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Evaluation of Transient Voltage Behaviour During Load Changes in Automotive PEM Fuel Cells

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Abstract

Polymer electrolyte fuel cells reach high efficiency and zero emissions even under highly dynamic loads. Power fluctuations, sudden load changes, start up and shut down procedures cause locally very high as well as very low voltages. These undesired voltage levels accelerate the degradation of the cells in terms of carbon corrosion, platinum oxidation and membrane decomposition. Experiments with single cells are capable to indicate, which conditions are most harmful to the cell. The voltage response during load steps shows characteristic under- and overshoots. The amount of these over- and undershoots are directly correlated to the amount of the extend of the load change. The shape and the relaxation time of the voltage curve are dependent on the operation conditions of the cell in terms of humidity, pressure and stoichiometry.

Introduction

During the last decade several car manufacturers provide fuel cell cars for commercial sales. The benefits of fuel cell cars are their high efficiency, zero emissions and renewable fuel production methods. The fuel cell propulsion system has to overcome some barriers to be competitive on the commercial market. The major barriers are the costs of the system and the lifetime. The lifetime of fuel cells is greatly influenced by the operation conditions. Very high and low voltage levels are known to accelerate the degradation in terms of catalyst, carbon catalyst support and membrane degradation. In stationary applications the maintenance of stable voltages is easy to achieve by constant operation conditions. In contrast automotive applications always have high dynamic load changes and altering operation conditions. These dynamic changes cause undesired voltage levels and can harm the fuel cell. An example of typical load changes is given by the 'New European Drive Cycle' that is used to simulate real driving conditions and is shown in Figure.1

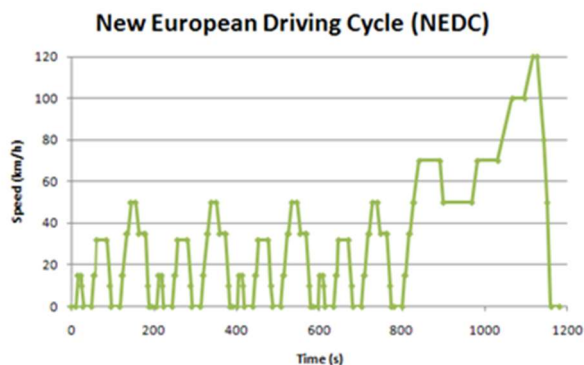


Figure 1: Load changes according to the NEDC [1]

To reduce the degradation induced by load changes it is of high interest to understand the mechanisms that occur inside the cell during transient operation conditions. To investigate the mechanisms laboratory scale single cells are capable to

give insides of the actual processes. To transfer this knowledge to industry and real automotive applications it has to be considered that automotive fuel cell systems have distinct differences to 'normal' laboratory cells. The most significant differences are the humidification of the gases and the hydrogen recirculation. For laboratory scale cells the hydrogen and the air are humidified separately and the amount of humidification can be adjusted as desired. In cars only the cathode can be humidified actively and the anode is supplied with dry hydrogen. The hydrogen can only be humidified by water transport through the membrane. The water can accumulate on the cathode side. The hydrogen recirculation system enables the enrichment of humidity but also enriches gases like nitrogen and carbon dioxide that also diffuse through the membrane. This accumulation especially of inert gases reduces the efficiency of the systems. Consequently, frequent purging of the anode with fresh hydrogen and draining of the condensed excessive water is necessary.

For fundamental research this deviation is ignored and the focus is on the water transport mechanisms in the cell and how they are influenced. In Figure.2 the basic water transport mechanisms are shown. The most important mechanisms are the self-humidification of the cathode side by product water. The water drag with protons, which is the amount of water that is attached to a proton during the transport through the membrane and the back diffusion of water forced by concentration gradients from the cathode to the anode.

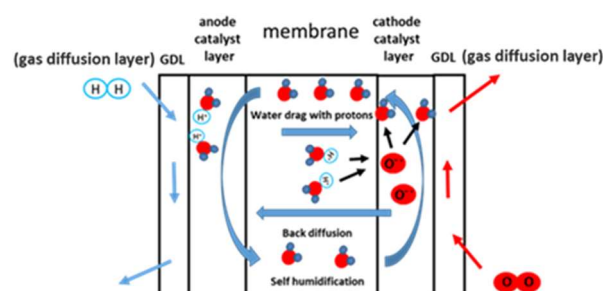


Figure 2: Schematic illustration of proton exchange membrane (PEM) and the mechanisms that influence the water management inside the membrane [2]

The water management is also greatly influence by the geometry of the flow field and the applied operating pressure. As long as water is produced on the cathode the design of the flow field channels in terms of width and height as well as the length have significant effects on the water management. The interaction of heat and water production on the cathode can lead to a two phase flow, consisting of humidified gas and a liquid water phase. Under extreme conditions this can lead to undesired condensation inside the channels. To eliminate these influence factors, the measurements were done with a so called segmented zero cell. The detailed description of this cell type and the used materials are explained in the next chapter.

Materials and Methods

The cell that was used for this experiments was a segmented 25 cm² cell. The cell consisted of 5 separate graphite flow fields with a dimension of 40*40*5 mm. The combination of these 5 segments and the isolation spacing resulted in a total flow field with a length of 25 cm and a width of 1 cm.

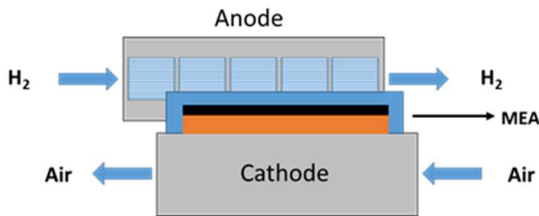


Figure 3: Zero cell with 5 segments and counter flow configuration

The single MEA components are shown in figure 4. The MEA (membrane-electrode-assembly) is the heart of the fuel cell where the reactions take place. It consists of an CCM (catalyst coated membrane) and an attached GDL (gas diffusion layer). The CCM consists of a membrane (Nafion) that is sandwiched between two electrodes.

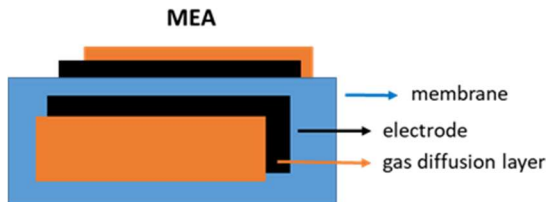


Figure 4: Components of the MEA

The single segments were thermally and electrically isolated by a polycarbonate matrix. Each segment was heated with a Peltier element to minimize the heat transfer from one to another segment and to keep the segment temperature constant. The operating conditions of the cell during load cycle measurements are shown in table 1.

Table 1. Materials and operating conditions

parameter	value
Ansolute gas pressure (both sides)	1,013 bar
Fuel cell temperature	60 °C
Relative humidity	0 – 1
Anode stoichiometry	1,2
Cathode stoichiometry	2,15
Flow configuration	Counterflow
Channel length	250 mm
Channel and land width and height	1 mm
Membrane thickness (nafion 212)	0,05 mm
Catalyst layer thickness	0,0085 mm
Platinum loading	0,5 mg * cm ⁻²
GDL tickness	0,41
Effective area	25 cm ²

The measurement procedure consisted of an initial activation and the load step measurements. The activation was performed by voltage cycling between 0.4, 0.6 and 0.8 V. Consecutively the load step measurement was done by ramping the current up to 12.5 A and keeping this value for 1 hours followed by a current change from 12.5 A to 5 A. The second load step was from 5 A back to 12.5 A. The following steps were done in the same way with a greater extent of the load step. The test system was a Scribner Associates 890CL

test system and the conditioning system was controlled by an in-house programmed LabVIEW software. Because the voltage response is more significant under dry conditions the anode was supplied with dry hydrogen and the cathode was partially humidified to 50 % relative humidity. The gas supply was constant at a stoichiometry according to Table 1 for a current of 12.5 A.

Results

The results of the measurement are shown in Figure 4. The voltage at 12.5 A developed a constant value at about 0.425 V. After the current decreased to 5 A a voltage increase can be seen and no constant voltage value was achieved. This behaviour was attributed to the dry and excessive constant gas flow. That means that too much gas supply can dry out the membrane. After the following load increasing step to 12.5 A a significant voltage undershoot is visible. This undershoot is followed by a fast increase above the corresponding level that was observed before the first load decreasing step at 12.5 A. The following steps showed a similar behaviour. The difference between the load steps is that the under- and overshoots show a greater extend with greater load steps. The relaxation time to reach a constant voltage level is also longer for bigger load steps. The results for each segment of the cathode side are shown in Figure 5. The segment number one is related to the air inlet and number five is placed at the cell outlet. A distinct difference in the measured current for each segment is visible. The first and the fifth segments show similar trends and the lowest values compared to the other segments. The dominant high current of the second segment is always observable.

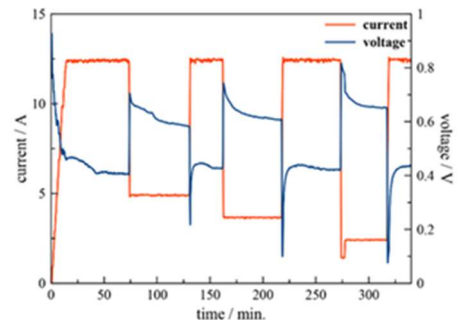


Figure 5: voltage response behaviour during load steps with dry gases

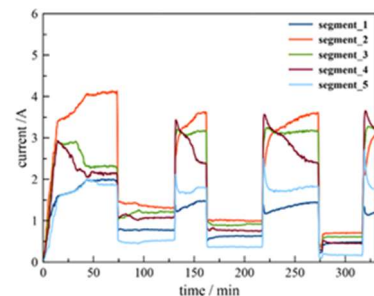


Figure 6: current distribution during load steps between 5 segments

Conclusion

It can be concluded that increasing load steps influences the water transport of the membrane in that way that the voltage over- and undershoots are also increased [3,4]. The constant voltage levels that were achieved during high current periods show that the amount of produced water was sufficient to reach a constant performance. During low current periods the release of water/humidity took more time and no constant

voltage level were observed. For the results of the single segments it can be concluded that the first segment showed low current values because of the only partially humidified air. The produced water from the first segment effected the second segment in that way that the humidification was much better than for the first, resulting in much higher current values. The third and fourth segment undergo contrary effects. On the one hand the product water from the first two segments will increase the hydration of the membrane but can also cause mass transport limitations because of diffusion limitation through liquid water. On the other hand, the dry hydrogen that enters the anode at the outlet side of the cathode will dry out the fifth segment but will transport water from the anode inlet to the anode outlet. This dry out of the fifth element is obviously also responsible for the similar shape of the current curve compared to the first element.

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References

- [1] Jia-Shiun C. *Energies* (2015), 8, 4697 – 4723;
doi:10.3390/en8064697
- [2] Mengbo J. & Zidong W. *Energies* (2009), 2, 1057-1106;
doi:10.3390/en20401057
- [3] Edwards, R. L., & Demuren, A. (2016). *International Journal of Energy and Environmental Engineering* 7, (3), 329-341,
doi:10.1007/s40095-016-0209-1
- [4] Haubrock J. dissertation (2020),
Parametrierung elektrischer Äquivalentschaltbilder
von PEM Brennstoffzellen
doi:10.25673/4841