

Untitled

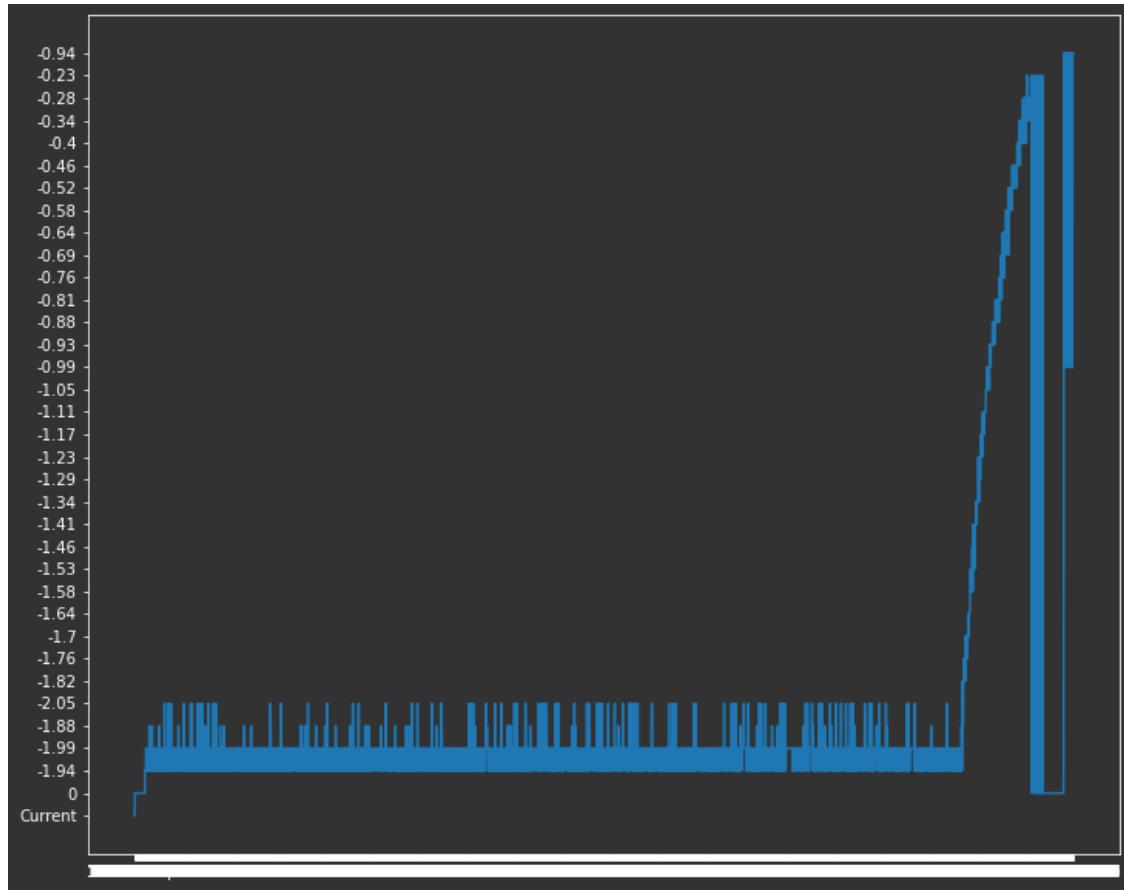
August 29, 2022

```
[2]: #Using Real time data
try:
    import liionpack as lp
except:
    !pip install -q git+https://github.com/pybamm-team/liionpack.git@main
    import liionpack as lp
import pybamm
import numpy as np
import os
import pandas as pd
import matplotlib.pyplot as plt

nproc = os.cpu_count()
os.chdir(pybamm.__path__[0] + "/..")
```

```
[3]: # import Real time data from file
Real_time_data = pd.read_csv(r"C:\Users\Engineering\Desktop\Data Science/
    ↪Samsung-50E 7S11P.csv", comment="#",
                                header=None).to_numpy()
```

```
[4]: # Current vs Time stamp graphical Analysis
with plt.rc_context(lp.lp_context()):
    plt.figure(figsize=(12, 10))
    plt.plot(Real_time_data[:, 0], Real_time_data[:, 1]) # The first column is
    ↪the time stamp and the second is the current.
```



```
[21]: Np = 11
Ns = 7
I_mag = 2.0
Rsmall = 1e-6
OCV_init = 4.0
Nspm = Np * Ns
# Generate the netlist
netlist = lp.setup_circuit(Np=Np, Ns=Ns, Rb=Rsmall, Rc=Rsmall, Ri=3e-2, I=I_mag, V=OCV_init)
# Define additional output variables
output_variables = [
    "Volume-averaged cell temperature [K]",
    "Discharge capacity [A.h]",
    "Current [A]",
    "Battery voltage [V]",
    "Cell temperature [K]",
    "Terminal voltage [V]",
]
# Define a cycling experiment using PyBaMM
```

```

experiment = pybamm.Experiment(
    ↪#experiment for constant charge
    [
        "Charge at 2 A for 30 minutes",
        "Rest for 15 minutes",
        "Discharge at 2 A for 30 minutes",
        "Rest for 15 minutes",
    ]
    * 3,
    period="10 seconds",
)
experiment = pybamm.Experiment(
    ↪#experiment for constant discharge
    [
        (
            "Discharge at 2 A for 30 minutes",
            "Rest for 15 minutes",
            "Charge at 2 A for 30 minutes",
            "Rest for 15 minutes",
        )
    ]
    * 3,
    period="10 seconds",
)
# Define the PyBaMM parameters
parameter_values = pybamm.ParameterValues("Chen2020")
parameter_values.update({"Total heat transfer coefficient [W.m-2.K-1]": ↪
    ↪"[input]"})
htc = np.random.random(Nspm) * 50.0
inputs = {"Total heat transfer coefficient [W.m-2.K-1]": htc}
# Solve the pack
output = lp.solve(
    netlist=netlist,
    sim_func=lp.thermal_simulation,
    parameter_values=parameter_values,
    experiment=experiment,
    output_variables=output_variables,
    inputs=inputs,
    initial_soc=0.5,
    nproc=nproc
)

```

Stepping simulation: 0% | 0/1621 [00:00<?, ?it/s]

ValueError

Input In [21], in <cell line: 47>()

Traceback (most recent call last)

```

45 inputs = {"Total heat transfer coefficient [W.m-2.K-1]": htc}
46 # Solve the pack
--> 47 output = lp.solve(
48     netlist=netlist,
49     sim_func=lp.thermal_simulation,
50     parameter_values=parameter_values,
51     experiment=experiment,
52     output_variables=output_variables,
53     inputs=inputs,
54     initial_soc=0.5,
55     nproc=nproc
56 )

File ~\anaconda3\lib\site-packages\liionpack\solver_utils.py:426, in solve
    ↵solve(netlist, sim_func, parameter_values, experiment, inputs, ↵
    ↵external_variables, initial_soc, nproc, output_variables, manager)
423     rm = lp.CasadiManager()
424     lp.logger.notice("manager instruction not supported, using default")
--> 426 output = rm.solve(
427     netlist=netlist,
428     sim_func=sim_func,
429     parameter_values=parameter_values,
430     experiment=experiment,
431     output_variables=output_variables,
432     inputs=inputs,
433     external_variables=external_variables,
434     nproc=nproc,
435     initial_soc=initial_soc,
436     setup_only=False,
437 )
438 return output

File ~\anaconda3\lib\site-packages\liionpack\solvers.py:363, in GenericManager.
    ↵solve(self, netlist, sim_func, parameter_values, experiment, inputs, ↵
    ↵external_variables, output_variables, initial_soc, nproc, setup_only)
361 self.evaluate_actors()
362 if not setup_only:
--> 363     self._step_solve_step(external_variables)
364     return self.step_output()

File ~\anaconda3\lib\site-packages\liionpack\solvers.py:374, in GenericManager.
    ↵_step_solve_step(self, external_variables)
372 step = 0
373 while step < self.Nsteps and vlims_ok:
--> 374     vlims_ok = self._step(step, external_variables)
375     if vlims_ok:
376         step += 1

```

```

File ~\anaconda3\lib\site-packages\liionpack\solvers.py:412, in GenericManager.
    ↪_step(self, step, external_variables)
    408 self.restarting = (
    409     step > 0 and self.protocol[step] != 0.0 and self.protocol[step - 1]
    ↪== 0.0
    410 )
    411 # 02 Get the actor output - Battery state info
--> 412 self.get_actor_output(step)
    413 # 03 Get the ocv and internal resistance
    414 temp_v = self.output[0, step, :]

File ~\anaconda3\lib\site-packages\liionpack\solvers.py:665, in CasadiManager.
    ↪get_actor_output(self, step)
    663 def get_actor_output(self, step):
    664     tic = ticker.time()
--> 665     self.output[:, step, :] = self.actors[0].output()
    666     toc = ticker.time()
    667     lp.logger.info(
    668         "Casadi actor output got in time " + str(np.around(toc - tic, ↪
    ↪3)) + "s"
    669     )

```

ValueError: could not broadcast input array from shape (66,77) into shape (7,77)

[7]: `experiment.operating_conditions # View the experiment steps`

[7]: [{}'electric': (2.0, 'A'), 'time': 1800.0, 'period': 10.0, 'dc_data': None}, {}'electric': (0, 'A'), 'time': 900.0, 'period': 10.0, 'dc_data': None}, {}'electric': (-2.0, 'A'), 'time': 1800.0, 'period': 10.0, 'dc_data': None}, {}'electric': (0, 'A'), 'time': 900.0, 'period': 10.0, 'dc_data': None}, {}'electric': (2.0, 'A'), 'time': 1800.0, 'period': 10.0, 'dc_data': None}, {}'electric': (0, 'A'), 'time': 900.0, 'period': 10.0, 'dc_data': None}, {}'electric': (-2.0, 'A'), 'time': 1800.0, 'period': 10.0, 'dc_data': None}, {}'electric': (0, 'A'), 'time': 900.0, 'period': 10.0, 'dc_data': None}, {}'electric': (2.0, 'A'), 'time': 1800.0, 'period': 10.0, 'dc_data': None}, {}'electric': (0, 'A'), 'time': 900.0, 'period': 10.0, 'dc_data': None}, {}'electric': (-2.0, 'A'), 'time': 1800.0, 'period': 10.0, 'dc_data': None}, {}'electric': (0, 'A'), 'time': 900.0, 'period': 10.0, 'dc_data': None}]

[8]: `# The default included data is the 'Cell current [A]', 'Terminal voltage ↪[V]', and 'Measured battery open circuit voltage [V]'.`

SPMe = pybamm.models.full_battery_models.lithium_ion.SPMe()
SPMe.variable_names()

[8]: ['Time',
 'Time [s]',
 'Time [min]',

```

'Time [h]',
'x',
'x [m]',
'x_n',
'x_n [m]',
'x_s',
'x_s [m]',
'x_p',
'x_p [m]',
'r_p',
'r_p [m]',
'r_n',
'r_n [m]',
'Current density variable',
'Total current density',
'Total current density [A.m-2]',
'Current [A]',
'C-rate',
'Discharge capacity [A.h]',
'Porosity',
'Separator porosity',
'Positive electrode porosity',
'X-averaged separator porosity',
'X-averaged positive electrode porosity',
'Negative electrode porosity',
'X-averaged negative electrode porosity',
'Leading-order porosity',
'Leading-order separator porosity',
'Leading-order positive electrode porosity',
'Leading-order x-averaged separator porosity',
'Leading-order x-averaged positive electrode porosity',
'Leading-order negative electrode porosity',
'Leading-order x-averaged negative electrode porosity',
'Porosity change',
'Separator porosity change',
'Positive electrode porosity change',
'X-averaged separator porosity change',
'X-averaged positive electrode porosity change',
'Negative electrode porosity change',
'X-averaged negative electrode porosity change',
'Leading-order x-averaged separator porosity change',
'Leading-order x-averaged positive electrode porosity change',
'Leading-order x-averaged negative electrode porosity change',
'Negative electrode interface utilisation variable',
'X-averaged negative electrode interface utilisation variable',
'Negative electrode interface utilisation',
'X-averaged negative electrode interface utilisation',

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'Positive electrode interface utilisation variable',
'X-averaged positive electrode interface utilisation variable',
'Positive electrode interface utilisation',
'X-averaged positive electrode interface utilisation',
'Negative particle crack length [m]',
'Negative particle crack length',
'X-averaged negative particle crack length',
'X-averaged negative particle crack length [m]',
'Negative particle cracking rate',
'X-averaged Negative particle cracking rate',
'Positive particle crack length [m]',
'Positive particle crack length',
'X-averaged positive particle crack length',
'X-averaged positive particle crack length [m]',
'Positive particle cracking rate',
'X-averaged Positive particle cracking rate',
'Negative electrode active material volume fraction',
'X-averaged negative electrode active material volume fraction',
'Negative electrode capacity [A.h]',
'Negative particle radius',
'Negative particle radius [m]',
'Negative electrode surface area to volume ratio',
'Negative electrode surface area to volume ratio [m-1]',
'X-averaged negative electrode surface area to volume ratio',
'X-averaged negative electrode surface area to volume ratio [m-1]',
'Negative electrode active material volume fraction change',
'X-averaged negative electrode active material volume fraction change',
'Positive electrode active material volume fraction',
'X-averaged positive electrode active material volume fraction',
'Positive electrode capacity [A.h]',
'Positive particle radius',
'Positive particle radius [m]',
'Positive electrode surface area to volume ratio',
'Positive electrode surface area to volume ratio [m-1]',
'X-averaged positive electrode surface area to volume ratio',
'X-averaged positive electrode surface area to volume ratio [m-1]',
'Positive electrode active material volume fraction change',
'X-averaged positive electrode active material volume fraction change',
'Positive electrode volume-averaged velocity',
'Positive electrode volume-averaged velocity [m.s-1]',
'Negative electrode volume-averaged velocity',
'Negative electrode volume-averaged velocity [m.s-1]',
'Positive electrode volume-averaged acceleration',
'Positive electrode volume-averaged acceleration [m.s-1]',
'X-averaged positive electrode volume-averaged acceleration',
'X-averaged positive electrode volume-averaged acceleration [m.s-1]',
'Negative electrode volume-averaged acceleration',

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'Negative electrode volume-averaged acceleration [m.s-1]',
'X-averaged negative electrode volume-averaged acceleration',
'X-averaged negative electrode volume-averaged acceleration [m.s-1]',
'Positive electrode pressure',
'X-averaged positive electrode pressure',
'Negative electrode pressure',
'X-averaged negative electrode pressure',
'Separator pressure',
'X-averaged separator pressure',
'Separator transverse volume-averaged velocity',
'Positive electrode transverse volume-averaged velocity',
'Separator transverse volume-averaged velocity [m.s-2]',
'Positive electrode transverse volume-averaged velocity [m.s-2]',
'X-averaged separator transverse volume-averaged velocity',
'X-averaged positive electrode transverse volume-averaged velocity',
'X-averaged separator transverse volume-averaged velocity [m.s-2]',
'X-averaged positive electrode transverse volume-averaged velocity [m.s-2]',
'Transverse volume-averaged velocity',
'Transverse volume-averaged velocity [m.s-2]',
'Negative electrode transverse volume-averaged velocity',
'Negative electrode transverse volume-averaged velocity [m.s-2]',
'X-averaged negative electrode transverse volume-averaged velocity',
'X-averaged negative electrode transverse volume-averaged velocity [m.s-2]',
'Separator transverse volume-averaged acceleration',
'Positive electrode transverse volume-averaged acceleration',
'Separator transverse volume-averaged acceleration [m.s-2]',
'Positive electrode transverse volume-averaged acceleration [m.s-2]',
'X-averaged separator transverse volume-averaged acceleration',
'X-averaged positive electrode transverse volume-averaged acceleration',
'X-averaged separator transverse volume-averaged acceleration [m.s-2]',
'X-averaged positive electrode transverse volume-averaged acceleration
[m.s-2]',
'Transverse volume-averaged acceleration',
'Transverse volume-averaged acceleration [m.s-2]',
'Negative electrode transverse volume-averaged acceleration',
'Negative electrode transverse volume-averaged acceleration [m.s-2]',
'X-averaged negative electrode transverse volume-averaged acceleration',
'X-averaged negative electrode transverse volume-averaged acceleration
[m.s-2]',
'Negative particle concentration',
'Negative particle concentration [mol.m-3]',
'X-averaged negative particle concentration',
'X-averaged negative particle concentration [mol.m-3]',
'R-averaged negative particle concentration',
'R-averaged negative particle concentration [mol.m-3]',
'Average negative particle concentration',
'Average negative particle concentration [mol.m-3]',
```

'Negative particle surface concentration',
'Negative particle surface concentration [mol.m-3]',
'X-averaged negative particle surface concentration',
'X-averaged negative particle surface concentration [mol.m-3]',
'Negative electrode extent of lithiation',
'X-averaged negative electrode extent of lithiation',
'Minimum negative particle concentration',
'Maximum negative particle concentration',
'Minimum negative particle concentration [mol.m-3]',
'Maximum negative particle concentration [mol.m-3]',
'Minimum negative particle surface concentration',
'Maximum negative particle surface concentration',
'Minimum negative particle surface concentration [mol.m-3]',
'Maximum negative particle surface concentration [mol.m-3]',
'Positive particle concentration',
'Positive particle concentration [mol.m-3]',
'X-averaged positive particle concentration',
'X-averaged positive particle concentration [mol.m-3]',
'R-averaged positive particle concentration',
'R-averaged positive particle concentration [mol.m-3]',
'Average positive particle concentration',
'Average positive particle concentration [mol.m-3]',
'Positive particle surface concentration',
'Positive particle surface concentration [mol.m-3]',
'X-averaged positive particle surface concentration',
'X-averaged positive particle surface concentration [mol.m-3]',
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'X-averaged positive electrode extent of lithiation',
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'Maximum positive particle concentration [mol.m-3]',
'Minimum positive particle surface concentration',
'Maximum positive particle surface concentration',
'Minimum positive particle surface concentration [mol.m-3]',
'Maximum positive particle surface concentration [mol.m-3]',
'Porosity times concentration',
'Separator porosity times concentration',
'Positive electrode porosity times concentration',
'Negative electrode porosity times concentration',
'Negative current collector temperature',
'Negative current collector temperature [K]',
'X-averaged negative electrode temperature',
'X-averaged negative electrode temperature [K]',
'Negative electrode temperature',
'Negative electrode temperature [K]',
'X-averaged separator temperature',

'X-averaged separator temperature [K]',
'Separator temperature',
'Separator temperature [K]',
'X-averaged positive electrode temperature',
'X-averaged positive electrode temperature [K]',
'Positive electrode temperature',
'Positive electrode temperature [K]',
'Positive current collector temperature',
'Positive current collector temperature [K]',
'Cell temperature',
'Cell temperature [K]',
'X-averaged cell temperature',
'X-averaged cell temperature [K]',
'Volume-averaged cell temperature',
'Volume-averaged cell temperature [K]',
'Ambient temperature [K]',
'Ambient temperature',
'Negative current collector potential',
'Negative current collector potential [V]',
'Inner SEI thickness',
'Inner SEI thickness [m]',
'Outer SEI thickness',
'Outer SEI thickness [m]',
'X-averaged inner SEI thickness',
'X-averaged inner SEI thickness [m]',
'X-averaged outer SEI thickness',
'X-averaged outer SEI thickness [m]',
'SEI thickness',
'SEI [m]',
'Total SEI thickness',
'Total SEI thickness [m]',
'X-averaged SEI thickness',
'X-averaged SEI thickness [m]',
'X-averaged total SEI thickness',
'X-averaged total SEI thickness [m]',
'X-averaged negative electrode resistance [Ohm.m2]',
'Inner SEI interfacial current density',
'Inner SEI interfacial current density [A.m-2]',
'X-averaged inner SEI interfacial current density',
'X-averaged inner SEI interfacial current density [A.m-2]',
'Outer SEI interfacial current density',
'Outer SEI interfacial current density [A.m-2]',
'X-averaged outer SEI interfacial current density',
'X-averaged outer SEI interfacial current density [A.m-2]',
'SEI interfacial current density',
'SEI interfacial current density [A.m-2]',
'X-averaged SEI interfacial current density',

'X-averaged SEI interfacial current density [A.m-2]',
'Inner SEI on cracks thickness',
'Inner SEI on cracks thickness [m]',
'Outer SEI on cracks thickness',
'Outer SEI on cracks thickness [m]',
'X-averaged inner SEI on cracks thickness',
'X-averaged inner SEI on cracks thickness [m]',
'X-averaged outer SEI on cracks thickness',
'X-averaged outer SEI on cracks thickness [m]',
'SEI on cracks thickness',
'SEI on cracks [m]',
'Total SEI on cracks thickness',
'Total SEI on cracks thickness [m]',
'X-averaged SEI on cracks thickness',
'X-averaged SEI on cracks thickness [m]',
'X-averaged total SEI on cracks thickness',
'X-averaged total SEI on cracks thickness [m]',
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'Inner SEI on cracks interfacial current density [A.m-2]',
'X-averaged inner SEI on cracks interfacial current density',
'X-averaged inner SEI on cracks interfacial current density [A.m-2]',
'Outer SEI on cracks interfacial current density',
'Outer SEI on cracks interfacial current density [A.m-2]',
'X-averaged outer SEI on cracks interfacial current density',
'X-averaged outer SEI on cracks interfacial current density [A.m-2]',
'SEI on cracks interfacial current density',
'SEI on cracks interfacial current density [A.m-2]',
'X-averaged SEI on cracks interfacial current density',
'X-averaged SEI on cracks interfacial current density [A.m-2]',
'Lithium plating concentration',
'Lithium plating concentration [mol.m-3]',
'X-averaged lithium plating concentration',
'X-averaged lithium plating concentration [mol.m-3]',
'Dead lithium concentration',
'Dead lithium concentration [mol.m-3]',
'X-averaged dead lithium concentration',
'X-averaged dead lithium concentration [mol.m-3]',
'Lithium plating thickness',
'Lithium plating thickness [m]',
'X-averaged lithium plating thickness [m]',
'Dead lithium thickness',
'Dead lithium thickness [m]',
'X-averaged dead lithium thickness [m]',
'Loss of lithium to lithium plating [mol]',
'Loss of capacity to lithium plating [A.h]',
'Negative electrode lithium plating reaction overpotential',
'X-averaged negative electrode lithium plating reaction overpotential',

'Negative electrode lithium plating reaction overpotential [V]',
'X-averaged negative electrode lithium plating reaction overpotential [V]',
'Lithium plating interfacial current density',
'Lithium plating interfacial current density [A.m-2]',
'X-averaged lithium plating interfacial current density',
'X-averaged lithium plating interfacial current density [A.m-2]',
'Negative crack surface to volume ratio [m-1]',
'Negative crack surface to volume ratio',
'Negative electrode roughness ratio',
'X-averaged negative electrode roughness ratio',
'Positive crack surface to volume ratio [m-1]',
'Positive crack surface to volume ratio',
'Positive electrode roughness ratio',
'X-averaged positive electrode roughness ratio',
'Electrolyte transport efficiency',
'Positive electrolyte transport efficiency',
'X-averaged positive electrolyte transport efficiency',
'Negative electrolyte transport efficiency',
'X-averaged negative electrolyte transport efficiency',
'Separator transport efficiency',
'X-averaged separator transport efficiency',
'Leading-order electrolyte transport efficiency',
'Leading-order positive electrolyte transport efficiency',
'Leading-order x-averaged positive electrolyte transport efficiency',
'Leading-order negative electrolyte transport efficiency',
'Leading-order x-averaged negative electrolyte transport efficiency',
'Leading-order separator transport efficiency',
'Leading-order x-averaged separator transport efficiency',
'Electrode transport efficiency',
'Positive electrode transport efficiency',
'X-averaged positive electrode transport efficiency',
'Negative electrode transport efficiency',
'X-averaged negative electrode transport efficiency',
'Leading-order electrode transport efficiency',
'Leading-order positive electrode transport efficiency',
'Leading-order x-averaged positive electrode transport efficiency',
'Leading-order negative electrode transport efficiency',
'Leading-order x-averaged negative electrode transport efficiency',
'Separator volume-averaged velocity',
'Separator volume-averaged velocity [m.s-1]',
'Separator volume-averaged acceleration',
'Separator volume-averaged acceleration [m.s-1]',
'X-averaged separator volume-averaged acceleration',
'X-averaged separator volume-averaged acceleration [m.s-1]',
'Volume-averaged velocity',
'Volume-averaged velocity [m.s-1]',
'Volume-averaged acceleration',

```
'X-averaged volume-averaged acceleration',
'Volume-averaged acceleration [m.s-1]',
'X-averaged volume-averaged acceleration [m.s-1]',
'Pressure',
'Negative electrode open circuit potential',
'Negative electrode open circuit potential [V]',
'X-averaged negative electrode open circuit potential',
'X-averaged negative electrode open circuit potential [V]',
'Negative electrode entropic change',
'Negative electrode entropic change [V.K-1]',
'X-averaged negative electrode entropic change',
'X-averaged negative electrode entropic change [V.K-1]',
'Positive electrode open circuit potential',
'Positive electrode open circuit potential [V]',
'X-averaged positive electrode open circuit potential',
'X-averaged positive electrode open circuit potential [V]',
'Positive electrode entropic change',
'Positive electrode entropic change [V.K-1]',
'X-averaged positive electrode entropic change',
'X-averaged positive electrode entropic change [V.K-1]',
'Negative effective diffusivity',
'Negative effective diffusivity [m2.s-1]',
'X-averaged negative effective diffusivity',
'X-averaged negative effective diffusivity [m2.s-1]',
'Negative particle flux',
'X-averaged negative particle flux',
'Negative electrode SOC',
'Negative electrode volume-averaged concentration',
'Negative electrode volume-averaged concentration [mol.m-3]',
'Total lithium in negative electrode [mol]',
'Positive effective diffusivity',
'Positive effective diffusivity [m2.s-1]',
'X-averaged positive effective diffusivity',
'X-averaged positive effective diffusivity [m2.s-1]',
'Positive particle flux',
'X-averaged positive particle flux',
'Positive electrode SOC',
'Positive electrode volume-averaged concentration',
'Positive electrode volume-averaged concentration [mol.m-3]',
'Total lithium in positive electrode [mol]',
'Electrolyte concentration',
'Electrolyte concentration [mol.m-3]',
'Electrolyte concentration [Molar]',
'X-averaged electrolyte concentration',
'X-averaged electrolyte concentration [mol.m-3]',
'X-averaged electrolyte concentration [Molar]',
'Negative electrolyte concentration',
```

'Negative electrolyte concentration [mol.m-3]',
'Negative electrolyte concentration [Molar]',
'Separator electrolyte concentration',
'Separator electrolyte concentration [mol.m-3]',
'Separator electrolyte concentration [Molar]',
'Positive electrolyte concentration',
'Positive electrolyte concentration [mol.m-3]',
'Positive electrolyte concentration [Molar]',
'X-averaged negative electrolyte concentration',
'X-averaged negative electrolyte concentration [mol.m-3]',
'X-averaged separator electrolyte concentration',
'X-averaged separator electrolyte concentration [mol.m-3]',
'X-averaged positive electrolyte concentration',
'X-averaged positive electrolyte concentration [mol.m-3]',
'Ohmic heating',
'Ohmic heating [W.m-3]',
'X-averaged Ohmic heating',
'X-averaged Ohmic heating [W.m-3]',
'Volume-averaged Ohmic heating',
'Volume-averaged Ohmic heating [W.m-3]',
'Irreversible electrochemical heating',
'Irreversible electrochemical heating [W.m-3]',
'X-averaged irreversible electrochemical heating',
'X-averaged irreversible electrochemical heating [W.m-3]',
'Volume-averaged irreversible electrochemical heating',
'Volume-averaged irreversible electrochemical heating [W.m-3]',
'Reversible heating',
'Reversible heating [W.m-3]',
'X-averaged reversible heating',
'X-averaged reversible heating [W.m-3]',
'Volume-averaged reversible heating',
'Volume-averaged reversible heating [W.m-3]',
'Total heating',
'Total heating [W.m-3]',
'X-averaged total heating',
'X-averaged total heating [W.m-3]',
'Volume-averaged total heating',
'Volume-averaged total heating [W.m-3]',
'Current collector current density',
'Current collector current density [A.m-2]',
'Leading-order current collector current density',
'Inner SEI concentration [mol.m-3]',
'X-averaged inner SEI concentration [mol.m-3]',
'Outer SEI concentration [mol.m-3]',
'X-averaged outer SEI concentration [mol.m-3]',
'SEI concentration [mol.m-3]',
'X-averaged SEI concentration [mol.m-3]',

'Loss of lithium to SEI [mol]',
'Loss of capacity to SEI [A.h]',
'X-averaged negative electrode SEI interfacial current density',
'Negative electrode SEI interfacial current density',
'Negative electrode SEI interfacial current density [A.m-2]',
'Negative electrode SEI volumetric interfacial current density',
'X-averaged negative electrode SEI volumetric interfacial current density',
'Negative electrode SEI volumetric interfacial current density [A.m-3]',
'X-averaged negative electrode SEI volumetric interfacial current density
[A.m-3]',
'X-averaged positive electrode SEI interfacial current density',
'Positive electrode SEI interfacial current density',
'Positive electrode SEI interfacial current density [A.m-2]',
'X-averaged positive electrode SEI volumetric interfacial current density',
'Positive electrode SEI volumetric interfacial current density',
'Inner SEI on cracks concentration [mol.m-3]',
'X-averaged inner SEI on cracks concentration [mol.m-3]',
'Outer SEI on cracks concentration [mol.m-3]',
'X-averaged outer SEI on cracks concentration [mol.m-3]',
'SEI on cracks concentration [mol.m-3]',
'X-averaged SEI on cracks concentration [mol.m-3]',
'Loss of lithium to SEI on cracks [mol]',
'Loss of capacity to SEI on cracks [A.h]',
'X-averaged negative electrode SEI on cracks interfacial current density',
'Negative electrode SEI on cracks interfacial current density',
'Negative electrode SEI on cracks interfacial current density [A.m-2]',
'Negative electrode SEI on cracks volumetric interfacial current density',
'X-averaged negative electrode SEI on cracks volumetric interfacial current
density',
'Negative electrode SEI on cracks volumetric interfacial current density
[A.m-3]',
'X-averaged negative electrode SEI on cracks volumetric interfacial current
density [A.m-3]',
'X-averaged positive electrode SEI on cracks interfacial current density',
'Positive electrode SEI on cracks interfacial current density',
'Positive electrode SEI on cracks interfacial current density [A.m-2]',
'X-averaged positive electrode SEI on cracks volumetric interfacial current
density',
'Positive electrode SEI on cracks volumetric interfacial current density',
'X-averaged negative electrode lithium plating interfacial current density',
'X-averaged positive electrode lithium plating interfacial current density',
'X-averaged positive electrode lithium plating volumetric interfacial current
density',
'Negative electrode lithium plating interfacial current density',
'Negative electrode lithium plating interfacial current density [A.m-2]',
'Positive electrode lithium plating interfacial current density',
'Positive electrode lithium plating interfacial current density [A.m-2]',

'Positive electrode lithium plating volumetric interfacial current density',
'Negative electrode lithium plating volumetric interfacial current density',
'X-averaged negative electrode lithium plating volumetric interfacial current density',
'Negative electrode lithium plating volumetric interfacial current density [A.m-3]',
'X-averaged negative electrode lithium plating volumetric interfacial current density [A.m-3]',
'X-averaged negative electrode total interfacial current density',
'X-averaged negative electrode total interfacial current density [A.m-2]',
'SEI film overpotential',
'X-averaged SEI film overpotential',
'SEI film overpotential [V]',
'X-averaged SEI film overpotential [V]',
'Negative electrode exchange current density',
'X-averaged negative electrode exchange current density',
'Negative electrode exchange current density [A.m-2]',
'X-averaged negative electrode exchange current density [A.m-2]',
'Negative electrode reaction overpotential',
'X-averaged negative electrode reaction overpotential',
'Negative electrode reaction overpotential [V]',
'X-averaged negative electrode reaction overpotential [V]',
'X-averaged negative electrode surface potential difference',
'X-averaged negative electrode surface potential difference [V]',
'X-averaged positive electrode total interfacial current density',
'X-averaged positive electrode total interfacial current density [A.m-2]',
'Positive electrode exchange current density',
'X-averaged positive electrode exchange current density',
'Positive electrode exchange current density [A.m-2]',
'X-averaged positive electrode exchange current density [A.m-2]',
'Positive electrode reaction overpotential',
'X-averaged positive electrode reaction overpotential',
'Positive electrode reaction overpotential [V]',
'X-averaged positive electrode reaction overpotential [V]',
'X-averaged positive electrode surface potential difference',
'X-averaged positive electrode surface potential difference [V]',
'Negative electrode interfacial current density',
'X-averaged negative electrode interfacial current density',
'Negative electrode interfacial current density [A.m-2]',
'X-averaged negative electrode interfacial current density [A.m-2]',
'Negative electrode volumetric interfacial current density',
'X-averaged negative electrode volumetric interfacial current density',
'Negative electrode volumetric interfacial current density [A.m-3]',
'X-averaged negative electrode volumetric interfacial current density [A.m-3]',
'Positive electrode interfacial current density',
'X-averaged positive electrode interfacial current density',
'Positive electrode interfacial current density [A.m-2]',

'X-averaged positive electrode interfacial current density [A.m-2]',
'Positive electrode volumetric interfacial current density',
'X-averaged positive electrode volumetric interfacial current density',
'Positive electrode volumetric interfacial current density [A.m-3]',
'X-averaged positive electrode volumetric interfacial current density [A.m-3]',
'Negative electrode potential',
'Negative electrode potential [V]',
'X-averaged negative electrode potential',
'X-averaged negative electrode potential [V]',
'Negative electrode ohmic losses',
'Negative electrode ohmic losses [V]',
'X-averaged negative electrode ohmic losses',
'X-averaged negative electrode ohmic losses [V]',
'Gradient of negative electrode potential',
'Negative electrode current density',
'Negative electrode current density [A.m-2]',
'Negative electrolyte potential',
'Negative electrolyte potential [V]',
'Separator electrolyte potential',
'Separator electrolyte potential [V]',
'Positive electrolyte potential',
'Positive electrolyte potential [V]',
'Electrolyte potential',
'Electrolyte potential [V]',
'X-averaged electrolyte potential',
'X-averaged electrolyte potential [V]',
'X-averaged negative electrolyte potential',
'X-averaged negative electrolyte potential [V]',
'X-averaged separator electrolyte potential',
'X-averaged separator electrolyte potential [V]',
'X-averaged positive electrolyte potential',
'X-averaged positive electrolyte potential [V]',
'X-averaged electrolyte overpotential',
'X-averaged electrolyte overpotential [V]',
'Gradient of separator electrolyte potential',
'Gradient of positive electrolyte potential',
'Gradient of electrolyte potential',
'Gradient of negative electrolyte potential',
'Electrolyte current density',
'Electrolyte current density [A.m-2]',
'Negative electrolyte current density',
'Negative electrolyte current density [A.m-2]',
'Positive electrolyte current density',
'Positive electrolyte current density [A.m-2]',
'X-averaged concentration overpotential',
'X-averaged electrolyte ohmic losses',
'X-averaged concentration overpotential [V]',

'X-averaged electrolyte ohmic losses [V]',
'Negative electrode surface potential difference',
'Negative electrode surface potential difference [V]',
'Electrolyte flux',
'Electrolyte flux [mol.m-2.s-1]',
'Total lithium in electrolyte',
'Total lithium in electrolyte [mol]',
'Sum of electrolyte reaction source terms',
'Sum of positive electrode electrolyte reaction source terms',
'Sum of x-averaged positive electrode electrolyte reaction source terms',
'Sum of interfacial current densities',
'Sum of volumetric interfacial current densities',
'Sum of positive electrode interfacial current densities',
'Sum of x-averaged positive electrode interfacial current densities',
'Sum of positive electrode volumetric interfacial current densities',
'Sum of x-averaged positive electrode volumetric interfacial current densities',
densities',
'Sum of negative electrode electrolyte reaction source terms',
'Sum of x-averaged negative electrode electrolyte reaction source terms',
'Sum of negative electrode interfacial current densities',
'Sum of x-averaged negative electrode interfacial current densities',
'Sum of negative electrode volumetric interfacial current densities',
'Sum of x-averaged negative electrode volumetric interfacial current densities',
densities',
'Interfacial current density',
'Interfacial current density [A.m-2]',
'Exchange current density',
'Exchange current density [A.m-2]',
'Positive electrode potential',
'Positive electrode potential [V]',
'X-averaged positive electrode potential',
'X-averaged positive electrode potential [V]',
'Positive electrode ohmic losses',
'Positive electrode ohmic losses [V]',
'X-averaged positive electrode ohmic losses',
'X-averaged positive electrode ohmic losses [V]',
'Gradient of positive electrode potential',
'Positive electrode current density',
'Positive electrode current density [A.m-2]',
'Electrode current density',
'Positive current collector potential',
'Positive current collector potential [V]',
'Local voltage',
'Local voltage [V]',
'Terminal voltage',
'Terminal voltage [V]',
'Positive electrode surface potential difference',

```

'Positive electrode surface potential difference [V]',
'X-averaged open circuit voltage',
'Measured open circuit voltage',
'X-averaged open circuit voltage [V]',
'Measured open circuit voltage [V]',
'X-averaged reaction overpotential',
'X-averaged reaction overpotential [V]',
'X-averaged solid phase ohmic losses',
'X-averaged solid phase ohmic losses [V]',
'X-averaged battery open circuit voltage [V]',
'Measured battery open circuit voltage [V]',
'X-averaged battery reaction overpotential [V]',
'X-averaged battery solid phase ohmic losses [V]',
'X-averaged battery electrolyte ohmic losses [V]',
'X-averaged battery concentration overpotential [V]',
'Battery voltage [V]',
'Change in measured open circuit voltage',
'Change in measured open circuit voltage [V]',
'Local ECM resistance',
'Local ECM resistance [Ohm]',
'Terminal power [W]',
'Power [W]',
'Resistance [Ohm]',
'LAM_ne [%]',
'LAM_pe [%]',
'LLI [%]',
'Loss of active material in negative electrode [%]',
'Loss of active material in positive electrode [%]',
'Loss of lithium inventory [%]',
'Loss of lithium inventory, including electrolyte [%]',
'Total lithium [mol]',
'Total lithium in particles [mol]',
'Total lithium lost [mol]',
'Total lithium lost from particles [mol]',
'Total lithium lost from electrolyte [mol]',
'Total lithium lost to side reactions [mol]',
'Total capacity lost to side reactions [A.h]']

```

[22]: #use plot_cell_data_image to produce a snapshot of the system in image format
 ↪which has the same dimensions as the number of
 #cells in parallel and series.

```

data = output["Volume-averaged cell temperature [K]"][-1, :]
lp.plot_cell_data_image(netlist, data, tick_labels=False, figsize=(15, 6))

data = output["Terminal voltage [V]"][-1, :]
lp.plot_cell_data_image(netlist, data, tick_labels=False, figsize=(15, 6))

```

```

data = output["Discharge capacity [A.h]"][-1, :]
lp.plot_cell_data_image(netlist, data, tick_labels=False, figsize=(15, 6))

data = output["Current [A]"][-1, :]
lp.plot_cell_data_image(netlist, data, tick_labels=False, figsize=(15, 6))

data = output["Battery voltage [V]"][-1, :]
lp.plot_cell_data_image(netlist, data, tick_labels=False, figsize=(15, 6))

data = output["Cell temperature [K]"][-1, :]
lp.plot_cell_data_image(netlist, data, tick_labels=False, figsize=(15, 6))

lp.plot_pack(output)

```

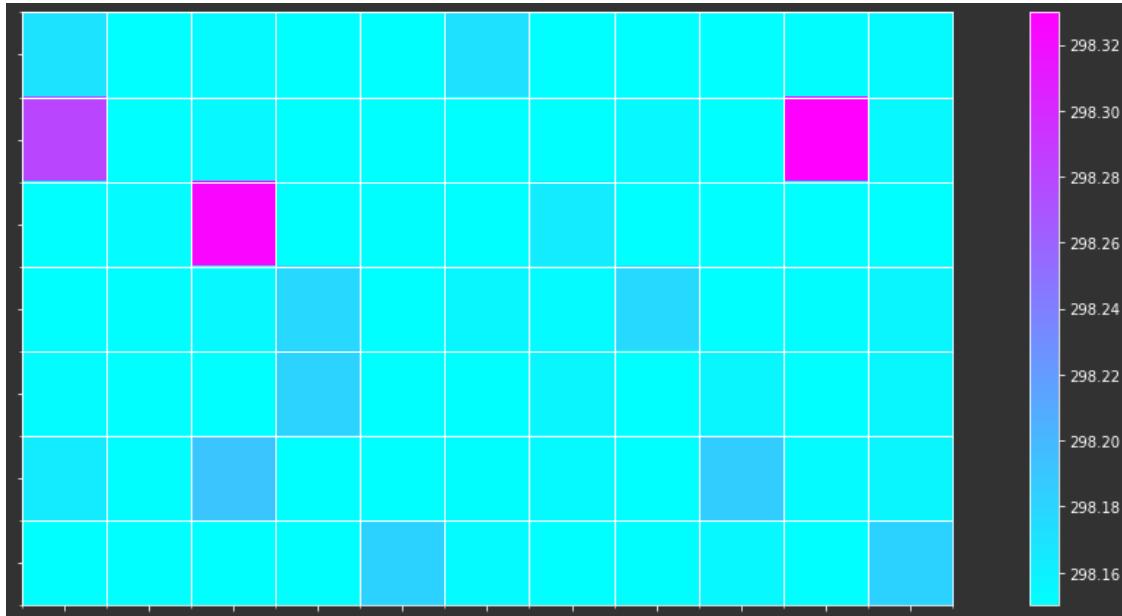
KeyError Traceback (most recent call last)

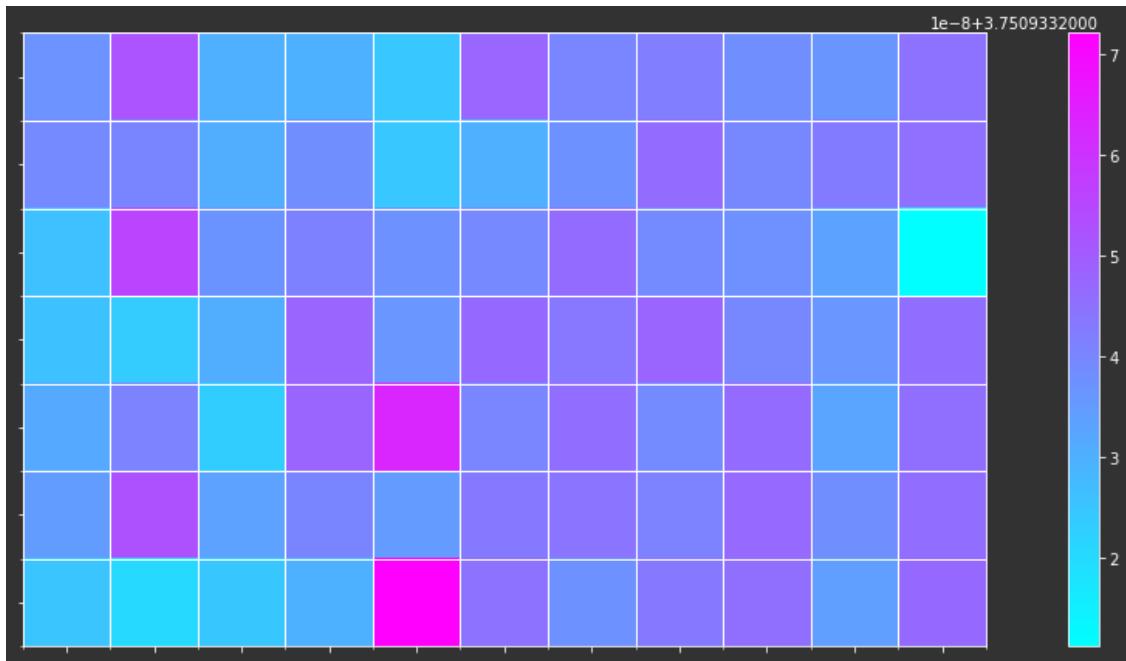
```

Input In [22], in <cell line: 9>()
    6 data = output["Terminal voltage [V]"][-1, :]
    7 lp.plot_cell_data_image(netlist, data, tick_labels=False, figsize=(15, 6))
    ↵6))
----> 9 data = output["Discharge capacity"][-1, :]
    10 lp.plot_cell_data_image(netlist, data, tick_labels=False, figsize=(15, 6))
    ↵6))
    12 data = output["Current [A]"][-1, :]

```

KeyError: 'Discharge capacity'





```
[10]: print(netlist)
```

	desc	node1	node2	value	node1_x	node1_y	node2_x	node2_y	\
0	Rbn0	1	2	0.000001	0	0	1	0	
1	Rbn1	2	3	0.000001	1	0	2	0	
2	Rbn2	3	4	0.000001	2	0	3	0	
3	Rbn3	4	5	0.000001	3	0	4	0	
4	Rbn4	5	6	0.000001	4	0	5	0	
..	
249	Rbp18	240	241	0.000001	8	21	9	21	
250	Rbp19	241	242	0.000001	9	21	10	21	
251	Rtp1	232	243	0.000010	0	21	-1	21	
252	IO	243	0	0.000000	-1	21	-1	0	
253	Rtn1	0	1	0.000010	-1	0	0	0	
				power_loss					
0				3.745041e-16					
1				2.263199e-16					
2				1.468662e-15					
3				1.372269e-15					
4				9.059868e-16					
..				..					
249				1.608823e-17					
250				2.296912e-17					

```
251 1.262177e-24
252 0.000000e+00
253 1.806194e-20
```

[254 rows x 9 columns]

```
[ ]: 
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[ ]: 
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[ ]: 
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```
[ ]: 
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