ABOUT THE SUSTAINABILITY, CONTROL AND COSTS OF HYDROGEN PRODUCTION IN HYBRID PLANTS WITH RENEWABLE ENERGY SOURCES

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Abstract - The paper presents aspects regarding the construction and operation of hybrid plants consisting of renewable energy sources, electrolyzes and hydrogen and electricity storage facilities that have been obtained. The authors analyze the energy processes in hydrogen production stations in order to optimize operating costs. The cheap electricity obtained for example through photovoltaic panels, can supply the electrolysis stations and the resulting hydrogen in this case, will have low production costs without negative ecological impact. At the end of paper are stated some conclusions that resulted from the study.

Keywords: modelling, reliability protection system, electrical network.

1. INTRODUCTION

European energy policies are focused on developing technologies that lead to increased energy conversion efficiency, reduction of energy intensity, environmental protection and sustainable development. Or, these desideratums can be fulfilled with the help of renewable energy sources. In order to increase their use and ensure a reserve in case of intimacy, hybrid technologies for hydrogen production have appeared and are being studied more and more intensely with the help of electricity from power plants with renewable energy sources. (RES). Thus, it has begun to take shape through European and national legislation[1][2], encouraging the production, storage and use of hydrogen on a larger scale, which is seen as an energy source of the future, with rapid development. At present, however, hydrogen has a minor contribution to the global energy supply. Challenges remain to be overcome in terms of cost competitiveness, scale of production, infrastructure required and the perception of safety. However, hydrogen is expected to allow emission-free transport, domestic heating and industrial processes, as well as inter-seasonal energy storage, in the future. At European Union(EU) level, the emphasis is on the importance of classifying different types of hydrogen and wants uniform terminology everywhere at the membres states to make a clear distinction between renewable hydrogen and low-carbon hydrogen.

The Hydrogen is currently creating transportation and storage problems, processes that involve high costs.

2. PRODUCTION, STORAGE AND UTILIZATION OF HYDROGEN AND ELECTRICITY FROM RENEWABLE ENERGY SOURCES

Renewable energies are those that recover naturally faster than they can be consumed on a short scale of time and have a low ecological impact. The category of Renewable energies, as specified in the Romanian legislation includes [3]: biomass energy, wind energy, river water power under 10 MW, geothermal energy and solar energy. Electricity produced from renewable sources can be used directly by producers but also through green certificates that are given additionally and which are sold separately on a dedicated market.

Because hydrogen is not found naturally in the Earth, it must be produced (or extracted) from substances that contain it in appreciable quantities: natural gas and other hydrocarbons, coal, biomass and water. Due to the diversity of hydrogen-containing substances in large quantities, it turns out that it can be produced anywhere in the world, using appropriate processes to separate it. Hydrogen has an energy content of 122 kJ / g which is 2.75 times higher than that of carbon-based fuels. Hydrogen in contact with atmospheric air is an explosive mixture, if the hydrogen is 3.3÷74 %, the most dangerous mixture is 30% hydrogen and 70% air.

Hydrogen production is achieved by several methods [4]: thermal (thermochemical decomposition of water, gasification of coal and biomass or pyrolysis of biomass, etc.), chemical (electrochemical- as electrolysis and photochemical ways, both having water as their raw material)and biological(anacrobic fermentation processes of biomass, biomass processing with fermentative microorganisms, algae photosynthesis, etc).

Hydrogen storage can be achieved in all three forms of aggregation: liquid solid and gaseous [5]. Through the international project HyUnder, in which Romania also participates, is investigated the possibility of storing hydrogen in gaseous form in undergound caves. Solid form storage is done by Carbon Nanostructures, Metal Hydrides, Metal Borohydrides, Kubas-Type Hydrogen etc. Liquid storage can be done in pressure-tight tanks or through organic hydrogenated liquid carriers [5].

The hydrogen produced, transported and stored is then used in fuel cells, where, by burning in oxygen, it produces electricity and hot water, or in hydrogen engines, where, by burning, it produces mechanical energy and, as a residue water [4]. Other uses of hydrogen are [6]: welding, missile fuel, jet fuel, fusion fuel in nuclear power plants, ammonia manufacturing, raw material in the hydrogenation process, coolant, cryogenics, gas for deep diving, etc.

Primary storage of renewable energy is practiced mainly in the case of water energy and biomass. Dams with natural accumulation or accumulation by pumping are the procedures used to store hydraulic energy. Electricity generated from renewable sources is stored in batteries (with Pb, Ni-Cd, Ag etc.) for use in intermittent natural energy or in case of power outages in public grids.

3. RENEWABLE ENERGY SOURCES IMPLICATION IN ECOLOGICAL HYDROGEN PRODUCTION. HYBRID PLANTS

Comparing the various methods of obtaining hydrogen, it can be seen that only the one with RES can become truly competitive in accordance with European environmental legislation. Water electrolysis uses as a primary source of electricity one of the renewable energies mentioned forming hybrid systems.

Figure 1 shows the scheme of a hybrid RES - hydrogen installation with the primary sources at the input (wind energy, solar energy) and the consumption network at the output for hydrogen and electric energy (electricity grid). The scheme allows the automatic control and adjustment of some parameters of wind aggregates, photovoltaic panels and hydrogen, by using an expert S.C.A.D.A. type system. The adjustment areas on which action is taken are those framed by dashed red lines.

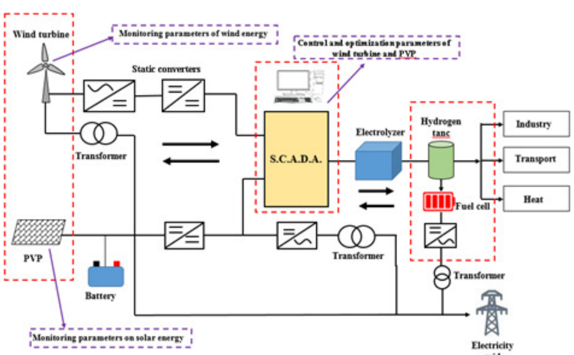

Fig. 1. Structure of an intelligent hybrid RES-Hydrogen plants

Such as in[7], the architecture of the microgrid is characterized by the use of a mixed topology, which uses D.C. and A.C. buses to ensure the interconnection between equipment and the main electrical grid. All of the generation and consumption subsystems are connected to the internal D.C. bus-bars, supported by the battery bank. This forms a hybrid intelligent model used to divide the entire set of extracted data into different control clusters. It communicates with the system of sensors and transducers in the installations through a programmable logic controller(PLC). The hybrid installation can be controlled remotely with a mobile smart device.

4. SUSTAINABILITY OF PROJECTS FOR HYDROGEN PRODUCTION BY RES

As in other areas, in assessing the sustainability of hydrogen production projects must take into account technical and economic aspects, ecological criteria and social impact. For example, to obtain environmentally friendly hydrogen, manufacturing costs may be higher than in the case of more polluting technologies that are cheaper.

The control of the production of electricity and hydrogen in the analyzed installations, the careful use of primary resources that are ecological in the case of RES are necessary principles to ensure a sustainable development of the society.

The operation of RES requires in the substantiation of the decision to carry out a project the analysis of criteria such as: the existence of high potential, distance from the source, the possibility of connection to electrical relays, the existence of consumers, means of capitalizing on evacuated energy, thermal or electrical etc.

There are other categories of ecological processes for hydrogen production with RES but without the involvement of electrolysis. A biological way to produce hydrogen from solar energy involves interaction with photosynthetic microorganisms. By chemically stimulating an enzyme called hydrogenase, hydrogen gas is then obtained. This process occurs only in the presence of cyano-bacteria and green algae, which have the ability to use solar energy through photosynthesis producing hydrogen using their own metabolism [8]. Unfortunately, however, algae being single-celled plants naturally produce very small amounts of hydrogen.

The environmental credentials of hydrogen production depend at first by the origin of the electricity used regardless of the process. A wide variety of waste and low-value materials, such as agricultural (renewable) biomass, can be used to produce hydrogen through ecological biochemical processes. Hydrogen is described in code of colors, as „green“ (from RES), „black“ (from oil, bituminous coal), „brown“ (from the gasification of brown coal or lignite), „gray“ (from natural gas) or „blue“ (natural gas with low CO_2 emissions) depending on how environmentally friendly its production process [9].

4.1. Evaluation of natural potential of RER

The first step in making the decision to carry out an energy project with RES is to assess their energy potential. In conducting studies, the primary potential of RER(Renewable Energy Resources) can be assessed by direct measurements, which are more recommended but require higher costs, by consulting scientific papers and specialized reports, which introduce the risk that the values obtained are not current due to climate change. or by accessing online databases or potential maps, managed by various institutions operating in the field of RES. These databases and digital maps are easy to use, accurate and periodically adjusted with values of energy parameters collected by measurements or taken by satellites. Is the case of the web platform that is integrated in the structure of IRENA - International Renewable Energy Agency, which allows the identification of the potential for all categories of renewable energies[10]. Other platforms contain data for only one form of energy.

Simulation examples for the RER potential are presented in figure 2, with the utilization of the platform from [11] and respectively in figure 3 with the use of the platform from [12]. The analyzed region corresponds to the territory of Bihor County, Romania.

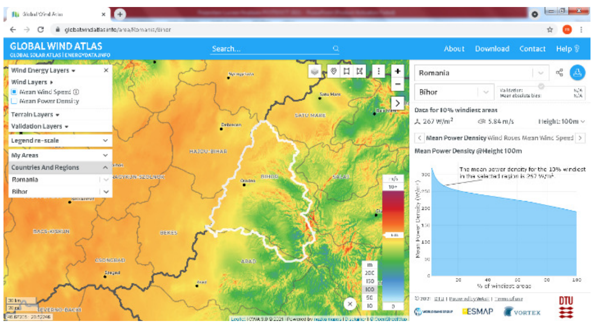

Fig. 2. Wind behavior (speed, power density) in Bihor County

Fig. 3. Monthly solar radiation and energy output from PV system

With the natural RER parameters and the climatic data of the mentioned location region will be given in chapter 5, the results of a calculation for evaluation of hydrogen production by RES.

4.2. Ways to increase the electricity avalability at hybrid plants RES- Hydrogen

For the extraction of the maximum primary energy potential of the RER, adjustment measures must be adopted so that the availability of electricity at the entrance to the electrolysis plant is optimal. For this purpose, it is possible to act on the control systems with execution elements mounted on the wind turbines and the photovoltaic panels. Automatic adjustment can be achieved by implementing fuzzy controllers. Fuzzy logic was initiated by L.Zadeh(1965) and operates with vague lexical values of input and output variables (such as "water is hot" or "the temperature is high") and has inference rules formulated according to the need for adjustment and the level of energy parameters necessary for the optimal operation of the installations [13]. A fuzzy set expresses the degree to which an element belongs to a set. Belonging to a set is described by a membership function. Hence the characteristic function of a fuzzy set is allowed to have values between 0 and 1, which denotes the degree of membership of an element in a given set[13]. Fuzzy controllers are represented by if-then rules. An expert fuzzy system consists of the fuzzifier, inference engine, rule base and defuzzifier. The input variables in the fuzzy system for the analyzed case,s are: for wind power plants: wind speed, wind duration, turbine orientation, turbine height, redundancy, energy accumulation, inverter efficiency, rotor diameter; for photovoltaic power plants: radiation intensity, radiation duration, panel orientation, shading / nebulosity, reservation, energy storage, inverter efficiency and redundance degree.

Figure 4 shows a process flow chart created by the authors to highlight the way of adjusting the parameters of photovoltaic panels to achieve the proposed purpose.

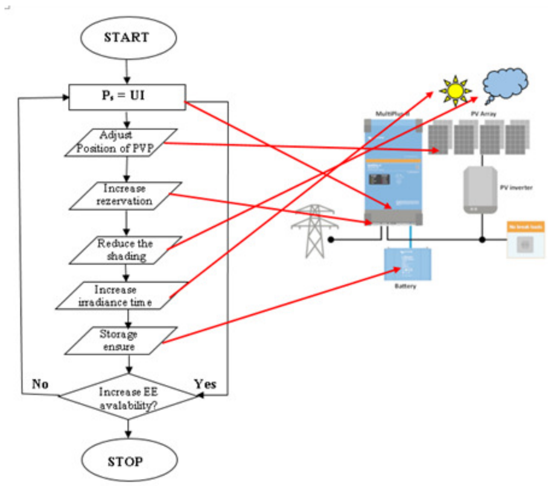

Fig. 4. Flowchart for fuzzy controllers and regulators of photovoltaic panels

In the figure 4, with red arrows are indicated the components of the system on which they act or which have an influence on the optimal operation of the photovoltaic panels.

5. PERFORMANCES AND COSTS OF HYDROGEN PRODUCTION

The current costs for hydrogen based on fossil fuels amount to around 1.5 Eur / kg for the EU, being highly dependent on natural gas prices. The estimated costs for hydrogen based on fossil fuels with carbon capture and storage amount to about 2 Eur / kg, and for hydrogen from renewable sources to 2.5 ÷ 5.5 Eur / kg[2].

The cost of hydrogen obtained by the electrolytic process depends on the cost of electricity but also on the cost of natural gas and coal. The consumption of electricity for the production of one kg of hydrogen 50 years ago was 56 kWh / kg, later the consumption decreased to 44 kWh / kg, and now the consumption is estimated at 36 kWh / kg. These performances were obtained by improving technologies and especially by using ion exchange membranes in electrolyzers, where the density of electric current on the electrodes is higher and the use of porous electrodes, which contributes to increasing the rate of cathodic reaction on the electrode[2].

Depending on the production method, Table 1 shows the costs of hydrogen according to the evaluations in the dedicated literature[5].

Table 1. Costs of hydrogen methods production

Method	Fuels	Efficiency (%)	H_2 costs($/GJ)
Gasification	Biomass, oil, coal	42 ÷ 47	10 ÷ 12
Electrolysis	Water	35 ÷ 42	20 ÷ 25
Pyrolysis	Biomass, coal	48	9 ÷ 13
Steam reforming	Natural gas, oil	65 ÷ 75	5 ÷ 8

It is evaluated by an example of calculation, the annual hydrogen production based on a hybrid system consisting of two parallel structures S_1 (solar) and S_2 (wind). The structure of the solar system includes the following components: 10 PVP with capacity P_s= 150 W each and total power P_{ts} = 1500 W, 1 electrolyzer with P_{elz} = 100 W, 1 fuel cell with P_c = 100 W, inverter with P_i = 1000 VA. The structure of the wind system includes the following components: 2 wind turbine with capacity P_w= 1500 W per unit and total power P_{tw} = 3000 W, 1 electrolyzer with P_{elz} = 100 W, 1 fuel cell with P_c = 100 W, inverter with P_i = 2000 VA. The value of the voltage at the exit of the system and at the consumer is U_n= 230 V, A.C.

The considered meteorological conditions indicating the periods during the year of maximum electrical capacity of the RES are: wind speed w_s= 4.2 m/s, solar radiation intensity I_s= 6.2 kWh/m^2/day, relative humidity h_r= 52.5; athmosferic pressure P_a = 92.5 kPa, external air temperature T_a = 21.5 °C, ground temperature t_g = 19.5°C.

The structure of electric energy with the destinations considered, is highlighted in Figure 5, for the analysis duration t_A = 1 year.

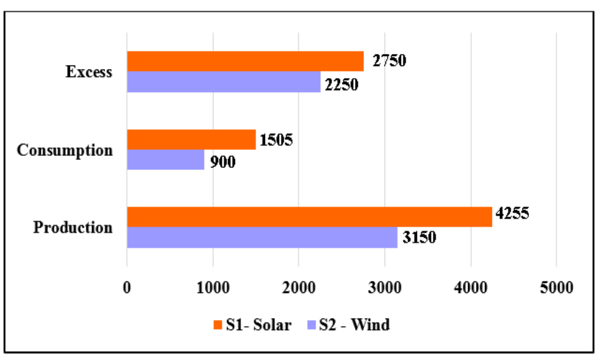

Fig. 5. Quantities of electricity involved in the analyzed systems

For the two structures the electricity has the following components:

- From solar(S_1): the produced Energy E_{Ps} = 4255 kWh/year, consumed energy from PVP is E_{Cs} = 1505 kWh/year, the excess of energy used for the electrolyzer E_{Exs} = E_{elz}= 2750 kWh/year;
- From wind(S_2): the produced Energy E_{Pv} = 3150 kWh/year, consumed energy from wind aggregates is E_{Cv} = 900 kW/year, the excess of energy used for the electrolyzer E_{Exv} = E_{elz}= 2250 kWh/year;

The estimation of the electrolytic production of hydrogen can be modeled considering the electrolyzer as an ideal device the applied formula resulting from Faraday's law being adjusted with the correction parameters resulting from practice.

Thus, the calculation was performed by applying the model from [14], according to the next formula:

$$V_H^{prod} = 0.4467 \cdot n_c \cdot I_{elz} \cdot \eta_F \text{ , [m}^3\text{/h]} \qquad (1)$$

With:

$$\eta_F = \frac{V_H^{prod}}{V_H^{calc}} \qquad (2)$$

and:

$$V_H^{calc} = n_c \cdot \frac{R \cdot I_{elz} \cdot T_a \cdot t_s}{F \cdot P_a \cdot z} \quad \text{[m}^3\text{/h]} \qquad (3)$$

Where:

η_F is Faraday efficiency of electrolyze(0.98÷0.99);

V_H^{prod} – volume of hydrogen production; V_H^{calc} - volume of calculated hydrogen; n_c – number of cells from electrolyzer stack-ul (6 pieces for 1 kW);

R – the ideal gas constant (8314 J/mol K); I_{elz} – electrical current at electrolizer (A), it is calculated from the available electricity with the formulas of electromagnetism; T_a - atmospheric temperature in Kelvin degrees(K) (273 + °C);

t_s - electrolyzer operating time (h) ;F - Faraday's constant (96.485 C/mol);P_a – atmospheric pressure, P_a =1·10^5 Pa; z - the number of excess electrons for hydrogen is equal to 2.

The calculation results are shown in figure 6.

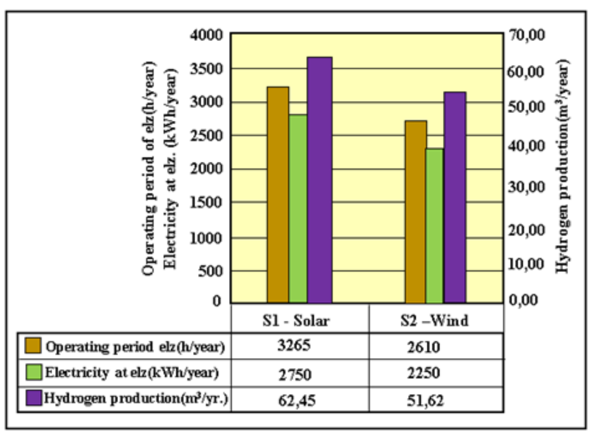

Fig. 6. Calculation results for hydrogen production

All prices for electricity production from renewable sources can be taken from the web platform of the commercial operator from Romania [15].

In text of paper, the signification of notations / abbreviations, is (in order of appearance): RES - Renewable Energy Source; S.C.A.D.A. - Supervisory Control and Data Acquisition**,** PLC - Programmable logic Controller; IRENA - International Renewable Energy Agency; RER – Renewable Energy Resources; PVP – Photovoltaic Panels

6. CONCLUSION

In the conditions of taking over the electricity from the RES market, from distributors and suppliers of electric energy, the operational costs of the electrolysis installations for the production of hydrogen increase very much. A more cost-effective solution is one in which the hydrogen producer uses electricity from its own renewable energy facilities by integrating the controllers programmed with fusion logic based on the optimally selected control parameters, the RES - hydrogen hybrid installations can be efficiently regulated so that the energy availability at the exit from the system is maximum, based on extracting the maximum primary energy potential from the system of maximizing the operating parameters within the analyzed system. The electrolytic production of hydrogen from RES such as solar and wind, respectively the provision of electricity through hydrogen fuel cells, can play an important role in covering the energy needs for periods with peak consumption or for intermittent periods in the supply resulting in the reduction of excess of electric energy that is not needed by consumers.

In both individual and hybrid hydrogen plants, RES can greatly contribute to sustainable development of energy sector. The RES potential being particularly rich can ensure a secure energy future and the optimal capitalization of the potential can be done by developing new technologies for converting primary renewable energy into other forms of energy required by anthropogenic processes.

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