Assessing the Implications of Large-Scale Hydrogen Production on Power Transmission Systems

Kai Sun (EECS) and Feng Yuan Zhang (MABE)

1. Background and Objective

The need to transition to a clean and sustainable energy future is becoming increasingly urgent due to climate change and other environmental threats that pose risks to the well-being of both people and the planet. The United States has set a goal of achieving 100% clean electricity by 2035 [1]. Hydrogen has emerged as a promising solution to address the challenges of the climate crisis, energy security, and resilience. As a versatile and clean energy carrier, hydrogen can be produced from renewable sources through electrolysis and utilized for energy storage or electricity generation using fuel cells or hydrogen-based gas turbines. The utilization and production of hydrogen can help mitigate the uncertainties associated with the increasing penetration of renewable generation and facilitate its integration towards reaching 100%. On one hand, hydrogen can be used for flexible, reliable, and dispatchable electrical power, as well as for long-duration energy storage. On the other hand, electrolyzers can dynamically respond to fluctuations in renewable power, providing grid services in addition to energy storage. Particularly, electrolyzers located in regions with high levels of renewable penetration can effectively manage variable loads on the grid by utilizing excess capacity during peak production to produce hydrogen instead of curtailing power. Moreover, the integration of electrolyzers with solar and offshore wind generation in regions with transmission constraints can create an additional revenue stream for renewable generation.

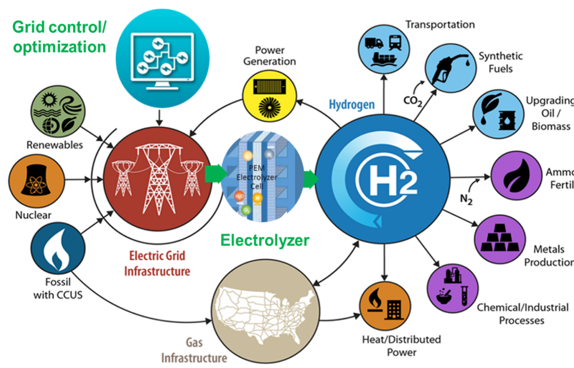

Fig. 1: Renewable and Hydrogen-Powered Grid [1]

As the production of hydrogen through water electrolyzers scales up within a power system, it will not only impact the system's load distribution and daily load curve but also have implications for the stability and dynamic performance of the power transmission system. This proposed research seed project aims to investigate the implications of large-scale hydrogen production on power transmission systems. The findings from this project will contribute to our future proposals for related grants of the Department of Energy (DOE) or the National Science Foundation (NSF) for the establishment of a hydrogen-powered grid to achieve the goal of 100% clean electricity.

2. Technical Approach and Tasks

In this project, a power transmission system with varying levels of renewable penetration will be modeled. Hydrogen electrolyzer models, along with their power electronic interface models, will be integrated into different locations of the system, close to synchronous generators or renewable generators. Contingency analyses will be conducted to simulate disturbances, including power system contingencies, failures and variations in hydrogen production operations, and uncertainties in renewable generation. The project will investigate potential impacts on power system stability and reliability, as well as explore possible mitigation strategies by adjusting the operation strategy of electrolyzers.

The project aims to address the following two questions:

- What are the impacts of integrating and operating large-scale water electrolyzers on the stability and reliability of a power transmission system under both minor and major disturbances?

- Can hydrogen production effectively accommodate and compensate for the intermittency and uncertainties of renewable energy sources in electricity generation through the operational flexibility of water electrolyzers?

Specifically, the project will conduct these tasks:

Task 1: Modeling of system-level electrolyzers for grid integration studies. The primary objective of this task is to develop a comprehensive system-level hydrogen production model that can be used for grid integration studies. PI Zhang will construct this system-level model based on physics-based electrochemical models that captures the behavior of hydrogen production stacks or cells [2][3]. The model will be designed to be applicable to various practical water electrolyzers in terms of size and type. It will consider the intermittent electricity supply, allowing for direct utilization of electricity from connected renewable energy resources. Practical limits related to hydrogen storage and transportation will also be incorporated into the model to ensure its practicality and real-world applicability.

Task 2: Modeling of a power transmission grid with adjustable renewable penetration. In this task, PI Sun will develop both small and large-scale power system models based on the Kundur's two-area system and the Western Interconnection system [4]. These models will be designed to reflect different levels of renewable energy penetration, specifically focusing on solar and wind farms. To study the impact of hydrogen production, stability issues will intentionally be introduced into the models. The objective is to assess how hydrogen production can either mitigate or worsen these stability issues, providing insights into the potential benefits and challenges of integrating hydrogen production into the power transmission system.

Task 3: Placement of electrolyzers. In this task, PIs Sun and Zhang will work together to determine suitable locations for placing electrolyzers within the integrated hydrogen and grid models. The selection of these locations will take into consideration factors such as the impact on the load distribution within the system and the availability of energy resources in neighboring areas. By strategically placing electrolyzers, the research team aims to optimize the integration of hydrogen production into the power transmission system while ensuring efficient and effective utilization of resources.

Task 4: Selection of contingencies from both the grid and hydrogen production. PIs Sun and Zhang will collaborate on defining a comprehensive list of disturbances that can impact the stability of the power transmission system. This list will encompass power system contingencies originating from the grid side, as well as failures or disturbances associated with the operations of electrolyzers in hydrogen production. By identifying and studying these contingencies, the project aims to gain a deeper understanding of the potential stability challenges with the grid integration of hydrogen production.

Task 5: Stability impact studies on hydrogen production. PI Sun will utilize a MATLAB-based grid simulator to simulate the selected list of disturbances. Both small and large-scale disturbances will be simulated to assess the dynamic performance and stability of the power transmission system. The evaluation will be guided by NERC standards related to bulk electric systems with inverter-based resources, providing a reliable framework for assessing the stability impacts of hydrogen production. The findings from these studies will contribute to understanding the implications and potential challenges associated with large-scale hydrogen production in the power system.

Task 6: Project conclusion. In this final task, PIs Sun and Zhang will analyze and discuss the results obtained from the previous tasks. They will summarize the new findings and insights gained throughout the project, with the aim of generating innovative proposal ideas for future research. These proposal ideas will be targeted towards DOE and NSF grants, allowing for the continuation and expansion of research in the field of hydrogen production and its integration into the power transmission system. Study results will be submitted to peer-reviewed conferences and journals in the fields of power systems and hydrogen production.

The timeline of tasks for 12 months is given in this table:

Tasks	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
1	X	X	X									
2	X	X	X									
3				X	X	X						
4					X	X	X					
5								X	X	X	X	
6											X	X

3. Intellectual Merits

This interdisciplinary proposal aims to address the challenges associated with large-scale hydrogen production and its integration into power transmission systems. By incorporating system-level water electrolyzer models into power transmission systems, the project endeavors to offer valuable insights into the impacts of hydrogen production on grid stability and reliability. The inclusion of adjustable renewable penetration levels in the power grid models enables a comprehensive analysis of the intricate interactions between hydrogen production, renewable energy integration, and grid dynamics. The proposed selection of disturbances from both the grid and hydrogen production sides further enhances the study's robustness and comprehensiveness. Additionally, the project will consider the optimal placement of electrolyzers, taking into account available renewable energy resources. Through simulating various disturbances and adhering to NERC standards, the project ensures the practical value and applicability of the study results. Overall, the seed research efforts under this project will facilitate the development of a systematic approach to understanding the implications of large-scale hydrogen production on power transmission systems, effectively addressing a critical research gap and paving the way for future innovations in the field.

4. External funding sources and targeted amounts

- NSF EPCN (Energy, Power, Control, and Networks) Program ($500,000)
- DOE Hydrogen Production Program (($500,000)
- DOE Advanced Grid Modeling Program ($1,000,000)

5. References

[1]. “DOE National Clean Hydrogen Strategy and Roadmap,” U.S. Department of Energy, September 2022

[2]. Z. Xie, S. Yu, X. Ma, K. Li, L. Ding, W. Wang, D.A. Cullen, H.M. Meyer, H. Yu, J. Tong, Z. Wu, F.-Y. Zhang, MoS2 nanosheet integrated electrodes with engineered 1T-2H phases and defects for efficient hydrogen production in practical PEM electrolysis, Applied Catalysis B: Environmental 313 (2022) 121458.

[3]. F.J. Folgado, D. Orellana, I. González, A.J. Calderón, Processes Supervision System for Green Hydrogen Production: Experimental Characterization and Data Acquisition of PEM Electrolyzer, 19 (2022) 36.

[4]. H. Yuan, R. S. Biswas, J. Tan, and Y. Zhang, “Developing a reduced 240-bus WECC dynamic model for frequency response study of high renewable integration,” in IEEE PES Transmission and Distribution Conference and Exposition (IEEE PES T&D) October 12–15, 2020.