Technical Report

Data and Telemetry Award 2021

Fortis Saxonia is competing at the Shell Eco-marathon in the Urban Concept category with the vehicle called UrbanSAX. It uses a hydrogen fuel cell stack of 46 cells that provides a rated power of 2 kW. It directly powers the motor without using any additional energy storage. In the following report data collected from previous Shell Eco-marathon attempts will be analysed. Based on this, an approach to reduce the amount of needed hydrogen will be presented. Finally, an estimation about the expected improvements will be made.

Evaluation of previous results from Shell eco-marathon

In the latest competition our vehicle had a quite high consumption of hydrogen. After the event the logged data from this attempt (see Figure 1) was analysed and the following problem was found.

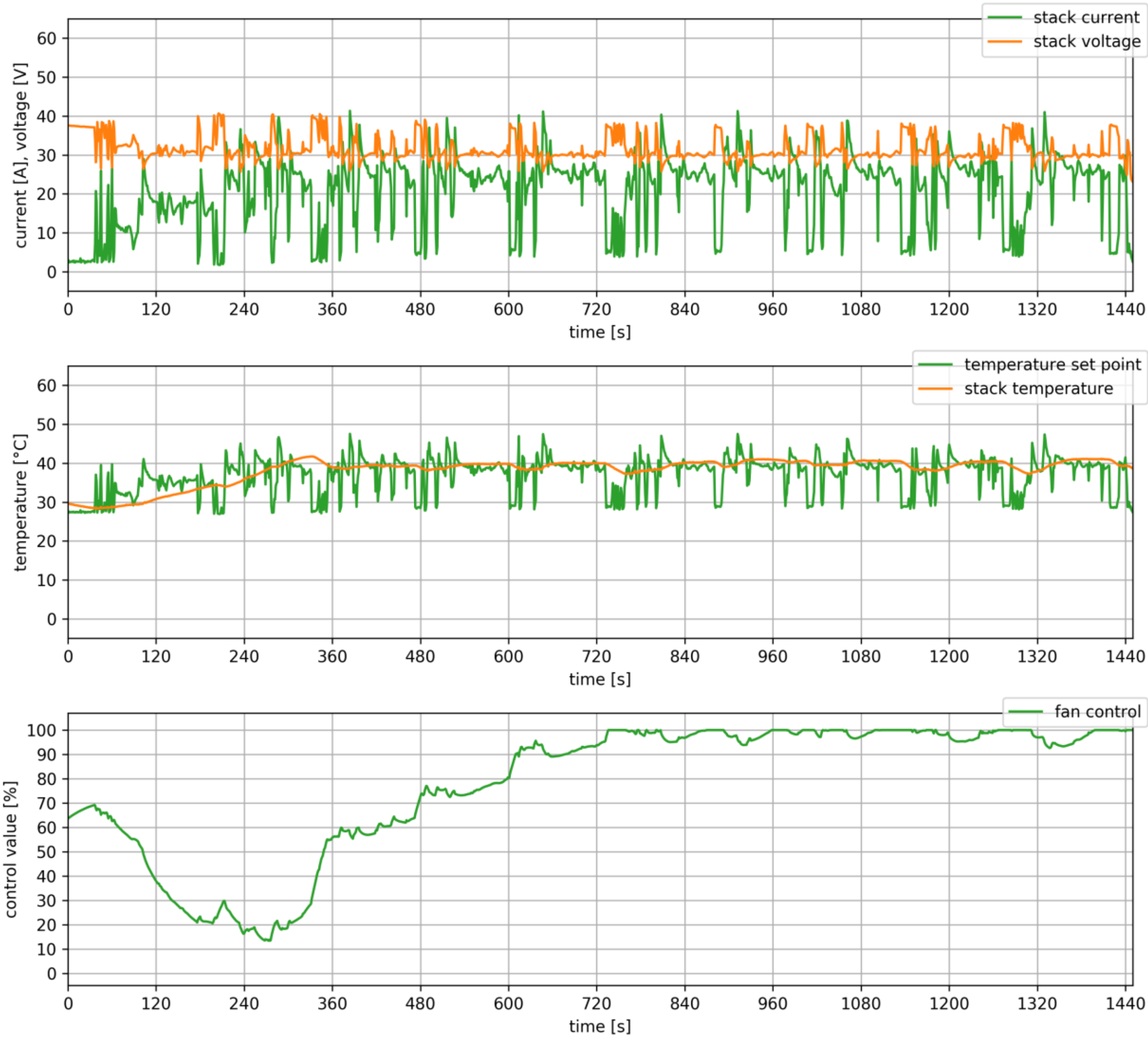

Figure 1 Graphical representation of the logged data from the fuel cell control.

The used control algorithm (see Figure 2) tries to keep the fuel cell at a reasonable temperature to prevent damages to it. Therefore, the temperature set point is dynamically calculated based on the electrical current drawn from the cells. The fan itself is controlled by a PI controller.

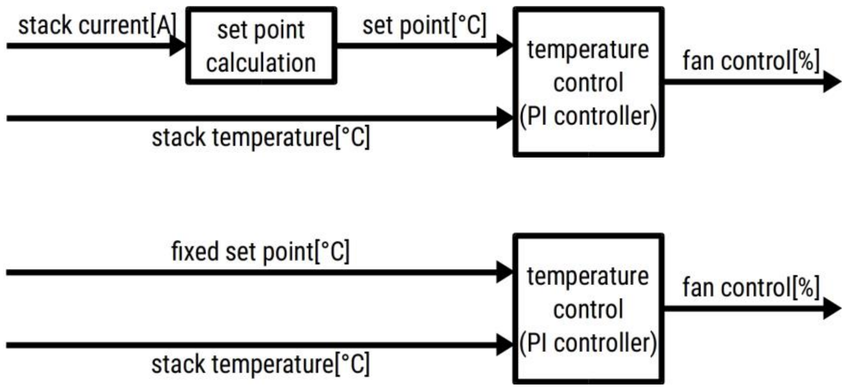

Figure 2 Block diagrams of the old (top) and new (bottom) temperature controllers.

However, the curves on the track as well as acceleration and braking manoeuvres make it impossible to draw a constant current from the fuel cell. This leads to frequent changes in the set point which sum up at the integrative term of the controller. Eventually this results in the cooling fan rotating at its top speed which in turn leads to a too low temperature in the whole system. Therefore, the performance is reduced and the hydrogen consumption increases.

This shows that the used control algorithm is not suitable for this use case. Although it covers the whole range of possible current values, the adjustment takes quite some time. Hence it is suboptimal for this application where frequent changes are a usual thing to happen.

Suggested design

To prevent the problem described it was decided to change the temperature control algorithm from the dynamic to a fixed set point (see Figure 2). In this way the fluctuation of the required energy as well as the phases where no energy is needed (braking, standstill) will no longer affect the control algorithm. Instead, the speed of the fan only depends on the current temperature and the set point. This also means the driving style will not influence the fuel cell performance anymore.

The calculation of the set point to use can be influenced by empirical knowledge from previous runs as well as the current conditions on the track. If this value is set too low initially the car will not be able to reach the required speed. Vice versa, if it is set too high the fuel cell provides too much energy which increases the amount of consumed hydrogen. To prevent these cases the driver has the possibility to correct the set point while the system is running by pressing buttons on the steering wheel. This creates the possibility to further control the fuel cell performance while the car is driving.

To detect whether the set point needs to be corrected is not trivial. For this, the measured values of the fuel cell, the state of the control algorithm and the vehicle speed need to be considered. As there does not exist a possibility to perform this analysis automatically, it requires a human expert with knowledge of the whole fuel cell system. As the driver is already busy with driving the vehicle this needs to be done by another member of the team. This person can have a detailed look at all available real-time data from the telemetry system and decide whether a change is needed or not. Since the voice contact between driver and team is kept permanently, decisions about necessary adjustments can be easily communicated.

In addition to the vehicle speed all relevant data from the fuel cell would be needed to implement this concept. This includes the current that is drawn from it as well as its voltage and temperature. Furthermore, information about the internal state of the control algorithm, mainly regarding the temperature set point, fan control value and error state, would be useful. Since all this information is provided on the internal CAN (Controller Area Network) bus of the car, it would be the most convenient approach to provide a possibility to connect the telemetry system to the CAN bus. The raw message data could be stored on a server from where the team would read, extract and analyse its currently needed data itself. This would provide a solution that could be easily used by every competing team.

Expected improvement

To assess the possible improvement the polarization curve of the fuel cell was analysed. A polarization curve shows what voltage can be expected when a given current is drawn from the stack. For current values below the maximum allowed value this curve can be approximated by a linear function.

Using the logged data, it is possible to create the polarization curve from the current and voltage values. For that the average stack voltage for each possible current (discretized to a certain granularity) is calculated and used for a linear regression. Thereby the polarization curve can be obtained as a formula representation.

To evaluate the curve present during the Eco-marathon run a reference curve, to which it can be compared, is needed. As reference the data from the first run of our fuel cell stack was chosen. Back then it was running at nearly optimal conditions which lead to the maximum performance that is realistically possible.

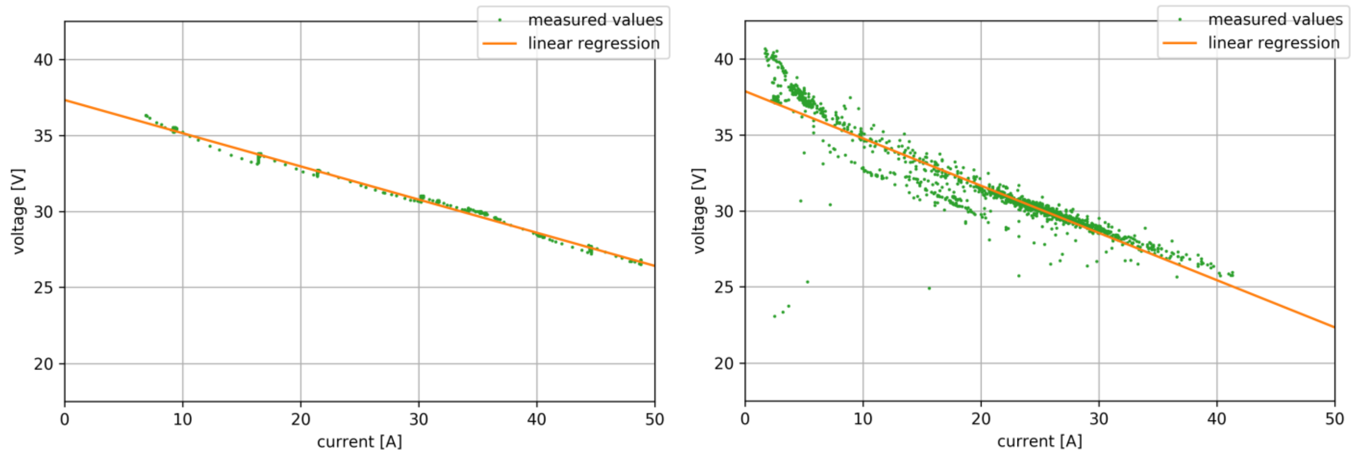

Figure 3 Polarization curves of the first operation (left) and the SEM run (right).

The obtained polarization curves are shown in Figure 3. They can be described using the following formulas.

- First run: $U_{first}(I) = -0.2181 \frac{V}{A} \times I + 37.3176\ V$
- SEM run: $U_{SEM}(I) = -0.3106 \frac{V}{A} \times I + 37.8633\ V$

As seen in the figure and formulas the fuel cell had a lower performance and larger voltage deviations during the SEM run. The aim is to achieve the same performance as during the first run by using the approach described above.

With the help of these polarization curves it is possible to calculate how much power the fuel cell provides for a given current curve. By using the logged data for electrical current from the SEM run this power can be calculated for both polarization curves ($P = \int I(t) \times U\big(I(t)\big)\, dt$). This gives the following results:

- First run: $P_{first} = 266.3471\ Wh$
- SEM run: $P_{SEM} = 251.3655\ Wh$

As the calculated result for the SEM run is near to the real result ($P_{real} = 251.1899\ Wh$) it can be assumed that the used approximation is valid.

Comparing the results shows that the better polarization curve produces $5.96\ \%$ more power. Using this additional power, it would be able to operate the fuel cell at lower currents while the resulting power stays the same. This in turn leads to a lower hydrogen consumption and an extended range. Thereby it is expected to reduce the overall consumption up to these $5.96\ \%$.

Summary

In this concept possible ways to reduce our hydrogen consumption were searched, proposing a new approach to control the temperature of the fuel cell stack. By using a fixed set point algorithm, the fuel cell will be more robust towards changes of the needed power. After implementing this approach, a performance increase or consumption decrease of about $5.96\ \%$ can be expected.