

```
In [1]: pip install tensorflow
```

```
Requirement already satisfied: tensorflow in d:\virtualenv\myenv\lib\site-packages (2.16.1)
Requirement already satisfied: tensorflow-intel==2.16.1 in d:\virtualenv\myenv\lib\site-packages (from tensorflow (2.16.1))
Requirement already satisfied: absl-py>=1.0.0 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (2.1.0)
Requirement already satisfied: astunparse>=1.6.0 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (1.6.3)
Requirement already satisfied: flatbuffers>=23.5.26 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (24.3.25)
Requirement already satisfied: gast!=0.5.0,!0.5.1,!0.5.2,>=0.2.1 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (0.5.4)
Requirement already satisfied: google-pasta>=0.1.1 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (0.2.0)
Requirement already satisfied: h5py>=3.10.0 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (3.11.0)
Requirement already satisfied: libclang>=13.0.0 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (18.1.1)
Requirement already satisfied: ml-dtypes~0.3.1 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (0.3.2)
Requirement already satisfied: opt-einsum>=2.3.2 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (3.3.0)
Requirement already satisfied: packaging in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (24.1)
Requirement already satisfied: protobuf!=4.21.0,!4.21.1,!4.21.2,!4.21.3,!4.21.4,!4.21.5,<5.0.0dev,>=3.20.3 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (4.25.3)
Requirement already satisfied: requests<3,>=2.21.0 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (2.32.3)
Requirement already satisfied: setuptools in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (70.1.0)
Requirement already satisfied: six>=1.12.0 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (1.16.0)
Requirement already satisfied: termcolor>=1.1.0 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (2.4.0)
Requirement already satisfied: typing-extensions>=3.6.6 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (4.12.2)
Requirement already satisfied: wrapt>=1.11.0 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (1.16.0)
Requirement already satisfied: grpcio<2.0,>=1.24.3 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (1.64.1)
Requirement already satisfied: tensorboard<2.17,>=2.16 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (2.16.2)
Requirement already satisfied: keras>=3.0.0 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (3.4.0)
Requirement already satisfied: tensorflow-io-gcs-filesystem>=0.23.1 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (0.31.0)
Requirement already satisfied: numpy<2.0.0,>=1.23.5 in d:\virtualenv\myenv\lib\site-packages (from tensorflow-intel==2.16.1->tensorflow) (1.26.3)
Requirement already satisfied: wheel<1.0,>=0.23.0 in d:\virtualenv\myenv\lib\site-packages (from astunparse>=1.6.0->tensorflow-intel==2.16.1->tensorflow) (0.43.0)
Requirement already satisfied: rich in d:\virtualenv\myenv\lib\site-packages (from keras>=3.0.0->tensorflow-intel==2.16.1->tensorflow) (13.7.1)
Requirement already satisfied: namex in d:\virtualenv\myenv\lib\site-packages (from keras>=3.0.0->tensorflow-intel==2.16.1->tensorflow) (0.0.8)
Requirement already satisfied: optree in d:\virtualenv\myenv\lib\site-packages (from keras>=3.0.0->tensorflow-intel==2.16.1->tensorflow) (0.11.0)
Requirement already satisfied: charset-normalizer<4,>=2 in d:\virtualenv\myenv\lib\site-packages (from requests<3,>=2.21.0->tensorflow-intel==2.16.1->tensorflow) (3.3.2)
Requirement already satisfied: idna<4,>=2.5 in d:\virtualenv\myenv\lib\site-packages (from requests<3,>=2.21.0->tensorflow-intel==2.16.1->tensorflow) (3.7)
Requirement already satisfied: urllib3<3,>=1.21.1 in d:\virtualenv\myenv\lib\site-packages (from requests<3,>=2.21.0->tensorflow-intel==2.16.1->tensorflow) (2.2.2)
Requirement already satisfied: certifi>=2017.4.17 in d:\virtualenv\myenv\lib\site-packages (from requests<3,>=2.21.0->tensorflow-intel==2.16.1->tensorflow) (2024.6.2)
Requirement already satisfied: markdown>=2.6.8 in d:\virtualenv\myenv\lib\site-packages (from tensorboard<2.17,>=2.16->tensorflow-intel==2.16.1->tensorflow) (3.6)
Requirement already satisfied: tensorboard-data-server<0.8.0,>=0.7.0 in d:\virtualenv\myenv\lib\site-packages (from tensorboard<2.17,>=2.16->tensorflow-intel==2.16.1->tensorflow) (0.7.2)
Requirement already satisfied: werkzeug>=1.0.1 in d:\virtualenv\myenv\lib\site-packages (from tensorboard<2.17,>=2.16->tensorflow-intel==2.16.1->tensorflow) (3.0.3)
Requirement already satisfied: MarkupSafe>=2.1.1 in d:\virtualenv\myenv\lib\site-packages (from werkzeug>=1.0.1->tensorboard<2.17,>=2.16->tensorflow-intel==2.16.1->tensorflow) (2.1.5)
Requirement already satisfied: markdown-it-py>=2.2.0 in d:\virtualenv\myenv\lib\site-packages (from rich->keras>=3.0.0->tensorflow-intel==2.16.1->tensorflow) (3.0.0)
Requirement already satisfied: pygments<3.0.0,>=2.13.0 in d:\virtualenv\myenv\lib\site-packages (from rich->keras>=3.0.0->tensorflow-intel==2.16.1->tensorflow) (2.18.0)
Requirement already satisfied: mdurl~0.1 in d:\virtualenv\myenv\lib\site-packages (from markdown-it-py>=2.2.0->rich->keras>=3.0.0->tensorflow-intel==2.16.1->tensorflow) (0.1.2)
Note: you may need to restart the kernel to use updated packages.
```

```
[notice] A new release of pip is available: 24.1 -> 24.2
[notice] To update, run: python.exe -m pip install --upgrade pip

In [2]: import tensorflow as tf
tf.test.is_gpu_available()

WARNING:tensorflow:From C:\Users\giorg\AppData\Local\Temp\ipykernel_11240\3326022288.py:2: is_gpu_available (from tensorflow.python.framework.test_util) is deprecated and will be removed in a future version.
Instructions for updating:
Use `tf.config.list_physical_devices('GPU')` instead.

Out[2]: False

In [3]: from tensorflow.python.client import device_lib
print(device_lib.list_local_devices())

[name: "/device:CPU:0"
device_type: "CPU"
memory_limit: 268435456
locality {}
incarnation: 2186686193332498869
xla_global_id: -1
]

In [4]: pip install pandas

Requirement already satisfied: pandas in d:\virtualenv\myenv\lib\site-packages (2.2.2)
Requirement already satisfied: numpy>=1.23.2 in d:\virtualenv\myenv\lib\site-packages (from pandas) (1.26.3)
Requirement already satisfied: python-dateutil>=2.8.2 in d:\virtualenv\myenv\lib\site-packages (from pandas) (2.9.0.post0)
Requirement already satisfied: pytz>=2020.1 in d:\virtualenv\myenv\lib\site-packages (from pandas) (2024.1)
Requirement already satisfied: tzdata>=2022.7 in d:\virtualenv\myenv\lib\site-packages (from pandas) (2024.1)
Requirement already satisfied: six>=1.5 in d:\virtualenv\myenv\lib\site-packages (from python-dateutil>=2.8.2->pandas) (1.16.0)
Note: you may need to restart the kernel to use updated packages.

[notice] A new release of pip is available: 24.1 -> 24.2
[notice] To update, run: python.exe -m pip install --upgrade pip

In [5]: pip install matplotlib

Requirement already satisfied: matplotlib in d:\virtualenv\myenv\lib\site-packages (3.9.0)
Requirement already satisfied: contourpy>=1.0.1 in d:\virtualenv\myenv\lib\site-packages (from matplotlib) (1.2.1)
Requirement already satisfied: cycler>=0.10 in d:\virtualenv\myenv\lib\site-packages (from matplotlib) (0.12.1)
Requirement already satisfied: fonttools>=4.22.0 in d:\virtualenv\myenv\lib\site-packages (from matplotlib) (4.53.0)
Requirement already satisfied: kiwisolver>=1.3.1 in d:\virtualenv\myenv\lib\site-packages (from matplotlib) (1.4.5)
Requirement already satisfied: numpy>=1.23 in d:\virtualenv\myenv\lib\site-packages (from matplotlib) (1.26.3)
Requirement already satisfied: packaging>=20.0 in d:\virtualenv\myenv\lib\site-packages (from matplotlib) (24.1)
Requirement already satisfied: pillow>=8 in d:\virtualenv\myenv\lib\site-packages (from matplotlib) (10.2.0)
Requirement already satisfied: pyparsing>=2.3.1 in d:\virtualenv\myenv\lib\site-packages (from matplotlib) (3.1.2)
Requirement already satisfied: python-dateutil>=2.7 in d:\virtualenv\myenv\lib\site-packages (from matplotlib) (2.9.0.post0)
Requirement already satisfied: six>=1.5 in d:\virtualenv\myenv\lib\site-packages (from python-dateutil>=2.7->matplotlib) (1.16.0)
Note: you may need to restart the kernel to use updated packages.

[notice] A new release of pip is available: 24.1 -> 24.2
[notice] To update, run: python.exe -m pip install --upgrade pip

In [6]: import os
import pandas as pd
from matplotlib import pyplot as plt
import numpy as np
from config import Config
from utils import normalize
```

## Definitions

### Paths Declaration

Qui, di seguito, vengono riportati i path relativi al dataset di training, validation e testing. In particolare, il dataset di validation coincide con il primo dataset di testing contenuto nella cartella './LGHG2@n10C\_to\_25degC/Test'. Infatti, all'interno della directory './LGHG2@n10C\_to\_25degC/Test' sono presenti 5 possibili insiemi di dati così da poter essere sfruttati durante il testing.

```
In [7]: config = Config(
    data_dir='./data',
```

```

        train_data_subdir='train/',
        val_data_subdir='test/',
        test_data_subdir='test/'
    )

data_dir = ['test', 'train', 'val']
train_data_dir = ['TRAIN_LGHG2@n10degC_to_25degC_Norm_5Inputs.csv']
val_data_dir = ['01_TEST_LGHG2@n10degC_Norm_(05_Inputs).csv', '02_TEST_LGHG2@0degC_Norm_(05_Inputs).csv', '03_TEST_LGHG2@10degC_Norm_(05_Inputs).csv', '04_TEST_LGHG2@25degC_Norm_(05_Inputs).csv']
test_data_dir = ['01_TEST_LGHG2@n10degC_Norm_(05_Inputs).csv', '02_TEST_LGHG2@0degC_Norm_(05_Inputs).csv', '03_TEST_LGHG2@10degC_Norm_(05_Inputs).csv', '04_TEST_LGHG2@25degC_Norm_(05_Inputs).csv']

```

## Data Importing

```
In [8]: train_data_filename = os.listdir(config.get_train_data_dir())[0]
train_data_path = os.path.join(config.get_train_data_dir(), train_data_filename)

train_data = pd.read_csv(train_data_path)
train_data
```

Out[8]:

	V	I	Temp	V_avg	I_avg	SOC
0	0.385148	0.75102	0.303101	0.385148	0.75102	0.206417
1	0.385152	0.75102	0.304591	0.385150	0.75102	0.206417
2	0.385156	0.75102	0.306081	0.385152	0.75102	0.206417
3	0.385160	0.75102	0.307572	0.385154	0.75102	0.206417
4	0.385164	0.75102	0.309062	0.385156	0.75102	0.206417
...	...	...	...	...	...	...
669951	0.478843	0.75102	0.008477	0.459558	0.75102	0.283243
669952	0.478843	0.75102	0.008477	0.459699	0.75102	0.283243
669953	0.478843	0.75102	0.008477	0.459839	0.75102	0.283243
669954	0.478961	0.75102	0.008477	0.459979	0.75102	0.283243
669955	0.478961	0.75102	0.008477	0.460117	0.75102	0.283243

669956 rows × 6 columns

```
In [9]: train_data.columns

Out[9]: Index(['V', 'I', 'Temp', 'V_avg', 'I_avg', 'SOC'], dtype='object')

In [10]: X_train = train_data[['V', 'I', 'Temp', 'V_avg', 'I_avg']].values
X_train.shape
```

Out[10]: (669956, 5)

```
In [11]: X_train

Out[11]: array([[0.38514793, 0.75102009, 0.30310108, 0.38514793, 0.75102009],
   [0.38515183, 0.75102009, 0.30459129, 0.38514988, 0.75102009],
   [0.38515573, 0.75102009, 0.3060815 , 0.38515183, 0.75102009],
   ...,
   [0.47884278, 0.75102009, 0.00847709, 0.45983939, 0.75102009],
   [0.4789612 , 0.75102009, 0.00847709, 0.45997861, 0.75102009],
   [0.4789612 , 0.75102009, 0.00847709, 0.46011672, 0.75102009]])
```

```
In [12]: y_train = train_data['SOC'].values
y_train.shape
```

Out[12]: (669956,)

```
In [13]: y_train

Out[13]: array([0.20641667, 0.20641667, 0.20641667, ..., 0.28324333, 0.28324333,
   0.28324333])
```

```
In [14]: val_data_filename = os.listdir(config.get_val_data_dir())[3]
val_data_path = os.path.join(config.get_val_data_dir(), val_data_filename)

val_data = pd.read_csv(val_data_path)
val_data
```

Out[14]:

	V	I	Temp	V_avg	I_avg	SOC
0	0.966960	0.748900	0.920678	0.966960	0.748900	1.000000
1	0.966020	0.746992	0.920677	0.966490	0.747946	0.999990
2	0.965901	0.746992	0.917845	0.966294	0.747628	0.999983
3	0.965783	0.747098	0.917845	0.966166	0.747496	0.999973
4	0.965665	0.746992	0.917845	0.966066	0.747395	0.999963
...	...	...	...	...	...	...
47512	0.298614	0.751020	0.926344	0.292723	0.751020	0.136623
47513	0.298614	0.751020	0.926344	0.292761	0.751020	0.136623
47514	0.298614	0.751020	0.926344	0.292798	0.751020	0.136623
47515	0.298614	0.751020	0.929177	0.292834	0.751020	0.136623
47516	0.298614	0.751020	0.929177	0.292871	0.751020	0.136623

47517 rows × 6 columns

In [15]: 

```
X_val = val_data[['V', 'I', 'Temp', 'V_avg', 'I_avg']].values
y_val = val_data['SOC'].values
```

## Data Normalization

In [16]: 

```
normalized_X_train = normalize(X_train)
normalized_X_train
```

Out[16]: 

```
array([[-0.63365322,  1.        , -1.        , -0.63365322,  1.        ],
       [-0.63908898,  1.        , -1.        , -0.63909772,  1.        ],
       [-0.64456116,  1.        , -1.        , -0.64457869,  1.        ],
       ...,
       [ 0.26690492,  1.        , -1.        ,  0.21572031,  1.        ],
       [ 0.26722387,  1.        , -1.        ,  0.21609528,  1.        ],
       [ 0.26722387,  1.        , -1.        ,  0.21646728,  1.        ]])
```

In [17]: 

```
normalized_X_val = normalize(X_val)
normalized_X_val
```

Out[17]: 

```
array([[ 1.        , -1.        ,  0.57551079,  1.        , -1.        ],
       [ 0.99571585, -1.        ,  0.58256774,  1.        , -0.99130679],
       [ 0.99642139, -1.        ,  0.55815534,  1.        , -0.99419975],
       ...,
       [-0.98163938,  0.44653221,  1.        , -1.        ,  0.44653221],
       [-0.98183573,  0.44006032,  1.        , -1.        ,  0.44006032],
       [-0.98194943,  0.44002819,  1.        , -1.        ,  0.44002819]])
```

## FNN

### Training Parameters Declaration

In [18]: 

```
no_features = 5 # Number of inputs features (variables: V, I, Temp, V_avg, I_avg)
no_responses = 1 # Number of outputs (SOC)
no_hidden_units = 55 # Number of optimal hidden units 'N', where each hidden unit for FNN represents a Neuron.

epochs = 50 # Number of epochs
no_training = 3 # Number of training execution
mini_batch_size = 64
```

### FNN Structure

In [19]: 

```
from tensorflow import keras
from tensorflow.keras import layers
from custom import CustomLeakyReLU, CustomClippedReLU
```

In [20]: 

```
model = keras.Sequential([
    layers.Input(shape=(no_features,)),
    layers.Dense(
        no_hidden_units,
```

```

        activation=keras.activations.tanh
    ),
    layers.Dense(
        no_hidden_units,
        activation=CustomLeakyReLU(negative_slope=0.3)
    ),
    layers.Dense(
        no_responses,
        activation=CustomClippedReLU()
    )
)
])

```

```

In [21]: lr_schedule = keras.optimizers.schedules.ExponentialDecay(
    initial_learning_rate=0.01,
    decay_steps=20000,
    decay_rate=0.9,
    staircase=False
)

optimizer = keras.optimizers.SGD(
    learning_rate=lr_schedule
)

```

```

In [22]: model.compile(
    optimizer=optimizer,
    loss='mse'
)

```

```
In [23]: model.summary()
```

Model: "sequential"

Layer (type)	Output Shape	Param #
dense (Dense)	(None, 55)	330
dense_1 (Dense)	(None, 55)	3,080
dense_2 (Dense)	(None, 1)	56

Total params: 3,466 (13.54 KB)

Trainable params: 3,466 (13.54 KB)

Non-trainable params: 0 (0.00 B)

```

In [24]: for t in range(no_training):
    print(f'Start of the new training session...')
    print(f'Training session {t+1}/{no_training}')
    history = model.fit(
        x=normalized_X_train,
        y=y_train,
        epochs=epochs,
        batch_size=mini_batch_size,
        validation_data=(
            normalized_X_val,
            y_val
        ),
        verbose=1,
    )
    print('\n')

```

Start of the new training session...  
Training session 1/3  
Epoch 1/50  
**10469/10469** 12s 1ms/step - loss: 0.0154 - val\_loss: 0.0034  
Epoch 2/50  
**10469/10469** 13s 1ms/step - loss: 0.0038 - val\_loss: 0.0029  
Epoch 3/50  
**10469/10469** 12s 1ms/step - loss: 0.0034 - val\_loss: 0.0025  
Epoch 4/50  
**10469/10469** 12s 1ms/step - loss: 0.0030 - val\_loss: 0.0023  
Epoch 5/50  
**10469/10469** 13s 1ms/step - loss: 0.0028 - val\_loss: 0.0021  
Epoch 6/50  
**10469/10469** 13s 1ms/step - loss: 0.0027 - val\_loss: 0.0020  
Epoch 7/50  
**10469/10469** 15s 1ms/step - loss: 0.0025 - val\_loss: 0.0019  
Epoch 8/50  
**10469/10469** 12s 1ms/step - loss: 0.0024 - val\_loss: 0.0018  
Epoch 9/50  
**10469/10469** 11s 1ms/step - loss: 0.0024 - val\_loss: 0.0017  
Epoch 10/50  
**10469/10469** 12s 1ms/step - loss: 0.0023 - val\_loss: 0.0016  
Epoch 11/50  
**10469/10469** 13s 1ms/step - loss: 0.0023 - val\_loss: 0.0016  
Epoch 12/50  
**10469/10469** 11s 1ms/step - loss: 0.0022 - val\_loss: 0.0015  
Epoch 13/50  
**10469/10469** 12s 1ms/step - loss: 0.0022 - val\_loss: 0.0015  
Epoch 14/50  
**10469/10469** 12s 1ms/step - loss: 0.0022 - val\_loss: 0.0015  
Epoch 15/50  
**10469/10469** 13s 1ms/step - loss: 0.0022 - val\_loss: 0.0015  
Epoch 16/50  
**10469/10469** 12s 1ms/step - loss: 0.0021 - val\_loss: 0.0014  
Epoch 17/50  
**10469/10469** 12s 1ms/step - loss: 0.0021 - val\_loss: 0.0014  
Epoch 18/50  
**10469/10469** 12s 1ms/step - loss: 0.0021 - val\_loss: 0.0014  
Epoch 19/50  
**10469/10469** 12s 1ms/step - loss: 0.0021 - val\_loss: 0.0014  
Epoch 20/50  
**10469/10469** 14s 1ms/step - loss: 0.0021 - val\_loss: 0.0014  
Epoch 21/50  
**10469/10469** 12s 1ms/step - loss: 0.0021 - val\_loss: 0.0014  
Epoch 22/50  
**10469/10469** 12s 1ms/step - loss: 0.0021 - val\_loss: 0.0014  
Epoch 23/50  
**10469/10469** 12s 1ms/step - loss: 0.0021 - val\_loss: 0.0014  
Epoch 24/50  
**10469/10469** 12s 1ms/step - loss: 0.0021 - val\_loss: 0.0013  
Epoch 25/50  
**10469/10469** 14s 1ms/step - loss: 0.0021 - val\_loss: 0.0013  
Epoch 26/50  
**10469/10469** 12s 1ms/step - loss: 0.0021 - val\_loss: 0.0013  
Epoch 27/50  
**10469/10469** 15s 1ms/step - loss: 0.0020 - val\_loss: 0.0013  
Epoch 28/50  
**10469/10469** 12s 1ms/step - loss: 0.0021 - val\_loss: 0.0013  
Epoch 29/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0013  
Epoch 30/50  
**10469/10469** 14s 1ms/step - loss: 0.0020 - val\_loss: 0.0013  
Epoch 31/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0013  
Epoch 32/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0013  
Epoch 33/50  
**10469/10469** 14s 1ms/step - loss: 0.0020 - val\_loss: 0.0013  
Epoch 34/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0013  
Epoch 35/50  
**10469/10469** 17s 2ms/step - loss: 0.0020 - val\_loss: 0.0013  
Epoch 36/50  
**10469/10469** 15s 1ms/step - loss: 0.0020 - val\_loss: 0.0013  
Epoch 37/50  
**10469/10469** 15s 1ms/step - loss: 0.0020 - val\_loss: 0.0013  
Epoch 38/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0013  
Epoch 39/50  
**10469/10469** 12s 1ms/step - loss: 0.0020 - val\_loss: 0.0013  
Epoch 40/50

```

10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0013
Epoch 41/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0013
Epoch 42/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0013
Epoch 43/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0013
Epoch 44/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0013
Epoch 45/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0013
Epoch 46/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0013
Epoch 47/50
10469/10469 ━━━━━━━━ 12s 1ms/step - loss: 0.0020 - val_loss: 0.0013
Epoch 48/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0013
Epoch 49/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 50/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0013

```

Start of the new training session...

Training session 2/3

```

Epoch 1/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 2/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 3/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0013
Epoch 4/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 5/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 6/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 7/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 8/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 9/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 10/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 11/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 12/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 13/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 14/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 15/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 16/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 17/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 18/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 19/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 20/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 21/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 22/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 23/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 24/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 25/50
10469/10469 ━━━━━━━━ 15s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 26/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 27/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 28/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012

```

Epoch 29/50  
**10469/10469** 14s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 30/50  
**10469/10469** 15s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 31/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 32/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 33/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 34/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 35/50  
**10469/10469** 16s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 36/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 37/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 38/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 39/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 40/50  
**10469/10469** 14s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 41/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 42/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 43/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 44/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 45/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 46/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 47/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 48/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 49/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 50/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012

Start of the new training session...  
 Training session 3/3  
 Epoch 1/50  
**10469/10469** 15s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 2/50  
**10469/10469** 14s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 3/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 4/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 5/50  
**10469/10469** 14s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 6/50  
**10469/10469** 14s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 7/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 8/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 9/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 10/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 11/50  
**10469/10469** 15s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 12/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 13/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 14/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 15/50  
**10469/10469** 14s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 16/50  
**10469/10469** 13s 1ms/step - loss: 0.0020 - val\_loss: 0.0012  
 Epoch 17/50

```

10469/10469 ━━━━━━━━ 15s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 18/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 19/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 20/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 21/50
10469/10469 ━━━━━━━━ 15s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 22/50
10469/10469 ━━━━━━━━ 13s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 23/50
10469/10469 ━━━━━━━━ 15s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 24/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 25/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 26/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 27/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 28/50
10469/10469 ━━━━━━━━ 16s 2ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 29/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 30/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 31/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 32/50
10469/10469 ━━━━━━━━ 15s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 33/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 34/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 35/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 36/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 37/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 38/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 39/50
10469/10469 ━━━━━━━━ 16s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 40/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 41/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 42/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 43/50
10469/10469 ━━━━━━━━ 15s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 44/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 45/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 46/50
10469/10469 ━━━━━━━━ 16s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 47/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 48/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 49/50
10469/10469 ━━━━━━━━ 14s 1ms/step - loss: 0.0020 - val_loss: 0.0012
Epoch 50/50
10469/10469 ━━━━━━━━ 15s 1ms/step - loss: 0.0020 - val_loss: 0.0012

```

## Model Saving

```
In [25]: model_path = './models/dl/soc_estimation_dl.keras'
model.save(model_path)
```

## Model History

```
In [27]: hist = pd.DataFrame(history.history)
hist['epoch'] = history.epoch
hist.tail()
```

```
Out[27]: loss  val_loss  epoch
```

	loss	val_loss	epoch
45	0.001983	0.001228	45
46	0.001983	0.001228	46
47	0.001983	0.001228	47
48	0.001983	0.001228	48
49	0.001983	0.001228	49

```
In [28]: pd.DataFrame(history.history).plot(figsize=(8,5))
plt.show()
```

