

DEVELOPMENT OF A CABINET BASED ON FUEL CELL TECHNOLOGY AND SOLAR ENERGY

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Abstract. *In recent years, there has been intensive research on clean and renewable energy production. Two main reasons have been pointed out: pollution caused by oil fuels consumption and their depletion, which increases their production costs. Fuel Cells have shown to be a clean and renewable energy source, which turns them into a promising solution, although technology hurdles still need to be overcome. Fuel Cells produce electricity, water and heat consuming hydrogen and pure oxygen or air. This prototype combines different components to produce a fuel cell and solar driven based cabinet for energy production, which is a Regenerative Fuel Cell System (RFC) with the potential for space applications. The system contains: a photovoltaic panel, a charge controller, 4 batteries, a DC/AC current inverter, a fuel cell stack and a hydrogen storage bottle. The photovoltaic panel charges the batteries, while the charge controller controls the batteries loading. Batteries are connected to a DC/AC inverter. The inverter is connected to the fuel cell control system, which controls the hydrogen consumption in order to produce the necessary output power. The system proved to be efficient and capable to use renewable energy sources (solar and fuel cell technology) in a cabinet. It is also possible to transform this prototype into a sustainable system just installing an Electrolyzer, which will produce the hydrogen required to run the fuel cell stack.*

Keywords: *Regenerative Fuel Cell System, solar driven cabinet.*

1. INTRODUCTION

The goals of this project are to design and build a cabinet that could be used to run electronic packages using renewable energy sources. In other words the system is able to generate its own energy, combining two different energy sources (hydrogen and solar energy). Each source will be used for specific situations, which will be further discussed in this paper.

First the control system configuration and all the different operating possibilities are explained. After that the results obtained for arrangement of system's parts are showed and discussed and finally the necessary improvements are presented.

2. METHODOLOGY

2.1 The system

The Photovoltaic Panel under sun incidence charges the batteries. This charging is controlled by the Xantrex equipment.

There are several different operating possibilities in the system, which will depend on the combination of the following parameters: batteries charge, hydrogen cylinder pressure, and sun incidence. All the different working possibilities are a product of the combination of the positions on and off (closed and opened) of the 7 circuit breakers in the system (abbreviated as S1, S2, S3, S4, S5, S6 and S7). The system's layout is seen in Fig. 1.

The discussion starts with the operating regimes under sun incidence.

The first working possibility is when there is sun light, the batteries are fully charged and the hydrogen cylinder pressure is acceptable (inside the interval of 80 and 200 psi). In this case the fan will be fed by the electric energy produced by the NEXA Fuel Stack. Only S1, S4 and S5 will be opened while S2, S3, S6 and S7 will be closed.

The second possibility is when the hydrogen pressure is below the lower limit (80 psi), there is sun light and the batteries voltage is above 12.5V. Then the electrolyzer produces hydrogen that reloads the cylinder while the batteries feed the fan. The electrolyzer is fed by the batteries, but the first one needs 110V alternating current to work, as the batteries produce 12V direct current, therefore it is necessary the presence of the inverter. In this case S1, S3 and S6 will be opened while S2, S4, S5 and S7 will be closed.

Other possibility is when the batteries voltage is critical (i.e., between 12.5 and 11.5 V), the hydrogen cylinder pressure is acceptable and there is sun light, then the Xantrex charges the batteries and the NEXA Stack feeds the fan. Then S1, S2, S3, S6 and S7 will be closed and only S4 and S5 will be opened.

Another possibility is when the charge level of the batteries is not below 11.5 V, there is sun light and the hydrogen cylinder pressure is below the lower limit. In this case, the Xantrex keeps recharging the batteries, both electrolyzer and

fuel cell stack are not fed and the fan is fed by the batteries. When this happens, S1, S5 and S7 will be closed while the rest of the circuit breakers will be opened.

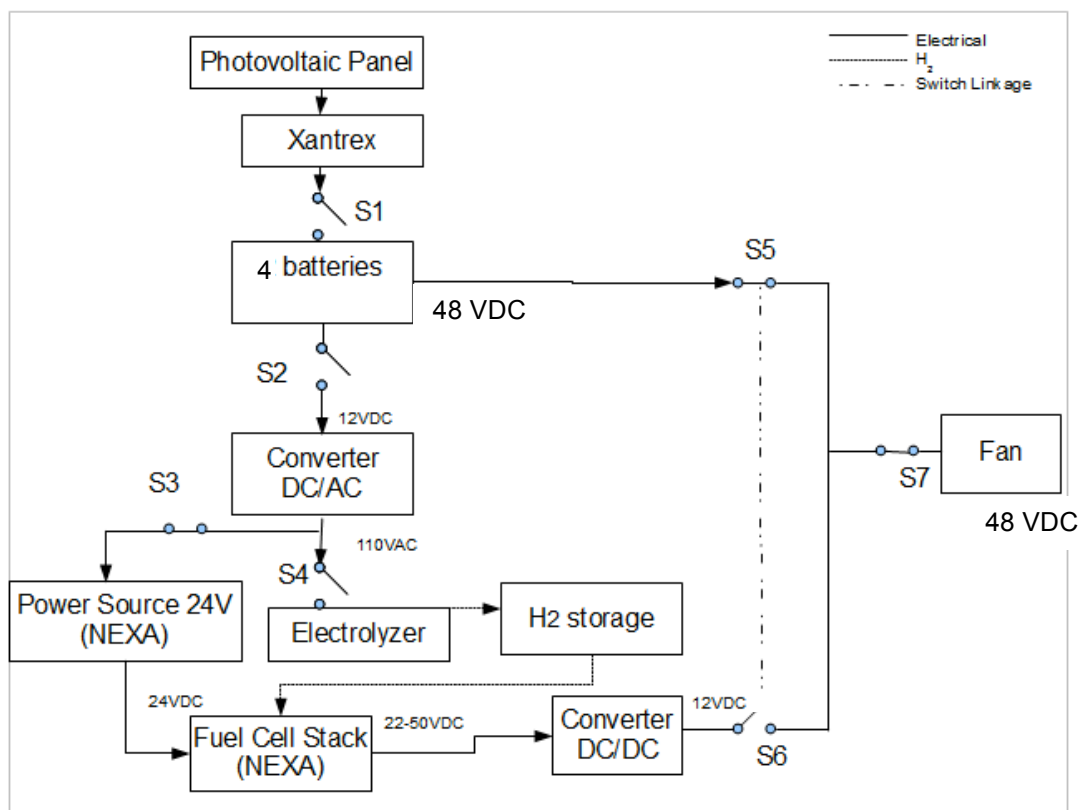


Figure 1. Control System Layout.

The last possibility is when the batteries voltage is below 11.5 V. When this happens, only the Xantrex charges the batteries and the rest of the system has to be off. Therefore only S1 will be closed and others circuit breakers will be opened.

A detail that cannot be forgotten is that every time the NEXA fuel cell stack feeds the fan, the DC/DC converter is needed, because of the fact that the NEXA's output is a function of the hydrogen's incoming pressure and the load required (in the present study the fan working load). In other words, the DC/DC converter converts the output stack voltage (22-50V) to the fan input voltage 48 V.

Another detail is that when hydrogen is needed for the fuel cell stack, a pressure regulating valve must be regulated to the required pressure (80 psi).

In the absence of sun incidence, the fan is powered by the fuel cell stack until the hydrogen storage bottle pressure level drops below 80 psi. Upon hydrogen shortage, the batteries take over until the sun appears again, and the system enters the sun incidence mode, according to the previously discussed alternatives.

2.2 Hydrogen Storage

The hydrogen storage is one of the essential parts of the system and, due to its complexity, will be explained individually and separated from the whole system. First of all, to guarantee the hydrogen's purity, it is necessary to create vacuum at the line where the hydrogen flows, inside the storage system. In order to do that a "Tecnal TE-068" Vacuum Pump is used. The hydrogen's final storage is made in a cylinder with capacity of 0.007 m³ (in water volume). The pressure inside reaches a maximum of 200 psi, due to the electrolyzer's capacity. To make sure that the H₂ does not return both to the vacuum pump and the electrolyzer, check valves and block valves were installed along the line. This also guarantees that H₂ is not wasted in the process. For safety measures, safe fire valves were installed too, and, in order to measure the hydrogen pressure on the line, the same was done to a manometer. The storage line also serves to feed the Ballard stack with hydrogen. In the present case the fuel cell stack's working pressure is constant and set to 80 psi.

3. RESULTS

3.1 Solar Panel – Xantrex – Batteries

The Solar Panel charges the batteries as the Xantrex control the operation. In a day with high solar irradiation, by 3 PM, during the execution of a test, the batteries had been charged by a voltage around 13.5V and a maximum current of 2.45A. The current ranged between 2.39V and 2.45V, as the solar light presence was more or less intense.

3.2 Batteries – Inverter – Electrolyzer

In order to load the cylinder, the inverter's presence is necessary. The electrolyzer needs to be fed by 110 VAC, as the batteries deliver 12VDC. To solve this, a DC/AC inverter (12V to 110V) was used. In the experiment, the batteries were placed in parallel and had initially 12.41V. In its warm-up (that takes approximately 64 minutes), the electrolyzer consumed a current of 1.05A. After that, it began to produce hydrogen to its inner tank, until it reached the desired pressure (200 psi). This stage lasts 5 minutes and consumes a current of 3.24 A. The maintenance of the hydrogen flow also consumes 3.24 A and depends also on the load demand. The total test time was 78 minutes and the final voltage of the batteries was 11.99V.

3.3 Stack's Output – Converter – Fan's Input

When there is an acceptable hydrogen pressure inside the cylinder, the fans are fed by the Ballard stack. However, this stack produces a voltage that varies between 22V and 50V. Therefore, a DC/DC converter with a 12V output is needed. In this experiment, the Ballard stack was supplied by a pressure of 100 psi, and provided enough energy to the fan's operation. The fan, in 30 minutes, consumed 12 liters of hydrogen at standard conditions of temperature and pressure, which means 0.4 liters per minute.

The current that passed by the fan was 0.34 A, while the current that was demanded by the Ballard was 0.14A (both direct currents). The cell's work voltage varied from 36.6 V to 36.7 V, as the voltage applied to the fan was 47.9V.

4. DISCUSSION

The results obtained after the conclusion of all experiments, in general, complied with the expectations showing the feasibility of the cabinet. The batteries' charge is enough to feed the fan, although the batteries charging (2.45A) is much lower than its discharging when they are feeding both the fan and the electrolyzer. The batteries have also proven to provide enough energy for the electrolyzer's warm up and filling up.

The HOGEN electrolyzer used in the first prototype configuration releases the oxygen produced during the electrolysis to the atmosphere. For this reason, air or oxygen from an external source are required to feed the fuel cell stack. The water vapor produced by the fuel cell stack is also released to the atmosphere. Therefore, for space applications, the first prototype is not ready yet. For achieving that goal, an electrolyzer that allows the oxygen to be stored, and a fuel cell stack that allows the water vapor to be condensed and returned to the electrolyzer for consumption will be required. Those items were not available commercially to this project. However, it is a matter of developing the specific items as described to produce a system that allows for a closed water cycle, with a minimum of make-up water, for space applications.

5. NEW DEVELOPMENT

5.1 Current prototype

The Photovoltaic Panel under sun incidence charges the 12 volts batteries. This charging is controlled by the charger controller.

There are basically two different operating possibilities in the system, the first one is using the batteries charge to generate the desired output power, and the second is generate this power by the electric energy produced by the NEXA Fuel Stack. However the selection of which arrangement will be used depends on the combination of the following parameters: batteries charge, hydrogen cylinder pressure, and sun incidence. These two different working possibilities are controlled by a manual switch, as shown in Fig. 3, which controls the electrical flow. The system's layout is seen in Fig. 4.



Figure 2. Manual switch (left), fuel cell control system (center), and internal view (right).

The manual switch has the function to command the arrangement of the 4 batteries. The batteries can be connected in series, delivering an output voltage of 48 VDC; or in parallel, delivering an output voltage of 12 VDC.

Selecting the series arrangement the loads will be fed by the batteries charge since their voltage requirement is 48 VDC. This mode can be used when there is sun light and the batteries are fully charged. On the other hand, when the batteries voltage is critical or during bad weather conditions (cloudy days or night time) the best option is to arrange the batteries in parallel in order to generate electricity using the fuel cell stack. By connecting the batteries in parallel an electrical potential of 12 VDC is supplied, but the fuel cell control system in Fig. 1 needs 110V alternating current to work. Since the batteries produce 12V direct current, it is necessary the presence of the inverter.

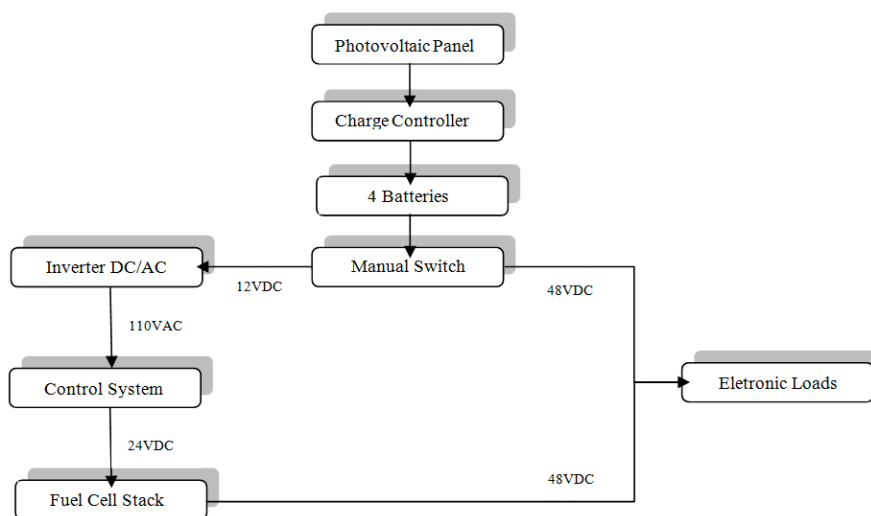


Figure 3. Current System's layout.

The cabinet also has 4 cutout switches to protect each battery and several timed breakers used to connect the batteries in series or parallel according to the position of the manual switch.

5.2 Future Improvements

In order to close the energy cycle and transform the current system into a sustainable cabinet, the electrolyzer will be reconnected with the system. The produced hydrogen will supply the fuel cell stack and the oxygen will be obtained directly from the atmosphere. When energy is not required by the load, hydrogen is stored in the hydrogen bottle for later consumption on demand.

Another possible future change will be to replace the 12/110 V inverter by a 48/110 V one, working with the batteries in series in order to increase the system's efficiency.

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7. RESPONSIBILITY NOTICE

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