SIMULATION SOLAR HYDROGEN SYSTEM UNDER CLIMATE OF MALAYSIA

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Abstract: - A hybrid photovoltaic-fuel cell system employing an electrolyzer for hydrogen generation was studied and simulated. The simulation program, Simulation Solar Hydrogen System (SSHS) was designed by using Graphical User Interface (GUI) in MATLAB® software. SSHS was used to predict and optimize a solar hydrogen system for Malaysian climatic conditions. Results obtained through simulations with various conditions were compared with experiment data. An economic analysis revealed that solar hydrogen systems have the potential for commercialization in Malaysia. Furthermore, with the reduction of the COE, this system will be more reliable and well accepted.

Key-words: - Solar Hydrogen; Photovoltaic; Fuel cell; Economic analysis

1. **Introduction**

Hydrogen is the simplest element known to exist, most abundant gas in the universe, and it is found only in compound form. Since hydrogen gas is not occurring in nature in its elemental or molecular form, it must be manufactured. There are several ways to do this. One of the ways is by the electrolysis, which is splitting water into basic element – hydrogen and oxygen. Although there are many methods have been developed for production of hydrogen from renewable energy, the only one currently practical and cleanest way is using proton exchange membrane (PEM) electrolyzer combined with photovoltaic technology [1-2]. The production of hydrogen by electrolysis of water is a mature technology, very efficient, and does not involve moving parts.

Research simulations of various system configurations have been performed in order to better understand how to design solar hydrogen systems. A simulation study with transient system simulation program (TRNSYS) was conducted by Ulleberg et al. [3] and concluded that the developed simulation tool was capable of finding system configurations that satisfy various energy demands for solar-hydrogen system. Yu et al. [4] presented the designed software (PSCAD/EMTDC) that can advance the commercial readiness and effectively simulated the hydrogen production system. They showed that the developed simulation model can be one of the most useful methods in the research of solar hydrogen production systems.

At present, the hydrogen production by renewable energy sources cannot compete with the conventional fossil fuels. However, many studies revealed that with the improvement of system performance and the reduction of system costs in certain condition, the future expected values do show promising results [5-6]. Zoulias et al. [7] conducted a techno-economic analysis to the hydrogen-based system and estimated that this system will be economically favourable as long as a 50% reduction on the cost of electrolyser and a 40% reduction on the cost of hydrogen tanks are made.

Malaysia has a tropical, humid climate with temperatures within 25.6°C - 27.8°C. Malaysia receives average solar radiation within 600 – 700 W/m^2 and the monthly average solar radiation is within 4000 – 5000 Wh/m^{2}day. Malaysia on an average receives about 5 hours of sunshine everyday and the relative humidity falls within 82 - 88%, varying from place to place and from month to month. Since Malaysia has abundant sunshine and solar radiation, the solar-powered hydrogen systems would have great potential to be commercialized [8].

In this paper, we focused on a simulation program to predict a solar hydrogen system which can optimize the utilization of hydrogen under Malaysia climate conditions. The collected solar radiation data obtained from the data acquisition system located in the National University of

Malaysia were used in the simulation program. The simulation results were compared with experiment data to evaluate the effectiveness of the simulation model. Thus, the simulation model can provide guidelines to design a reliable solar hydrogen system. Finally, an economic analysis was conducted to determine the possibility of commercializing domestic hydrogen production by solar hydrogen system under Malaysia climate conditions.

2. Methodology and Modelling

The solar hydrogen system consists of a PV module with maximum power point tracker, Hogen 40 ® electrolyzer, SMC 5000 inverter, a Proton Exchange Membrane fuel cell, and a vertical standing storage tank for hydrogen. Figure 1 shows the diagram for grid-connected solar hydrogen system in the present study.

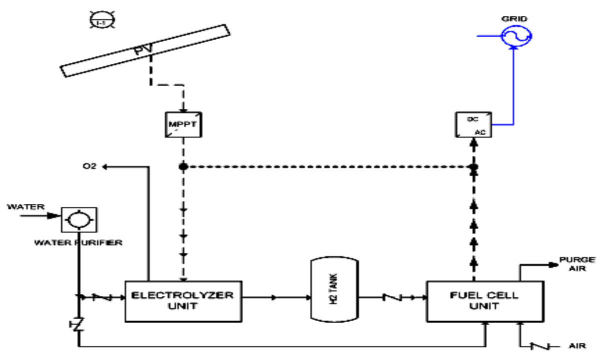

FIGURE 1. Grid-Connected Solar Hydrogen System

Figure 2 shows the flowchart of the control algorithm for solar hydrogen system. When the sunlight available, the PV modules generate clean electricity, which is used to run an electrolyzer for a hydrogen production. In addition, the PV is interconnected to the utility power grid, and controlled by a 5 kW inverter. When the sunlight not available, the system uses electricity from grid to operate the electrolyzer to ensure continuous production of hydrogen. On the other hand, when the hydrogen storage tank is full, the excess power will be sent back to the grid. Finally the fuel cell system will operate to meet load demand.

i) Photovoltaic system

The photovoltaic system consists of 40 multi-crystal photovoltaic (PV) panels, connected in series to give a peak power of 4.8 kW. In this system, the electricity from PV panels was used to run an electrolyzer for hydrogen production. The characteristic of the photovoltaic system is stated as follows [9]:

$$I = I_L - I_O \left\{ \exp\left(\frac{V + I.R_s}{a} \right) - 1 \right\} \qquad (1)$$

where I_L is photocurrent; I_o is saturation current; R_s is series resistance; a is coefficients; I is current and V is voltage.

ii) Electrolyzer system

In this study, the electrolyzer system consists of a Hogen 40 hydrogen generator, a water purification unit, and a compressor. The system can generate hydrogen gas and after passing through a hydrogen gas purifier, stored in a vertical standing hydrogen storage tank. The hydrogen storage tank is equipped with a gas management system to ensure safety in its operation the characteristic of the electrolyzer system are expressed as follows [10]:

$$V_{el} = V_0 + V_{act} + V_{ohm} \qquad (2)$$

which V_{el} is voltage electrolyzer; V_0 is open circuit voltage; V_{act} is polar activity voltage; V_{ohm} is resistance polarization voltage.

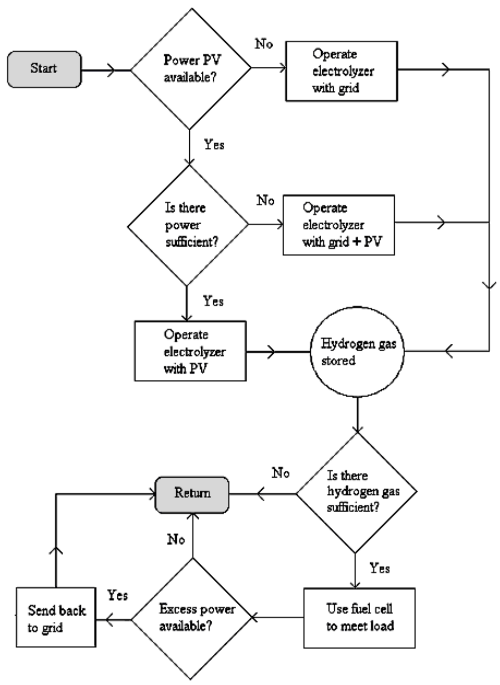

FIGURE 2. Flowchart of Solar Hydrogen System

iii) Fuel cell system

The proton exchange membrane PEM fuel cell stack, designed by UKM fuel cell group, was used in this study. The PEM fuel cell is a process just reverse of the PEM electrolysis process. The PEM fuel cell uses a polymer membrane as its electrolyte. Under load cell, voltages are affected by ohmic losses, anode and cathode polarization, and temperature. Neglecting polarization losses, the cell voltage under load is expressed as follow:

$$V = V_o - iAR - b\log(iA) \qquad (3)$$

which V_o is open circuit reversible cell potential; i is current density; A is cell area; R is ohmic resistance; and b is Tafel slope.

3. Simulation

The SSHS was programmed using graphical user interface (GUI) in Matlab and is capable as follows;

i) To calculate the efficiency and electric energy produced by PV modules.
ii) To calculate the efficiency and hydrogen production by electrolyzer systems.
iii) To calculate the efficiency and hydrogen consumption by fuel cell systems.

Figure 3 shows the layout for the designed SSHS program in Matlab software. This program is user friendly and flexible. It can be used to predict or size the solar hydrogen system with better efficiency, reliability and economics according to Malaysian climate. In general, the SSHS program is divided into two modes; free mode and SSHS mode.

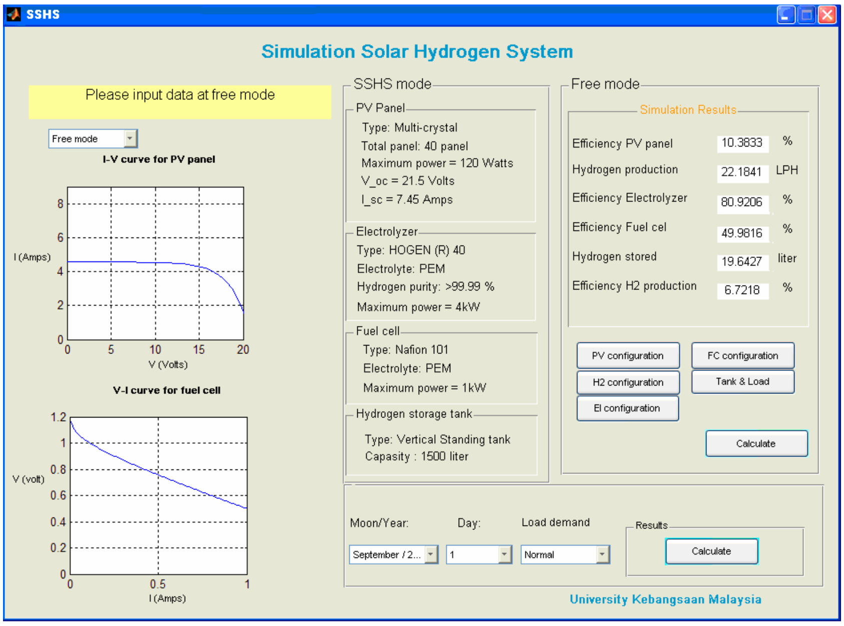

FIGURE 3. SSHS program layout

i) *Free mode*

The Free mode is presented to run a simulation of a solar hydrogen system which is stated above. The solar radiation, ambient temperature, cell temperature, characteristic of PV panels, characteristic of electrolyzer, and characteristic of fuel cell are free input parameters to the computer program. The simulated results will then be displayed at the simulation results interface in the SSHS program.

ii) SSHS mode

The SSHS mode is presented to run a simulation of a solar hydrogen system and the simulation results were compared with the actual experiment data. Temperature of the panels and solar radiation data over a 3 month period (November 2006 though January 2007), which was collected in a specific location in UKM, were input into the program. In the future, more collected data can be added into the program and a complete data bank for the program established. This mode can run the simulation based on the collected data and all the related parameters fixed according to the solar hydrogen system at the experiment.

Figure 4 shown that the energy output from photovoltaic module, inverter, grid and energy to PEM electrolyzer. It is clearly show that the energy from PV module is insufficient power to operate the electrolyzer except day 3.

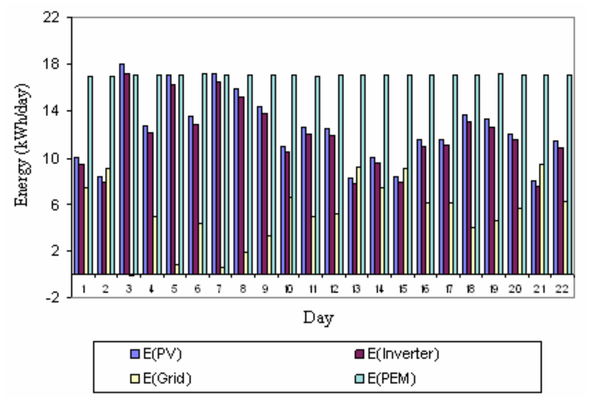

FIGURE 4. Energy output from photovoltaic module, inverter, grid and energy to PEM electrolyzer.

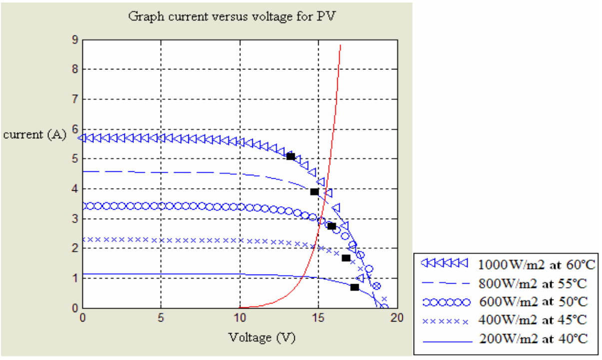

FIGURE 5. I-V curve for PV under the various conditions.

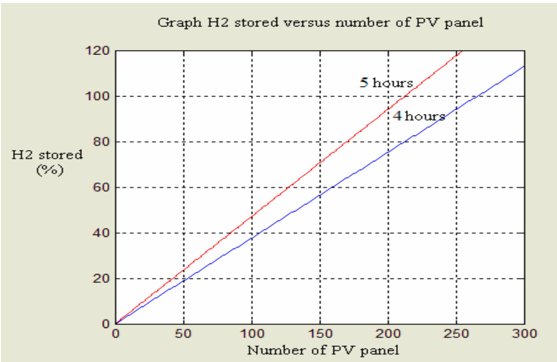

FIGURE 6. Results of simulation for SSHS

Figure 5 show that the I-V curves for PV panels under the various condition. Symbol (■) is presented as the maximum power point for each I-V curve. From the figure, we can estimate the increase in the open circuit voltage when the temperatures decrease. Besides that, the short circuit current also slowly decreases with respect to the solar radiation. With the given data, the SSHS program has calculated the number of PV panels that will satisfy the condition of hydrogen storage system. The results for this case are shown in Figure 6. It is clear that the percentage for hydrogen storage tank was higher when the system received more solar radiation for a day with the same number of PV panels. However, the average solar radiation for Malaysia is usually 5 hours in a day [8].

4. Economic Analysis

A GUI program has been designed to perform an economic analysis of the solar hydrogen system. Economic study is important to determine the project reliability and feasibility. In this section, the major parameters need to be determined is life cycle costs (LCC), payback period (PP), and cost of electricity (COE). The cost is determined based on the initial capital required for a solar hydrogen system, operation and maintenance costs, replacement cost, and the production rate of hydrogen.

Figure 7 shows a layout of the GUI program designed to perform the cost analyses discussed above. The payback period calculated in this study is 41 years, indeed quite a long time to recover back initial cost. However, if the tariff can be increased, the time period will become shorter and the system will be more economic to implement in the future. The COE calculated is RM0.93/kWh and the result shows that this system has high cost of electricity.

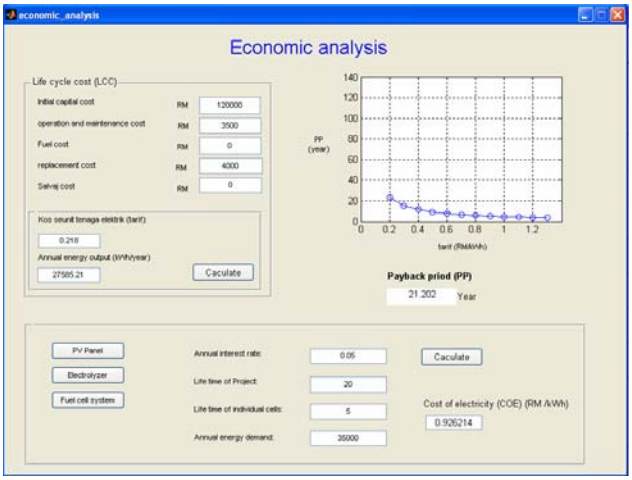

FIGURE 7. Economic Analysis Layout

5. Conclusion

This paper presented a simulation to predict and optimize of a solar hydrogen system. An economical evaluation was also studied for the system. Simulation program, SSHS was successfully designed and effectively simulated the solar hydrogen system. Comparison with experiment data, revealed that the designed SSHS program can be a useful tool to simulate solar hydrogen systems. Also, the SSHS program has a great potential to be develop as a powerful simulation program in the future. Since the cost of electric (COE) generated by solar hydrogen system today is still too expensive and prohibitive (RM 0.93/ kWh), there is evidence to show that solar hydrogen systems will become more competitive in the near future.

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