Physical and empirical PEM fuel cell model with the main focus on the current ripple effect

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Abstract: H_2 PEM fuel cells transform the chemical energy of hydrogen into electric power (d.c. current). But in real life applications, the d.c. current produced in a fuel cell stack needs to be converted to a.c. current, to be compatible with the existing electrical power grid (**fig.3**, **fig.4** right hand side). Power electronic devices such as inverters are known to convert d.c.current into a.c.current. But when fuel cell based systems are connected to the electrical power grid through an inverter (d.c. to a.c. converter), it has been observed that unwanted a.c.current ripples were present in the current of the fuel cell (**fig.3**, **fig.4** left hand side). These current ripples, consisting of several harmonics in low and high frequency range are detrimental to the satisfactory operation of the fuel cell stack in question, possibly resulting in cell degradation. This fuel cell model is part of a project which is aimed at analysing the long-term and the short-term effects of the current ripples on PEM fuel cells.

fig.1: fuel cell research centre ZBT in Duisburg

Sinus Power Station
SHS 400
high cost

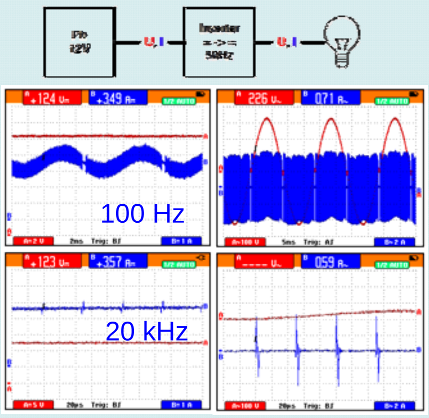

fig.3: voltage and current characteristic on either side of an inverter coupled to a load acid battery

Ansmann Power2Go
120+ - Inverter
low cost

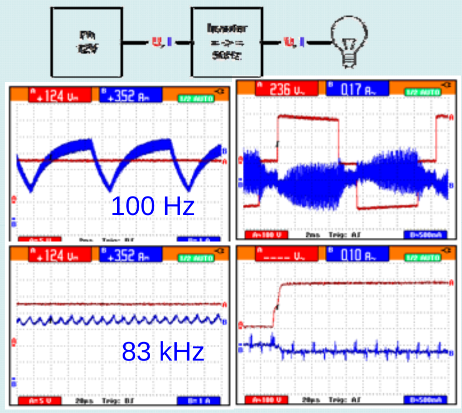

fig.4: voltage and current characteristic on either side of an inverter coupled to a load acid battery

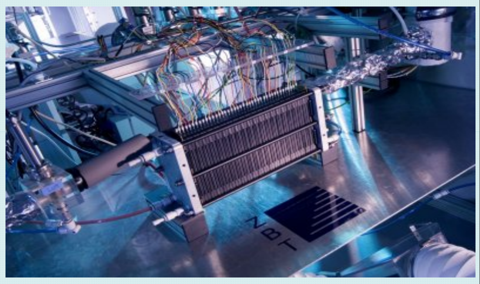

fig.2: typical fuel cell experimental rig at ZBT

PEMFC Model: There are many physical, one dimensional fuel cell models found in the literature. They can be divided into two main groups:
One group (i) is developed with the main focus on the static voltage-current characteristic and takes conditions like the different medic supplies, the fuel cell temperature and the water content into account. These models are sometimes extended with time variant transfer elements to approach dynamic behaviour.
The second group (ii) is developed with the main focus on the dynamic behaviour of the fuel cell. Based on the measurement data of an electro chemical impedance spectroscopy (EIS) an potential equivalent circuit diagram (ECD) is parameterised. To describe phenomena which are not typical for electronic circuits (e.g. diffusion losses) ECD are extended with mathematical approximation blocks to describe such an behaviour.

This model is a combination of both types (i) (ii) of PEMFC models.

Each side of the membrane is represented by one constant volume. The mass end energy of the volumes change with the incoming gas flow, the gas flow out of the fuel cell and the reaction of the fuel cell (**fig.5**). The basic ideas of this part of the model can be found in the one dimensional model of J.T. Pukrushpan [1].
The connection to the electric model is given by the partial pressures of the required gases for the electro-chemical process. The electric model simulates the static voltage losses like the activation losses and the ohmic losses. The electric simulation is based on a potential ECD to simulate additionally the dynamic behaviour of the fuel cell. The most significant dynamic element is assumed to be the double layer capacity of the three phase layer at anode and cathode. These double layer capacities can be represented with the ECD shown in (**fig.6**) or a similar ECD.

Diffusion losses have a great influence on the voltage-current characteristic of a fuel cell at higher currents. The proper place of action is the gas diffusion layer and for this reason part of the gas simulation.
Unlike the established simulations, where the diffusion losses are calculated as a part of the electric system, this model will simulate these losses as part of the gas model.

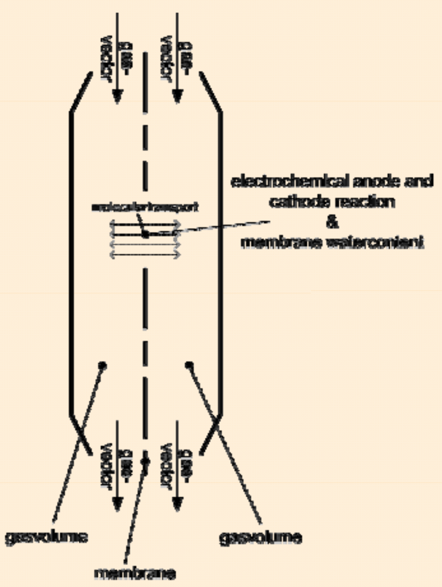

fig.5: concept of the gas-system simulation

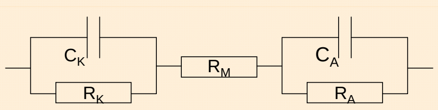

fig.6: equivalent circuit diagram of the electrical-system simulation

Approach: In order to analyse the long-term and the short-term effects of the current ripples on PEM fuel cells, a test rig is built at ZBT (**fig.1**, **fig.2**, **fig.7**) to supply three short stacks under equal and constant conditions in matter of the medic supply. The cathode is supplied with tempered and humidified air, the anode is supplied with fresh and dry hydrogen. For the humidification the off-gas is circulated.

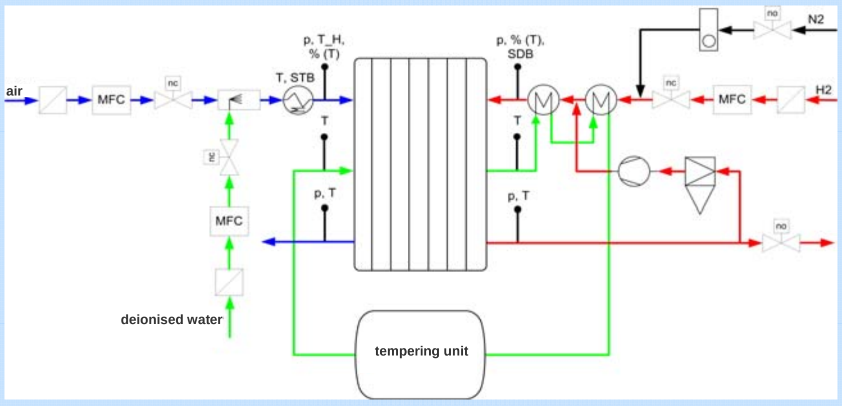

fig.7: flow chart of the test rig

One stack is run with pure d.c. current, while for the two other stacks additional synthetically produced a.c. signals of certain frequencies and amplitudes are super-imposed.
At wish the super-imposed a.c. current can be turned of to run an EIS for every stack. The period of the EIS and the performance of the EIS itself is parameterized to minimize the disturbance of the long-term loading.

As part of the project the electric loads are designed and will load the fuel cell with the permanent d.c. current, the super-imposed a.c. current is also used for the EIS. (**fig.8**)

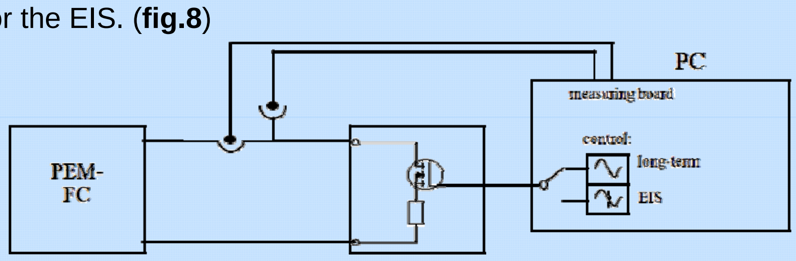

fig.8: arrangement of the current load

The main component is a power-MOS-FET which is controlled by a frequency output board. The current and voltage terminals of the fuel cells are measured by a M2i.4652 measuring board with high resolution from the Spectrum-Instrumentation.

Thanks to Forschungsvereinigung Elektrotechnik at ZVEI e.V. for sponsoring this project (15279 N) with allocated funds from Bundesministeriums für Wirtschaft und Technologie (BMWi) through Arbeitsgemeinschaft industrieller Forschungsvereinigungen „Otto-von-Guericke“ e.V. (AiF).

[1] J. T. Pokrushpan, A. G. Stefanopoulou, H. Peng, Control of Fuel Cell Power Systems – Prinziples, Modeling, Analysis ans Feedback Design; Springer Verlag, 2004

5th Symposium on Fuel Cell Modelling and Experimental Validation, Winterthur (CH) 11.-12.03.2008