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ENERGY PRODUCTION FROM RENEWABLE RESOURCES

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Abstract: *This paper meets the needs of the provisions of Directive 2010/31/EU on the energy performance of buildings which sets targets to stimulate the development of energy efficient buildings. The package "Energy - Climate Change", sets for 2020 emissions reduction of greenhouse gases in the EU by at least 20% compared to 1990 and increase to 20% the share of renewable energy in total EU energy consumption.*

This paper presents some tests, on an experimental stand at a small scale, on energy production from renewable resources. The results from experiments can be extended and applied to buildings in order to increase their efficiency, reduce gas emissions and to reach the provisions of Directive 2010/31/EU.

Key words: *solar modules, wind turbine, hydrogen, fuel cells.*

1. Introduction

To improve energy security and reduce emissions of greenhouse gases, the Directive 2010/31/EU supports the inclusion of energy produced from renewable resources in the network.

This is complicated because the main renewable wind and solar power, are by their nature highly variable and have some degree of unpredictability.

Increase the proportion of energy from renewable sources requires a backup from other types of renewable energy for any shortfalls in power supply to consumers [1]. Hydrogen and fuel cells can provide stability and predictability of the electricity network.

Besides the main production of electricity, the system produces heat and hot water that can be recovered, increasing the overall efficiency of the hybrid system.

An autonomous hybrid system is a generator of electricity. It can be composed of at least two different energy sources exploiting either classic or renewable resources.

Currently the most used and least expensive are hybrid systems that combine technologies for producing electricity from wind and solar power, and the issue flicker in supply and the peak demand is solved by using diesel generators due to low costs of acquisition and maintenance.

However, diesel generators operation in terms of environment are not suitable for any location, particularly where quietness and air quality must be maintained between certain values [2].

A solution for zero environmental impact is given by the use of hydrogen produced locally using electrolyzers and then used by fuel cells to generate electricity.

This system, hydrogen - fuel cells,

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without impact on air quality and carbon-free, complements the hybrid systems in order to store energy produced in excess due to a lack of consumer or situations climatological favourable to production of larger quantities of energy from renewable resources such as summer. The disadvantage of this solution is the acquisition and maintenance cost of electrolyzers, containers for storage and fuel cells compared to diesel generator, but because of environmental norms in some locations served by the autonomous hybrid system, these costs are justified [3].

2. Experimental Set-Up

Experimental measurements were carried out in the Reasearch Laboratory of the Buiding Services Faculty of the Technical University from Cluj-Napoca, where exists an experimental stand “Clean Energy Trainer” that contains components for producing energy from solar and wind sources, components for producing and storing hydrogen and a fuel cell stack that has 5 individual cells.

2.1. The energy production system from solar source

The production of electricity from solar source is made up of two solar panels and two lamps for lighting. The goal of the lamps is to simulate sun as procedures are carried out in an enclosed space. Experimental stand "Clean Energy Trainer" is at a small-scale and all its components have reduced dimensions that can introduce errors of up to ±5%. Technical data of a photovoltaic panel are shown in Table 1.

2.2. The energy production system from wind source

The production of electricity from wind source is made up of a horizontal axis wind turbine and an axial fan to simulate wind. Wind energy is converted into electricity using wind turbine.

Table 1

Technical data of a photovoltaic panel

Name	Specification	M.U.
Voltage	2,0	V
Current	0,6	A
Power	1,2	W
Weight	89	g
Length	135	mm
Width	95	mm
Thickness	30	mm
Active area	$4 \times 8*10^{-3}$	m^2

This energy can, as in the case of the system for the production of energy from sun, stored in batteries, inserted within the public network, used by different users, or may be used by electrolysers to produce hydrogen and oxygen [4].

Technical data of the wind turbine are shown in Table 2.

Table 2

Technical data of the wind turbine

Name	Specification	M.U.
Power	1,2	W
Starting voltage	5,4	V
Voltage	3,5	V
Short circuit intensity	0,5	A
The maximum intensity	0,15	A
Rotor blades	6	Pieces

2.3. Production and storage system of hydrogen

The production and storage system of hydrogen is made up of two electrolyzers, four storage containers (two hydrogen and two oxygen) and their connection hoses.

Electrolyzers can receive energy from solar module and/or wind module, or from the network through the data monitor [5].

Hydrogen and oxygen obtained are stored in storage canisters and then used by fuel cells to produce electricity. Table 3 presents the technical data of an electrolyzer.

Table 3

Technical data of an electrolyzer

Name	**Specification**	**M.U.**
Hydrogen production	5	cm^3/min
Oxygen production	2,5	cm^3/min
Power	1,16	W
Maximum voltage allowed	2,0	V
Weight	54	g
Length	50	mm
Width	40	mm
Thickness	57	mm

2.4. Fuel cell stack

Experimental stand "Clean Energy Trainer" has an assembly of fuel cells that consists in five individual fuel cells. With these devices, the internal energy of hydrogen is converted into electricity. Fuel cells are proton exchange membrane what means that are in the category of the fuel cells operating at low temperatures, below 100°C. Technical data of a fuel cell are shown in Table 4.Besides the above components, the “Clean Energy Trainer” stand also comprises a data monitor, a specialized software and measurement and control devices.With the components above were performed different tests in order to reach the largest energy production of a hybrid system.

One of the configuration is presented in Figure 1.

Technical data of a fuel cell Table 4

Name	Specification	M.U.
Fuel cell stack power	1	W
Fuel cell power	0,2	W
Voltage	0,4÷0,96	V
Weight	430	g
Length	60	mm
Width	35	mm
Thickness	70	mm

3. Results and Discussions

The simple and inexpensive solution for exploitation of renewable resources for energy production is the use of photovoltaic panels. In figure 2 are shown the characteristic curves (current – voltage, voltage – power) of energy production variation by a single photovoltaic panel, from the “Clean Energy Trainer” stand.

The solar module has a maximum power (0.12 W) approx. at the values of voltage 0.4 V and current 300 mA (with one 75 W lamp). This can be seen from the current/voltage characteristic curve.

The data obtained are relatively far from manufacturer data where is specified that a single photovoltaic panel can have a power of 1.2 W. Because of this results were performed more test to see if the they improve but without modifying the distance of the PV panel from the lamp. It was performed an optimization of the system by modifying the inclination angle of photovoltaic panel and run the software several times.

Improved results were obtained. The solar modules reached a maximum power (246 mW) approx. at the values of voltage 1.7 V and current 145 mA. Starting from approx. 1.5 V a clear formation of gas can be observed, the voltage where electrolyzer starts to split water [6].

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Fig. 1. *One configuration of the hydrid system*

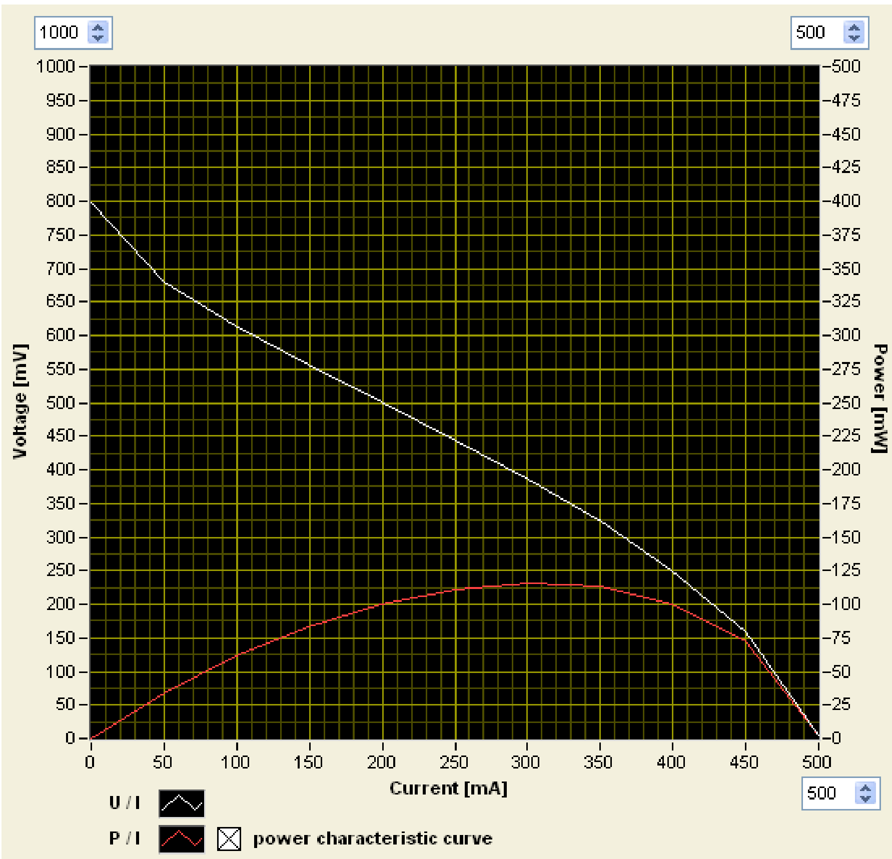

Fig. 2. *The characteristic curves of one PV panel*

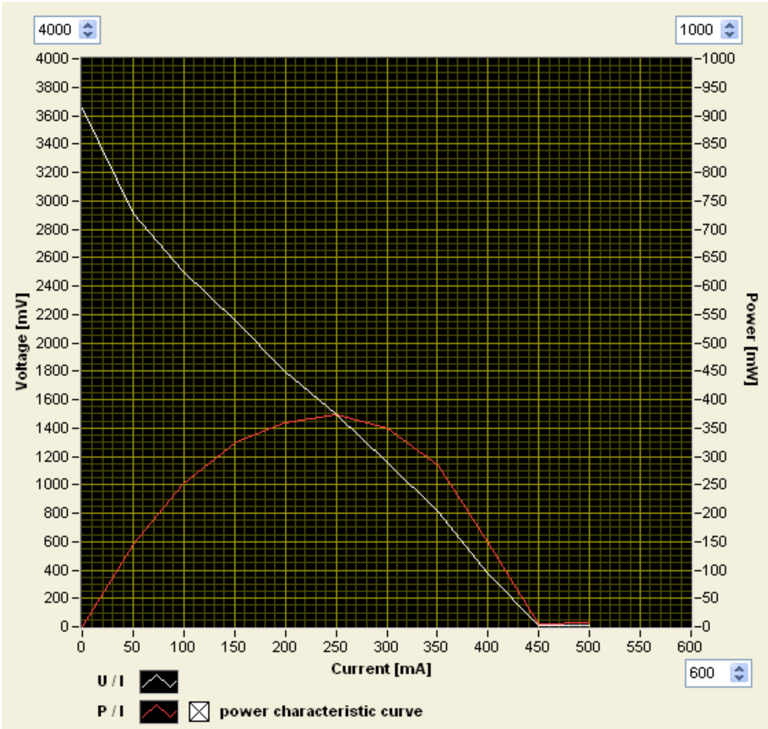

Fig. 3. *The characteristic curves of the wind turbine*

Wind turbines are the next solutions for producing energy from renewable resources in terms of costs. A wind turbine utilizes the energy of air masses and converts it into electrical energy [7].

The angle of inclination of the rotor blades has a significant influence on the power of a wind generator. If the rotor blades are not aligned favorably, the rotor may not rotate. On this small wind generator (from Clean Energy Trainer) it is better to use several rotor blades.

For the production of energy were used on row 4, 5 and 6 blades to observe their influence on the voltage-current and voltage-power characteristic curves. The best results were obtained when using 6 blades, the graph with the variation of the characteristic curves are shown in figure 3.

It was also observed that the wind generator rotates best when the rotor is aligned perpendicularly to the direction of the wind. The wind turbine reached a maximum power (375 mW) approx. at the values of voltage 1.4 V and current 250 mA. As for the solar module, the results obtained are far from manufacturer data, with all optimizations performed in the tests runs.

Because the “Clean Energy Trainer” software has no section designed to connect photovoltaic panels to wind turbine (they can be connected togheter only to consumers) in order to see the variation of the voltage-current and voltage-power characteristic curves, it was passed to the next tests phase, namely hydrogen production by water electrolysis.

Initially, to decompose water into hydrogen and oxygen, electrolyzers were connected to the electricity network [8].

Theoretically, this value lies at 1.23 V, however, the overvoltage with this reaction still has to be taken into consideration.

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Overvoltage results from several material specific factors and can be regarded as a type of activation energy.

In the following tables (5, 6, 7 and 8) are presented the quantities of hydrogen and oxygen generated with the electrolyzers at the voltage of 1.8 V connected to electricity network, solar modules, wind turbine and in the end to the photovoltaic panels and wind turbine togheter.

Electrolyzers connected to the electricity network Table 5

Time [min]	**Current [mA]**	**Hydrogen [cm³]**	**Oxygen [cm³]**
1	0.8	7	3.5
2	0.8	14	7
3	0.8	21	10.5
4	0.8	28	14

Electrolyzers connected to the solar modules Table 6

Time [min]	**Current [mA]**	**Hydrogen [cm³]**	**Oxygen [cm³]**
1	0.8	1.5	0.75
2	0.8	3	1.5
3	0.8	4.5	2.25
4	0.8	6	3

Electrolyzers connected to the wind turbine Table 7

Time [min]	**Current [mA]**	**Hydrogen [cm³]**	**Oxygen [cm³]**
1	0.8	3.5	1.75
2	0.8	7	3.5
3	0.8	10.5	5.25
4	0.8	14	7

From the tables above it can be observed that the fastest hydrogen production was when the electrolyzers were connected to the electricity network.

Electrolyzers connected to the PV panels and wind turbine Table 8

Time [min]	**Current [mA]**	**Hydrogen [cm³]**	**Oxygen [cm³]**
1	0.8	5	2.5
2	0.8	10	5
3	0.8	15	7.5
4	0.8	20	10

Then was when the electrolyzers were connected to both photovoltaic panels and wind turbine. Also, can be noticed that the wind turbine has generated significantly more hydrogen than solar modules. The slowest hydrogen production was when the electrolyzers were connected to the PV panels [9].

With hydrogen produced the fuel cells were connected in order to produce electricity. A fuel cell transforms the internal energy of hydrogen resulting electricity and water.

The tests were performed on one fuel cell because the entire stack consumption is very high and the hydrogen production is slow.

At the beginning of the tests the fuel cell had a very low voltage-power characteristic curve, ie low power (0.1 W). But, after several runs of tests the voltage-power characteristic curve improved so much that was almost reached the value of technical data from the manufacturer regarding the power of one fuel cell (0.19 W). This means that fuel cells have high efficiency in energy production.

The differences between the results from the first and the final test can be observed in the graphs from figure 4 and 5.

4. Conclusions

In this paper were presented some experiments about energy production from renewable resources, hydrogen generation and fuel cell operation.

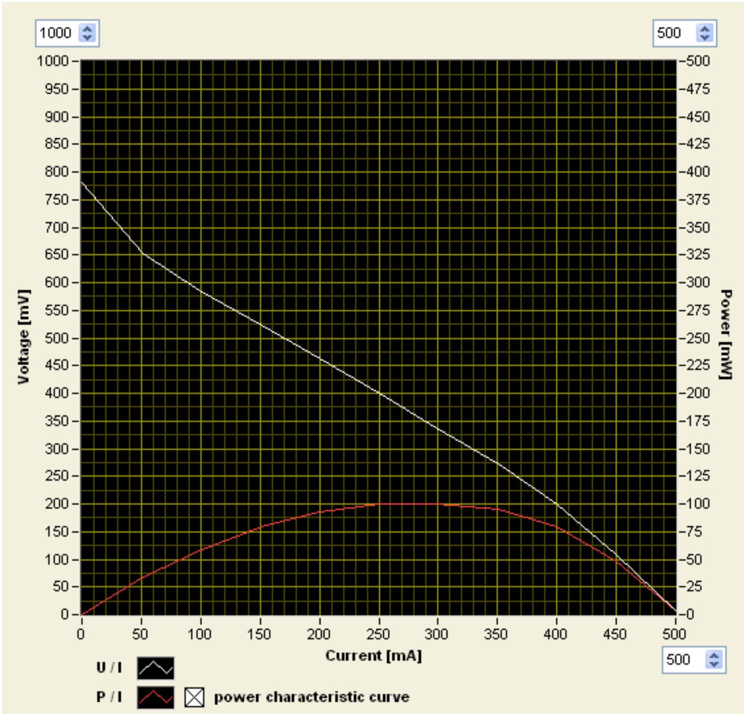

Fig. 4. *The characteristic curves of the fuel cell at the beginning of tests*

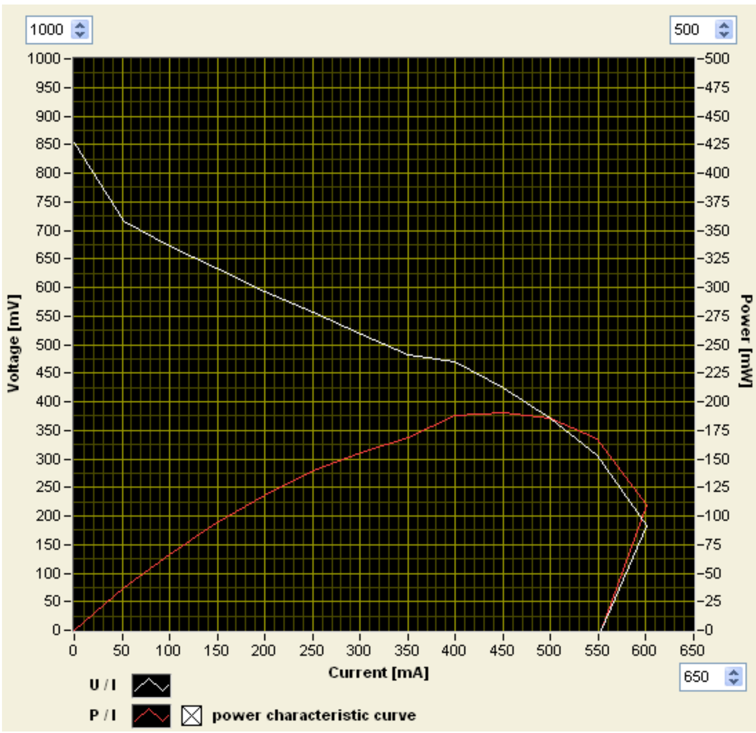

Fig. 5. *The characteristic curves of the fuel cell at the end of tests*

Power than solar modules. In order to be able to provide the same power with PV panels, significantly more solar modules are required.

Then, when the tests regarding hydrogen generation were performed, the wind turbine had also a better efficiency in producing hydrogen. However the best results were obtained when hydrogen was generated by both wind turbine and photovoltaic panels.

As regarding the fuel cell tests, we can conclude that shows high efficiency in electricity production. As long as fuel cells are powered with hydrogen produce electricity like batteries. Besides this, fuel cells, has as a result of internal energy transformation of hydrogen hot water that brings extra efficiency to system.

Neither wind nor Sun are continuously available 24 hours per day. For times in which they are not available or only very little, it would be advantageous to be able to save the energy generated during the day and when there is a lot of wind. If hydrogen was generated as an intermediate storage and converted into current by the fuel cells, such phases could be overcome.

To increase the efficiency of buildings and to reduce greenhouse gas emissions, the introduction of electricity generation from renewable resources and hydrogen – fuel cells system represents the most viable solution.

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