



Cell voltage analysis

HyFaB PEM stack, 10 cells (real) · 2025-07-28 04:00 · 2.17 h

DATA QUALITY: GOOD**BETA**

Beta: the methods and thresholds are checked on synthetic recordings with known faults and on public data, not yet on customers' recordings - read the findings as indicators to look at.

System / stack	HyFaB PEM stack, 10 cells (real)
Test	Stoichiometry sensitivity after 2300 h
Operator	–
Tags	real, fuel cell, 2300 h, stoichiometry
Recording	PEM 10-cell stack - 2300 h - gas stoichiometry test.csv
Period	2025-07-28 04:00:29 – 2025-07-28 06:10:28 (2.17 h)
Rounds	7800 at 1.00 rounds/s
Cells	10 analysed of 11 (10 connected)
Application	fuel cell
Cell voltage limits	none
Left out	nothing

Notes

Current steps 0.36-2.3 A/cm² at anode/cathode stoichiometry 1.4/1.6, 1.9/2.1, 1.5/1.7; ramps ~1 A/s; ends switched off. Expect: no faults, Cell 11 lowest, 4.1 s coolant oscillation. Fensterle et al. 2026, Zenodo 10.5281/zenodo.20715542, CC BY 4.0. Cell 6 is not a cell (end plate / sense lead).

01 Findings

- 1 inputs read about 0 V and were left out (not connected).
- Cell 5 changed by -1.4 mV relative to the others at 05:42:03.
- Periodic pattern in the stack voltage every 4.1 s.

DATA QUALITY	COVERAGE	CELL VOLTAGE	STACK VOLTAGE (MEAN)
good	100.0 %	0.013 ... 0.918 V	6.57 V
SPREAD (MEDIAN)	STD BETWEEN CELLS	LOAD STEPS · LEVELS	PERSISTENTLY LOW / HIGH
8.1 mV	2.34 mV	14 · 10	0 / 0

02 PEM fuel cell

- 25 s near open circuit (mean cell above 0.85 V, 0.3 % of the time): high-potential stress for the catalyst.
- Uniformity (lowest / mean cell) down to 97.2 % at 0.513 V a cell (Cell 11 lowest).

mean cell	lowest cell	lowest	uniformity	CV	time
0.766 V	Cell 11	0.765 V	99.8 %	0.11 %	5.0 min
0.762 V	Cell 11	0.760 V	99.8 %	0.15 %	10.0 min
0.695 V	Cell 11	0.691 V	99.4 %	0.29 %	5.0 min
0.688 V	Cell 11	0.684 V	99.4 %	0.32 %	15.0 min
0.680 V	Cell 11	0.675 V	99.3 %	0.35 %	11.7 min
0.672 V	Cell 11	0.667 V	99.2 %	0.38 %	12.6 min
0.590 V	Cell 11	0.581 V	98.5 %	0.71 %	5.0 min
0.579 V	Cell 11	0.568 V	98.0 %	0.88 %	5.9 min
0.574 V	Cell 11	0.564 V	98.1 %	0.83 %	5.7 min
0.513 V	Cell 11	0.499 V	97.2 %	1.18 %	9.9 min

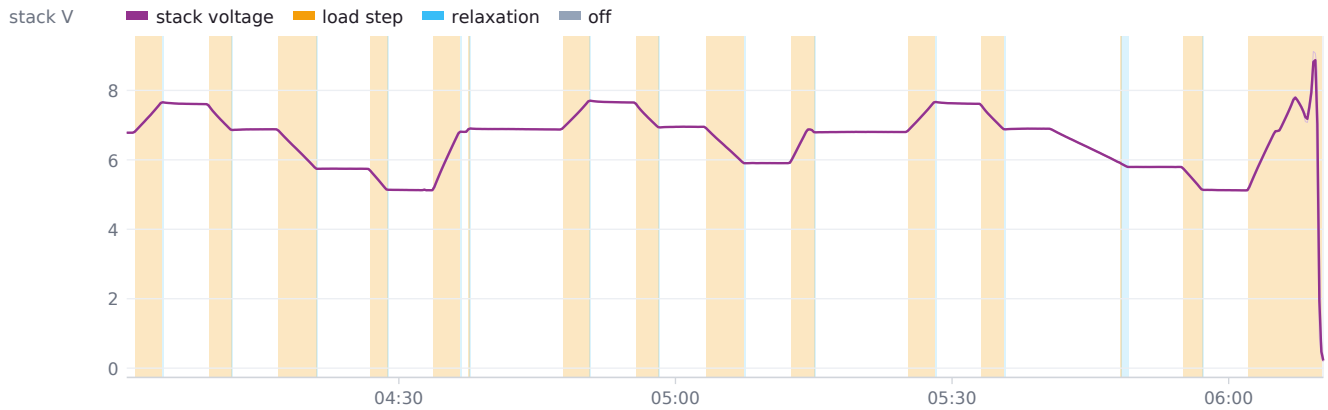
Each operating level: uniformity is the lowest cell over the mean cell.

Near open circuit (mean cell > 0.85 V): 25 s (0.3 %); highest cell 0.918 V (Cell 9). No regular purge pattern.

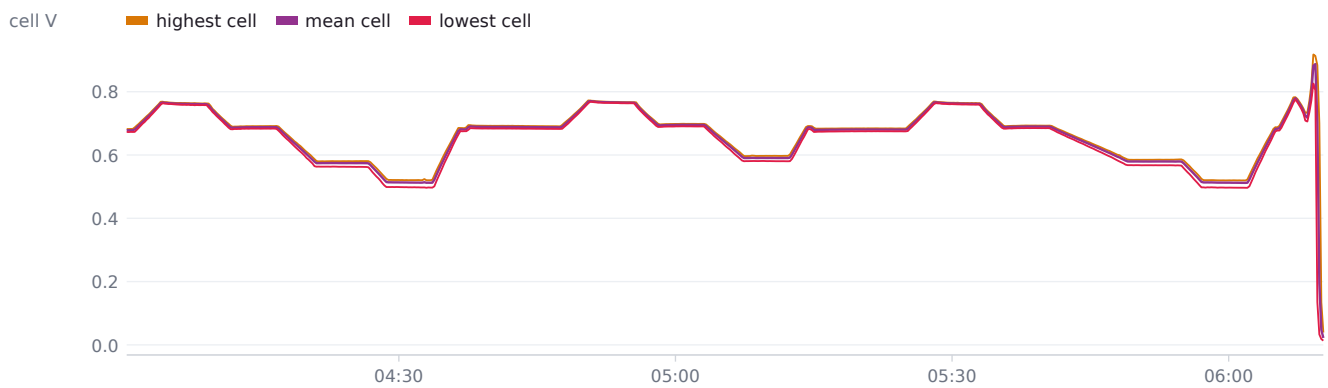


03 Overview

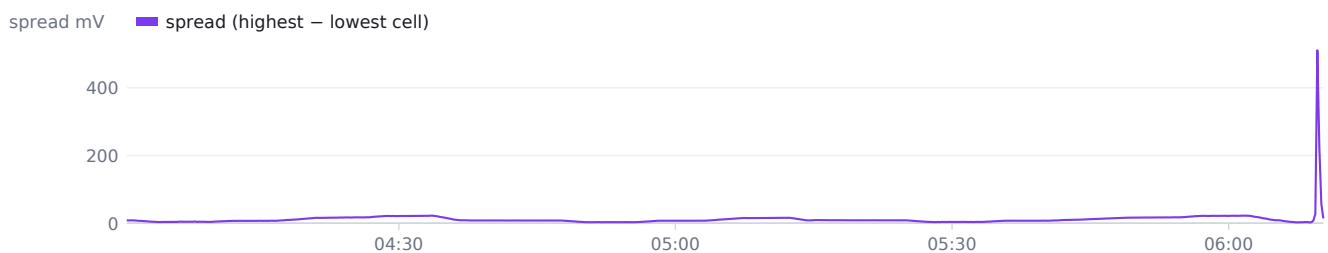
Stack voltage and operating states



Lowest, mean and highest cell



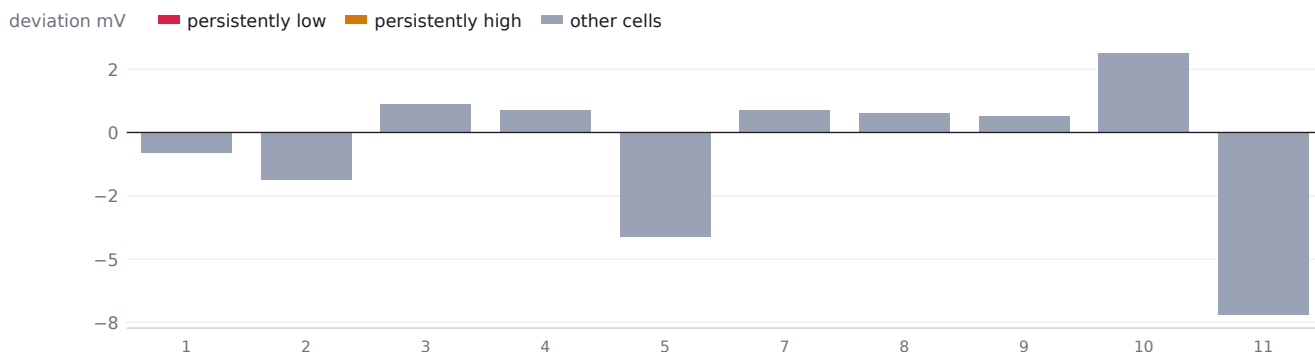
Spread between cells





04 Cells compared

Mean deviation from the typical cell (steady time)



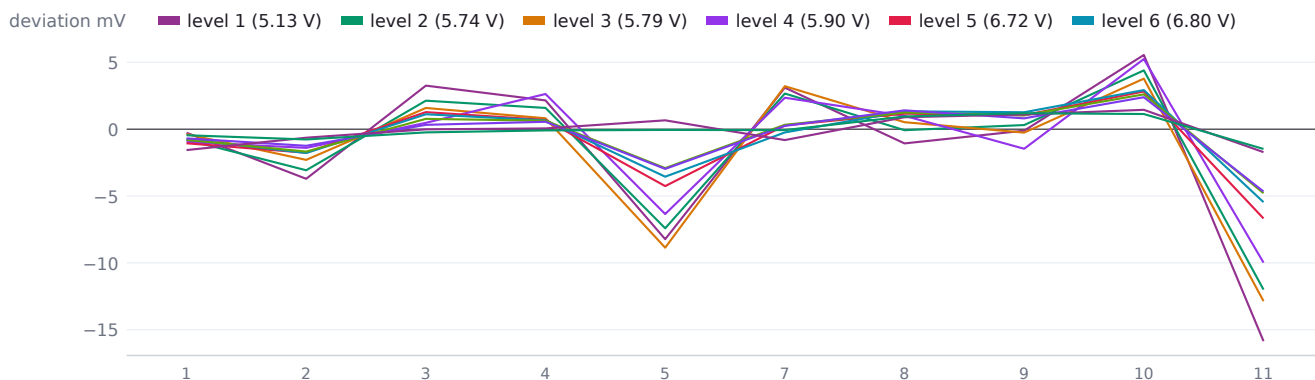
Red: persistently low · amber: persistently high.

05 Cells at each operating level

The cells compared within each steady level alone (the voltage-only counterpart of filtering by cycle or step): a cell that is fine at one load and weak at another shows here.

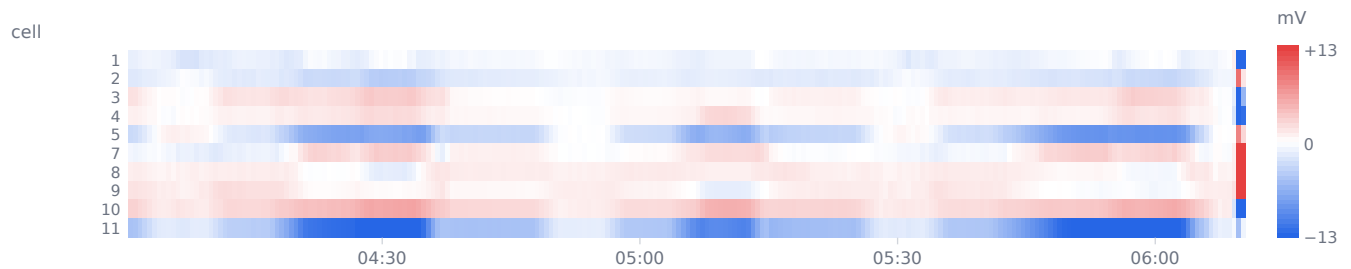
level	stack V	mean cell V	time	spread	std	lowest cells
1	5.13 V	0.514 V	9.9 min	21.4 mV	6.07 mV	Cell 11 (-15.9 mV), Cell 5 (-8.2 mV), Cell 2 (-3.7 mV)
2	5.74 V	0.576 V	5.7 min	16.4 mV	4.79 mV	Cell 11 (-12.0 mV), Cell 5 (-7.4 mV), Cell 2 (-3.1 mV)
3	5.79 V	0.581 V	5.9 min	16.7 mV	5.07 mV	Cell 11 (-12.9 mV), Cell 5 (-8.9 mV), Cell 2 (-2.3 mV)
4	5.90 V	0.591 V	5.0 min	15.2 mV	4.21 mV	Cell 11 (-10.0 mV), Cell 5 (-6.3 mV), Cell 9 (-1.5 mV)
5	6.72 V	0.672 V	12.6 min	8.8 mV	2.53 mV	Cell 11 (-6.7 mV), Cell 5 (-4.3 mV), Cell 2 (-1.8 mV)
6	6.80 V	0.681 V	11.7 min	8.4 mV	2.41 mV	Cell 11 (-5.5 mV), Cell 5 (-3.6 mV), Cell 2 (-1.8 mV)
7	6.88 V	0.689 V	15.0 min	7.6 mV	2.19 mV	Cell 11 (-4.8 mV), Cell 5 (-2.9 mV), Cell 2 (-1.7 mV)
8	6.95 V	0.695 V	5.0 min	7.0 mV	2.00 mV	Cell 11 (-4.7 mV), Cell 5 (-3.0 mV), Cell 2 (-1.2 mV)
9	7.62 V	0.762 V	10.0 min	3.5 mV	1.14 mV	Cell 11 (-1.7 mV), Cell 1 (-1.6 mV), Cell 7 (-0.8 mV)
10	7.66 V	0.766 V	5.0 min	2.8 mV	0.84 mV	Cell 11 (-1.5 mV), Cell 2 (-0.8 mV), Cell 1 (-0.5 mV)

Deviation from the typical cell, per level



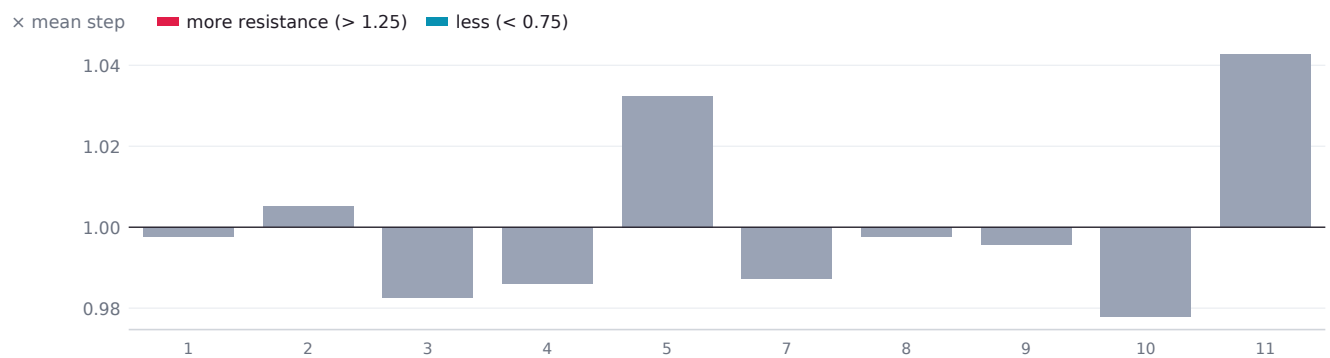


Deviation map (cell × time)



mV from the stack's typical cell; blue below, red above.

Response to load steps



14 steps · the same current through every cell: above 1 means more resistance.

06 Data quality

issue	
info	Cell 6 reads -13.1 mV: probably not connected
info	Cell 1: 573 isolated spikes
info	Cell 2: 65 isolated spikes
info	Cell 3: 20 isolated spikes
info	Cell 7: 64 isolated spikes
info	Cell 8: 70 isolated spikes
info	Cell 9: 30 isolated spikes
info	Cell 10: 23 isolated spikes

Coverage 100.00 % · 0 gaps · 878 isolated spikes · 0 stuck · 1 inputs not connected · score good

07 Operating states

state	share of the time
steady	66.0 %
transient	32.4 %
relaxing	1.3 %
off	0.3 %

level	stack voltage	time	share
1	5.129 V	9.9 min	7.6 %
2	5.744 V	5.7 min	4.4 %
3	5.795 V	5.9 min	4.6 %
4	5.905 V	5.0 min	3.8 %
5	6.723 V	12.6 min	9.7 %
6	6.802 V	11.7 min	9.0 %
7	6.881 V	15.0 min	11.6 %
8	6.950 V	5.0 min	3.9 %
9	7.620 V	10.0 min	7.7 %



level	stack voltage	time	share
10	7.663 V	5.0 min	3.8 %

0 starts · 1 stops · 14 load steps · stack noise 3.14 mV

08 Uniformity and position

Spread median / max	8.1 mV / 605.4 mV
Std between cells	2.34 mV
Coefficient of variation	0.34 %
Spread trend (within levels)	none
Gradient along the stack	-0.123 mV/cell
End cells vs the middle	-2.5 mV

09 Cells to look at

No cell stands out.

10 Changes during the recording

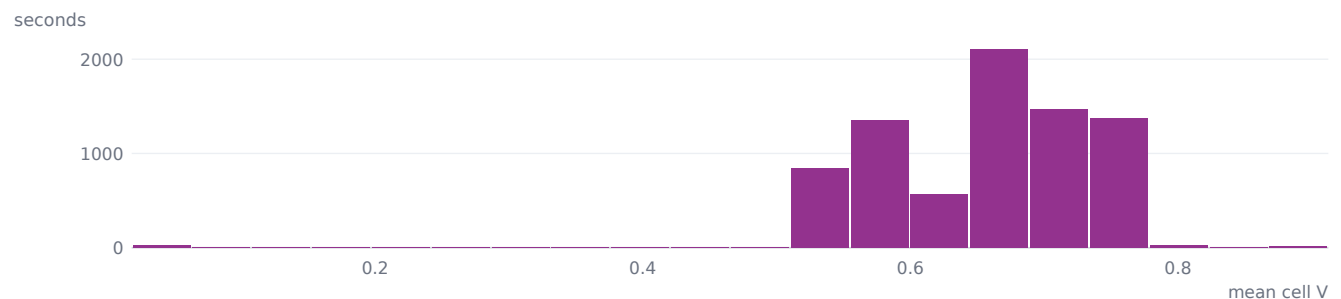
cell	kind	from	change
Cell 5	step	05:42:03	-1.4 mV

11 Patterns

periodic in the stack voltage	strength
every 4.1 s	×428 the background

Typical noise 273 μ V · 12.0 stack voltage cycles (rainflow)

Time at mean cell voltage



12 Events

time	event
05:42:03	warning Cell 5 shifted up relative to the others (CUSUM)
06:09:40–06:09:44	warning Cell 10 far below the other cells: down to 256 mV



13 All cells

mean, std and deviation over the steady time; min and max over the whole recording. L1... : the mean deviation at each operating level.

cell	mean V	min V	max V	std mV	dev. mV	step ×	L1 mV	L2 mV	L3 mV	L4 mV
Cell 1	0.6554	0.0156	0.9157	76.65	-0.8	1.00	-0.3	-0.8	-0.4	-1.0
Cell 2	0.6544	0.0186	0.9116	77.70	-1.9	1.01	-3.7	-3.1	-2.3	-1.4
Cell 3	0.6574	0.0157	0.9110	76.01	1.1	0.98	3.3	2.1	1.6	0.5
Cell 4	0.6571	0.0157	0.9062	76.22	0.9	0.99	2.2	1.6	0.8	2.6
Cell 5	0.6521	0.0191	0.9131	79.77	-4.1	1.03	-8.2	-7.4	-8.9	-6.3
Cell 7	0.6571	0.0197	0.9164	75.52	0.9	0.99	3.1	2.7	3.2	2.4
Cell 8	0.6570	0.0211	0.9150	77.46	0.8	1.00	-1.1	-0.1	0.5	1.0
Cell 9	0.6569	0.0234	0.9177	77.44	0.7	1.00	-0.1	0.3	-0.3	-1.5
Cell 10	0.6594	0.0134	0.9042	75.59	3.1	0.98	5.6	4.4	3.8	5.2
Cell 11	0.6490	0.0179	0.9119	81.39	-7.2	1.04	-15.9	-12.0	-12.9	-10.0

14 Method

Cell voltages only: no current, temperature or gas data. Every round of the recording is a row of cell voltages in stack order; a cell missing from a round stays missing. Operating states come from the stack voltage: its slope over 15 s against its noise (ramps included), holds of ≥ 30 s as plateaus, plateaus grouped into levels within 0.5 %, steps between plateaus. Each cell is compared with the stack's typical cell (25 % trimmed mean) during steady time; robust z-scores use 1.4826·MAD. Trends: Theil-Sen slope on 10 s means with a Mann-Kendall test; changes of single cells: CUSUM and PELT, a drift or a step whichever fits better (at a change of operating point said as such); periodic patterns: Welch's spectra of the holds, only lines recurring in half of them; groups: k-means on PCA; stress: rainflow counting (ASTM E1049). Relative step response: the cells carry the same current, so dV of a cell over the mean dV at a load step ranks their resistance. Thresholds are not yet validated per application and are listed here.

Deviation limit	4.0 robust sigma
Persistently low / high	in ≥ 50 % of the steady time
Smallest change reported	1.0 mV
Input not connected	median < 0.02 V while cells read > 0.2 V
Open sense wire	neighbours within 20 μ V
Far below the others	$z < -6$, ≥ 5.0 mV and ≥ 3 % of the typical cell
CUSUM	$k = 0.5$, $h = 8.0$
PEM fuel cell	reversal < 0 V; dip ≥ 50 mV and 10 % below the cell's usual place within 10 s, 1 s-2 min, stack holding; low OCV > 10 mV and 4sigma below (mean cell > 0.85 V); purges: ≥ 5 regular jumps of the stack; flooding: slow fluctuation 3× typical, ≥ 2 mV; dry-out: load response share +8 %; high potential: mean cell > 0.85 V
Source file	/Users/vltvch/Documents/Eris analysis recordings/real PEM fuel cell stack/PEM 10-cell stack - 2300 h - gas stoichiometry test.csv
File layout	cells (0 rows not readable)
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Software	Kolibrík CVM 2.0.0
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