LUCIS: A Learning Experience to Improve Lifetime and Operating Strategies in Low Power PEM Fuel Cells

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Abstract

LUCIS, a demonstration project co-financed by the Innovation Agency in Portugal (AdI), was carried out in the framework of the DEMTEC Programme (Incentives to Technologically Innovative Pilot Systems). Its main goals were: Validate the reliability of proton exchange membrane fuel cells (PEMFC) when used in practical situations and the competitive advantages that these solutions can represent compared to conventional solutions; Evaluate impacts associated with the use of hydrogen and the benefits to business competitiveness. This project allowed a learning experience in real applications of low power PEMFC. Demonstrations were grouped in two large categories that covered several applications of PEMFC. The prototypes used were produced by SRE (Portugal) and were specifically designed to be used in small power applications, portable, traction or stationary. In this work, the technological validation was carried out for different stacks with power from 10 to 100W. Hydrogen was supplied by compressed gas bottles and metallic hydrides. All the fuel cells were previously characterized in specialized laboratories. Recommendations were drawn for every application in order to improve fuel cell lifetime and operating strategies.

Keywords: *PEMFC; hydrogen; battery charger; power supply; demonstration projects*

1 Introduction

1.1 The New Energy Paradigm - The role of Hydrogen

The energy industry, motivated by the recent increases in the fossil fuels costs, works toward an adjustment of the role of traditional technologies. This creates an opportunity for the emergence of new technologies and redefining the scope and nature of government regulations. Moreover, the requirements for reduction/ elimination of gaseous emissions (particularly carbon dioxide) that contribute to the greenhouse effect, question the existing energetic platforms and impose the need to search for energy supply new solutions that are not dependent on fossil fuels, creating, therefore, a new energy paradigm.

The need of that new model comes from the interaction of the following propelling forces [1]:

- The emerging technologies that can provide sources of distributed generation with benefits not available to traditional and centralized energy sources;
- An increase in the concerns regarding the energy supply security is associated to the vulnerability of the centralized energy production to accidents or sabotage;
- The inevitable emergence of more environmental constraints in energy production, since this represents an important part in local and global pollution.

In the emerging energy paradigm the hydrogen will play, in the future, an important role in order to optimize renewable energies use since that, in addition to the source also the carrier or energy vector must be as far as possible, clean and safe [1,2].

Indeed, the historic evolution of fuel usage has taken to increase the ratio of hydrogen, and the result should, in theory, reach the use of pure hydrogen as a fuel.

The hydrogen is potentially a clean energy vector, whose calorific value is three times higher than oil and its use will contribute to the requirement of reduction/elimination of greenhouse gas emissions. Therefore it's essential to disseminate information in order to promote hydrogen as an inexhaustible, clean and renewable energy source that will minimize economic, political and environmental problems that arise from use of fossil fuels[1]. Moreover, as fuel cell technology matures and the time for commercialization decreases, test on reliability and durability of fuel cells are felt necessary.

1.2 The LUCIS Project

The LUCIS project - Demonstration of Hydrogen Fuel Cell in real environment, under DEMTEC - Incentives System for Implementation of Pilot Projects Related to Products, Processes and Systems Technologies, had the purpose of demonstrating the potential of the technology related with hydrogen as energy vector, through fuel cells (FC).

The project allowed the implementation of hydrogen fuel cells for use as battery chargers or as a power supply (replacement of battery), for 4 different demonstrator entities, with the aim of:

- validate the reliability of current technology for applications in real environment;
- evaluate competitive advantages against other conventional solutions;
- evaluate impacts of logistics, related to the conditions of hydrogen supply;
- evaluate business, social and cultural impacts associated with the implementation of hydrogen as fuel;
- evaluate the advantages of fuel cell use for both business competitiveness and the Economy, taking into account the market dimension;
- identify problems associated with performance, the system behavior in real situation, and suggest solutions for promoting the dissemination of its application in each demonstrator.

This paper reports on the results obtained from the monitoring of power systems using fuel cells, which were implemented in a real environment under the LUCIS project.

The fuel cells were produced by SRE (Portuguese manufacturer) and were specifically designed to be used in small power applications, portable, traction or stationary.

In SRE fuel cells the air (oxidant) is supplied by a fan of low consumption which allows the cooling of the cathode and water removal. Dry hydrogen (fuel) is supplied at 200 mbar. The operating temperatures are normally below 30 ºC. Normally these technologies operate under pressure, i.e. there is a control that allows the admission of hydrogen according to the required voltage. The stack for 100 W (HW-125) incorporates a battery buffer with capacity 10Ah/24V to startup. Furthermore, they have a digital display that indicates the voltage of the stack and of the battery.

2 Demonstration Projects and Results

The selected demonstrations covered a wide range of illustrative examples of the potential of FC as shown in Table 1.

Table 1 Demostration Projects in the framework of the LUCIS project

	Demonstration Project	*Demonstrator*	*Power (W)*
1	Back-up/UPS Communication systems (SNPC)	CMTV	200
2	Video surveillance	AEA	200
3	Battery charger	AUTOSIL	200
4	Traffic lights	CMTV	200
5	Back-up (emergency lighting)	INETI	200
6	UPS - Power Supply for a lab. bench	INETI	200

Moreover, the demonstrations were grouped in two large categories, with applications of fuel cells as battery substitutes and as battery chargers.

3.1 PEM fuel cells as battery charger

3.1.1 Back-up/UPS of communication systems for Civil Protection (SNPC)

Torres Vedras City Hall (CMTV) in its promotion for environmental protection and integration of renewable energy (Torres Vedras has one of the most significant wind farms in Portugal), includes the use of hydrogen as an energy vector. In this context, a demonstration project was promoted, see table 1, with the objective of testing a FC as a source of backup, particularly for situations where it was intended to have large autonomy systems, such as in the National Office of Communications Civil Protection.

The system is currently composed by a radio and a battery that usually has to be connected to a conventional energy source.

The new solution contemplates the integration of Battery + Fuel Cell + Photovoltaic Panel. The photovoltaic panel will aim to simplify the logistics of hydrogen involved in this project.

The systems were installed in the area of Torres Vedras, distributed by four entities: the GNR, the PSP, the Fire Department and City Hall.

3.1.2 Video Surveillance in highway A8 (AEA)

AEA, Autoestradas do Atlântico, is a highway concessionaire interested in promoting powering of their video surveillance system using FC in addition to solar photovoltaic systems and wind power, see figure 1.

The photovoltaic panel is the primary source of energy that will ensure the supply of energy in the system. Since the energy captured by the sun and wind is not available in most of the day, the FC system comes as a secondary source to the video surveillance systems. Four posts are covered in this project with the following advantages:

- with the use of an integrated photovoltaic (PV)/hydrogen fuel cell (FC), it is possible to optimise the rate of availability and reliability of the energy supply system in remote locations,

- the use of PV system/FC reduces the huge costs that results from the over sizing of the PV panels, especially when an availability and reliability rate of more than 90% is sought,

- the integrated system will reduce the capacity of accumulators, which is usually extremely high when it is used for the photovoltaic panel's solution.

Fig.1 AEA demonstration project site. Fuel cell installation is also shown.

Another demonstration of fuel cells as battery chargers was made at AUTOSIL, a Portuguese company that manufacture batteries, as battery-starters (car) and industrial batteries. The project entails the simultaneous charging of a number of batteries (10) with a capacity of about 25Ah/12V. SRE 200 W power supplies with 12 V stabilized output were used.

The use of FC as a battery charger allows more flexibility in its use.

3.2 PEMFC as battery substitutes

3.2.1 Traffic lights for road works (CMTV)

A new solution for the powering of traffic lights used in road works is the replacement of the battery by a power source with maximum power output of 200 W and stabilized to 12 V. The solution includes a battery 'buffer' of 25 Ah/24V.
The application uses compressed hydrogen of the type 20H, with a capacity of 3.5 m^3. The system autonomy was extended to 36 hours.

Fig.2 Traffic Lights Demonstration Project showing fuel cell and hydrogen storage.

3.2.1 Backup systems for emergency lighting (INETI)

INETI is a National Research Institute for Engineering, Technology and Innovation with the mission of promoting technological innovation for business development and contribute to increase competitiveness in the context of a sustainable progress of the economy in Portugal.

A demonstration of a replacement of a battery for a FC/H_2 system was done at INETI.

Emergency exit lightening is usually associated with a big capacity batteries or a modest autonomy. The emergency lightening system under study, include the use of 3.6V NiCd batteries, with a storage capacity of 4Ah. A general view of the interior of the cases of the emergency light is shown in figure 6a).

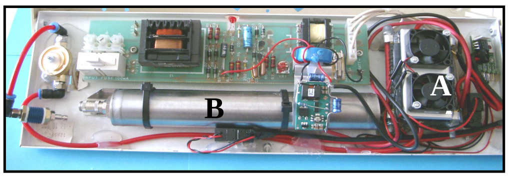
The use of FC as backup system for emergency lighting is a way to extend the autonomy of the system and avoid the use of toxic batteries.

The replacement of the energy system in the emergency lightening was carried out replacing the NiCd battery and introducing a fuel cell (A) connected with a hydrogen storage system based on metal hydrides (B), figure 6b). Figure 6c) shows the schematic drawing of the corresponding electrical circuit.

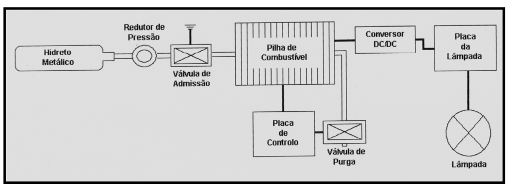
In absence of electric current the hydrogen fuel cells will provide the lightening of the emergency exit with no lag time.

In this case the system with hydrogen fuel cells can enlarge the system autonomy and give others advantage such as easier logistic and maintenance of the battery.

(a)



(b)



(c)

Figure 6 – Inside of the emergency lightening with a battery as energy source (a); Replacement of the battery for (A) fuel cell - (B) hydrogen storage system (b); general schematics of the electrical circuit of the system (c).

The fuel cell used was a 16SR4 with technology PEM, assembled with 16 cells in series with a nominal power of 15W and a reaction area of 3.8cm^2 per MEA. The capacity of the metal hydride storage is of 50NL H2.

3.2.2 UPS- Power Supply for a lab. bench

The demonstration aims to validate PEM fuel cells use as a replacement battery for an UPS installed in the Electrochemistry laboratory to feed a laboratory bench, devoted to polarization curves and impedance spectroscopy measurements. The main objective was to extend the current system autonomy (6 hours), in order to find compatibilities with the time necessary for critical laboratory experiences.

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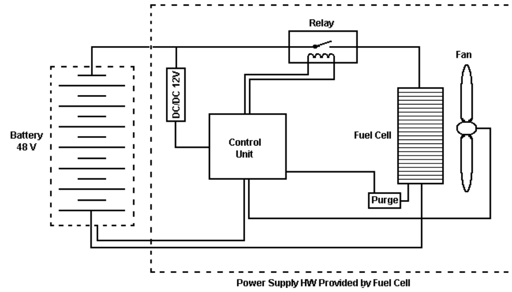

Figure 7. Schematic drawing of the electrical circuit for a UPS- Power supply for a laboratory bench.

3.3 Other demonstration projects

Albufeira City Hall promoting energy efficiency and environmental protection engaged in four demonstration projects in the LUCIS scope:

Power supply to the Vice-president office: Demonstration of FC as back-up power/UPS. The solution ensured the supply of electricity for lighting. The power was estimated in 200 W, with peak values of 500 W. For SRE this represented a major test to their product with the objective of approaching other markets.

Powering water pumps and lighting: Electrical power is supplied to 12 light projectors and the water pump used in a fountain. The implemented system consists of a hybrid system with a photovoltaic panel and a fuel cell of 400 W with an inverter.

Lamps for street lighting: Powering two lamps for lighting of the public car park opposite the City Hall of Albufeira. The implemented system consists of a hybrid system with a photovoltaic panel and a fuel cell.

Kid Kart: Recharging of the internal battery and powering the engine of a kid kart. The system implemented under this project consists of a hybrid system of a photovoltaic panel and a PEM fuel cell.

Figure 8 Kid Kart and implemented hybrid fuel cell system.

The study of several HW-125 fuel cell systems (before its installation on different demonstrations) was done at INETI´s and INEGI's fuel cell laboratories.

4. Discussion of the Results

4.1 The Technology

The main characteristics of the developed PEM technology [3,4]:

- Hydrogen supply in dead-end mode, with periodical purges,
- Use of low pressure non-modified hydrogen,
- Optimized flow field configuration for maximum stack performance and stability,
- Axial flow channels for air supply to the cathode and simultaneous cooling of the stack,
- Low operating temperatures
- Passive water management

4.2 Detected anomalies

When batteries were substituted by fuel cells, polarity inversion of the last stack cells was detected, this is thought to be due to poor water management, excessive water and flooding, associated to hydrogen starvation.

The polarity reversal in cell operation is probably due to water electrolysis that might take place in the last stack cells and can permanently damage the fuel cell.

This anomaly occurs, generally, when the fuel cell plays the role of power source rather than in the case of battery charger.
This problem can be overtaken if: the diodes for fuel cell protection are reinforced; if a control of the hydrogen storage (pressure and flux) is implemented, so minimizing the possibility of starvation.

4.3 Issues to be considered in future developments

Fuel cells proved to be excellent candidates for the replacement of batteries, with minimal management.

The tests in conditions of low temperature operation revealed that start-up is not affected by long periods of non-operation, even if the optimal working temperature was ~ 40ºC the start-up time was less than 1 minute.

In all performed tests, the peripherical cells of the stack presented voltage values lower than central cells. The stack polarization curve shows that it is affected by the fuel cell position; a horizontal position was found more favourable. It is suggested that a gravity effect contributes for excessive water accumulation at the open cathode.It is suggested that for a low power fuel cell where water management is done in a passive fashion, the relative position of cathode can be relevant. This is also related with polarity reversal phenomenon as described in section 4.2.

Autonomy of the systems was limited by the choice of the storage method (4.5 h in the case of the emergency lights)

The need for the adoption of efficient logistics for hydrogen supply was felt.

In many of the demonstrated applications fuel cells will be in *stand-by* for long periods of time. In order to verify reliability of the systems periodic testing is suggested.

4.4 Storage Solutions and Competitive Advantages

Tables 2 and 3 present the used storage solutions and competitive advantages regarding conventional solutions for all validated applications.

Table 2 Storage solutions used for implemented applications of fuel cells.

Project	***Storage solutions***
Fuel cell as a battery charger - AUTOSIL	H_2 bottles 200 bar /200L NH_2,
Emergency lights - INETI	Metallic Hydrides, 50 L NH2 capacity
Back-up system SNPC- CMTVD	H_2 bottles 200 bars; capacity 1m^3 NH2.
Traffic lights - CMTVD	H_2 bottles 200 bars; capacity 200L NH_2
Video surveillance - AEA	2 H_2 bottles; 200 bar, 9m^3 NH_2,

Table 3 Competitive advantage Vs. conventional solutions when using fuel cells in validated applications.

Project	*Competitive advantage vs. Conventional solution*
Fuel cell as a battery charger- AUTOSIL	Gain in O&M allowing charging of batteries with a portable system.
Emergency lights- INETI	Gains in O&M. Substitution of toxic batteries, NiCd in the present case. Extended autonomy and simplicity in the recharging of the system
Back-up system SNPC- CMTVD	Autonomy extension of the system in black-out circumstances
Traffic lights- CMTVD	Gains in O&M. Eliminating the need of recharging of the battery
Video surveillance - AEA	Economic advantages, avoiding over dimensioning of renewable power sources. Expected increase in the reliability of the proposed hybrid solution.

5. Conclusions

The first studies made in the scope of this Project were related with the performance of HW-125 fuel cells assembled in SRE – Soluções Racionais de Energia, for which the global project had great importance, once it allowed to test their technology in real situations.

The studies, conducted by INETI's specialized teams, demonstrated that the SRE's fuel cells were affected by conditions such as pressure, flux, humidification, reagents gases and temperature.

HW-125, when used as battery recharger, was stable, being also observed continuity in its current and in the power delivered. Fuel cells optimum operating temperature is around 40 ºC, the performed tests proved that when used at room temperature its start-up isn't affect, having a duration inferior to a minute. Besides that, the battery incorporation (never totally discharged) allows a quick fuel cell start-up. However, is suggested a reliability improvement through elimination of configuration problems and in the parameterization of the charge controller, as well as polarity inversion. Nevertheless, in the present test phase, it was not possible to conclude about the reliability for the commercial usage of this kind of technology.

When HW-125 fuel cell is used as power supply problems appear being essential to overpass them: the durability and reliability must be assured and the problems related with water accumulation due to the fuel lack in the last cell of the stack are in the origin of polarities inversion. It is suggested that to suppress these problems, diodes reinforcement and hydrogen level control in the vessel should be implemented.

This systems comparing to the conventional ones are, from an environmental point of view, an improvement because of the absence of gas emissions (formed by harmful or greenhouse gases). Like expected, being portable allow the transport to remote places and, inclusively, are proper to integrated with energy production solutions. Yet, the autonomy extensions of this kind of systems are always related with the storage capability and/or local hydrogen generation.

Concerning the proposed goals for each demonstrator, the applicability of fuel cells technology outside of a laboratory environment, was demonstrated with excellent results:

- For AUTOSIL, the project has proved an increase in their batteries performance, since their local recharge becomes feasible. These brings advantages from an economic point of view, avoiding significant higher costs from the fuels used to feed an internal combustion engine. Because AUTOSIL chargers aren't an important part of his sails, they consider the hypothesis of an integrated solution with hydrogen production through renewables, instead of the single application of fuel cells as battery chargers.

- For INETI, as demonstrator and responsible for monitoring the several installed systems, the project had a huge interest given that it was seen as a natural extension of previous research work. In relation with the emergency lights systems, it is suggested the implementation of a system that favours the management of emergency lights in the whole building. The storage system should be converted in an autonomous system that allows a better maintenance.

- For demonstrations developed for Torres Vedras City Hall, a higher autonomy for backup systems for Civil Protection National Service and the possibility to eliminate periodic battery recharges, in case of traffic lights, were guaranteed.

- For video surveillance system, the achieved results had demonstrated the existence of major advantages, from an economic point of view, since it avoided the over dimensioning of photovoltaic panels.

- Generally, the installed systems autonomy is directly dependent of the local hydrogen storage/generation capability, which imposes an efficient supply logistics.

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