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DYNAMIC MODELING AND EXPERIMENTAL VALIDATION OF A PEM-BASED SYSTEM INTEGRATED WITH RENEWABLE POWER SOURCES

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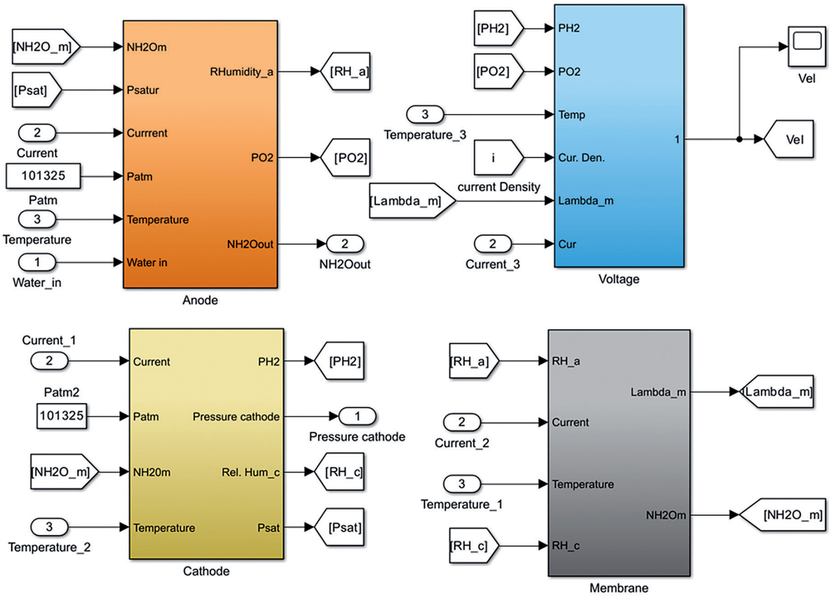
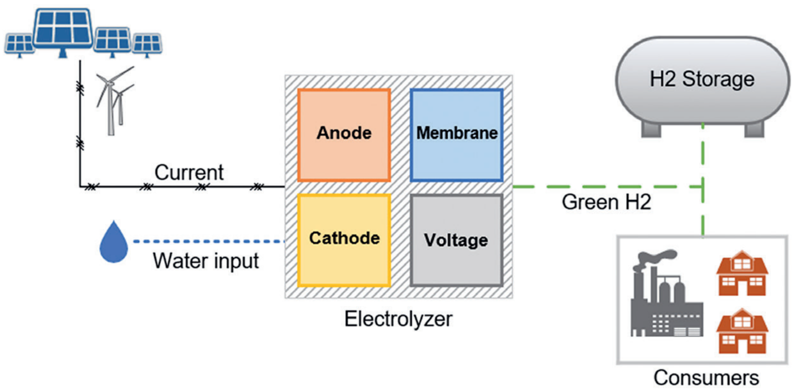
Abstract – In recent years, hydrogen (H_2) has gained significant attention as a key element in the global energy transition due to its potential to reduce carbon emissions and support sustainable energy systems. Governments and industries have increasingly invested in hydrogen technologies to decarbonize sectors such as transportation, industry, and power generation. Hydrogen can be classified according to its production pathway into gray, blue, brown/black, and green hydrogen, with green hydrogen representing the most environmentally sustainable option and the focus of this study. Green hydrogen is produced via water electrolysis powered by renewable energy sources, using surplus energy from wind, solar, or hydropower to split water into hydrogen and oxygen. This process is carried out by electrolyzers, with the main types being proton exchange membrane (PEM), alkaline, and solid oxide electrolyzers. Among these, PEM electrolyzers offer notable advantages, particularly in renewable energy applications. They respond quickly to power fluctuations, produce high-purity hydrogen suitable for fuel cells, and feature compact designs capable of operating at higher current densities. Owing to these advantages, this study focuses on PEM electrolyzers and their integration with renewable energy sources. The first stage of this study involves the development of a detailed mathematical model of the electrolyzer. To accurately capture the dynamic interactions within the system, the PEM electrolyzer model is structured into four interconnected submodels: the anode, cathode, membrane, and voltage components (Figure (a)). The system is implemented in MATLAB/Simulink®, with current (A), water mass flow rate ($kg \cdot s^{-1}$), pressure (Pa), and temperature (°C) defined as the primary input variables. In the second stage, the simulation results are validated against experimental data obtained from a prototype operating at the Hydrogen Center laboratory. Finally, the validated electrolyzer model is integrated into an energy-hub framework that incorporates renewable energy sources, hydrogen storage systems, and multiple categories of end users, including industrial and residential consumers as depicted in Figure (b).

Keywords – Electrolysis; energy storage; green-gases; hydrogen production; sector coupling



Simulink view of the electrolyzer model



Integration of the electrolyzer in an energy-hub

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