Control and Automation System of Power Generation Hhrough Photovoltaic-Hydrogen Technology to Lighting

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ABSTRACT

At present, it is very important study new power generation systems, like a photovoltaic-hydrogen. This is a hybrid system where the photovoltaic modules are used to provide power to the electrolyzer for producing hydrogen and oxygen through the water electrolysis. Gases produced are stored to be supplied when they are required into a fuel cell to generate electrical power.

The prototype is integrated by solar photovoltaic modules to generate 8964KJ every day (2.49 KWh/day), a PEM electrolyzer is used to produce hydrogen from $1x10^{-6}$ m^3/s to $5x10^{-6}$ m^3/s at 7KPa to 827KPa. The prototype has a variable volume storage system at atmospherically conditions (295.15 K and 77.99KPa) and a fuel cell stack can be operated in a range of 50 W to 150 W.

The system is able to operate with different fuel cells in a range of $1.67x10^{-7}$ m^3/s to $1.67x10^{-5}$ m^3/s hydrogen flow. In order to be a safe system and make easier the regulation flow, it is really important to develop a control and automation system. In this project, it is proposed a closed loop system where the hydrogen and oxygen required is selected in a control panel. Gasses flow is controlled by pumps and proportional electro-valves that use a recirculation system which is monitored by flow sensors. Algorithm main aspect is the flow regulation, because the gases are storage in a variable volume system where the flow is not constant. Also, the project includes a monitoring system where power energy behavior can be reviewed.

Keywords: Fuell Cells; Automation; Renewable Energy

1. Introduction

We live in a world where technology grew up very fast and it almost requires electrical energy, society depends more and more of it, this is the reason it is really important to innovate in power sources as we do in electronic devices. At present, the main power source is fossil fuels, however it generate pollution and it is a nonrenewable source. In spite of different renewable power sources have been developed like solar, wind and geothermal energy. The society still depending on fossil fuels, this is mainly in oil countries like Mexico where sustainable power sources are not sufficiently supported. It is really important to develop new power sources that do not pollute the environment and that are able to satisfy the requirements of the society, it must be understand that we have to be more ecological.

The aim of this paper is exposing the advances of the photovoltaic-hydrogen system design and the development of the control and automation system to produce electricity in a safe and controlled way. In this project solar energy is used as primary power source and hydrogen as secondary power source. Therefore, solar energy can be used in an efficient way during the day that is when it can be converted as electrical energy, at nights hydrogen is used as the secondary power source to produce electrical energy.

The process consist in generate hydrogen and oxygen from the water using an electrolyzer that requires electrical energy produced by the solar panels in the day, the gases are stored in a tank and at night these are used by the PEM fuel cell that is an electrochemical energy converter to produce direct current (DC) electricity from hydrogen and oxygen, required for the charge (LED lamps).

The system is integrated by a solar photovoltaic modules to generate 8964 KJ every day (2.49 KWh /day), a PEM electrolyzer where the hydrogen is produced at 55KPa in a flow of $1x10^{-6}$ m^3/s, a pressure regulator where the hydrogen is delivered at 55KPa in a flow of $1.67x10^{-6}$ m^3/s, a variable volume storage system at atmospherically conditions in Mexico City (295.15 K and 77.99KPa) which capacity is 0.03 m^3 of hydrogen and 0.015 m^3 of oxygen , a control system where the hydrogen and oxygen are regulated automatically in a range of $1.67x10^{-7}$ m^3/s to $1.67x10^{-5}$ m^3/s , creating a flexible system that it is able to operate with different PEM fuel cells and a fuel cell stack that is operated at 50 W using $1.33x10^{-5}$ m^3/s of hydrogen and $6.67x10^{-6}$ m^3/s of oxygen. The charge consist in two LED lamps that requires 12V and consumes 2A each one.

Implementing an automatic control system that controls the gases delivery in to de PEM fuel cell it is really important because the PEM fuel cell requires a continual gases flows for a better performance, the control system monitors in a real time the flow rates hydrogen and oxygen and as consequence adjust it in relation with the wanted flow, selected by an operator.

2. Experimental

Photovoltaic system dimension and design was made by studying the electrical requirements of electrolyzer and the sunlight in Mexico City, where the average of peak sunlight is 18000s (5 hours). This information was taken from Geophysics Institute of Universidad Autónoma de México (UNAM), figure 1. [1]

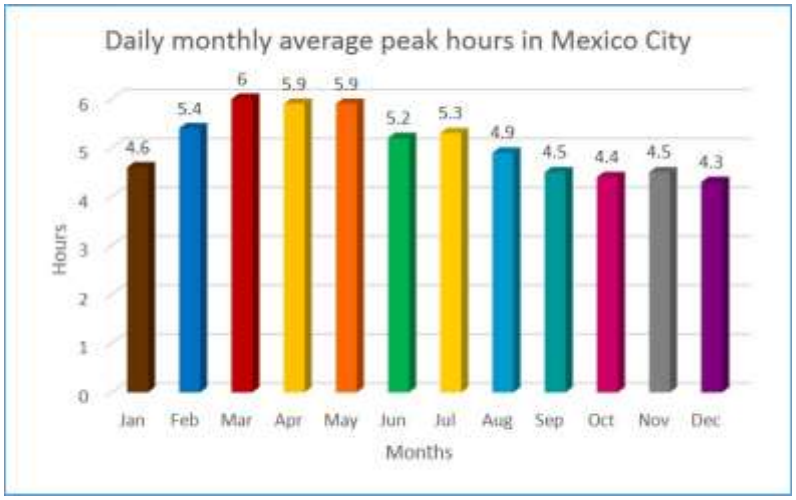

Fig 1. Daily monthly average peak hours in Mexico City

México City has an excellent position to get sun light, one of these reasons is that it is located near of equator where the hours of sun light are relative continual in the all seasons and months, in consequence the peak hours are also continual, allowing to have a stable photovoltaic system. [1]

The photovoltaic system is composed for 6 polycrystalline silicon modules of 85 W each one, this modules were connected in a series-parallel arrangement to producing 510 W in the peak sunlight and during the day is achieved 8956.8KJ (2.488KWh). This is enough to use the electrolyzer that requires 340W or 1224KJ (0.34KWh). [2, 3]

It was designed a photovoltaic system type island, which needs a DC/DC regulator and an inverter, these devices were purchased according with the electrical characteristics of solar panels and the electrolyzer. The performance of solar panels in Mexico City was studied according to the electrical behavior with the electrolyzer. The electrical specifications of the solar panels, the DC/DC regulator and inverter are presented in the table 1. [2, 4]

Table 1. Electrical specifications of photovoltaic system

Electrical Performance under Standard Test Conditions each panel		DC/DC Regulator	
Maximum Power	87W (+10%/ -5%)	Nominal Voltage	12/24V
Maximum Power Voltage	17.4V	Maximum Current	20A
Maximum Power Current	5.02A	Inverter	
Open Circuit Voltage	21.7	Output Voltage	120VAC
Short Circuit Current	5.34A	Output Frequency	60Hz
*STC: Irradiance 1000W/m^2 AM1.5 Spectrum, module temperature 25°C			

It was used a commercial PEM electrolyzer manufactured by Peak Scientific company, model PH300 which capacity production is 1x10^{-6} m^3/s to 5x10^{-6} m^3/s at different pressures 7KPa to 827KPa. This device uses alternate current, 110V at 60Hz, 340W. [3]

Production process of hydrogen and oxygen was analyzed in the commercial electrolyzer, where it was understood the internal structure. Schematic diagram was developed presented in the figure and table 2, where it can be appreciated the different components of it. [3]

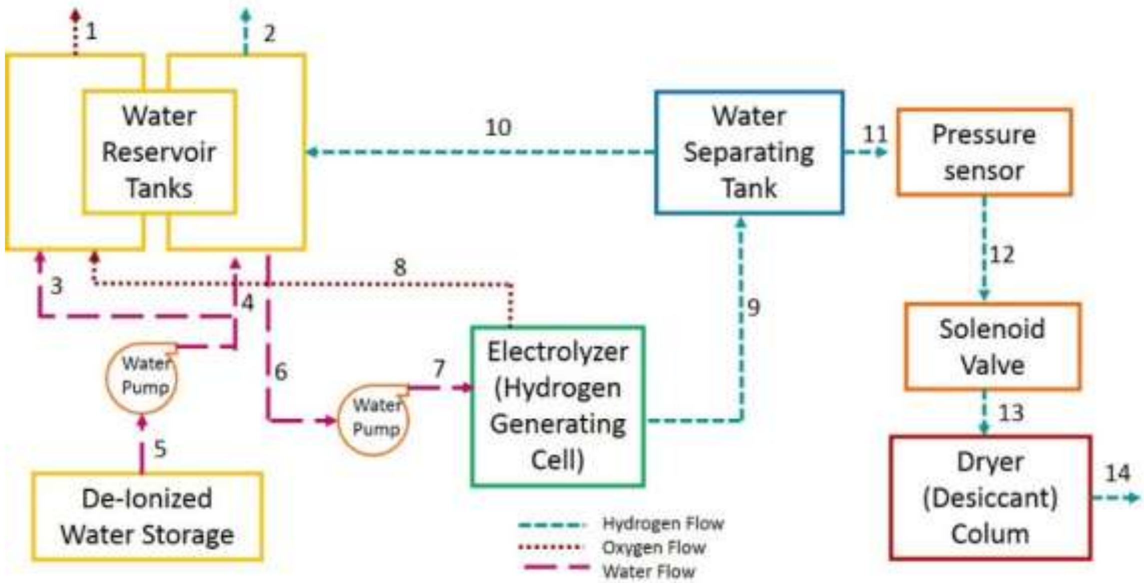

Fig 2. PEM Electrolyzer PEAK Scientific PH300 System

Table 2. PEM electrolyzer PEAK Scientific PH300 System

Flow	Typology	Flow	Typology	Flow	Typology
1	O_2 Delivery	6	H_2O	11	H_2
2	H_2 Vent	7	H_2O	12	H_2
3	H_2O	8	$O_2 + H_2O$	13	H_2
4	H_2O	9	$H_2 + H_2O$	14	H_2 Delivery
5	H_2O	10	$H_2 + H_2O$		

Electrochemical and electrical performance of electrolyzer was also analyzed, the following parameters were measuring: current and voltage directly in the cell and the hydrogen and oxygen flow delivery, it was made at different pressures at atmospherically conditions in Mexico City.

Storage system was designed to satisfy the demand for the fuel cell, it is important to mention hydrogen has the highest energy content per unit weight but not per unit volume. It is relatively low volumetric energy content is a significant challenge for storage. Stationary hydrogen storage systems have less stringent requirements, it can occupy a relatively large volume, operate at lower temperatures and pressures and time to refueling can be large, in the appropriate conditions. Also, the storage was designed in order to save energy, storage systems like pressured tanks need a compressor to store gases and that requires more energy, hydrides systems to store hydrogen are really efficient, however this systems are expensive and requires significant careless, for those reasons it was designed a variable volume system at atmospherically Mexico City conditions.[5, 6]

Hydrogen and oxygen storage system consists in a principal container manufactured in acrylic which contains water, into this big container there are two floating capsules or containers, where hydrogen and oxygen are stored. These were also made of acrylic with joints coated aluminum anodized layer. The connections were designed anti-spark for handling hydrogen gas. The gas storage capacity is 0.015 m^3 of oxygen and 0.03 m^3 of hydrogen. The storage system is feasible because the water avoids that gases get way for the bottom of the containers.

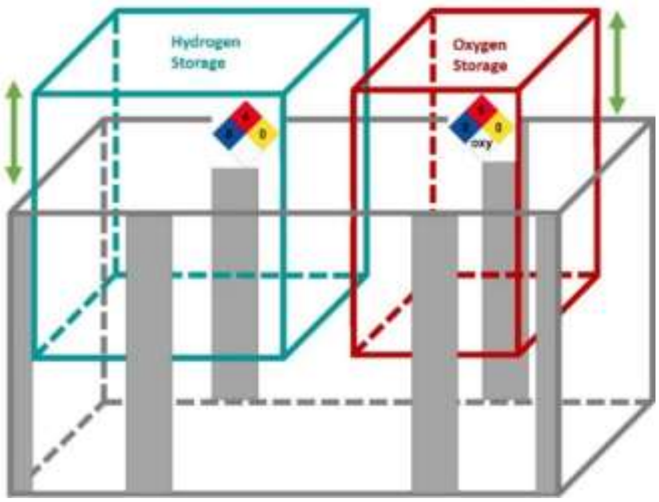

Fig 3. Hydrogen and oxygen storage system

Different connections were designed so the storage system requires to operate adequately from the electrolyzer and the fuel cell, increasing the efficiency and security of the process. [7, 8]

PEM fuel cell was designed at CINVESTAV by a research group. The proton exchange membrane fuel cell (PEMFC) is composed of bipolar plates, end plates, membrane electrode assemblies (MEAs) and gas diffusion layers (GDLs). Among the constituents of PEMFCs, the bipolar plate is a key component that collects and conducts the current from cell to cell. Bipolar plates and endplate were made of low porosity graphite. The fuel cell stack designed in this project contains 20 individual cells, each having a 0.0035m^2 active area. The cells are stacked in a series configuration with current collectors placed on the anode and cathode sides. The components considered in the volume size restriction are: endplates, current collectors, bipolar plates, all sealing materials, and MEAs. The dimensions of stack are 0.13m x 0.140 m x 0.075m when the stack is fully assembled and compressed and its weigh is 1.6 Kg. [9, 10]

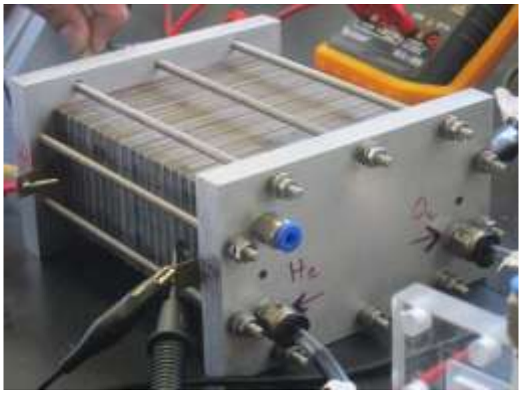

Fig 4. PEM Fuel Cell Stack

PEM fuel cell at 1.33x10^{-5} m^3/s of hydrogen and 6.65x10^{-6} m^3/s of oxygen is expected to generate 18V at opened circuit. It was designed an automatic system of gases regulation to the fuel cell, allowing to use different PEM fuel cells for future experiments, and a continual supplement, generating experiments with more precision. [9]

The aim of the photovoltaic-hydrogen system is to energize two LED lamps in a time frame, according with the PEM fuel cell electrical characteristics. In the design of the LED lamps, it was studied the congruence of electrical conditions and the high LEDs efficiency. [10]

3. Results and discussion

According with the statistical information about the sun light in México City, it can be determinate that the photovoltaic system is able to satisfy the electrical demand of PEM electrolyzer. Time of hydrogen production was studied based in the storage system. Considering losses in the photovoltaic system up to 20% by temperature, cables, inverter controller, among others, having available 7164KJ every day (1.99 KWhr/ day). [1]

It was analyzed the electrical behavior of the PEM electrolyzer at different pressures and a continual flow, 1x10^{-6} m^3/s as we can see in the figure 5.

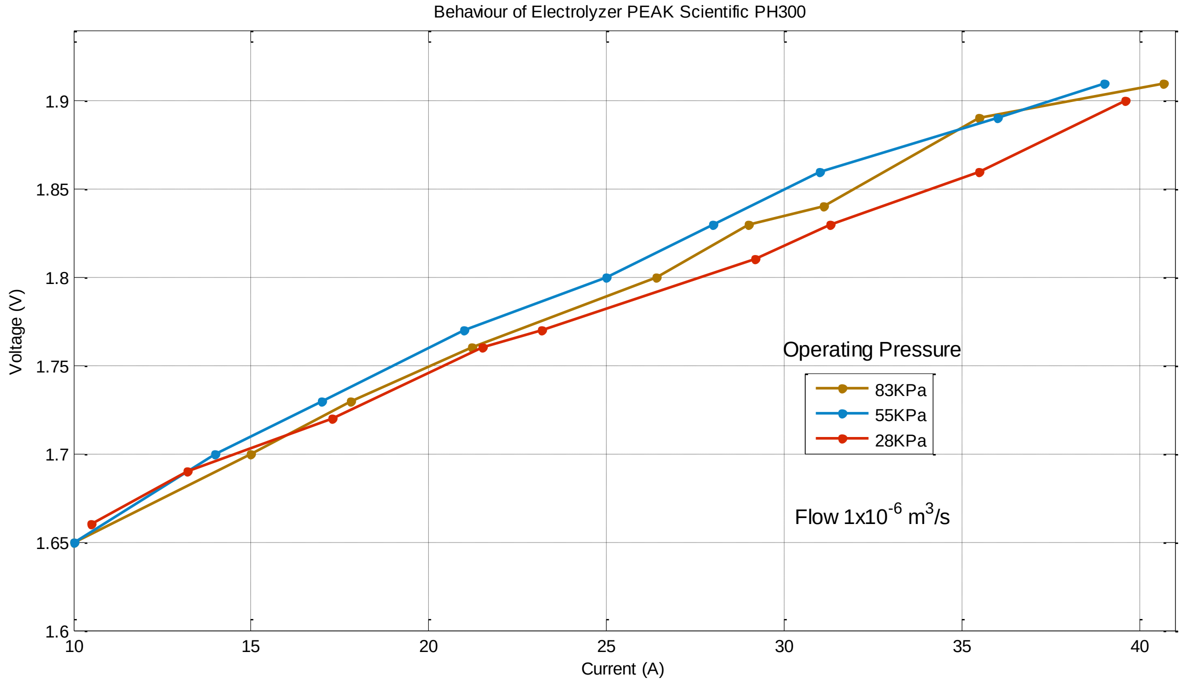

Fig 5. Electrolyzer PEAK scientific PH300 electrical behavior

We can appreciate in the graphic the PEM electrolyzer electrical behavior that is too similar at different pressures in a continual flow. It is able to understand that the operating pressure does not depend of the gases production. Analyzing the electrolyzer system and the gases production it was possible to determinate that the electrolyzer only controls the hydrogen production, where it works at maximum capacity 5x10^{-6} m^3/s until getting the selected pressure, thus the pressure is not relevant before obtained the selected pressure. It was found that it is really important that the equipment operate at 20% of hydrogen production, 1x10^{-6} m^3/s, for security and durability conditions.

For a correct operation of PEM electrolyzer, it was implemented a pressure regulator for the hydrogen delivery, it was made of resistant plastic, the regulator have an emergency valve, and a manometer. This regulator was implemented to control the electrolyzer system, avoiding algorithm mistakes in this. [7]

Understanding the electrical behavior in relation to the pressure it was studied the best operating pressure between 28KPa to 83KPa presented in the figure 6.

It was studied the delivery behavior at different pressures, the hydrogen deliver measure was made after the pressure regulator, changing considerably the behavior of it, compared with the oxygen delivery. As we can see the best delivery pressure is at 48KPa, however it was decided to work at 55KPa in relation to the stoichiometric oxygen production, getting a proportional gases delivery, reducing the time of recharge the storage system, considering that the minimum pressure to store is 3.6KPa.

According with the hydrogen and oxygen production and the storage system capacity, PEM electrolyzer operating at conditions before mentioned, it has to work for 16822 s (4.7hours) every day in relation to the photovoltaic system analysis, the system is able to provide enough electrical energy to perform this process part.

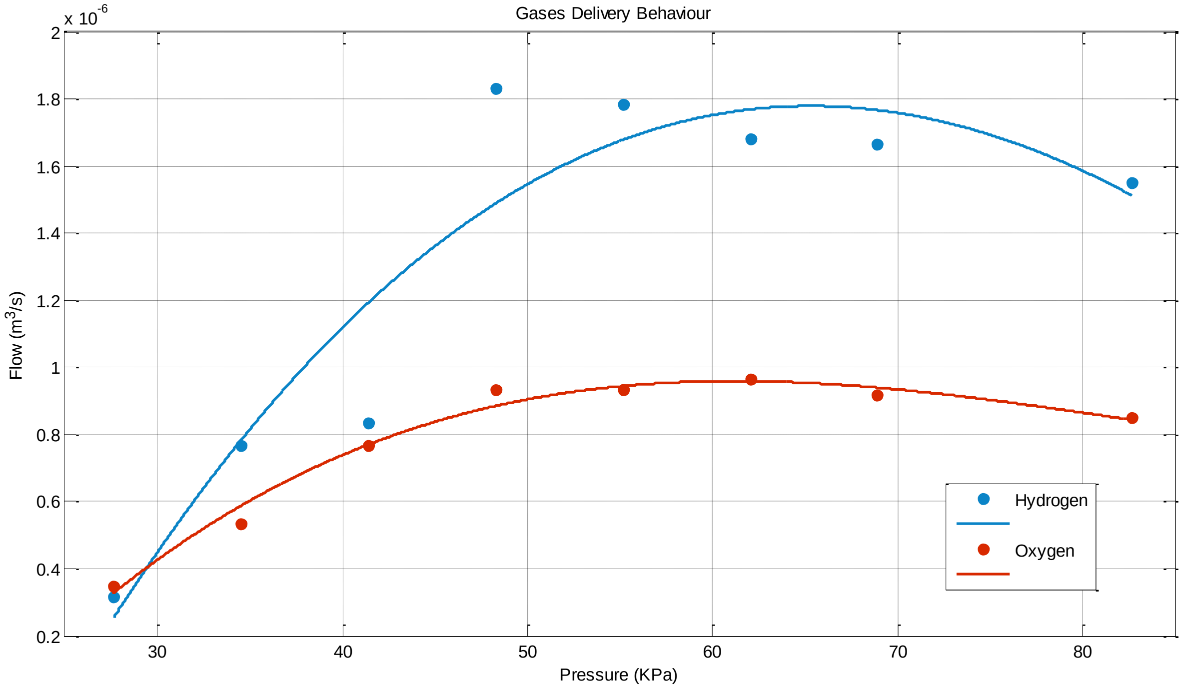

Fig 6. Gases delivery behavior

Mass quantity was analyzed from the hydrogen and oxygen storage, finding that the system is able to store only $9.5145x10^{-4}$ Kg of hydrogen and $7.5499x10^{-3}$ Kg of oxygen, proving the arduousness of store gases, principally hydrogen. In relation with these results and considering the intake gases, the quantity stored of it is sufficient only for 2400s (40minutes) of PEM fuel cell operation, for this reason this system is considering demonstrative and as an emergency lighting system. [5]

This was obtained using the ideal gases equation, taking in consideration that is a feasible equation because the gases are a low operating pressure and in relation with it their dew point is an extremely low temperature, far away from the operating temperature (295.15 K and 77.99KPa).[11]

$$PV = nRT \quad (1)$$

Schematic diagram was developed as we can see in the figure 7 where different connections and lines have been detailed that de global system requires for a correct and safe operation, in the table 3 they are explained. [7,12,13]

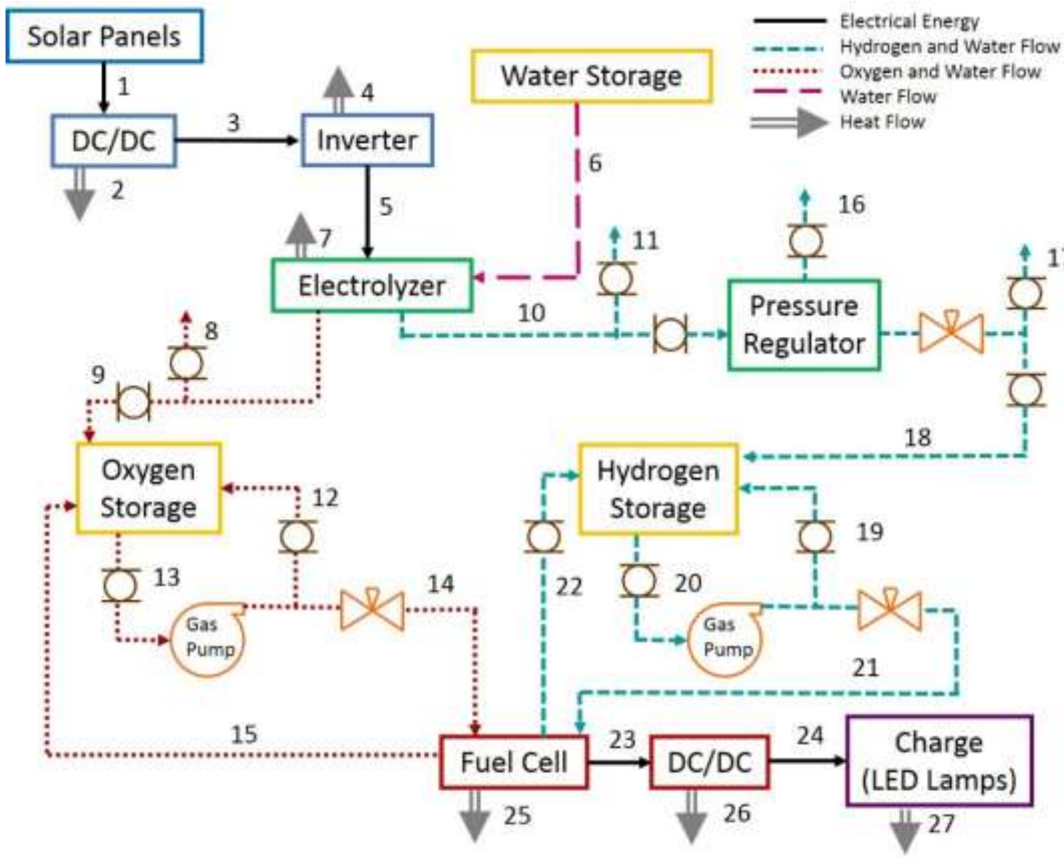

Fig 7. Photovoltaic-hydrogen system schematic diagram

Table 3. Information of photovoltaic-hydrogen system schematic diagram

Flow	Typology	Flow	Typology	Flow	Typology
1	Electrical Energy	10	H_2	19	H_2 Recirculation
2	Heat Flow	11	Purge	20	H_2
3	Electrical Energy	12	O_2 Recirculation	21	H_2 Regulated
4	Heat Flow	13	O_2	22	$H_2 + H_2O$ Recirculation
5	Electrical Energy	14	O_2 Regulated	23	Electrical Energy
6	H_2O	15	$O_2 + H_2O$ Recirculation	24	Electrical Energy
7	Heat Flow	16	Purge	25	Heat Flow
8	Purge	17	Purge	26	Heat Flow
9	O_2	18	H_2	27	Heat Flow

The de-ionized water line appears in colour pink, the hydrogen lines appears in blue and oxygen lines in colour red, in the diagram we can also see the heat flows, this flows are really important because they show the areas where the global system has a considerable energy loses. [7]

One of the important lines are the purge lines, these are really important because the operating gases have to be really pure to have a better electrochemical reaction mainly for hydrogen, it is really dangerous to have a combination of air and hydrogen, thus the system reduce the explosion risk. [7, 6]

For the global system was planned two recirculation lines for the hydrogen storage and two for the oxygen system, the first recirculations come to the pumps, this lines are important because they care the an excessive effort when the valves are not totally open. The second recirculations come to the fuel cell where there are the non-reaction gases with water. These lines save hydrogen and oxygen and increase fuel cell operation period. The diagram makes easier the operation of the system, and it allows to analyse the electrical process generation in the right way. [6]

We can see needle valves and pumps in colour orange, these system parts will be controlled by an automatic system, presented in the figure 8. It will be developed for gases regulation and it will allow to have a controlled system, therefore it will increase the precision of the fuel cell system. [12]

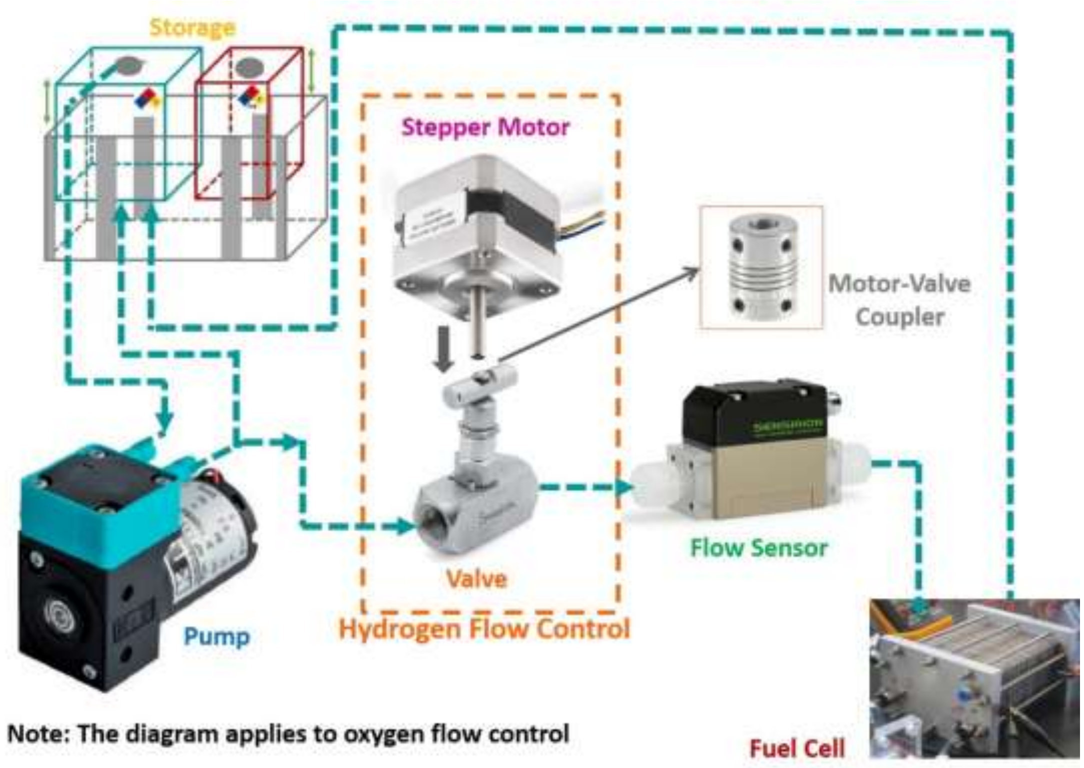

Fig 8. Gases regulation automatic control system

In the diagram we can see the different devices that the hydrogen line requires to be controlled in an automatically way, with the aim of supply a regulated and continual flow in the period time of fuel cell operation, the diagram applies to oxygen flow control. [12, 13, 14]

The automatic control system is a closed loop control or feedback control system, this type of control consists in a system that maintains a prescribed relationship between the output and the reference input by comparing them and using the difference as a means of control. In a closed-loop control system the actuating error signal, which is the difference between the input signal and the output signal, is fed to the controller so as to reduce the error and bring the output. [15]

The control regulation system is formed by a pump, it operates in a rage voltage from 5 to 12V, it will used when the storage system is not able to satisfy the selected flow, the system has a valve, this have a stepper motor which function will be regulate the gases flow to the PEM fuel cell, it is really important because it will allow that the system can be automatic. The system will have a flow sensor, this device is very important because it will measure the gases flow and the obtained information will be compared with the selected flow, thus the system will know if it is needed to increase the flow or reduce it. The sensor converts a physical variable, in this case the flow rate into an electrical signal which will be received for an integrated circuit. [6, 10, 15]

The mentioned system will allow to regulate the gases flow in a range of $1.67x10^{-7}$ m^3/s to $1.67x10^{-5}$ m^3/s, making possible work with different PEM fuel cells, the system will also control the gases flow in a relation with the operating time because where gases are stored it is a variable volume storage. When the gases are used, the flow rate supplied presents a decrement in relation with the time, and the automatic control system will right the gases flow rate. [7, 11]

It was obtained that PEM fuel cell at open circuit voltages is around 18 V with a capacity for 50W when is used $1.33x10^{-5}$ m^3/s of hydrogen flow and the measured maximum power density, W_{max}, is 150 W (14 A and 10.5 V) when is operated with $5x10^{-5}$ m^3/s of hydrogen flow. [9]

The PEM fuel cell was implemented to supply electrical energy for two LED lamps, each one consumes 25 W and operating optimal conditions are 12.5 V and 2 A. LED lamps was designed in order to be efficient, the high luminous efficiency was determined using LED’s of 1 W with an efficiency of 100 lm/W. It was used special regulator for LED´s arrangement. [5, 10]

4. Conclusions

In this paper, it was demonstrated how a photovoltaic-hydrogen system can be integrated with different devices that this requires for a correct performance with the aim to satisfy the electric power demand of low-power devices such as LED lamps. It was proposed a control and automation system with the aim of regulate the gases flow rate, allowing to used different PEM fuel cells and they can be regulated a constant flow rate.

Solar-hydrogen-fuel cell technology has an impact on the global energy international scenery. Note further that since the development of hydrogen system is a continuous effort, demonstrative hydrogen system may contribute to improving the role of hydrogen in society. Ignoring the existence of public support and acceptance would definitely lead to a misleading policy towards “green” solar hydrogen planning and its infrastructure management. Then, experience indicates that greater knowledge about renewables energies and hydrogen system can imply higher political, social and research support. Therefore, with better understanding, imply greater attitude to support a sustainable environment and hydrogen technology, which can consistently involve greater support for the applications of hydrogen and hybrid systems.

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