



# Hydrogen Production by Water Electrochemical Photolysis Using PV-Module

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**Abstract:** The experimental research on hydrogen production by water electrochemical splitting is presented in the article. In the study low temperature electrolytic unit with 26<sup>th</sup>% KOH liquid solution and small-scale photovoltaic module (PV-module) were used to convert solar energy into molecular hydrogen. Speeds and volumes of average monthly hydrogen production are defined for Kyiv insolation using experimental facilities. The method applied can be proposed to estimate hydrogen amount generated when combining the conventional electrolysis process and photovoltaic module for compensating the long term fluctuations of solar photovoltaics.

**Keywords:** Hydrogen, Electrolysis, Photovoltaic Module, Solar Energy

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## 1. Introduction

Stabilizing future atmospheric CO<sub>2</sub>-levels at less than a doubling of pre-industrial levels will be a difficult task because it requires a continuous flow of new carbon-free power 2-3 times greater than today's energy supply to sustain economic development for a global population approaching 10 billion people by the middle of 21<sup>st</sup> century [1].

The sun and wind are the two largest sustainable sources of carbon-free power. However, to realize their potential, they must overcome a key hurdle – a challenge of their intermittent nature. Unlike other forms of renewable energy such as hydropower and geothermal energy, the energy generated by wind and photovoltaics fluctuates. This fluctuation poses a sizable challenge to their power grid integration and a widespread adoption as the mainstream power sources [1, 2].

There are several potential answers to the intermittency challenge and one of the more viable solutions is a credible form of electricity storage [2].

Power storage can improve the efficiency and reliability of the electric utility system by reducing the spinning reserve requirements to meet peak power demands. This makes better use of efficient base load generation and allows greater use of intermittent renewable energy technologies. Energy storage technologies include utility battery storage, flywheel storage, superconducting magnetic energy storage, compressed air energy storage, pumped hydropower, and super capacitors.

Additionally, hydrogen may be used as an energy storage medium [3, 4].

Concerning pumped hydropower and compressed air energy storage systems, hydrogen storage has somewhat higher investment costs and a lower efficiency. Simultaneously, it has significantly higher energy density and hence, significantly higher energy capacity. This, combined with fuel cell technology, makes hydrogen storage most appropriate for the compensation of long-term fluctuations [2].

To have a highly effective and efficient renewable-hydrogen system, hydrogen should be used at the chosen time. When renewable resources are available, e.g. the sun is shining, and electricity is needed, the electric current should be used immediately. To meet even higher electricity demands, energy can be supplied directly from renewable resources as well as from hydrogen stores. As demands decrease, the extra electricity from renewables can be converted and stored as hydrogen.

Additionally, hydrogen provides a connecting point between renewable electricity production, transportation, and portable energy needs. In transportation applications, hydrogen provides a way to convert renewable resources to fuel for vehicles. In portable energy, hydrogen with fuel cells can be used as an important power source for mobile electronic devices, offering key advantages over conventional batteries. It will increase operating times, it will reduce the

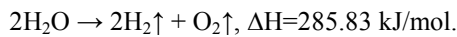
weight, and it can be recharged easily. At the same time, hydrogen can store energy for a long period without any power dissipation.

This entire portfolio of options makes renewable hydrogen systems more effective in providing flexible and reliable energy in the most necessary forms [5].

## 2. Fundamental Principal

The water electrochemical photolysis is a method exploiting photovoltaic modules for generating low-grade electric energy used for hydrogen production by conventional water electrolysis [6, 7].

Electrolysis is a process that occurs when direct current passes through the electrolytic system composed of an anode, a cathode and electrolyte. The resulting reaction is as follow [8, 9]:



Hydrogen production by the conventional water electrolysis obeys the Faraday's law of electrolysis [10]:

$$m = K \times q,$$

with  $m$  – separated substance mass,  $K$  – electrochemical equivalent,  $q$  – electrical charge passed through the electrolyte.

In turn, the electrical charge is defined as follow [10]:

$$q = I \times \tau,$$

with  $I$  – electrical current,  $\tau$  – operating time of electrolyzer.

The electrochemical equivalent  $K$  of a chemical element is the mass transported by one coulomb of electricity, e.g. the electrochemical equivalent for hydrogen is  $1.045 \cdot 10^{-8} \text{ kg/C}$  [8].

Hydrogen production by conventional electrolysis process has the following advantages over other hydrogen producing methods [6, 11]:

- the produced hydrogen is about 99% pure,
- the electrolytic cell is simple, continuous, automatic, and without gear motion,
- the most widespread chemical substance notably water is used in electrolysis,
- and finally, there is possibility of using renewable energy sources for hydrogen production.

Objective of the research is to study the average monthly hydrogen productions by water electrochemical photolysis using PV-module for Kiev insolation.

## 3. Experimental Method

Principle circuit of the experimental facility that was used for hydrogen production by the conventional water electrolysis is presented in fig. 1.

The photovoltaic module generated electric energy and the electric current went to the electrolyzer by cords. The electrolyzer was a tank with two carbon electrodes immersed

in the electrolyte. Transparent plastic tubes were located over carbon electrodes for capturing hydrogen and oxygen bubbles. These tubes had graded scales with a division value equal to 0.2 ml.

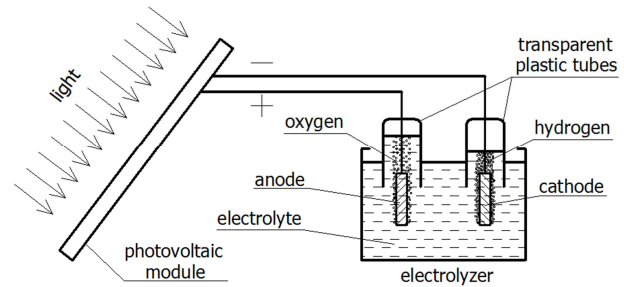


Figure 1. Principle circuit of the experimental facility. [12].

When light acted on the sloping surface of the photovoltaic module, the electrolysis process began. After that molecular hydrogen was created on the cathodic surface and oxygen was created on the anodic surface. Hydrogen and oxygen bubbles rose to hollow tubes displacing the electrolyte. Hydrogen production speed was determined by captured gas quantity per unit time.

In the experiment 26<sup>th</sup>% KOH liquid solution was used as the electrolyte for electrolysis process.

Characteristics of the used PV-module and electrolyzer are presented in the table 1 and table 2 respectively.

Table 1. Characteristics of the photovoltaic module [12].

Type of photovoltaic module	KV-10W/12V
Type of silicon	mono
Overall PV-module dimensions, mm	527×233×34
Maximum power, W	10±3%
Efficiency, %	10
Voltage at maximum power, V	16.5
Current at maximum power, A	0.7
Open-circuit voltage, V	20
Short-circuit current, A	0.84
Active surface area, m <sup>2</sup>	≈0.1

Table 2. Characteristics of the electrolyzer [12].

Pressure	standard
Temperature, °C	75
Type of electrolyte	KOH liquid solution
Electrolyte concentration, %	26
Electrolyte volume, liters	1
Electrode material	carbon
Electrode surface area, mm <sup>2</sup>	1120
Maximal current density, A/cm <sup>2</sup>	0,025
Distance between electrodes, mm	16

Photo of the used experimental facility is illustrated in fig. 2.

## 4. Implementation and Results

When determining the PV-module average monthly current-voltage curves, the standard procedure was used. However instead of a constant light source, the light source with adjustable radiation intensity was utilized. It enabled to influence the PV-module sloping surface by controlling

radiation intensities, which were equal to the Kiev average monthly solar intensities (table 3).

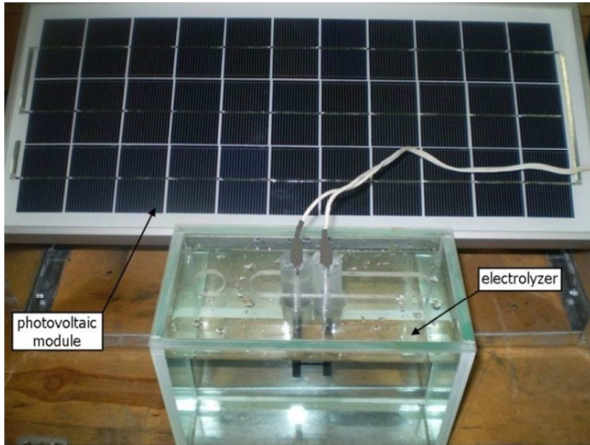


Figure 2. Photo of the experimental facility. [12].

As a result, the average monthly current-voltage curves were determined for Kiev insolation (fig. 3). Thus, in this diagram the larger average monthly solar intensity (June) satisfies the greater amount of electrical current.

Table 3. Kiev insolation data.

Month	Average monthly solar intensities that act on sloping surface of PV-module, W/m <sup>2</sup>
January	77.8
February	106.4
March	153.8
April	170.7
May	197.5
June	213.1
July	206.4
August	198.7
September	183.1
October	137.1
November	59.9
December	52.3

The slope angle of the photovoltaic module was equal to 50° (latitude angle of Kiev).

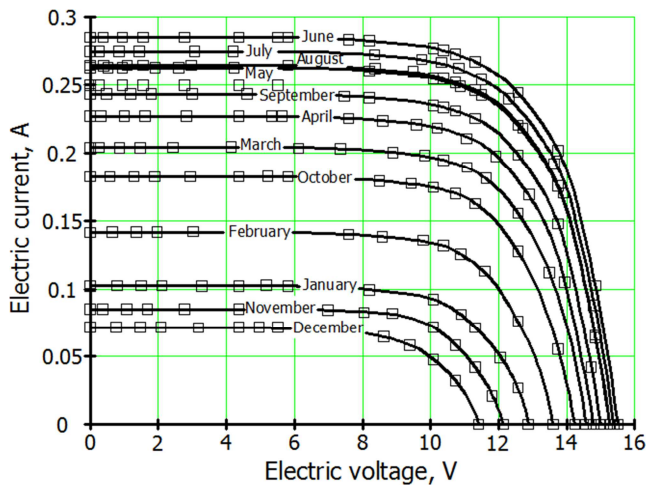


Figure 3. Average monthly current-voltage curves of the photovoltaic module for Kiev insolation.

For determination of the hydrogen producing operating points in the electrolysis process, the experimental current-voltage curve of electrolyzer with 26<sup>th</sup>% KOH liquid solution was tested (fig. 4). Here, with low electrolysis voltage less than 1.23 V, hydrogen production does not occur. Practical zero value of the electrical current confirms non-hydrogen generation. Increasing the voltage to more than 1.23 V generates hydrogen exponentially.

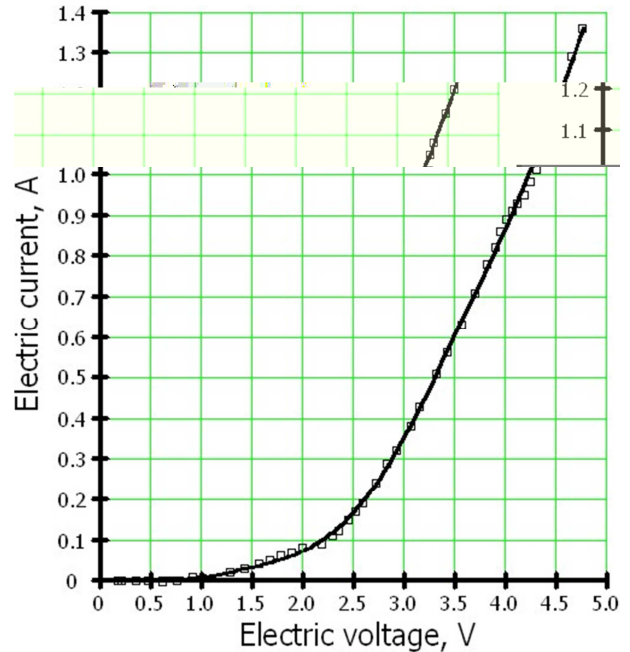


Figure 4. Electrolysis current-voltage curve (electrolyte is 26<sup>th</sup>% KOH liquid solution).

The intersections of the electrolysis current-voltage curve and the average monthly current-voltage curves of the photovoltaic module determined the operating points of hydrogen production for each month (fig. 5). In this diagram, operating electric currents are equal to the short-circuit currents of the photovoltaic module. Thus, the PV-module operation with an electrolyzer corresponds to the short-circuit conditions.

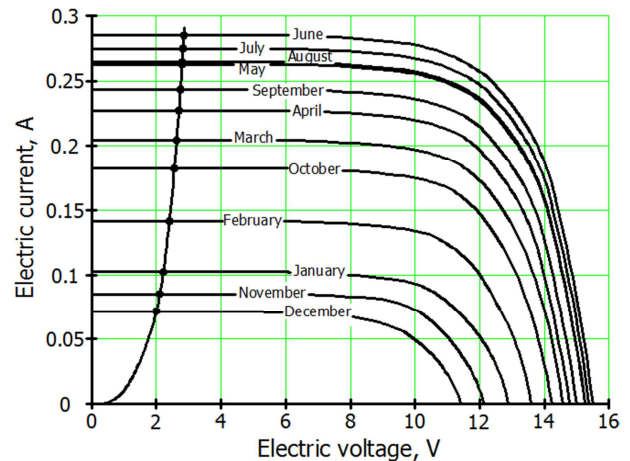


Figure 5. Operating points of hydrogen production by the experimental facility for Kiev insolation.



A photo of the hydrogen producing process is shown in fig. 6.

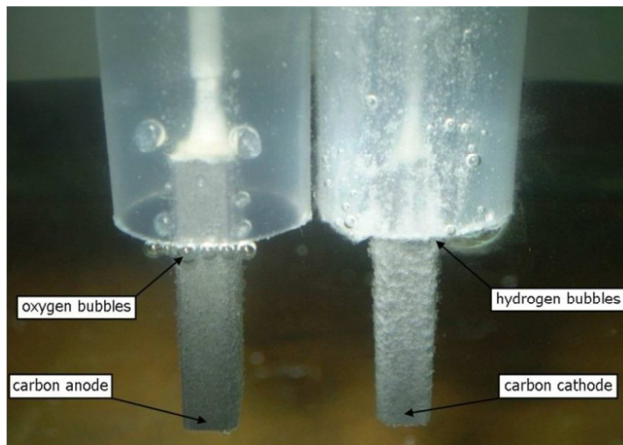


Figure 6. Process of hydrogen production. [12]

Thus, in the issue of performed experiments, the speeds of hydrogen production by the electrolysis process were determined for each month (fig. 7). As expected in June, the speed of hydrogen production is maximal (about 0.035 milliliters/second) and minimal speed is in December (about 0.009 milliliters/second).

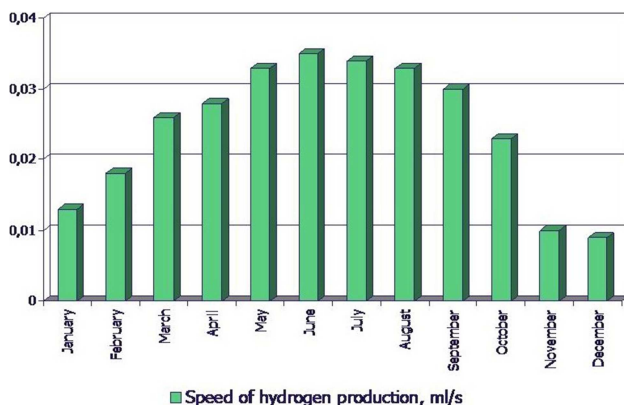


Figure 7. Speeds of hydrogen production by the experimental facility for Kiev insolation.

Volumes of produced hydrogen by the experimental facility for Kiev insolation are shown in fig. 8.

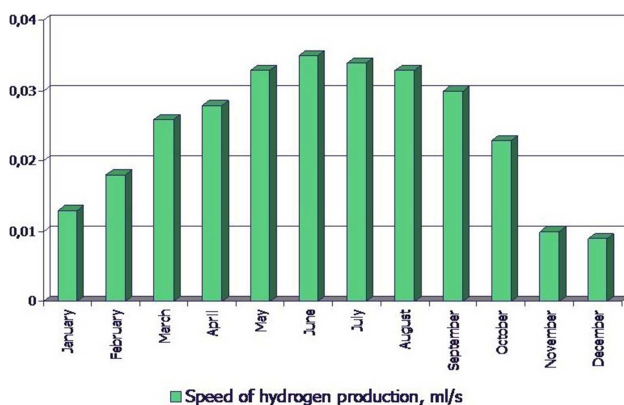


Figure 8. Volumes of hydrogen production by the experimental facility for Kiev insolation.

Thus, in June and July volumes of produced hydrogen undoubtedly are the highest (about 0.092 m<sup>3</sup>/month).

The average energy required for producing a normal cubic meter of hydrogen and 0.5 cubic meter of oxygen by the experimental facility is about 5.7 kW-hours.

Overall efficiency of the solar energy conversion into molecular hydrogen is about 5.2%. In the first place this very low efficiency is due to low efficiency of used PV-module (about 10%).

## 5. Conclusion

Average monthly hydrogen generation can be estimated using a method proposed in the paper. The method is based on utilization of the Faraday's law of electrolysis and operating electric currents defined for each month through intersection of the electrolysis current-voltage curve and the average monthly current-voltage curves of the PV-module.

The method proposed can be applied for estimation of speeds and volumes of hydrogen production combining the conventional water electrolysis and photovoltaics, e.g. when compensation of long term fluctuation of solar PV is needed.

The energy required for producing a cubic meter of hydrogen and 0.5 cubic meter of oxygen by the experimental facility is about 5.7 kW-hours.

Currently this method of hydrogen production, notably using PV-modules has very low efficiency, e.g. the overall efficiency of solar energy conversion into molecular hydrogen is about 5.2% only. First of all this very low efficiency is due to low efficiency of the used PV-module. Therefore for increasing the overall efficiency of the solar energy conversion into molecular hydrogen it is necessary to use more effective PV-modules and also improve efficiency of the electrolysis process.

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