Study of a photovoltaic system for hydrogen production in Algeria

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Abstract - *Due to the intermittency of renewable energy and its dependence on climatic conditions, it is necessary to store the energy produced, since it is clean and having a big calorific value. Hydrogen is the better energy carrier at this moment. This work deals with the production of solar hydrogen by water electrolysis. The energy for the dissociation of water is supplied by a photovoltaic (PV) system. The operation of the PV system, design and study was considered for the region of Tamanrasset in the South of Algeria. The study examined the influence of electrolysis pressure and temperature on the performance of the facility.*

Résumé - *En raison de l'intermittence des énergies renouvelables et de leurs dépendances des conditions climatiques, il est nécessaire de stocker l'énergie produite à partir de ces dernières. Car il est propre et ayant une grande valeur calorifique, l'hydrogène est pour le moment le meilleur vecteur énergétique. Ce travail traite de la production d'hydrogène solaire par électrolyse de l'eau. L'énergie pour la dissociation de l'eau est fournie par un système photovoltaïque (PV). Le fonctionnement, la conception, ainsi que l'étude du système PV ont été faits pour la région de Tamanrasset dans le sud de l'Algérie. L'étude a examiné l'influence de la pression et la température d'électrolyse sur le rendement de l'installation.*

Mots clés: Energie solaire - Photovoltaïque - Electrolyse - Production d'hydrogène – TRNSYS - Sahara.

1. INTRODUCTION

The existence of a huge solar potential and the sufficient quantity of water with the availability of vast spaces for the installation of solar energy collection and conversion systems, make the Algerian Sahara a strategic place for production of solar hydrogen [1]. A considerable number of works are underway in order to develop the production of solar hydrogen [2-8].

There are different ways to produce solar hydrogen; they may be [10-12]:

- Photo electrochemical,
- Photo organic,
- Thermo chemical,

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- Or indirectly by generating electricity from the sun that used to produce hydrogen.

In this work, we will design and simulate the operation of a pilot plant for solar hydrogen production in the region of Tamanrasset, the hydrogen will be produced from water and solar energy. In our case [13-14], we have adopted an indirect method which uses a system coupling a PV field to an alkaline electrolyser. This choice is justified by the fact that this kind of installation is very easy to implement due to the availability of different components. However, in this type of installation, we have a source of energy, which are the solar array and the charge, here, the electrolyser.

These two main components are linked by an interface, which is the power converter. Thus, the operation of each component affects with different and independent way each other as long as the interface is as reliable as possible.

So, the operation optimizing of such facility, means to independently optimize both components. In this work, the influence of operating conditions of the electrolyser (pressure and temperature) on the operation of the facility was investigated.

2. MODELING

The simulation of our plant was done using TRNSYS software. The TRNSYS is a complete and scalable environment for simulation of transient system. Used mainly by engineers and researchers to validate new energy concepts. The TRNSYS needs meteorological data in order to perform the simulation. The data we have used are an average of a sample of data collected over a period of 40 years.

2.1 TRNSYS model

The schematic model of our system is shown in figure 1 where:

- Type 109-TMY2 is the component responsible for reading the file of meteorological data;
- Type 194 is the component that represents the solar array;
- Type 205 is the component that represents the power controller;
- Type 175b is the component that represents the power converter;
- Type 160a is the component that represents the electrolyser;
- Type 164b is the component that represents the hydrogen storage tank.

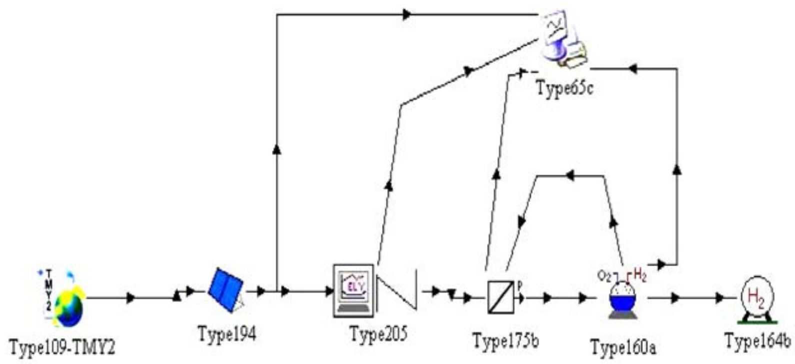

Fig. 1: Project of installation of hydrogen production on TRNSYS

2.2 Photovoltaic Panel

In our case, we have used the PV panel model proposed by the TRNSYS simulation software in order to perform our calculations. The model used is based on an equivalent circuit (Fig. 2) of five parameters [15-18]. The principle of this model is to scale up, the most accurate possible information supplied by the manufacturer under standard conditions (1000 W/m^2, 25 °C) to other operating conditions [15].

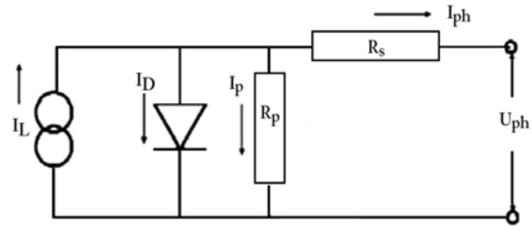

Fig. 2: Equivalent circuit [7]

The current-voltage equation of the circuit of the figure is given by the following expression [15-18]:

$$I_{ph} = I_L - I_0 \times \left[e^{\frac{U_{ph} + I_{ph} \times R_s}{a}} - 1 \right] - \frac{U_{ph} + I_{ph} \times R_s}{R_p} \qquad (1)$$

Where,

$$a = \frac{N_s \times n_I \times k \times T_c}{q} \qquad (2)$$

2.3 Controller

The controller used in this model is a modified version of that proposed by TRNSYS. This modification makes the electrolyzer operate directly with the power supplied by the solar array.

2.4 The power converter

The power converter used (Type 175) is a mathematical model based on empirical performance curve for electric power converter (DC / DC) or transformer (DC / AC or AC / DC) [15].

2.5 Electrolyser

The model is based on a combination of purely theoretical laws of thermodynamics, heat transfer and electrochemical empirical expression. A thermal model is also included.

An equation of current voltage dependent on temperature is used; this equation is designed for alkaline advanced technology electrolyser [15].

The characteristic equation of the electrolyser is given as follows [15], [19-21]:

$$U_{cell} = U_{rev} + `r \times \frac{I_{ely}}{area} + `s \times \log\left[\frac{`t \times I_{ely}}{area} + 1 \right] \qquad (3)$$

where,

$$\grave{r} = r_1 + r_2 \times T_{ely} \quad (4)$$

$$\grave{s} = s_1 + s_2 \times T_{ely} + s_2 \times T_{ely}^2 \quad (5)$$

$$\grave{t} = t_1 + \frac{t_2}{T_{ely}} + \frac{t_3}{T_{ely}^2} \quad (6)$$

2.6 Validation

In order to validate the used model, we have simulated the operation of the electrolyser in order to compare obtained current voltage curves by those obtained by Busquet [9]. An installation was set in order to test the performance of the electrolyser which we have used. The electrolyser has an advanced technology, with 3.6 kW of power and an operating pressure of 4.6 bars.

The following figure (Fig. 3), shows the variation of the voltage versus electrolysis current for different electrolysis temperatures.

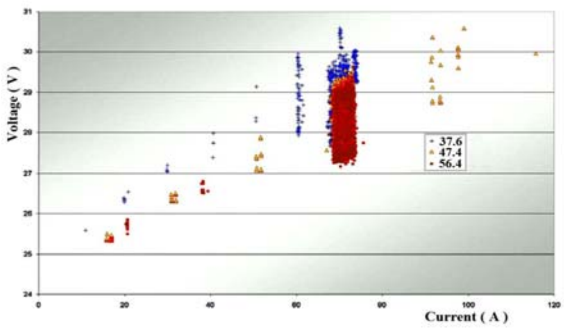

Fig. 3: U-I curves for different values of the electrolysis temperature [9]

We have reproduced the same conditions in our simulations. The following figure gives the curves obtained for the same temperatures.

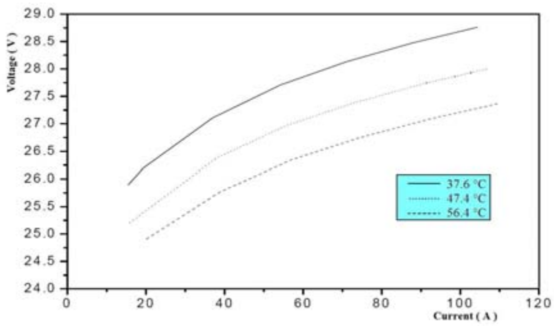

Fig. 4: Simulated U-I curves for different values of the electrolysis temperature

We can notice by comparing the two figures that the results of our simulation are in the ranges of experimental results demonstrating the reliability of the mode.

3. DIMENSIONING AND OPTIMIZATION OF COMPONENTS

A solar hydrogen facility including an electrolyser with a production capacity of 450 l/h was designed and optimized. Its task is to quantify the electricity needs of the facility to let the photovoltaic plant run in optimum condition in the Tamanrasset region. The PV plant includes 22 PV modules with peak power of 22 kW.

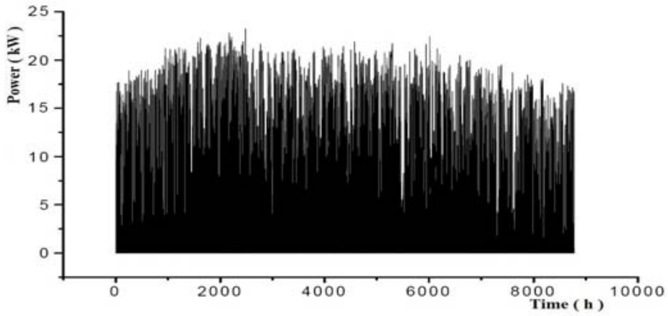

Fig. 5: Power generated by photovoltaic panels during a year (admitted to the electrolyser)

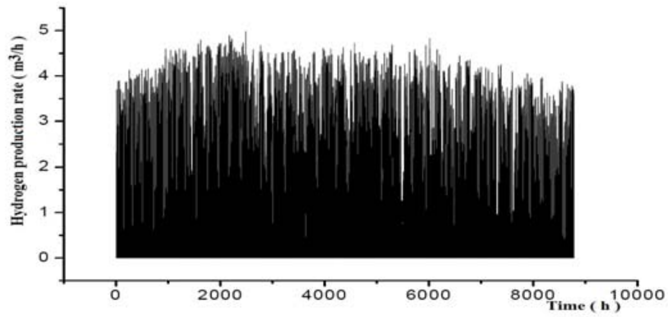

Fig. 6: Rate of hydrogen production during a year

As can be seen in Fig. 5 and Fig. 6 above, the operating duration of installation under normal conditions is 16.26 % of the total operating duration.

The amount of hydrogen produced is 10772.64 m^3 which is equivalent to (1.0782×10^{11} J) with a yield of 5.33 %. Note that the power does not reach the safety value.

The maximum power recorded is 23.4 kW. For the Tamanrasset region, there is relatively little variation in solar radiation and thus the power produced by the solar arrays. Therefore, the hydrogen production is relatively stable during the year.

4. FACILITY STUDY

After the design of our facility, we will now study this system by assessing the influence of variation of operating temperature and pressure of the electrolyser on the facility function.

In our case, the day of 12th April was chosen as a day where the simulations were performed, due to favourable meteorological conditions for proper operation of the photovoltaic generator.

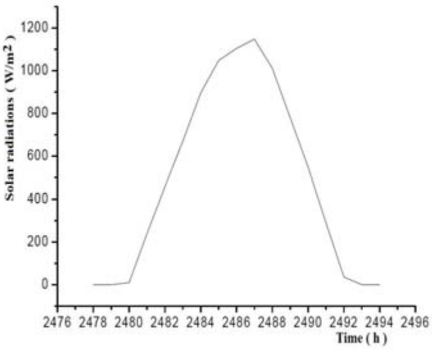

Fig. 7: Solar radiation for 12th April

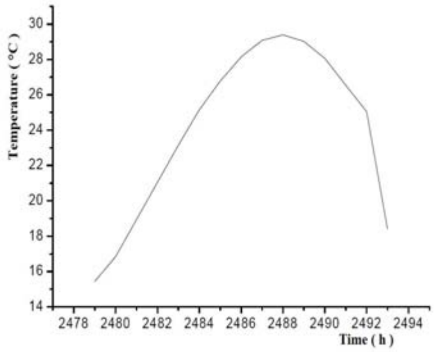

Fig. 8: Temperature during a 12th April

The previous figures (Fig. 7 and Fig. 8) show respectively the evolution of the intensity of solar radiation and temperature during the day. We can see the evolution of temperature during the day; it remains most of the time above 20°C, but it never reach 30°C.

We note that when the intensity reaches 1000 W/m^2 in the morning, the temperature is around 25 °C which corresponds to the ideal operating conditions of the solar array, and then the temperature continue to increase, but without being very important.

Figure 9, shows the evolution of the power produced by the solar array during the day of 12th April. We can see that the power reaches the value of 18 kilowatts at 10:30 AM and the power remains higher for 5 hours with an overload operating for 2 hours.

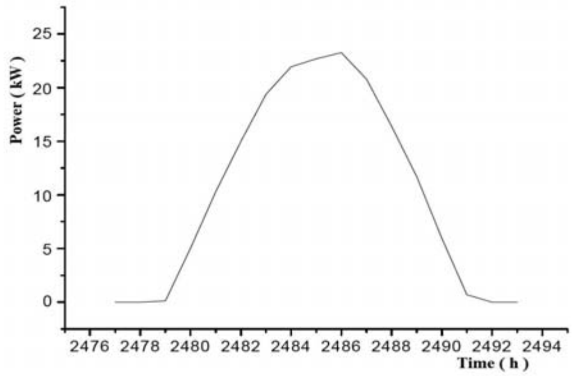

Fig. 9: Power generated by the panels for a 12th April

4.1 Variation of the operating temperature of the electrolyser

We varied the operating temperature from 50 °C to 80 °C, and then calculated the performance of the electrolyser and the production rate.

The following figures (Fig. 10 and Fig. 11) show the variations of performance depending on the electric power supplied to the electrolyser.

We can clearly see in Fig. 10 and Fig. 11, that at the operating pressure of 7 bars, while increasing the operating temperature of the electrolyser, this leads to an increase of performance and then its production rate.

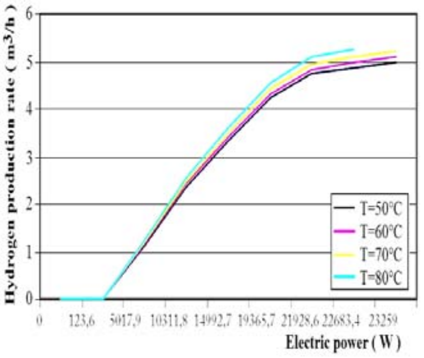

Fig. 10: Rate of hydrogen production based on the electrical power produced by photovoltaic panels

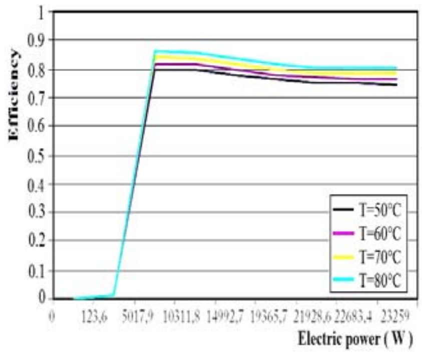

Fig. 11: Total efficiency of the electrolyser according to the electrical power produced byPV at (T_{def} , p =7)

This allows us to say that the increase in efficiency is due to the fact that temperature promotes dissociation of water on the one hand; on the other hand, the increase in operating temperature also means that we remove less heat from the electrolyser and then is recovered.

4.2 Variation of operating pressure of the electrolyser

As for the temperature, we vary the operating pressure of the electrolyser from the atmospheric pressure at a pressure of 25 bars and this for different temperatures. We have seen that the temperature increase had a positive repercussions on the operation of the electrolyser, in the following we will see the effect of pressure on it, and if the effect of temperature will change or not with pressure.

For this purpose, we have considered seven points of pressure (p = 1 bar, p = 5 bars, p = 7 bars, p = 9 bars, p = 15 bars, p = 20 bars, p = 25 bars).

4.2.1 (at T = 50 °C)

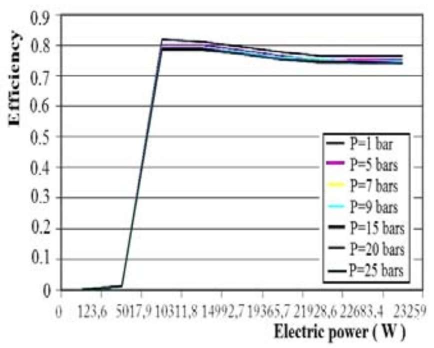

Fig. 12: Total efficiency of the electrolyser according to the electrical power produced by PV panels for T=50°C

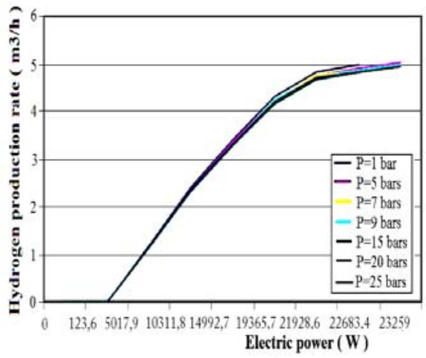

Fig. 13: Rate of hydrogen production based on the electrical power produced by photovoltaic panels for T = 50°C

We note that the graphs in Fig. 12 have the same shape. Efficiencies increased slightly between 0 and 5 kW and more rapidly between 5 kW and 10 kW peak at around 10 kilowatts, and finally decreases very little between 10 kilowatts and 23 kilowatts.

We also note that the graphs are superimposed for very small values of power, and they differ slightly with an increase of power to 10 kW, finally the gap between them decreases very little between 10 and 23 kW.

Note that the increase in pressure decreases the efficiencies.

In terms of production rate (Fig. 13), the same remarks are made, superposition of graphs for very small values of the power and then slight deviation with the increase in power up to 23 kilowatts.

Note that the increase in pressure decreases the production rate as shown in the previous figure (Fig. 13).

4.2.2 (at T = 60 °C and at T = 80 °C)

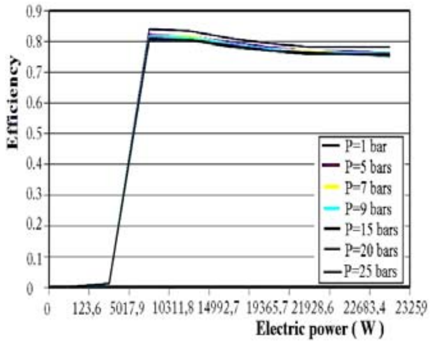

Fig. 14: Total efficiency of the electrolyser according to the electrical power produced by photovoltaic panels for T = 60 °C

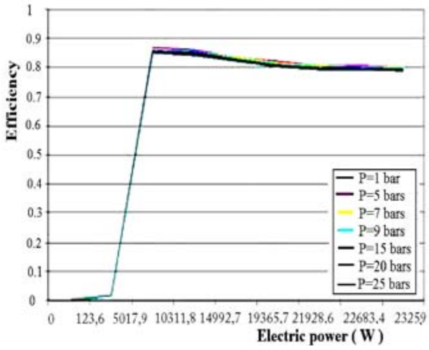

Fig. 15: Total efficiency of the electrolyser according to the electrical power produced by photovoltaic panels for T = 80 °C

For T = 60 °C (Fig. 14), we note the same behavior as for the temperature T = 50 °C and the pressure has the same effect on performance. The difference is that in this case the efficiencies are higher than for T = 50 °C this is due to the effect of temperature.

As for other cases (T = 50 °C and T = 60 °C) the graphs have the same shape (Fig. 15), but the gap between the graphs decrease and the efficiencies are higher which can be explained by the increase in temperature.

As we have seen in the preceding paragraphs, an increase of pressure results in a slight reduction in efficiency and hydrogen production. We have obtained the same results for other temperatures.

5. CONCLUSIONS

In conclusion, we can say that our results are consistent with the theoretical expectation, because as we have seen, the increase in temperature favors the dissociation of water and thus increases the performance of our electrolyzer, while the increase in pressure results in a decrease in performance.

The interest of increasing pressure is that the gases (Oxygen and Hydrogen) are already at the desired pressure at the exit of the elctrolyzer and does not require an installation for compression. Increasing the operating temperature will allow us to reduce the size of auxiliary cooling equipment.

The results obtained by the simulations in the region chosen for the design of the facility provide information on the potential of production and its specifics.

OUTLOOK

The current work has focused on designing a solar hydrogen plant, but since the primary source of energy, on which the system depends, is intermittent and has a different availability from one region to another, we must therefore assess the potential of hydrogen production for different regions and seasons, in order to improve the system operating.

Finally, to better assess the influence of pressure and the interest to increase the pressure electrolysis, it would be interesting to do a comprehensive study that includes the storage of hydrogen produced.

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