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

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Abstract: H2 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.

One group (i) is developed with the main focus on the static voltage-current characteristic of a fuel cell at different operating conditions. 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 electric circuit diagram (ECD) parameterized. The electric model simulates the static voltage losses like the activation losses and the ohmic losses. The electric simulation is based on a potential electric circuit diagram (ECD) parameterized. 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 PEMFC 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.

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.

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)

The main component is a power-MOSFET 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.

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