Control of Multi-Stack PEM Water Electrolyzer Systems: From Optimal Operating Regimes to Control Structure Design

Marius Fredriksen, Johannes Jäschke

Department of Chemical Engineering, Norwegian University of Science and Technology, Trondheim, NO-7491, Norway (e-mail: marius.fredriksen@ntnu.no, johannes.jaschke@ntnu.no).

Abstract: Proton Exchange Membrane (PEM) water electrolysis is a promising technology for producing green hydrogen from renewable energy sources such as wind and solar power. To achieve industrially relevant capacities, modern PEM systems employ multiple stacks operating in parallel. To reduce equipment costs, the stacks often share common balance-of-plant units, such as gas-liquid separators, which separate the produced hydrogen and oxygen from the circulating water exiting the stacks. These multi-stack configurations, however, greatly increase the system complexity and make plantwide operation more challenging than for single-stack systems, which are more commonly studied in the current literature.

In our previous work (Fredriksen and Jäschke, 2026), we characterized the steady-state optimal operating regime of a two-stack PEM system by mapping active constraint regions across a range of system power loads from 6 to 120 kW, with the upper operating point for each stack set to 60 kW. The stacks share separators and a buffer tank, but each has its own heat exchanger. A key finding is that differences in Faraday efficiencies between stacks lead to an asymmetric optimal power distribution, with the more efficient stack preferentially loaded. This, in turn, elevates the hydrogen-to-oxygen (HTO) ratio in the less efficient stack—a critical safety constraint, as HTO ratios above the lower explosion limit (4 vol%) can form combustible gas mixtures that pose a hazard to equipment and personnel. In a single-stack system, the HTO ratio can be controlled by adjusting the pressure gradient across the stack membrane, as presented in Fredriksen and Jäschke (2025). However, because the stacks share separators, the pressure difference cannot be adjusted independently for each stack. Thus, the more efficient stack may need to operate at suboptimal pressures to satisfy the less efficient stack's HTO constraint. Alternatively, more power must be supplied to the less efficient stack, increasing its oxygen production rate to dilute the crossover hydrogen, at the cost of overall hydrogen output.

Building on these findings, this work aims to develop a control structure for the two-stack PEM system using well-established methods such as Skogestad's top-down control design approach (Skogestad and Postlethwaite, 2007). The identified active constraint regions from our previous work indicate which variables need to be controlled and which can be manipulated across different power loads, providing a natural foundation for this design approach. Additionally, because the HTO ratio within the stacks is not directly measurable, a state estimator will be required, and the resulting control structure will be validated dynamically using our system models.

Keywords: Green hydrogen production, Proton exchange membrane water electrolysis, Process control, System safety

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TOOLS IN THE WRITING PROCESS

During the preparation of this work, the authors used Claude to suggest phrasing and improve overall language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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