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Technical Note

Optimized photovoltiac system for hydrogen production

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Abstract

Hydrogen, which can be produced by water electrolysis, can play an important role as an alternative to conventional fuels. It is regarded as a potential future energy carrier. Photovoltaic arrays can be used in supplying the water electrolysis systems by their energy requirements. The use of photovoltaic energy in such systems is very suitable where the solar hydrogen energy systems are considered one of the cleanest hydrogen production technologies, where the hydrogen is obtained from sunlight by directly connecting the photovoltaic arrays and the hydrogen generator. This paper presents a small PV power system for hydrogen production using the photovoltaic module connected to the hydrogen electrolyzer with and without maximum power point tracker. The experimental results developed good results for hydrogen production flow rates, in the case of using maximum power point tracker with respect to the directly connected electrolyzer to the photovoltaic modules.

Keywords: Photovoltaic; Hydrogen production; Maximum power point tracking; Electrolyzers

1. Introduction

Solar power is destined to make a significant contribution to world energy supply for reasons of both the finite amounts of fossil fuels and environmental damage consciousness. It is emphasized that the global environmental damage caused thermodynamically is more

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Nomenclatures

$\eta_{\text{electrolyzer}}$	electrolyzer efficiency
η_{overall}	overall system efficiency
Q	hydrogen flowrate (ml/s)
E	the calorific value for hydrogen (J/ml)
V_L	load voltage (V)
I_L	load current (A)
H	solar radiation intensity (W/m^2)
A	PV module area (m^2)

alarming to life on earth than the risk of exhausting the finite amount of fossil fuels being consumed at the present rate [1]. In that sense, solar technology can be categorized into three major systems, namely: (a) solar heating and cooling of space, (b) solar thermal conversion, and (c) photovoltaic cells. Among the renewable energy systems, the photovoltaic cells, which generate direct current electric energy when exposed to solar radiant energy, can be considered the most important source of energy. It generates electricity with a little impact on the environment, have no moving parts to wear out, modular, which means that they can be matched to a need for power at any scale, can be used as independent power source or in combination with others, and they are reliable with long live.

Hydrogen can play an important role as an alternative to conventional fuels. One of the most attractive features of hydrogen as an energy carrier is that it can be produced from water. Also, hydrogen has the highest energy content per unit mass as compared to chemical fuel and can be substituted in place of hydrocarbons in a board range of applications [2]. Its burning process is non-polluting and it can be used in the fuel cells to produce both electricity and useful heat. Hydrogen production using direct solar energy and electrolyzer systems can be achieved in various ways [3]. The following methods can be mentioned: (i) solar thermal electrical power generation and water electrolysis, and (ii) photovoltaic electrical power and water electrolysis. The last method has an additional advantage, as the direct current electrical power produced by a photovoltaic generator can be supplied directly to an electrolyzer.

Various experimental and theoretical references studied the production of the hydrogen by an electrolyzer using the PV energy [1–3]. The electrolysis of a synthetic alkaline was carried out at different temperatures varying between 10 and 80 °C and the effect of the electrolyte temperature on the rate of hydrogen production was studied [2]. A mathematical model has been developed to determine and optimize the thermal and economical performance of large scale photovoltaic electrolyzer systems, either with fixed or sun tracking panels using hourly solar radiation data [3]. Lehman et al. [4] reported the performance, safety, and maintenance issues of photovoltaic power plant which used hydrogen energy storage and fuel cell regenerative technology. Abdallah et al. [5] developed a model for solar–hydrogen energy system by obtaining relationships for and between the main energy and energy related parameters.

The present paper studies the integration between the solar photovoltaic array and water electrolysis unit for hydrogen production. A photovoltaic module is coupled with the electrolyzer unit by two ways: (a) direct coupling, and (b) coupling with the maximum power point tracker system to optimize the solar array output power to get the optimum electric current and voltage from the PV array. The actual requirements of hydrogen production systems from energy are studied. The theoretical and experimental studies for the maximum power point tracker (MPPT) used are published in [6,7]. Also, the control circuits of the system has been built and the photovoltaic system is installed in the experimental site in Solar Energy Department (Cairo, Egypt).

2. Experimental setup

Fig. 1 shows the overall photovoltaic–hydrogen power system. The overall system consists of:

(a) The photovoltaic module.
(b) The water electrolyzer.
(c) The maximum power point tracker.

2.1. Photovoltaic module

The PV module is a monocrystalline silicon type with maximum output of 53 W with an open circuit voltage of 21.7 V and short circuit current of 3.27 A at STC. The PV module generates the dc power that is transferred to the water electrolyzer directly or through the MPPT. The PV module is supported up on a tilted structure from steel frames. The tilt angle is fixed at 30° with horizontal and the structure is mounted such that the module is facing south direction.

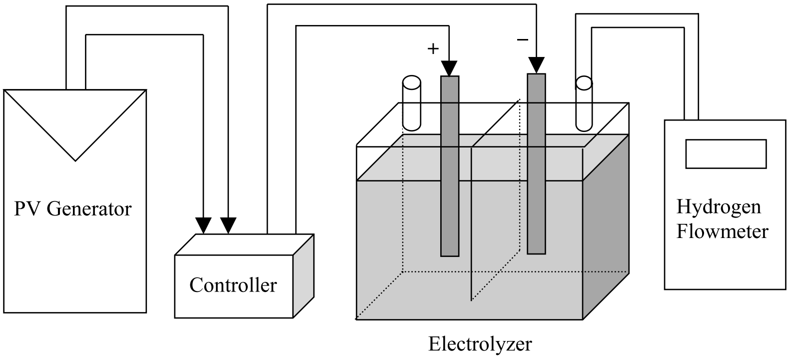

Fig. 1. A schematic diagram for the photovoltaic–hydrogen power system.

2.2. Water-electrolyzer

The electrolyzer is used for the electrolysis and the hydrogen produced at the cathode is measured using a digital flowmeter. As shown in Fig. 1 the electrolyzer consists of an acrylic box with the dimensions of $20 \times 15 \times 15$ cm. The box is divided into two chambers by an acrylic separator. The electrodes that have a cross-section area of 2 cm^2 are made of nickel and immersed in the electrolyte and were fitted on the chambers surface by a rubber stoppers. The electrodes were connected to the photovoltaic module directly (without MPPT) or through the MPPT. The electrolyte used is potassium hydroxide with a concentration of 27%, according to the highest conductivity with concentration [8].

2.3. Maximum power point tracker

The maximum power point tracker is used to optimize the transmitted photovoltaic module power to increase the overall system efficiency. The MPPT consists of a step-down dc–dc converter with the input and output filters, and the driving circuit. The MPPT drives the operating point of the PV module to the maximum power point detected by the control system [6,7].

2.4. Measuring instruments

The overall system parameters are measured accurately and recorded continuously for data storing as follows:

- The PV module and the electrolyzer voltages and currents are measured using digital voltmeters and ammeters with accuracies of 0.01 V and 0.001 A, respectively.
- A thermopile pyranometer of type Kipp & Zonen (model CM5-774035) is used to measure the solar radiation intensity. The pyranometer is mounted at the PV module structure and parallel to the module surface.
- A type K thermocouple is used to measure the PV module surface and ambient temperatures.
- The hydrogen flow rate is measured with Wheaton Scientific Digital Flowmeter with accuracy of 0.1 ml/min.

3. Results and discussion

The hydrogen production system using the photovoltaic module with and without maximum power point tracker was built and tested and the following data are recorded for discussion.

3.1. Direct coupling

In the direct coupling, the water electrolyzer was connected directly to the photovoltaic module, without maximum power point tracker. Fig. 2 shows the solar radiation intensity and the ambient temperature recorded for a sample day, while the corresponding electrolyzer voltage and current were shown in Fig. 3 (direct coupling). The produced hydrogen flow rate was shown in Fig. 4, for the same day. From the figures it is clear that the photovoltaic module current is directly affected by the solar radiation intensity. As well as, increasing the electrolyzer current increases the hydrogen production flow rate, as shown in Fig. 5. Fig. 5 shows the relation between the hydrogen flow rate and the electrolyzer current. The electrolyzer efficiency and the overall system efficiency for the direct coupling system are calculated according to the following equations:

$$\eta_{\text{electrolyzer}} = \frac{Q \cdot E}{V_{\text{L}} \cdot I_{\text{L}}} \tag{1}$$

$$\eta_{\text{overall}} = \frac{Q \cdot E}{H \cdot A_{\text{m}}} \tag{2}$$

Fig. 6 shows the electrolyzer and overall system efficiencies. It is clear that the smaller photovoltaic module efficiency decreases the overall system efficiency. Also the module is not operating at its maximum power point.

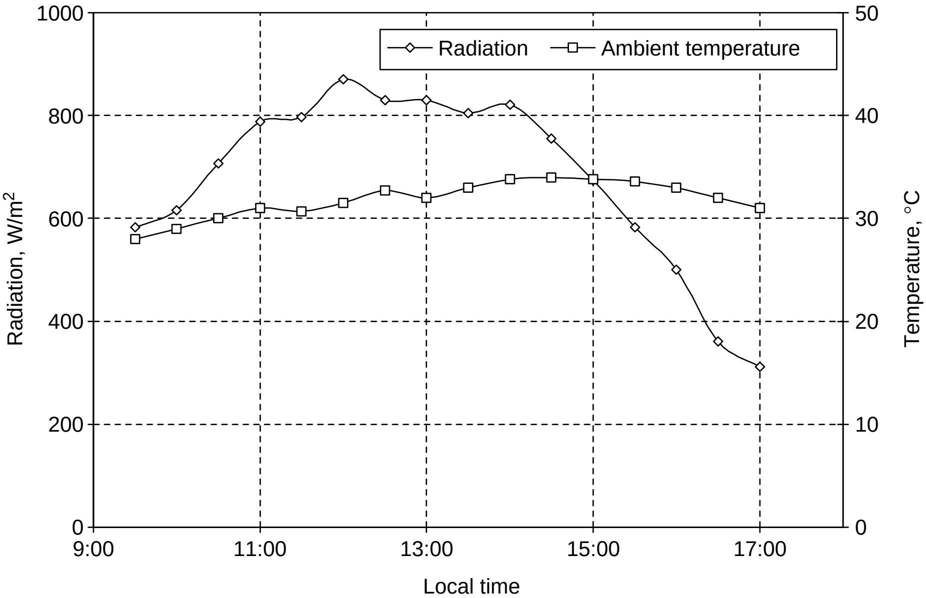

Fig. 2. Solar radiation and ambient temperature measured for a certain day in July as a sample of measurements.

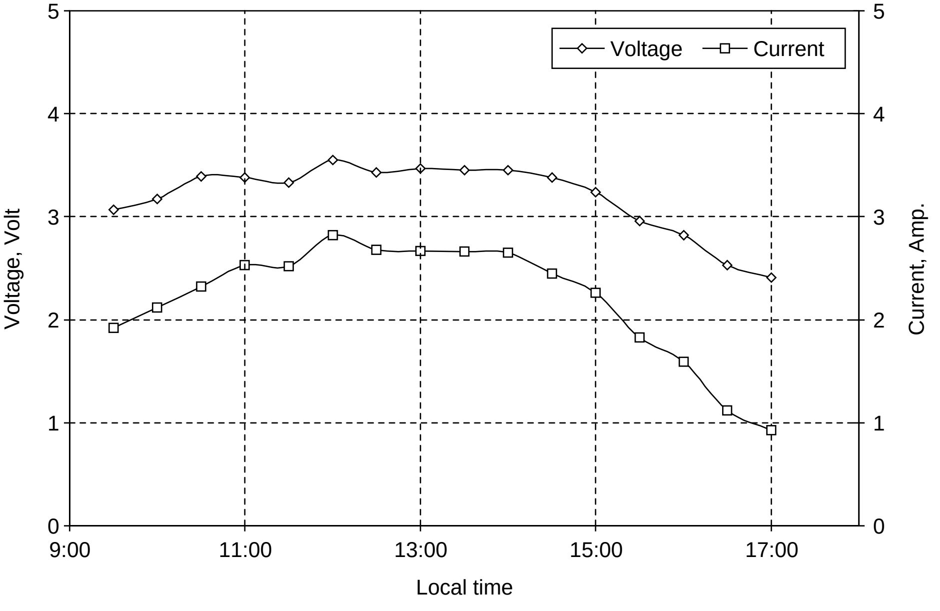

Fig. 3. Load voltage and load current measured for the direct coupling system during the day in Fig. 2.

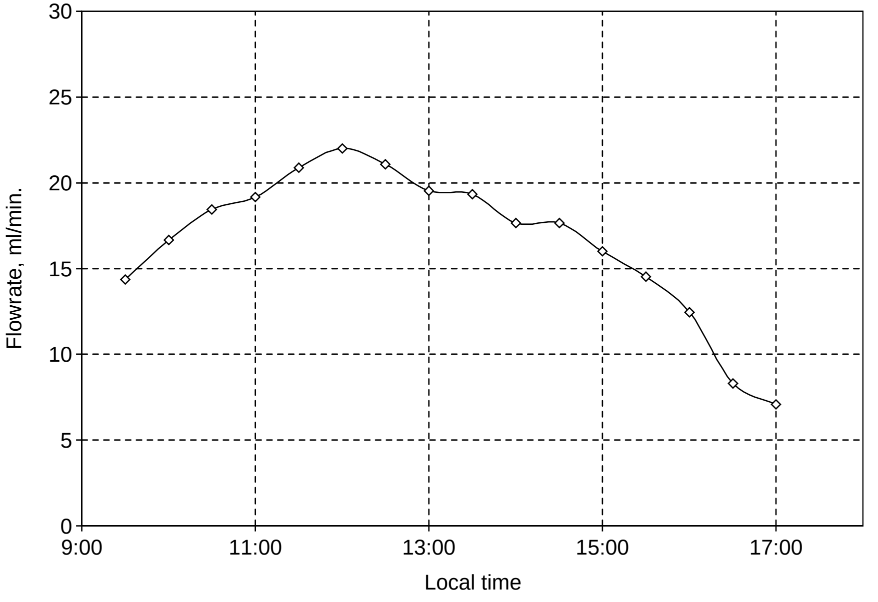

Fig. 4. Hydrogen flowrate measured for the direct coupling system.

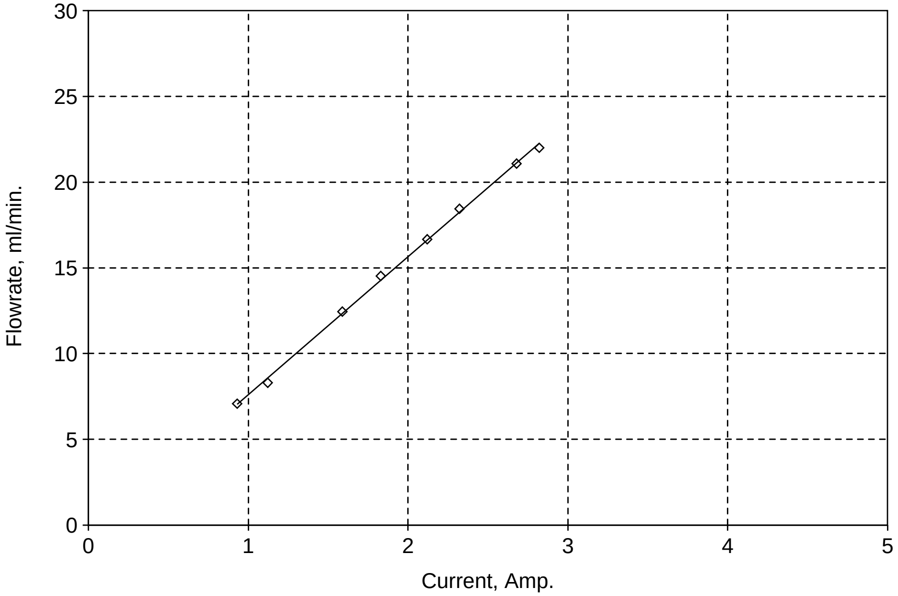

Fig. 5. Hydrogen flowrate versus the electrolyzer current measured for the direct coupling system.

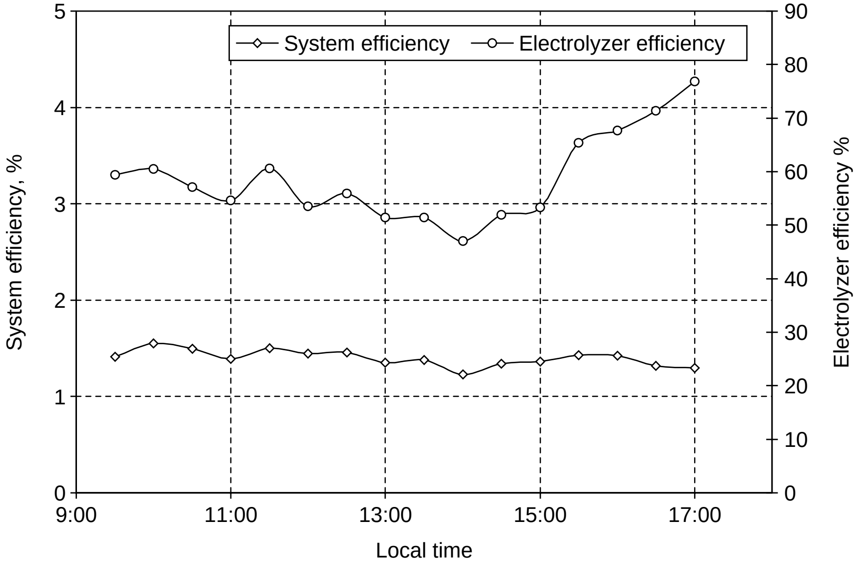

Fig. 6. Overall system and electrolyzer efficiencies measured for the direct coupling system.

3.2. Coupling with MPPT

The main advantage of the maximum power point tracker is to adjust the photovoltaic module current and voltage to the optimum electrolyzer values needed for the maximum hydrogen production. Fig. 7 shows the solar radiation intensity and the ambient temperature measured for a sample day in the case of coupling with the MPPT, while Fig. 8 shows the corresponding photovoltaic module and electrolyzer voltages and currents during the experiments. The hydrogen flow rate in this case was shown in Fig. 9. It is clear that the system operates around the maximum power point of the PV module and the maximum power point tracker increases the system current and accordingly increases the hydrogen flow rate. The electrolyzer efficiency and the system efficiency are shown in Fig.10.

For comparison, the hydrogen flow rate in case of direct coupling and coupling with the MPPT in relation to the variation of solar radiation intensity are shown in Fig. 11. It is clear that using the MPPT optimize the system performance, which in return increases the system current for the same radiation intensity, which leads to higher hydrogen production. The overall system efficiencies in the case of direct coupling and with the MPPT are shown in Fig. 12. From these figures it is clear that although the electrolyzer efficiency slightly decreases with the MPPT, due to the higher electrolyte temperature and higher Ohmic loses, the overall system efficiency increases than that of the direct coupling case.

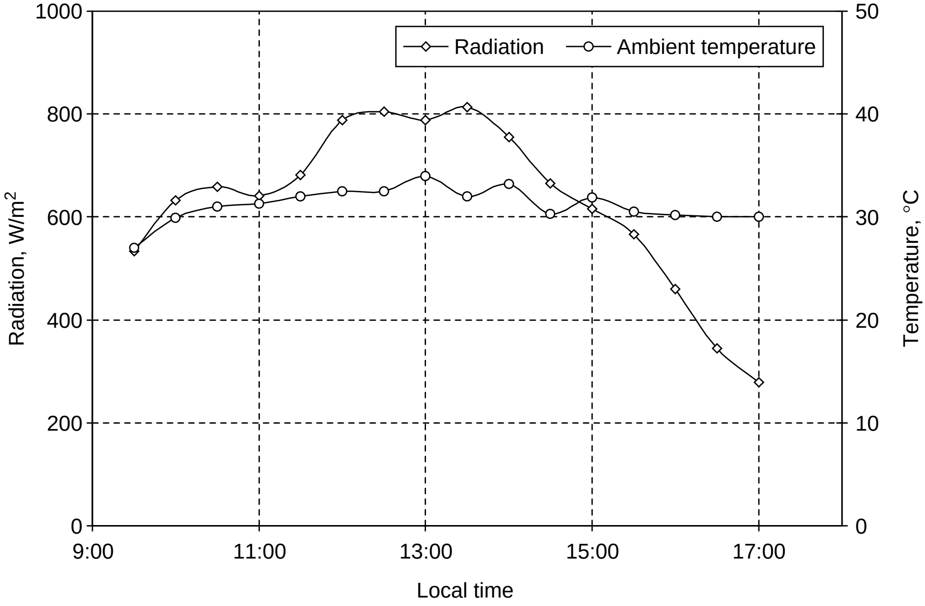

Fig. 7. Solar radiation and ambient temperature measured for a certain day in July for the system with MPPT.

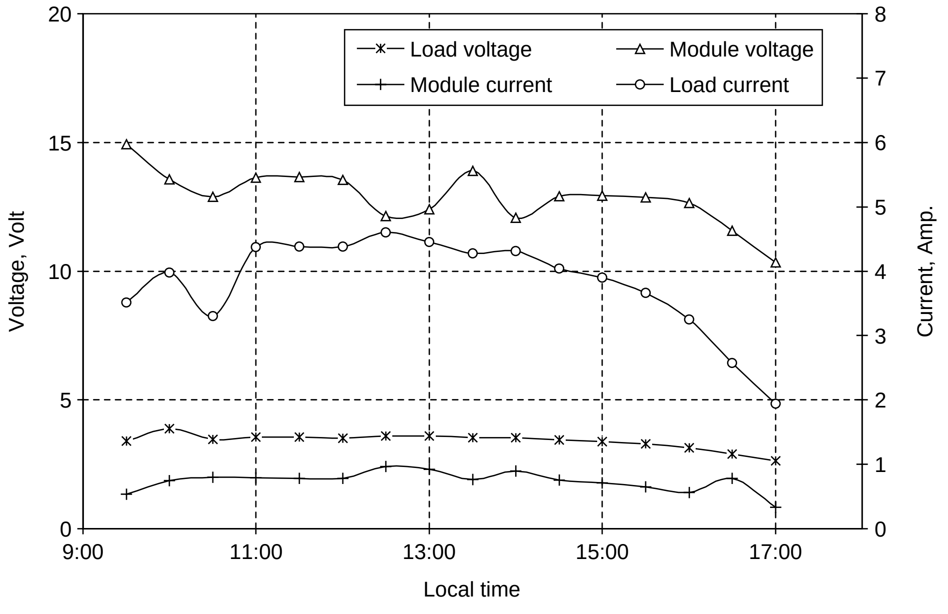

Fig. 8. PV module and electrolyzer voltages and currents measured for the MPPT system.

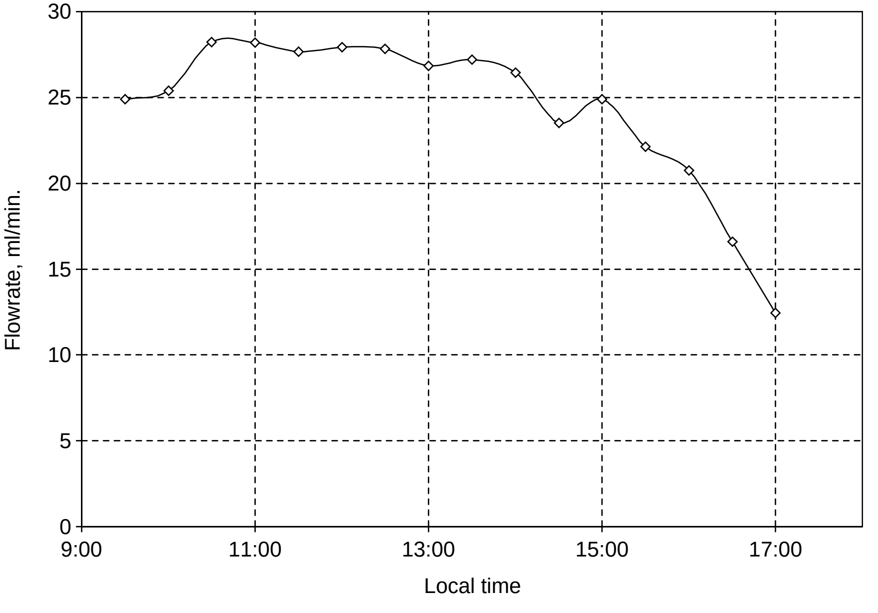

Fig. 9. Hydrogen flowrate measured for the system with MPPT.

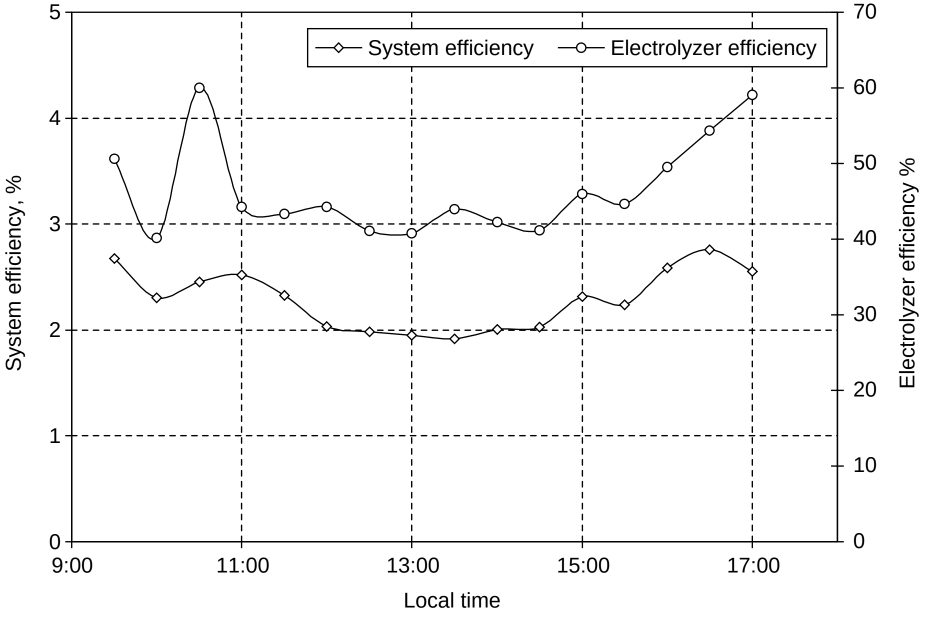

Fig. 10. Overall system and electrolyzer efficiencies measured for the system with MPPT.

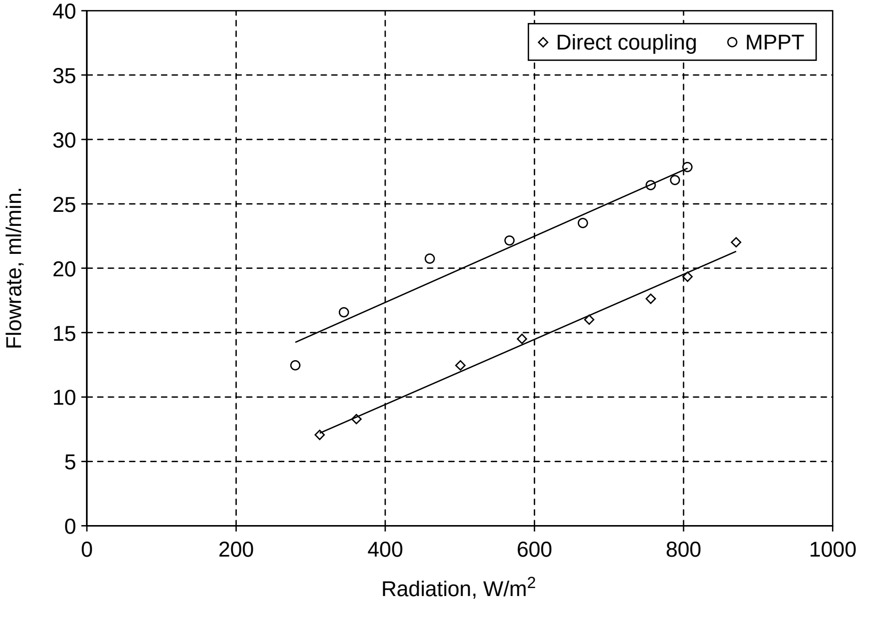

Fig. 11. Hydrogen flowrate versus solar radiation measured for the direct coupling system and for MPPT.

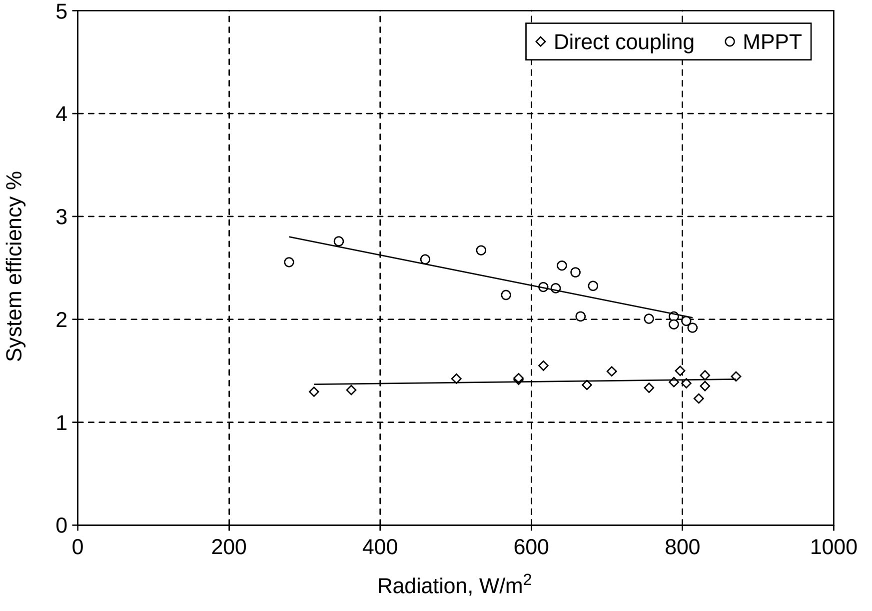

Fig. 12. Overall system efficiency versus solar radiation measured for the direct coupling system and for MPPT.

4. Conclusions

An experimental system was built for hydrogen production using photovoltaic energy with and without using maximum power point tracker. The system was designed and assembled for testing. It is shown from the experimental results that the hydrogen production can be more useful by using the photovoltaic energy from the side of view the environmental considerations. It is found that the average electrolyzer efficiencies are 60 and 50% in case of direct coupling and with the MPPT, while the overall system efficiencies are found to be 1.5 and 2.3% for both cases, respectively. The small efficiencies are due to the losses in the electrolyte, the losses in the controller and that due to the surface temperature. Also, it is found that the environmental conditions such as solar intensity, ambient temperature and the module surface temperature have a large effect on the system performance and the rate of hydrogen production.

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