balancing_resistance

September 30, 2024

0.1 Calculate Time to Fully Balance a Pack

Criteria: * Previous resistance: 15 Ohms * New resistance (inernal to IC): 39 Ohms

Tasks: * Determine time required to balance cells * Set a maximum voltage difference for cell balancing to occur * Test this difference at different max/min voltages to observe differences (with low voltage balancing for instance)

Criteria: * Balancing maximum voltage range: 0.4 V (we shouldn't see greater than this) * Balancing typical voltage range: 0.2-0.3 V * If the balancing process takes longer than **5 hours**, we decide that it is insufficient. * Compare this with the 15 Ohm resistance for reference * Look at heat dissipated from resistors for interest

Evaluation range: * Max voltages: 2.9 - 4.2 V * Voltage ranges: 0.2 - 0.4 V

Analytical Process: * Iterative: * PRIOR: set the voltage, time –> evaluate the capacity from curves * evaluate the current * calculte the capacity loss * search for the next voltage * increment the time

Required data: * Molicel P28A Capacity vs Voltage Curves during discharge * Lowest C-Rate plot only (because C-rate is less than 0.5 continuously)

[1]:
```python
# Upload data from Molicel
import pandas as pd
import numpy as np
import pickle

curve_data = pd.read_csv("Discharge_0.5C.csv")

curve_data.loc[:,'SoC'] / 100 * 2.8 * 5
```

[1]:
```
0        13.903460
1        13.897042
2        13.894903
3        13.892765
4        13.890625
           …
3256    -0.360654
3257    -0.362794
3258    -0.364934
3259    -0.367073
```

```
3260    -0.377766
Name: SoC, Length: 3261, dtype: float64
```

[2]:
```
# Simple typical max current calculation:
IC_resistance = 39  # Ohms
Ex_resistance = 15  # Ohms

IC_max_current = 4.2 / 39
Ex_resistance = 4.2 / 15

max_capacity = 2.8 * 5
C_rate = IC_max_current / max_capacity
C_rate

# Parameter combinations
dt = 1    # seconds
secsToHours = 1/3600
min = 3.5
max = 4.2
max_voltage = np.arange(min, max, 0.1)
Vrange = 0.4

# Initialize dictionary to save data
keyList = []
for key in max_voltage:
    keyList.append(str(round(key, 1)))

# Nested Dict
storeDict = {}
for label in keyList:
    storeDict = {**storeDict, label: {"Time": [], "Voltage": [], "Current": [],␣
 ↪"SoC": [], "Capacity": []}}

for j in range(0, len(max_voltage)):
    # Loop to analyze multiple parameter combinations:
    print("pass")
    # Clear maxV
    maxV = round(max_voltage[j], 1)

    # Initialize parameters
    time = []
    voltage = []
    capacity = []
    SoC = []
    current = []
    i = 0
```

```python
    # Search for initial capacity
    index = np.searchsorted(-curve_data.loc[:,'Voltage'], -maxV)
    cap0 = max_capacity * curve_data.loc[curve_data.index[index],'SoC'] / 100

    # Initial parameters
    time.append(dt)
    voltage.append(maxV)
    capacity.append(cap0)
    SoC.append(cap0 / max_capacity * 100)
    thisVMin = maxV

    # Start loop
    while thisVMin > (maxV - Vrange):
        # Determine current:
        current.append(voltage[i] / IC_resistance)

        # Capacity loss (Ah)
        cap_loss = current[i] * dt * secsToHours

        # Next capacity
        capacity.append(capacity[i] - cap_loss)
        SoC.append(capacity[i+1] / max_capacity * 100)

        # Search for next voltage
        index = np.searchsorted(-curve_data.loc[:,'SoC'], -SoC[i+1])
        voltage.append(curve_data.loc[curve_data.index[index], 'Voltage'])

        # Increment time
        time.append(time[i] + dt)

        # Set Min Voltage
        thisVMin = voltage[i+1]

        # increment variable
        i = i + 1

    # Save data to nicer format
    storeDict[str(maxV)]["Time"] = time
    storeDict[str(maxV)]["Current"] = current
    storeDict[str(maxV)]["Voltage"] = voltage
    storeDict[str(maxV)]["Capacity"] = capacity
    storeDict[str(maxV)]["SoC"] = SoC
# repeat

# Save data to Pickle file
outfile = "balancing_0.4V.pkl"
with open(outfile, "wb") as file:
```

```
    pickle.dump(storeDict, file)
```

pass
pass
pass
pass

```
---------------------------------------------------------------------------
KeyboardInterrupt                         Traceback (most recent call last)
~\AppData\Local\Temp\ipykernel_19608\1939963942.py in ?()
     64         capacity.append(capacity[i] - cap_loss)
     65         SoC.append(capacity[i+1] / max_capacity * 100)
     66 
     67         # Search for next voltage
---> 68         index = np.searchsorted(-curve_data.loc[:,'SoC'], -SoC[i+1])
     69         voltage.append(curve_data.loc[curve_data.index[index],␣
 ↪'Voltage'])
     70 
     71         # Increment time

c:\Users\mjmox\anaconda3\envs\FormulaE\Lib\site-packages\pandas\core\generic.py
 ↪in ?(self)
   1542                 # [ExtensionArray, ndarray[Any, Any]]"; expected
   1543                 # "_SupportsNeg[ndarray[Any, dtype[Any]]]"
   1544                 return operator.neg(values)  # type: ignore[arg-type]
   1545 
-> 1546         new_data = self._mgr.apply(blk_func)
   1547         res = self._constructor_from_mgr(new_data, axes=new_data.axes)
   1548         return res.__finalize__(self, method="__neg__")

c:
 ↪\Users\mjmox\anaconda3\envs\FormulaE\Lib\site-packages\pandas\core\internals\managers.
 ↪py in ?(self, f, align_keys, **kwargs)
    357                     # otherwise we have an ndarray
    358                     kwargs[k] = obj[b.mgr_locs.indexer]
    359 
    360             if callable(f):
--> 361                 applied = b.apply(f, **kwargs)
    362             else:
    363                 applied = getattr(b, f)(**kwargs)
    364             result_blocks = extend_blocks(applied, result_blocks)

c:
 ↪\Users\mjmox\anaconda3\envs\FormulaE\Lib\site-packages\pandas\core\internals\blocks.
 ↪py in ?(self, func, **kwargs)
    389         """
    390         apply the function to my values; return a block if we are not
    391         one
```

```
    392         """
--> 393         result = func(self.values, **kwargs)
    394
    395         result = maybe_coerce_values(result)
    396         return self._split_op_result(result)

c:\Users\mjmox\anaconda3\envs\FormulaE\Lib\site-packages\pandas\core\generic.py
 ↪in ?(values)
   1540             else:
   1541                 # error: Argument 1 to "neg" has incompatible type "Union
   1542                 # [ExtensionArray, ndarray[Any, Any]]"; expected
   1543                 # "_SupportsNeg[ndarray[Any, dtype[Any]]]"
-> 1544                 return operator.neg(values)  # type: ignore[arg-type]

KeyboardInterrupt:
```

Retest with 0.2V difference:

[44]:
```
# Simple typical max current calculation:
IC_resistance = 39  # Ohms
Ex_resistance = 15  # Ohms

IC_max_current = 4.2 / 39
Ex_resistance = 4.2 / 15

max_capacity = 2.8 * 5
C_rate = IC_max_current / max_capacity
C_rate

# Parameter combinations
dt = 1     # seconds
secsToHours = 1/3600
min = 3.5
max = 4.2
max_voltage = np.arange(min, max, 0.1)
Vrange = 0.2

# Initialize dictionary to save data
keyList = []
for key in max_voltage:
    keyList.append(str(round(key, 1)))

# Nested Dict
storeDict = {}
for label in keyList:
    storeDict = {**storeDict, label: {"Time": [], "Voltage": [], "Current": [],␣
 ↪"SoC": [], "Capacity": []}}
```

```python
for j in range(0, len(max_voltage)):
    # Loop to analyze multiple parameter combinations:
    print("pass")
    # Clear maxV
    maxV = round(max_voltage[j], 1)

    # Initialize parameters
    time = []
    voltage = []
    capacity = []
    SoC = []
    current = []
    i = 0

    # Search for initial capacity
    index = np.searchsorted(-curve_data.loc[:,'Voltage'], -maxV)
    cap0 = max_capacity * curve_data.loc[curve_data.index[index],'SoC'] / 100

    # Initial parameters
    time.append(dt)
    voltage.append(maxV)
    capacity.append(cap0)
    SoC.append(cap0 / max_capacity * 100)
    thisVMin = maxV

    # Start loop
    while thisVMin > (maxV - Vrange):
        # Determine current:
        current.append(voltage[i] / IC_resistance)

        # Capacity loss (Ah)
        cap_loss = current[i] * dt * secsToHours

        # Next capacity
        capacity.append(capacity[i] - cap_loss)
        SoC.append(capacity[i+1] / max_capacity * 100)

        # Search for next voltage
        index = np.searchsorted(-curve_data.loc[:,'SoC'], -SoC[i+1])
        voltage.append(curve_data.loc[curve_data.index[index], 'Voltage'])

        # Increment time
        time.append(time[i] + dt)

        # Set Min Voltage
        thisVMin = voltage[i+1]
```

```
        # increment variable
        i = i + 1

    # Save data to nicer format
    storeDict[str(maxV)]["Time"] = time
    storeDict[str(maxV)]["Current"] = current
    storeDict[str(maxV)]["Voltage"] = voltage
    storeDict[str(maxV)]["Capacity"] = capacity
    storeDict[str(maxV)]["SoC"] = SoC
# repeat

# Save data to Pickle file
outfile = "balancing_0.2V.pkl"
with open(outfile, "wb") as file:
    pickle.dump(storeDict, file)
```

```
pass
pass
pass
pass
pass
pass
pass
pass
```

Redo the above calculations, but this time with an SoC range instead of a voltage range - still start at an initial voltage, but then control by a set drop in SoC

[45]:
```
# Simple typical max current calculation:
IC_resistance = 39   # Ohms
Ex_resistance = 15   # Ohms

IC_max_current = 4.2 / 39
Ex_resistance = 4.2 / 15

max_capacity = 2.8 * 5
C_rate = IC_max_current / max_capacity

# Parameter combinations
dt = 1     # seconds
secsToHours = 1/3600
min = 3.7
max = 4.2
max_voltage = np.arange(min, max, 0.1)
SoCRange = 20       # %

# Initialize dictionary to save data
```

```python
keyList = []
for key in max_voltage:
    keyList.append(str(round(key, 1)))

# Nested Dict
storeDict = {}
for label in keyList:
    storeDict = {**storeDict, label: {"Time": [], "Voltage": [], "Current": [],␣
↪"SoC": [], "Capacity": []}}

for j in range(0, len(max_voltage)):
    # Loop to analyze multiple parameter combinations:
    print("pass")
    # Clear maxV
    maxV = round(max_voltage[j], 1)

    # Initialize parameters
    time = []
    voltage = []
    capacity = []
    SoC = []
    current = []
    i = 0

    # Search for initial capacity
    index = np.searchsorted(-curve_data.loc[:,'Voltage'], -maxV)
    cap0 = max_capacity * curve_data.loc[curve_data.index[index],'SoC'] / 100

    # Initial parameters
    time.append(dt)
    voltage.append(maxV)
    capacity.append(cap0)
    SoC_initial = cap0 / max_capacity * 100
    SoC.append(SoC_initial)
    deltaSoC = 0

    # Start loop
    while deltaSoC < SoCRange:
        # Determine current:
        current.append(voltage[i] / IC_resistance)

        # Capacity loss (Ah)
        cap_loss = current[i] * dt * secsToHours

        # Next capacity
        capacity.append(capacity[i] - cap_loss)
        SoC.append(capacity[i+1] / max_capacity * 100)
```

```
        # Search for next voltage
        index = np.searchsorted(-curve_data.loc[:,'SoC'], -SoC[i+1])
        if index == 3261:
            print("PAUSE")
        voltage.append(curve_data.loc[curve_data.index[index], 'Voltage'])

        # Increment time
        time.append(time[i] + dt)

        # Set SoC difference
        deltaSoC = abs(SoC_initial - SoC[i+1])

        # increment variable
        i = i + 1

    # Save data to nicer format
    storeDict[str(maxV)]["Time"] = time
    storeDict[str(maxV)]["Current"] = current
    storeDict[str(maxV)]["Voltage"] = voltage
    storeDict[str(maxV)]["Capacity"] = capacity
    storeDict[str(maxV)]["SoC"] = SoC
# repeat

# Save data to Pickle file
outfile = "balancing_20SoC.pkl"
with open(outfile, "wb") as file:
    pickle.dump(storeDict, file)
```

```
pass
pass
pass
pass
pass
```

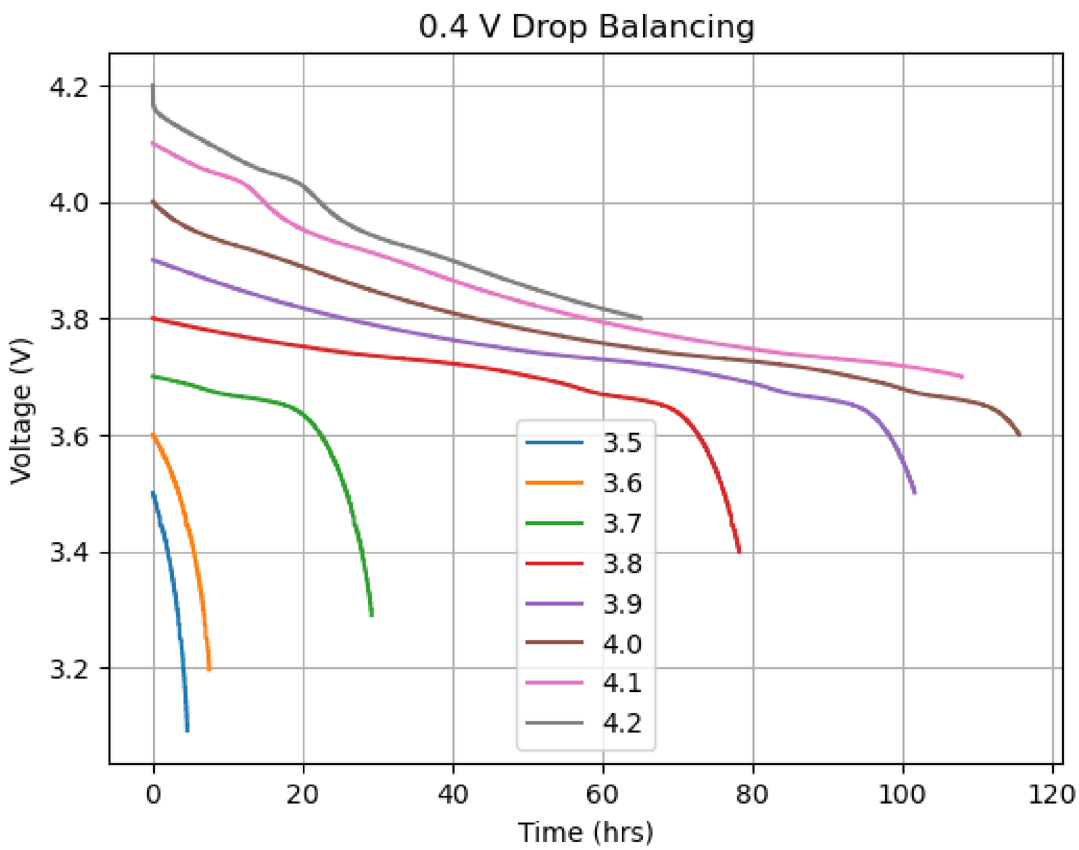
Upload data and analyze it

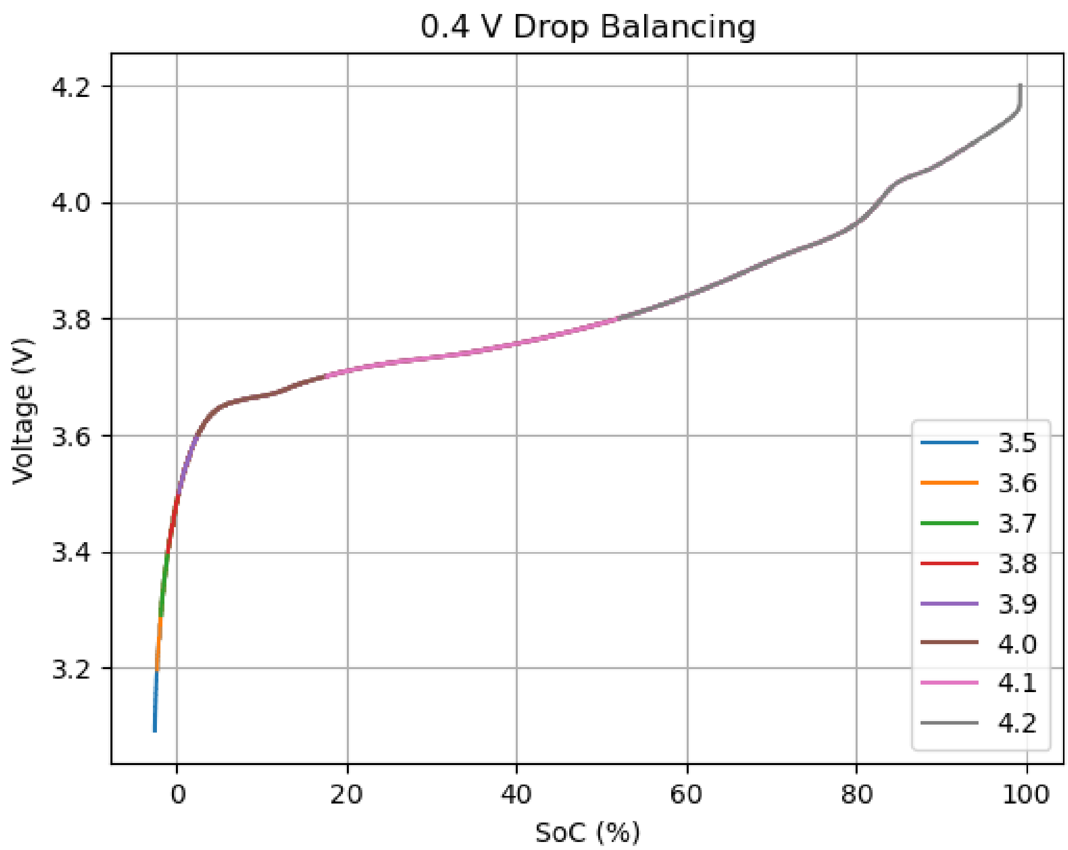
[47]:
```
# Analyze the data
import pickle

infile_04 = "balancing_0.4V.pkl"
infile_02 = "balancing_0.2V.pkl"
infile_20 = "balancing_20SoC.pkl"

with open(infile_04, "rb") as file:
    data04 = pickle.load(file)

with open(infile_02, "rb") as file:
```

```python
    data02 = pickle.load(file)

with open(infile_20, "rb") as file:
    data20 = pickle.load(file)
```

Determine the maximum time required for each balancing cycle

[50]:
```python
import matplotlib.pyplot as plt
import numpy as np

# Plot the time vs voltage for each balancing cycle
keys04 = data04.keys()

# Plot from 0.4 V section
for key in keys04:
    time = np.array(data04[key]["Time"]) / 3600
    voltage = data04[key]["Voltage"]

    plt.plot(time, voltage, label=str(key))

plt.xlabel("Time (hrs)")
plt.ylabel("Voltage (V)")
plt.title("0.4 V Drop Balancing")
plt.grid()
plt.legend()
plt.show()

# Plot from 0.4 V section
for key in keys04:
    voltage = data04[key]["Voltage"]
    SoC = np.array(data04[key]["SoC"])

    plt.plot(SoC, voltage, label=str(key))

plt.xlabel("SoC (%)")
plt.ylabel("Voltage (V)")
plt.title("0.4 V Drop Balancing")
plt.grid()
plt.legend()
plt.show()
```

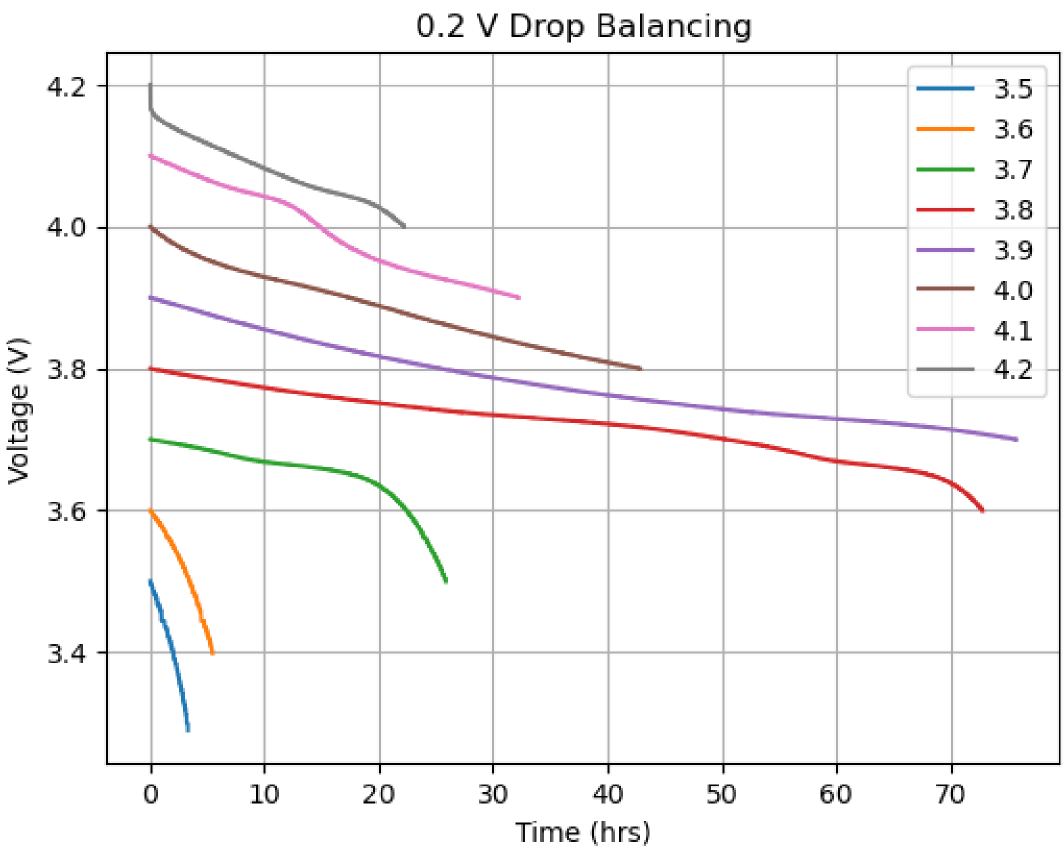

0.4 V Drop Balancing
Voltage (V)
Time (hrs)
4.2
4.0
3.8
3.6
3.4
3.2
0
20
40
60
80
100
120
3.5
3.6
3.7
3.8
3.9
4.0
4.1
4.2

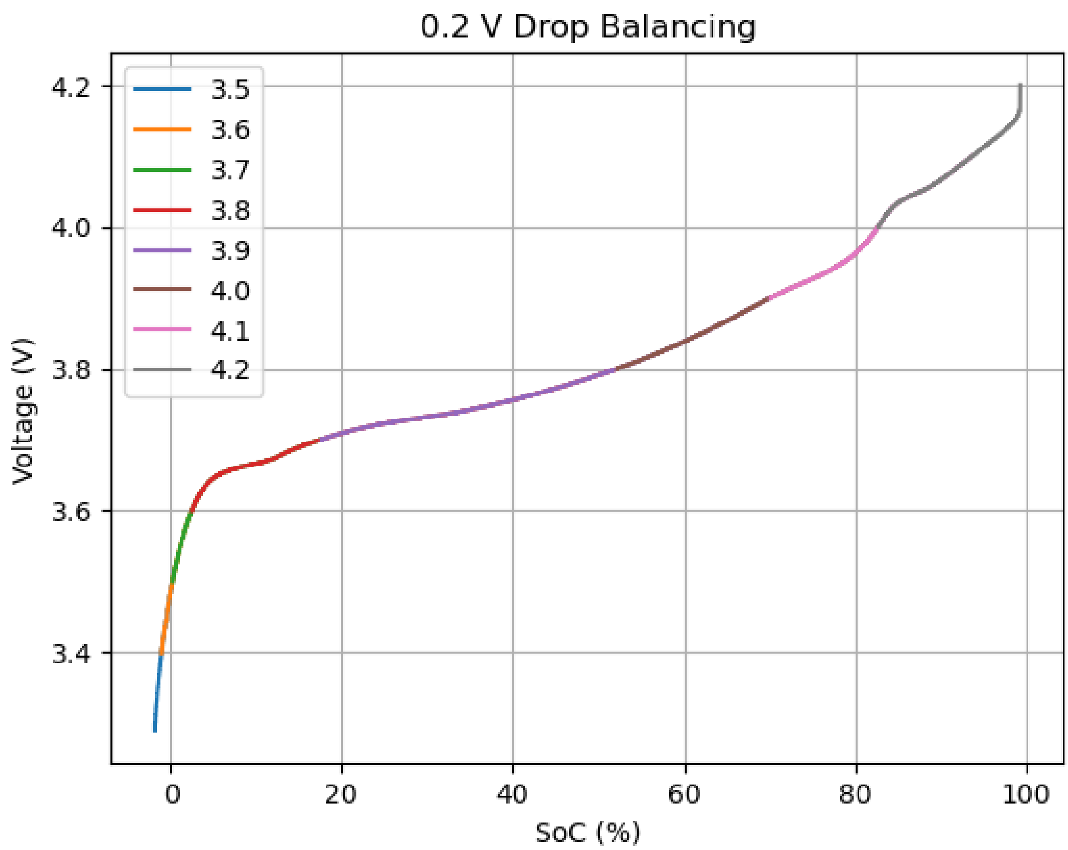


Re-evaluate this with the 0.2 V Drop Instead - Since the drops I calculated don't necessarily represent the change in SoC. Notice that above, the 4.0 option covered the most change in SoC, so it makes sense that it would take the longest. Now I'm wondering whether I should have organized the data in that way instead.

[51]:
```
import matplotlib.pyplot as plt
import numpy as np

# Plot the time vs voltage for each balancing cycle
keys02 = data02.keys()

# Plot from 0.2 V section
for key in keys02:
    time = np.array(data02[key]["Time"]) / 3600
    voltage = data02[key]["Voltage"]

    plt.plot(time, voltage, label=str(key))

plt.xlabel("Time (hrs)")
plt.ylabel("Voltage (V)")
```

```python
plt.title("0.2 V Drop Balancing")
plt.grid()
plt.legend()
plt.show()

# Plot from 0.2 V section
for key in keys02:
    voltage = data02[key]["Voltage"]
    SoC = np.array(data02[key]["SoC"])

    plt.plot(SoC, voltage, label=str(key))

plt.xlabel("SoC (%)")
plt.ylabel("Voltage (V)")
plt.title("0.2 V Drop Balancing")
plt.grid()
plt.legend()
plt.show()
```





Checking with 15 Ohm Resistance

Checking for Sumrath with two different values: * 10 Ohm * 22 Ohm

[6]:
```
def balance(Ex_resistance):
    import numpy as np
    import pickle
    import pandas as pd
    import matplotlib.pyplot as plt

    # Simple typical max current calculation:

    # Upload data from Molicel
    curve_data = pd.read_csv("Discharge_0.5C.csv")

    curve_data.loc[:,'SoC'] / 100 * 2.8 * 5

    max_capacity = 2.8 * 5

    # Parameter combinations
    dt = 1     # seconds
```

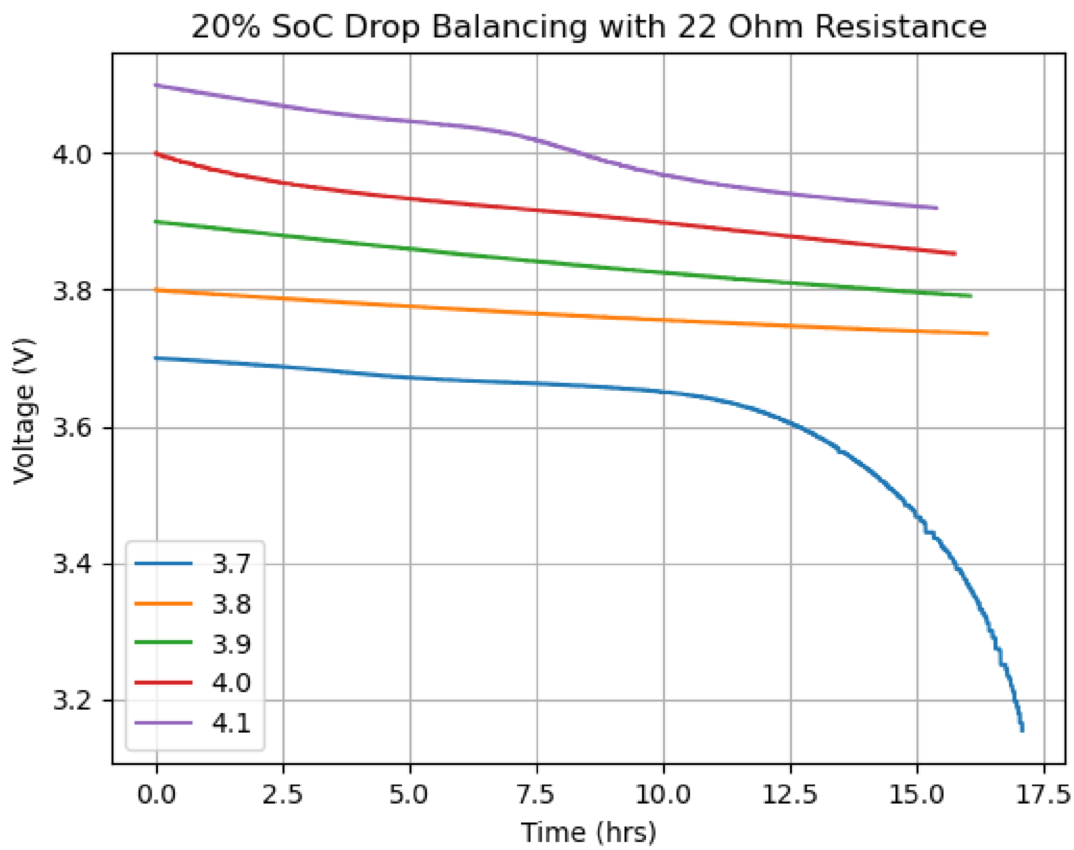
```
secsToHours = 1/3600
min = 3.7
max = 4.2
max_voltage = np.arange(min, max, 0.1)
SoCRange = 20       # %

# Initialize dictionary to save data
keyList = []
for key in max_voltage:
    keyList.append(str(round(key, 1)))

# Nested Dict
storeDict = {}
for label in keyList:
    storeDict = {**storeDict, label: {"Time": [], "Voltage": [], "Current":␣
↪[], "SoC": [], "Capacity": []}}

for j in range(0, len(max_voltage)):
    # Loop to analyze multiple parameter combinations:
    print("pass")
    # Clear maxV
    maxV = round(max_voltage[j], 1)

    # Initialize parameters
    time = []
    voltage = []
    capacity = []
    SoC = []
    current = []
    i = 0

    # Search for initial capacity
    index = np.searchsorted(-curve_data.loc[:,'Voltage'], -maxV)
    cap0 = max_capacity * curve_data.loc[curve_data.index[index],'SoC'] /␣
↪100

    # Initial parameters
    time.append(dt)
    voltage.append(maxV)
    capacity.append(cap0)
    SoC_initial = cap0 / max_capacity * 100
    SoC.append(SoC_initial)
    deltaSoC = 0

    # Start loop
    while deltaSoC < SoCRange:
        # Determine current:
```

```python
            current.append(voltage[i] / Ex_resistance)

            # Capacity loss (Ah)
            cap_loss = current[i] * dt * secsToHours

            # Next capacity
            capacity.append(capacity[i] - cap_loss)
            SoC.append(capacity[i+1] / max_capacity * 100)

            # Search for next voltage
            index = np.searchsorted(-curve_data.loc[:,'SoC'], -SoC[i+1])
            if index == 3261:
                print("PAUSE")
            voltage.append(curve_data.loc[curve_data.index[index], 'Voltage'])

            # Increment time
            time.append(time[i] + dt)

            # Set SoC difference
            deltaSoC = abs(SoC_initial - SoC[i+1])

            # increment variable
            i = i + 1

        # Save data to nicer format
        storeDict[str(maxV)]["Time"] = time
        storeDict[str(maxV)]["Current"] = current
        storeDict[str(maxV)]["Voltage"] = voltage
        storeDict[str(maxV)]["Capacity"] = capacity
        storeDict[str(maxV)]["SoC"] = SoC
    # repeat

    # Save data to Pickle file
    outfile = "balancing_20SoC_Ex.pkl"
    with open(outfile, "wb") as file:
        pickle.dump(storeDict, file)

def plot_balance(Ex_resistance):
    infile_20_Ex = "balancing_20SoC_Ex.pkl"

    with open(infile_20_Ex, "rb") as file:
        data20Ex = pickle.load(file)

    # Plot the time vs voltage for each balancing cycle
    keys20Ex = data20Ex.keys()

    # Plot from 0.2 V section
```

```
    for key in keys20Ex:
        time = np.array(data20Ex[key]["Time"]) / 3600
        voltage = data20Ex[key]["Voltage"]

        plt.plot(time, voltage, label=str(key))

    plt.xlabel("Time (hrs)")
    plt.ylabel("Voltage (V)")
    plt.title(("20% SoC Drop Balancing with " + str(Ex_resistance) + " Ohm␣
 ↪Resistance"))
    plt.grid()
    plt.legend()
    plt.savefig(("20%_SoC_Balancing_" + str(Ex_resistance) + "Ohm.png"))
    plt.show()
```

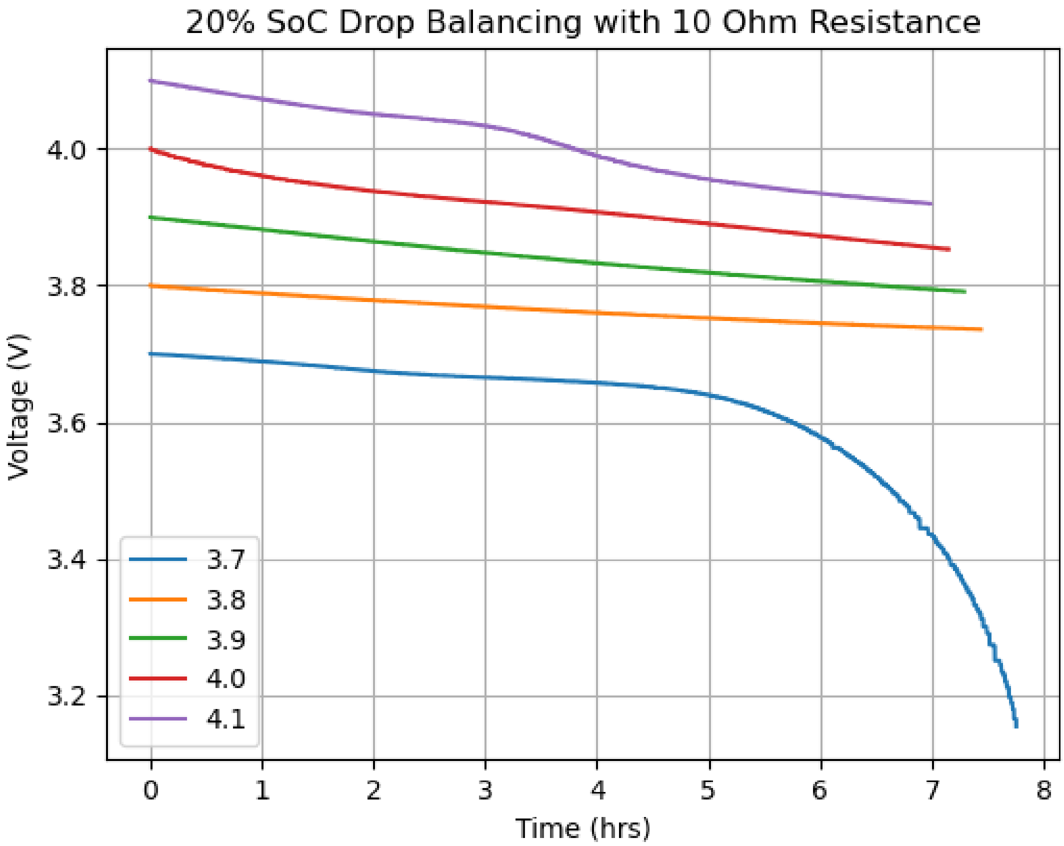
[7]:
```
balance(22)     # run the balancing code with 22 Ohm resistance

plot_balance(22)
```

```
pass
pass
pass
pass
pass
```



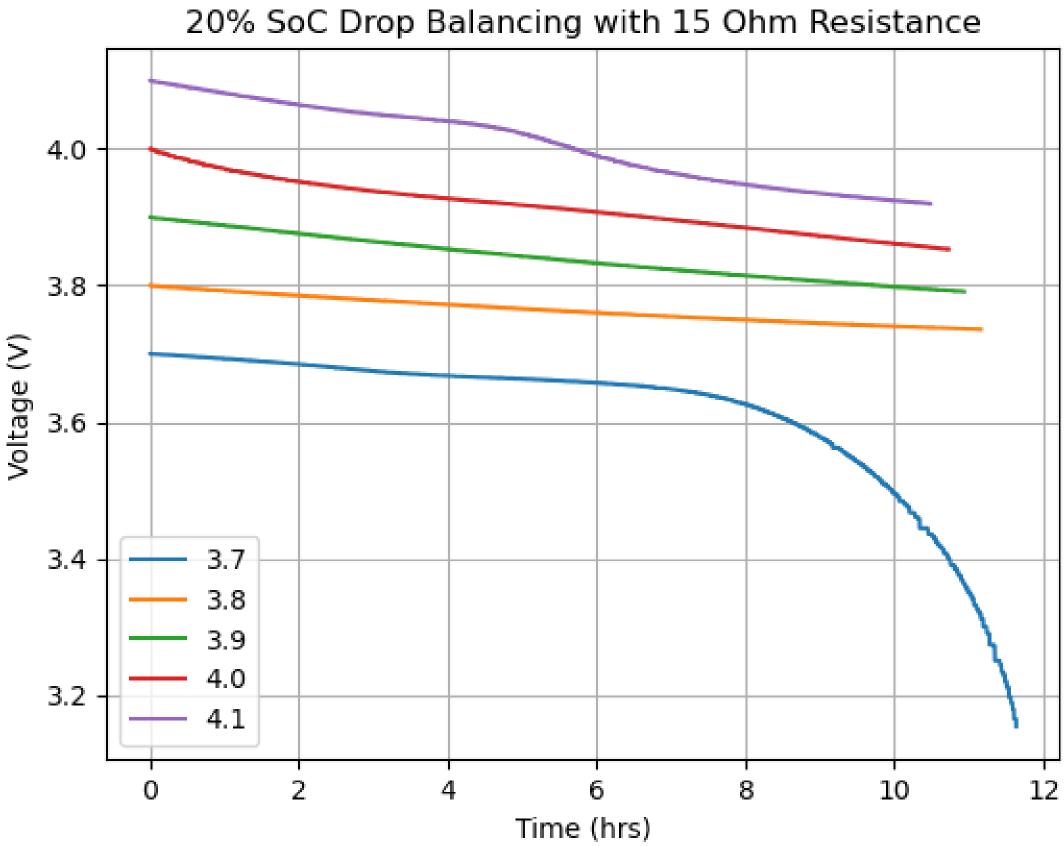

```
[8]: balance(10)          # run the balancing code with 10 Ohm resistance

     plot_balance(10)
```

```
pass
pass
pass
pass
pass
```



[9]:
```
balance(15)

plot_balance(15)
```

```
pass
pass
pass
pass
pass
```


20% SoC Drop Balancing with 15 Ohm Resistance
Voltage (V)
Time (hrs)
3.7
3.8
3.9
4.0
4.1