Analysis of a wind-hydrogen system connected to the electrical grid

José Luis Bernal-Agustín[1], Rodolfo Dufo-López[1], Luis Correas-Usón[2], Ismael Aso-Aguarta[2]

[1] Electrical Engineering Department., University of Zaragoza, Zaragoza (Spain).
Tel: +34976761921, Fax: +34976762226 jlbernal@unizar.es , rdufo@unizar.es
[2] Foundation for the development of new hydrogen technologies in Aragon, Huesca (Spain).
Tel: +34974215258, lcorreas@hidrogenoaragon.es , iaso@hidrogenoaragon.es

1 Introduction

This paper presents a technical and economical analysis of a Wind-Hydrogen system connected to the electrical grid (Fig. 1) located near Zaragoza (Spain).

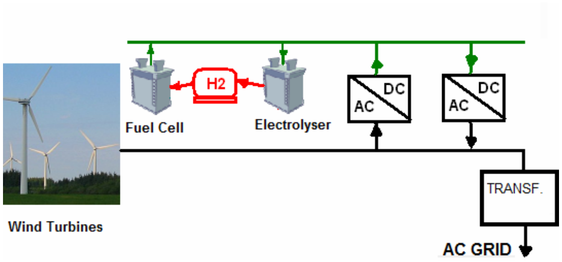

Fig. 1. Wind-Hydrogen system

The electrical energy generated by the wind turbines is used to generate hydrogen in the electrolyser during the hours of day in which the sale price is low (at night and some hours in the evening, off-peak hours), whereas in the rest of hours, in which the price of energy and electrical demand are high (peak hours), electrical energy is sold to the grid, including the electrical energy generated by the fuel cell using the hydrogen previously generated by the electrolyser.

This paper is based on previous works [1, 2]. The simulations and economic calculations have been carried out using GRHYSO software [3].

2 Methods

The Wind-Hydrogen system consists of three 225 kW wind turbines, a 500 kW electrolyser, a 60 kg hydrogen tank and a 250 kW fuel cell. The system will be studied using an hourly time step (Δt = 1h), during one year. Every hour the following input data must be estimated:

- The wind speed hourly data, given by the average hourly values for the last few years. Average wind speed is 5.6 m/s.
- The electricity price hourly data. 2007 Spanish electricity market price data have been used (Fig. 2). In Fig. 3 the annual average market price and the market price for a concrete day (for example, January 3rd) are shown.

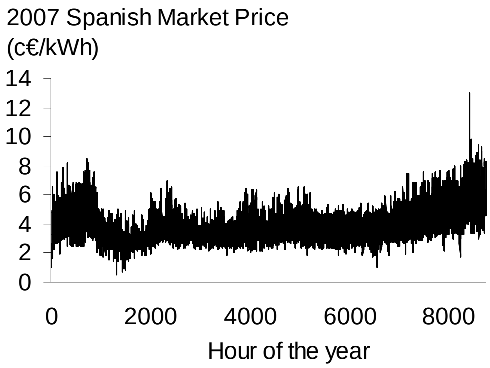

Fig. 2. 2007 Spanish Market price

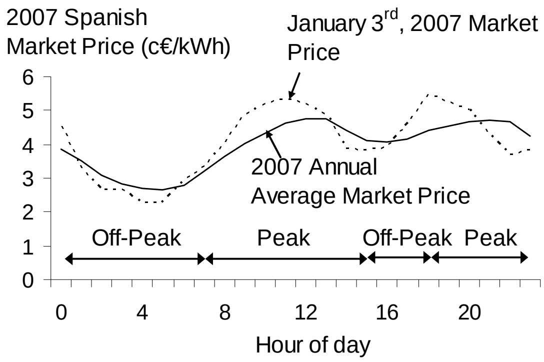

Fig. 3. 2007 Average Spanish Market price and price of January 3rd.

The electrical energy produced by the wind turbines will be used to generate hydrogen in the electrolyser if the hour of the day is between 0 and 6 a.m. or between 15 and 17 p.m. (off-peak hours), otherwise it will be sold to the electrical grid, added to the electricity produced by the fuel cell.

The economical analysis is done throughout the life of the system (20 years). Net Present Value (*NPV*) of the system is calculated, which includes the discounted present values of the incomes of electricity sales and the costs of the initial investment plus the discounted present values of all future costs throughout the total life of the installation.

2.1. Economical data.

The nominal interest rate contemplated is 5% annually. The annual general inflation rate contemplated is 3%. The period of study contemplated is 20 years, the same as the estimated duration of the wind turbines. The initial fixed costs for the installation, engineering, etc. are 2% of the initial investment. The efficiency of the transformer and transmission lines to connect it to the electrical grid is 96%. The price of the m^2 of land is 2 €/ m^2.

It has been assumed that the electricity generated by the wind turbines is sold in the electricity market. For this it is necessary to assign hourly prices. Those corresponding to 2007 in Spain have been used (Fig. 2). An additional amount should be added to the selling price of each of the electricity hours for the sale of electricity from the wind turbines (bonus): 3.0272 c€/kWh, with a higher limit of 8.779 and a lower of 7.3663 c€/kWh. The final objective of this additional amount that increases the price of the energy that is sold, and that has been generated by wind turbines, is to economically encourage this type of installation, and is defined by current legislation [4, 5].

The inflation of the selling price of the electricity contemplated is 3% a year.

The electric generation by fuel cells in Spain can be sold at a fixed price of 12.1533 c€/kWh [4, 5], or it can be sold in the electricity market. In the case of the fuel cells, there is no additional amount (bonus) that increases the hourly price of the electric market. It is economically more profitable to sell the energy at a fixed price and not to go the electricity market.

2.2. System components.

2.2.1. Wind Turbines.

There are 3 wind turbines of 225 kW. The hub height is 55 m. The type of ground roughness considered is class 1 (0.03 m roughness length). The estimated acquisition cost is 245 k€ each and the annual O&M costs are 2% of the acquisition costs. The lifespan is 20 years. The surface of land used is 260 m^2/kW.

2.2.2. Electrolyser.

There is a 500 kW electrolyser. The minimum input power is 10% of the nominal power and the lifespan is 10 years. The efficiency contemplated is 70 % of Higher Heating Value of Hydrogen, including the losses in the auxiliary compression elements.

The acquisition cost of the alkaline electrolyser, including the compression equipment, is approximately 1 M€.

The annual costs of operation, maintenance and insurance can be considered to be 4% of the acquisition costs [6, 7]. A lifespan of 10 years has been contemplated [6]. The consumption of distilled water is 11 liters per each kg of H_2 generated. The estimated cost for the distilled water is of 1 €/m^3.

2.2.3. Fuel Cell.

There is a 250 kW fuel cell. The acquisition and O&M costs of the fuel cell depend on the technology, on the manufacturer and on the operating conditions. The purchase costs considered here are 375 k€, and those of O&M (including scheduled maintenance, plus fuel cell stack refurbishment) are 2.5 €/h. The lifespan considered is 30,000 h.

The minimum input power is 10% of the nominal power. The maximum efficiency is 43% of the Lower Heating Value of hydrogen at 20% of rated power.

2.2.4. Hydrogen storage tank.

There is a 60 kg hydrogen tank. A cost of 30 k€ has been contemplated. The costs of operation and maintenance are considered to be included in those of the electrolyser. The lifespan considered is 20 years.

In order to calculate the electrolyser and fuel cell replacement costs, the annual inflation rate contemplated for electrolyser and fuel cell costs is -20% (prices will decrease at 20% annual) and the limit expected of the maximum variation of the hydrogen components costs is -80%, this limit will be achieved in 7.2 years; after then, the hydrogen components will be assumed to see their prices increased in line with general inflation.

2.2.5. Inverter.
An inverter of the same power as the fuel cell (250 kW) has been contemplated. The cost for the inverter is 37 k€. The lifespan is 10 years and the efficiency depends on the output power. The O&M cost is included in that of the fuel cell.

2.2.6. Rectifier.
The system rectifier has the same power as the electrolyser (500 kW). The cost of the rectifier is 60 k€, the lifetime is 10 years and the efficiency is 90%. The O&M cost is included in that of the wind turbines.

3 Results

The investment cost of the Wind-Hydrogen system is 2.679 M€ with an initial rate of return of 2.45%. The NPV is -2.040 M€, i.e., the Wind-Hydrogen is not profitable (*NPV*<0).

Comparing with the Wind-Only system (without hydrogen components), where all the energy generated by the wind turbines is sold to the grid, this Wind-Only system has an investment cost of 1.108 M€ with an initial rate of return of 12.91% and the *NPV* is 1.3 M€, i.e., profitable system.

Sensitivity analysis of wind speed and acquisition and O&M costs of hydrogen components have been done (Table 1).

Wind-Hydrogen system is economically acceptable (*NPV*>0) only in some cases of the sensitivity analysis, considering high average wind speed and hydrogen components costs much lower than present ones (10%). However, the *NPV* of the Wind-Only system is much higher (Table 2).

Table 1. *NPV* of the Wind-Hydrogen system (M€). Sensitivity analysis.

	Hydrogen components Costs and of Section 2.2	Hydrogen components Costs 50% of Section 2.2	Hydrogen components Costs 10% of Section 2.2
Average wind speed 5.6 m/s	-2.040	-0.82	**0.155**
Average wind speed 4.7 m/s (-20%)	-2.521	-1.305	-0.332
Average wind speed 6.7 m/s (+20%)	-1.638	-0.416	**0.561**

Table 2. NPV of the Wind-Only system (M€). Wind speed sensitivity analysis.

	NPV (M€)
Average wind speed 5.6 m/s	**1.3**
Average wind speed 4.7 m/s (-20%)	**0.684**
Average wind speed 6.7 m/s (+20%)	**1.815**

In the cases of 5.6 m/s average wind speed, the electricity generated by the wind turbines in the year is 2.16 GWh. In the Wind-Only system, the electricity sold to the grid is 2.07 GWh/year.

However, in the Wind-Hydrogen system, the total annual electrical energy sold to the grid is 1.562 GWh. The electricity sold from wind turbines is 1.48 GWh (95% of total sold) and the electricity from fuel cell is 0.082 GWh (5% of total sold).

The total energy sold to the grid by the Wind-Hydrogen system is only the 72% of the electricity sold by the Wind-Only system, due to the losses in the electricity-hydrogen-electricity conversion process.

In the Wind-Hydrogen system, during peak periods the energy sold to the grid is higher than in the case of Wind-Only systems (5% higher, electrical energy generated by the fuel cell). However, during off-peak periods, the energy sold by the Wind-Hydrogen system is about 30% lower than energy sold by the Wind-Only system.

4 Conclusions

A Wind-hydrogen system economically competitive implies costs of electrolysers and fuel cells much lower than present ones and higher government subsidies to the electricity sold to the grid.

We can conclude that the Wind-Hydrogen systems are technically suitable for generation management, although they have high energy losses.

In order to stimulate the possible installation of these systems, in order to manage the generation and also promote the use of renewable energy sources, a much higher selling price of the electricity generated by the fuel cell than that currently set by [1, 2] is necessary.

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