DEVELOPMENT TO TECHNOLOGY READINESS LEVEL 9 OF THE CONTROL AND MONITORING TECHNOLOGY OF AN AIR-COOLED PEM FUEL CELL

Bruno Bueno Furquim [1]; Fabio da Silva Teixeira [2]; Ugo Ibusuki [3]

[1]*Engineering, Modeling and Applied Social Sciences, Federal University of ABC, Santo André, Brazil, bruno.furquim@aluno.ufabc.edu.br;*
[2] *Engineering, Modeling and Applied Social Sciences, Federal University of ABC, Santo André, Brazil, fabio.t@aluno.ufabc.edu.br*
[3]*Engineering, Modeling and Applied Social Sciences, Federal University of ABC, Santo André, Brazil, ugo.ibusuki@ufabc.edu.br*

ABSTRACT

This document outlines a proposal to raise the maturity of a monitoring and control system designed for hydrogen fuel cells with natural air cooling, advancing from TRL 5 to TRL 9 within the automotive sector. The primary goal is to guarantee optimal performance and efficiency during full operation, all while establishing a dependable supply chain for essential components. Moreover, dedicated efforts are aimed at enhancing the reliability and scalability of this technology, offering distinct advantages for streamlined series production that supports Full Cell Electric Vehicles (FCEVs). This, in turn, simplifies their seamless integration with electric powertrain systems in diverse urban and industrial transport environments.

Keywords: Fuel Cell, Hydrogen, Electric Vehicles, Efficiency, Technology Readiness Level.

Introduction

Reducing dependence on fossil fuels and the search for safe, environmentally friendly, and reliable energy supplies are essential for humanity, sustainability, and a high quality of life. With this, the research and development of hydrogen application currently receives high involvement from the private sector [1] and governments around the world [2][3]. The growing interest in hydrogen is also clearly reflected in the scientific literature, as demonstrated by the number of annual publications that has increased elevenfold over a 20-year period [4].

On a global scale, hydrogen is expected to play a significant role in achieving net zero emissions by 2050 [5]. During COP26, the United Nations (UN) climate conference, the Brazilian government presented a new goal of reducing greenhouse gas emissions by 50% by 2030 and neutralizing carbon emissions by 2050. As also government announcements from major industrialized countries around the world and policy programs to promote hydrogen-based technologies [6].

Among the hydrogen-based technologies is the proton exchange membrane fuel cell (PEMFC), an efficient energy converter that converts hydrogen and oxygen into water and electricity. It has been developed for various applications, including portable applications, land transport, and stationary power generation [7]. The PEMFC is a complex system consisting of different components that can be influenced by many factors, such as material properties, geometric design operating conditions and finally in control strategies, which will be improved in the development of this project.

DOI: 10.55592/ISE.2023.3675628

The TRL Maturity Levels

Technology Readiness Level (TRL) is a method used to assess the technical maturity of our technology and facilitate understanding of the phases needed to move forward in the process towards market, described in Fig 1 [18].

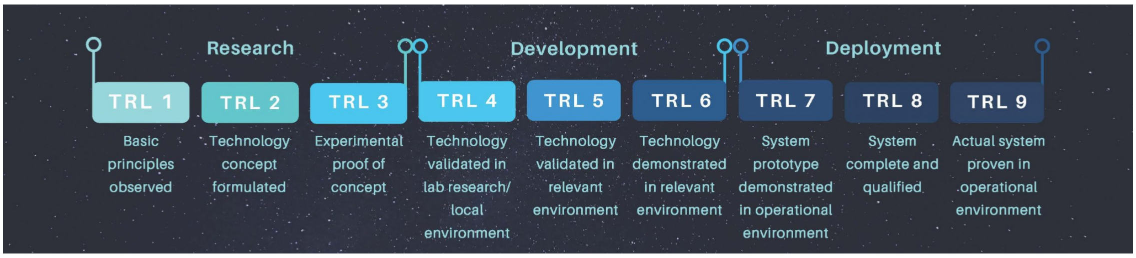

Figure 1 - Phases and state of the art in levels of technological maturity.

In general, TRL definition are: ideation (TRL 1), conception (TRL 2), proof of concept of critical function (TRL 3), optimization (TRL 4), prototyping (TRL 5) and scale-up (TRL 6), demonstration in production environment (TRL 7), production (TRL 8), continued production (TRL 9). It can thus be seen that the TRL scale encompasses the various phases of a Research, Development and Innovation (RD&I) Project program from which our project will follow for its full development.

What has been developed so far by the members of our project, the same ones that currently make up the Challenger team at UFABC fits TRL 5 prototyping, since the basic technological components were integrated with the Ballard Model 1020ACS fuel cell, through laboratory testing and documented performance testing.

Therefore, for the monitoring and control system to achieve continuous production (TRL 9) it will be necessary to prove that the technology works in its final form, and under expected conditions. A fully completed, tested, qualified and demonstrated system that is produced in an industrial environment with performance achieved to specification, without the need for adjustments to the product or production process, maintaining its configuration in all required operational requirements and specifications.

Methodology

High-pressure system

A hydrogen fuel cell system comprises interconnected components for efficient energy generation. The Hydrogen Tank stores essential pure hydrogen fuel. The ABNT 218-2 Connector links the cylinder valve to high-pressure control with specialized design. The Ball Valve in the pressurization system ensures airtight shut-off via a pivoting hollow ball. The High Pressure Hose transports hydrogen to the pressure regulator. The Pressure Regulator crucially maintains stability by preventing excess pressure build-up. See Fig. 2 for a schematic of the pressure regulator's key components.

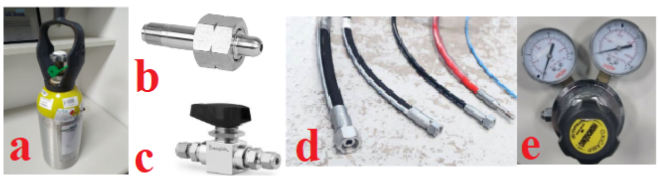

Figure 2 - a)Hydrogen cylinder, b)ABNT 218-2 connection, c)Ball valve, d)high pressure hose and e)Pressure regulator.

DOI: 10.55592/ISE.2023.3675628

Low Pressure System

For pressure control systems and energy storage a relief valve operates automatically to perform gradual pressure adjustments, opening or closing as changes in the system's pressure occur. A hydrogen accumulator, made of stainless steel allowing the system to handle extreme demand variations. A pressure transducer converts pressure levels into electrical voltages, communicating information to the operator. A solenoid valve safely manages the flow of liquids and gasses, safeguarding the system from abnormal pressures. John Guest pneumatic connections offer high flow and pressure resistance for efficient element connections. Fuel cells, unlike batteries, transform continuously injected reactants into electrical energy. The components also include a reservoir to preserve materials, washer connectors for varied pressure services, pneumatic connections enabling tool-free assembly, and low-pressure hoses that provide flexibility and stability in fluid movement. Together, these elements form a versatile set for pressure control and energy storage operations that can be seen in Fig 3.

Figure 3 - f)Relief valve, g)2L Hydrogen accumulator, h)Pressure transducer, i)Shut-off valve, j)John Ghest ¼" NPT connection, k)Connectors washers, l)Polyurethane hose and m)Fuel cell.

Monitoring and Control System

To enable the development of a control and monitoring system, 3 main steps were made available in the laboratories of IPEN (Nuclear and Energy Research Institute):

- Purge Test which was focused on determining the most appropriate purge valve for the system given the flow restrictions determined by the manufacturer;
- Air Starve in which we focused on cleaning and internally deoxidizing the fuel cell plates so that it delivers maximum performance in the process;
- Extraction of the Polarization Curve to validate our theoretical model of the cell in order to determine the power available to extract from the Stack, allowing us to design our energy braking system and control software to embed on our PCB board.

Initially, the project was tested with relay modules and an Arduino Uno microcontroller, that is, equipment easily found in the Brazilian market. However, due to the successful implementation of these components and the need to raise the technology to a level of maturity close to commercialization, it was imperative to develop boards such as those shown in figure 4 and figure 5.

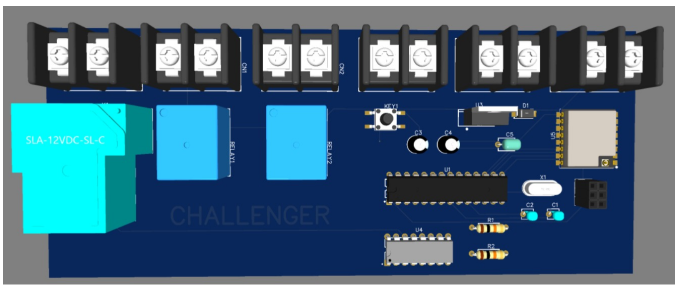

Figure 4 - Control PCB

DOI: 10.55592/ISE.2023.3675628

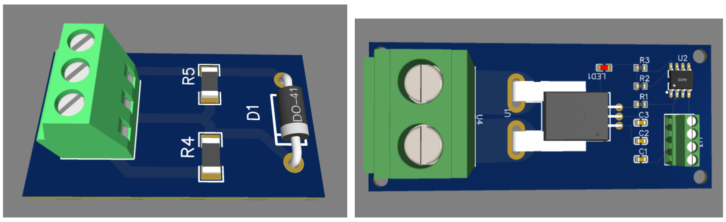

Figure 5 - Monitoring Current and Voltage PCBs

Results and discussion

In table 1 we have the approximate cost of shipping components present, whether on the national or global market, in a TRL 9 vehicle. A design was made on the computer (CAD), as shown in figure 6, of what it would be like to bring together the most appropriate components for this technology, also taking into account weight, size and purchasing accessibility. As a result, we obtain that it is possible to develop and ship this technology, but we have a major problem associated with the cost of implementation.

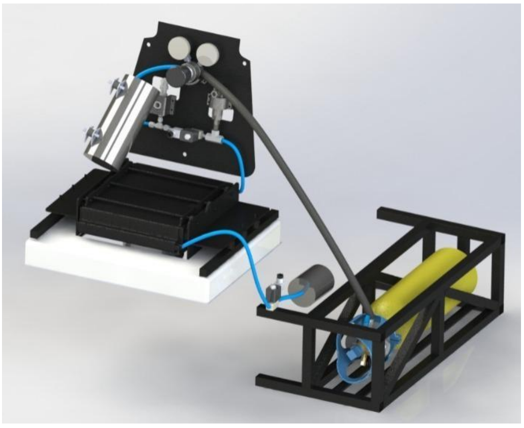
Figure 6 - Computer aided design (CAD) of components assembly

System	**Costs**
High Pressure	R$ 18.008,45
Low Pressure	R$ 29.350,82
Monitoring and Control	R$ 3.195,17
Fastening	R$ 250,00
Accumulator	R$ 11.214,8

Table 1 - Implementing Costs

Conclusion

A highly promising market centered on the decarbonization of transport is rapidly emerging on a global scale and to achieve this objective, a TRL 5 prototype (Figure 7) was created and verified using Proton Exchange Membrane (PEM) technology, carried out by students at the Federal University of ABC. The overall objective of this project is to advance the technological readiness of the prototype

DOI: 10.55592/ISE.2023.3675628

to a pre-commercial stage. This involves specific objectives such as improving the accuracy of the fuel cell control algorithm and adapting the system for integration into a universal module. Furthermore, it is necessary to bring in companies committed to developing and improving fastening technology and materials so that component costs can be reduced. In conclusion, there is a great possibility of accessing this decarbonization market, but there are steps to be overcome in relation to the supply chain.

Figure 7 - Formula Student with Fuel Cell H2 Technology embedded

Acknowledgment

Our thanks go especially to the entire Federal University of ABC community, IPEN (Nuclear and Energy Research Institute) mentors and also to our workmates from the Challenger Electric Racing Team.

References

[1] "Global Hydrogen Review", 2021.

[2] "Hydrogen Lead Projects", 2021, URL: <https://www.wasserstoff-leitprojekte.de/>. Access in: 01/9/2023.

[3] D. Schlund, S. Schulte and T. Sprenger, "The who's who of a hydrogen market ramp-up: A stakeholder analysis for Germany", Renew. Sustain. Energy Rev., vol. 154, pp. 111810, Feb. 2022.

[4] "What do we know about green hydrogen supply costs?", URL: <https://ieeexplore.ieee.org/document/9921127>. Access in: 01/9/2023.

[5] H. Council, "Hydrogen for Net Zero-A Critical Cost-competitive Energy Vector", 2021. <https://www.mckinsey.com/capabilities/sustainability/our-insights/five-charts-on-hydrogens-role-in-a-net-zero-future>. Access in: 01/2/2023.

[6] "The future of hydrogen – opportunities and challenges", <https://www.sciencedirect.com/science/article/pii/S0360319908015061>. Access in: 01/18/2023.

[7] "Recent development in design a state-of-art proton exchange membrane fuel cell from stack to system: Theory, integration and prospective", <https://www.sciencedirect.com/science/article/pii/S0360319922055306>. Access in: 01/27/2023.