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A SIMPLIFIED CONTROL STRATEGY FOR OPTIMAL LOW-PRESSURE OPERATION OF PEMFC SYSTEMS FOR AVIATION APPLICATION

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Abstract

Introduction:

The use of PEM fuel cells as power source is a promising approach to contribute to the decarbonization of the aviation sector. The harsh environmental conditions, i.e. low temperature and low pressure, to which fuel cells are exposed in aviation applications strongly affect the fuel cell's performance [1]. In order to minimize the resulting power losses, an adaption of the control parameters is required. In previous studies, fuel cells were primarily characterized under low-pressure conditions [2], [3], [4] and some indications how to overcome the associated power losses at specific pressure levels were given [5], [6], [7].

Objectives:

The present study aims at deriving a full pressure dependent control strategy for low-pressure operation of a PEMFC system, i.e. optimal control parameters as functions of the pressure and the current density. Furthermore, the proposed optimization procedure shall be transferable to various other PEMFC systems for future aviation applications.

Experimental setup and methods:

A PEMFC system is operated inside a low-pressure chamber, where pressure and temperature can be controlled to simulate altitude conditions. The fuel cell system is composed of a self-humidifying 120 cells Hydrogenics HyPM HD 10-120 PEMFC stack with an active cell area of 195 cm² and 12 kW nominal power output, an anode recirculation pump and a cooling unit. A blower supplies the cathode inlet with air from the low-pressure atmosphere.

To identify the optimal operating conditions for low-pressure operation of the PEMFC system, a parameter study with 480 measuring points is performed based on statistical design of

experiment methods, i.e. using a D-optimal design approach. Therefore, the stack temperature T and the cathode stoichiometry λ are varied at different current density i and chamber pressure p levels. The experimental results allow to derive model equations for the system net power $P_{net}(t, p, i, T, \lambda)$ and the relative humidity $rH(p, i, T, \lambda)$. For P_{net}, a constant degradation is considered by incorporating the runtime t.

Results:

Initially conducted polarization curve measurements under low-pressure conditions by using the manufacturer's default parameters for T and λ control show significant net power losses of up to 59% at 491 hPa with respect to 980 hPa, see the black dashed line in Figure 1a. The power losses primarily result due to stack drying. From the results of the parameter study, the optimal values for T and λ control under low-pressure conditions are determined by optimizing the net power model equation such that $P_{net}(t, p, i, T_{opt}, \lambda_{opt}) = \max\{P_{net}(t, p, i)\}$. The optimal stoichiometry λ_{opt} exhibits a strong nonlinear dependence on p and i. However, the optimal stack temperature follows, in a first approximation, the linear relation $T_{opt}(p) = (26.48 + 0.037\ p)$ [°C], with p in hPa. Applying the optimized parameters yields a significantly higher net power at low-pressure operation compared to the use of the default parameters, see the black solid line in Figure 1a. At 497 hPa, the net power increase is as high as 29%, see the red line with the corresponding axis on the right in Figure 1a.

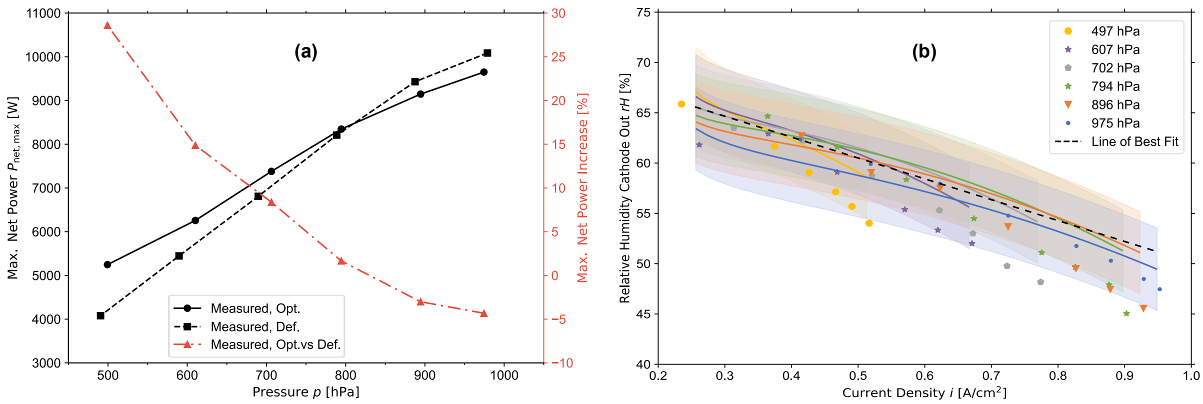

Figure 1: (a) Maximum net power obtained by using optimized and default parameters, the black lines correspond to the left axis. Increase of the maximum net power by applying optimal parameters, the red line corresponds to the right axis. (b) The solid lines show the model prediction of the optimal relative humidity $rH(p, i, T_{opt}, \lambda_{opt})$ for the different pressure levels. The model prediction intervals are indicated by the area shaded in the corresponding color. The black dashed line of best fit approximates the trend of all shown model prediction curves. The markers represent experimental data obtained with optimized control parameters.

It is well known that the maintenance of optimal fuel cell humidification conditions is crucial for high performance as well as durability. In Figure 1b the optimal relative humidity predicted by the regression model $rH(p, i, T_{opt}, \lambda_{opt})$ is shown for the investigated pressure levels. Remarkably, the prediction curves lie almost on top of each other. Moreover, they lie within each other's prediction intervals indicated by the shaded areas shown in the same color as the corresponding model prediction curves. This indicates that the optimal relative humidity at the cathode outlet is pressure independent and follows, in a first approximation, the black dashed line of best fit $rH_{opt}(i) = (70.9 - 20.7\ i)$ [%], with i in A/cm². For comparison, the measured relative humidity during experiments with optimized control parameters, are shown as colored markers in Figure 1b.

Conclusions:

A simplified control strategy yielding high system net power at low-pressure operation can be implemented by controlling the pressure dependent stack temperature according to $T_{opt}(p)$ = (26.48 + 0.037 p) [°C]. On the other hand, the cathode stoichiometry can be used to maintain the relative humidity at the cathode outlet in its current density dependent optimal state according to $rH_{opt}(i)$ = (70.9 – 20.7 i) [%] with an accuracy of about ±5%. However, to achieve the highest possible net power, the stack temperature and the cathode stoichiometry have to be set according to the identified pressure and current density dependent optimal parameters $T_{opt}(p, i)$ *and* $\lambda_{opt}(p, i)$.

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