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Processes Supervision System for Green Hydrogen Production: Experimental Characterization and Data Acquisition of PEM Electrolyzer †

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Abstract: Green hydrogen is the term used to reflect the fact that hydrogen is generated from renewable energies. This process is commonly performed by means of water electrolysis, decomposing water molecules into oxygen and hydrogen in a zero emissions process. Proton exchange membrane (PEM) electrolyzers are applied for such a purpose. These devices are complex systems with non-linear behavior which impose the measurement and control of several magnitudes for an effective and safe operation. In this context, the modern paradigm of Digital Twin (DT) is applied to represent and, even, predict the electrolyzer abehavior under different operating conditions. To build this cyber replica, a paramount previous stage consists of characterizing the device by means of the curves that relate current, voltage and hydrogen flow. To this aim, this paper presents a processes supervision system focused on the characterization of a experimental PEM electrolyzer. This device is integrated in a microgrid for production of green hydrogen using photovoltaic energy. Three main functions must be performed by the supervision system: measurement of the process magnitudes, data acquisition and storage, and real-time visualisation. To accomplish these tasks, firstly, a set of sensors measure the process variables. In second place, a programmable logic controller is responsible of acquiring the signals provided by the sensors. Finally, LabVIEW implements the user interface as well as data storage functions. The process evolution is observed in real-time through the user interface composed by graphical charts and numeric indicators. The deployed process supervision system is reported together with experimental results to prove its suitability.

Keywords: electrolyzer; supervision; proton exchange membrane; data acquisition; green hydrogen; microgrid; renewable energy

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1. Introduction

In the last decade, innovation efforts on hydrogen and its applications have led to hydrogen taking on a major role in key sectors such as energy [1] and automotive [2]. Hydrogen is obtained by means of devices called electrolyzers, which separate a compound into its primary elements through the process of electrolysis. Proton Exchange Membrane electrolyzers (PEM) are used in combination with water to produce hydrogen without generating emissions. Its applications within microgrids are highlighted, where the electrolyzer is powered by a renewable energy source (RES), and the product resulting from its operation is called green hydrogen. In combination with a fuel cell, hydrogen constitutes a secondary energy storage and generation system for the microgrid. This back-up system makes it possible to cope with temporary variations in energy demand.

Electrolyzers are complex devices with non-linear behaviour [3,4], the control of which involves a series of measurements on various quantities to ensure optimal [5] and safe operation [6]. Digital Twins (DT) are used in this context to study and predict the operation of the electrolyzer. This virtual tool makes it possible to isolate the device from its physical environment and to modify the operating conditions through simulation. In order to design the DT of the electrolyzer, it is necessary to develop a model describing its operation. Therefore, it is necessary to carry out a characterization procedure on the equipment to determine its expressions and characteristic curves. Characterization is a vital process in the study of a complex device such as the electrolyzer, allowing the veracity of the technical features provided by the manufacturer to be checked, as well as its operation in a given operating range. This article describes the design and implementation of a supervision system for the characterization of a PEM electrolyzer. This device is installed in a microgrid for green hydrogen generation powered by photovoltaic energy [7]. The monitoring system is based on LabVIEW, a software specialised in the design of instrumentation, measurement and visualisation systems through a visual programming language. This package is widely used to develop graphical user interfaces [8] and embedded systems.

The structure of the rest of the document is as follows. Section 2 describes the installed PEM electrolyzer, as well as the elements used for sensing and actuation. Section 3 describes the principle of operation of the designed monitoring system together with the interactions of the components involved. Finally, the main conclusions of the work are detailed.

2. Materials and Methods

This section deals with the PEM electrolyzer together with the sensors and actuators associated with its operation.

2.1. PEM Electrolyzer

The PEM electrolyzer consists of a set of cells arranged in series, forming a stack, or in parallel. These cells are the elementary units responsible for carrying out the electrolysis process. In the case of water, the electrochemical process produced is shown in Equation 1:

$$H_2O\ (l)\ + E \rightarrow H_2(g) + \frac{1}{2}O_2(g) \tag{1}$$

where E refers to the electrical energy needed to carry out the electrolysis. The PEM electrolyzer installed in the microgrid consists of a stack of 6 cells in series. The geometry and components of the electrolyzer are shown in Figure 1. Figure 1b shows the cathode, membrane and anode structure that characterizes each cell.

(**a**) (**b**)

Figure 1. Installed PEM electrolyzer.

2.2. Sensing and Actuation

The operation process of the electrolyzer involves electrical and fluidic variables. For this reason, a set of sensors and actuators are available to measure and control the device, ensuring correct operation within the nominal parameters set by the manufacturer. Table 1 presents a list of measured variables and control signals together with the components used for their measurement or actuation.

Table 1. Control variables and signals involved in the operation of the electrolyzer.

Control Variable/Signal	Device
Voltage (V)	Potentiometer
Current (A)	Hall effect sensor
Temperature (°C)	PT-100
Pressure (atm)	Pressure transmitter
Hydrogen flow rate (mL/min)	Digital Thermal Mass Flow Meter for Gases
Water purge	Electrovalve
Water level sensor	Electro-optical level sensor
ON/OFF power supply stack	Relay

From this table, the water level sensor and water purge signals are highlighted. Both signals are key to the maintenance of the equipment involved. On the one hand, the presence of water in the feed tank ensures that the electrolyzer does not operate in a vacuum, deteriorating its internal components. On the other hand, the purging of water prevents the accumulation of water in the hydrogen bus, ensuring that sensitive devices such as the flow meter operate without the presence of moisture.

The sensors and actuators of the system are connected to a programmable logic controller (PLC) that governs the system and translates the electrical signals measured by the sensors into logical values.

3. Deployment and Results

For the implemented system to acquire the connotation of a supervision system, it must perform three basic functions: measurement of the physical system variables, data acquisition and storage to be able to have a data history, and real-time representation of the system information [9,10]. The measurement of the variables and the management of the system is carried out through the sensors and actuators mentioned in the previous section.

Data acquisition is solved by means of open platform communications (OPC). OPC brings together a number of industry-grade specifications with the aim of providing an open communication protocol between devices and applications in the automation domain [11]. One of these specifications is Data Access (DA) which is oriented towards sharing process data and is widely applied in industrial environment. This protocol is based on a client/server typology for real-time communication and data acquisition from devices such as PLCs. The data transmission between the PLC and the supervision system designed in LabVIEW has been solved by means of this communication protocol. To this end, LabVIEW provides the user with a local server called NI OPC Server to configure and manage the connection between devices.

Finally, real-time representation and data storage are performed through a virtual instrument (VI) programmed in LabVIEW. This way, the operator is informed about the process status in a continuous and user-friendly manner, being data stored for further development of the DT. The diagram in Figure 2 represents the interaction between the components that make up the monitoring system and the functions performed by each of them.

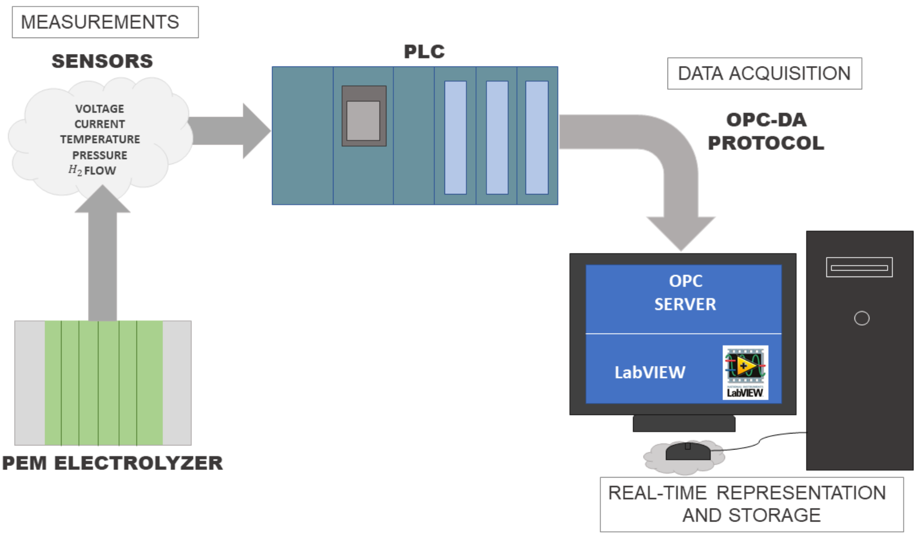

Figure 2. Supervision system and interaction between components.

The LabVIEW VI provides the user with a graphical interface to visualise the state of the system. To do this, numerical indicators are used to represent the instantaneous value of the electrolyzer parameters and graphical charts to represent their evolution over time. Moreover, a synoptic scheme illustrates the experimental setup to facilitate the interaction with the user. At the same time, there are buttons called Stop and Save Data programmed to stop the execution of the VI and save the data received, respectively. Figure 3 shows the appearance of this interface when the system is operating under real conditions.

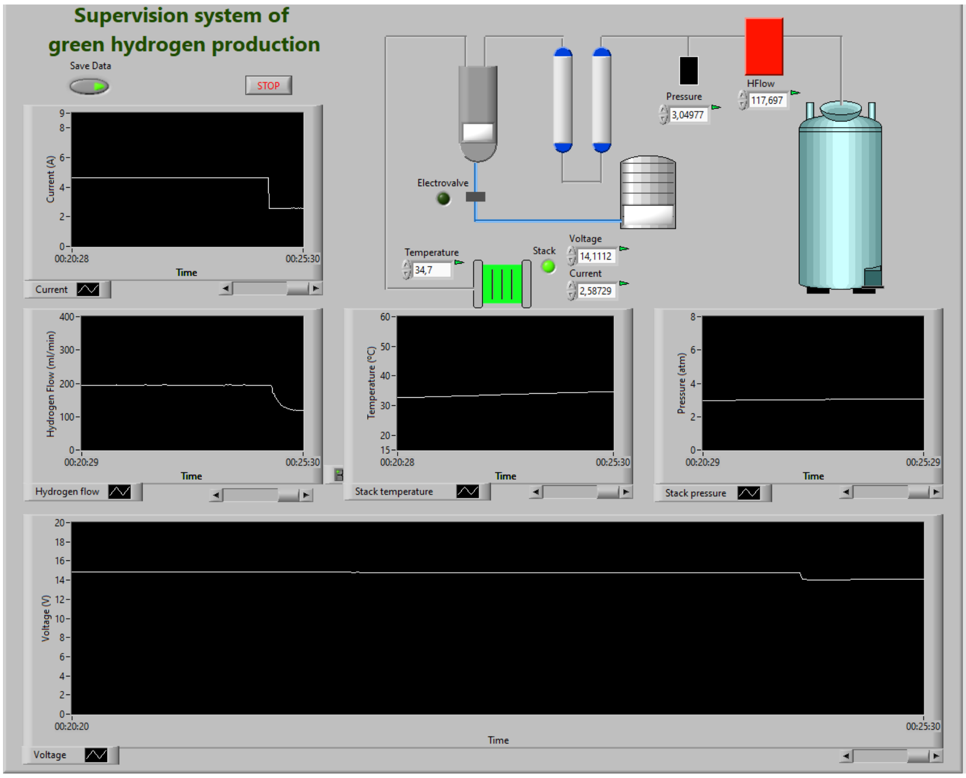

Figure 3. LabVIEW graphical interface to supervise green hydrogen production.

As can be seen in the current graph in Figure 3, the input current of the electrolyzer has been reduced in order to visualise the impact of this phenomenon on the rest of the system variables. As a result, the voltage and hydrogen production are appreciably reduced. The associated graphs show the difference in the speed at which these parameters are modified, highlighting the progressive variation in hydrogen production. Data acquisition and storage are successfully performed which allows to further tracing of characteristic curves of the PEM electrolyzer operation.

4. Conclusions

This paper has presented a supervision system to monitor and characterize the green hydrogen generation process through a PEM electrolyzer framed in a photovoltaic-powered microgrid. This system performs the functions of measurement, data acquisition and storage, as well as the real-time representation of the key variables of the process. Part of these functions are performed through LabVIEW software via a local OPC DA server and a graphical user interface. The interface provides a user-friendly environment for controlling the electrolyzer and visualising the evolution of the most significant parameters of the process. Future research guidelines will deal with the development of DT of the electrolyzer using the data gathered with the developed system.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Xie, Y.; Ueda, Y.; Sugiyama, M. Greedy energy management strategy and sizing method for a stand-alone microgrid with hydrogen storage. *J. Energy Storage* **2021**, *44*, 103406. https://doi.org/10.1016/j.est.2021.103406.
2. He, H.; Wang, X.; Chen, J.; Wang, Y.-X. Regenerative Fuel Cell-Battery-Supercapacitor Hybrid Power System Modeling and Improved Rule-Based Energy Management for Vehicle Application. *J. Energy Eng.* **2020**, *146*, 04020060. https://doi.org/10.1061/(asce)ey.1943-7897.0000708.
3. Atlam, O.; Kolhe, M. Equivalent electrical model for a proton exchange membrane (PEM) electrolyser. *Energy Convers. Manag.* **2011**, *52*, 2952–2957. https://doi.org/10.1016/j.enconman.2011.04.007.
4. Guilbert, D.; Vitale, G. Dynamic emulation of a PEM electrolyzer by time constant based exponential model. *Energies* **2019**, *12*, 750. https://doi.org/10.3390/en12040750.
5. Scheepers, F.; Stähler, M.; Stähler, A.; Rauls, E.; Müller, M.; Carmo, M.; Lehnert, W. Improving the efficiency of PEM electrolyzers through membrane-specific pressure optimization. *Energies* **2020**, *13*, 612. https://doi.org/10.3390/en13030612.
6. Frensch, S.H.; Fouda-Onana, F.; Serre, G.; Thoby, D.; Araya, S.S.; Kær, S.K. Influence of the operation mode on PEM water electrolysis degradation. *Int. J. Hydrogen Energy* **2019**, *44*, 29889–29898. https://doi.org/10.1016/j.ijhydene.2019.09.169.
7. Portalo, J.M.; González, I.; Calderón, A.J. Monitoring system for tracking a PV generator in an experimental smart microgrid: An open-source solution. *Sustainability* **2021**, *13*, 8182. https://doi.org/10.3390/su13158182.
8. González, I.; Calderón, A.J.; Andújar, J.M. Novel remote monitoring platform for RES-hydrogen based smart microgrid. *Energy Convers. Manag.* **2017**, *148*, 489–505. https://doi.org/10.1016/j.enconman.2017.06.031.
9. Mancera, J.J.C.; Manzano, F.S.; Andújar, J.M.; Vivas, F.J.; Calderón, A.J. An optimized balance of plant for a medium-size PEM electrolyzer. Design, control and physical implementation. *Electronics* **2020**, *9*, 871. https://doi.org/10.3390/electronics9050871.
10. Hosseinzadeh, N.; Al Maashri, A.; Tarhuni, N.; Elhaffar, A.; Al-Hinai, A. A real-time monitoring platform for distributed energy resources in a microgrid—pilot study in oman. *Electronics* **2021**, *10*, 1803. https://doi.org/10.3390/electronics10151803.
11. González, I.; Calderón, A.J.; Figueiredo, J.; Sousa, J.M.C. A literature survey on open platform communications (OPC) applied to advanced industrial environments. *Electronics* **2019**, *8*, 510. https://doi.org/10.3390/electronics8050510.