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Challenges of automotive fuel cell stack testing

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Summary

Fuel cell vehicles are one of the most promising technologies to reduce greenhouse gas emission and to enable local zero emission mobility. Besides the costs for the fuel cell and tank system, the hydrogen infrastructure and lifetime requirement are the main issues.

To meet fuel cell stack lifetime requirements (> 6000hrs) under full dynamic operating including cold and air starts a good understanding of aging mechanism is mandatory. Considering the demand of low platinum loading and hydrogen fuel quality issues the automotive fuel cell stack lifetime testing under highly reproducible test conditions is important to support stack component development and optimization.

The impact of different test station design and the transfer function of test station data to real world data are still not fully understood. This paper describes main challenges of automotive fuel cell stack testing on laboratory test stations.

1 Introduction

1.1 Fuel Cell Vehicle technology

Fuel cell vehicles are one of the most promising technologies to reduce greenhouse gas emission from the transport sector and to enable local zero emission mobility. The big advantage compared to pure battery vehicles is the fast charging time with gaseous hydrogen. Meanwhile fuel cell technology has advanced considerably and first vehicles are available commercially. Yet some challenges are remaining. Besides the costs for the fuel cell and tank system, the lifetime requirement is the main challenge.

Lifetime and durability testing of full size automotive stacks and short stack on test stations in laboratories is mandatory to support the development activities of car manufacturer. The benefit of test station data as compared to real world data is the perfect reproducibility and the possibility to measure additional parameters with sensors that are not available in fuel cell vehicles. Both enable a better understanding of e.g. aging effects. The transfer function of test station data to real world data is of huge interest to assess the test results gained in laboratory environment.

Under the aspect of low platinum loading in combination with studying the effects of hydrogen quality, lifetime testing is today maybe even more interesting and relevant than years before. The relation of aging effects resulting from voltage cycling, temperature and relative humidity variation, temporary starvation effects and hydrogen contaminants is not fully understood.

1.2 Automotive stack testing

The electric power requested from full size automotive stacks typically exceeds 100kW; some requirements go up to 150kW. With an active are of about 300cm² and a current density of more than 2.5 A/cm² the total electric current can rise above 750A. The cell count of state of the art fuel cell stacks is in the range of 300 to 400 cells which results in an open circuit voltage of approximately 400 V_{DC}. These electric parameters define the electronic load specifications. The load dynamic response requirement is below one second from 10 to 90% maximum power.

These requirements must be fulfilled by the electric and the reactant supply part of the fuel cell system. Insufficient reactant supply for the fuel cell stack is one of the main aging issues. Since an anode loop is established in fuel cell systems and fuel cell test stations, lack of hydrogen supply during dynamic operation is less relevant. But air supply needs to be designed well to ensure sufficient availability of air on the cathode side also under dynamic load operating. In test stations, mass flow controllers (MFC) are typically used which have a limited dynamic response. But even more relevant is the overall cathode supply with its internal volume in between the MFC and the stack. This inner volume typically reduces the cathode dynamic response additionally. Nevertheless specific optimized test stand controls enable full dynamic operation of fuel cell stacks also on test stations.

Reactant humidification is another relevant topic. Many different humidification techniques are available. Due to that the pros and cons of the individual designs need to be considered carefully.

1.3 Test protocols

Many different test protocols for single cell and stack testing are available [1], e.g. from DOE, JARI, NEDO, IEC, SAE etc. Also in Europe many protocols are available from EU projects like FCTestNet, FCTesQA and FCH-JU Stack-Test. Several accelerated test protocols (AST) for different cell and stack components are established.

But on the other hand the transfer functions of all those existing test station protocols into the real world application still seems to be not publicly available. To close this gap there was an EU Horizon 2020 Call for Proposals H2020-JTI-FCH-2017-1 under the topic FCH-04-5-2017 “Definition of Accelerated Stress Testing (AST) protocols deduced from understanding of degradation mechanisms of aged stack components in Fuel Cell systems”.

On single cell level, harmonization activities are supporting the demand for comparable test results. Single cell operating conditions are already defined by [2]. The cell hardware harmonization is a further approach to gain comparable result to benchmark cell and stack components. On the other hand also in full size hardware which is very individual for different applications harmonized test protocols can support benchmark activities.

On stack levels, generally accepted harmonized endurance test protocols are not yet available. One approach for harmonizing a load profile especially for Fuel Cell Stack lifetime investigation was made within the FCH-JU Stacktest project [3]. The so called Fuel Cell Dynamic Load Cycle FC-DLC (defined on [2] and [3]) is an artificial stack electric load profile defined by 35 single test points (see Figure 1). The maximum load refers to the nominal maximum power of the operated stack. In case of an automotive stack it may be defined by the current density of e.g. 1.5 A/cm². In case of an active area the stack load at 100% corresponds then to 450A.

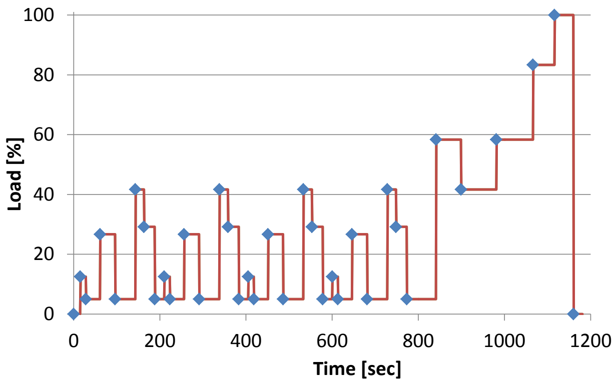

Figure 1 Fuel Cell Dynamic Load Cycle FC-DLC

1.4 Test hardware

Understanding the influence of cell and stack hardware on one hand, but on the other hand influence of the test station itself is a very relevant topic. Defining the cell or stack operating conditions and the test profile will not automatically lead to results which are comparable one by one. Of course the consumed reactant quality needs to be considered, but also the test station dynamic properties may have an impact on the result, at least for dynamic tests.

As mentioned before, a misfit of reactant supply dynamics to the electric load drawn from the stack is resultion in considerable stress to the stack. Yet, electronic loads delivered as part of commercial available test stations or purchased individually have specific dynamic properties; this is also due to the controls interface to the test station. If e.g. the load profile (with the electric current setpoint) and the data acquisition sampling rate are both defined on a one second time base, if not recorded in high temporal resolution, it will remain unclear what actually is happening within this one second. If we agree that the load transient is a major stress for stack components, the load up and down transients in Amps per second are a really relevant parameter to monitor and possibly control [4]. Data acquisition with higher sampling rates than 1 Hz (e.g. 1 kHz or more) is needed to explain the actual load transients.

1.5 Challenges

The challenges of dynamic stack testing are explained based on the experience from different EU projects including round robin testing of fuel cell stacks running on different test stations in different European fuel cell labs. Although reasonable coherence of results could be achieved, more work is needed to identify the sources of remaining inconsistencies. Furthermore, the influence of reactant quality is increasingly relevant since the catalyst loading will be reduced further on.

Selected results from full size automotive stack durability tests within FCH-JU AutostackCORE [5] are used to demonstrate the demand for further improvement of test protocols with the objective of better comparability.

A method to distinguish between reversible and irreversible voltage decay is explained based on durability test results of automotive short stacks with full active operated under FC-DLC for several thousand hours.

The challenges in automotive fuel cell stack testing are categorized in a) the infrastructure, b) the fuel cell test station, c) the test protocol and d) the data acquisition, investigation and visualization, especially in case of long-term durability testing.

Infrastructure: Automotive fuel cell stacks have a typical power range up to $100kW_{el}$ or more. The required media flows for the air on the cathode side easily exceeds 5000 Nl/min or 100 g/sec, and for hydrogen on the anode side up to 1500 Nl/min or 2 g/sec. An automotive full size stack can consume more than some hundred kilogram of hydrogen per day if it´s operated at full load.

Also the thermal heat produced by a full size automotive stack exceeds 150 kW_{th} and needs to be handled by the infrastructure.

Fuel Cell Test Station: There are not too many manufacturer of commercially available large Fuel Cell Test Stations worldwide. A deep understanding about the test station requirements is needed to specify the test station in a way that can be integrated in the existing infrastructure.

Especially the dynamic properties of the test stations are an important issue. E.g. the gas humidification subsystem, the pressure controls, and the hydrogen and air supply are highly relevant to get reliable and comparable test results. Sufficient hydrogen and air supply during transient loads is most relevant because reactant starvation is known as one of the most severe electrode degradation mechanism.

For durability testing a fully automated and unattended operating is mandatory. This requires a carefully defined alarm handling with automated shutdown procedure to ensure safe operation all time.

The (partly) reduced dynamic properties of a Test Station compared to the final application inside a vehicle are often discussed.

Test protocol: If the test results are benchmarked to other test stations or laboratories, the clear and unambiguous definition of the test protocol is very important. Test protocol should consider on one hand the Fuel Cell Stack operating conditions, on the other hand the dynamic transients from one to the other test point, and finally also the exact definition of the chronologic order of the individual test points with ramp and dwell time etc.

All parameters that may influence the test results need to be considered. This may be e.g. the reactant quality, the pressure, temperature and humidification controls, and the load profile.

Having a harmonized nomenclature for the relevant stack operating conditions and the corresponding Test Station parameters is very helpful if results from different test stations are compared.

Data acquisition: Especially long term durability testing on full size stack level generates a large number of individual data. In case of a complete single cell voltage monitoring (CVM) there are several hundred individual cell voltages, plus all the other test parameters. Typically the sampling rate is 1 Hz. This means that for a durability run with e.g. 3000 operating hours more than 10 million single datasets are recorded. A database is recommended to store this large amount of data.

Then handling of large amount of data, but also the investigation and visualization is something that needs to be considered!

Finally it needs to be understood that the method of data investigation can have a significant impact to the test result. Especially the voltage degradation investigation is very sensible regarding different methods of investigation and the results may vary if the method is not exactly defined.

As already mentioned above the biggest challenge in automotive fuel cell stack testing is maybe the transfer of laboratory test results in the real world which means vehicle application. There is still a lack of publicly available information on how to transfer the results measured on a Fuel Cell Test Station into the final vehicle application, especially regarding lifetime.

If one tested full size automotive stack has a measured voltage decay of 15 µV/hr on a test station performing a well-defined dynamic protocol including start-stops, what is then the expected lifetime inside a vehicle?

2 Selected Results

Two exemplary results are shown in this paper, the first from the project FCH-JU Stacktest, and the second from FCH-JU AutostackCore. Both examples are durability test for lifetime investigation based on the FC-DLC.

When we are using the FC-DLC for lifetime investigation, we typically analyze three or four of the overall 35 test points defined within the FC-DLC. Typically the following test points are investigated: Test point #29 (@ 5% full load), #31 (42%), #32 (58.3%), and #34 (100%). One test point is defined as the averaged value of the average cell voltage over 10 sec at the end of each test point.

Those four test points of the FC-DLC are now plotted in a time chart over the stack operating hours line shown in Figure 2.

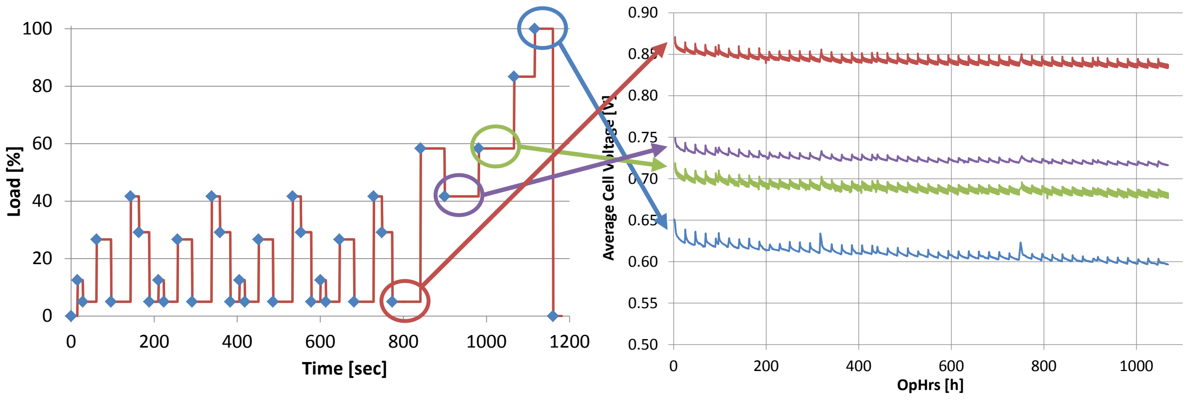

Figure 2 Transfer of cell voltages from FC-DLC into time chart

The cell voltage decay can now be calculated for the individual stack load points based on the time chart.

In the following sections, selected examples of endurance testing using the FC-DLC are discussed. The purpose of the first example is to investigate the impact of start-stop on the Fuel Cell Stack voltage degradation. Therefore a well-defined start-stop protocol was developed including frequent air starts. The used protocol was defined shown in Figure 3.

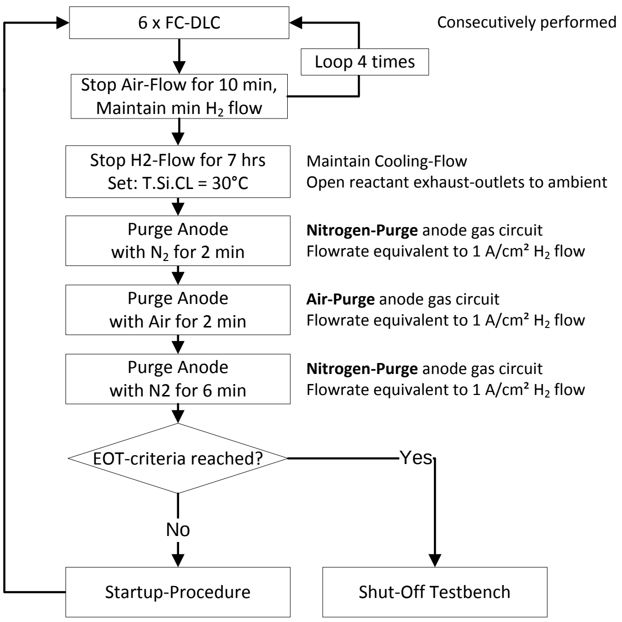

Figure 3 Start-stop durability protocol

This durability protocol was performed for about 3000 stack operating hours. The cell voltage decay over time is shown in Figure 4. The irreversible voltage drops are the slopes of the linear regressions of the corresponding average cell voltages. In this start-stop durability test the irreversible cell voltage drop was 6, 8 and 27 µV/hr for 5, 42 and 100% stack load respectively. The obvious oscillation especially in the 100% load values is the result of the start-stop durability protocol and reflects the reversible (recoverable) cell voltage drop. The irreversible degradation was additionally confirmed by regularly performed polarization curves under reference operating conditions.

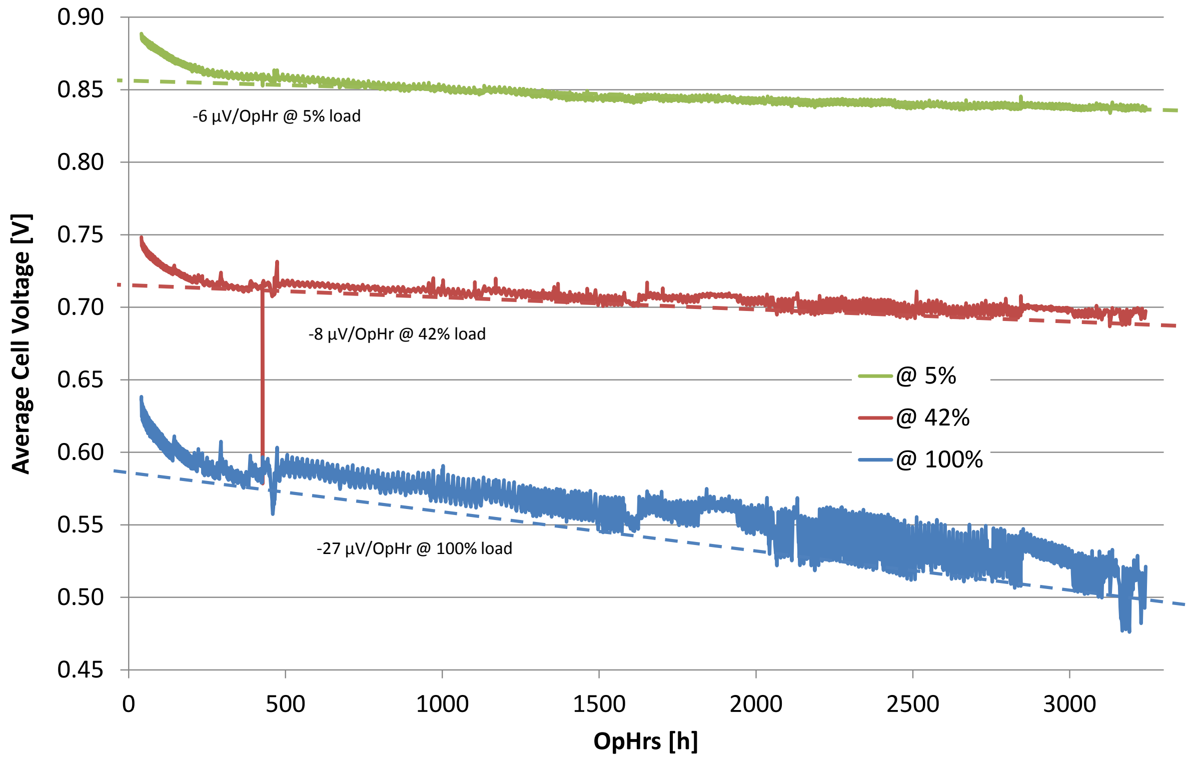

Figure 4 Start-stop durability result

The second example is from FCH-JU AutostackCORE and was performed with a short stack for about 1000 OpHrs (see Figure 5). This durability test was defined by 20 hours under FC-DLC (60 cyles) followed by 4 hours cold soak including shutdown and startup. In this example the reversible versus irreversible voltage decay is very obvious. For further explanation regarding this effect see [3].

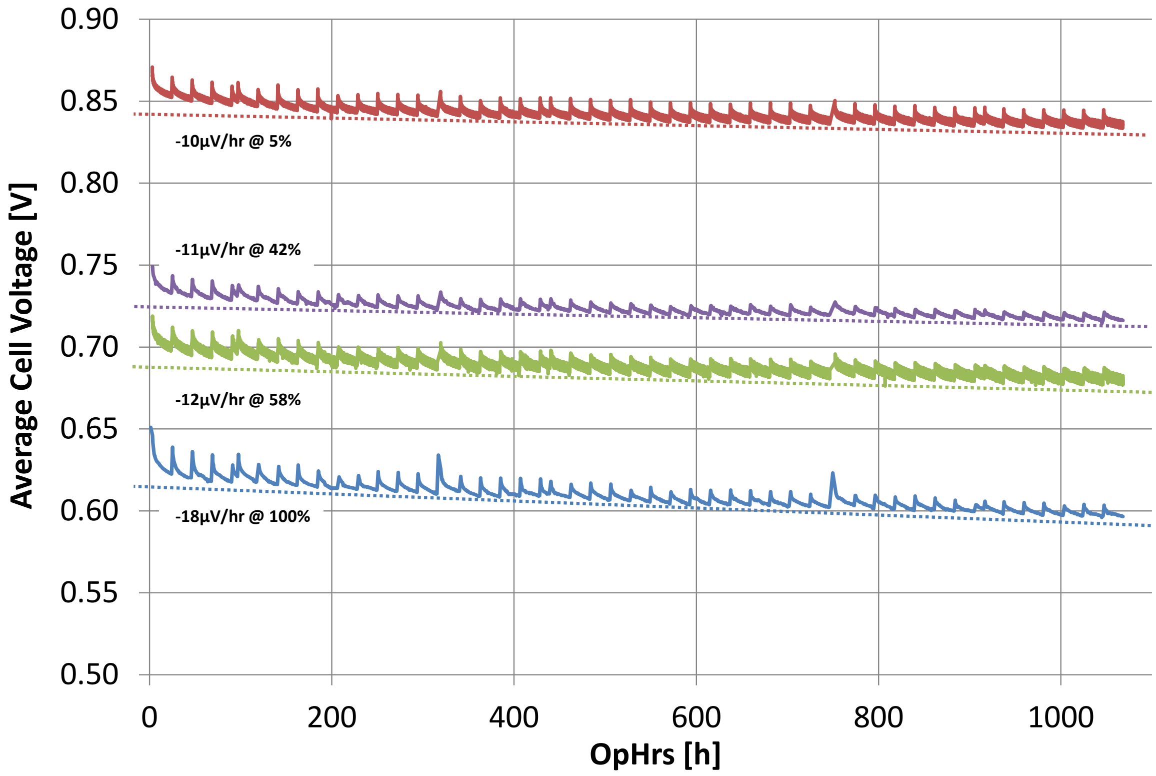

Figure 5 Automotive fuel cell stack durability test

The irreversible cell voltage decay in Figure 5 is 10, 11, 12 or 18 µV/hr at 5, 42, 58 or 100% nominal stack load. The U.S. DOE lifetime target for automotive application is 5500 operating hours. The accepted 10% performance loss of the fuel cell stack corresponds to 10 µV/hr irreversible voltage loss at nominal stack load. This example shows that we came close to these lifetime target for the fuel cell stack.

3 Discussion

Testing and characterizing Fuel Cell stacks for automotive application is very important to support the product development for Fuel Cell Vehicles. Even if it is not possible to operate the stack under the identical conditions like in the final application, especially regarding dynamic behavior, the test on Test stations give valuable information on performance and lifetime. The big benefit in Test station operating versus real world operation are the uninterrupted 24/7 operating and the very high reproducibility of test protocols under well-defined conditions. The 24/7 operating delivers test results within a reasonable amount of calendar hours, ideally 3000 OpHrs within about just four months. The highly reproducible test conditions allow e.g. a detailed investigation of the impact of different operating conditions on the stack lifetime.

Acknowledgement

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References

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