machine_learning_1

March 29, 2020

1 Machine Learning using datasets in Group A

Data reflective of those of rail operations. LDPRF 2097 is used for training while LDPRF 2098 is used for testing. Systematic reduction of datasets in 10% increments

1.0.1 Import necessary libraries

[1]:
```
import numpy as np
import pandas as pd
import copy
import tensorflow as tf
from tensorflow import keras
from tensorflow.keras import layers

# import codebase
import thermalModel_main as tmm
import thermalModel_groupB as tm_gb

import importlib
importlib.reload(tmm)
importlib.reload(tm_gb)
```

```
Using TensorFlow backend.
```

[1]:
```
<module 'thermalModel_groupB' from
'C:\\Users\\user\\Anaconda3\\lib\\thermalModel_groupB.py'>
```

1.1 ANN Ah Model

1.1.1 Data loading and cleaning

[2]:
```
df = tm_gb.load_csv(filename = 'LDPRF_2097.csv',
#                     data_list = ['Program time','AhCha','AhDch','Temp'],
                    features_list = ['runtime_s','AhCha','AhDch','Amb','Temp'],
                    mode = 0)
```

```
df1 = tm_gb.load_csv(filename = 'LDPRF_2098.csv',
#                       data_list = ['Program time','AhCha','AhDch','Temp'],
                      features_list = ['runtime_s','AhCha','AhDch','Amb','Temp'],
                      mode = 0)
```

```
C:\Users\user\Anaconda3\lib\thermalModel_groupB.py:47: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: http://pandas.pydata.org/pandas-
docs/stable/indexing.html#indexing-view-versus-copy
  df['second'][set_index[index]:set_index[index+1]] =
df['second'][set_index[index]:set_index[index+1]] + second_increment[index]
C:\Users\user\Anaconda3\lib\thermalModel_groupB.py:49: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: http://pandas.pydata.org/pandas-
docs/stable/indexing.html#indexing-view-versus-copy
  df['second'][set_index[index]:] = df['second'][set_index[index]:] +
second_increment[index]
C:\Users\user\Anaconda3\lib\thermalModel_groupB.py:56: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: http://pandas.pydata.org/pandas-
docs/stable/indexing.html#indexing-view-versus-copy
  df['second'][set_index[index]:] = df['second'][set_index[index]:] +
seconds_summation[index]
```

[3]:
```
ANN_Ah_models_2097 = {}
ANN_Ah_me_2097 = {}

sections_list = [round(i, 2) for i in np.linspace(start = 0.9, stop = 0.1, num␣
 ↪= 9, endpoint = True)]
num_rows = df.shape[0]

for i in range(len(sections_list)):
    boundary = int(num_rows * sections_list[i])
    reduced_df = df[:boundary].copy(deep=True)

    reduced_df.drop(columns = ['runtime_s'], inplace = True)
    try:
        df1.drop(columns = ['runtime_s'], inplace = True)
    except:
        pass

    print(reduced_df.describe())
    print(df1.describe())
```

```
   Ah_models_2097, Ah_me_2097 = tmm.loop_run_instances(identifier = "ANN" +␣
↪'_' + str(sections_list[i]),
                                                       loop_name =␣
↪"Ah_model",
                                                       num_layers = 1,
                                                       train_dataframe =␣
↪reduced_df,
                                                       test_dataframe = df1,
                                                       num_inputs = 3,
                                                       start_window_size =␣
↪1,
                                                       end_window_size = 1,
                                                       window_size_step = 1,
                                                       test_size = 0,
                                                       num_epochs = 1000)

   ANN_Ah_models_2097["ANN" + '_' + str(sections_list[i])] = Ah_models_2097
   ANN_Ah_me_2097["ANN" + '_' + str(sections_list[i])] = copy.
↪deepcopy(Ah_me_2097)
```

```
              AhCha          AhDch           Amb           Temp
count  392255.000000  392255.000000  3.922550e+05  392255.000000
mean      113.702847     131.687044  2.579465e+01      34.137644
std        65.565231      67.188310  2.212207e-10       2.093237
min         0.000000       0.000000  2.579465e+01      25.794650
25%        57.448000      73.137500  2.579465e+01      32.352610
50%       113.693000     130.609000  2.579465e+01      34.975800
75%       170.261000     190.321000  2.579465e+01      35.740890
max       228.876000     248.523000  2.579465e+01      36.615290
              AhCha          AhDch           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00015: early stopping
Time to train model: 212.21359968185425 seconds
              AhCha          AhDch           Amb           Temp
count  348671.000000  348671.000000  3.486710e+05  348671.000000
mean      101.045414     118.726430  2.579465e+01      33.929579
std        58.195447      59.653824  1.974637e-10       2.121352
min         0.000000       0.000000  2.579465e+01      25.794650
```

```
25%        50.315500      65.808000  2.579465e+01      31.915410
50%       101.217000     117.995000  2.579465e+01      34.757200
75%       152.429000     170.382000  2.579465e+01      35.631590
max       203.865000     223.020000  2.579465e+01      36.615290
               AhCha          AhDch           Amb          Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00331: early stopping
Time to train model: 3876.7292017936707 seconds
               AhCha          AhDch           Amb          Temp
count  305087.000000  305087.000000  3.050870e+05  305087.000000
mean       88.409023     105.782708  2.579465e+01      33.661466
std        50.845185      52.134872  1.669210e-10       2.129966
min         0.000000       0.000000  2.579465e+01      25.794650
25%        45.228000      60.406000  2.579465e+01      31.806110
50%        89.035000     107.177000  2.579465e+01      34.429300
75%       133.105000     152.285000  2.579465e+01      35.412990
max       177.354000     197.575000  2.579465e+01      36.505990
               AhCha          AhDch           Amb          Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00045: early stopping
Time to train model: 442.98811435699463 seconds
               AhCha          AhDch           Amb          Temp
count  261503.000000  261503.000000  2.615030e+05  261503.000000
mean       75.791567      92.857192  2.579465e+01      33.314920
std        43.510339      44.635610  1.261962e-10       2.099121
min         0.000000       0.000000  2.579465e+01      25.794650
25%        38.245000      55.024000  2.579465e+01      31.696820
50%        74.972000      92.787000  2.579465e+01      33.882800
75%       113.693000     130.609000  2.579465e+01      35.085100
max       152.429000     170.382000  2.579465e+01      36.287390
```

```
                AhCha           AhDch            Amb            Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00020: early stopping
Time to train model: 198.97020721435547 seconds
                AhCha           AhDch            Amb            Temp
count  217919.000000  217919.000000  2.179190e+05  217919.000000
mean       63.199796      79.950900  2.579465e+01      32.872735
std        36.202967      37.160824  6.917860e-11       2.018040
min         0.000000       0.000000  2.579465e+01      25.794650
25%        31.270000      47.854000  2.579465e+01      31.478220
50%        64.452000      81.299000  2.579465e+01      33.008410
75%        93.466000     110.787000  2.579465e+01      34.757200
max       126.039000     145.061000  2.579465e+01      35.850190
                AhCha           AhDch            Amb            Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00303: early stopping
Time to train model: 2442.8782608509064 seconds
                AhCha           AhDch            Amb            Temp
count  174335.000000  174335.000000  1.743350e+05  174335.000000
mean       50.631069      67.060033  2.579465e+01      32.297380
std        28.920562      29.708943  1.634608e-11       1.839602
min         0.000000       0.000000  2.579465e+01      25.794650
25%        24.306000      40.684000  2.579465e+01      31.150320
50%        50.315000      65.808000  2.579465e+01      31.915410
75%        74.972000      92.787000  2.579465e+01      33.882800
max       101.216000     117.995000  2.579465e+01      35.303690
                AhCha           AhDch            Amb            Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
```

```
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Time to train model: 6621.616890668869 seconds
               AhCha          AhDch           Amb           Temp
count  130751.000000  130751.000000  1.307510e+05  130751.000000
mean       38.097767      54.184753  2.579465e+01      31.534202
std        21.692845      22.290556  4.544649e-11       1.455033
min         0.000000       0.000000  2.579465e+01      25.794650
25%        20.825000      37.092000  2.579465e+01      30.931720
50%        38.245000      55.024000  2.579465e+01      31.696820
75%        57.448000      73.136000  2.579465e+01      32.352610
max        74.972000      92.787000  2.579465e+01      34.101400
               AhCha          AhDch           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00092: early stopping
Time to train model: 399.1638240814209 seconds
              AhCha         AhDch           Amb          Temp
count  87167.000000  87167.000000  8.716700e+04  87167.000000
mean      25.596328     41.319628  2.579465e+01     30.869706
std       14.548537     14.921958  4.097368e-11      1.236341
min        0.000000      0.000000  2.579465e+01     25.794650
25%       13.864000     29.212000  2.579465e+01     30.494520
50%       24.306000     40.684000  2.579465e+01     31.259620
75%       38.245000     55.024000  2.579465e+01     31.696820
max       50.314000     65.808000  2.579465e+01     32.134010
               AhCha          AhDch           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
```

```
Restoring model weights from the end of the best epoch
Epoch 00229: early stopping
Time to train model: 652.3643748760223 seconds
```

	AhCha	AhDch	Amb	Temp
count	43583.000000	43583.000000	4.358300e+04	43583.000000
mean	13.134120	28.477074	2.579465e+01	30.348772
std	7.658945	7.765900	2.755872e-11	1.501125
min	0.000000	0.000000	2.579465e+01	25.794650
25%	6.916000	21.094500	2.579465e+01	29.729430
50%	13.864000	29.211000	2.579465e+01	30.822420
75%	20.825000	37.092000	2.579465e+01	31.478220
max	24.306000	40.684000	2.579465e+01	32.134010

	AhCha	AhDch	Amb	Temp
count	435839.000000	435839.000000	4.358390e+05	435839.000000
mean	126.437695	143.968215	2.626750e+01	34.934164
std	72.927347	74.268447	6.600594e-11	1.938317
min	0.000000	0.000000	2.626750e+01	26.267500
25%	64.531000	80.996500	2.626750e+01	33.803260
50%	126.152000	144.421000	2.626750e+01	35.741030
75%	188.089000	207.443000	2.626750e+01	36.386950
max	252.044000	270.765000	2.626750e+01	37.032870

```
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00036: early stopping
Time to train model: 52.4007830619812 seconds
```

[4]:
```
importlib.reload(tmm)
importlib.reload(tm_gb)
ANN_Ah_models_2097_df = tm_gb.extract_complexity(nested_model_dictionary =␣
 ↪ANN_Ah_models_2097,
                                                  nested_errors_dictionary =␣
 ↪ANN_Ah_me_2097)
```

[5]:
```
ANN_Ah_models_2097_df
```

[5]:

	Percentage_reduced	NN_size	mean_error
0	10	16	0.036776
1	20	16	0.088432
2	30	16	-0.577850
3	40	16	-0.757336
4	50	16	0.481733
5	60	16	-1.755333
6	70	16	-9.130228
7	80	16	3.022391
8	90	16	-2.007231

1.2 ANN IV Model

1.2.1 Data loading and cleaning

[6]:
```
df = tm_gb.load_csv(filename = 'LDPRF_2097.csv',
#                     data_list = ['Program time','AhCha','AhDch','Temp'],
                    features_list =␣
 ↪['runtime_s','Current','Voltage','Amb','Temp'],
                    mode = 1)

df1 = tm_gb.load_csv(filename = 'LDPRF_2098.csv',
#                     data_list = ['Program time','AhCha','AhDch','Temp'],
                     features_list =␣
 ↪['runtime_s','Current','Voltage','Amb','Temp'],
                     mode = 1)
```

[7]:
```
ANN_IV_models_2097 = {}
ANN_IV_me_2097 = {}

sections_list = [round(i, 2) for i in np.linspace(start = 0.9, stop = 0.1, num␣
 ↪= 9, endpoint = True)]
num_rows = df.shape[0]

for i in range(len(sections_list)):
    boundary = int(num_rows * sections_list[i])
    reduced_df = df[:boundary].copy(deep=True)

    reduced_df.drop(columns = ['runtime_s'], inplace = True)
    try:
        df1.drop(columns = ['runtime_s'], inplace = True)
    except:
        pass

    print(reduced_df.describe())
    print(df1.describe())

    IV_models_2097, IV_me_2097 = tmm.loop_run_instances(identifier = "ANN" +␣
 ↪'_' + str(sections_list[i]),
                                                        loop_name =␣
 ↪"IV_model",
                                                        num_layers = 1,
                                                        train_dataframe =␣
 ↪reduced_df,
                                                        test_dataframe = df1,
                                                        num_inputs = 3,
                                                        start_window_size =␣
 ↪1,
                                                        end_window_size = 1,
```

```
                                                        window_size_step = 1,
                                                        test_size = 0,
                                                        num_epochs = 1000)

    ANN_IV_models_2097["ANN" + '_' + str(sections_list[i])] = IV_models_2097
    ANN_IV_me_2097["ANN" + '_' + str(sections_list[i])] = copy.
↪deepcopy(IV_me_2097)
```

```
             Current        Voltage           Amb           Temp
count  392255.000000  392255.000000  3.922550e+05  392255.000000
mean       -0.604674       3.779421  2.579465e+01      34.137644
std        86.197685       0.091355  2.212207e-10       2.093237
min      -177.304100       3.543280  2.579465e+01      25.794650
25%         0.009580       3.736000  2.579465e+01      32.352610
50%         0.009580       3.771040  2.579465e+01      34.975800
75%         0.019150       3.810510  2.579465e+01      35.740890
max       222.608110       4.160100  2.579465e+01      36.615290
             Current        Voltage           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00217: early stopping
Time to train model: 2927.498827934265 seconds
             Current        Voltage           Amb           Temp
count  348671.000000  348671.000000  3.486710e+05  348671.000000
mean       -0.624317       3.783654  2.579465e+01      33.929579
std        86.262130       0.091306  1.974637e-10       2.121352
min      -176.853920       3.552340  2.579465e+01      25.794650
25%         0.009580       3.741840  2.579465e+01      31.915410
50%         0.009580       3.775060  2.579465e+01      34.757200
75%         0.019150       3.816350  2.579465e+01      35.631590
max       222.608110       4.160100  2.579465e+01      36.615290
             Current        Voltage           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
```

```
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00066: early stopping
Time to train model: 813.8303060531616 seconds
             Current        Voltage           Amb           Temp
count  305087.000000  305087.000000  3.050870e+05  305087.000000
mean       -0.851556       3.787880  2.579465e+01      33.661466
std        86.132321       0.091286  1.669210e-10       2.129966
min      -176.442050       3.560390  2.579465e+01      25.794650
25%         0.009580       3.748280  2.579465e+01      31.806110
50%         0.009580       3.779290  2.579465e+01      34.429300
75%         0.019150       3.821480  2.579465e+01      35.412990
max       222.474030       4.160100  2.579465e+01      36.505990
             Current        Voltage           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00246: early stopping
Time to train model: 2640.64737033844 seconds
             Current        Voltage           Amb           Temp
count  261503.000000  261503.000000  2.615030e+05  261503.000000
mean       -0.650107       3.792625  2.579465e+01      33.314920
std        86.047824       0.091401  1.261962e-10       2.099121
min      -176.375000       3.562210  2.579465e+01      25.794650
25%         0.009580       3.755130  2.579465e+01      31.696820
50%         0.009580       3.782720  2.579465e+01      33.882800
75%         0.019150       3.827620  2.579465e+01      35.085100
max       221.391780       4.160100  2.579465e+01      36.287390
             Current        Voltage           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00107: early stopping
```

```
Time to train model: 987.0084373950958 seconds
             Current        Voltage            Amb           Temp
count  217919.000000  217919.000000  2.179190e+05  217919.000000
mean       -0.973715       3.797023  2.579465e+01      32.872735
std        85.900076       0.091887  6.917860e-11       2.018040
min      -176.375000       3.562210  2.579465e+01      25.794650
25%         0.009580       3.761980  2.579465e+01      31.478220
50%         0.009580       3.786340  2.579465e+01      33.008410
75%         0.019150       3.829030  2.579465e+01      34.757200
max       221.391780       4.160100  2.579465e+01      35.850190
             Current        Voltage            Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00042: early stopping
Time to train model: 310.9139573574066 seconds
             Current        Voltage            Amb           Temp
count  174335.000000  174335.000000  1.743350e+05  174335.000000
mean       -0.707373       3.802184  2.579465e+01      32.297380
std        85.814511       0.092661  1.634608e-11       1.839602
min      -176.375000       3.562210  2.579465e+01      25.794650
25%         0.009580       3.769220  2.579465e+01      31.150320
50%         0.009580       3.791180  2.579465e+01      31.915410
75%         0.019150       3.838500  2.579465e+01      33.882800
max       220.932060       4.160100  2.579465e+01      35.303690
             Current        Voltage            Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00295: early stopping
Time to train model: 1740.5563218593597 seconds
             Current        Voltage            Amb           Temp
count  130751.000000  130751.000000  1.307510e+05  130751.000000
mean       -1.256612       3.806869  2.579465e+01      31.534202
```

```
std        85.629164       0.094039  4.544649e-11       1.455033
min      -176.375000       3.562210  2.579465e+01      25.794650
25%         0.009580       3.775870  2.579465e+01      30.931720
50%         0.009580       3.795000  2.579465e+01      31.696820
75%         0.009580       3.838900  2.579465e+01      32.352610
max       219.878550       4.160100  2.579465e+01      34.101400
             Current        Voltage           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00006: early stopping
Time to train model: 26.20138168334961 seconds
            Current       Voltage           Amb           Temp
count  87167.000000  87167.000000  8.716700e+04  87167.000000
mean      -0.828209      3.812962  2.579465e+01     30.869706
std       85.550621      0.095139  4.097368e-11      1.236341
min     -176.375000      3.562210  2.579465e+01     25.794650
25%        0.009580      3.783520  2.579465e+01     30.494520
50%        0.009580      3.798830  2.579465e+01     31.259620
75%        0.009580      3.839300  2.579465e+01     31.696820
max      219.294320      4.160100  2.579465e+01     32.134010
             Current        Voltage           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00121: early stopping
Time to train model: 374.0686926841736 seconds
            Current       Voltage           Amb           Temp
count  43583.000000  43583.000000  4.358300e+04  43583.000000
mean      -2.458174      3.816734  2.579465e+01     30.348772
std       85.260487      0.096784  2.755872e-11      1.501125
min     -176.375000      3.562210  2.579465e+01     25.794650
25%        0.009580      3.788150  2.579465e+01     29.729430
50%        0.009580      3.803660  2.579465e+01     30.822420
```

```
75%         0.009580      3.840310  2.579465e+01     31.478220
max       219.294320      4.160100  2.579465e+01     32.134010
              Current        Voltage           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00015: early stopping
Time to train model: 22.986265897750854 seconds
```

1.3 ANN Hybrid Model

1.3.1 Data loading and cleaning

[8]:
```
df = tm_gb.load_csv(filename = 'LDPRF_2097.csv',
#                     data_list = ['Program␣
 ↪time','Current','Voltage','AhCha','AhDch','Temp'],
                    features_list =␣
 ↪['runtime_s','Current','Voltage','AhCha','AhDch','Amb','Temp'],
                    mode = 2)

df1 = tm_gb.load_csv(filename = 'LDPRF_2098.csv',
#                     data_list = ['Program␣
 ↪time','Current','Voltage','AhCha','AhDch','Temp'],
                    features_list =␣
 ↪['runtime_s','Current','Voltage','AhCha','AhDch','Amb','Temp'],
                    mode = 2)
```

[9]:
```
ANN_hybrid_models_2097 = {}
ANN_hybrid_me_2097 = {}

sections_list = [round(i, 2) for i in np.linspace(start = 0.9, stop = 0.1, num␣
 ↪= 9, endpoint = True)]
num_rows = df.shape[0]

for i in range(len(sections_list)):
    boundary = int(num_rows * sections_list[i])
    reduced_df = df[:boundary].copy(deep=True)

    reduced_df.drop(columns = ['runtime_s'], inplace = True)
    try:
        df1.drop(columns = ['runtime_s'], inplace = True)
```

```
    except:
        pass

    print(reduced_df.describe())
    print(df1.describe())

    hybrid_models_2097, hybrid_me_2097 = tmm.loop_run_instances(identifier =␣
↪"ANN" + '_' + str(sections_list[i]),
                                                                loop_name =␣
↪"hybrid_model",
                                                                num_layers =␣
↪1,
                                                               ␣
↪train_dataframe = reduced_df,
                                                               ␣
↪test_dataframe = df1,
                                                                num_inputs =␣
↪5,
                                                               ␣
↪start_window_size = 1,
                                                               ␣
↪end_window_size = 1,
                                                               ␣
↪window_size_step = 1,
                                                                test_size =␣
↪0,
                                                                num_epochs =␣
↪1000)

    ANN_hybrid_models_2097["ANN" + '_' + str(sections_list[i])] =␣
↪hybrid_models_2097
    ANN_hybrid_me_2097["ANN" + '_' + str(sections_list[i])] = copy.
↪deepcopy(hybrid_me_2097)
```

```
             Current        Voltage          AhCha          AhDch  \
count  392255.000000  392255.000000  392255.000000  392255.000000
mean       -0.604674       3.779421     113.702847     131.687044
std        86.197685       0.091355      65.565231      67.188310
min      -177.304100       3.543280       0.000000       0.000000
25%         0.009580       3.736000      57.448000      73.137500
50%         0.009580       3.771040     113.693000     130.609000
75%         0.019150       3.810510     170.261000     190.321000
max       222.608110       4.160100     228.876000     248.523000

                Amb           Temp
count  3.922550e+05  392255.000000
```

```
mean   2.579465e+01      34.137644
std    2.212207e-10       2.093237
min    2.579465e+01      25.794650
25%    2.579465e+01      32.352610
50%    2.579465e+01      34.975800
75%    2.579465e+01      35.740890
max    2.579465e+01      36.615290
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00051: early stopping
Time to train model: 696.8630373477936 seconds
             Current        Voltage          AhCha          AhDch  \
count  348671.000000  348671.000000  348671.000000  348671.000000
mean       -0.624317       3.783654     101.045414     118.726430
std        86.262130       0.091306      58.195447      59.653824
min      -176.853920       3.552340       0.000000       0.000000
25%         0.009580       3.741840      50.315500      65.808000
50%         0.009580       3.775060     101.217000     117.995000
75%         0.019150       3.816350     152.429000     170.382000
max       222.608110       4.160100     203.865000     223.020000

                Amb           Temp
count  3.486710e+05  348671.000000
mean   2.579465e+01      33.929579
std    1.974637e-10       2.121352
min    2.579465e+01      25.794650
25%    2.579465e+01      31.915410
50%    2.579465e+01      34.757200
75%    2.579465e+01      35.631590
```

```
max    2.579465e+01      36.615290
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00009: early stopping
Time to train model: 104.92103576660156 seconds
             Current        Voltage          AhCha          AhDch  \
count  305087.000000  305087.000000  305087.000000  305087.000000
mean       -0.851556       3.787880      88.409023     105.782708
std        86.132321       0.091286      50.845185      52.134872
min      -176.442050       3.560390       0.000000       0.000000
25%         0.009580       3.748280      45.228000      60.406000
50%         0.009580       3.779290      89.035000     107.177000
75%         0.019150       3.821480     133.105000     152.285000
max       222.474030       4.160100     177.354000     197.575000

                Amb           Temp
count  3.050870e+05  305087.000000
mean   2.579465e+01      33.661466
std    1.669210e-10       2.129966
min    2.579465e+01      25.794650
25%    2.579465e+01      31.806110
50%    2.579465e+01      34.429300
75%    2.579465e+01      35.412990
max    2.579465e+01      36.505990
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
```

```
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00081: early stopping
Time to train model: 818.1604588031769 seconds
             Current        Voltage          AhCha          AhDch  \
count  261503.000000  261503.000000  261503.000000  261503.000000
mean       -0.650107       3.792625      75.791567      92.857192
std        86.047824       0.091401      43.510339      44.635610
min      -176.375000       3.562210       0.000000       0.000000
25%         0.009580       3.755130      38.245000      55.024000
50%         0.009580       3.782720      74.972000      92.787000
75%         0.019150       3.827620     113.693000     130.609000
max       221.391780       4.160100     152.429000     170.382000

                Amb           Temp
count  2.615030e+05  261503.000000
mean   2.579465e+01      33.314920
std    1.261962e-10       2.099121
min    2.579465e+01      25.794650
25%    2.579465e+01      31.696820
50%    2.579465e+01      33.882800
75%    2.579465e+01      35.085100
max    2.579465e+01      36.287390
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
```

```
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00018: early stopping
Time to train model: 174.4618525505066 seconds
             Current        Voltage          AhCha          AhDch  \
count  217919.000000  217919.000000  217919.000000  217919.000000
mean       -0.973715       3.797023      63.199796      79.950900
std        85.900076       0.091887      36.202967      37.160824
min      -176.375000       3.562210       0.000000       0.000000
25%         0.009580       3.761980      31.270000      47.854000
50%         0.009580       3.786340      64.452000      81.299000
75%         0.019150       3.829030      93.466000     110.787000
max       221.391780       4.160100     126.039000     145.061000

                Amb           Temp
count  2.179190e+05  217919.000000
mean   2.579465e+01      32.872735
std    6.917860e-11       2.018040
min    2.579465e+01      25.794650
25%    2.579465e+01      31.478220
50%    2.579465e+01      33.008410
75%    2.579465e+01      34.757200
max    2.579465e+01      35.850190
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
```

```
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00037: early stopping
Time to train model: 291.59030318260193 seconds
             Current        Voltage          AhCha          AhDch  \
count  174335.000000  174335.000000  174335.000000  174335.000000
mean       -0.707373       3.802184      50.631069      67.060033
std        85.814511       0.092661      28.920562      29.708943
min      -176.375000       3.562210       0.000000       0.000000
25%         0.009580       3.769220      24.306000      40.684000
50%         0.009580       3.791180      50.315000      65.808000
75%         0.019150       3.838500      74.972000      92.787000
max       220.932060       4.160100     101.216000     117.995000

                Amb           Temp
count  1.743350e+05  174335.000000
mean   2.579465e+01      32.297380
std    1.634608e-11       1.839602
min    2.579465e+01      25.794650
25%    2.579465e+01      31.150320
50%    2.579465e+01      31.915410
75%    2.579465e+01      33.882800
max    2.579465e+01      35.303690
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00053: early stopping
Time to train model: 324.4124550819397 seconds
```

```
             Current        Voltage          AhCha          AhDch  \
count  130751.000000  130751.000000  130751.000000  130751.000000
mean       -1.256612       3.806869      38.097767      54.184753
std        85.629164       0.094039      21.692845      22.290556
min      -176.375000       3.562210       0.000000       0.000000
25%         0.009580       3.775870      20.825000      37.092000
50%         0.009580       3.795000      38.245000      55.024000
75%         0.009580       3.838900      57.448000      73.136000
max       219.878550       4.160100      74.972000      92.787000

                Amb           Temp
count  1.307510e+05  130751.000000
mean   2.579465e+01      31.534202
std    4.544649e-11       1.455033
min    2.579465e+01      25.794650
25%    2.579465e+01      30.931720
50%    2.579465e+01      31.696820
75%    2.579465e+01      32.352610
max    2.579465e+01      34.101400
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00022: early stopping
Time to train model: 95.7243902683258 seconds
             Current        Voltage          AhCha          AhDch             Amb  \
count  87167.000000  87167.000000  87167.000000  87167.000000  8.716700e+04
mean      -0.828209      3.812962     25.596328     41.319628  2.579465e+01
std       85.550621      0.095139     14.548537     14.921958  4.097368e-11
min     -176.375000      3.562210      0.000000      0.000000  2.579465e+01
25%        0.009580      3.783520     13.864000     29.212000  2.579465e+01
```

```
50%        0.009580      3.798830     24.306000     40.684000  2.579465e+01
75%        0.009580      3.839300     38.245000     55.024000  2.579465e+01
max      219.294320      4.160100     50.314000     65.808000  2.579465e+01

              Temp
count  87167.000000
mean      30.869706
std        1.236341
min       25.794650
25%       30.494520
50%       31.259620
75%       31.696820
max       32.134010
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00046: early stopping
Time to train model: 134.17318606376648 seconds
            Current       Voltage         AhCha         AhDch            Amb  \
count  43583.000000  43583.000000  43583.000000  43583.000000  4.358300e+04
mean      -2.458174      3.816734     13.134120     28.477074  2.579465e+01
std       85.260487      0.096784      7.658945      7.765900  2.755872e-11
min     -176.375000      3.562210      0.000000      0.000000  2.579465e+01
25%        0.009580      3.788150      6.916000     21.094500  2.579465e+01
50%        0.009580      3.803660     13.864000     29.211000  2.579465e+01
75%        0.009580      3.840310     20.825000     37.092000  2.579465e+01
max      219.294320      4.160100     24.306000     40.684000  2.579465e+01

              Temp
count  43583.000000
```

```
mean      30.348772
std        1.501125
min       25.794650
25%       29.729430
50%       30.822420
75%       31.478220
max       32.134010
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00021: early stopping
Time to train model: 30.89752769470215 seconds
```

1.4 ANN errors

[10]:
```
importlib.reload(tmm)
importlib.reload(tm_gb)

ANN_Ah_models_2097_df = tm_gb.extract_complexity(nested_model_dictionary =␣
 ↪ANN_Ah_models_2097,
                                                  nested_errors_dictionary =␣
 ↪ANN_Ah_me_2097)

ANN_IV_models_2097_df = tm_gb.extract_complexity(nested_model_dictionary =␣
 ↪ANN_IV_models_2097,
                                                  nested_errors_dictionary =␣
 ↪ANN_IV_me_2097)
```

```
ANN_hybrid_models_2097_df = tm_gb.extract_complexity(nested_model_dictionary =␣
↪ANN_hybrid_models_2097,
                                                     nested_errors_dictionary =␣
↪ANN_hybrid_me_2097)
```

[11]:
```
ANN_reductions_dict = {
    'Ah_model':ANN_Ah_models_2097_df,
    'IV_model':ANN_IV_models_2097_df,
    'hybrid_model':ANN_hybrid_models_2097_df
}
```

[12]:
```
import pickle

with open('ANN_%reductions_dict.pickle', 'wb') as handle:
    pickle.dump(ANN_reductions_dict, handle)

for key in ANN_reductions_dict.keys():
    ANN_reductions_dict[key].to_csv('ANN_%reductions_' + key + '.csv',␣
↪index=False)
```

1.5 DNN Ah Model

1.5.1 Data loading and cleaning

[13]:
```
df = tm_gb.load_csv(filename = 'LDPRF_2097.csv',
#                     data_list = ['Program time','AhCha','AhDch','Temp'],
                    features_list = ['runtime_s','AhCha','AhDch','Amb','Temp'],
                    mode = 0)

df1 = tm_gb.load_csv(filename = 'LDPRF_2098.csv',
#                     data_list = ['Program time','AhCha','AhDch','Temp'],
                     features_list = ['runtime_s','AhCha','AhDch','Amb','Temp'],
                     mode = 0)
```

[14]:
```
DNN_Ah_models_2097 = {}
DNN_Ah_me_2097 = {}

sections_list = [round(i, 2) for i in np.linspace(start = 0.9, stop = 0.1, num␣
↪= 9, endpoint = True)]
num_rows = df.shape[0]

for i in range(len(sections_list)):
    boundary = int(num_rows * sections_list[i])
    reduced_df = df[:boundary].copy(deep=True)

    reduced_df.drop(columns = ['runtime_s'], inplace = True)
    try:
        df1.drop(columns = ['runtime_s'], inplace = True)
```

```
    except:
        pass

    print(reduced_df.describe())
    print(df1.describe())

    Ah_models_2097, Ah_me_2097 = tmm.loop_run_instances(identifier = "DNN" +␣
↪'_' + str(sections_list[i]),
                                                        loop_name =␣
↪"Ah_model",
                                                        num_layers = 2,
                                                        train_dataframe =␣
↪reduced_df,
                                                        test_dataframe = df1,
                                                        num_inputs = 3,
                                                        start_window_size =␣
↪1,
                                                        end_window_size = 1,
                                                        window_size_step = 1,
                                                        test_size = 0,
                                                        num_epochs = 1000)

    DNN_Ah_models_2097["DNN" + '_' + str(sections_list[i])] = Ah_models_2097
    DNN_Ah_me_2097["DNN" + '_' + str(sections_list[i])] = copy.
↪deepcopy(Ah_me_2097)
```

```
              AhCha          AhDch           Amb           Temp
count  392255.000000  392255.000000  3.922550e+05  392255.000000
mean      113.702847     131.687044  2.579465e+01      34.137644
std        65.565231      67.188310  2.212207e-10       2.093237
min         0.000000       0.000000  2.579465e+01      25.794650
25%        57.448000      73.137500  2.579465e+01      32.352610
50%       113.693000     130.609000  2.579465e+01      34.975800
75%       170.261000     190.321000  2.579465e+01      35.740890
max       228.876000     248.523000  2.579465e+01      36.615290
              AhCha          AhDch           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00059: early stopping
```

```
Time to train model: 799.7260959148407 seconds
                AhCha           AhDch            Amb            Temp
count  348671.000000  348671.000000  3.486710e+05  348671.000000
mean      101.045414     118.726430  2.579465e+01      33.929579
std        58.195447      59.653824  1.974637e-10       2.121352
min         0.000000       0.000000  2.579465e+01      25.794650
25%        50.315500      65.808000  2.579465e+01      31.915410
50%       101.217000     117.995000  2.579465e+01      34.757200
75%       152.429000     170.382000  2.579465e+01      35.631590
max       203.865000     223.020000  2.579465e+01      36.615290
                AhCha           AhDch            Amb            Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00037: early stopping
Time to train model: 445.8795440196991 seconds
                AhCha           AhDch            Amb            Temp
count  305087.000000  305087.000000  3.050870e+05  305087.000000
mean       88.409023     105.782708  2.579465e+01      33.661466
std        50.845185      52.134872  1.669210e-10       2.129966
min         0.000000       0.000000  2.579465e+01      25.794650
25%        45.228000      60.406000  2.579465e+01      31.806110
50%        89.035000     107.177000  2.579465e+01      34.429300
75%       133.105000     152.285000  2.579465e+01      35.412990
max       177.354000     197.575000  2.579465e+01      36.505990
                AhCha           AhDch            Amb            Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00020: early stopping
Time to train model: 212.49689769744873 seconds
                AhCha           AhDch            Amb            Temp
count  261503.000000  261503.000000  2.615030e+05  261503.000000
mean       75.791567      92.857192  2.579465e+01      33.314920
```

```
std        43.510339      44.635610  1.261962e-10       2.099121
min         0.000000       0.000000  2.579465e+01      25.794650
25%        38.245000      55.024000  2.579465e+01      31.696820
50%        74.972000      92.787000  2.579465e+01      33.882800
75%       113.693000     130.609000  2.579465e+01      35.085100
max       152.429000     170.382000  2.579465e+01      36.287390
               AhCha          AhDch           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00031: early stopping
Time to train model: 279.5820343494415 seconds
               AhCha          AhDch           Amb           Temp
count  217919.000000  217919.000000  2.179190e+05  217919.000000
mean       63.199796      79.950900  2.579465e+01      32.872735
std        36.202967      37.160824  6.917860e-11       2.018040
min         0.000000       0.000000  2.579465e+01      25.794650
25%        31.270000      47.854000  2.579465e+01      31.478220
50%        64.452000      81.299000  2.579465e+01      33.008410
75%        93.466000     110.787000  2.579465e+01      34.757200
max       126.039000     145.061000  2.579465e+01      35.850190
               AhCha          AhDch           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00149: early stopping
Time to train model: 1156.0444922447205 seconds
               AhCha          AhDch           Amb           Temp
count  174335.000000  174335.000000  1.743350e+05  174335.000000
mean       50.631069      67.060033  2.579465e+01      32.297380
std        28.920562      29.708943  1.634608e-11       1.839602
min         0.000000       0.000000  2.579465e+01      25.794650
25%        24.306000      40.684000  2.579465e+01      31.150320
50%        50.315000      65.808000  2.579465e+01      31.915410
```

```
75%        74.972000      92.787000  2.579465e+01      33.882800
max       101.216000     117.995000  2.579465e+01      35.303690
               AhCha          AhDch           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00073: early stopping
Time to train model: 430.1439960002899 seconds
               AhCha          AhDch           Amb           Temp
count  130751.000000  130751.000000  1.307510e+05  130751.000000
mean       38.097767      54.184753  2.579465e+01      31.534202
std        21.692845      22.290556  4.544649e-11       1.455033
min         0.000000       0.000000  2.579465e+01      25.794650
25%        20.825000      37.092000  2.579465e+01      30.931720
50%        38.245000      55.024000  2.579465e+01      31.696820
75%        57.448000      73.136000  2.579465e+01      32.352610
max        74.972000      92.787000  2.579465e+01      34.101400
               AhCha          AhDch           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00216: early stopping
Time to train model: 982.3052158355713 seconds
              AhCha         AhDch           Amb          Temp
count  87167.000000  87167.000000  8.716700e+04  87167.000000
mean      25.596328     41.319628  2.579465e+01     30.869706
std       14.548537     14.921958  4.097368e-11      1.236341
min        0.000000      0.000000  2.579465e+01     25.794650
25%       13.864000     29.212000  2.579465e+01     30.494520
50%       24.306000     40.684000  2.579465e+01     31.259620
75%       38.245000     55.024000  2.579465e+01     31.696820
max       50.314000     65.808000  2.579465e+01     32.134010
               AhCha          AhDch           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
```

```
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00023: early stopping
Time to train model: 68.08826017379761 seconds
              AhCha          AhDch           Amb          Temp
count  43583.000000  43583.000000  4.358300e+04  43583.000000
mean      13.134120     28.477074  2.579465e+01     30.348772
std        7.658945      7.765900  2.755872e-11      1.501125
min        0.000000      0.000000  2.579465e+01     25.794650
25%        6.916000     21.094500  2.579465e+01     29.729430
50%       13.864000     29.211000  2.579465e+01     30.822420
75%       20.825000     37.092000  2.579465e+01     31.478220
max       24.306000     40.684000  2.579465e+01     32.134010
               AhCha           AhDch            Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean      126.437695     143.968215  2.626750e+01      34.934164
std        72.927347      74.268447  6.600594e-11       1.938317
min         0.000000       0.000000  2.626750e+01      26.267500
25%        64.531000      80.996500  2.626750e+01      33.803260
50%       126.152000     144.421000  2.626750e+01      35.741030
75%       188.089000     207.443000  2.626750e+01      36.386950
max       252.044000     270.765000  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Time to train model: 1519.4234840869904 seconds
```

1.6 DNN IV Model

1.6.1 Data loading and cleaning

[15]:
```
df = tm_gb.load_csv(filename = 'LDPRF_2097.csv',
#                     data_list = ['Program time','AhCha','AhDch','Temp'],
                    features_list =␣
 ↪['runtime_s','Current','Voltage','Amb','Temp'],
                    mode = 1)

df1 = tm_gb.load_csv(filename = 'LDPRF_2098.csv',
#                     data_list = ['Program time','AhCha','AhDch','Temp'],
                     features_list =␣
 ↪['runtime_s','Current','Voltage','Amb','Temp'],
                     mode = 1)
```

[16]:
```
DNN_IV_models_2097 = {}
DNN_IV_me_2097 = {}

sections_list = [round(i, 2) for i in np.linspace(start = 0.9, stop = 0.1, num␣
 ↪= 9, endpoint = True)]
num_rows = df.shape[0]

for i in range(len(sections_list)):
    boundary = int(num_rows * sections_list[i])
    reduced_df = df[:boundary].copy(deep=True)

    reduced_df.drop(columns = ['runtime_s'], inplace = True)
    try:
        df1.drop(columns = ['runtime_s'], inplace = True)
    except:
        pass

    print(reduced_df.describe())
    print(df1.describe())

    IV_models_2097, IV_me_2097 = tmm.loop_run_instances(identifier = "DNN" +␣
 ↪'_' + str(sections_list[i]),
                                                        loop_name =␣
 ↪"IV_model",
                                                        num_layers = 2,
                                                        train_dataframe =␣
 ↪reduced_df,
                                                        test_dataframe = df1,
                                                        num_inputs = 3,
                                                        start_window_size =␣
 ↪1,
                                                        end_window_size = 1,
                                                        window_size_step = 1,
                                                        test_size = 0,
                                                        num_epochs = 1000)

    DNN_IV_models_2097["DNN" + '_' + str(sections_list[i])] = IV_models_2097
    DNN_IV_me_2097["DNN" + '_' + str(sections_list[i])] = copy.
 ↪deepcopy(IV_me_2097)
```

	Current	Voltage	Amb	Temp
count	392255.000000	392255.000000	3.922550e+05	392255.000000
mean	-0.604674	3.779421	2.579465e+01	34.137644
std	86.197685	0.091355	2.212207e-10	2.093237
min	-177.304100	3.543280	2.579465e+01	25.794650
25%	0.009580	3.736000	2.579465e+01	32.352610
50%	0.009580	3.771040	2.579465e+01	34.975800

```
75%         0.019150       3.810510  2.579465e+01      35.740890
max       222.608110       4.160100  2.579465e+01      36.615290
             Current        Voltage           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00026: early stopping
Time to train model: 352.3450884819031 seconds
             Current        Voltage           Amb           Temp
count  348671.000000  348671.000000  3.486710e+05  348671.000000
mean       -0.624317       3.783654  2.579465e+01      33.929579
std        86.262130       0.091306  1.974637e-10       2.121352
min      -176.853920       3.552340  2.579465e+01      25.794650
25%         0.009580       3.741840  2.579465e+01      31.915410
50%         0.009580       3.775060  2.579465e+01      34.757200
75%         0.019150       3.816350  2.579465e+01      35.631590
max       222.608110       4.160100  2.579465e+01      36.615290
             Current        Voltage           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00175: early stopping
Time to train model: 2122.453068971634 seconds
             Current        Voltage           Amb           Temp
count  305087.000000  305087.000000  3.050870e+05  305087.000000
mean       -0.851556       3.787880  2.579465e+01      33.661466
std        86.132321       0.091286  1.669210e-10       2.129966
min      -176.442050       3.560390  2.579465e+01      25.794650
25%         0.009580       3.748280  2.579465e+01      31.806110
50%         0.009580       3.779290  2.579465e+01      34.429300
75%         0.019150       3.821480  2.579465e+01      35.412990
max       222.474030       4.160100  2.579465e+01      36.505990
             Current        Voltage           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
```

```
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00161: early stopping
Time to train model: 1756.5271933078766 seconds
             Current        Voltage            Amb           Temp
count  261503.000000  261503.000000  2.615030e+05  261503.000000
mean       -0.650107       3.792625  2.579465e+01      33.314920
std        86.047824       0.091401  1.261962e-10       2.099121
min      -176.375000       3.562210  2.579465e+01      25.794650
25%         0.009580       3.755130  2.579465e+01      31.696820
50%         0.009580       3.782720  2.579465e+01      33.882800
75%         0.019150       3.827620  2.579465e+01      35.085100
max       221.391780       4.160100  2.579465e+01      36.287390
             Current        Voltage            Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00007: early stopping
Time to train model: 62.816513538360596 seconds
             Current        Voltage            Amb           Temp
count  217919.000000  217919.000000  2.179190e+05  217919.000000
mean       -0.973715       3.797023  2.579465e+01      32.872735
std        85.900076       0.091887  6.917860e-11       2.018040
min      -176.375000       3.562210  2.579465e+01      25.794650
25%         0.009580       3.761980  2.579465e+01      31.478220
50%         0.009580       3.786340  2.579465e+01      33.008410
75%         0.019150       3.829030  2.579465e+01      34.757200
max       221.391780       4.160100  2.579465e+01      35.850190
             Current        Voltage            Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
```

```
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00108: early stopping
Time to train model: 822.5864324569702 seconds
             Current        Voltage           Amb           Temp
count  174335.000000  174335.000000  1.743350e+05  174335.000000
mean       -0.707373       3.802184  2.579465e+01      32.297380
std        85.814511       0.092661  1.634608e-11       1.839602
min      -176.375000       3.562210  2.579465e+01      25.794650
25%         0.009580       3.769220  2.579465e+01      31.150320
50%         0.009580       3.791180  2.579465e+01      31.915410
75%         0.019150       3.838500  2.579465e+01      33.882800
max       220.932060       4.160100  2.579465e+01      35.303690
             Current        Voltage           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00134: early stopping
Time to train model: 850.5716619491577 seconds
             Current        Voltage           Amb           Temp
count  130751.000000  130751.000000  1.307510e+05  130751.000000
mean       -1.256612       3.806869  2.579465e+01      31.534202
std        85.629164       0.094039  4.544649e-11       1.455033
min      -176.375000       3.562210  2.579465e+01      25.794650
25%         0.009580       3.775870  2.579465e+01      30.931720
50%         0.009580       3.795000  2.579465e+01      31.696820
75%         0.009580       3.838900  2.579465e+01      32.352610
max       219.878550       4.160100  2.579465e+01      34.101400
             Current        Voltage           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
```

```
Restoring model weights from the end of the best epoch
Epoch 00045: early stopping
Time to train model: 207.7735366821289 seconds
            Current       Voltage           Amb          Temp
count  87167.000000  87167.000000  8.716700e+04  87167.000000
mean      -0.828209      3.812962  2.579465e+01     30.869706
std       85.550621      0.095139  4.097368e-11      1.236341
min     -176.375000      3.562210  2.579465e+01     25.794650
25%        0.009580      3.783520  2.579465e+01     30.494520
50%        0.009580      3.798830  2.579465e+01     31.259620
75%        0.009580      3.839300  2.579465e+01     31.696820
max      219.294320      4.160100  2.579465e+01     32.134010
             Current        Voltage           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00123: early stopping
Time to train model: 376.386759519577 seconds
            Current       Voltage           Amb          Temp
count  43583.000000  43583.000000  4.358300e+04  43583.000000
mean      -2.458174      3.816734  2.579465e+01     30.348772
std       85.260487      0.096784  2.755872e-11      1.501125
min     -176.375000      3.562210  2.579465e+01     25.794650
25%        0.009580      3.788150  2.579465e+01     29.729430
50%        0.009580      3.803660  2.579465e+01     30.822420
75%        0.009580      3.840310  2.579465e+01     31.478220
max      219.294320      4.160100  2.579465e+01     32.134010
             Current        Voltage           Amb           Temp
count  435839.000000  435839.000000  4.358390e+05  435839.000000
mean       -0.497548       3.782469  2.626750e+01      34.934164
std        85.732075       0.086605  6.600594e-11       1.938317
min      -176.603480       3.557440  2.626750e+01      26.267500
25%         0.009560       3.741410  2.626750e+01      33.803260
50%         0.009560       3.773560  2.626750e+01      35.741030
75%         0.009560       3.813390  2.626750e+01      36.386950
max       222.893370       4.161120  2.626750e+01      37.032870
Run parameters: 1_[3, 3]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00131: early stopping
Time to train model: 192.08933639526367 seconds
```

1.7 DNN Hybrid Model

1.7.1 Data loading and cleaning

[17]:
```
df = tm_gb.load_csv(filename = 'LDPRF_2097.csv',
#                     data_list = ['Program␣
 ↪time','Current','Voltage','AhCha','AhDch','Temp'],
                    features_list =␣
 ↪['runtime_s','Current','Voltage','AhCha','AhDch','Amb','Temp'],
                    mode = 2)

df1 = tm_gb.load_csv(filename = 'LDPRF_2098.csv',
#                     data_list = ['Program␣
 ↪time','Current','Voltage','AhCha','AhDch','Temp'],
                    features_list =␣
 ↪['runtime_s','Current','Voltage','AhCha','AhDch','Amb','Temp'],
                    mode = 2)
```

[18]:
```
DNN_hybrid_models_2097 = {}
DNN_hybrid_me_2097 = {}

sections_list = [round(i, 2) for i in np.linspace(start = 0.9, stop = 0.1, num␣
 ↪= 9, endpoint = True)]
num_rows = df.shape[0]

for i in range(len(sections_list)):
    boundary = int(num_rows * sections_list[i])
    reduced_df = df[:boundary].copy(deep=True)

    reduced_df.drop(columns = ['runtime_s'], inplace = True)
    try:
        df1.drop(columns = ['runtime_s'], inplace = True)
    except:
        pass

    print(reduced_df.describe())
    print(df1.describe())

    hybrid_models_2097, hybrid_me_2097 = tmm.loop_run_instances(identifier =␣
 ↪"DNN" + '_' + str(sections_list[i]),
                                                                loop_name =␣
 ↪"hybrid_model",
                                                                num_layers =␣
 ↪2,
                                                               ␣
 ↪train_dataframe = reduced_df,
```

```
                                                                    ␣
↪test_dataframe = df1,
                                                                     num_inputs =␣
↪5,
                                                                    ␣
↪start_window_size = 1,
                                                                    ␣
↪end_window_size = 1,
                                                                    ␣
↪window_size_step = 1,
                                                                     test_size =␣
↪0,
                                                                     num_epochs =␣
↪1000)

   DNN_hybrid_models_2097["DNN" + '_' + str(sections_list[i])] =␣
↪hybrid_models_2097
   DNN_hybrid_me_2097["DNN" + '_' + str(sections_list[i])] = copy.
↪deepcopy(hybrid_me_2097)
```

```
             Current        Voltage          AhCha          AhDch  \
count  392255.000000  392255.000000  392255.000000  392255.000000
mean       -0.604674       3.779421     113.702847     131.687044
std        86.197685       0.091355      65.565231      67.188310
min      -177.304100       3.543280       0.000000       0.000000
25%         0.009580       3.736000      57.448000      73.137500
50%         0.009580       3.771040     113.693000     130.609000
75%         0.019150       3.810510     170.261000     190.321000
max       222.608110       4.160100     228.876000     248.523000

                Amb           Temp
count  3.922550e+05  392255.000000
mean   2.579465e+01      34.137644
std    2.212207e-10       2.093237
min    2.579465e+01      25.794650
25%    2.579465e+01      32.352610
50%    2.579465e+01      34.975800
75%    2.579465e+01      35.740890
max    2.579465e+01      36.615290
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
```

```
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5, 5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00027: early stopping
Time to train model: 372.9419221878052 seconds
             Current        Voltage          AhCha          AhDch  \
count  348671.000000  348671.000000  348671.000000  348671.000000
mean       -0.624317       3.783654     101.045414     118.726430
std        86.262130       0.091306      58.195447      59.653824
min      -176.853920       3.552340       0.000000       0.000000
25%         0.009580       3.741840      50.315500      65.808000
50%         0.009580       3.775060     101.217000     117.995000
75%         0.019150       3.816350     152.429000     170.382000
max       222.608110       4.160100     203.865000     223.020000

                Amb           Temp
count  3.486710e+05  348671.000000
mean   2.579465e+01      33.929579
std    1.974637e-10       2.121352
min    2.579465e+01      25.794650
25%    2.579465e+01      31.915410
50%    2.579465e+01      34.757200
75%    2.579465e+01      35.631590
max    2.579465e+01      36.615290
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
```

```
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5, 5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00014: early stopping
Time to train model: 171.56382513046265 seconds
             Current        Voltage          AhCha           AhDch  \
count  305087.000000  305087.000000  305087.000000  305087.000000
mean       -0.851556       3.787880      88.409023     105.782708
std        86.132321       0.091286      50.845185      52.134872
min      -176.442050       3.560390       0.000000       0.000000
25%         0.009580       3.748280      45.228000      60.406000
50%         0.009580       3.779290      89.035000     107.177000
75%         0.019150       3.821480     133.105000     152.285000
max       222.474030       4.160100     177.354000     197.575000

                Amb           Temp
count  3.050870e+05  305087.000000
mean   2.579465e+01      33.661466
std    1.669210e-10       2.129966
min    2.579465e+01      25.794650
25%    2.579465e+01      31.806110
50%    2.579465e+01      34.429300
75%    2.579465e+01      35.412990
max    2.579465e+01      36.505990
             Current        Voltage          AhCha           AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5, 5]_relu_earlyStop
```

```
Restoring model weights from the end of the best epoch
Epoch 00087: early stopping
Time to train model: 931.6025130748749 seconds
             Current        Voltage          AhCha          AhDch  \
count  261503.000000  261503.000000  261503.000000  261503.000000
mean       -0.650107       3.792625      75.791567      92.857192
std        86.047824       0.091401      43.510339      44.635610
min      -176.375000       3.562210       0.000000       0.000000
25%         0.009580       3.755130      38.245000      55.024000
50%         0.009580       3.782720      74.972000      92.787000
75%         0.019150       3.827620     113.693000     130.609000
max       221.391780       4.160100     152.429000     170.382000

                Amb           Temp
count  2.615030e+05  261503.000000
mean   2.579465e+01      33.314920
std    1.261962e-10       2.099121
min    2.579465e+01      25.794650
25%    2.579465e+01      31.696820
50%    2.579465e+01      33.882800
75%    2.579465e+01      35.085100
max    2.579465e+01      36.287390
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5, 5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00092: early stopping
Time to train model: 813.0406351089478 seconds
             Current        Voltage          AhCha          AhDch  \
count  217919.000000  217919.000000  217919.000000  217919.000000
mean       -0.973715       3.797023      63.199796      79.950900
```

```
std        85.900076       0.091887      36.202967      37.160824
min      -176.375000       3.562210       0.000000       0.000000
25%         0.009580       3.761980      31.270000      47.854000
50%         0.009580       3.786340      64.452000      81.299000
75%         0.019150       3.829030      93.466000     110.787000
max       221.391780       4.160100     126.039000     145.061000

                Amb           Temp
count  2.179190e+05  217919.000000
mean   2.579465e+01      32.872735
std    6.917860e-11       2.018040
min    2.579465e+01      25.794650
25%    2.579465e+01      31.478220
50%    2.579465e+01      33.008410
75%    2.579465e+01      34.757200
max    2.579465e+01      35.850190
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5, 5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00064: early stopping
Time to train model: 458.9676432609558 seconds
             Current        Voltage          AhCha          AhDch  \
count  174335.000000  174335.000000  174335.000000  174335.000000
mean       -0.707373       3.802184      50.631069      67.060033
std        85.814511       0.092661      28.920562      29.708943
min      -176.375000       3.562210       0.000000       0.000000
25%         0.009580       3.769220      24.306000      40.684000
50%         0.009580       3.791180      50.315000      65.808000
75%         0.019150       3.838500      74.972000      92.787000
max       220.932060       4.160100     101.216000     117.995000
```

```
                Amb           Temp
count  1.743350e+05  174335.000000
mean   2.579465e+01      32.297380
std    1.634608e-11       1.839602
min    2.579465e+01      25.794650
25%    2.579465e+01      31.150320
50%    2.579465e+01      31.915410
75%    2.579465e+01      33.882800
max    2.579465e+01      35.303690
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5, 5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00034: early stopping
Time to train model: 211.28458833694458 seconds
             Current        Voltage          AhCha          AhDch  \
count  130751.000000  130751.000000  130751.000000  130751.000000
mean       -1.256612       3.806869      38.097767      54.184753
std        85.629164       0.094039      21.692845      22.290556
min      -176.375000       3.562210       0.000000       0.000000
25%         0.009580       3.775870      20.825000      37.092000
50%         0.009580       3.795000      38.245000      55.024000
75%         0.009580       3.838900      57.448000      73.136000
max       219.878550       4.160100      74.972000      92.787000

                Amb           Temp
count  1.307510e+05  130751.000000
mean   2.579465e+01      31.534202
std    4.544649e-11       1.455033
min    2.579465e+01      25.794650
```

```
25%    2.579465e+01      30.931720
50%    2.579465e+01      31.696820
75%    2.579465e+01      32.352610
max    2.579465e+01      34.101400
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5, 5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00034: early stopping
Time to train model: 154.34490823745728 seconds
            Current       Voltage         AhCha          AhDch           Amb  \
count  87167.000000  87167.000000  87167.000000  87167.000000  8.716700e+04
mean      -0.828209      3.812962     25.596328     41.319628  2.579465e+01
std       85.550621      0.095139     14.548537     14.921958  4.097368e-11
min     -176.375000      3.562210      0.000000      0.000000  2.579465e+01
25%        0.009580      3.783520     13.864000     29.212000  2.579465e+01
50%        0.009580      3.798830     24.306000     40.684000  2.579465e+01
75%        0.009580      3.839300     38.245000     55.024000  2.579465e+01
max      219.294320      4.160100     50.314000     65.808000  2.579465e+01

              Temp
count  87167.000000
mean      30.869706
std        1.236341
min       25.794650
25%       30.494520
50%       31.259620
75%       31.696820
max       32.134010
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
```

```
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5, 5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00057: early stopping
Time to train model: 174.63523507118225 seconds
            Current       Voltage         AhCha         AhDch            Amb  \
count  43583.000000  43583.000000  43583.000000  43583.000000  4.358300e+04
mean      -2.458174      3.816734     13.134120     28.477074  2.579465e+01
std       85.260487      0.096784      7.658945      7.765900  2.755872e-11
min     -176.375000      3.562210      0.000000      0.000000  2.579465e+01
25%        0.009580      3.788150      6.916000     21.094500  2.579465e+01
50%        0.009580      3.803660     13.864000     29.211000  2.579465e+01
75%        0.009580      3.840310     20.825000     37.092000  2.579465e+01
max      219.294320      4.160100     24.306000     40.684000  2.579465e+01

              Temp
count  43583.000000
mean      30.348772
std        1.501125
min       25.794650
25%       29.729430
50%       30.822420
75%       31.478220
max       32.134010
             Current        Voltage          AhCha          AhDch  \
count  435839.000000  435839.000000  435839.000000  435839.000000
mean       -0.497548       3.782469     126.437695     143.968215
std        85.732075       0.086605      72.927347      74.268447
min      -176.603480       3.557440       0.000000       0.000000
25%         0.009560       3.741410      64.531000      80.996500
50%         0.009560       3.773560     126.152000     144.421000
75%         0.009560       3.813390     188.089000     207.443000
```

```
max       222.893370       4.161120     252.044000     270.765000

                Amb           Temp
count  4.358390e+05  435839.000000
mean   2.626750e+01      34.934164
std    6.600594e-11       1.938317
min    2.626750e+01      26.267500
25%    2.626750e+01      33.803260
50%    2.626750e+01      35.741030
75%    2.626750e+01      36.386950
max    2.626750e+01      37.032870
Run parameters: 1_[5, 5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00102: early stopping
Time to train model: 154.95783686637878 seconds
```

1.8 DNN errors

[19]:
```
importlib.reload(tmm)
importlib.reload(tm_gb)

DNN_Ah_models_2097_df = tm_gb.extract_complexity(nested_model_dictionary =␣
 ↪DNN_Ah_models_2097,
                                                  nested_errors_dictionary =␣
 ↪DNN_Ah_me_2097)

DNN_IV_models_2097_df = tm_gb.extract_complexity(nested_model_dictionary =␣
 ↪DNN_IV_models_2097,
                                                  nested_errors_dictionary =␣
 ↪DNN_IV_me_2097)

DNN_hybrid_models_2097_df = tm_gb.extract_complexity(nested_model_dictionary =␣
 ↪DNN_hybrid_models_2097,
                                                      nested_errors_dictionary =␣
 ↪DNN_hybrid_me_2097)
```

[20]:
```
DNN_reductions_dict = {
    'Ah_model':DNN_Ah_models_2097_df,
    'IV_model':DNN_IV_models_2097_df,
    'hybrid_model':DNN_hybrid_models_2097_df
}
```

[21]:
```
import pickle

with open('DNN_%reductions_dict.pickle', 'wb') as handle:
    pickle.dump(DNN_reductions_dict, handle)

for key in DNN_reductions_dict.keys():
```

```
    DNN_reductions_dict[key].to_csv('DNN_%reductions_' + key + '.csv',␣
↪index=False)
```