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Electrochemical Impedance Spectroscopy of Unitized Reversible Fuel Cells (URFC)

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Introduction

Unitized regenerative fuel cells (URFC) in combination with photovoltaic modules are attractive systems for space missions because they enable extended operation times and lower mass. During the planetary day electrical energy is stored as chemical energy which can be converted back during night into electricity by the fuel cell. All air-independent applications like space-crafts or space stations would profit significantly from the realization of URFCs. Significant advantages depending on power requirements for specific energy density can be expected from the use of a URFC (400-1000 Wh/kg) in comparison to secondary batteries (220-250 Wh/kg).

Experimental Details

At DLR a flexible dry powder spraying method for the manufacturing of membrane electrode assemblies (MEA) has been developed which was used to prepare bifunctional electrodes by mixing two different catalysts together (Pt and IrO_2). The loading of the electrodes was around 1.56 mg/cm² Pt at the hydrogen and 2.08 mg/cm² $Pt+IrO_2$ (1:1) at the oxygen side. on both sides 30 wt% Nafion® was added. As electrolyte Nafion® 1135 membrane was used and as gas diffusion layer SGL SIGRACET 35 DC was chosen.

The test of electrolysis and fuel cell mode were performed in a single cell test bench with MEAs of 23 cm². T_{cell}= 80°C for the fuel cell mode and T_{cell}= 90°C for the electrolysis mode providing water vapour. The H_2 and O_2 flow rates were 400 sccm and all measurements were performed at atmospheric pressure.

Results and Discussion

The polarization curves of fuel cell and electrolysis mode are shown in Fig 1.

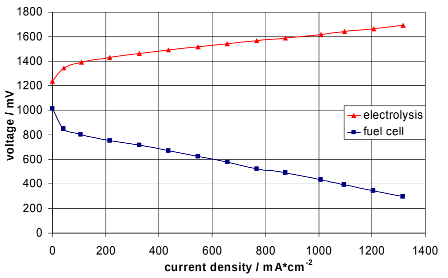

Fig 1: U(i)-curves of unitized regenerative fuel cell

Beside the U(i) curves the electrochemical impedance spectra (EIS) of the MEAs offers additional information about the performance of the components and the long-term stability. In Fig 2 the impedance spectra (left: Nyquist plot; right Bode plot) of a URFC in fuel cell and electrolysis mode are shown.

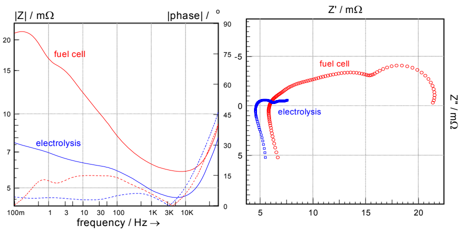

Fig 2: Nyquist plot (left) and Bode plot (right) of an unitized regenerative fuel cell

To understand the behaviour of the components (anode. cathode and electrolyte) a use of an equivalent circuit is advisable. While only one MEA for both operation modes is used the same circuit should be used for both simulations. In Fig 3 an easy circuit with all necessary components can be seen. It contains the charge transfer resistance/double layer capacity of anode and cathode, mass transport limitation, the ohmic resistance of the MEA and the wiring conductance.

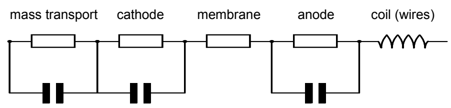

Fig 3: Equivalent circuit of a URFC

Table 1 summarize the results of the simulation of the impedance spectres. The overall error is around 2 %. the difference between spectres and fits is highest at very low and very high frequencies. The low ohmic resistance (membrane) in electrolysis is due to the liquid water inside the cell leading to a full humidification while the low values for anode and cathode are caused by the kinetics of the reactions.

Table 1: Results of simulation

Element	Fuel cell		Electrolysis	
Mass transport	3.82 mΩ		2.16 mΩ	
	414 F	1.224	6.71 F	0.563
Cathode	8.55 mΩ		1.76 mΩ	
	723 mF	0.715	198 mF	0.718
Mem-brane	5.71 mΩ		3.91 mΩ	
Anode	3.37 mΩ		0.53 mΩ	
	230 mF	0.682	23.8 mF	0.935
Coil	10.7 nH		18.9 nH	

Conclusions

Electrochemical impedance spectroscopy of an unitized reversible fuel cell was carried out and analyzed with an simple equivalent circuit for both operation modes. EIS of both operation modes can be adequately fitted by the equivalent circuit indicating a good representation.

To increase the understanding of the cell a more detailed model (e.g. with porous media and therefore the sensitivity to liquid water) and extended experimental setup are necessary.

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