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

```
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_
    \Rightarrow= 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" + L
→'_' + str(sections_list[i]),
                                                            loop_name =

→"Ah_model",
                                                            num_layers = 1,
                                                            train_dataframe =
→reduced_df,
                                                            test_dataframe = df1,
                                                            num_inputs = 3,
                                                            start_window_size = 
\hookrightarrow 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	AhCha 435839.000000	AhDch 435839.000000	Amb 4.358390e+05	Temp 435839.000000
count mean				-
	435839.000000	435839.000000	4.358390e+05	435839.000000
mean	435839.000000 126.437695	435839.000000 143.968215	4.358390e+05 2.626750e+01	435839.000000 34.934164
mean std	435839.000000 126.437695 72.927347	435839.000000 143.968215 74.268447	4.358390e+05 2.626750e+01 6.600594e-11	435839.000000 34.934164 1.938317
mean std min	435839.000000 126.437695 72.927347 0.000000	435839.000000 143.968215 74.268447 0.000000	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01	435839.000000 34.934164 1.938317 26.267500
mean std min 25%	435839.000000 126.437695 72.927347 0.000000 64.531000	435839.000000 143.968215 74.268447 0.000000 80.996500	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01 2.626750e+01	435839.000000 34.934164 1.938317 26.267500 33.803260
mean std min 25% 50%	435839.000000 126.437695 72.927347 0.000000 64.531000 126.152000	435839.000000 143.968215 74.268447 0.000000 80.996500 144.421000	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01 2.626750e+01 2.626750e+01	435839.000000 34.934164 1.938317 26.267500 33.803260 35.741030

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

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	AhCha 435839.000000	AhDch 435839.000000	Amb 4.358390e+05	Temp 435839.000000
count mean				-
	435839.000000	435839.000000	4.358390e+05	435839.000000
mean	435839.000000 126.437695	435839.000000 143.968215	4.358390e+05 2.626750e+01	435839.000000 34.934164
mean std	435839.000000 126.437695 72.927347	435839.000000 143.968215 74.268447	4.358390e+05 2.626750e+01 6.600594e-11	435839.000000 34.934164 1.938317
mean std min	435839.000000 126.437695 72.927347 0.000000	435839.000000 143.968215 74.268447 0.000000	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01	435839.000000 34.934164 1.938317 26.267500
mean std min 25%	435839.000000 126.437695 72.927347 0.000000 64.531000	435839.000000 143.968215 74.268447 0.000000 80.996500	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01 2.626750e+01	435839.000000 34.934164 1.938317 26.267500 33.803260

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
_				

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%				
0.1	64.531000	80.996500	2.626750e+01	33.803260
50%	64.531000 126.152000	80.996500 144.421000	2.626750e+01 2.626750e+01	33.803260 35.741030
50% 75%				
	126.152000	144.421000	2.626750e+01	35.741030

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
			2.020730e101	31.032010
_		relu_earlyStop	20 1	
lime to		6621.61689066886		_
	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
	74.972000	92.787000	2.579465e+01	34.101400
max				
	AhCha	AhDch	Amb	Temp
count	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			36.386950
max	252.044000	270.765000	2.626750e+01	37.032870
		relu_earlyStop	2.020,000.01	01.002010
_		• -	of the boot o	n o ah
	-	nts from the end	or the best e	pocn
-	00092: early st			
Time to		399.163824081420		
	AhCha	AhDch	Amb	Temp
count	87167.000000	87167.000000 8	.716700e+04 8	7167.000000
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		31.259620
75%	38.245000	55.024000 2		31.696820
	50.314000	65.808000 2		32.134010
max				
	AhCha	AhDch	Amb	Temp
count		435839.000000		
mean	126.437695		2.626750e+01	
std	72.927347		6.600594e-11	
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
15%	188.089000	207.443000	2.626750e+01	36.386950
75% max	188.089000 252.044000		2.626750e+01 2.626750e+01	36.386950 37.032870

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	n Amb	Temp
count	435839.000000	435839.000000	4.358390e+05	435839.000000
mean	126.437695	143.968215	5 2.626750e+01	34.934164
std	72.927347	74.268447	7 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
D	4 [0]	7 7 7.		

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	\mathtt{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_
    \Rightarrow= 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 =
     \hookrightarrow 1,
                                                                  end_window_size = 1,
```

	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

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	Current 435839.000000	Voltage 435839.000000	Amb 4.358390e+05	Temp 435839.000000
count mean		_		_
	435839.000000	435839.000000	4.358390e+05	435839.000000
mean	435839.000000 -0.497548	435839.000000 3.782469	4.358390e+05 2.626750e+01	435839.000000 34.934164
mean std	435839.000000 -0.497548 85.732075	435839.000000 3.782469 0.086605	4.358390e+05 2.626750e+01 6.600594e-11	435839.000000 34.934164 1.938317
mean std min	435839.000000 -0.497548 85.732075 -176.603480	435839.000000 3.782469 0.086605 3.557440	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01	435839.000000 34.934164 1.938317 26.267500
mean std min 25%	435839.000000 -0.497548 85.732075 -176.603480 0.009560	435839.000000 3.782469 0.086605 3.557440 3.741410	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01 2.626750e+01	435839.000000 34.934164 1.938317 26.267500 33.803260
mean std min 25% 50%	435839.000000 -0.497548 85.732075 -176.603480 0.009560 0.009560	435839.000000 3.782469 0.086605 3.557440 3.741410 3.773560	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01 2.626750e+01 2.626750e+01	435839.000000 34.934164 1.938317 26.267500 33.803260 35.741030

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	Current 435839.000000	Voltage 435839.000000	Amb 4.358390e+05	Temp 435839.000000
count mean		•		_
	435839.000000	435839.000000	4.358390e+05	435839.000000
mean	435839.000000 -0.497548	435839.000000 3.782469	4.358390e+05 2.626750e+01	435839.000000 34.934164
mean std	435839.000000 -0.497548 85.732075	435839.000000 3.782469 0.086605	4.358390e+05 2.626750e+01 6.600594e-11	435839.000000 34.934164 1.938317
mean std min	435839.000000 -0.497548 85.732075 -176.603480	435839.000000 3.782469 0.086605 3.557440	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01	435839.000000 34.934164 1.938317 26.267500
mean std min 25%	435839.000000 -0.497548 85.732075 -176.603480 0.009560	435839.000000 3.782469 0.086605 3.557440 3.741410	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01 2.626750e+01	435839.000000 34.934164 1.938317 26.267500 33.803260
mean std min 25% 50%	435839.000000 -0.497548 85.732075 -176.603480 0.009560 0.009560	435839.000000 3.782469 0.086605 3.557440 3.741410 3.773560	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01 2.626750e+01 2.626750e+01	435839.000000 34.934164 1.938317 26.267500 33.803260 35.741030

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 000EG0	3.773560	2.626750e+01	35.741030
/ 0	0.009560	3.113560	2.020750e+01	33.741030
75%	0.009560	3.813390	2.626750e+01 2.626750e+01	36.386950

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
	a .	77 7 .	A 7	_
	Current	Voltage	Amb	Temp
count	435839.000000	Voltage 435839.000000	Amb 4.358390e+05	Temp 435839.000000
count		•		-
	435839.000000	435839.000000	4.358390e+05	435839.000000
mean	435839.000000 -0.497548	435839.000000 3.782469	4.358390e+05 2.626750e+01	435839.000000 34.934164
mean std	435839.000000 -0.497548 85.732075	435839.000000 3.782469 0.086605	4.358390e+05 2.626750e+01 6.600594e-11	435839.000000 34.934164 1.938317
mean std min	435839.000000 -0.497548 85.732075 -176.603480	435839.000000 3.782469 0.086605 3.557440	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01	435839.000000 34.934164 1.938317 26.267500
mean std min 25%	435839.000000 -0.497548 85.732075 -176.603480 0.009560	435839.000000 3.782469 0.086605 3.557440 3.741410	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01 2.626750e+01	435839.000000 34.934164 1.938317 26.267500 33.803260

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

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	l 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
                                              Amb
                            Voltage
                                                             Temp
       435839.000000
                     435839.000000 4.358390e+05 435839.000000
count
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
                           4.161120 2.626750e+01
          222.893370
                                                        37.032870
max
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 =__
    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_
    \rightarrow= 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 =
num_layers =
\hookrightarrow 1,
→train_dataframe = reduced_df,
                                                                 Ш
→test_dataframe = df1,
                                                                  num_inputs =
⇒5,
→start_window_size = 1,
                                                                 Ш
→end_window_size = 1,
→window_size_step = 1,
                                                                  test_size =
⇔0,
                                                                  num_epochs =_u
→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			

```
2.579465e+01
                          34.137644
mean
std
       2.212207e-10
                           2.093237
       2.579465e+01
                          25.794650
min
25%
       2.579465e+01
                          32.352610
50%
       2.579465e+01
                          34.975800
75%
       2.579465e+01
                          35.740890
       2.579465e+01
                          36.615290
max
              Current
                              Voltage
                                                AhCha
                                                                AhDch
       435839.000000
                       435839.000000
                                       435839.000000
                                                       435839.000000
count
mean
           -0.497548
                             3.782469
                                           126.437695
                                                           143.968215
           85.732075
                                           72.927347
                                                            74.268447
std
                             0.086605
min
         -176.603480
                             3.557440
                                             0.000000
                                                             0.000000
25%
             0.009560
                                                            80.996500
                             3.741410
                                            64.531000
50%
             0.009560
                             3.773560
                                           126.152000
                                                           144.421000
75%
             0.009560
                             3.813390
                                          188.089000
                                                           207.443000
          222.893370
                                          252.044000
                                                           270.765000
                             4.161120
max
                 Amb
                                Temp
       4.358390e+05
                      435839.000000
count
       2.626750e+01
                          34.934164
mean
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
       2.626750e+01
                          37.032870
max
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
                                                AhCha
                                                                AhDch
              Current
                              Voltage
       348671.000000
                       348671.000000
                                       348671.000000
                                                       348671.000000
count
           -0.624317
                             3.783654
                                          101.045414
                                                           118.726430
mean
                                                            59.653824
           86.262130
                             0.091306
                                            58.195447
std
         -176.853920
                             3.552340
                                             0.000000
                                                             0.000000
min
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
          222.608110
                             4.160100
                                          203.865000
                                                           223.020000
max
                 Amb
                                Temp
       3.486710e+05
                      348671.000000
count
       2.579465e+01
                          33.929579
mean
std
       1.974637e-10
                           2.121352
       2.579465e+01
                          25.794650
min
25%
       2.579465e+01
                          31.915410
50%
       2.579465e+01
                          34.757200
75%
       2.579465e+01
                          35.631590
```

m 2 37	2.579465e+01	36.615290			
max	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		435839.000000			
count					
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			
_		_relu_earlyStop			
		nts from the end	of the best ep	och	
-	00009: early st				
Time to	o train model:	104.92103576660	156 seconds		
	Current	Voltage	AhCha	AhDch	\
count	Current 305087.000000	Voltage 305087.000000		AhDch 305087.000000	\
		_	AhCha		\
count	305087.000000	305087.000000	AhCha 305087.000000	305087.000000	\
count mean	305087.000000 -0.851556	305087.000000 3.787880	AhCha 305087.000000 88.409023	305087.000000 105.782708	\
count mean std	305087.000000 -0.851556 86.132321	305087.000000 3.787880 0.091286	AhCha 305087.000000 88.409023 50.845185	305087.000000 105.782708 52.134872	\
count mean std min	305087.000000 -0.851556 86.132321 -176.442050	305087.000000 3.787880 0.091286 3.560390	AhCha 305087.000000 88.409023 50.845185 0.000000	305087.000000 105.782708 52.134872 0.000000	\
count mean std min 25%	305087.000000 -0.851556 86.132321 -176.442050 0.009580	305087.000000 3.787880 0.091286 3.560390 3.748280	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000	305087.000000 105.782708 52.134872 0.000000 60.406000	\
count mean std min 25% 50%	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000	\
count mean std min 25% 50% 75%	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000	\
count mean std min 25% 50% 75%	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000	\
count mean std min 25% 50% 75%	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150 222.474030	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480 4.160100	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000	\
count mean std min 25% 50% 75% max	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150 222.474030	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480 4.160100	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000	\
count mean std min 25% 50% 75% max	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150 222.474030 Amb 3.050870e+05	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480 4.160100 Temp 305087.000000	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000	\
count mean std min 25% 50% 75% max count	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150 222.474030 Amb 3.050870e+05 2.579465e+01	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480 4.160100 Temp 305087.000000 33.661466	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000	
count mean std min 25% 50% 75% max count mean std	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150 222.474030 Amb 3.050870e+05 2.579465e+01 1.669210e-10	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480 4.160100 Temp 305087.000000 33.661466 2.129966	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000	
count mean std min 25% 50% 75% max count mean std min	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150 222.474030 Amb 3.050870e+05 2.579465e+01 1.669210e-10 2.579465e+01	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480 4.160100 Temp 305087.000000 33.661466 2.129966 25.794650	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000	
count mean std min 25% 50% 75% max count mean std min 25%	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150 222.474030 Amb 3.050870e+05 2.579465e+01 1.669210e-10 2.579465e+01 2.579465e+01	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480 4.160100 Temp 305087.000000 33.661466 2.129966 25.794650 31.806110	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000	
count mean std min 25% 50% 75% max count mean std min 25% 50%	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150 222.474030 Amb 3.050870e+05 2.579465e+01 1.669210e-10 2.579465e+01 2.579465e+01 2.579465e+01	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480 4.160100 Temp 305087.000000 33.661466 2.129966 25.794650 31.806110 34.429300	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000	
count mean std min 25% 50% 75% max count mean std min 25% 50% 75%	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150 222.474030 Amb 3.050870e+05 2.579465e+01 1.669210e-10 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480 4.160100 Temp 305087.000000 33.661466 2.129966 25.794650 31.806110 34.429300 35.412990 36.505990	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000	\
count mean std min 25% 50% 75% max count mean std min 25% 50% 75%	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150 222.474030 Amb 3.050870e+05 2.579465e+01 1.669210e-10 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 Current	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480 4.160100 Temp 305087.000000 33.661466 2.129966 25.794650 31.806110 34.429300 35.412990 36.505990 Voltage	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000 177.354000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000 197.575000	
count mean std min 25% 50% 75% max count mean std min 25% 50% 75% max count	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150 222.474030 Amb 3.050870e+05 2.579465e+01 1.669210e-10 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 435839.000000	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480 4.160100 Temp 305087.000000 33.661466 2.129966 25.794650 31.806110 34.429300 35.412990 36.505990 Voltage 435839.000000	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000 177.354000 AhCha 435839.000000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000 197.575000 AhDch 435839.000000	
count mean std min 25% 50% 75% max count mean std min 25% 50% 75% max count mean	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150 222.474030 Amb 3.050870e+05 2.579465e+01 1.669210e-10 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 435839.000000 -0.497548	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480 4.160100 Temp 305087.000000 33.661466 2.129966 25.794650 31.806110 34.429300 35.412990 36.505990 Voltage 435839.000000 3.782469	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000 177.354000 AhCha 435839.000000 126.437695	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000 197.575000 AhDch 435839.000000 143.968215	
count mean std min 25% 50% 75% max count mean std min 25% 50% 75% max count	305087.000000 -0.851556 86.132321 -176.442050 0.009580 0.009580 0.019150 222.474030 Amb 3.050870e+05 2.579465e+01 1.669210e-10 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 435839.000000	305087.000000 3.787880 0.091286 3.560390 3.748280 3.779290 3.821480 4.160100 Temp 305087.000000 33.661466 2.129966 25.794650 31.806110 34.429300 35.412990 36.505990 Voltage 435839.000000	AhCha 305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000 177.354000 AhCha 435839.000000	305087.000000 105.782708 52.134872 0.000000 60.406000 107.177000 152.285000 197.575000 AhDch 435839.000000	

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	
man	222.000010	1.101120	202.011000	210.100000	
	Amb	Temp			
count		435839.000000			
mean	2.626750e+01	34.934164			
std	6.600594e-11	1.938317			
min	2.626750e+01	26.267500			
	2.626750e+01	33.803260			
	2.626750e+01	35.741030			
	2.626750e+01	36.386950			
max	2.626750e+01	37.032870			
]_relu_earlyStop			
		hts from the end		och	
	00081: early s		or the best ep	ocn	
-	•	818.16045880317	60 seconds		
11me C	Current	Voltage	AhCha	AhDch	\
count	261503.000000	•		261503.000000	`
	-0.650107		75.791567	92.857192	
mean				44.635610	
std	86.047824		43.510339		
min	-176.375000		0.000000	0.000000	
25%	0.009580		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	Town			
	Amb	Temp			
	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
      2.626750e+01
                        37.032870
max
Run parameters: 1_[5]_relu_earlyStop
Epoch 00018: early stopping
```

Restoring model weights from the end of the best epoch

Epoch 00018: early stopping						
Time t	o 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

Time t	o train model:	291.59030318260	193 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			
	2.579465e+01	31.150320			
	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	
	۸ ا-	Т			
	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 pa]_relu_earlyStop			
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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		26.267500			
	2.626750e+01				
	2.626750e+01				
75%					
max	2.626750e+01				
		_relu_earlyStop			
_		nts from the end	of the best en	och	
	00022: early st		2020 op	-	
-	•	95.724390268325	8 seconds		
	Current	Voltage		AhDch	

	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	
		11100100	00101100		_,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	
	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		Dch \	
count	435839.000000	435839.000000	435839.000000	435839.000		
mean	-0.497548	3.782469	126.437695	143.968		
std	85.732075	0.086605	72.927347	74.268		
min	-176.603480	3.557440	0.000000	0.000	000	
25%	0.009560	3.741410	64.531000	80.996	500	
50%	0.009560	3.773560	126.152000	144.421	000	
75%	0.009560	3.813390	188.089000	207.443	000	
max	222.893370	4.161120	252.044000	270.765	000	
	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				
	2.626750e+01	35.741030				
75%	2.626750e+01	36.386950				
max	2.626750e+01	37.032870				
		_relu_earlyStop	n			
_		-	d of the best ep	o ch		
	00046: early st		i or the best ep	JOCH		
_		.opping 134.17318606376	SEAO gogonda			
lime c				A b D a b	۸ ا	\
	Current	Voltage	AhCha	AhDch	Amb	\
count				3583.000000	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					
	13503 000000					

count 43583.000000

```
30.348772
mean
std
           1.501125
          25.794650
min
25%
          29.729430
          30.822420
50%
75%
          31.478220
max
          32.134010
                             Voltage
             Current
                                               AhCha
                                                               AhDch
       435839.000000
                       435839.000000
                                       435839.000000
                                                      435839.000000
count
mean
           -0.497548
                            3.782469
                                          126.437695
                                                          143.968215
std
           85.732075
                            0.086605
                                           72.927347
                                                           74.268447
                                                            0.000000
min
         -176.603480
                            3.557440
                                            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
          222.893370
                            4.161120
                                          252.044000
                                                          270.765000
max
                Amb
                               Temp
       4.358390e+05
                      435839.000000
count
       2.626750e+01
                          34.934164
mean
std
       6.600594e-11
                           1.938317
                          26.267500
min
       2.626750e+01
25%
       2.626750e+01
                          33.803260
50%
       2.626750e+01
                          35.741030
75%
       2.626750e+01
                          36.386950
       2.626750e+01
                          37.032870
max
Run parameters: 1_[5]_relu_earlyStop
Restoring model weights from the end of the best epoch
Epoch 00021: early stopping
```

1.4 ANN errors

Time to train model: 30.89752769470215 seconds

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_
     \rightarrow= 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 =
\hookrightarrow "Ah_model",
                                                             num_layers = 2,
                                                             train_dataframe =
→reduced_df,
                                                             test_dataframe = df1,
                                                             num_inputs = 3,
                                                             start_window_size =
\hookrightarrow 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 pa	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

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
305087.000000	305087.000000	3.050870e+05	305087.000000
88.409023	105.782708	2.579465e+01	33.661466
50.845185	52.134872	1.669210e-10	2.129966
0.000000	0.000000	2.579465e+01	25.794650
45.228000	60.406000	2.579465e+01	31.806110
89.035000	107.177000	2.579465e+01	34.429300
133.105000	152.285000	2.579465e+01	35.412990
177.354000	197.575000	2.579465e+01	36.505990
AhCha	AhDch	Amb	Temp
435839.000000	435839.000000	4.358390e+05	435839.000000
126.437695	143.968215	2.626750e+01	34.934164
72.927347	74.268447	6.600594e-11	1.938317
0.000000	0.000000	2.626750e+01	26.267500
64.531000	80.996500	2.626750e+01	33.803260
126.152000	144.421000	2.626750e+01	35.741030
188.089000	207.443000	2.626750e+01	36.386950
252.044000	270.765000	2.626750e+01	37.032870
	305087.000000 88.409023 50.845185 0.000000 45.228000 89.035000 133.105000 177.354000 AhCha 435839.000000 126.437695 72.927347 0.000000 64.531000 126.152000 188.089000	305087.000000 305087.000000 88.409023 105.782708 50.845185 52.134872 0.000000 0.000000 45.228000 60.406000 89.035000 107.177000 133.105000 152.285000 177.354000 197.575000 AhCha AhDch 435839.000000 435839.000000 126.437695 143.968215 72.927347 74.268447 0.000000 0.000000 64.531000 80.996500 126.152000 144.421000 188.089000 207.443000	305087.000000 305087.000000 3.050870e+05 88.409023 105.782708 2.579465e+01 50.845185 52.134872 1.669210e-10 0.000000 0.000000 2.579465e+01 45.228000 60.406000 2.579465e+01 89.035000 107.177000 2.579465e+01 133.105000 152.285000 2.579465e+01 177.354000 197.575000 2.579465e+01 AhCha AhDch Amb 435839.000000 4.35839.00000 4.358390e+05 126.437695 143.968215 2.626750e+01 72.927347 74.268447 6.600594e-11 0.000000 0.000000 2.626750e+01 64.531000 80.996500 2.626750e+01 126.152000 144.421000 2.626750e+01 188.089000 207.443000 2.626750e+01

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

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	Tomp
	Allolia	AIIDCII	Allio	Temp
count	435839.000000	435839.000000	4.358390e+05	435839.000000
count mean				_
	435839.000000	435839.000000	4.358390e+05	435839.000000
mean	435839.000000 126.437695	435839.000000 143.968215	4.358390e+05 2.626750e+01	435839.000000 34.934164
mean std	435839.000000 126.437695 72.927347	435839.000000 143.968215 74.268447	4.358390e+05 2.626750e+01 6.600594e-11	435839.000000 34.934164 1.938317
mean std min	435839.000000 126.437695 72.927347 0.000000	435839.000000 143.968215 74.268447 0.000000	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01	435839.000000 34.934164 1.938317 26.267500
mean std min 25%	435839.000000 126.437695 72.927347 0.000000 64.531000	435839.000000 143.968215 74.268447 0.000000 80.996500	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01 2.626750e+01	435839.000000 34.934164 1.938317 26.267500 33.803260
mean std min 25% 50%	435839.000000 126.437695 72.927347 0.000000 64.531000 126.152000	435839.000000 143.968215 74.268447 0.000000 80.996500 144.421000	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01 2.626750e+01 2.626750e+01	435839.000000 34.934164 1.938317 26.267500 33.803260 35.741030

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

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	AhCha 435839.000000	AhDch 435839.000000	Amb 4.358390e+05	Temp 435839.000000
count mean				-
	435839.000000	435839.000000	4.358390e+05	435839.000000
mean	435839.000000 126.437695	435839.000000 143.968215	4.358390e+05 2.626750e+01	435839.000000 34.934164
mean std	435839.000000 126.437695 72.927347	435839.000000 143.968215 74.268447	4.358390e+05 2.626750e+01 6.600594e-11	435839.000000 34.934164 1.938317
mean std min	435839.000000 126.437695 72.927347 0.000000	435839.000000 143.968215 74.268447 0.000000	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01	435839.000000 34.934164 1.938317 26.267500
mean std min 25%	435839.000000 126.437695 72.927347 0.000000 64.531000	435839.000000 143.968215 74.268447 0.000000 80.996500	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01 2.626750e+01	435839.000000 34.934164 1.938317 26.267500 33.803260

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	n Amb	Temp
count	435839.000000	435839.000000	4.358390e+05	435839.000000

```
143.968215 2.626750e+01
                                                        34.934164
          126.437695
mean
std
           72.927347
                          74.268447 6.600594e-11
                                                         1.938317
            0.000000
                           0.000000 2.626750e+01
                                                        26.267500
min
25%
                          80.996500 2.626750e+01
           64.531000
                                                        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
       43583.000000
                    43583.000000 4.358300e+04
                                                 43583.000000
count
mean
          13.134120
                        28.477074 2.579465e+01
                                                     30.348772
std
           7.658945
                         7.765900 2.755872e-11
                                                      1.501125
                         0.000000 2.579465e+01
                                                     25.794650
min
           0.000000
25%
           6.916000
                        21.094500 2.579465e+01
                                                     29.729430
50%
                        29.211000 2.579465e+01
                                                     30.822420
          13.864000
                        37.092000 2.579465e+01
                                                     31.478220
75%
          20.825000
          24.306000
                        40.684000 2.579465e+01
                                                     32.134010
max
               AhCha
                              AhDch
                                              Amb
                                                             Temp
       435839.000000
                      435839.000000 4.358390e+05
                                                   435839.000000
count
mean
          126.437695
                         143.968215 2.626750e+01
                                                        34.934164
                          74.268447 6.600594e-11
std
           72.927347
                                                         1.938317
min
            0.000000
                           0.000000 2.626750e+01
                                                        26.267500
```

Time to train model: 1519.4234840869904 seconds

1.6 DNN IV Model

25%

50%

75%

1.6.1 Data loading and cleaning

64.531000

126.152000

188.089000

252.044000

80.996500 2.626750e+01

144.421000 2.626750e+01

207.443000 2.626750e+01

270.765000 2.626750e+01

33.803260

35.741030

36.386950

37.032870

```
[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_
     \Rightarrow= 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 =_{\sqcup}
      \hookrightarrow 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

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	Current 435839.000000	Voltage 435839.000000	Amb 4.358390e+05	Temp 435839.000000
count mean		•		-
	435839.000000	435839.000000	4.358390e+05	435839.000000
mean	435839.000000 -0.497548	435839.000000 3.782469	4.358390e+05 2.626750e+01	435839.000000 34.934164
mean std	435839.000000 -0.497548 85.732075	435839.000000 3.782469 0.086605	4.358390e+05 2.626750e+01 6.600594e-11	435839.000000 34.934164 1.938317
mean std min	435839.000000 -0.497548 85.732075 -176.603480	435839.000000 3.782469 0.086605 3.557440	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01	435839.000000 34.934164 1.938317 26.267500
mean std min 25%	435839.000000 -0.497548 85.732075 -176.603480 0.009560	435839.000000 3.782469 0.086605 3.557440 3.741410	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01 2.626750e+01	435839.000000 34.934164 1.938317 26.267500 33.803260

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

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
	100000.00000	433639.000000	4.3303300+03	±00000.000000
mean	-0.497548	3.782469	2.626750e+01	34.934164
mean std				
	-0.497548	3.782469	2.626750e+01	34.934164
std	-0.497548 85.732075	3.782469 0.086605	2.626750e+01 6.600594e-11	34.934164 1.938317
std min	-0.497548 85.732075 -176.603480	3.782469 0.086605 3.557440	2.626750e+01 6.600594e-11 2.626750e+01	34.934164 1.938317 26.267500
std min 25%	-0.497548 85.732075 -176.603480 0.009560	3.782469 0.086605 3.557440 3.741410	2.626750e+01 6.600594e-11 2.626750e+01 2.626750e+01	34.934164 1.938317 26.267500 33.803260

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

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	Current 435839.000000	Voltage 435839.000000	Amb 4.358390e+05	Temp 435839.000000
count mean		•		-
	435839.000000	435839.000000	4.358390e+05	435839.000000
mean	435839.000000 -0.497548	435839.000000 3.782469	4.358390e+05 2.626750e+01	435839.000000 34.934164
mean std	435839.000000 -0.497548 85.732075	435839.000000 3.782469 0.086605	4.358390e+05 2.626750e+01 6.600594e-11	435839.000000 34.934164 1.938317
mean std min	435839.000000 -0.497548 85.732075 -176.603480	435839.000000 3.782469 0.086605 3.557440	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01	435839.000000 34.934164 1.938317 26.267500
mean std min 25%	435839.000000 -0.497548 85.732075 -176.603480 0.009560	435839.000000 3.782469 0.086605 3.557440 3.741410	4.358390e+05 2.626750e+01 6.600594e-11 2.626750e+01 2.626750e+01	435839.000000 34.934164 1.938317 26.267500 33.803260

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 pa	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
	. 4 [0	0]]		

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	e 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_
     \Rightarrow= 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 =
      \hookrightarrow "hybrid_model",
                                                                            num_layers =
      \rightarrow 2,
      →train_dataframe = reduced_df,
```

	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	Town			
		Temp			
	4.358390e+05	435839.000000			
mean	2.626750e+01	34.934164			
	6.600594e-11	1.938317			
	2.626750e+01	26.267500			
25%	2.626750e+01	33.803260			
	2.626750e+01	35.741030			
75%	2.626750e+01	36.386950			
max	2.626750e+01	37.032870			
_		, 5]_relu_earlyS	-		
Restor	ing model weigl	nts from the end	of the best e	poch	
Epoch (00027: early st	topping			
Time to	o train model:	372.94192218780	52 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		
max	222.608110	4.160100	203.865000		
	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			
	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		`
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	
	0.009560				
25%		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			

```
2.626750e+01
                        26.267500
min
25%
      2.626750e+01
                        33.803260
50%
      2.626750e+01
                        35.741030
75%
      2.626750e+01
                        36.386950
      2.626750e+01
                        37.032870
max
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	1
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			
3.050870e+05	305087.000000			
2.579465e+01	33.661466			
1.669210e-10	2.129966			
2.579465e+01	25.794650			
2.579465e+01	31.806110			
2.579465e+01	34.429300			
2.579465e+01	35.412990			
2.579465e+01	36.505990			
Current	Voltage	AhCha	AhDch	\
435839.000000	435839.000000	435839.000000	435839.000000	
-0.497548	3.782469	126.437695	143.968215	
85.732075	0.086605	72.927347	74.268447	
-176.603480	3.557440	0.000000	0.000000	
0.009560	3.741410	64.531000	80.996500	
0.009560	3.773560	126.152000	144.421000	
0.009560	3.813390	188.089000	207.443000	
	3.050870e+05 2.579465e+01 1.669210e-10 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 2.579465e+01 Current 435839.00000 -0.497548 85.732075 -176.603480 0.009560 0.009560	3.050870e+05 305087.000000 2.579465e+01 33.661466 1.669210e-10 2.129966 2.579465e+01 25.794650 2.579465e+01 31.806110 2.579465e+01 34.429300 2.579465e+01 35.412990 2.579465e+01 36.505990 Current Voltage 435839.000000 435839.000000 -0.497548 3.782469 85.732075 0.086605 -176.603480 3.557440 0.009560 3.741410 0.009560 3.773560	3.050870e+05 305087.000000 2.579465e+01 33.661466 1.669210e-10 2.129966 2.579465e+01 25.794650 2.579465e+01 31.806110 2.579465e+01 34.429300 2.579465e+01 35.412990 2.579465e+01 36.505990 Current Voltage AhCha 435839.000000 435839.000000 435839.000000 -0.497548 3.782469 126.437695 85.732075 0.086605 72.927347 -176.603480 3.557440 0.000000 0.009560 3.741410 64.531000 0.009560 3.773560 126.152000	3.050870e+05 305087.000000 2.579465e+01 33.661466 1.669210e-10 2.129966 2.579465e+01 25.794650 2.579465e+01 31.806110 2.579465e+01 34.429300 2.579465e+01 35.412990 2.579465e+01 36.505990 Current Voltage AhCha AhDch 435839.000000 435839.000000 435839.000000 -0.497548 3.782469 126.437695 143.968215 85.732075 0.086605 72.927347 74.268447 -176.603480 3.557440 0.000000 0.000000 0.009560 3.741410 64.531000 80.996500 0.009560 3.773560 126.152000 144.421000

4.161120

	Amb	Temp
coun	t 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, 5]_relu_earlyStop

222.893370

max

252.044000

270.765000

Restoring model weights from the end of the best epoch $\,$

Epoch 00087: early stopping

Time to train model: 931.6025130748749 seconds

lime t	o train model:	931.60251307487	49 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			
	2.626750e+01				
	2.626750e+01				
	2.626750e+01	36.386950			
max	2.626750e+01				
-		, 5]_relu_earlyS	-	,	
	-	hts from the end	of the best ep	ocn	
_	00092: early s		701-		
lime t		813.04063510894		A1-D 1	\
	Current	O	AhCha	AhDch	\
count		217919.000000			
mean	-0.973715	3.797023	63.199796	79.950900	

std	OF 000076	0.091887	36.202967	37.160824	
	85.900076				
min 25%	-176.375000	3.562210 3.761980	0.000000 31.270000	0.000000	
	0.009580			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			
	2.579465e+01	33.008410			
	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 pa	rameters: 1_[5	, 5]_relu_earlyS	top		
Restor	ing model weigh	nts from the end	of the best ep	och	
Epoch	00064: early st	topping			
Time t	o train model:	458.96764326095	58 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
       1.743350e+05
                      174335.000000
count
       2.579465e+01
                          32.297380
mean
std
       1.634608e-11
                            1.839602
                          25.794650
min
       2.579465e+01
25%
       2.579465e+01
                          31.150320
50%
       2.579465e+01
                          31.915410
75%
       2.579465e+01
                          33.882800
max
       2.579465e+01
                          35.303690
                                                                       \
                                                AhCha
                                                                AhDch
              Current
                              Voltage
       435839.000000
                       435839.000000
                                       435839.000000
                                                       435839.000000
count
           -0.497548
                             3.782469
                                           126.437695
                                                           143.968215
mean
std
           85.732075
                             0.086605
                                           72.927347
                                                            74.268447
min
         -176.603480
                             3.557440
                                             0.00000
                                                             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
          222.893370
                             4.161120
                                          252.044000
                                                           270.765000
max
                 Amb
                                Temp
       4.358390e+05
                      435839.000000
count
mean
       2.626750e+01
                          34.934164
       6.600594e-11
std
                            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
       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
       130751.000000
                                       130751.000000
                                                       130751.000000
                       130751.000000
count
           -1.256612
mean
                             3.806869
                                            38.097767
                                                            54.184753
std
           85.629164
                             0.094039
                                            21.692845
                                                            22.290556
         -176.375000
                             3.562210
                                             0.000000
                                                             0.000000
min
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
                             4.160100
                                            74.972000
                                                            92.787000
          219.878550
max
                 Amb
                                Temp
       1.307510e+05
                      130751.000000
count
mean
       2.579465e+01
                          31.534202
       4.544649e-11
                            1.455033
std
       2.579465e+01
                          25.794650
min
```

```
25%
       2.579465e+01
                          30.931720
50%
       2.579465e+01
                          31.696820
75%
       2.579465e+01
                          32.352610
       2.579465e+01
                          34.101400
max
              Current
                              Voltage
                                                AhCha
                                                                AhDch
                                                                       \
                                                       435839.000000
       435839.000000
                       435839.000000
                                       435839.000000
count
mean
           -0.497548
                             3.782469
                                           126.437695
                                                           143.968215
           85.732075
std
                             0.086605
                                            72.927347
                                                            74.268447
min
         -176.603480
                             3.557440
                                             0.000000
                                                             0.00000
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
          222.893370
                             4.161120
                                           252.044000
                                                           270.765000
max
                 Amb
                                Temp
       4.358390e+05
                      435839.000000
count
       2.626750e+01
                          34.934164
mean
       6.600594e-11
                           1.938317
std
       2.626750e+01
min
                          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
       87167.000000
                      87167.000000
                                     87167.000000
                                                                   8.716700e+04
count
                                                    87167.000000
          -0.828209
                          3.812962
                                         25.596328
                                                       41.319628
                                                                   2.579465e+01
mean
                          0.095139
                                                                   4.097368e-11
std
          85.550621
                                         14.548537
                                                       14.921958
        -176.375000
                          3.562210
                                         0.000000
                                                         0.000000
                                                                   2.579465e+01
min
25%
           0.009580
                          3.783520
                                        13.864000
                                                       29.212000
                                                                   2.579465e+01
50%
           0.009580
                          3.798830
                                        24.306000
                                                                   2.579465e+01
                                                       40.684000
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
       87167.000000
count
          30.869706
mean
           1.236341
std
          25.794650
min
25%
          30.494520
50%
          31.259620
75%
          31.696820
          32.134010
max
              Current
                                                AhCha
                                                                AhDch
                              Voltage
       435839.000000
                       435839.000000
                                       435839.000000
                                                       435839.000000
count
```

mean	-0.497548	3.782469	126.437695	143.9682	215	
std	85.732075	0.086605	72.927347	74.2684	147	
min	-176.603480	3.557440	0.000000	0.0000	000	
25%	0.009560	3.741410	64.531000	80.9965	500	
50%	0.009560	3.773560	126.152000	144.4210	000	
75%	0.009560	3.813390	188.089000	207.4430	000	
max	222.893370	4.161120	252.044000	270.7650		
				_,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,		
	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 pa	rameters: 1_[5	, 5]_relu_earlyS	Stop			
Restor	ing model weigh	hts from the end	d of the best ep	ooch		
	00057: early st		-			
-	•	174.63523507118	3225 seconds			
	Current	Voltage	AhCha	AhDch	Amb	\
count	43583.000000	•		3583.000000	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					
lliax	Current	Voltago	AhCha	۸hT)ch \	
		Voltage		AhI		
count	435839.000000	435839.000000	435839.000000	435839.0000		
mean	-0.497548	3.782469	126.437695	143.9682		
std	85.732075	0.086605	72.927347	74.2684		
min	-176.603480	3.557440	0.000000	0.0000		
25%	0.009560	3.741410	64.531000	80.9965		
50%	0.009560	3.773560	126.152000	144.4210	000	
75%	0.009560	3.813390	188.089000	207.4430	000	

```
222.893370
                           4.161120
                                        252.044000
                                                        270.765000
max
                Amb
                              Temp
      4.358390e+05 435839.000000
count
mean
       2.626750e+01
                         34.934164
       6.600594e-11
                          1.938317
std
min
      2.626750e+01
                         26.267500
25%
      2.626750e+01
                         33.803260
50%
      2.626750e+01
                         35.741030
75%
       2.626750e+01
                         36.386950
       2.626750e+01
                         37.032870
max
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)
```