrogen production: athearetical case study", University of selcuk, 2147,9364, 2017.

[7] S. Mousawi, H. Werqozk, and M. Alahmad, "Studying the properties of PEM fuel cells and the dynamics of operation", Journal of Engineering Damascus university 2nd issue, 2009.

[8] J. Koponen, "Review of water electrolysis technologies and design of renewable hydrogen production systems", Master's Thesis 2015, Lappeenranta University of Technology.

[9] D. Hewedy, N.E. Mansor, and K. Ben Sauod, "Evaluation of solar energy and its application in Libya," *Glopal Libyan Journal.*, vol. 19, pp.2–19, 2017.

[10] A. Musa, H. Ahmed, K. Abuojlida "Performance Evaluation of PEMFC system using hydrogen produced from solar PV panel energy", MI-STA conference, Tripoli, Libya 2021.

[11] A. J. Shaban, "Forecasting of monthly average global solar radiation in Libya", Master of Science, Nicosia, 2019

[12] A. H. Abdol Rahim, A. S. Tijani, M. Fadhlullah, S. Hanapi, K. I. Sainan," Optimization of direct coupling solar PV panel and advance alkaline eletrolyzer system ", Energy Procedia: 79 (2015) 204-211.