ESTIMATION OF HYDROGEN PRODUCTION FROM WIND POWER IN THE SOUTH OF ALGERIA

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The current work gives an estimation of hydrogen production from wind power. Two aspects of the system are considered. Estimation of the wind power produced by three types of wind turbines generators and the energy required for the electrolysis process.
Wind data at seven sites of the south of Algeria were used. The hydrogen production at various sites has been found to vary according to the wind speed and the wind speed frequency distribution. However, for the same speed at different sites we obtained different values. For an average speed of 7.5 m/s at 30 m height, we obtained 3900 Nm^3 for the 10 kW wind turbine, 25350 Nm^3 for 50 kW and 99150 Nm^3 for 250 kW.

Keywords and codes: hydrogen production, electrolysis, wind power, wind turbine

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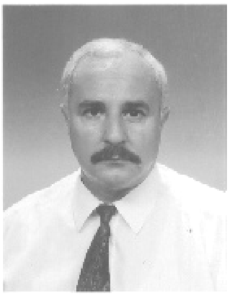
Evolution mensuelle de la ressource éolienne à travers l'Algérie, Revue des Energies Renouvelables, No. Special (ICPWE 2003). P.147-152. 2003.
Cartographie des ressources éoliennes de l'Algérie, Bulletin des Sciences géographique. 2003. No. 11. P. 23-28.



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Introduction

Nowadays, wind energy is one of the most economical energy sources with a well-known technology. Nevertheless, the instability caused by the wind turbines to the grid and the intermittence of the wind source, make necessary to develop efficient energy storage system [1].
Hydrogen as an energy vector, together with electrolyser and fuel cell technologies can provide a technical solution to this challenge. Such a system has been developed throughout the world [2-6].
Additionally, the use of hydrogen for a clean transportation fuel will increase the need of renewable hydrogen generating [7, 8]. Furthermore, the energy available for hydrogen production is strongly dependent on the wind energy resource [7]. In this context, the proposed study is interested to the hybrid system wind turbine-electrolyser. It assumes that the produced wind energy is delivered directly to the electrolyser for hydrogen production.
Several studies have been done on the wind power potential resources in Algeria [9-12]. As showed in the Fig. 1 [13], the south is the most promising region for wind power applications with mean wind speed range from 4 m/s to 10 m/s. The speed reaches 8 m/s in the region of Adrar.
Therefore, we focused our study on the south of Algeria which is characterized by a big desert, scattered populations and remote communities.
Wind speed data of seven sites situated in the big south of Algeria were used to provide an estimate of annual wind energy available for hydrogen production.
The characteristics of alkaline electrolysers [14] were used to estimate the rate of electrolytic hydrogen annually produced. The energy efficiency has been also considered.

Theoretical analysis

A promising option for hydrogen production from renewable resources is electrolysis [7].
Hydrogen is produced via electrolysis by passing electricity through two electrodes in water. The water molecule is split and produces oxygen at the anode and hydrogen at the cathode.
Electrolysis uses direct current (DC) electricity to split water into its basic elements of hydrogen and oxygen. Since this process uses only water as a source, it can produce up to 99.9995 % pure hydrogen and oxygen [15].
Three types of industrial electrolysis units are being produced today [14]. Two involve an aqueous solution of potassium hydroxide (KOH), which is used because of its high conductivity, and are referred to as alkaline electrolysers. These units can be either unipolar or bipolar. The third type of electrolysis unit is a Solid Polymer Electrolyte (SPE) electrolyser. These systems are also referred to as PEM or Proton Exchange Membrane electrolysers. In this unit the electrolyte is a solid ion conducting membrane as opposed to the aqueous solution in the alkaline electrolysers.

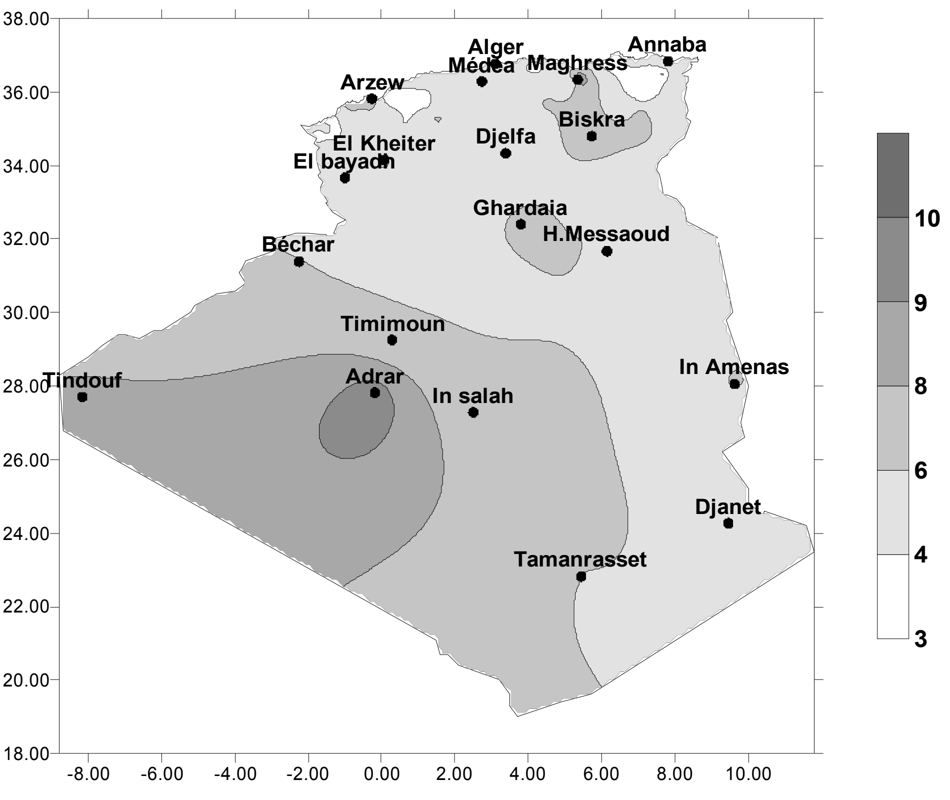

Fig. 1. Wind speed contours at a height of 30 m above ground (m/s) [13]

Regardless of the technology, the overall electrolysis reaction is the same: $H_2O \rightarrow ½\ O_2 + H_2$.
However, reaction at each electrode differs between PEM and alkaline systems.
The electrolysers usually tested for wind electrolyses are the alkaline ones [5, 8, 16], the PEM ones are in the state of development.
Therefore, we selected the alkaline electrolysers. Their electrical consumption is about 5 $kW/Nm^3 \cdot h^{-1}$ of hydrogen produced [5, 8, 16], with an energy efficiency minimal of 75 % [15].
Where, the energy efficiency is defined as the higher heating value (HHV) of hydrogen divided by the energy consumed by the electrolysis system per kilogram of hydrogen produced [15].
A schematic of the complete hybrid renewable energy system developed at the Hydrogen Research Institute (HRI) is presented in Fig. 2. It consists of a wind turbine (WT), coupled with an electrolyser powered by the excess electrical energy produced from the wind energy source. The electrolyser converts the electrical energy into hydrogen, which is stored in the form of compressed hydrogen. When the energy produced from the WT source is not enough, the stored hydrogen is converted back to electricity via a fuel cell generator [2].
In our study, we considered that the whole of the electrical energy produced from the wind turbine is fed to the electrolyser to produce hydrogen. The hybrid system is then reduced to the wind turbine and the electrolyser.

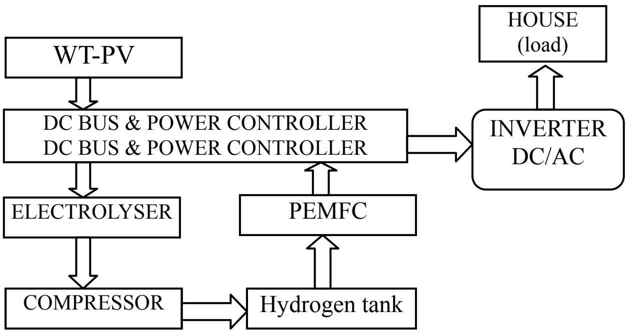

***Fig. 2.** Hybrid wind-hydrogen system diagram [2]*

Three types of wind turbine (WT) sizes were selected: small (10 kW), medium (50 kW) and large (250 kW). Their power curves are represented on the Fig. 3-5.
The WT is characterised by a cut-in speed, a rated speed and a cut-out speed. The power increase from the cut-in speed to the nominal speed at which it is nominal and it cuts at the cut-out speed.
The hub height of tower is 30 m above the ground.
The wind ressources are requiered to estimate the wind power available for the electrical production.

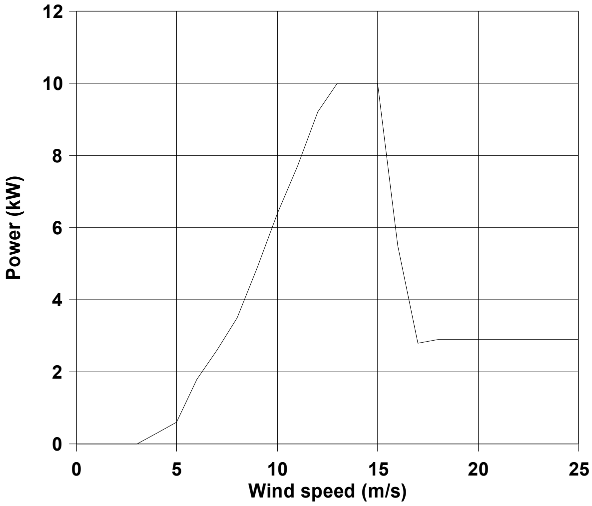

***Fig. 3.** Power curve of Bergey BWC Exe*

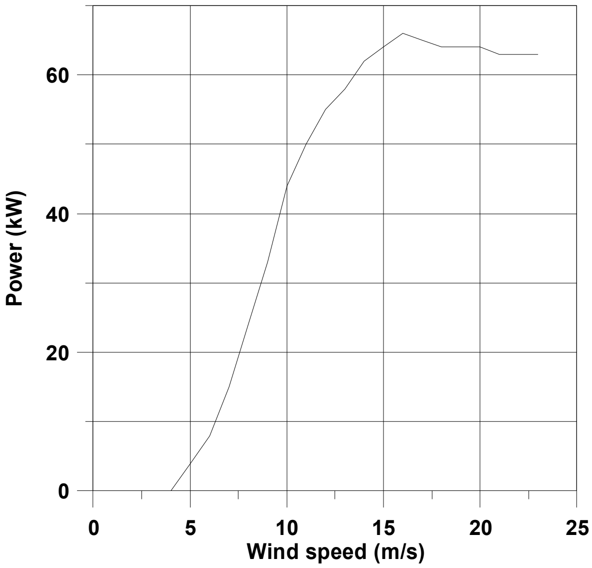

***Fig. 4.** Power curve of Entegrity Wind System AOC 15/50*

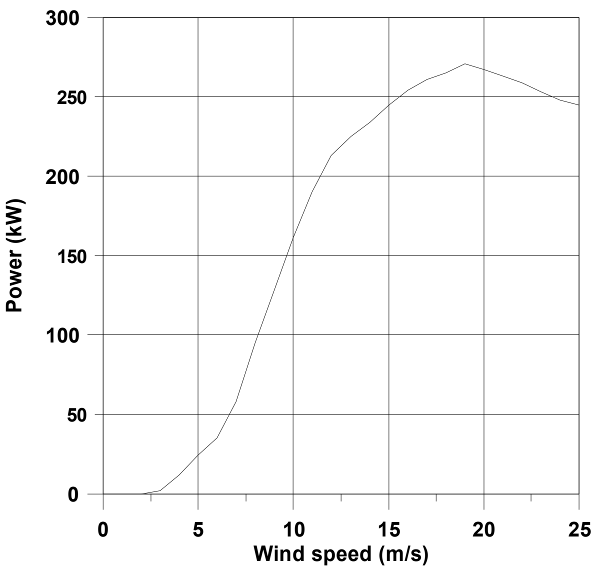

***Fig. 5.** Power curve of Nordex N 29*

Indeed, the wind power density is given at standard conditions of 15 °C and 101.3 kPa by the equation [17]

$$\overline{P} = \sum P(V_i) f_i \,, \tag{1}$$

where $P(V_i)$ is the wind turbine power produced at the wind speed V_i, f_i is the wind speed frequency at the wind speed V_i given by the Weibull distribution.

The Weibull function is a two parameter function used to estimate wind speed frequency distribution. It is expressed as [17]

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} \exp\left(\left(\frac{-V}{c}\right)^{k}\right), \tag{2}$$

where c is called the scale factor (m/s) and k is the shape factor (dimensionless).

The wind speed and the Weibull shape factor are adjusted vertically according to the power law model [18]

$$\frac{V_2}{V_1} = \left(\frac{Z_2}{Z_1}\right)^{\alpha} \tag{3}$$

$$a = a + b \ln V_1 \tag{4}$$

where V_1 is the observed wind speed at height Z_1 and V_2 is the calculated wind speed at height Z_2, α is the power law coefficient, it depends on the wind speed measurement.

$$\frac{k_2}{k_1} = \frac{1 - 0.088 \ln \dfrac{Z_1}{10}}{1 - 0.088 \ln \dfrac{Z_2}{10}} \,, \tag{5}$$

where k_1 is the Weibull shape factor at height Z_1 and k_2 is the Weibull shape factor at height Z_2.

Results and discussion

In order to estimate the wind power delivered to the electrolyser, the retscreen model for wind energy project [20] was used. The model calculates the annual wind energy delivered according the equation (1). The model considers the temperature and pressure adjustment coefficients and losses coefficient.

The wind speed and the weibull wind distribution estimated at 10 m [19] were adjusted according the equations (3), (4) and (5) at 30 m height for seven sites of the south of Algeria. The values obtained are given on the Table 1.

The power curves of the three wind turbines presented in Fig. 3, 4 and 5 and the annual mean wind speed and the weibull shape factor given in the Table 1 were used to simulate the wind power produced annually. The hydrogen production rate is 1 $Nm^3 \cdot h^{-1}$ at 5 kW input with an energy efficiency of 75 %.

The results obtained are plotted in the Fig. 6, 7 and 8 for the three WTs. It appears clearly that the hydrogen production depends on the wind speed and the size of the WT. A look at the Fig. 6, 7, 8 reveals that the highest production is observed for the highest windy site Adrar. The lowest value of 1800 Nm^3 is observed for Hassi-Messaoud. In Salah and Béchar for the 10 kW WT. While, the Figs 7, 8 shows that the lowest production is observed only for Hassi-Messaoud.

Table 1

Mean wind speed and shape factor at 30 m above the ground

Site	*V*(m/s)	*k* (m/s)
Adrar	7,5	2,4
Béchar	4,9	1,5
Hassi-Messaoud	4,9	1,7
In Amenas	5,6	2,1
In Salah	5	1,8
Timimoun	6,6	2,1
Tindouf	5,6	2,2

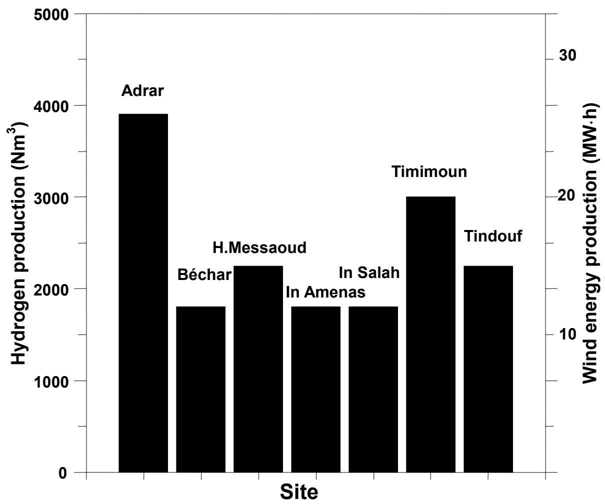

Fig. 6. *Hydrogen and wind power production by the 10 kW WT*

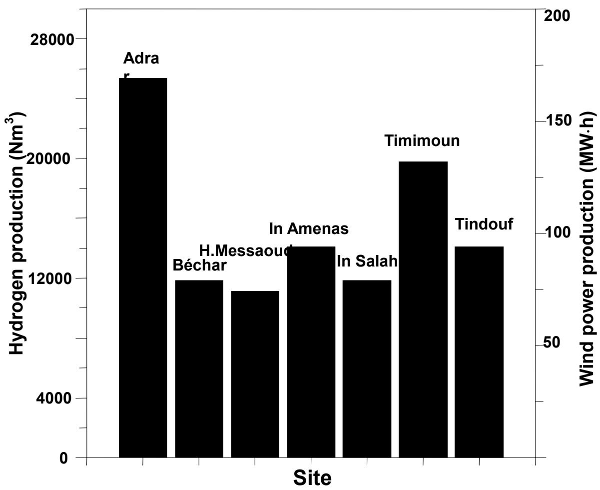

Fig. 7. *Hydrogen and wind power production by the 50 kW WT*

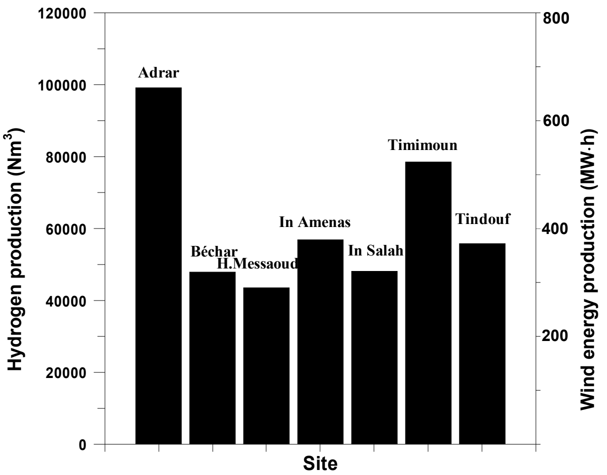

Fig.8. *Hydrogen and wind power production by the 250 kW WT*

These results indicate that for the same wind speed we obtain different values of hydrogen rate when we increase the WT size. Obviously, this means that the Weibull wind speed distribution can make the difference. On another hand, we noticed that the increase rate of hydrogen production for the three sizes of WT is approximately equal to the increase of the WT nominal power.

Conclusion

To evaluate the potential viability of electrolytic hydrogen wind production systems, it is important to make an accurate wind energy resource assessment.

This study gives a simplified methodology to evaluate the hydrogen production from the wind profile available and the wind power curve of a wind turbine.

The results indicate that the hydrogen production strongly depends on the wind speed and its frequency distribution.

Furthermore, in order to increase the efficiency of the hybrid wind-electrolyser system, it is primordial to choose the right wind turbine size for the best windy site.

References

1. Agbossou K., Kolhe M.L., Hamelin J., Bose T.K. Performance of a stand-alone renewable energy system based on energy storage as hydrogen // IEEE Transaction on energy conversion. 2004. Vol. 19, No 3. P. 633-640.
2. Agbossou K., Chahine R., Hamelin J., Laurencelle F. et al. Renewable energy systems based on hydrogen for remote application // Elsevier Journal of Power Sources. 2001. Vol. 96. P. 168-172.
3. Levene J.I., Kroposki B., Sverdrup G. Wind energy and production of hydrogen and electricity-opportunities for renewable hydrogen // National Renewable Energy Laboratory NREL Report. 2006. No. CP-560-39534. Golden. Colorado. USA.
4. Ntziachristos L., Kouridis C., Samaras Z., Pattas K. A wind-power fuel-cell hybrid system study on the non-interconnected Aegean islands grid // Renewable Energy. 2005. Vol. 30. P. 1471-1487.
5. Parrado C., Sopena D., Melgar A. et al. A 5 kW electrolyser/fuel cell system with hydrogen accumulation combined with a wind generator coupled to the electric grid // CD proceeding World Hydrogen Energy Congress WHEC16. 2006. Lyon. France.
6. Khan M.J., Iqbal M.T. Dynamic modeling and simulation of a small wind–fuel cell hybrid energy system // Renewable Energy. 2005. Vol. 30. P. 421-439.
7. Levene J.I., Mann M.K., Margolis R. et al. An analysis of hydrogen production from renewable electricity sources // National Renewable Energy Laboratory NREL Report. 2005. No. CP-560-37612. Golden. Colorado. USA.
8. Tafticht T., Agbossou K. Hydrogen production from optimal wind-PV energies systems // CD proceeding World Hydrogen Energy Congress WHEC16. 2006. Lyon. France.
9. Aîche-Hamane L. Contribution à l'élaboration de la carte du gisement énergétique éolien de l'Algérie // Mémoire de magister. 2003. Institut de mécanique, Université Saad Dahleb de Blida. Blida. Algérie.
10. Hamane L., Khellaf A. Cartographie des ressources éoliennes de l'Algérie // Bulletin des Sciences géographique. 2003. No.11. P. 23-28. Alger. Algérie.
11. Aîche-Hamane L., Khellaf A. Evolution mensuelle de la ressource éolienne à travers l'Algérie // Revue des Energies Renouvelables 2003. No. Spécial (ICPWE 2003). P. 147-152. Tlemcen. Algérie.
12. Hamane L., Khellaf A. Wind energy resources in Algeria // Proceeding World Renewable Energy Congress WREC 2000, 2000. P. 2352-2355. Brighton, UK.
13. Hamane L., Khellaf A. Evaluation des ressources energétiques éoliennes de l'Algérie // Proc. Colloque sur l'Héliotherme, l'Environnement et la Maitrise des Systèmes Solaires CHEMSS 2000, 2000. P. 374-379. Alger. Algérie.
14. Ivy J. Summary of electrolytic hydrogen production // National Renewable Energy Laboratory NREL Report. 2005. No. MP-560-36734. Golden. Colorado. USA.
15. Kroposki B., Levene J., Harrison K. et al. Electrolysis: information and opportunities for electric power utilities // National Renewable Energy Laboratory NREL Report. 2006. No. TP-81/40605. Golden. Colorado. USA.
16. Varkaraki E.A, Lymberopoulos N., Zoulias E. et al. Experiences from the operation of a wind-hydrogen pilot unit //CD proceeding World Hydrogen Energy Congress WHEC16. 2006. Lyon. France.
17. Aîche-Hamane L., Khellaf A., Ait Messaoudene N. Estimation de la puissance annuelle moyenne de sortie d'une éolienne // CD proceeding Séminaire Internationnal sur la Physique Energétique SIPE'5. 2000. Béchar. Algérie.
18. Justus C.G., Mikhail W.R. Height variation of wind speed and wind distributions statistics // Geophysical Research Letters. 1976. Vol. 3, No 5. P. 261-264.
19. Hammouche R. Atlas du Vent de l'Algérie // Office National de la Météorologie. 1991. Alger. Algérie.
20. RETScreen-wind energy project. Available on the site: www.retscreen.net