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Educational Station for the Generation and Use of Green Hydrogen

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Abstract. Globally, electrical energy predominantly derives from fossil fuels such as coal, oil, and natural gas, which significantly emit greenhouse gases, thereby accelerating ecosystem degradation and climate change. In response, recent decades have witnessed a surge in the development of clean, sustainable electricity generation technologies such as wind and solar photovoltaic systems. These renewable sources are expected to replace fossil fuel-based methods but are limited by their dependency on variable weather conditions, which cannot align with electricity demand. Periods when energy production exceeds demand highlight the critical role of innovative storage solutions. Notably, surplus energy can be utilized for hydrogen production via water electrolysis, producing "Green Hydrogen", which generates no polluting emissions. This shift towards sustainable technologies necessitates novel educational approaches. It is essential to revise curricula to include these technologies, ensuring students are well-prepared for the evolving energy sector. This article discusses the design and construction of a green hydrogen educational station built with commercial materials for laboratory use, embodying the integration of renewable energy technologies into academic programs and promoting hands-on learning experiences in energy management and sustainability.

Keywords. Green hydrogen, Sustainability, Renewable sources, Energy vector and Educational station.

1. Introduction

In recent decades, advancements in the renewable energy field have been steady, and the global implementation of such renewable energy facilities has been significant. As of now, approximately 29% of the world's energy production is derived from renewable sources. The International Renewable Energy Agency (IRENA) projects that this figure will increase to 90% by 2050, indicating a progressive rise in the total generation capacity of renewable energy facilities. It seems evident that the generation of energy from clean and renewable sources [1] and training in sustainability awareness in new generations [2] are goals to achieve in the future. In Spain, Organic Law 3/2020, dated December 29, 2020, represented an essential initiative by incorporating, for the first time, explicit references to Education for Sustainable Development and Global Citizenship Education, as delineated in the 2030 Agenda. This legislation underscores Spain's commitment to fulfilling the objectives outlined in the Environmental Education Action Plan for Sustainability (PAEAS) in accordance with European Union targets. The PAEAS, spanning 2021 to 2025, delineates the strategic directions for Environmental Education for Sustainability (EAS) in Spain through 2025 [3]. This Action Plan enumerates six operational axes, with a specific emphasis on the integration of sustainability within the educational and training system, designated as the operational axis number three. This focus underscores the imperative of equipping new generations with knowledge of environmentally friendly, clean, and inexhaustible technologies, thereby fostering a foundation for sustainability in their education. The incorporation of such themes into both university and non-university educational levels is a recognition of the importance of introducing sustainability principles from an early age. However, there are still few initiatives and projects to include hydrogen technology at diverse levels of education in Europe and the rest of the world. Outside of them, it is limited to postgraduate programs or small courses [4]. Some works [5] show interest in implementing their knowledge in the educational system focusing their efforts on specific parts such as the fuel cell and the electrolytic cell. In [6], a teaching device is presented where hydrogen is obtained through photocatalysis. The station explains the theoretical basis and the operating principle of a fuel cell in a practical way. A novel educational program [7] implements online teaching, within the framework of the H2 Green TECH project, which provides fundamental knowledge in hydrogen technologies. Other authors [8] explore online learning formulas using a standard commercial green hydrogen generation station to which it is possible to connect from anywhere in the world. Although all of them fulfil a didactic function, they do not address a general overview of the systems and devices that make up this technology. It is therefore important to continue along this line and reinforce the creation of teams, experiences and adequate educational resources that facilitate the training of new generations in this field.

In the designed installation, a photovoltaic panel has been used as the primary source of energy. The station has been developed using open access software, a 3D printer, and common materials. The electrical, electronic, and mechanical devices used are basic and commercial. All of this gives the station the versatility to add, replace, or eliminate parts of it, providing it with the typical characteristics of a prototype on which different educational experiences can be conduct allow training in green hydrogen technology.

2. Educational station design

Educational station allows the production, storage and use of green hydrogen. The components, as shows the Fig. 1, are placed on a desk for a clear and accessible visualization of the whole. Consists of the following parts:

2.1. Electrolyzer

It is the element in which the electrolysis of water is carried out. It is made up of cells. Fig. 2 shows the basic structure of one of these cells. It consists of a main casing that contains all its parts, the stainless-steel electrodes, the permeable membranes (domestic cloth) that physically separate the areas in which the hydrogen and oxygen are obtained, and two holes made in the upper part of the membrane casings for the scape of gases. The structure of the electrolyzer has been designed with the free access tool FreeCad and printed with a 3D printer. For the same potential difference between electrodes, the performance of the electrolyzer increases with the number of cells. An electrolyzer consisting of four cells has been designed for the station. Fig. 3 shows an internal schematic of the 4-cell electrolyzer built.

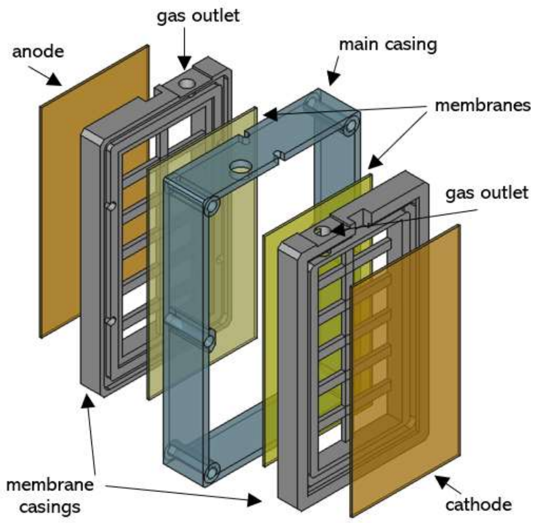

Fig. 2. Basic structure of an electrolyzer cell.

The connections made between chambers by means of pipes have been represented and thus redirect the oxygen and hydrogen obtained in each of them to the corresponding electrolyte deposit. Fig. 4 shows the built electrolyzer.

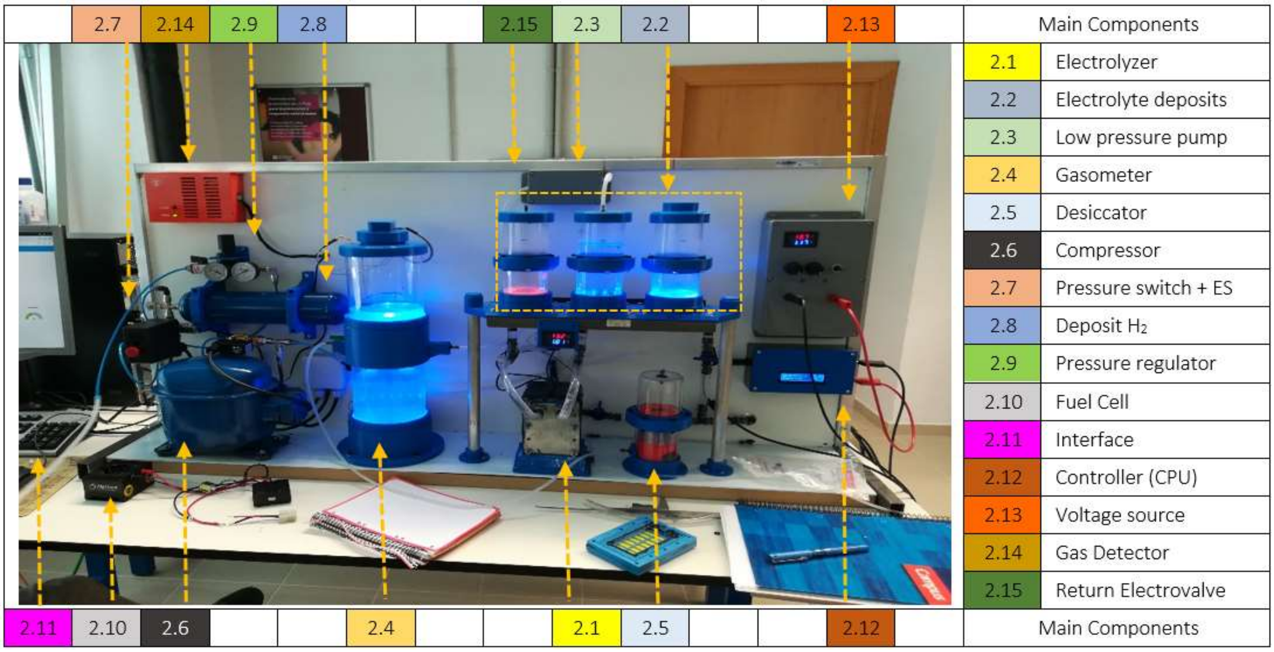

Fig.1. Configuration of the educational station.

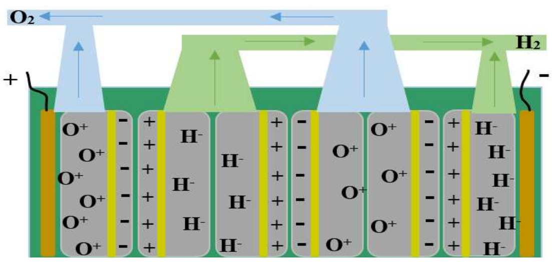

Fig. 3. Bipolar stacked cell electrolyzer.

Fig. 4. Self-built four cell electrolyzer.

2.2. Electrolyte and gas deposits

The electrolyte tank contains the water and electrolyte (NaOH) mixture for electrolysis. The other two are temporarily used to contain the hydrogen and oxygen generated (Fig 5). The hydrogen tank has a pipe at the top that redirects the hydrogen gas to a low-pressure pump. The oxygen tank is atmospheric. The tanks are connected at the bottom. A valve has also been placed to empty all of them.

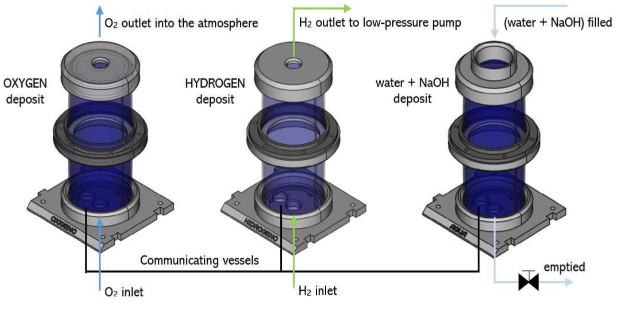

Fig. 5. Gas and electrolyte deposits.

2.3. Low-pressure pump

It serves to propel the hydrogen with sufficient pressure into the gasometer (Vcc=12 V, max. pressure 5 m.W.C.).

2.4. Gasometer

Composed of two polycarbonate vessels connected by a pipe and a level sensor located at the top. It works as a lung. Temporarily storing the hydrogen from the electrolyzer driven by the low-pressure pump into the lower glass of the gasometer. While the electro-valve is closed, all the hydrogen is driven into the glass pushing the water column to downwards due to the pressure this exerts (Fig. 6). Since the glasses are connected, the water column in the upper glass also moves, but in this case, upwards. The water level in the upper glass is proportional to the volume of hydrogen gas obtained. An ultrasonic sensor controls the level by acting on an electro-valve that removes the hydrogen.

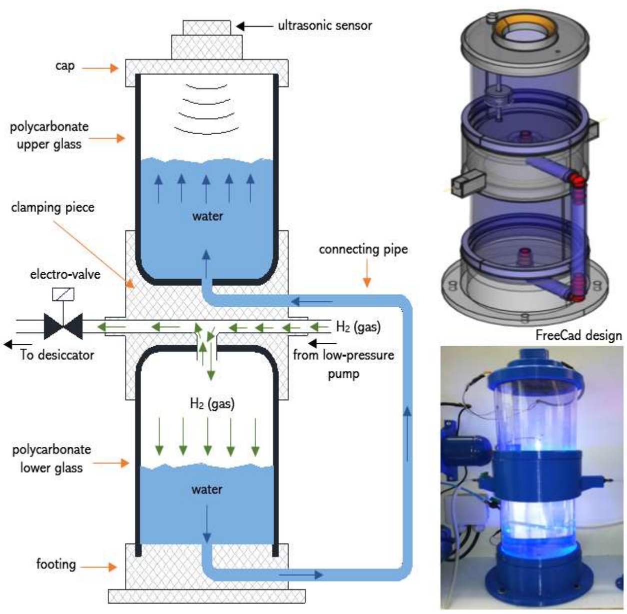

Fig. 6. Gasometer.

2.5. Desiccator

It contains a silica gel in its lower part whose mission is to eliminate moisture or water particles that accompany the hydrogen obtained before being stored (Fig. 7).

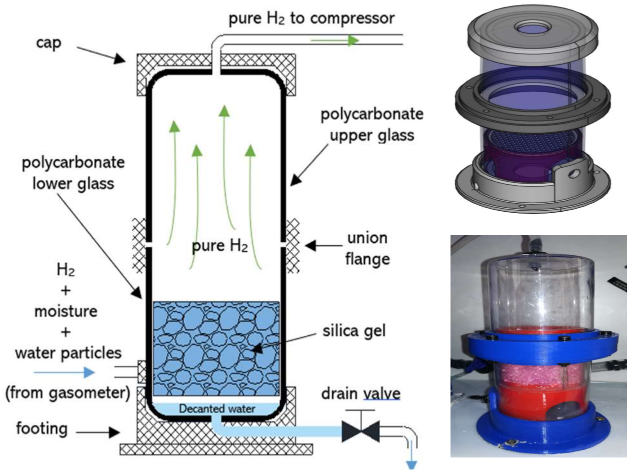

Fig. 7. Desiccator.

2.6. Compressor

Hydrogen is compressed before being stored to increase its energy power per unit volume. In industrial use, hydrogen can be compressed to pressures between 350-900 bars, depending on the application. In the case of the teaching station, it is compressed to a pressure of 8 bars and subsequently reduced by a pressure reducing valve to 0.5 bars, enough to operate the fuel cell used. Its main technical specifications are nominal power 200 W, hermetic piston compression type, working range up to 10 bars, nominal intensity 0.85 A, single-phase alternating power supply of 230 V, 50 Hz.

2.7. Pressure switch + Emergency stop

It cuts off the power supply when the pressure is outside the preset range. A minimum pressure (3 bars) and a maximum pressure (8 bars) are regulated independently. In this way, a differential pressure is achieved within which it keeps its internal contacts closed. Outside these limits the contacts open, modifying the circuit conditions. The contacts support a single-phase voltage of 250 V and a maximum intensity of 20 A. The pressure range is between 2 and 12 bars, with the minimum pressure differential being 1.5 bars and the maximum being 5 bars.

2.8. Deposit H_2

The compressed hydrogen is storage in a tank of 1000 c.c. capacity capable of withstanding pressures of up to 15 bars.

2.9. Pressure Regulator

Its function is to regulate and stabilize the pressure of the hydrogen stored in the H_2 tank. A manometer allows you to display the value of the output pressure achieved. The regulator used has a maximum working pressure of 10 bars, a working temperature range between +5ºC and +60º C and an adjustable pressure range between 0.5 and 8.5 bars.

2.10. Fuel cell

It is a device capable of converting a flow of hydrogen together with another flow of oxygen (in its pure state or combined with other elements, as occurs with air), into electrical energy. Unlike a battery, which has a limited useful life, the fuel cell can continue generating electrical energy uninterrupted as long as it has the necessary supply of hydrogen and oxygen. It consists of two chambers coated with a catalyst, formed by platinum nanoparticles fixed on carbon paper, which facilitate the Redox reactions that take place in both chambers. They are separated by a barrier (polymeric membrane electrolyte) that can be crossed by ions, but not by electrons. The cameras are connected to separate copper wires to offer the possibility of connecting a load, for example, a small motor or lightbulb (Fig. 8).

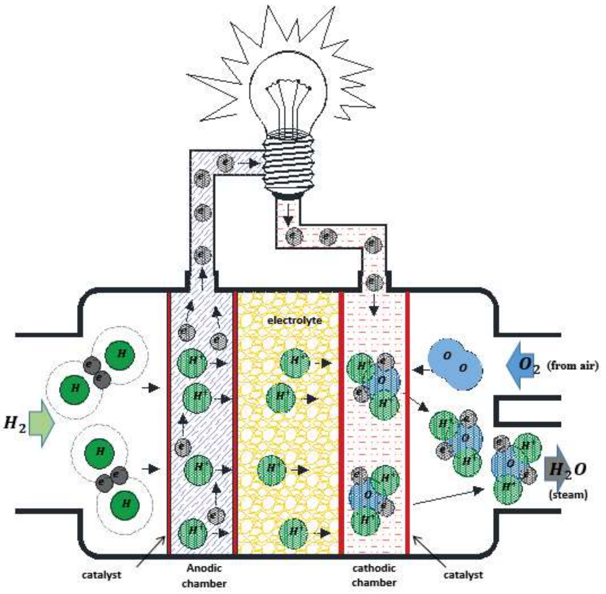

Fig. 8. Fuel cell.

2.11. Interface

Consisting of a personal computer (PC), it has implemented the free access software, Node-RED, which allows programming and communication with the controller (Arduino) of the system. It is also used to display process parameters (Fig. 9).

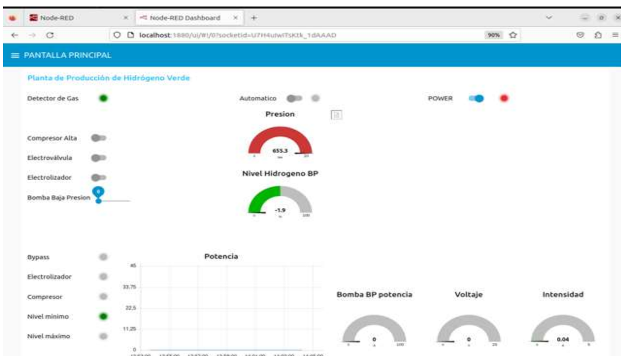

Fig. 9. Node-RED.

2.12. Controller

It is a programmable board “Arduino Uno”. Manages, based on the control program and the signals received from the system sensors, the behaviour of the process.

2.13. Power supply

Powered by the photovoltaic installation, it can supply two levels of direct voltage, +5 and +15 V, used to power different devices in the system, and a variable voltage between 1.5 V and 15 V to power the electrolyzer.

2.14. Gas detector

Arranged as a safety element, it stops the operation of the station, accompanied by an audible alarm signal, if it detects a high concentration of hydrogen or oxygen.

3. Station operation

As actions prior to starting up the station, it must be verified that the lower glass of the gasometer contains water in at least 3/4 of its total capacity and that all devices are connected. The start-up procedure is as follows (Fig. 10):

1.- The electrolyte tank is filled with a mixture of water and 5% sodium hydroxide (NaOH). Since it is connected to hydrogen and oxygen, they all reach the same level. Filling stops when ¾ of its maximum volume has been reached. Subsequent water fills are made through this tank.

2.- With the electrolyzer (ELEC) flooded with the water and NaOH mixture, a voltage of 1.5 V is applied between anode and cathode. Electrolysis of water begins. The applied voltage and current values are collected by the analogy inputs A6 and A7 of the controller. They are also shown on the V/I display.

3.- The oxygen generated is expelled into the atmosphere through the oxygen tank. The hydrogen is confined in the hydrogen tank and redirected by means of a low-pressure pump (PUMP) to the lower part of the gas holder (GAS). In this situation, electro-valves EV1 and EV2 are ON and OFF, respectively.

4.- The hydrogen displaces the water to the upper glass of the gasometer. An ultrasonic sensor allows you to know its level (analogy input A2). A second buoy sensor allows the maximum and minimum levels to be known (analogy inputs A3 and A4, respectively). Outside these limits, the controller stops the process by stopping powering the electrolyzer through a contact of the KM1 relay connected to digital output D4 of the controller.

5.- When the water level in the upper glass is appropriate, the ultrasonic sensor acts on the analogy input of the controller which causes the low-pressure pump (PUMP) to close the electro-valve EV1 and open EV2. The hydrogen passes from the gasometer to the desiccator (DESI).

6.- The compressor (COMP) is then connected through a contact of the KM2 relay. To do this, at that same moment the electro-valve EV3 opens to equalize the pressures between the inlet and outlet of the compressor and allow it to start. when it starts, EV3 shuts down.

7.- The hydrogen conducted through the desiccator loses the small particles of water and moisture that accompany it and enters the compressor through its low-pressure inlet. Here, the hydrogen is compressed to 8 bars and taken to the hydrogen tank (DEPH) for storage.

8.- When the ultrasonic sensor detects an insufficient water level, that is, a minimum hydrogen volume, it activates a signal in the controller so that it stops the compressor, closes the electro-valve EV2, opens EV1 and starts the low-pressure pump. (PUMP). The process begins again.

9.- At the outlet of the hydrogen tank, a pressure regulating valve (PRERE) is installed to adjust the pressure to the 0.5 bar required by the connected fuel cell (FUCE).

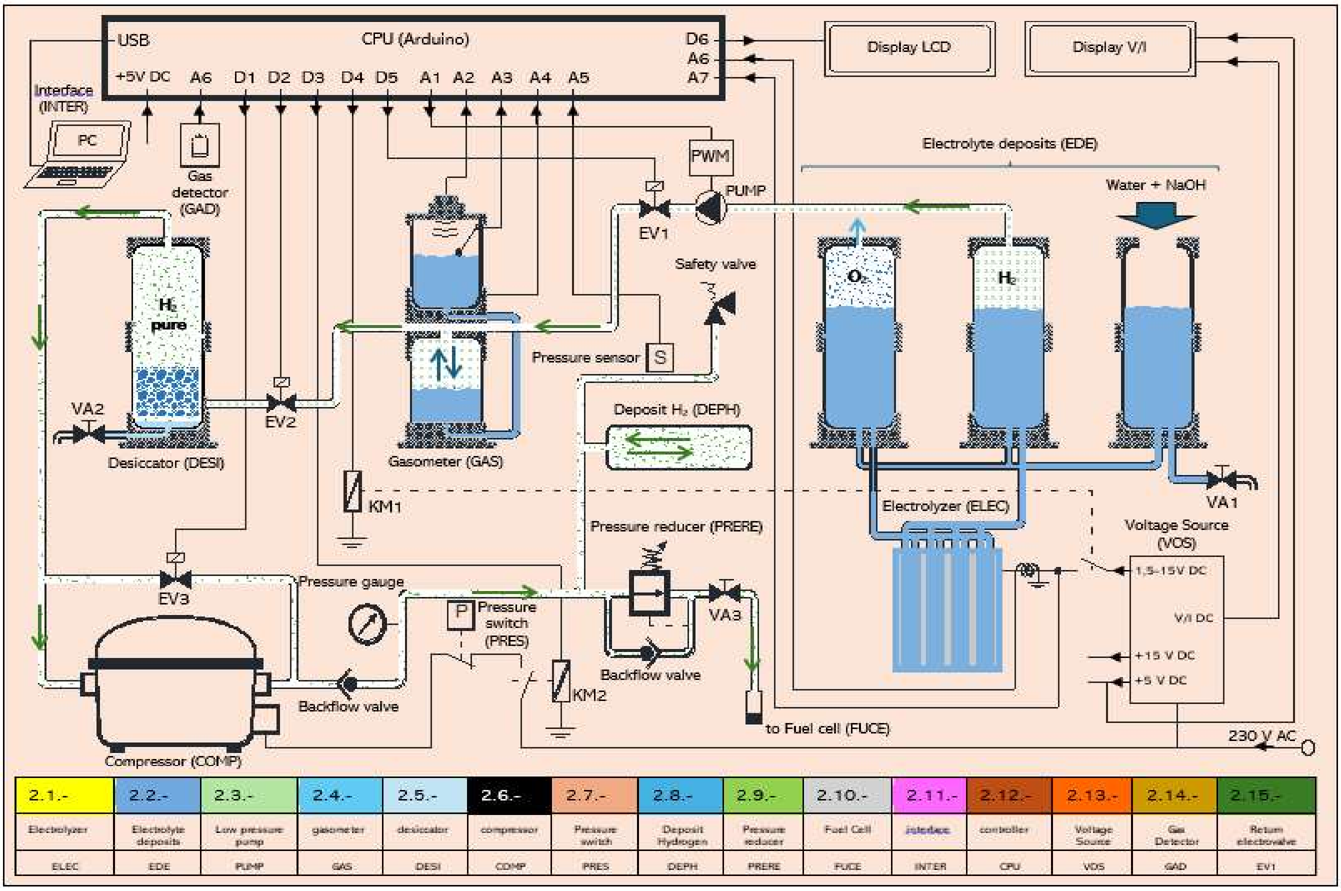

Fig. 10. General scheme of the educational station.

4. Educational station applications

The station obtains pressurized electrolytic hydrogen used to power fuel cells. In our case, it is applied to feed two PEM mod MT19S242 type cells available in the laboratory whose nominal power is 30W.

The Hydrogen, coming from the 8 bar steel tank, is supplied to the cells at a pressure of 0.5 bars after passing through a reducing valve. The adjustable electrical power system allows testing the behaviour of the alkaline electrolyzer in different work regimes, emulating the production of intermittent energy of a wind or photovoltaic installation.

The designed system for the station can control and monitoring all plant parameters in real time through an Arduino Uno development board that has the necessary analogy and digital inputs and outputs. The control program executed in C performs the following functions:

A. Reading of signals from sensors such as source voltage, electrolyzer voltage, current circulating through the electrolyzer, ultrasonic and buoy levels of the tanks, hydrogen pressure in the storage tank and the level of gas accumulated in the surroundings of the station.

B. On/Off on the different relays of the System. Low pressure pump activation relay (PWM), high pressure compressor activation relay (KM2), electrolyzer connection/disconnection relay (KM1) and compressor bypass valve activation.

C. The control software has 2 operating modes:

- Manual mode, it is the user who manually activates/deactivates all the station devices.
- Automatic Mode, it is the processor who controls in real time the connection/disconnection of the plant devices, based on the recorded by the sensors.

To visualize the global behaviour of the hydrogen production plant, a Dashboard has been developed using the free Node-Red application. With this software the user can design on a PC, *ad hoc*, the graphical interface screens that completely control the system. Thus, it is possible to observe and graphically represent the temporal evolution of the intensity that passes through the electrolyzer for different voltage levels, the instantaneous power consumed by it, the pressure in the hydrogen tank at each instant, the state of the gas detector or the condition of the compressors. Due to its design and construction, the installation is equipped with versatility that allows obtaining process characteristics under different operating conditions. Currently its fundamental application is teaching. It is used to train students in the knowledge of the integral operation of a green hydrogen installation with a photovoltaic plant as the primary source of energy. More specifically, laboratory tests are carried out to determine,

- the electrolyzer behaviour curve,
- performance,
- the consumed power vs. Mass of hydrogen obtained.

Other tests can be added to these to deepen the knowledge and optimization of this type of installations. For example,

- Study of the intensity-voltage curve of the alkaline electrolyzer,
- Study and/or graphic representation of power, performance, and intensity,
- Electrolyzer performance in different scenarios and subjected to intermittent work regimes,
- Overall performance of the electrochemical conversion process including the operation of the fuel cell.

5. Conclusion

Hydrogen derived from renewable sources, known as green hydrogen, is emerging as a promising energy storage solution. It offers a sustainable alternative to traditional fossil fuel-based electrical energy production, driven by both environmental concerns and technical advantages. The technology behind green hydrogen is relatively straightforward, enabling optimal utilization of energy produced by renewable facilities.

Given the significant role of this technology in future sustainable practices, it is crucial to incorporate knowledge of such environmentally friendly and inexhaustible technologies into educational curricula, focusing on sustainability. Consequently, integrating this subject into educational systems is essential.

This article outlines the autonomous design and assembly of an educational station dedicated to the generation, management, and application of green hydrogen. The station's simple and versatile design qualifies it as an effective educational tool that enhances scientific and technical understanding of renewable energy technologies. It facilitates a comprehensive understanding of the operational aspects of such facilities and supports various activities and laboratory experiments. These activities are designed to deepen students' knowledge and encourage active participation in the learning process.

At the ETSII of the University of La Rioja, this project has proven instrumental in introducing both undergraduate and master's students to green hydrogen technology. On a research level, it serves as a critical component for studying the behaviour of small smart grids powered by intermittent renewable sources.

Acknowledgment

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