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Zustandsübergänge von PEM-Brennstoffzellen unter luftfahrttechnischen Betriebsbedingungen: Herausforderungen und Lösungsansätze

F. Becker, A. Amrutkar, C. Gentner

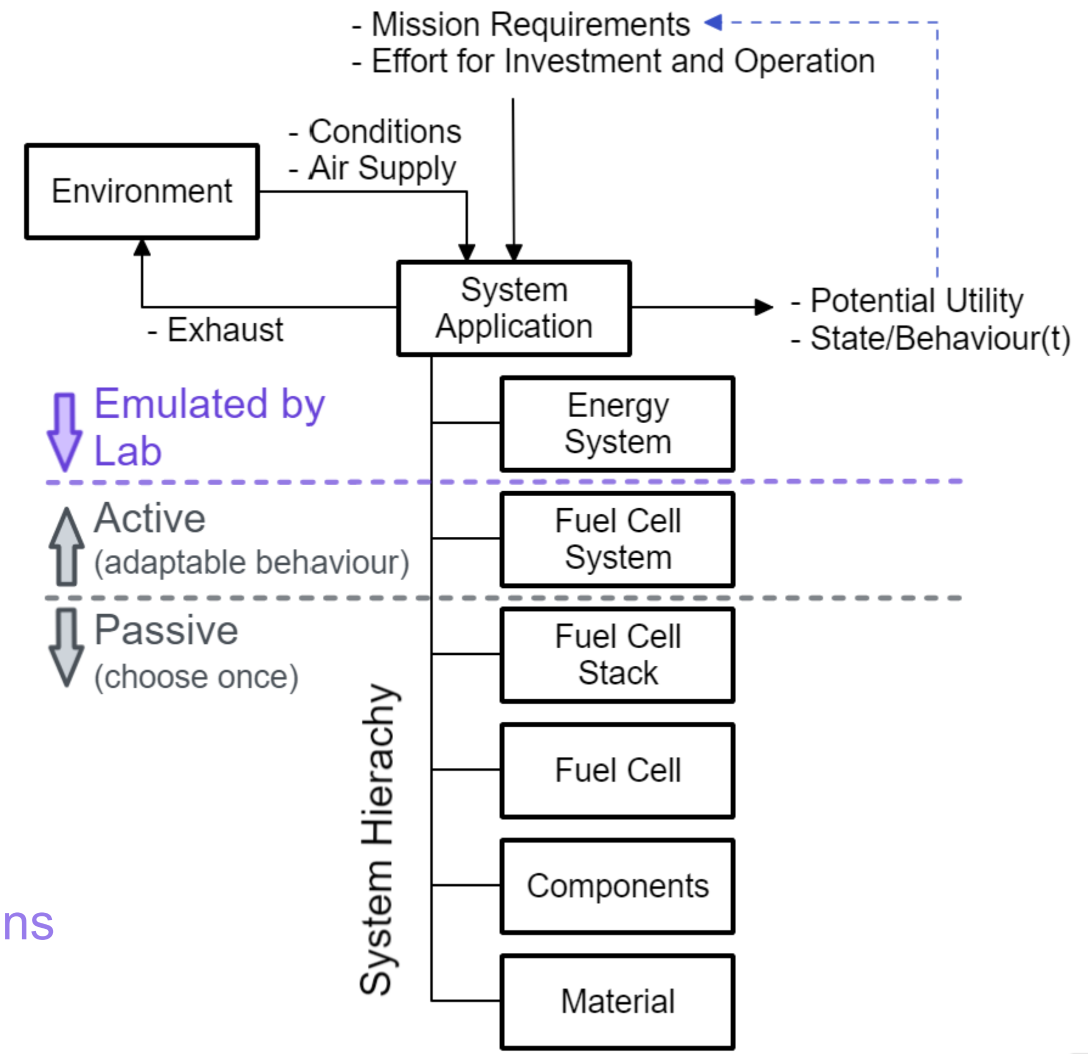
Content

1) Influencing Factors
2) Relevant Variables and Time Domains
3) Flight Phase Correlateted Issues for Fuel Cell
4) Degradation Related to State Transition
5) Experimental Results
6) Suggestions
7) Conclusion

Influencing Factors on Operational Behavior of Aeronautical PEM-Fuel Cell Systems

Misson Profile
- Airspeed
- Altitude
- Electric load demand
- Cooling capacity
- Inclination
- Shocks/vibration

Environment:
- Temperature
- Pressure
- Humidity
- Harsh weather conditions
- Pollutants



FC-System Setup
- System architecture
- Component selection

FC-System Control
- Edukt gas supply
- Electric power management
- Thermal management
- Water management

FC-System Behaviour
- System charcterisation
- Harming / limiting factors
- State transitions

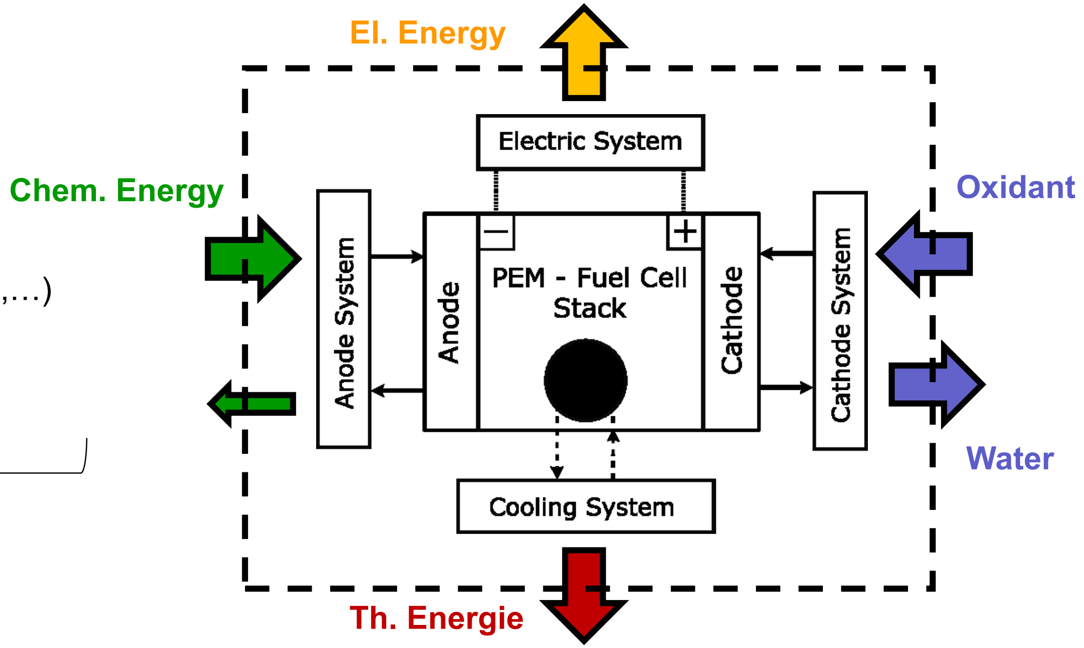
FC-Conditioning
- SoH management
- Op. procedures

Relevant state variables for Fuel Cell Stack

System Requirement →

Electic State variables
1. El. Current / Current Density
2. El. Voltage / Cell Voltages

→ **System Response**



Thermodynamic state variables
1. Gas Composition (H_2, H_2O, N_2,…)
2. Temperature
3. Pressure
4. Mass Flows

$$\boxed{\mathrm{rH} = \frac{p_{H_2O}}{p_{sat(T)}}}$$

p_{H_2O} : Partial pressure of water vapour [Pa]
$p_{sat}(T)$: Saturation vapour pressure [Pa]

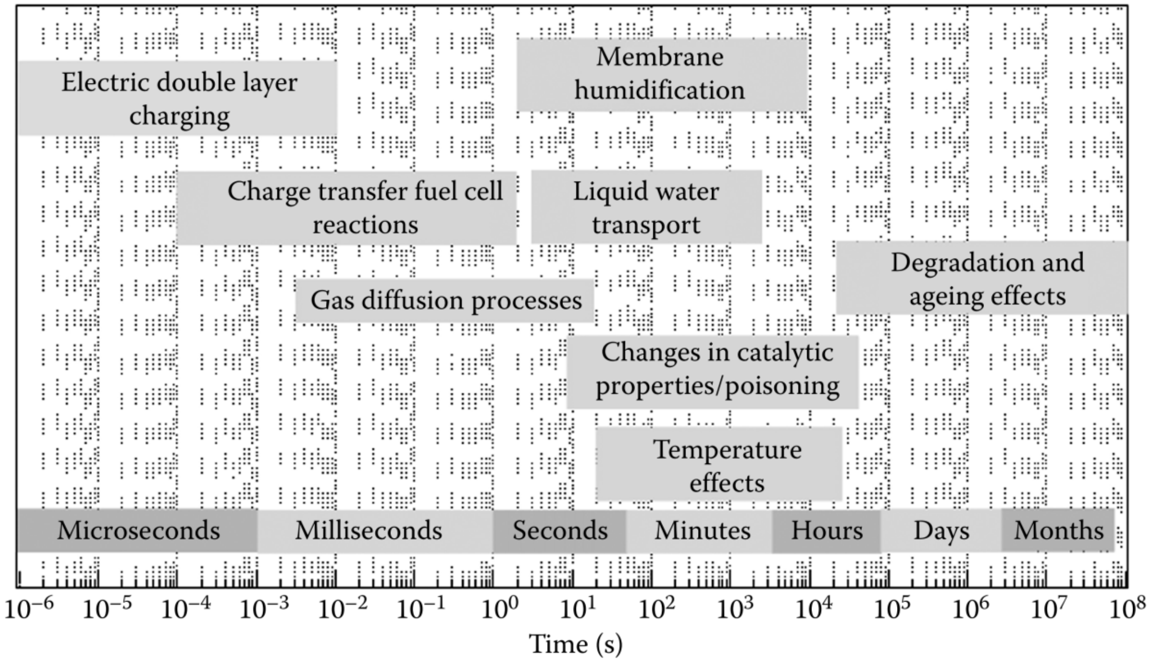
Thermodynamic state variables
1. Gas Composition (N_2, O_2, H_2O, …)
2. Temperature
3. Pressure
4. Mass Flows

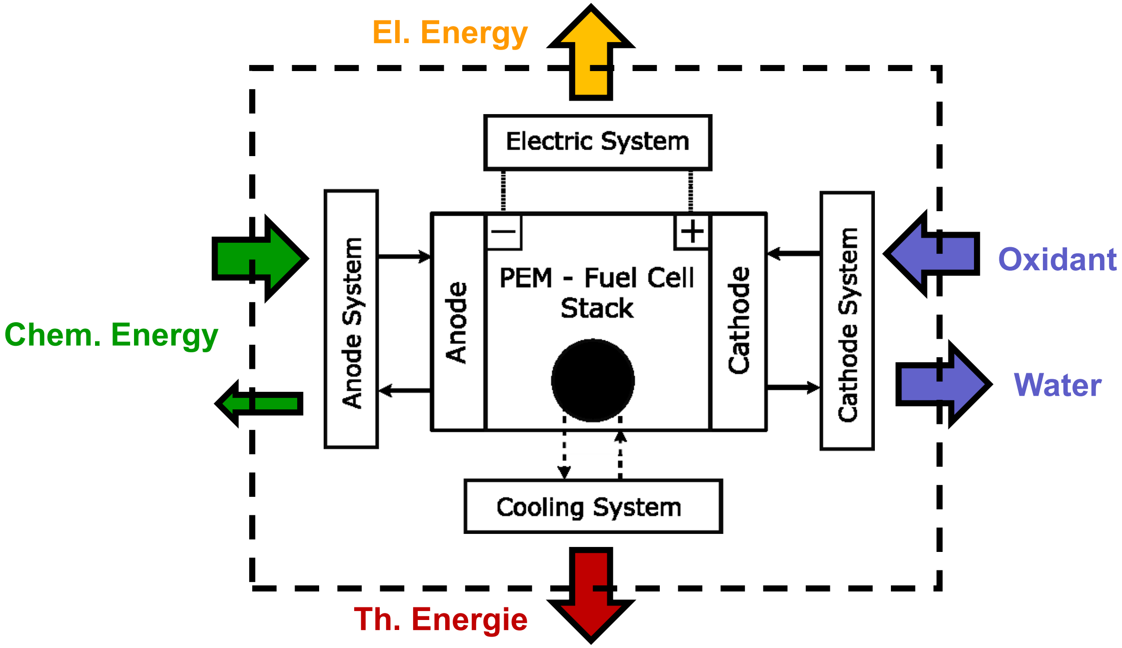
$$\boxed{\mathrm{rH} = \frac{p_{H_2O}}{p_{sat(T)}}}$$

Thermodynamic state variables
1. Specific Heat Capacity
2. Temperature and Temperature Difference
3. Pressure and Pressure Drop
4. Mass Flow

$$\boxed{2H_2 + O_2 \rightarrow 2H_2O + \text{El. Energy} + \text{Th. Energy}}$$

Time Domains of the Processes in PEM Fuel Cells

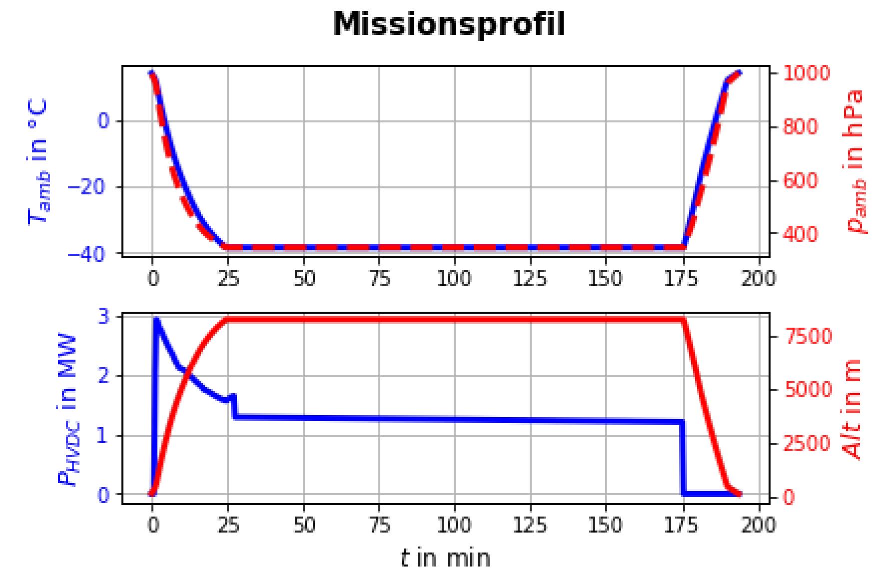


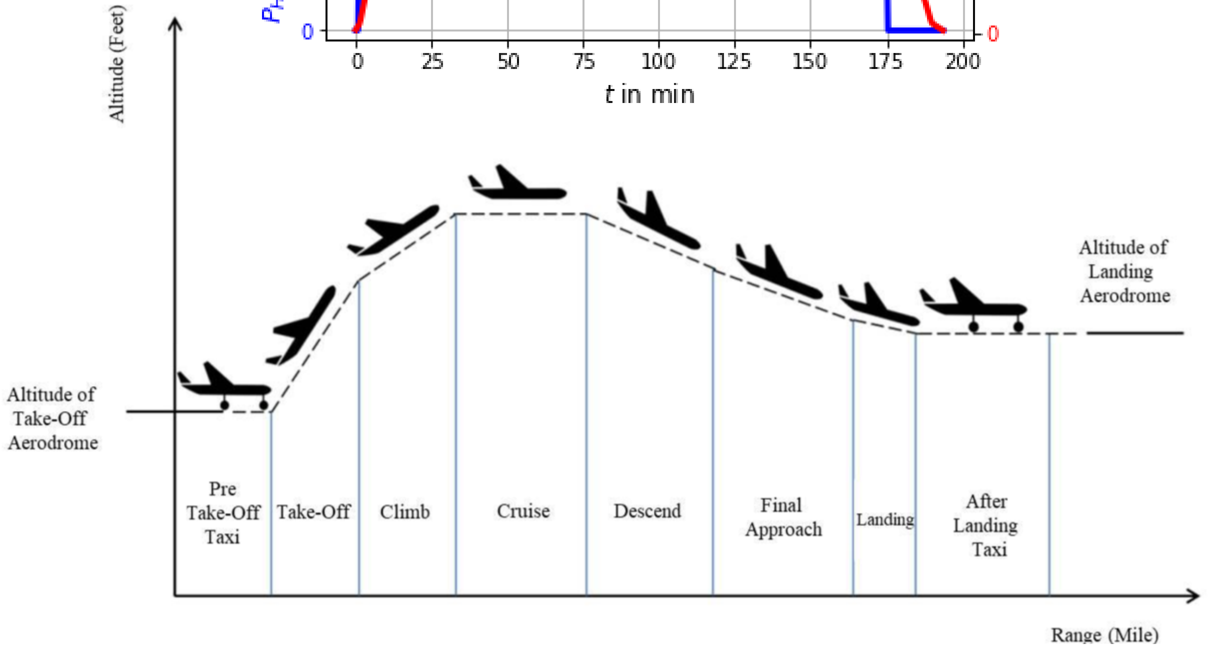


Wagner, Norbert , "Electrochemical Impedance Spectroscopy" , in PEM Fuel Cell Diagnostic Tools ed. Haijiang Wang , Xiao-Zi Yuan and Hui Li (Boca Raton: CRC Press, 25 Aug 2011), Routledge Handbooks Online.

Flight Phase Correlateted Issues for Fuel Cell due to **Mission Profile**

Flight phase(s)	Taxiing	Take-Off Climb	Taxiing Take-Off
Condition and cause	Low electric power demand	High electric power demand	Low aircraft velocity
Effect	High cell voltage	Low cell voltage	Reduced cooling capacity
Result	Fuel Cell degradation	High thermal exhaust energy	Limitation of electric power output
Possible mitigation strategies	- Increase electric power demand - Decrease efficiency by partial pressure reduction of educt gases - System recovery for reversible degradation - ...	- Decrease electric power demand - Increase efficiency by partial pressure increasement of educt gases - ...	- Decrease electric power demand - Increase efficiency - increase oxygen partial pressure - ...





[1] araçyakupoğlu, T. 2020. Emniyet İrtifasından Bilgiler: Genel Havacılık, Üretim ve Bakım Süreçleri. ISBN: 978-625-402-030-8, Nobel Akademik Yayıncılık, Ankara.

Degradation Related to State Transition

scientific reports

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A study of the influence of current ramp rate on the performance of polymer electrolyte membrane fuel cell

Mathan Chandran[1], Karthikeyan Palaniswamy[2]✉, N. B. Karthik Babu[3] & Oisik Das[4]✉

Durability and reliability are the key factors that prevent fuel cells from successful implementation in automotive sector. Dynamic load change is a common and frequent condition that the fuel cell has to undergo in automotive applications. Fuel cells are more sensitive to changes in load conditions and degrade based on load variation representing idling, rated power, and high power operating conditions. To examine the influence of dynamic load step on the fuel cell performance, two similar cells of active 25 cm^2 was tested under two different load step for the same dynamic load cycle. The main difference in dynamic load cycle 2 was the ramp rate which was fixed as 0.1, 0.3, and 0.25 $A/cm^2/s$ for 0.2, 0.6, and 1.0 A/cm^2 respectively. To investigate the degradative effects, polarization curves, electrochemical impedance spectroscopy, and field emission scanning electron microscopy were used. The results indicated that the degradation rate increased in both dynamic load cycles but however the impact of load change was comparatively minimal in dynamic load cycle 2. The total degradation in performance was 20.67% and 10.72% in dynamic load cycles 1 and 2 respectively. Fuel cell performance degraded in a manner that was consistent with the electrochemical impedance spectroscopy and cross-sectional analysis of field emission scanning electron microscopy. The results prove that the degradation rate is dependent on the load step and the number of load cycles. Severe catalyst degradation and delamination were observed in fuel cells operated under dynamic load cycle 1.

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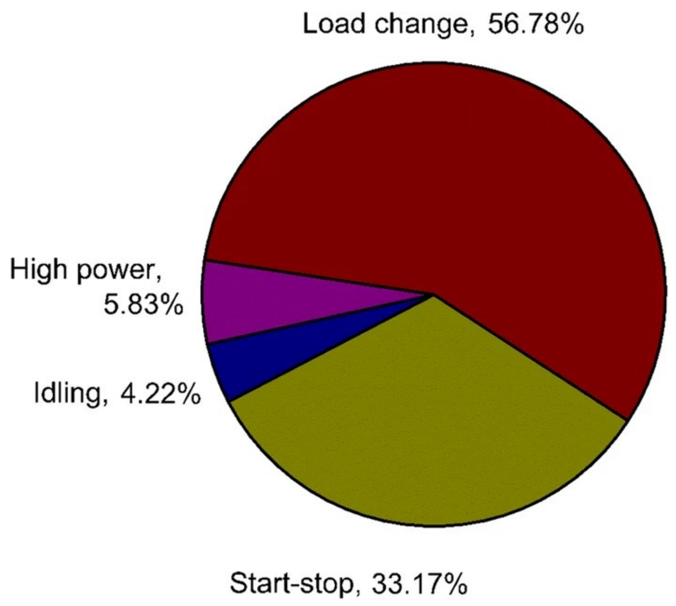


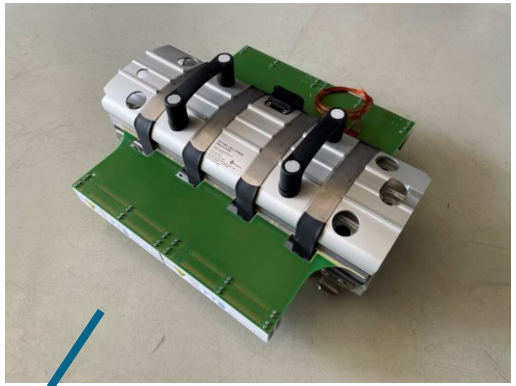
Figure 1. Degradation percentages of different operating conditions in a PEMFC.

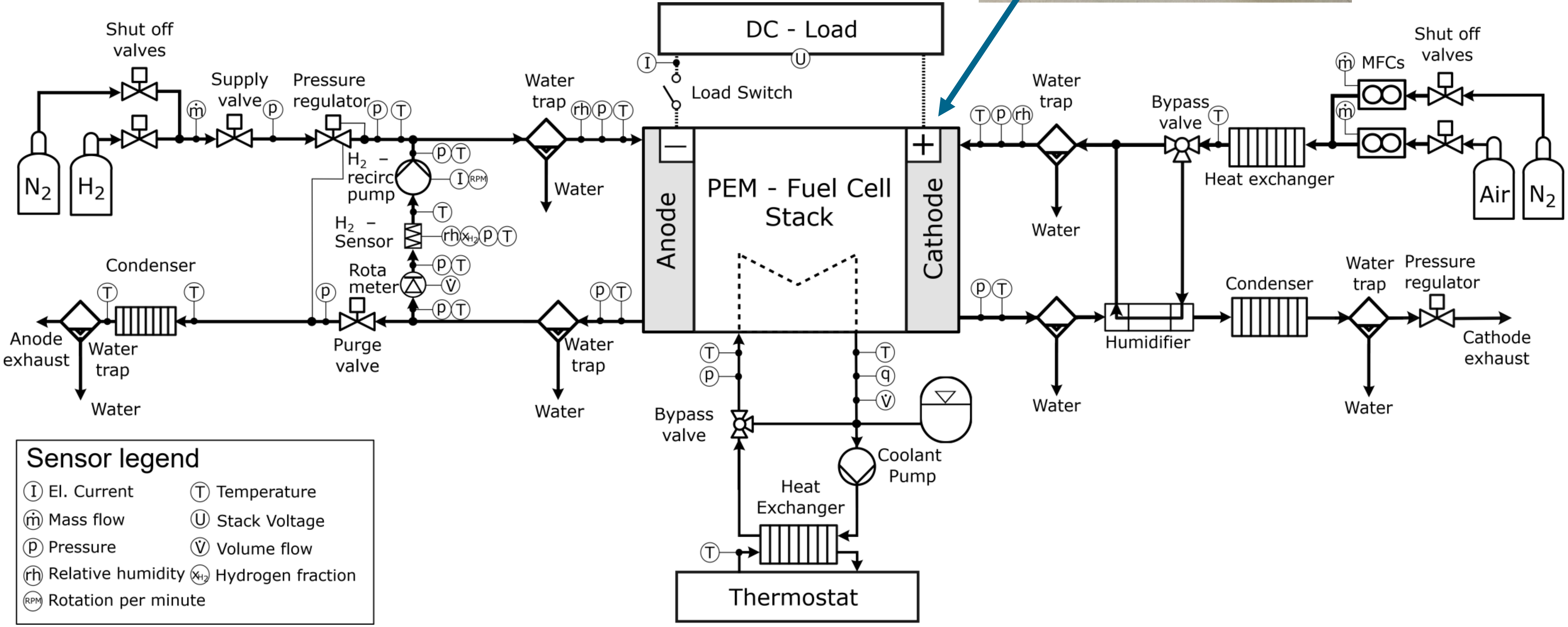
Further Investigation focuses on Ramp up Processes

M. Chandran, K. Palaniswamy, N. B. Karthik Babu, and O. Das, 'A study of the influence of current ramp rate on the performance of polymer electrolyte membrane fuel cell', Sci Rep, vol. 12, no. 1, p. 21888, Dec. 2022, doi: 10.1038/s41598-022-25037-0.

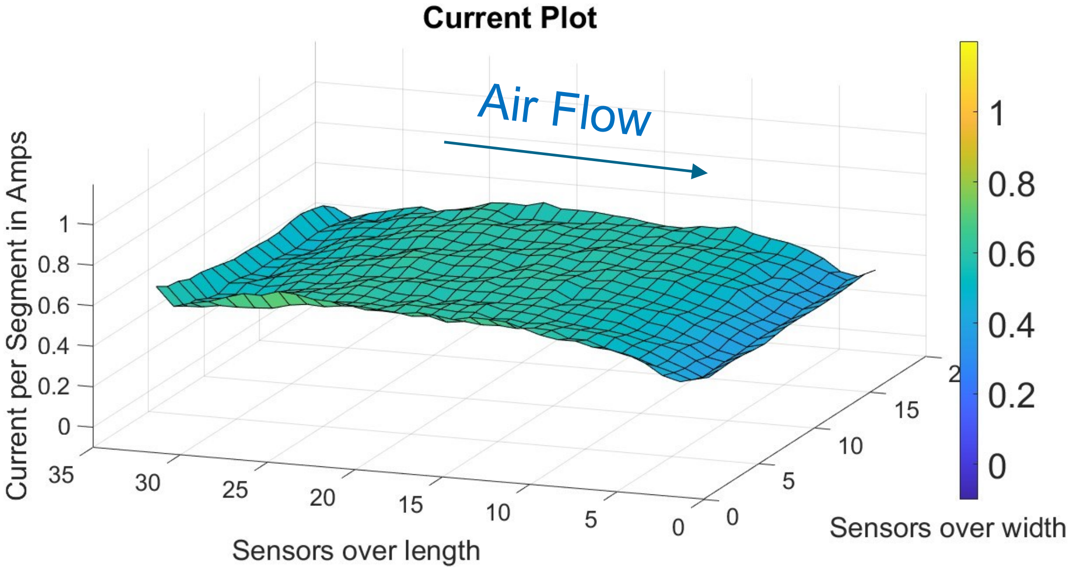
Experimental Setup

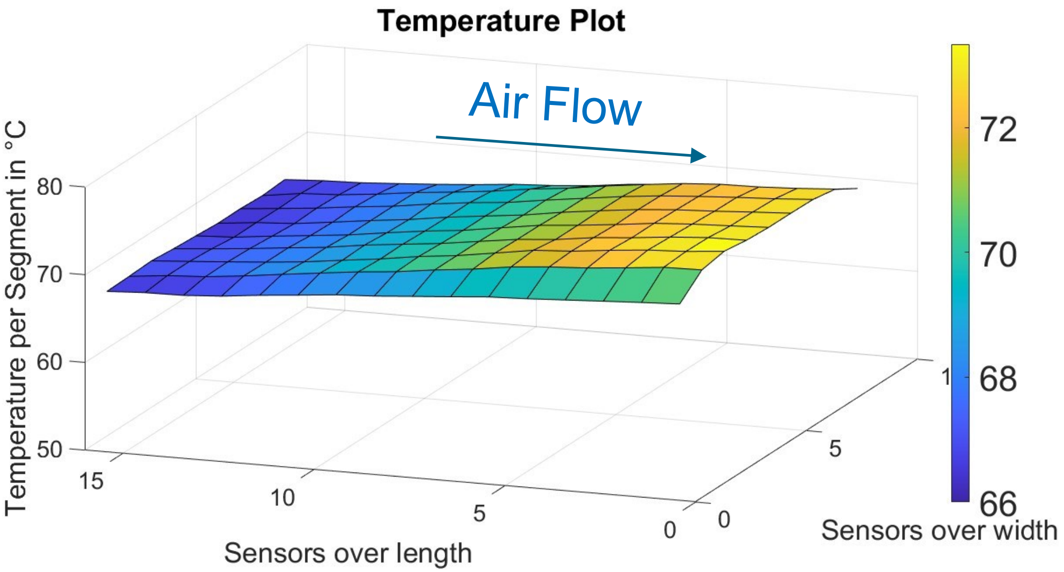
6 kW PEM-FC-Short Stack of 20 Cells including Segmented Measuring Plate
- Active Cell Ares : 300 cm²
- 32 x 17 Current measurement cells
- 16 x 9 temperature measurement cells

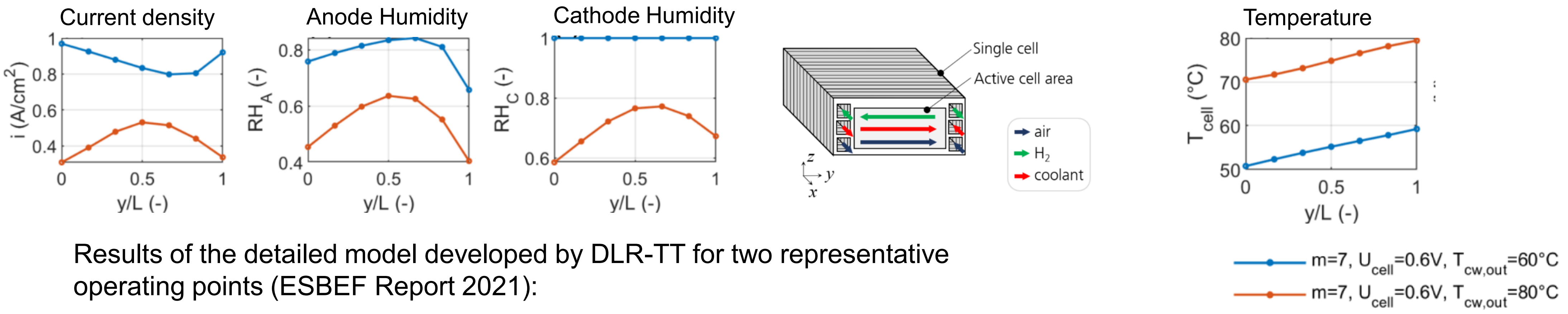




Segmented Measuring Plate
Validated Data at Stationary Operation



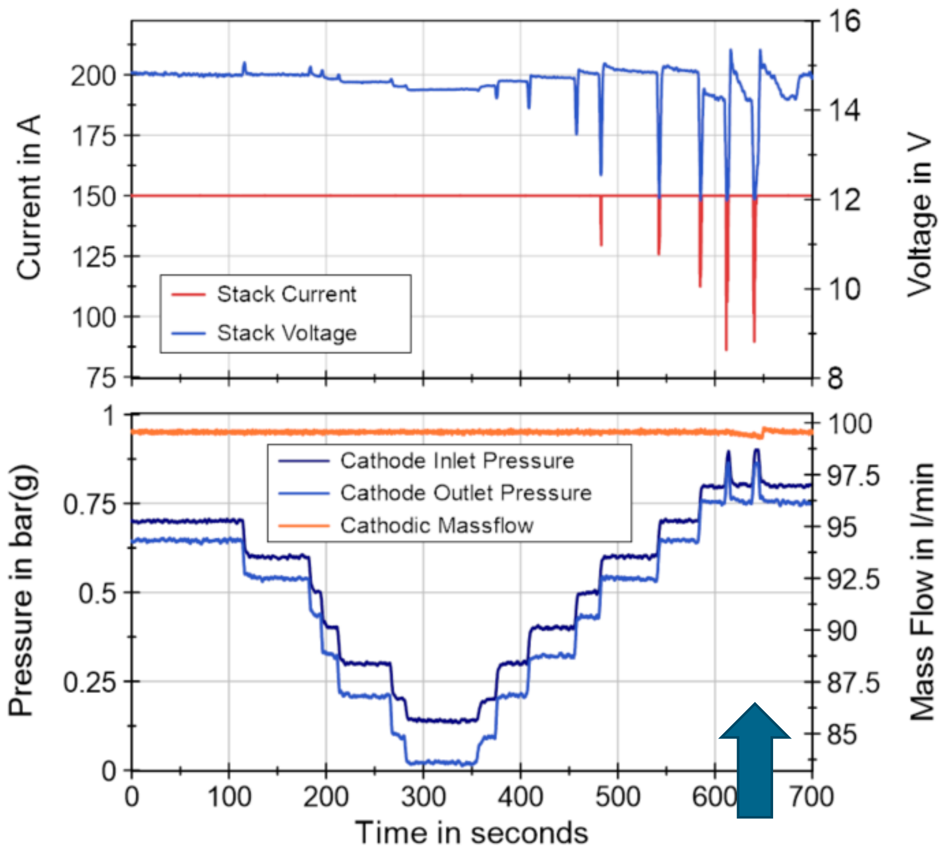


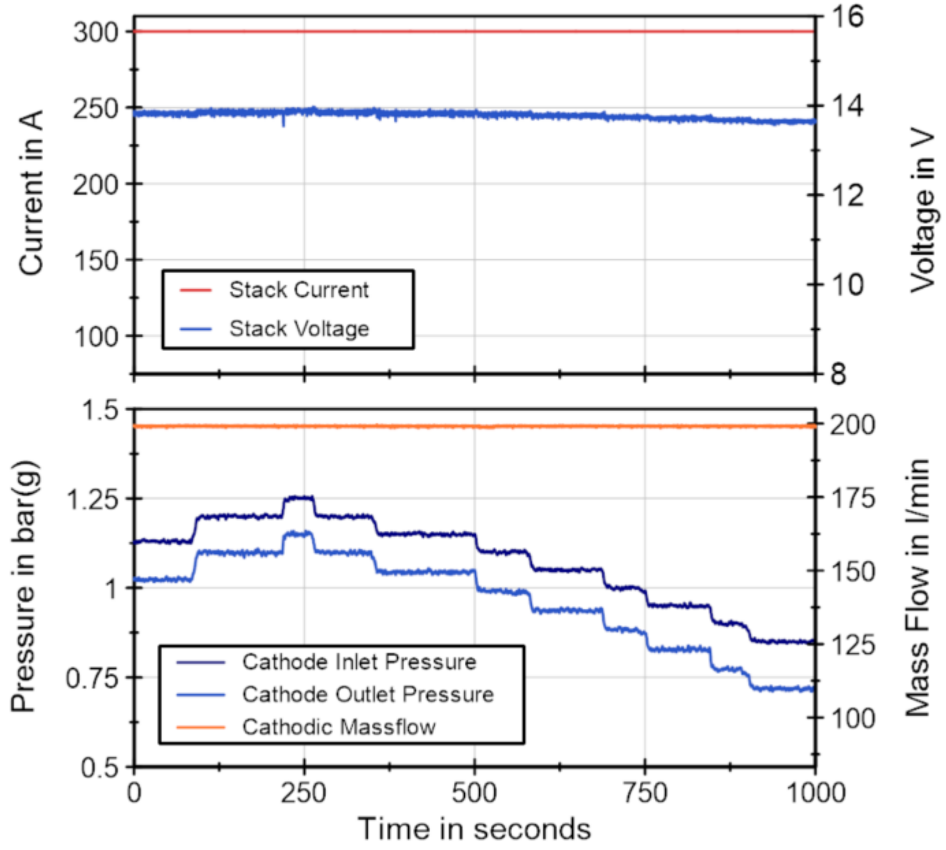


Results of the detailed model developed by DLR-TT for two representative operating points (ESBEF Report 2021):

Results
Increasing Operational Pressure at Cathode

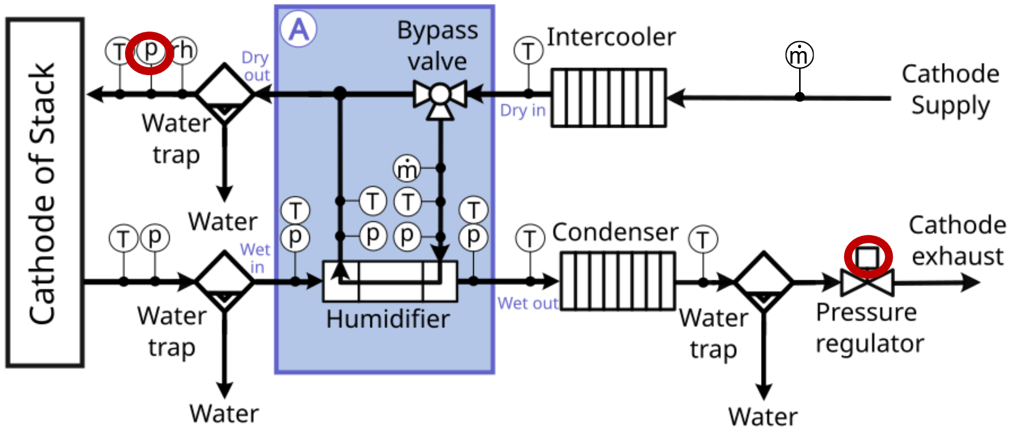
- Pressure decreasement is not critical but results in a lower stationary cell voltage
- Pressure increasement at low performance level will result in temporary voltage drops
  (in this case followed by current drops due to a set voltage limitation)

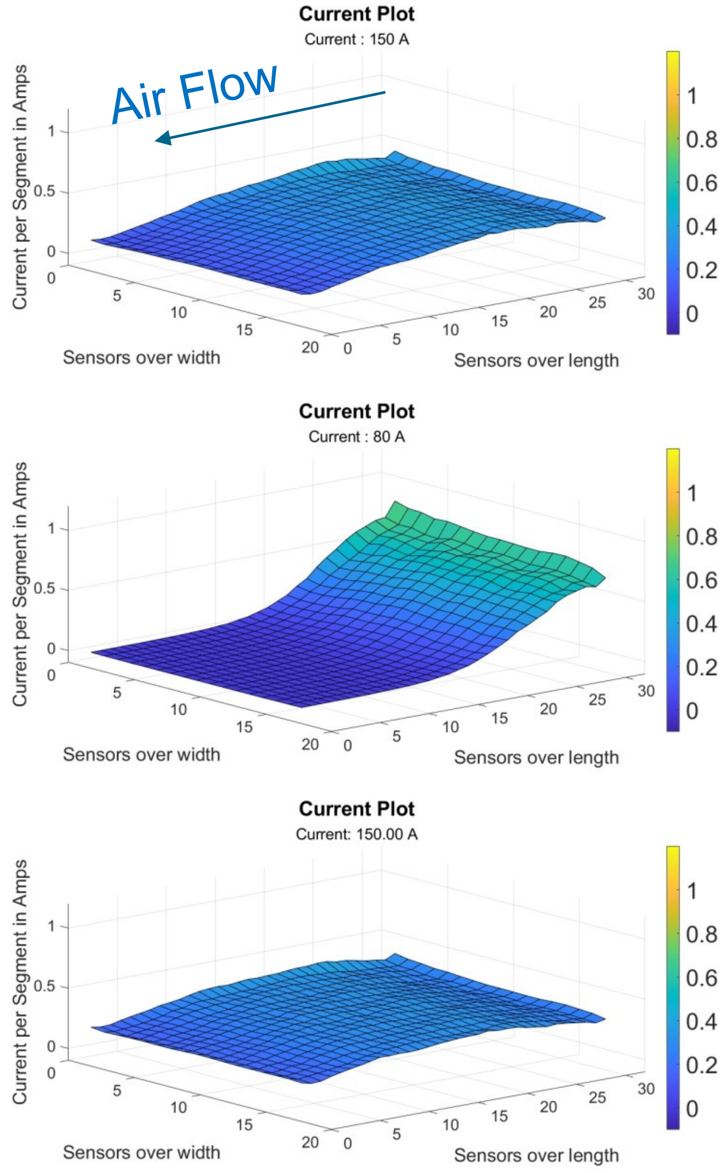




Results
Increasing Operational Pressure at Cathode

- At constant massflow at cathode supply the massflow at the stack outlet gets throttled for pressure increasement
- O2-Starvation at cathode outlet takes place during pressure increasement
- No current is measured at cathode outlet

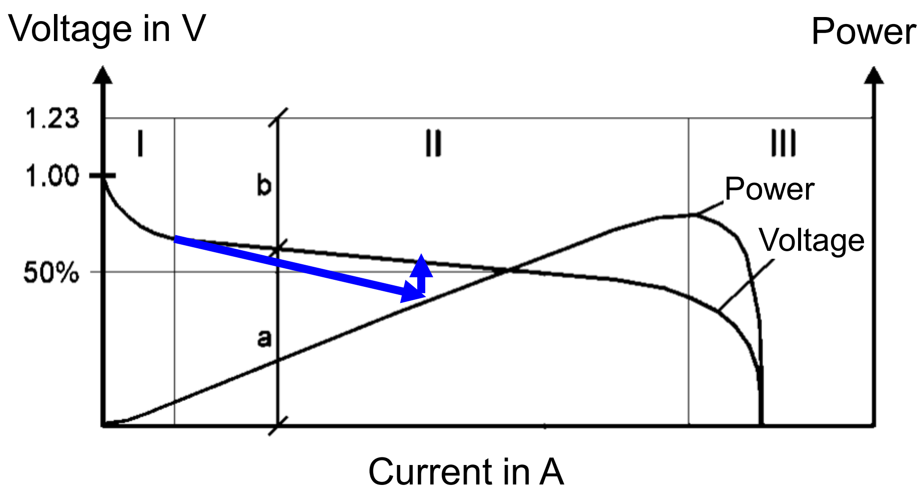


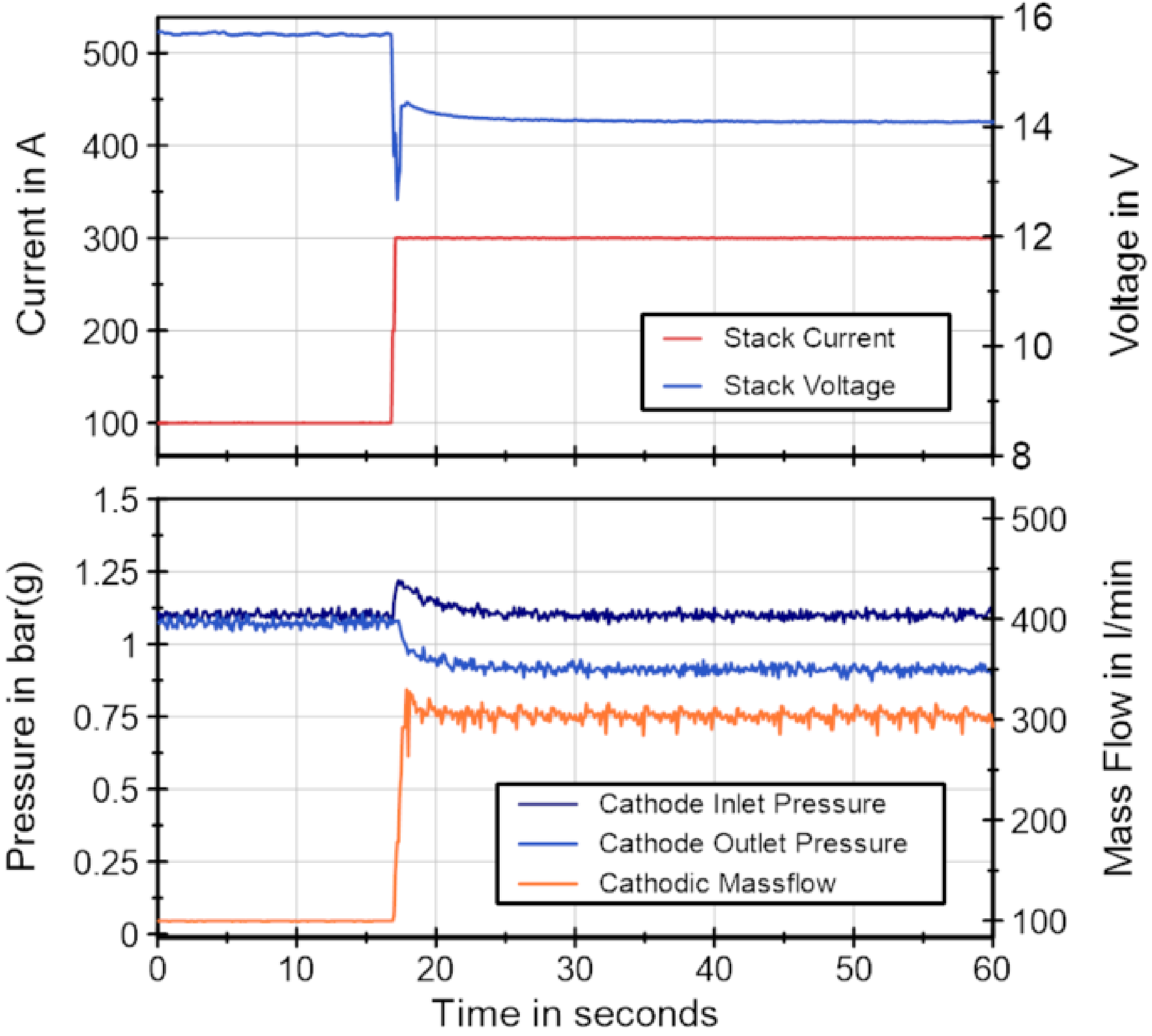


Results

Transient behaviour of a sudden load step from 100 A to 300 A at constant inlet pressure and O_2-stoic.

- Voltage drop observable, mainly due to O_2 - starvation
- The outlet pressure of cathode decreases at higher volume flows, when the inlet pressure is kept constant

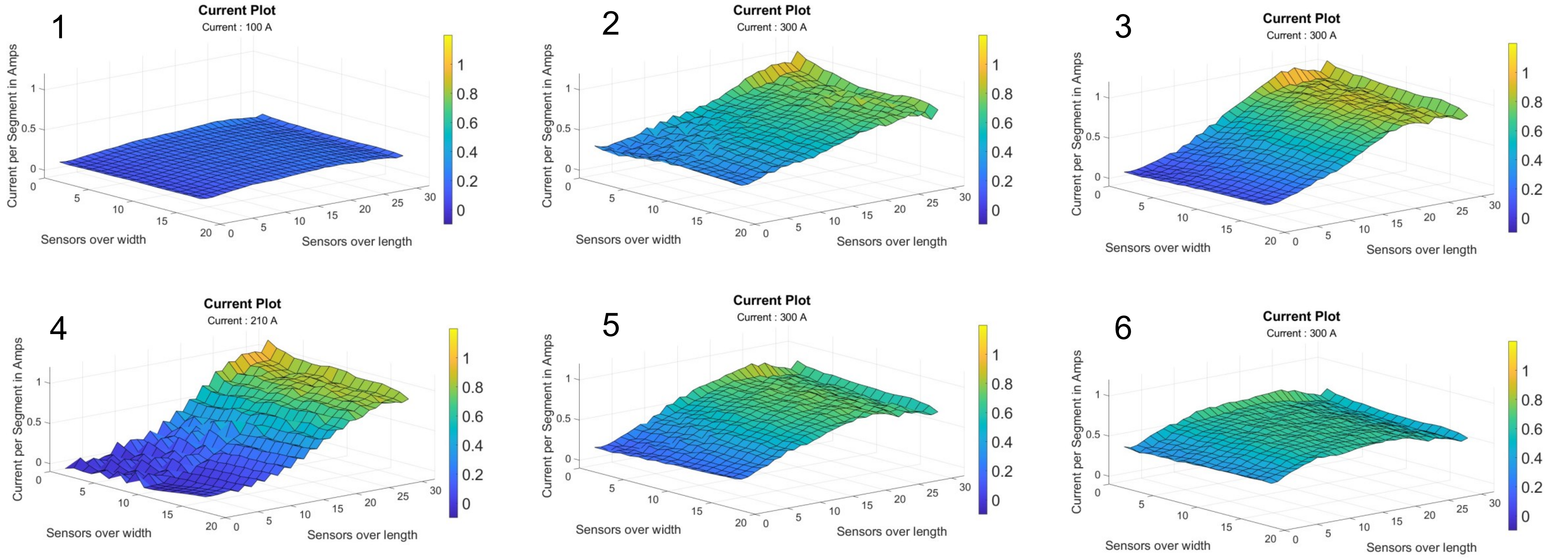




Results

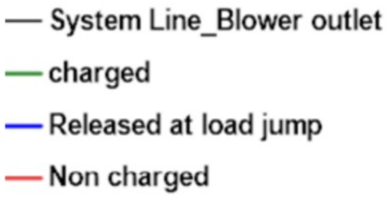
Transient behaviour of a sudden load step from 100 A to 300 A at constant inlet pressure and O_2-stoic.

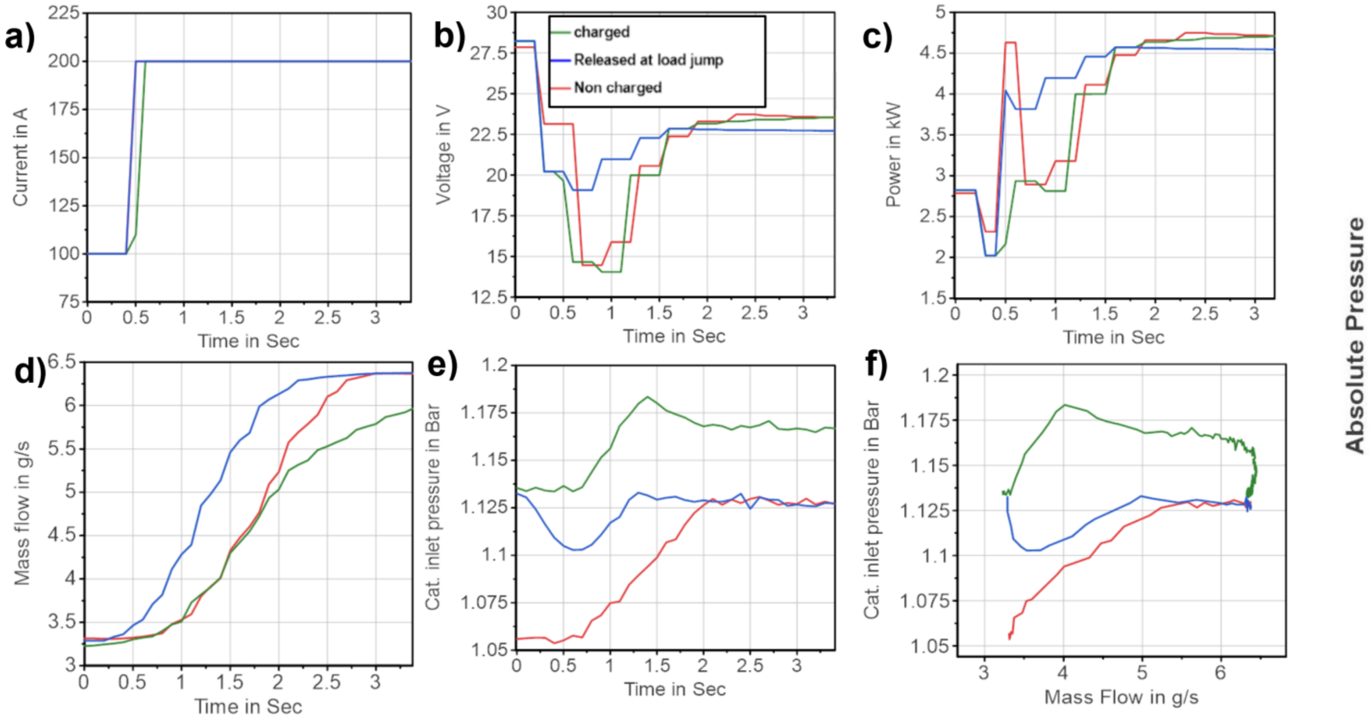
Samplerate 20 Hz (300 ms)



Suggestions

Improvement of Ramp Up a PEM-FC-System





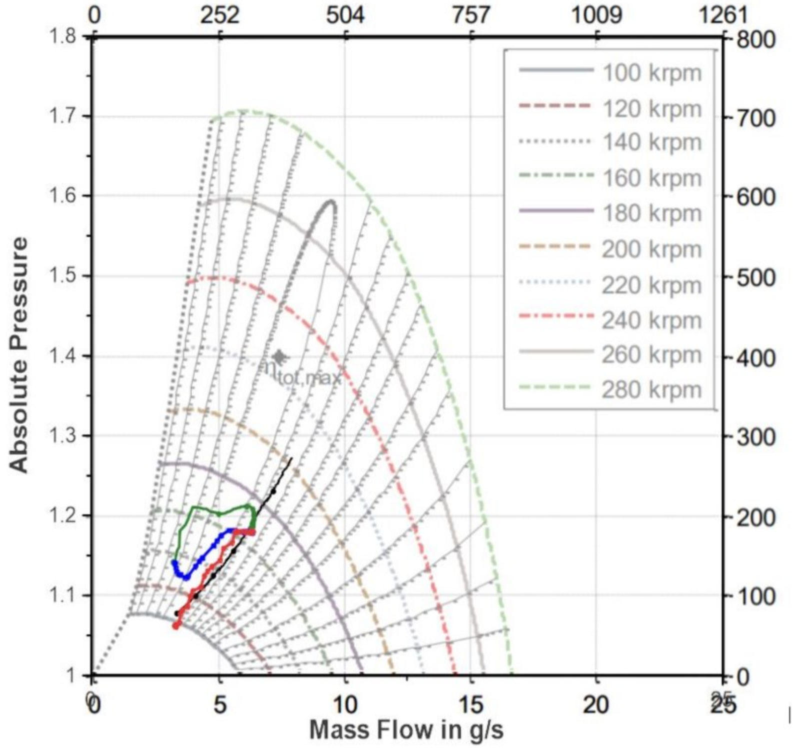


Abbildung 49: Vergleich des dynamischen Verhaltens bei offenem Betrieb, Druckaufladung und Druckentlastung während des Lastsprungs.

https://elib.dlr.de/144865/1/Master%20Thesis_36027_Krunal%20Keraliya.pdf

Conclusion

- Ramp-up processes are among the most severe in terms of degradation
- Sudden pressure and currnt increasements at low performance level will result in temporary voltage drops due to O_2-starvation at cathode outlet
- Releasing pressure during load jump prevents Blower Surge and O_2-starvation during load step

The increase of the set current should be adapted to the speed of the possible oxygen supply at the cathode outlet of the stack.

Thank you for Attention, some questions?

DLR

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nip
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