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Master's Thesis Suggestion

Transient Thermodynamic Analysis of Solar-Wind Driven PEM Electrolysis Plant with Flash-Power Water Purification System Integration

Background and Motivation:
PEM (Proton Exchange Membrane) electrolyzer plants play a critical role in storing renewable energy from solar and wind sources by producing hydrogen. However, a significant portion of input energy is lost as low-grade waste heat, which limits overall system efficiency. Efficient recovery and utilization of this waste heat is essential to improve the energy efficiency of the plant, reduce CO_2 emissions, and enhance the economic viability of green hydrogen production. One promising approach is the integration of a flash-based power and water purification system, which utilizes low-temperature waste heat to generate additional power while simultaneously purifying water. This dual-function system not only improves the overall efficiency of the electrolyzer plant but also contributes to sustainable water management.

Objective:
The objective of this master's thesis is to perform a detailed transient performance analysis of a megawatt-scale PEM electrolyzer plant operating under variable electricity input from renewable sources such as wind and solar energy. The study aims to evaluate the dynamic behavior of the sys- tem during daily operation and to develop strategies for improving overall plant efficiency. A key focus is the effective utilization of low-grade waste heat generated during hydrogen production and storage stages by integrating a flash-based power and water purification system. This integration is expected to enhance energy recovery, improve water purity, and contribute to the economic and environmental sustainability of hydrogen production.

Tasks:
1. Analyse the transient performance of the PEM electrolyzer under fluctuating renewable electricity input, reflecting real-world solar and wind generation patterns.
2. Identify and quantify the waste heat sources within the PEM electrolyzer plant, including their temperature levels, availability profiles, and recovery potential.
3. Integrate a flash evaporation system for simultaneous power generation and water purification using the recovered waste heat.
4. Conduct a detailed techno-economic analysis to evaluate the benefits of integrating the flash power water purification system, with a focus on reducing the cost of green hydrogen production.

5. Investigate operational conditions and design parameters that lead to improvements in system efficiency, CO_2 emission reductions, and economic performance.
6. Perform a sensitivity analysis to assess the impact of key parameters—such as heat recovery rate, system size, and electricity variability—on the optimal design and operation of the integrated system.

Methodology:

1. Literature Review: Conduct a comprehensive review of existing research, case studies, and commercial projects related to PEM electrolyzer plants, waste heat recovery, and flash-based power and water purification systems.
2. System Modelling: Develop a thermodynamic model of a PEM electrolyzer plant integrated with a flash power–water purification system, focusing on energy and mass balances.
3. Component-Level Analysis: Perform detailed thermodynamic analyses of each subsystem (e.g., electrolyzer stack, cooling system, flash chamber, hydrogen compression unit) to evaluate their contribution to overall system efficiency.
4. Economic Assessment: Carry out a cost-benefit analysis of integrating the flash system, including capital costs, operational and maintenance costs, and efficiency gains. Compare results with alternative waste heat recovery solutions.
5. Plant Selection: Identify representative megawatt-scale PEM electrolyzer plants as case studies for applying the proposed integration and analysis.
6. Component Identification and Thermodynamic Characterization: Identify all key components of the selected electrolyzer plant (e.g., power electronics, cooling units, hydrogen purification systems), and determine their thermodynamic behavior and interconnections.
7. Weather Data Collection: Obtain relevant local climate data, including solar irradiation and ambient temperature profiles, to simulate realistic plant operating conditions.
8. Economic Modelling: Formulate the fundamental equations and cost functions for the economic analysis, incorporating system lifespan, payback period, and efficiency-related savings.

Expected results:

A comprehensive technical analysis of the dynamic behavior and performance of a megawatt- scale PEM electrolyzer plant under variable renewable electricity input. Detailed evaluation of plant efficiency and operational response, identifying key factors influencing system stability and hydro- gen production efficiency under transient conditions. Assessment of the contribution of the integrated flash-power water purification system to overall system performance, including its role in waste heat utilization and water purification during dynamic operation. A complete techno-economic analysis, quantifying the economic benefits of integrating the flash-power system compared to conventional waste heat management approaches. Determination of the optimal system configuration, including component sizing and integration layout, tailored for both technical and economic performance. Development of a yearly operational strategy based on realistic weather data and renewable electricity profiles, aimed at maximizing system efficiency and minimizing hydrogen production cost.

The start date for the work is scheduled for October 1, 2025.
The scope of the work is designed for 6 months including documentation.