An Economic Analysis of Hydrogen Production Using Wind Power

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Abstract-In this study, an economic analysis of wind - hydrogen systems has been carried out. The annual energy output of a private sector wind power facility in Izmir Cesme is used as referenced. According to the annual electrical energy curves of the plant, potential hydrogen amount and electrical energy values are calculated. The hydrogen power plant has been calculated to operate at approximately 30% load factor and the hydrogen cost is found to be 0,033 \$/MJ. According to the change of the load factor, the potential electricity costs are calculated and presented in diagrams. Unit hydrogen cost at a load factor of 0,20 is 0,048 \$/MJ and falls to 0,015 \$/MJ at a load factor of 0,80. The effects increasing power and increasing load factor on the hydrogen unit cost are explained through diagrams and the results are discussed.

Keywords: Wind energy ; Hydrogen energy; Economic analysis

1. Introduction

Studies on wind-hydrogen systems are increasing every day. Sherif et al. have expressed that the wind-hydrogen systems can be developed parallel to the wind power plants and that utilizing these environmental-friendly systems individually or interconnected to a network can be highly effective [1]. Ozdamar et al. have measured the wind power potential of Izmir Cesme and have pointed out that this can be much more economical as the wind technologies advance [2]. Granovskii M. Et al., have studied the emissions of the Wind power plants and have concluded that the emission values for the same power levels are reduced in great rates compared to those of the natural gas fueled thermal power plants [3]. Studies for the purpose of finding the ideal power source have created some criteria. These are; not being harmful to the environment, being able to be used efficiently in applied science fields, being easily obtained in nature, being easily implemented using simple and low-cost systems [4].

2. Introduction of the System

Electrolysis process requires electrical energy to operate. In this study the aim is to use the electrical energy obtained from the wind power plant to produce Hydrogen in gas form by means of electrolysis. Wind turbines are generally used to meet the electricity demand of their local area and sometimes connected to the energy network. System consists of the wind turbine, buildings and the electrical hardware machines as shown in figure 1 [5].

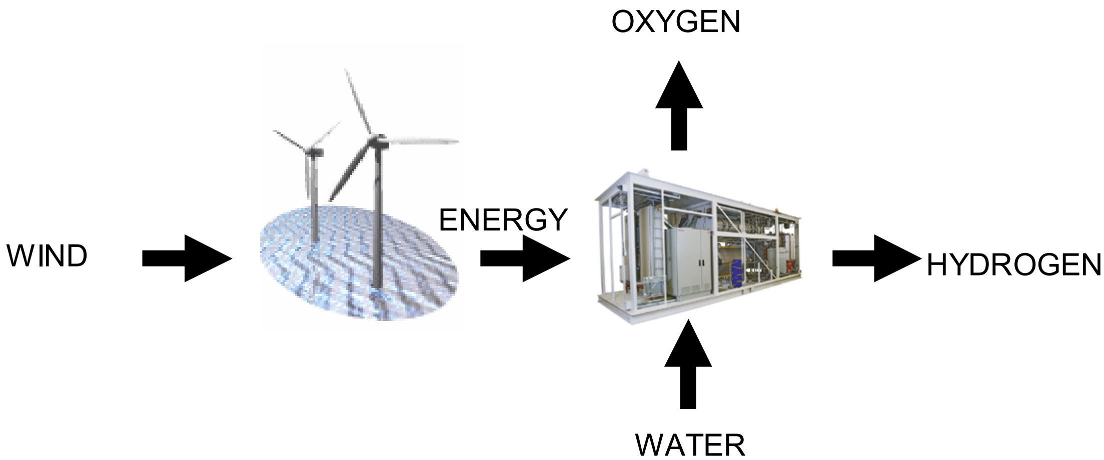

Fig. 1. System Model

3. Description of the region

All the data is gathered from the wind power plant located at Izmir Cesme Germiyanli village, which is marked on the map illustrated in figure 2.

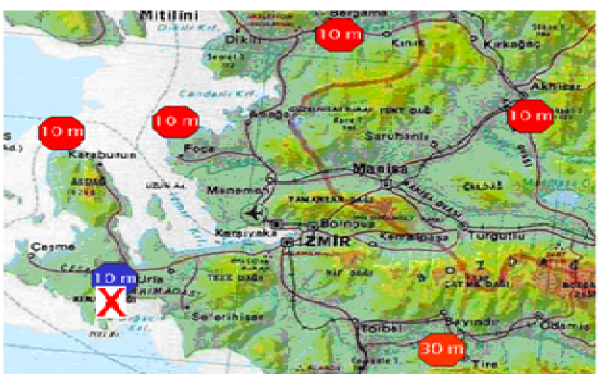

Fig. 2. System location [7]

When the wind data on Table 1 is determined, the average wind speed is calculated higher value than Turkey average. Therefore, this region is among the most suitable one for wind power plants in Turkey [6].

There are three wind turbines of 500 kW which belong to Demirer AS located in Germiyanli Village. This wind power plant is one of the first in Turkey. Specifications of the turbines of this plant are given in Table 1. All three turbines are identical, products of Enercon and are operational since 1998.

Table 1. Wind Turbine Specifications

Installed capacity	500 kW
Rotor Diameter	48 m
Rotor Height	76 m
Turbine Concept	Variable speed, without transmission
Rotation Direction	Clockwise
Blade Number	3
Sweep area	1.810 m^2
Blade Material	Fiberglass
Rotor Velocity	40 - 80 m/s
Start-up speed	3 m/s
Average Operation Velocity	13 m/s
Cut Off Velocity	34 m/s

4. System Data

In this study, power and energy data of the Germiyanli Wind power plant of the year 2002 is used. Initial data consist of the annual operation time and the annual power production values of each turbine and these are given in Fig. 3. These values are courtesy of Demirer AS that has installed and is operating the plant. Cost analysis is conducted based on these figures. Annual electric energy productions from these wind turbines are calculated. According to (Fig.4, Fig.5, Fig.6) this calculation, first turbine produces 1.293.960 kWh, second turbine produces 1.305.360 kWh and third turbine produces 1.3297.20 kWh.

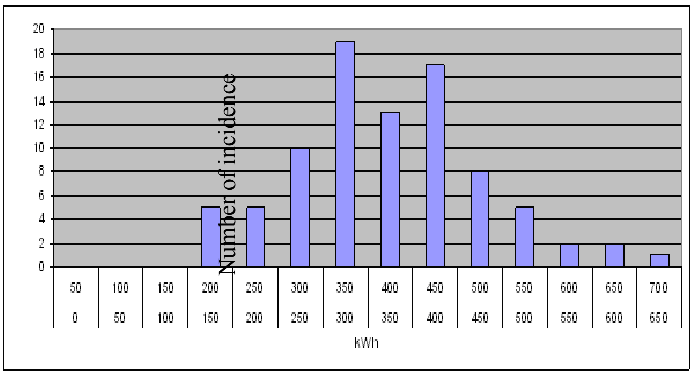

Fig. 3. Distribution of total production of the turbines over the months

Figure 4. ,5. and 6. show three unit turbines of the wind power plant and their operating ranges in 2002. According to the diagrams turbines are operating under 30% network load factor. Fig.3,4,5,6, are given by Demirer A.S. and data gathered from these figures.

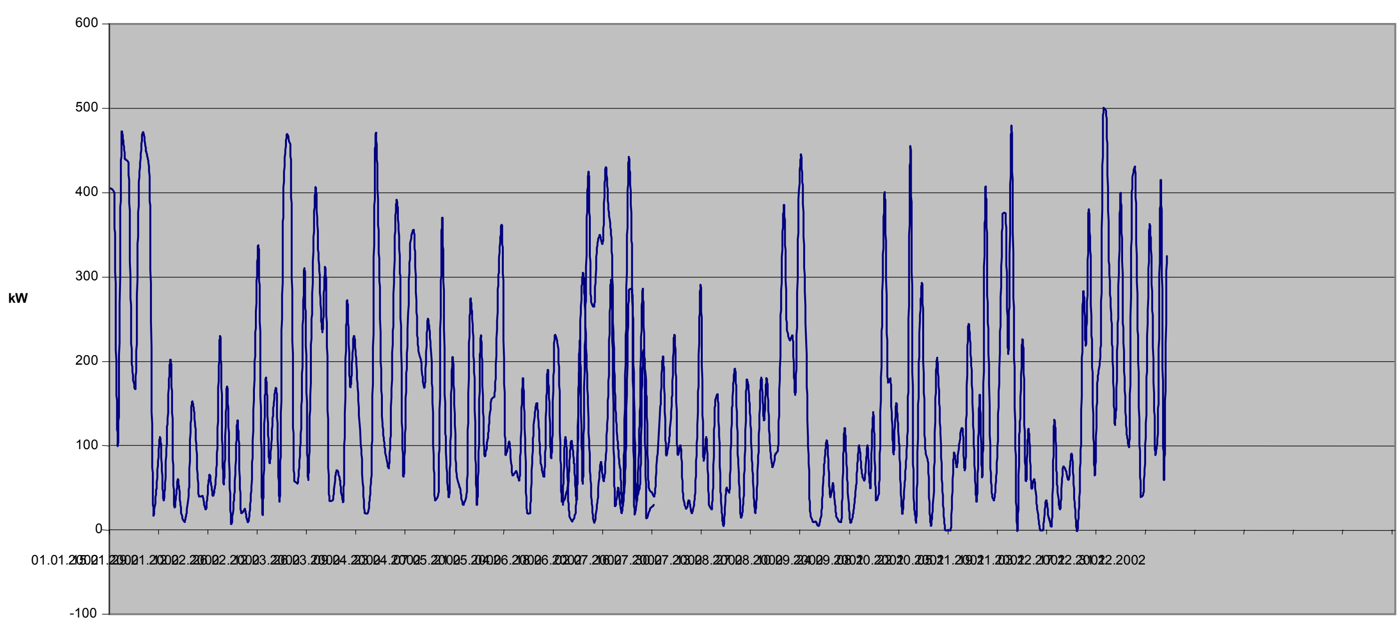

Fig. 4. Annual power production of the first turbine

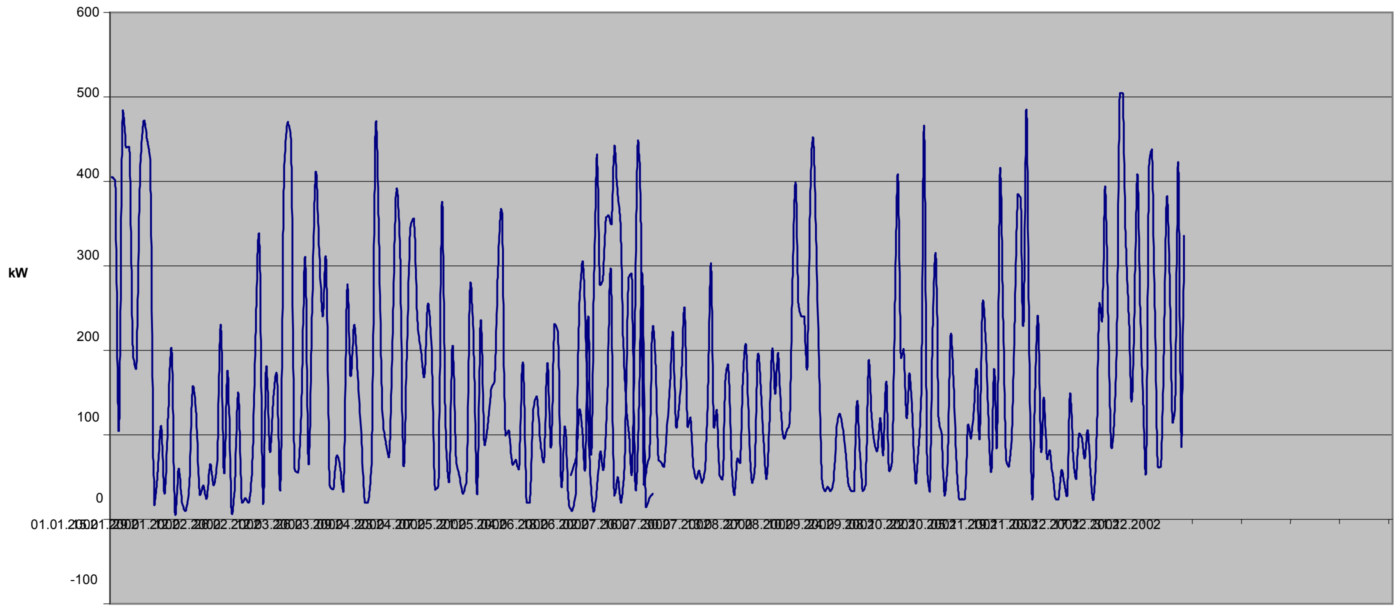

Fig.5. Annual power production of the second turbine

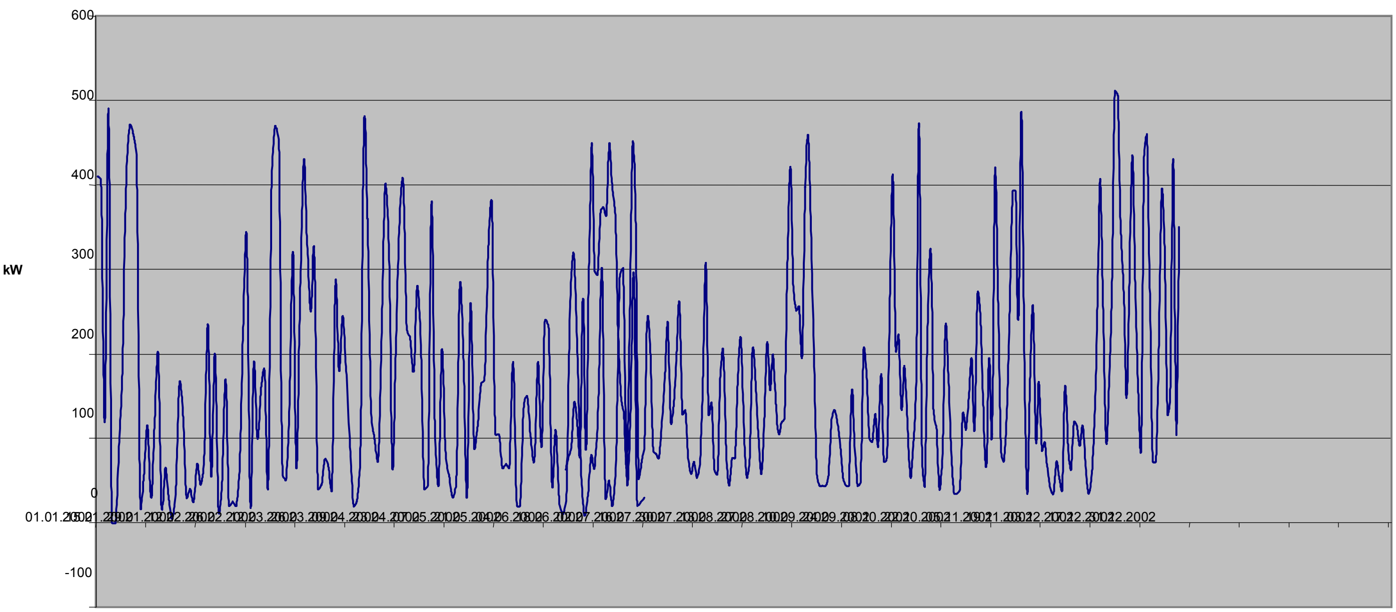

Fig. 6. Annual power production of the third turbine

5. Economic model of the system

In order to calculate the Hydrogen potential of the wind power plant, the following items should be denoted in mathematical terms [8, 9].

- Economical model of the electrical energy unit cost of the wind power plant
- Economical model of the Hydrogen production and unit cost of the electrolysis systems
- Determining the cost economy

5.1. Economic model of electrical energy unit cost of a wind power plant

There are several modes that can be used in energy cost calculations. In this study, calculations are carried out using the constant annual capital cost method [5]. Capital required for the investment is 100% financed by the investment corporations. The amount of the debt has a due date of 25 years for the wind power plants and 20 years for the electrolysis systems. Table 2 shows the assumptions made for the calculations of the wind power energy unit cost. In order to calculate the electrical energy cost of the wind power plant, the value of investment value per unit power should be known. In Fig. 7 unit investment values of the wind power plants installed all over the world between 2000-2005 are marked and the unit plant cost curve is created [10,11,12]. The value of 1.880 $/kW is a product of this curve. Since the power value is low, plant unit cost is high. It is obvious that as technology makes progress, costs will decrease. Therefore the plant unit cost curve is subject to updates.

Calculations of the electrical energy unit cost for the wind power plant with different load factors result the figures given in Fig. 8.

Table 2. Assumptions made for the calculations of the wind power energy and electrolysis system

	Wind power	Electrolysis system
Interest rate (i) (%)	5	5
Plant life span(n) (year)	25 year	20 year
Load factor (L_f) (%)	0,30	0,98
Base power (N_e) (kW)	500 kW	2383 kg/day
Plant unit cost (C_s) ($/kW)	1.880 $/kW (Fig.7.)	3.518.000 $
Escalation rate (e) (%)	6	------------
Construction time(year)	3 years	------------
Wind power spending time	1.year %30, 2.year %50, 3.year %20	
Operation & Maintenance cost/ total installation cost	%2	%5 [13]

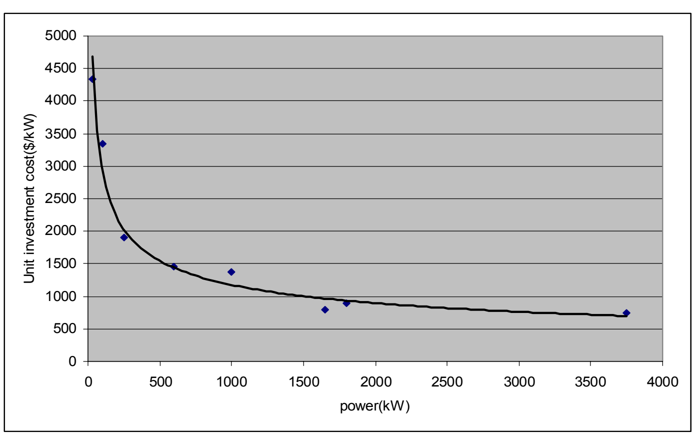

Fig. 7. Plant unit cost diagram [14, 15]

Amortization coefficient;

$$C_{rf}=\frac{i(1+i)^n}{(1+i)^n-1} \tag{1}$$

Electrical energy unit cost for the wind power plant is;

$$g_e=\frac{1.02\sum_{t=1}^{s} C_s N_e\, C_{rf}\, y(t)(1+e)^t[(1+i)^{s-t}]}{E} \quad (\$/kWh)(2)$$

5.2. Economic Model of the Electrolysis Cost

Costs of the electrolysis system are calculated according to the amortization method. Assumptions for the electrolysis system are given in Table 2. Hydrogen unit cost is the sum of three figures;

a. Installation unit cost (Mte) that is the ratio of annual amortization payment to the annual hydrogen production.

b. Operation and maintenance costs can be expressed as an annual operation and maintenance costs (Mie) over the annual hydrogen production.

c. Energy cost, which is annual energy amount multiplied by the energy unit cost. It is assumed that all the energy produced by the wind power plant is used in producing hydrogen.

In order to calculate the total cost of hydrogen, plant cost, operation and maintenance costs and energy costs must be added up.

$$g_{H2}=Mte+Mie+Mel \qquad (\$/kg) \qquad (3)$$

$$g_{H2}=\frac{(1.05C_sC_{rf}+Eg)e_{H2}}{E} \ (\$/kg) \qquad (4)$$

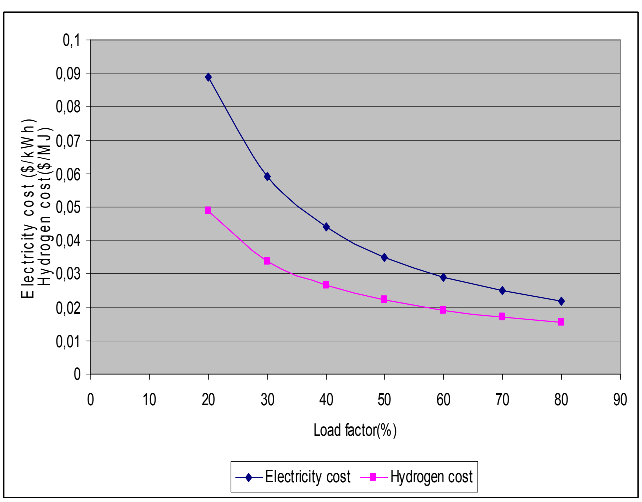

Fig. 8. Hydrogen production costs variation in relation to the net work load factor

Considering the annual energy production of the turbines, total annual hydrogen potential of the wind turbines is calculated. The first wind turbine could produces 21.582 kg hydrogen per year, the second one 21.772 kg hydrogen per year and the third turbine produces 22.178 kg hydrogen per year.

The effect of the load factor on the electrical energy and hydrogen unit costs indicates that as the load factor increases, electrical energy and hydrogen unit costs decrease. Calculations of the hydrogen energy unit cost with different load factors result the figures given in Fig. 8.

6. Conclusions

Annual Hydrogen potentials of the three turbines of 500 kW are 21.582 kg, 21.772,1 kg and 22.178,4 kg respectively. The annual average load factor of the plant is approximately 0, 30. Hydrogen unit cost according to this value is 0,033 $/MJ. Electrical energy costs of the plant are calculated for different load factors and as it can conclude from the diagrams, electrical energy unit cost decreases as the load factor increases. Therefore, Hydrogen unit cost is 0,048 $/MJ under a load factor of 0, 20 and decreases to 0,015 $/MJ under a load factor of 0,80. Consequently, should the wind speeds allow, it is always economically more efficient to operate the turbines under higher load factors. In conclusion, although Hydrogen power is a high-cost resource for the moment, considering the advantages over the other resources, and the effects on the human beings, environment and ecological balance, intensive studies should be carried out for the advancement of the use of Hydrogen in every field of application economically.

Acknowledgements

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Nomenclature

Crf	Amortization coefficient
C_s	Capital cost ($)
e	Annual escalation rate (%)
e_{H2}	Energy needed to produce 1 kg of Hydrogen
E	Annual energy (kWh)
g_e	Energy unit cost ($/kWh)
g_{H2}	Hydrogen unit cost ($/kg)
i	Interest rate (%)
n	Amortization period, day of the year, plant life span
N_e	Plant power (kW)
S	Construction time (year)
t	Time (year)
y(t)	Annual spending rate during the construction period (%)