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Dynamic modeling of alkaline electrolyzers for diagnostic purposes

«Development of innovative models and techniques for the diagnostics and performance monitoring of alkaline electrolyzers»

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1 INTRODUCTION

Today, the interest in using hydrogen as an energy carrier, especially from renewables, is increasing. Models for simulating the operation of alkaline electrolyzers are available in the literature [1, 2], but they often overlook real-world issues like malfunctions and failures, which can compromise electrolyzer performance. Moreover, connecting them to fluctuating energy sources can lead to quick degradation and reduced lifespan.

OBJECTIVES

- Development of a transient model for AEL
- Scaling up and validation of the model using a real device
- Development of a fault detection and identification algorithm

2 METHODS

❖ FIRST PHASE - Modeling

Modeling of a 3MW alkaline electrolyzer using [2] as a reference, but with the integration of a temperature control to prevent overheating of the stack, and a liquid level control to prevent excessive filling or emptying of gas-liquid separators.

Implementation of the stack model using the MATLAB/Simulink software.

ELECTROCHEMICAL MODEL [2]

$$U_{cell} = U_{rev} + U_{ohm} + U_{act} + U_{con} \rightarrow 0$$

$$U_{rev} = U^{o}_{rev} + \left(R/_{zF}\right)\ln\left(\left(P - P_{v,KOH}\right)\left(P - P_{v,KOH}\right)^{0.5} / a_{H_2O,KOH}\right)$$

$$U_{ohm} = (\alpha_1 + \alpha_2 T) i_{cell}$$

$$U_{act} = s \cdot \log\left(\left(\beta_1 + \beta_2/_{T} + \beta_3/_{T^2}\right) i_{cell} + 1\right)$$

PRODUCTION MODEL [3]

$$n_{H_2} = \eta_{Far}\left(I_{cell}/_{zF}\right) U_{cell}$$

$$\eta_{Far} = \left((i_{cell})^2 / \left(f_1 + (i_{cell})^2\right)\right) f_2$$

$$f_1 = f_{11} + f_{12} T$$

$$f_2 = f_{21} + f_{22} T$$

THERMAL MODEL [1]

$$C_t \, {dT}/_{dt} = \dot{Q}_{gen} - \dot{Q}_{loss} - \dot{Q}_{cool}$$

$$\dot{Q}_{gen} = n_{cell} I_{cell} (U_{cell} - U_{tn})$$

$$\dot{Q}_{loss} = 1/_{R_t} \, (T - T_{amb})$$

$$\dot{Q}_{cool} = C_{cw}\left(T_{cw,out} - T_{cw,in}\right) = UA_{hx} \cdot LMTD$$

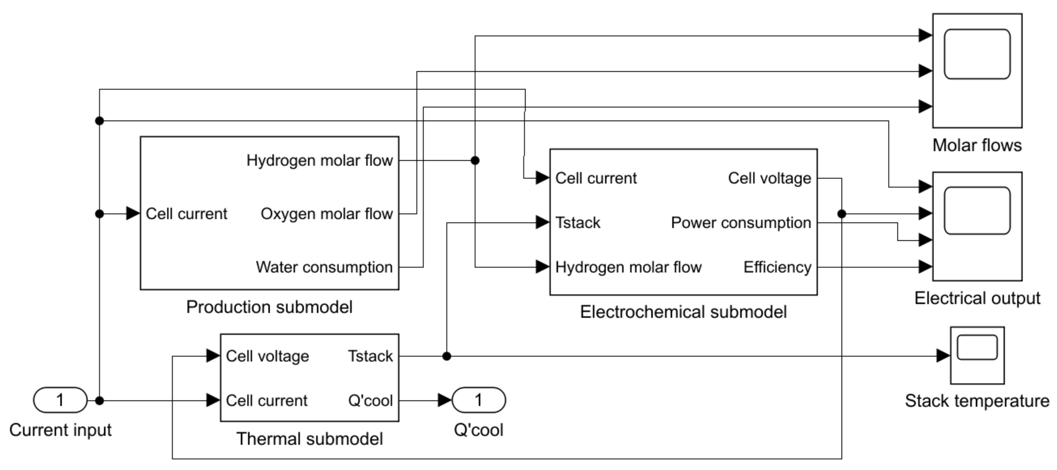


Fig.1 – Simulink stack model

Dynamic modeling of the electrolyzer in MATLAB/Simscape.

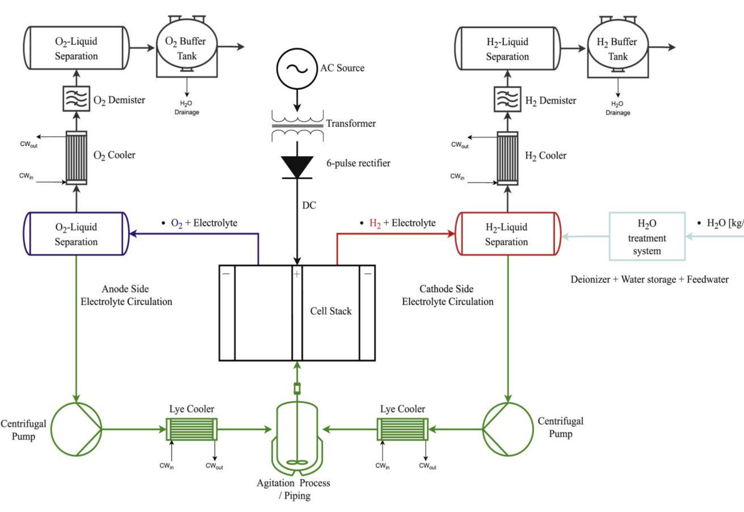


Fig.2 – Alkaline electrolyzer plant process diagram

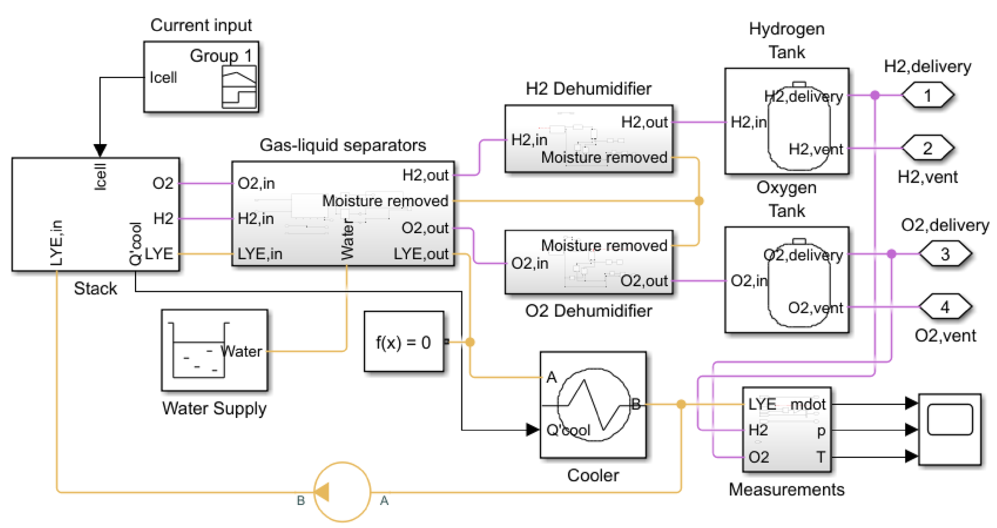


Fig.3 – Simscape electrolyzer model

❖ SECOND PHASE - Scaling up and validation

Scaling up of the model using parameters from a real device.

Pressure [bar]	Hydrogen production nominal flowrate [Nm³/h]	Oxygen production nominal flowrate [Nm³/h]	Nominal power [kW]
8	10	5	60

Table 1 – McPhy Piel H-15 Hydrogen Generator operating parameters

Operational data collection from the stack and U-I curve fitting according to [1].

Validation of the model against measured data.

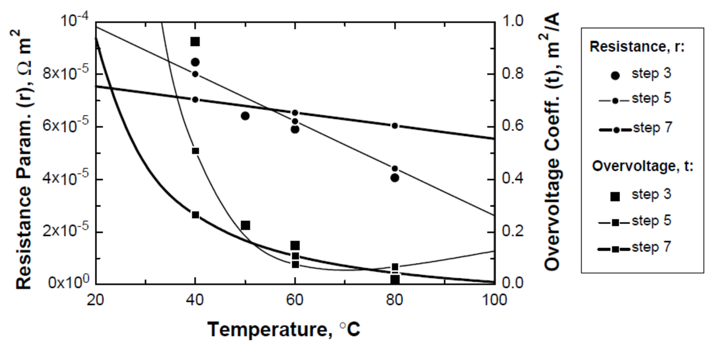
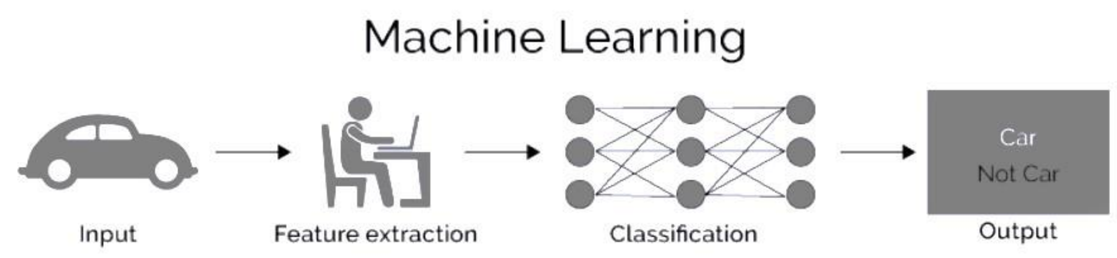


Fig.4 – Electrolyzer I-U curve fitting; illustration of a step-by-step procedure [1].

❖ THIRD PHASE - Fault detection

Machine learning model development using neural networks and regression algorithms.

Model training to identify patterns associated with faults.



Real-time monitoring of the electrolyzer performance.

3 PRELIMINARY and EXPECTED RESULTS

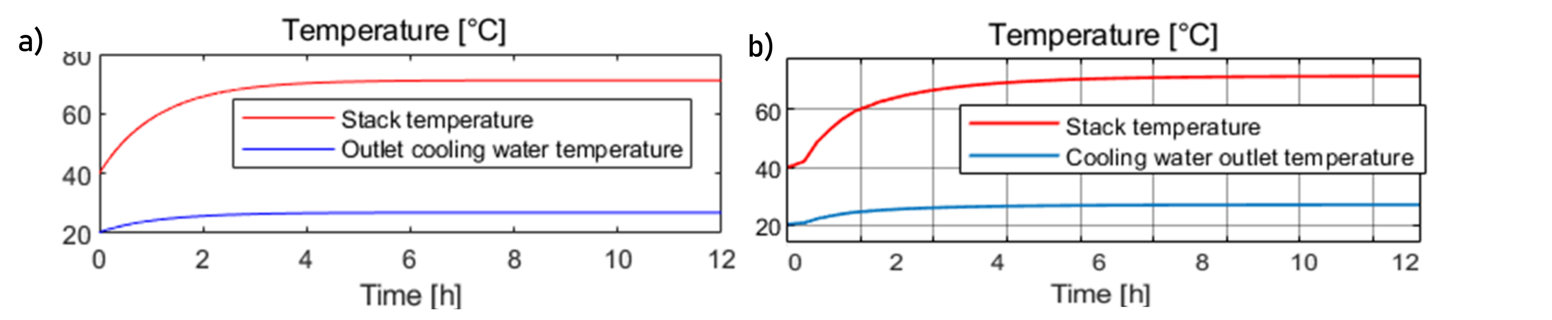


Fig.5 – Stack temperature and Outlet cooling water temperature of 3MW Matlab stack model (a) and 3MW Simulink stack model (b)

- Results obtained by the simulation carried out with the Simulink model of the 3MW alkaline stack are very close to those obtained with the Matlab model, whose reference model [2] was validated.

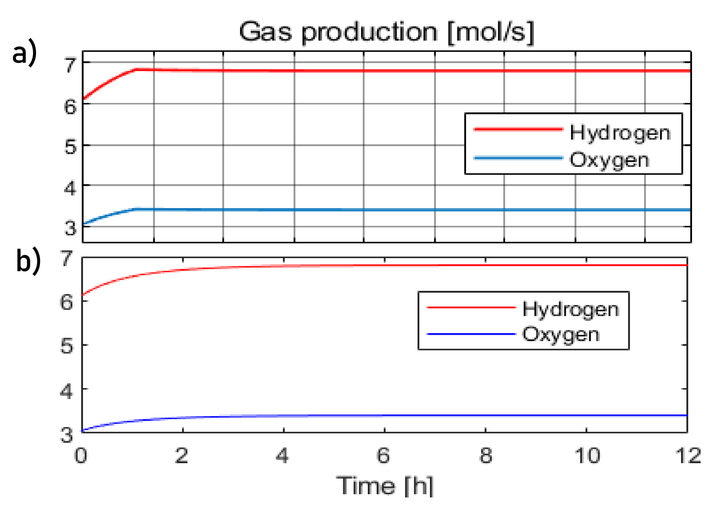


Fig.6 – Gas production flow rates of Matlab stack model (b) and Simulink stack model (a)

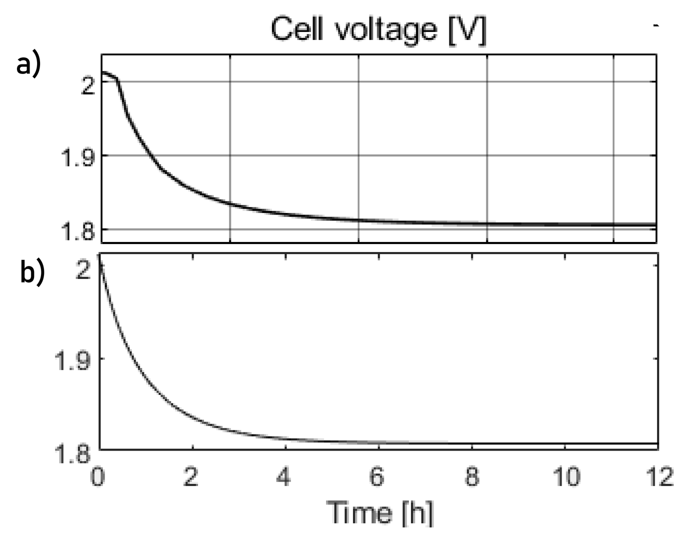


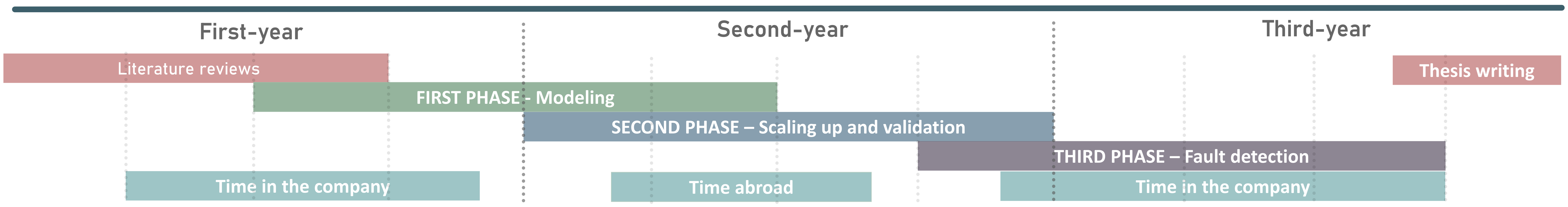
Fig.7 – Cell voltage of Matlab stack model (b) and Simulink stack model (a)

- The developed model will be scaled and validated based on a real electrolyzer (McPhy Piel H-15 Hydrogen Generator) and will serve as the foundation for the development of a fault diagnostic tool.
- The application of machine learning will offer a promising solution to enhance the prediction accuracy of the model.

4 CONCLUSIONS

- This research project started with the Matlab modeling of a 3MW alkaline electrolyzer, using the study by Sakas et al. [2] as a reference.
- The stack modeling will be implemented using MATLAB/Simulink and MATLAB/Simscape software.
- The model will be scaled up and validated using data from a real industrial device.
- The development of a fault detection and identification algorithm will offer a promising solution to enable timely corrective maintenance ensuring extended durability and reliability of the electrolyzer.

5 TIMELINE



6 PUBLICATIONS and CONFERENCES

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[1] Ulleberg I. Modeling of advanced alkaline electrolyzers: a system simulation approach. Int J Hydrogen Energy, vol. 28, 2003, p. 21-3. https://doi.org/10.1016/S0360-3199(02)00033-2.
[2] G. Sakas, A. Ibáñez-Rioja, V. Ruuskanen, A. Kosonen, J. Ahola, and O. Bergmann, "Dynamic energy and mass balance model for an industrial alkaline water electrolyzer plant process," Int J Hydrogen Energy, vol. 47, no. 7, pp. 4328–4345, Jan. 2022, doi: 10.1016/j.ijhydene.2021.11.126.
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[4] M. Maruf-ul-Karim and M. T. Iqbal, "Dynamic modeling and simulation of alkaline type electrolyzers," 2009 Canadian Conference on Electrical and Computer Engineering, St. John's, NL, Canada, 2009, pp. 711-715, doi: 10.1109/CCECE.2009.5090222.