System Level Modelling of a Fuel Cell Road Vehicle for Common Driving Conditions

TRA275 Fuel Cell Systems

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INTRODUCTION & BACKGROUND

This project explores the working constraints of a hybrid Proton Exchange Membrane Fuel Cell (PEMFC) powered electric vehicle using real driving test cycles in GT-SUITE to determine its performance under different conditions.

The PEMFC is the most widely used type of fuel cell and is made of polymer electrolyte membranes, such as Nafion, which act as the proton conductor, while Platinum-based materials serve as catalysts for electrochemical reactions carried out at low temperatures. These fuel cells are appealing due to their low operating temperature, high power density, and ease of scaling, making them a promising candidate for the next generation of power sources for transportation, stationary, and portable applications. [1]

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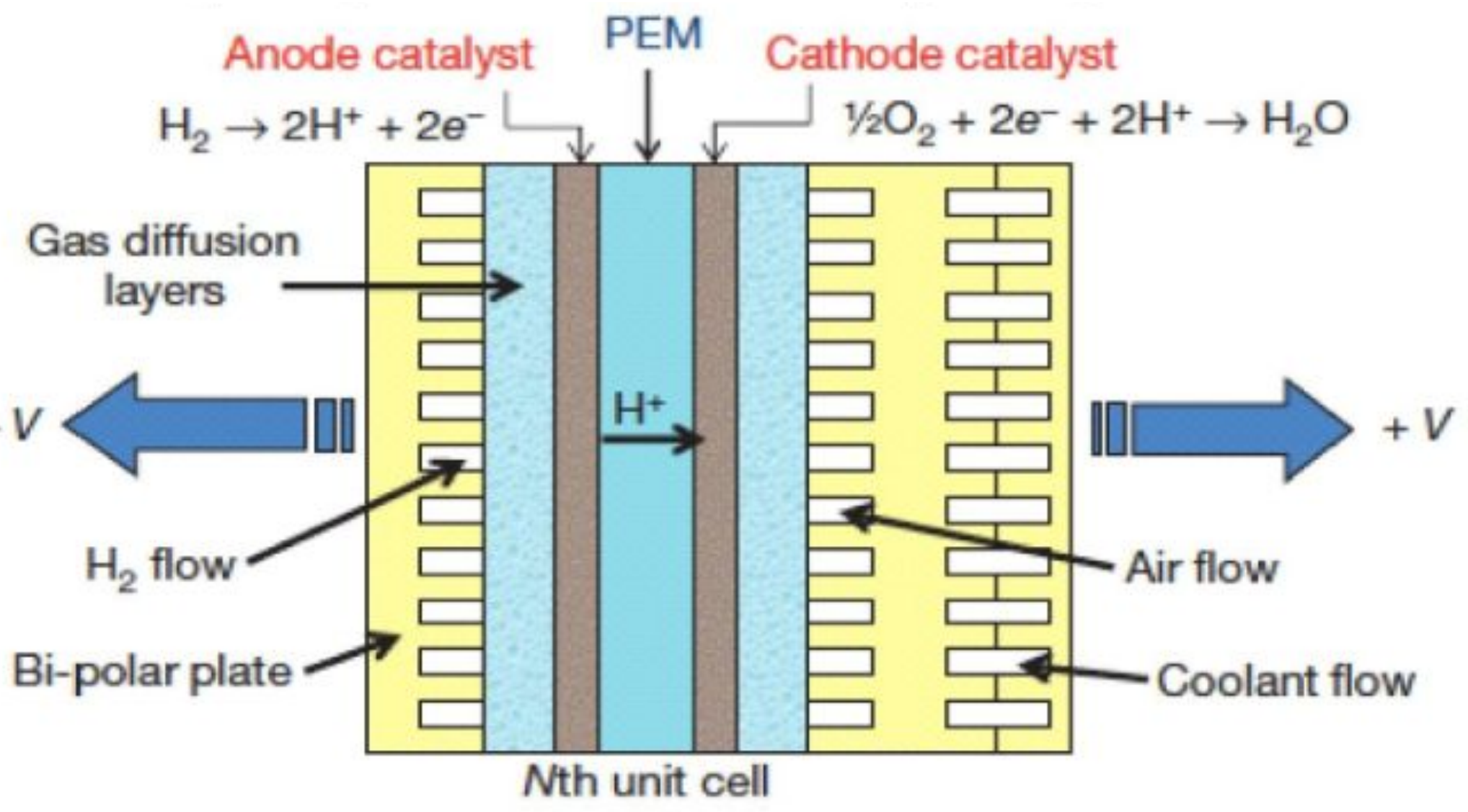

Figure 1: Cross Section of PEM Fuel Cell [1]

METHODOLOGY

The Fuel Cell Stack model in GT-SUITE models the flow, mass transfer, heat transfer, and electrical power generation of a Fuel Cell. The anode and cathode channels are modeled as pipe objects with circular cross-section with an orifice upstream, which calculates the mass flow rate between the adjacent flow volumes. Hydrogen is removed from the anode pipe, oxygen is removed from the cathode pipe, and water vapor is added to the cathode pipe at a rate based on electron production from the chemical reaction needed to match the current being produced. The internal losses generate heat that is transferred to the thermal mass of the fuel cell. The heat is then transferred to the anode and cathode fluids as well as the coolant and/or external environment. The coolant system is modeled in the same manner as the anode and cathode channels. The fuel cell is run in the Power Request mode, i.e. the net power requested of the fuel cell is provided and the flow, mass transfer, and heat transfer of the system respond accordingly.

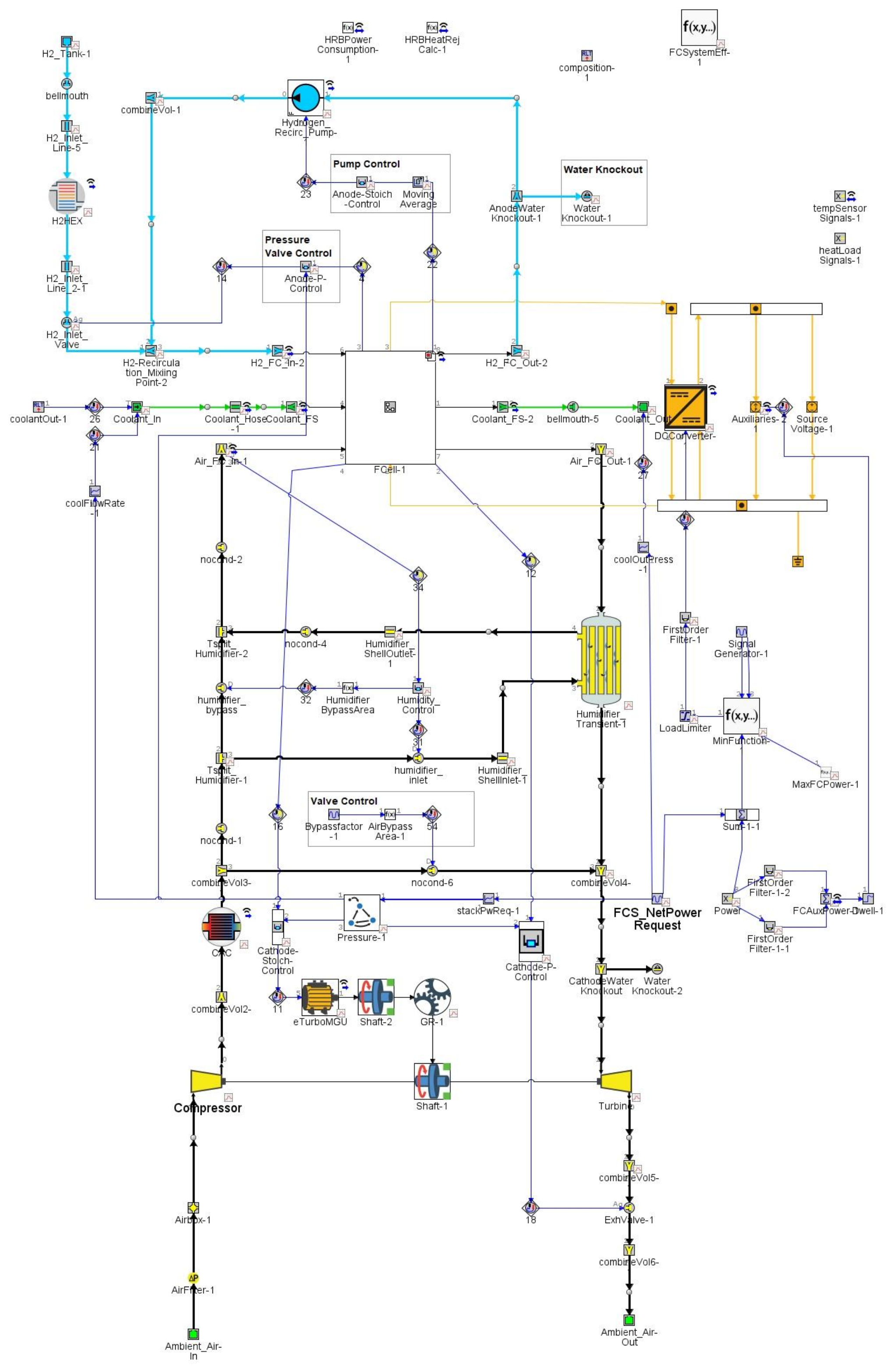

Figure 2: Model of the PEM fuel cell system used in GT-SUITE

The fuel cell model also includes parameters like membrane conductivity, reaction kinetics, gas flow rates, and thermal conductivity of materials to characterise the fuel cell. These parameters are set based on experimental data or theoretical calculations. GT-SUITE can conduct sensitivity analysis by varying parameters within the model and observing their effects on the system's performance. For instance, changing the membrane's thickness or adjusting the flow rate of reactant gases can help us understand how these factors impact fuel cell efficiency and power output.

GRAPHS, RESULTS & DISCUSSION

In Figure 3, the left side shows the response of the fuel cell system model (see Figure 2) in GT-SUITE for a series of step changes to the power request that help us in understanding different aspects of the fuel cell system detailed in the next section. The right side shows the response to a section of power request changes taken from a real drive cycle. In the graphs, we can see that fuel cell takes some time to adjust to its new demand, this behaviour is due to the components settings of PID controller in the fuel cell. The proportional component (Kp) is set to improve the transient response rise time and settling time and the integral component (Ki) is used to improve the steady state response.

Anode and Cathode Flow Control

Higher power output requires more hydrogen and oxygen. Therefore, the pressure set point on both anode and cathode side is raised when the power demand increases and is lowered when the demand decreases.

In Figures 3b and 3c, the blue line shows the actual fuel and air pressure at stack inlet which follow the changing target set point shown in red.

FC Stack Electrical Power & System Efficiency

The FC Stack has a slow response and it can take a long time to reach the target power level. This is the reason why a fuel cell electric vehicle is always a hybrid with batteries where the batteries provide for the fast transients in the power demand.

For the most part, the system efficiency is between 45-65%. The efficiency reduces somewhat when the fuel cells operate at higher power levels but recovers when the power level falls.

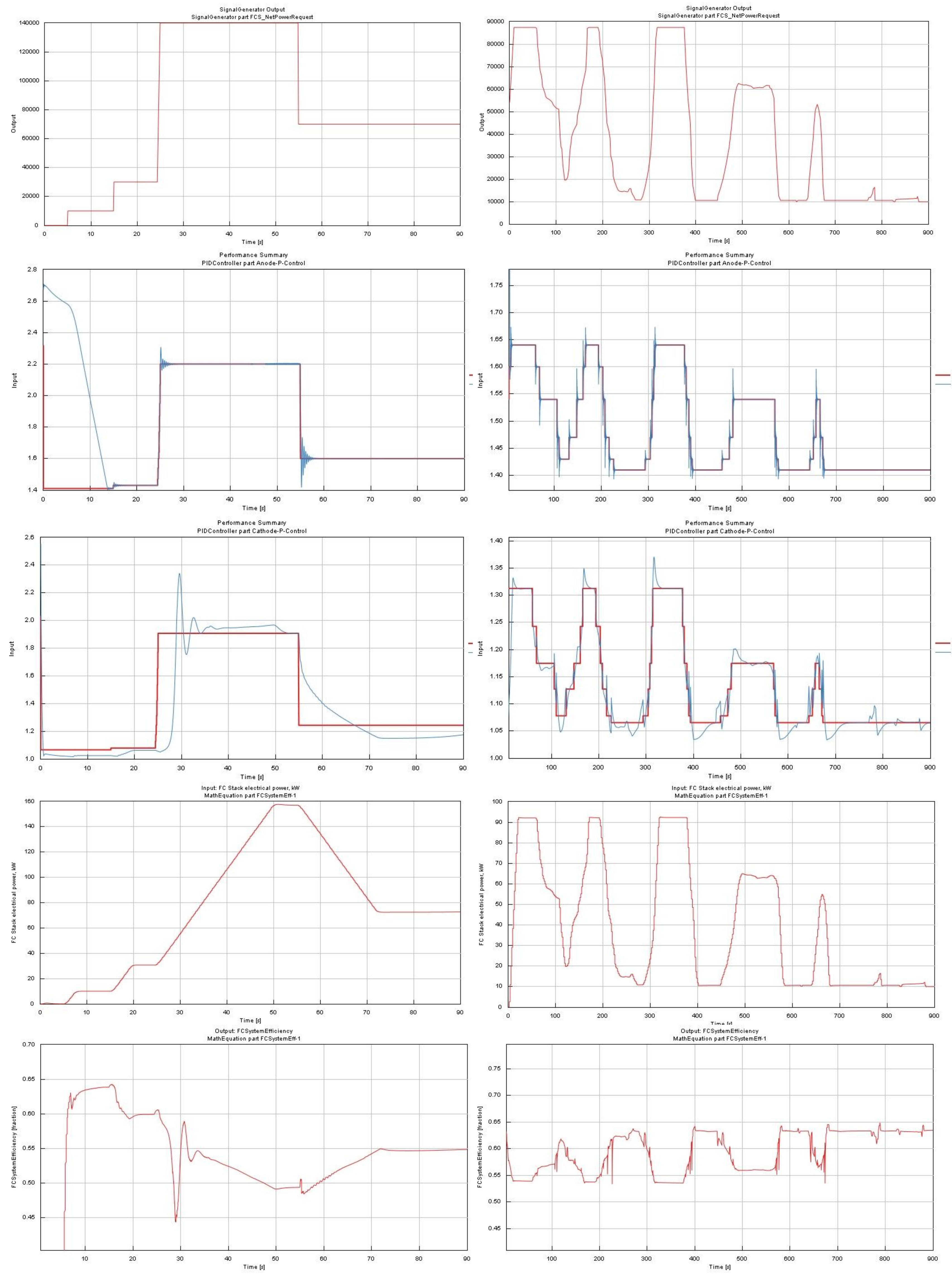

Figure 3: Top to Bottom for step response and drive cycle resp.
(a) Power Request, (b) Anode Pressure Control, (c) Cathode Pressure Control, (d) Actual Power, (e) FCS Efficiency.

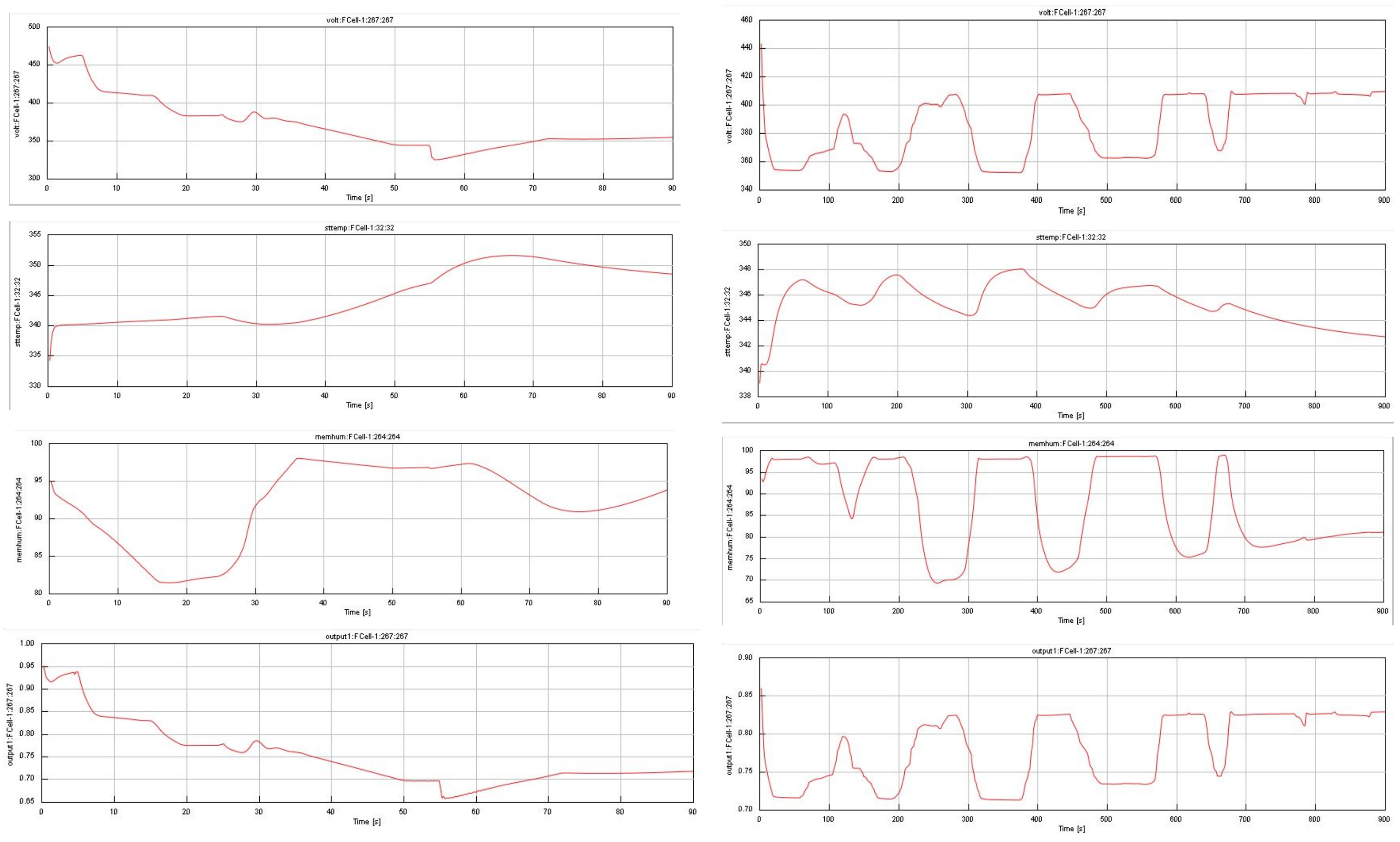

Figure 4: Top to Bottom for step response and drive cycle resp.
(a) Stack voltage in V, (b) Stack temperature in K, (c) Membrane RH in %, (d) Single cell voltage in V.

FC Stack Voltage, Temperature and Humidity

The graphs in Figure 4 demonstrate that an increase in power results in a decrease in stack and cell voltages. The data also indicates that the fuel cell system efficiency reduces with the increase in stack current due to increase in losses in the fuel cell, such as transport loss, as well as increase in power required in the Electric Turbocharger (ETC). As the power is increased the water production in the membrane increases, thus the Relative Humidity (RH) in the membrane increases as long as the Membrane Electrode Assembly (MEA) is not overheating. The reduction in efficiency also leads to an increase in heat losses, thus increasing the requirements on the vehicle cooling system.

In a fuel cell, the relative humidity of the membrane is critical in determining its power output and durability. It is essential to maintain the membrane's relative humidity between 80% to 95% to ensure efficient ion transport and minimal ohmic losses. In the driving cycle, several factors can impact fuel cell performance and durability, such as MEA RH reduction at low power requests, single cell voltage increase above 0.8V during low load operations causing catalyst degradation, and stack temperature oscillations coupled with RH swings in the MEA causing mechanical stresses due to swelling/shrinking cycles.

REFERENCES:

1. Wang, Y., Diaz, D. F. R., Chen, K. S., Wang, Z., & Adroher, X. C. (2020). Materials, technological status, and fundamentals of PEM fuel cells–a review. *Materials today*, *32*, 178-203.