

TRA275 Fuel Cell Systems

System-level modeling of a fuel-cell road vehicle for common driving conditions

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Introduction

This project focuses on running a PEM fuel cell system model in *GT-Suite* while analyzing the impact of a given driving cycle on system and stack parameters. Additionally, it aims to deepen the understanding of the underlying physical equations governing the model.

Background

Operating in "Power Request Mode", the model dynamically adjusts system parameters to achieve a specified power output, $P_{FCS,net}$. The fuel cell system efficiency, η_{FCS} , can be described by Eq.1. Here, P_{Stack} , represents the net power produced by the stack, while, P_{Aux} , accounts for the power consumed by the auxiliary equipment, and, $P_{Loss, DCDC}$, for power loss at the DCDC. Dividing by the maximum fuel power available, $P_{Fuel,max}$, the fuel cell system efficiency can be obtained.

$$\eta_{FCS} = \frac{P_{FCS,net}}{P_{Fuel,max}} = \frac{P_{Stack} - P_{Aux} - P_{Loss, DCDC}}{P_{Fuel,max}} \quad (1)$$

The fuel cell stack power output is given by Eq.2, where, V_{Stack} , represents the stack voltage and, I_{Stack} , is the stack current. The stack voltage, V_{Stack} , can be further decomposed into the stack open circuit voltage, V_{Nernst} , subtracting V_{Act} , V_{Ohm} , V_{Mt} , V_{delOC} , that represent the activation, ohmic, mass transport, and open circuit voltage losses, respectively.

$$P_{Stack} = V_{Stack} \cdot I_{Stack} = (V_{Nernst} - V_{Act} - V_{Ohm} - V_{Mt} - V_{delOC}) \cdot I_{Stack} \quad (2)$$

The model obtains the activation voltage loss, V_{Act} , using the *Butler-Volmer* equation, the ohmic voltage loss, V_{Ohm} , is given by *Springer*, and the mass transport voltage loss, V_{Mt} , is described by *Knudsen* [1]. A detailed description of the equations used in *GT-Suite* can be found in the user manuals [2]. Fig.1 illustrates the model configuration.

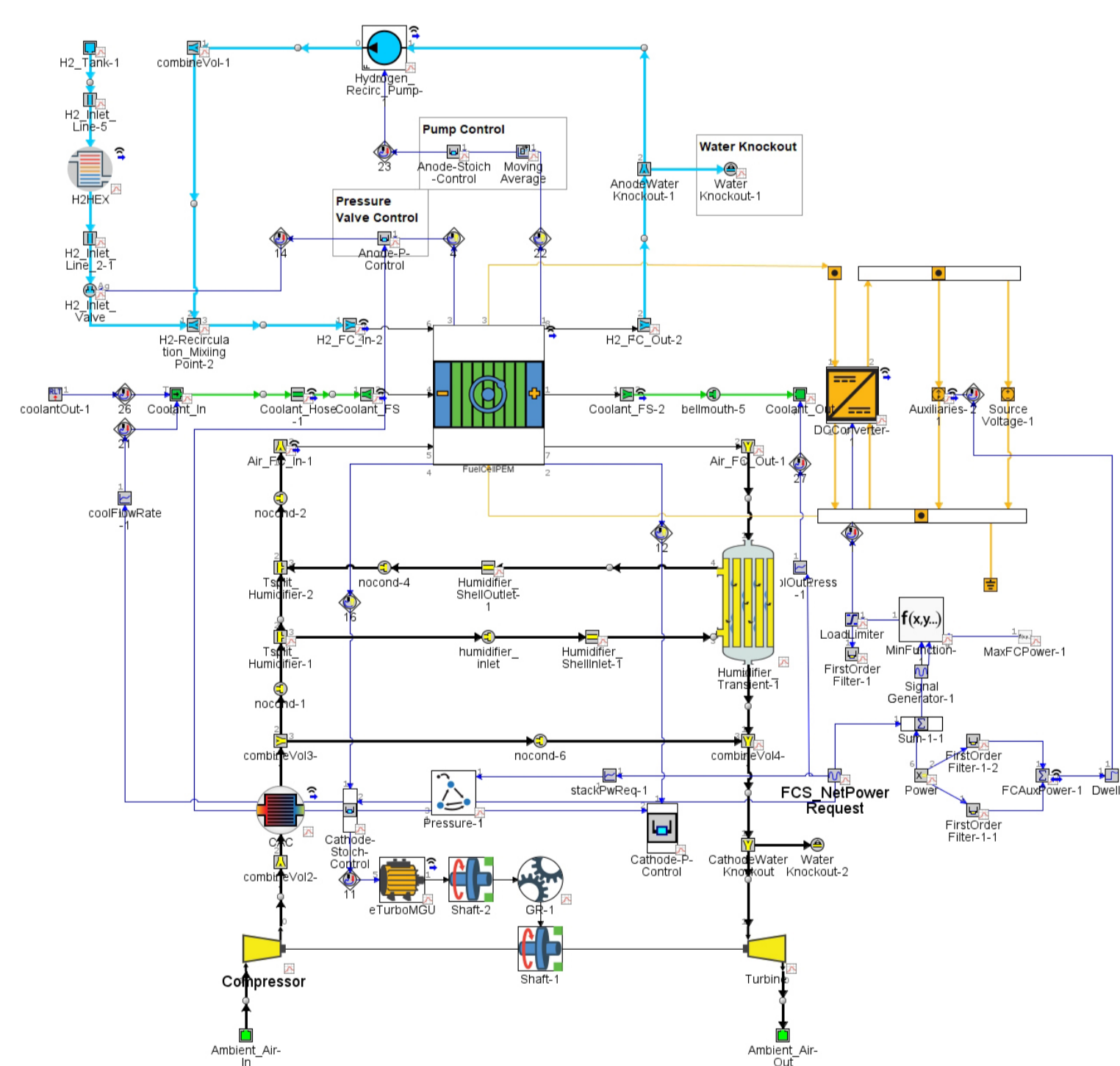


Figure 1: GT-SUITE model of the proton exchange membrane fuel cell system.

Results and Discussion

Running a "Step-Function Cycle" and a "Heavy-Duty Cycle", this work focused on analyzing the variables depicted in Fig.2. Several observations were made, analyzing Fig.2(a) and Fig.2(b) it is possible to observe that the system current and voltage seem to react well to the moderate and abrupt step changes. Minor voltage overshoots were observed, which can be attributed to the typical dynamics of reactance flow in response to varying operating conditions. Additionally, on Fig.2(c) and Fig.2(d) it is possible to see that the activation losses are the most predominant, as expected. In Fig.2(e) and Fig.2(f), it is noticeable that the oxygen consumed is eight times greater than the hydrogen consumed. This leads to water production that aligns with the average mass flow rates of both hydrogen and oxygen consumption, and the resulting curve is the sum of both, in accordance with the principle of mass conservation.

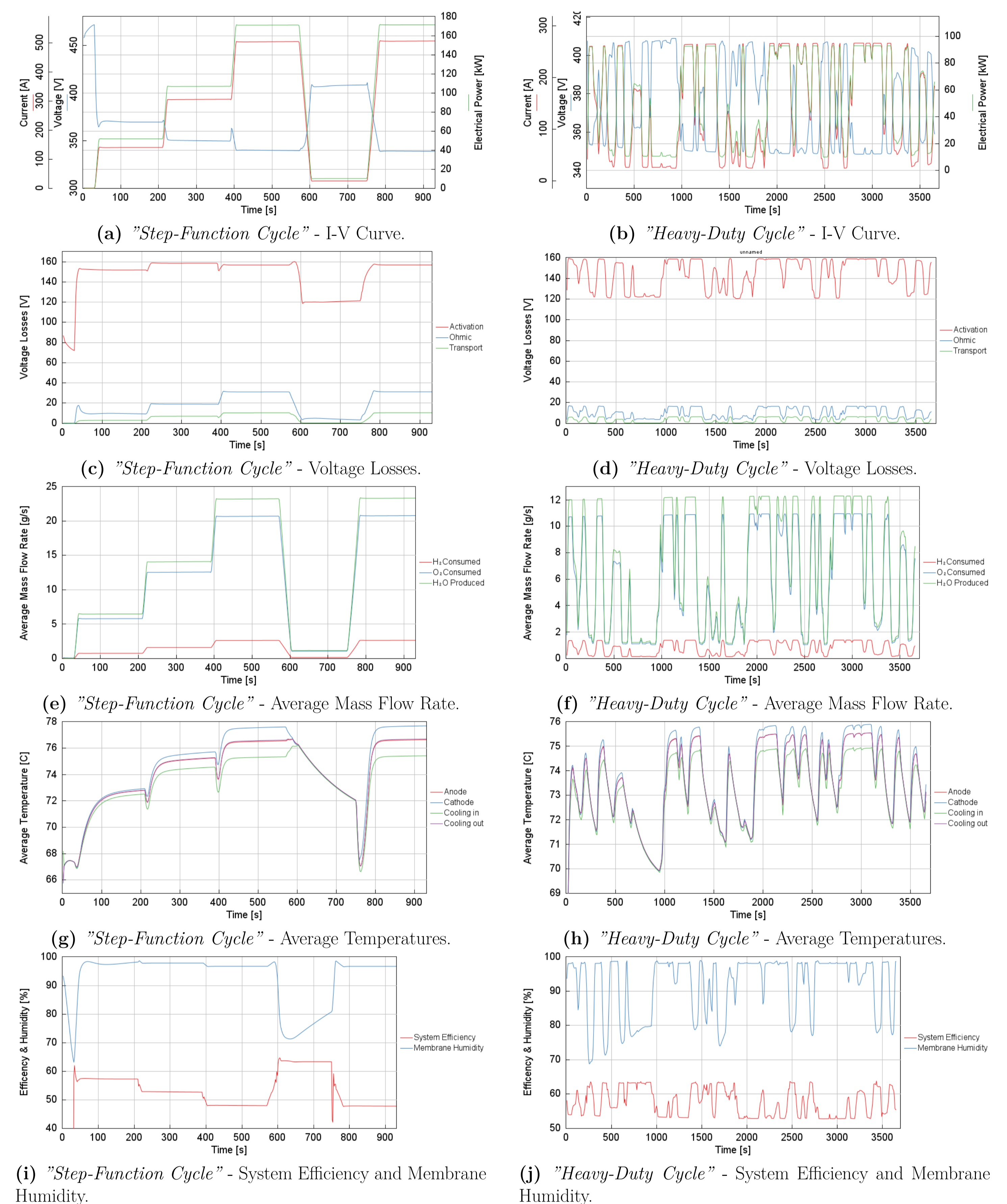


Figure 2: Fuel Cell System parameters behavior while running the "Step-Function Cycle" (left column) and the "Heavy-Duty Cycle" (right column).

In Fig.2(g) and Fig.2(h), the temperatures remain well-aligned, improving reaction efficiency. However, at higher loads, the temperature difference between the cathode and hydrogen increases, likely due to higher thermal gradients. The observed overshoots are linked to the coolant control system, where the derivative action of the PID controller amplifies the response during rapid thermal changes. Finally, analyzing Fig.2(i) and Fig.2(j), it is clear that membrane humidity levels drop to 70-80% during abrupt minimal power requests, with the control system responding to restore the humidity back to normal levels.

Conclusions

The analysis of the "Step-Function Cycle" and "Heavy-Duty Cycle" revealed stable system responses to power changes, with minor voltage overshoots due to reactance dynamics. Oxygen consumption was eight times higher than hydrogen, confirming mass conservation. Temperature alignment improved efficiency, though higher loads caused increased thermal gradients. Membrane humidity decreases significantly in response to abrupt negative step changes.

References

- [1] Springer et al. Polymer electrolyte fuel cell model. *Journal of the electrochemical society*, 11(138(8)):2334–2342, 1991.
- [2] Gamma Technologies. *GT-Suite User Manual*, 2024.

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