



# TORQUE PREDICTION FROM EV GEARBOX

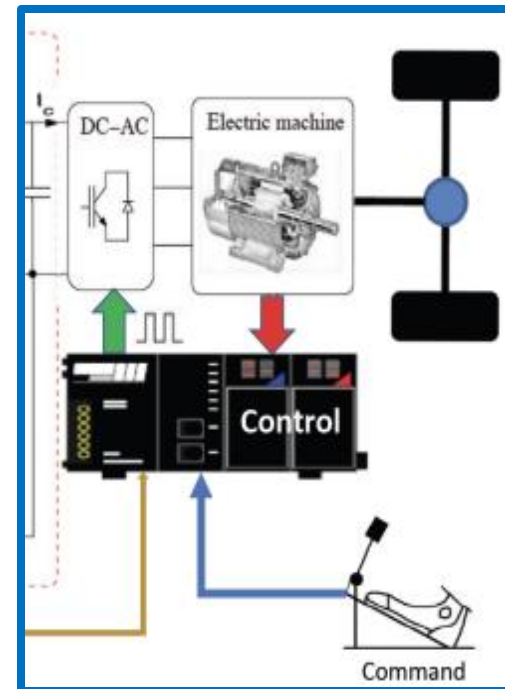
Rodrigo Pérez Salinas

Desmond Nii Ashitey Hammond

Niklas Handke

# INTRODUCTION

- **Electrical Torque estimation** is required to control electrical vehicles
- **Precise control** of the motor requires input of costly sensors (current, voltage, rpm, **torque**...)



# INTRODUCTION

- **Model of the electrical motor** uses voltage, current, flux, inductances, speed and resistance as an input
- **Electrical torque** given by equation with current and flux
- **Flux** is directly correlated to voltage, but expensive to measure
- **Task** is to approximate the solution of a fifth order differential equation

The synchronous motor modeling follows:

$$v_{ds} = r_s i_{ds} + \rho \lambda_{ds} - \omega_r \lambda_{qs} \quad 1$$

$$v_{qs} = r_s i_{qs} + \rho \lambda_{qs} + \omega_r \lambda_{ds} \quad 2$$

$$\lambda_{ds} = L_d i_{ds} + \lambda_m \quad 3$$

$$\lambda_{qs} = L_q i_{qs} \quad 4$$

The electrical torque equation is:

$$T_e = \left(\frac{3}{2}\right) \left(\frac{P}{2}\right) (\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}) \quad 5$$

And, the mechanical model of torque is

$$T_e = J \frac{d}{dt} \omega_r + B_m \omega_r + T_L \quad 6$$

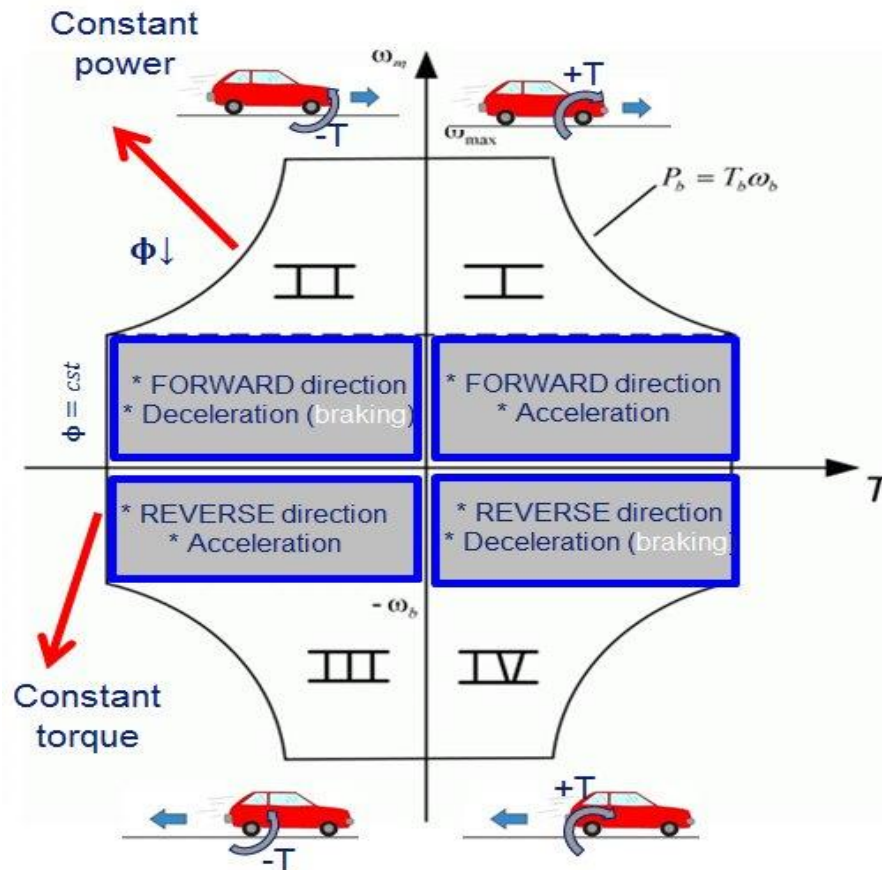
# DATASET



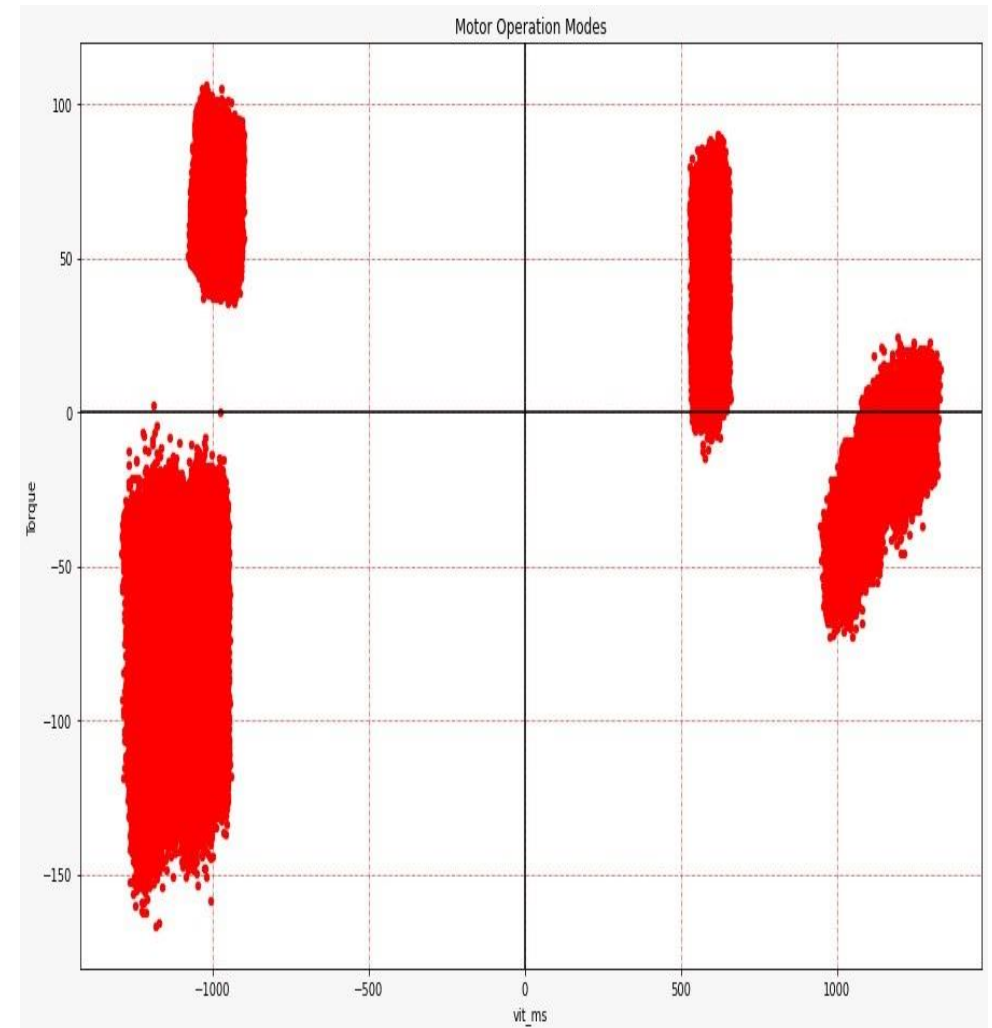
- **10** motor testbench results
- **390k** datapoints with 46 parameters each, given in Excel-sheets
- measured and **estimated** inputs and one output parameter for torque
- **Problems:**
  - No units
  - Some of the data is estimated
  - Not very balanced dataset



# DATA ISSUES



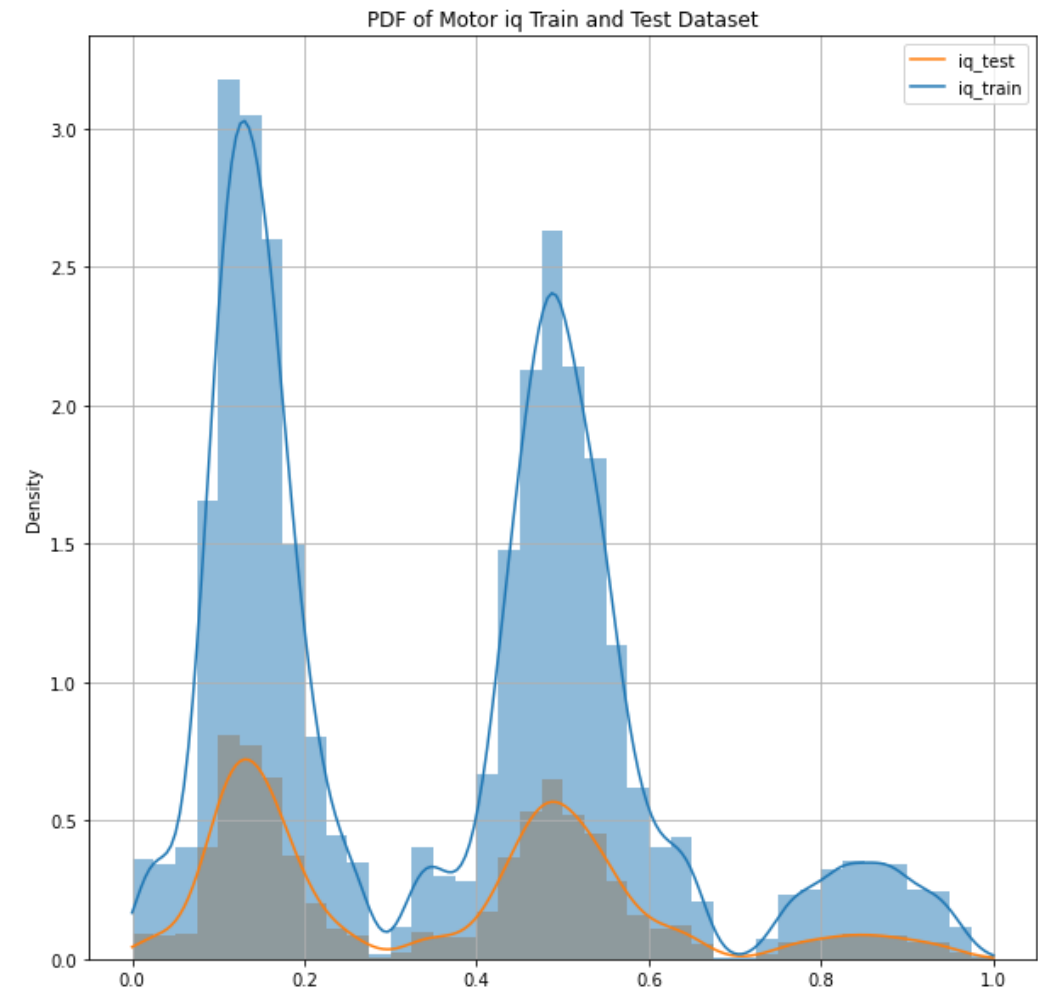
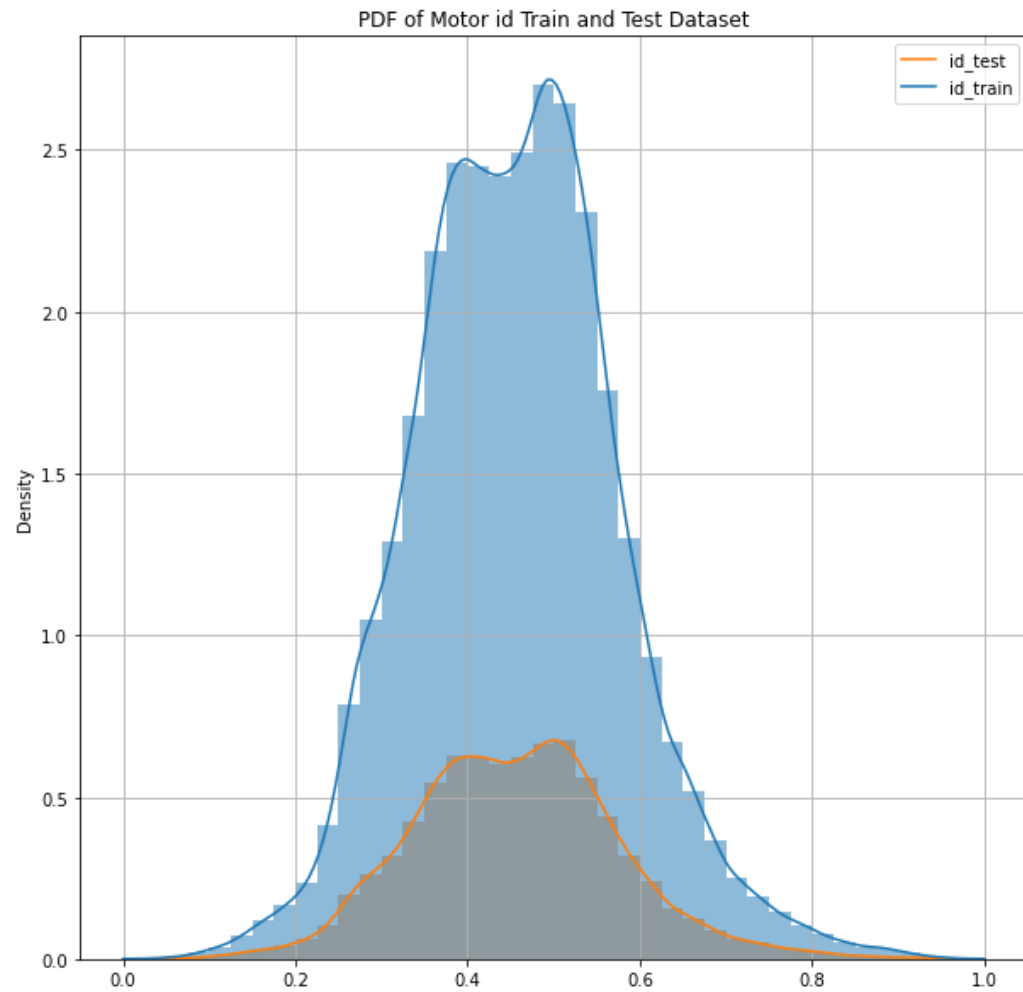
Sarrazin, Mathieu & Gillijns, Steven & Janssens, Karl & Van der Auweraer, Herman & Verhaege, Kevin. (2014). Vibro-acoustic measurements and techniques for electric automotive applications. INTERNOISE 2014 - 43rd International Congress on Noise Control Engineering: Improving the World Through Noise Control.



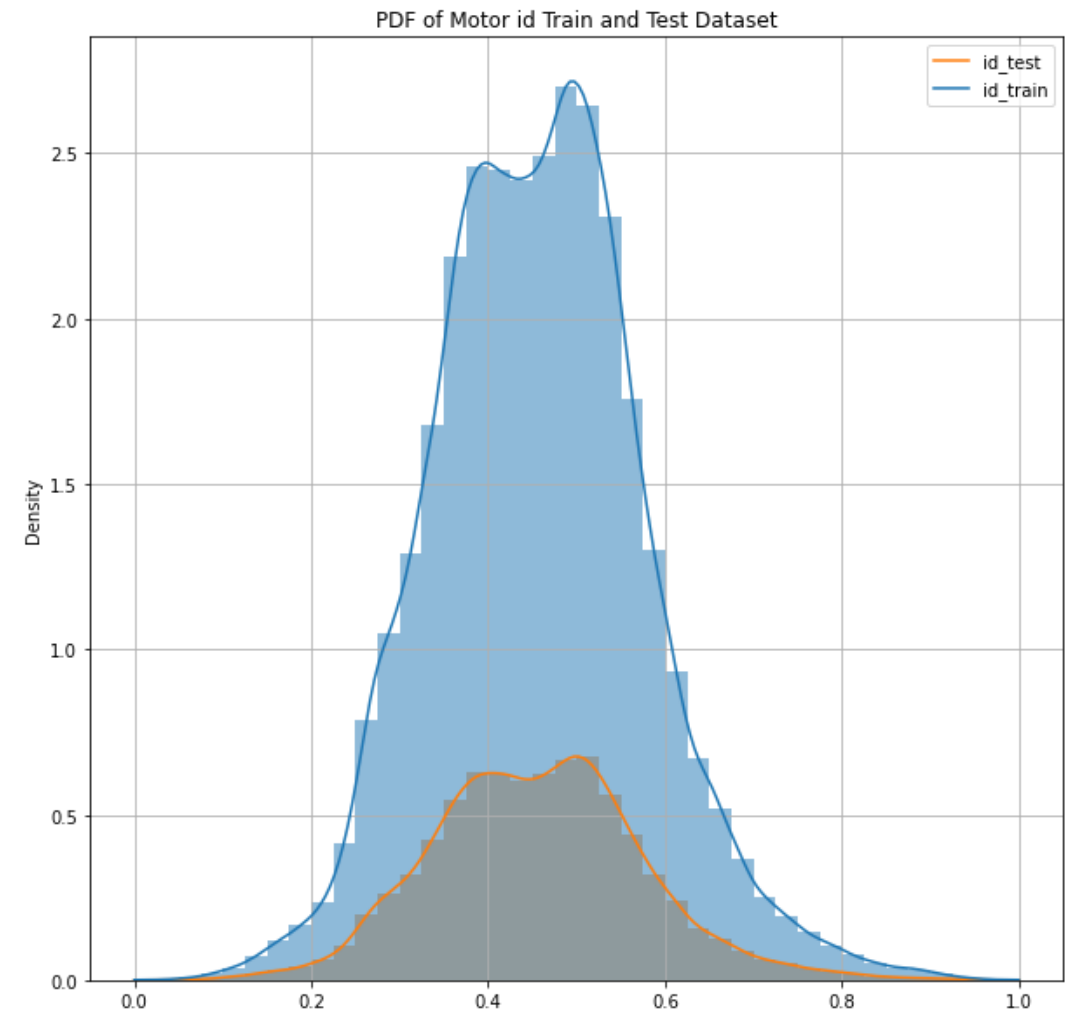
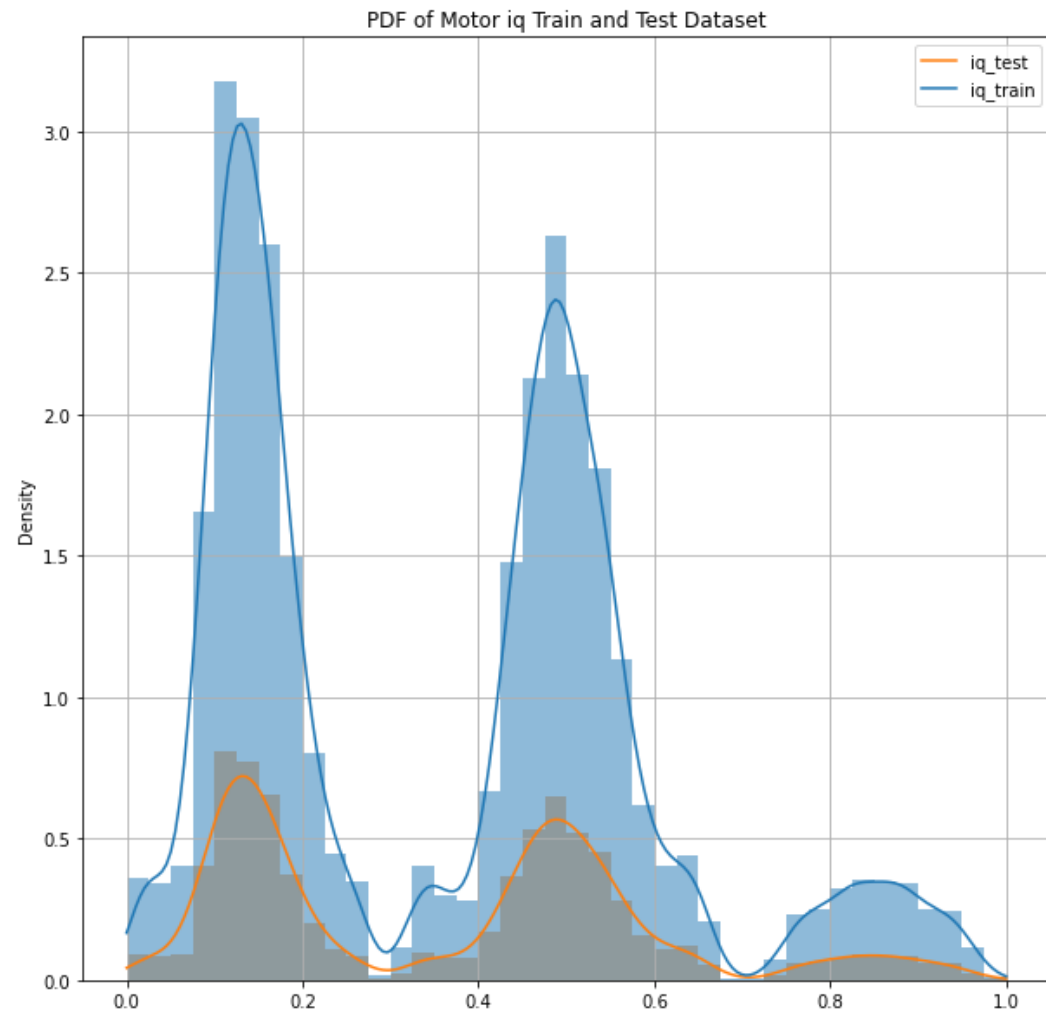
# DATA INPUT

- **4 Inputs:** 2 Currents ( $i_{ds}$  and  $i_{dq}$ ) in A and 2 voltages ( $v_d$  and  $v_q$ ) in V
- **1 output:** torque in Nm
- **Normalize** the data to the unit interval by *MinMaxScaler*
- **Training split** of 80%

# DATA DISTRIBUTION

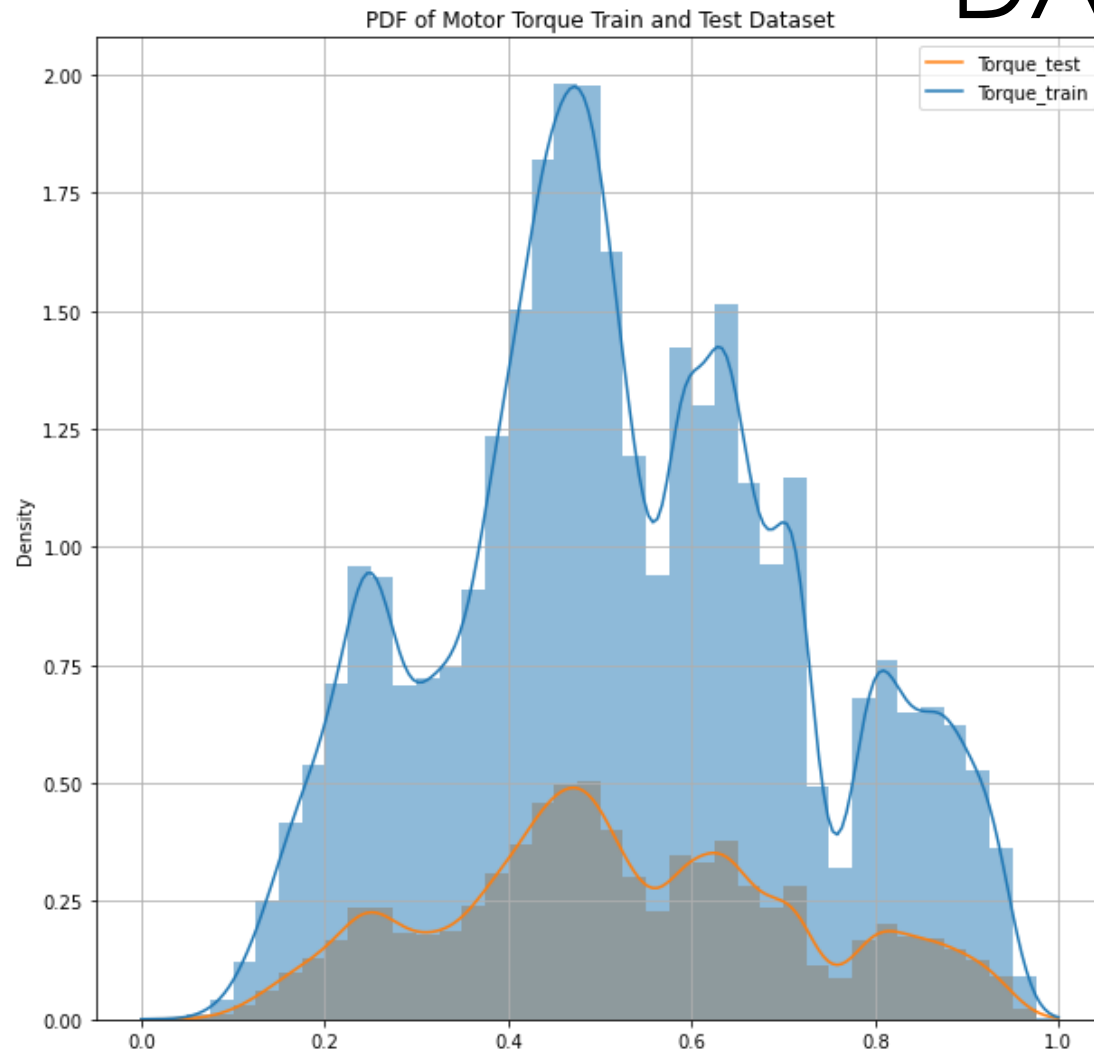


# DATA DISTRIBUTION





# DATA DISTRIBUTION



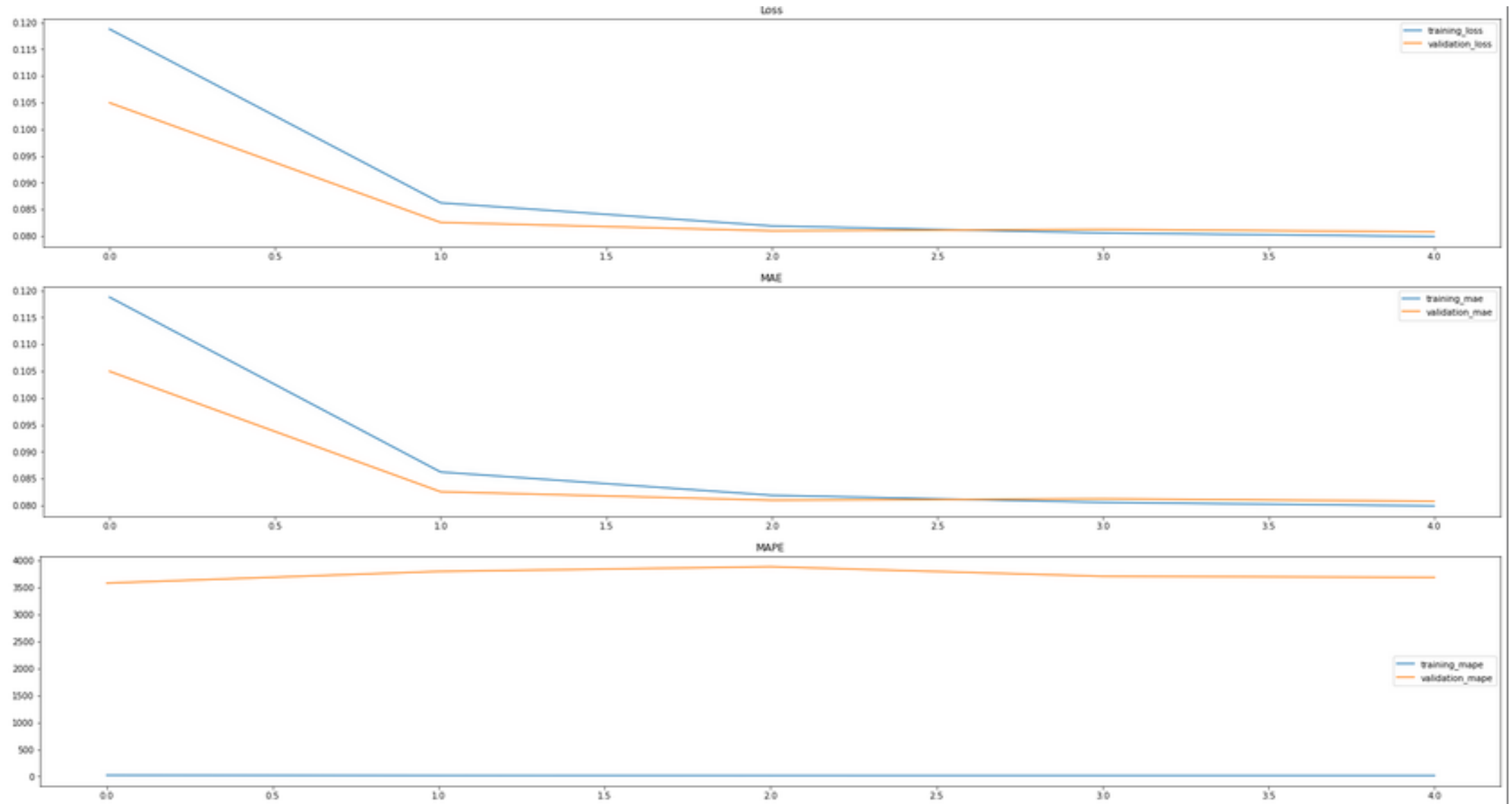
# FIRST APPROACH

EPOCHS=5

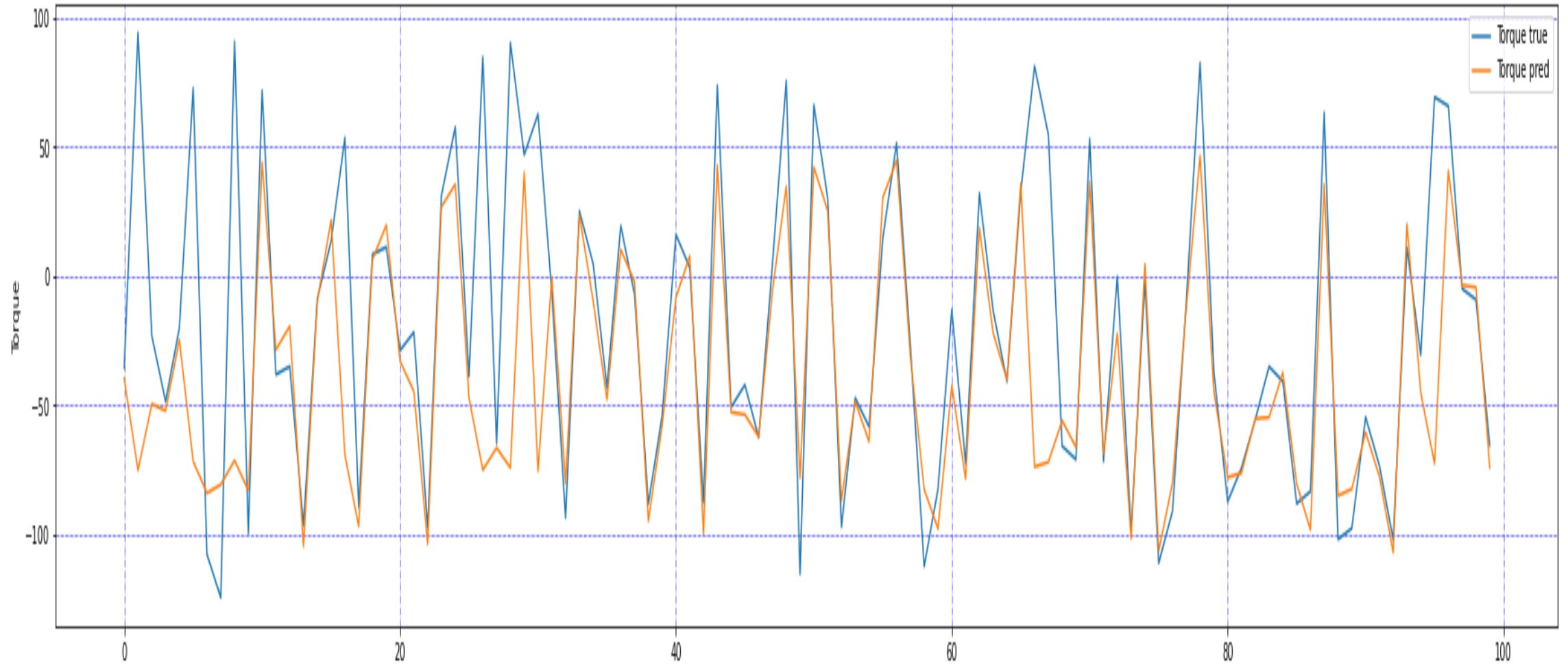
```
model = Sequential(name='Torque_Prediciton_Model')
model.add(Input(name='Input_Layer', shape=( x_train.shape[-1])))
model.add(Dense(units=50, activation='gelu', name='Hidden_Layer'))
model.add(Dense(units=y_train.shape[-1], activation='linear', name='Output_Layer'))

optimizer = Adam(learning_rate=1e-3, amsgrad=False)
model.compile(loss=['mae', 'mse', 'mape'], optimizer=optimizer, metrics=['mse', 'mape', 'mae'])
model.summary()
```

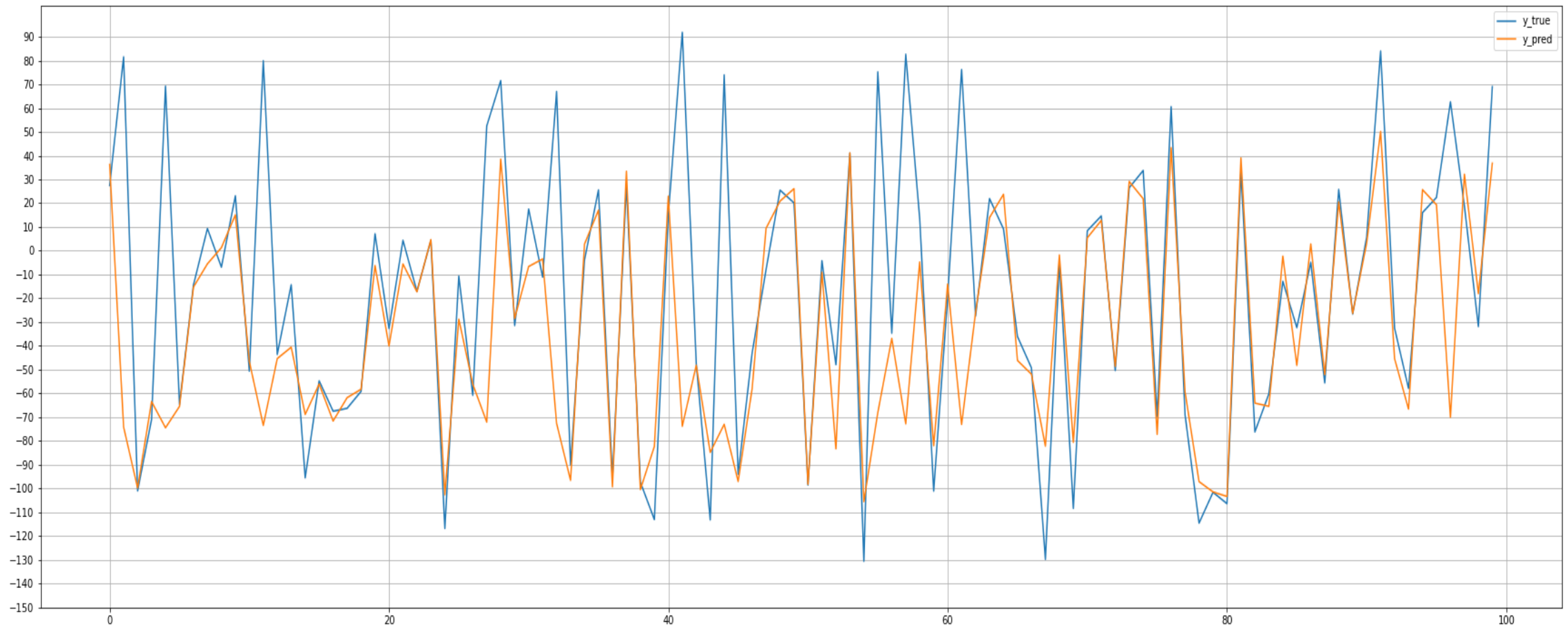
# FIRST APPROACH



# FIRST APPROACH



# FIRST APPROACH





# SECOND APPROACH

```
def create_model():
    inputs = keras.Input(name='InputLayer', shape=(num_x_signals))
    dropout=0.01
    num_layers=2
    num_units = 50
    steps = 5

    x_encode = Dense(units=num_units, activation='gelu', use_bias=True)(inputs)
    x_encode = tf.expand_dims(x_encode, axis=-2)
    x_encode = Conv1D(filters=num_units, kernel_size=4, strides=1, activation='gelu', data_format='channels_first')(x_encode)
    x_encode = Dropout(dropout)(x_encode)

    for i in range(num_layers):
        #num_units = num_units - steps
        # x_encode = LayerNormalization()(x_encode)
        x_encode = Dense(units=num_units, activation='gelu', use_bias=True)(x_encode)
        # x_encode = tf.expand_dims(x_encode), axis=1)
        #x_encode = Conv1D(filters=num_units, kernel_size=4, strides=1, activation='gelu', data_format='channels_first')(x_encode)
        x_encode = Dropout(dropout)(x_encode)

    x_encode = Flatten()(x_encode)
    x_encode = Dropout(dropout)(x_encode)
    outputs = Dense(units=num_y_signals, activation='gelu', use_bias=True, name='Output_Layer')(x_encode)

    #optimizer = Adam(learning_rate=1e-3, amsgrad=True)
    model = Model(inputs, outputs, name='Torque_Predicition_model')
    optimizer = Adam(learning_rate=1e-3, amsgrad=False)
    model.compile(loss=CustomLoss, optimizer=optimizer, metrics=['mse', 'mape', 'mae'])
    model.build((None, 1, num_x_signals))

    return model

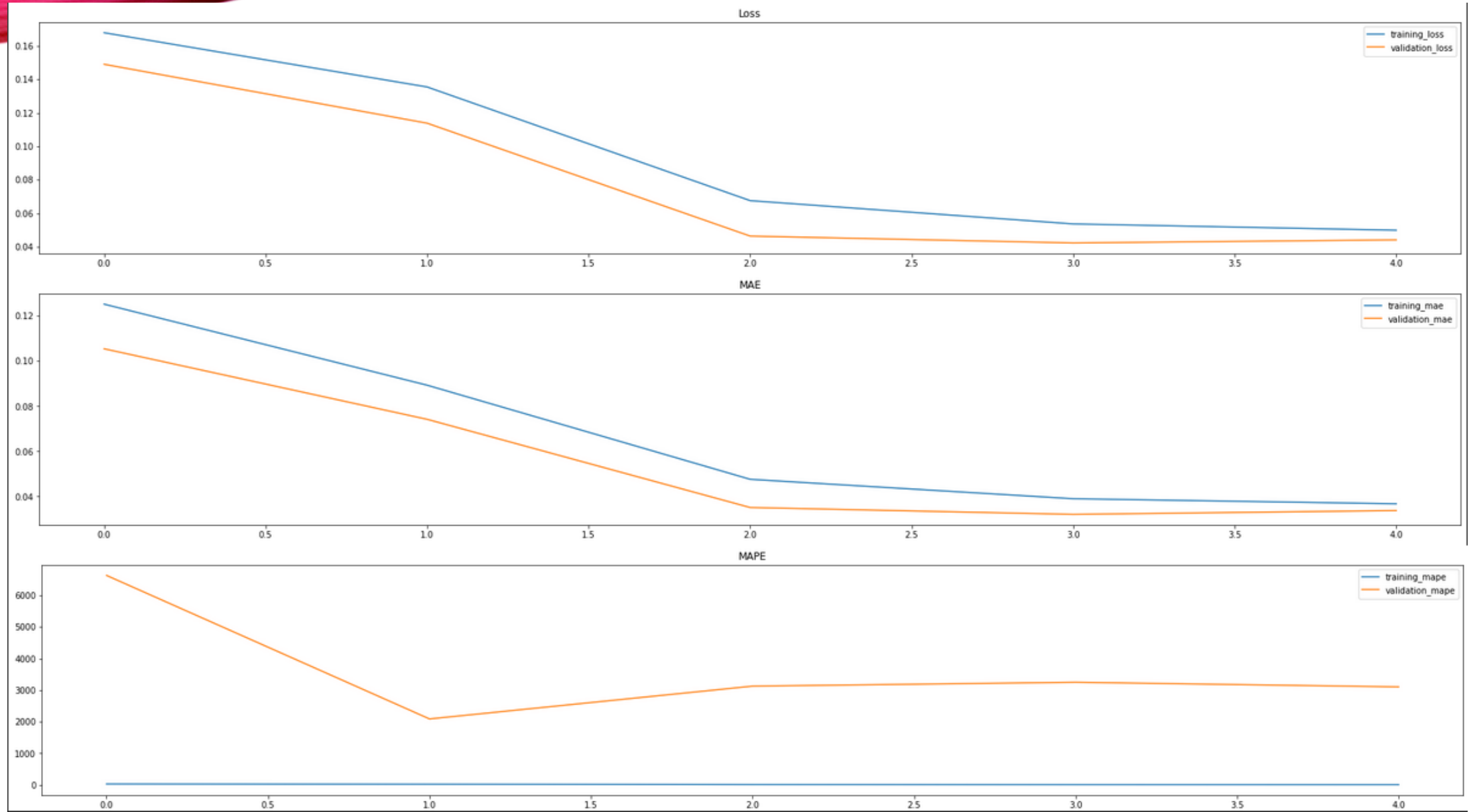
model = create_model()
model.summary()
```

# SECOND APPROACH

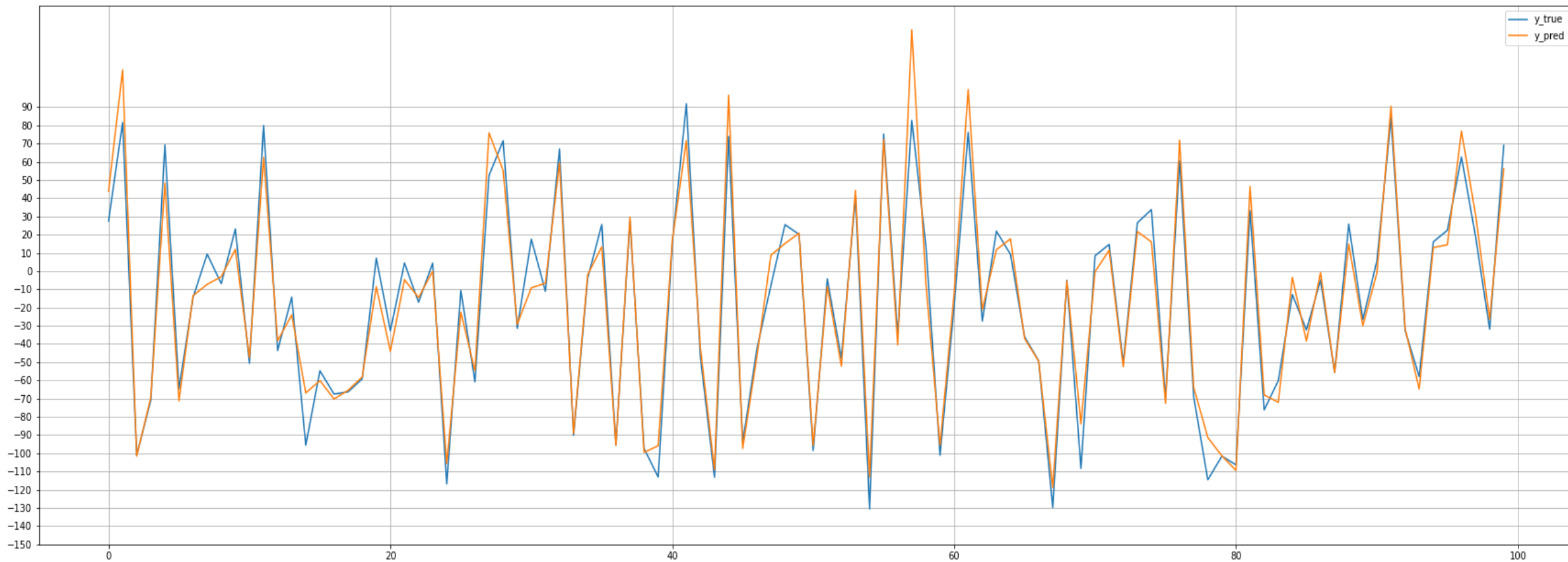
- 3 dense layers
- 1 Convolution1D layer
- 4 dropout layers

| Layer (type)                | Output Shape   | Param # |
|-----------------------------|----------------|---------|
| InputLayer (InputLayer)     | [(None, 4)]    | 0       |
| dense (Dense)               | (None, 50)     | 250     |
| tf.expand_dims (TFOpLambda) | (None, 1, 50)  | 0       |
| conv1d (Conv1D)             | (None, 50, 47) | 250     |
| dropout (Dropout)           | (None, 50, 47) | 0       |
| dense_1 (Dense)             | (None, 50, 50) | 2400    |
| dropout_1 (Dropout)         | (None, 50, 50) | 0       |
| dense_2 (Dense)             | (None, 50, 50) | 2550    |
| dropout_2 (Dropout)         | (None, 50, 50) | 0       |
| flatten (Flatten)           | (None, 2500)   | 0       |
| dropout_3 (Dropout)         | (None, 2500)   | 0       |
| Output_Layer (Dense)        | (None, 1)      | 2501    |
| Total params: 7,951         |                |         |
| Trainable params: 7,951     |                |         |
| Non-trainable params: 0     |                |         |

# SECOND APPROACH

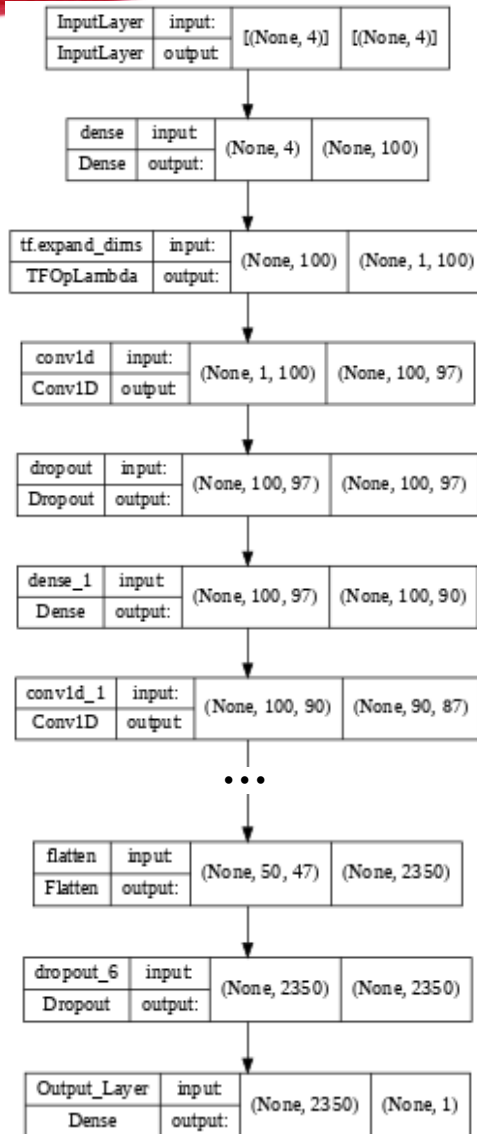


# SECOND APPROACH



# FINAL MODEL

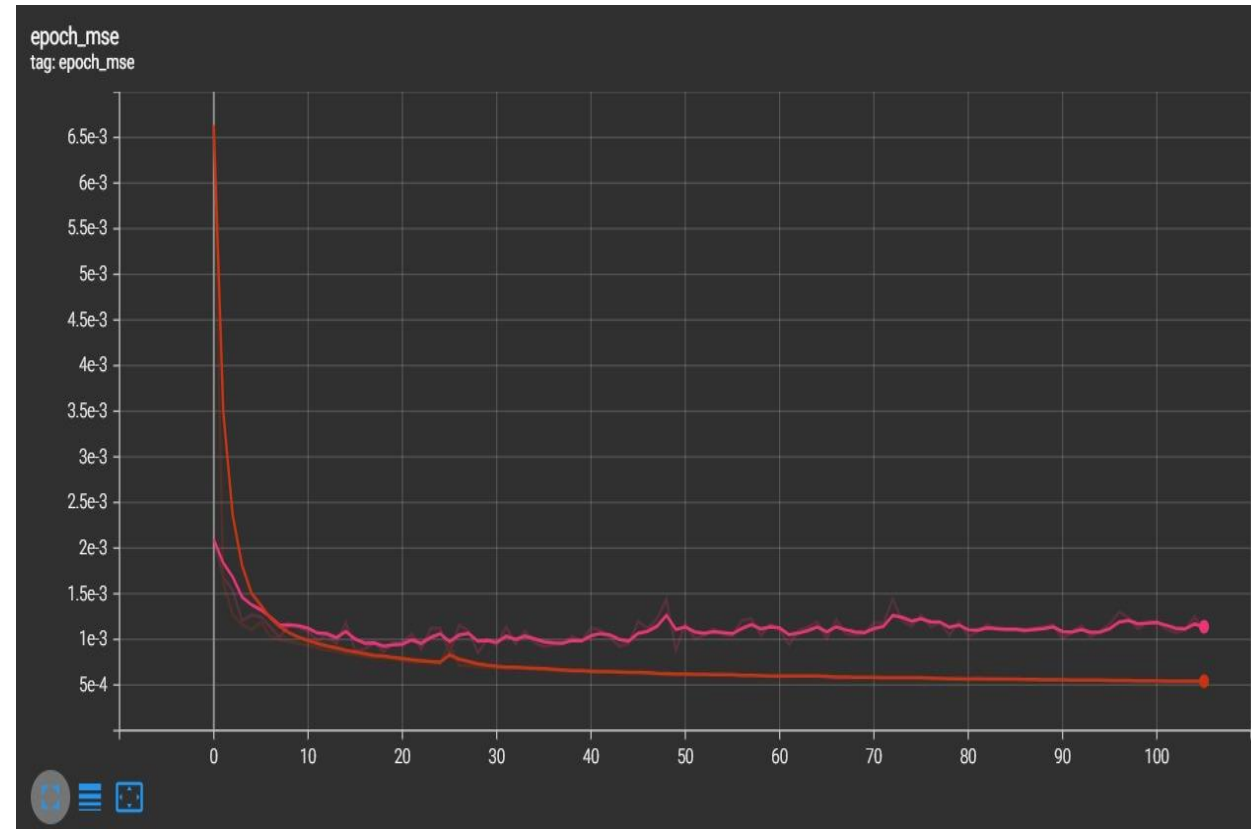
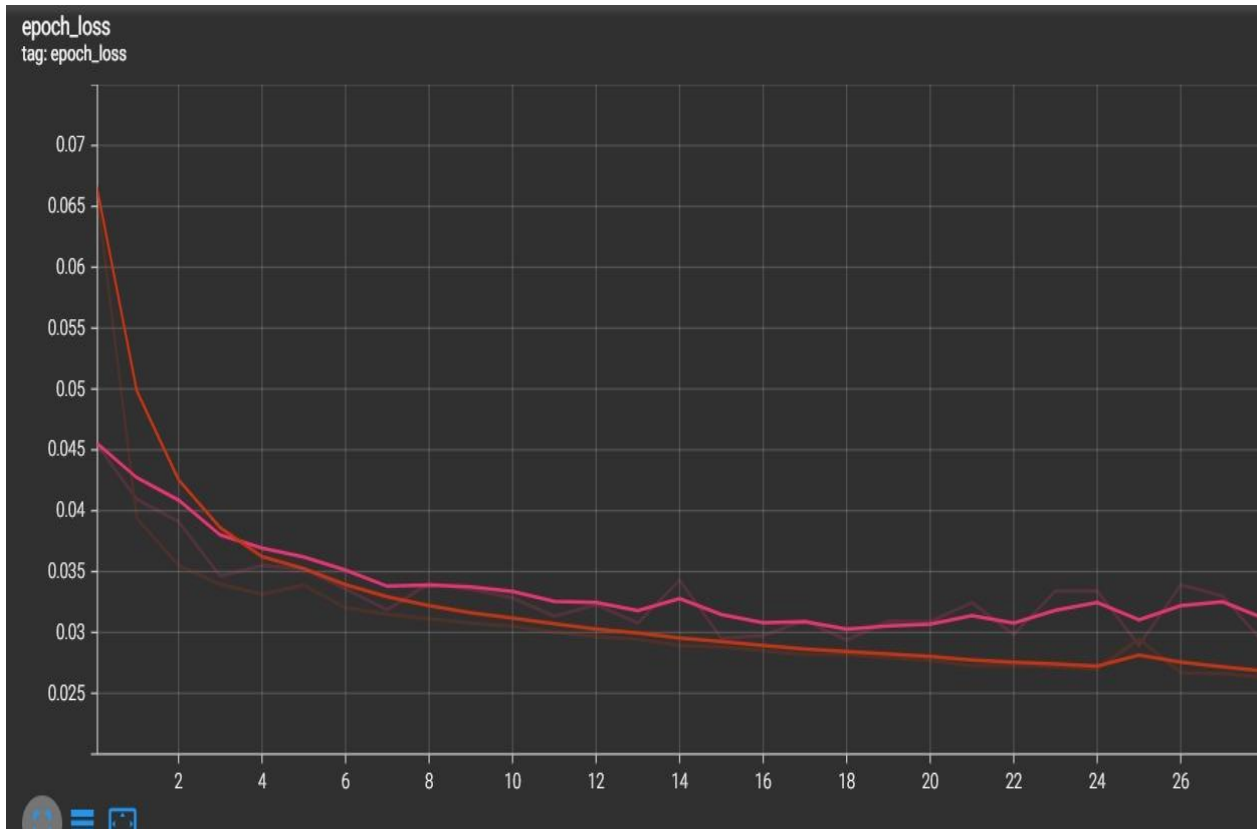
- Metrics: MAE, MSE and MAPE
- 5CNN +100 units DNN -10/step
- GeLu for CNNs and ReLu for DNNs
  - Dropout layers 0.2
- Optimizer=Adam + amsgrad
  - Batch size: 256
- Early stopping patience=40



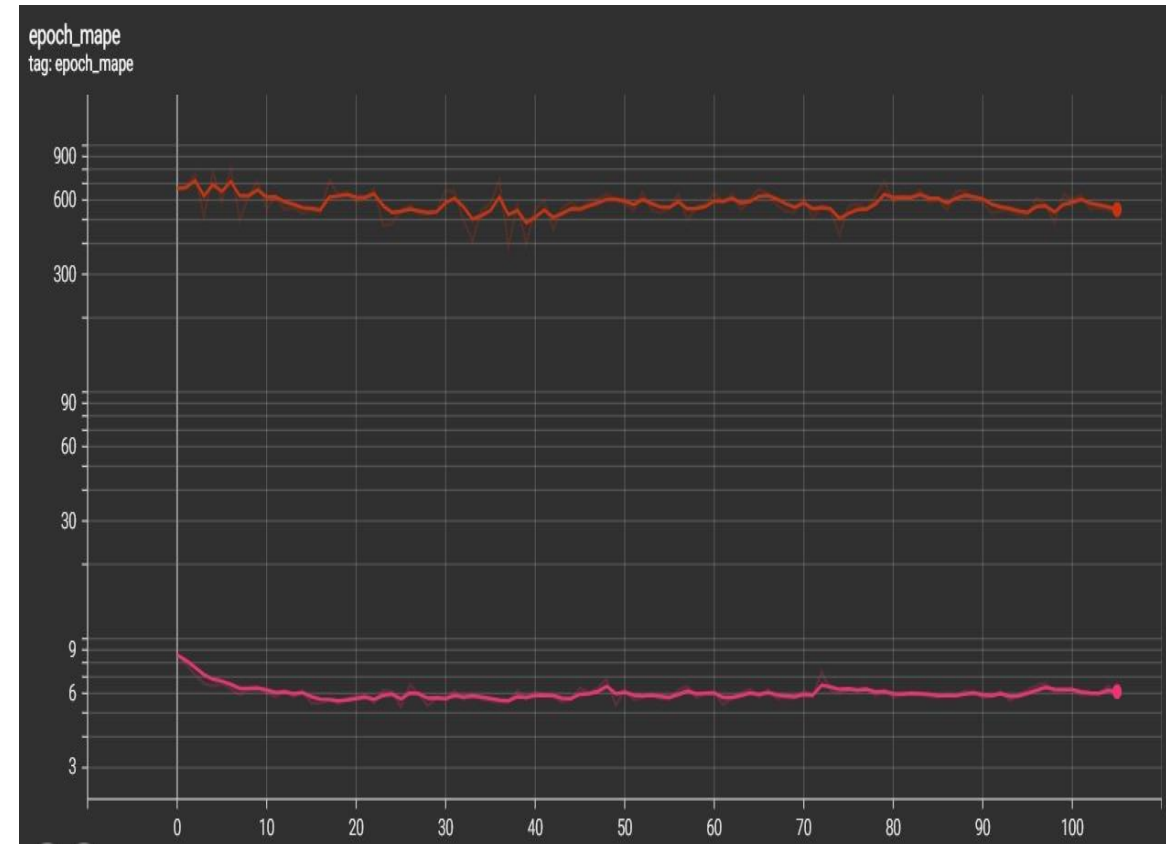
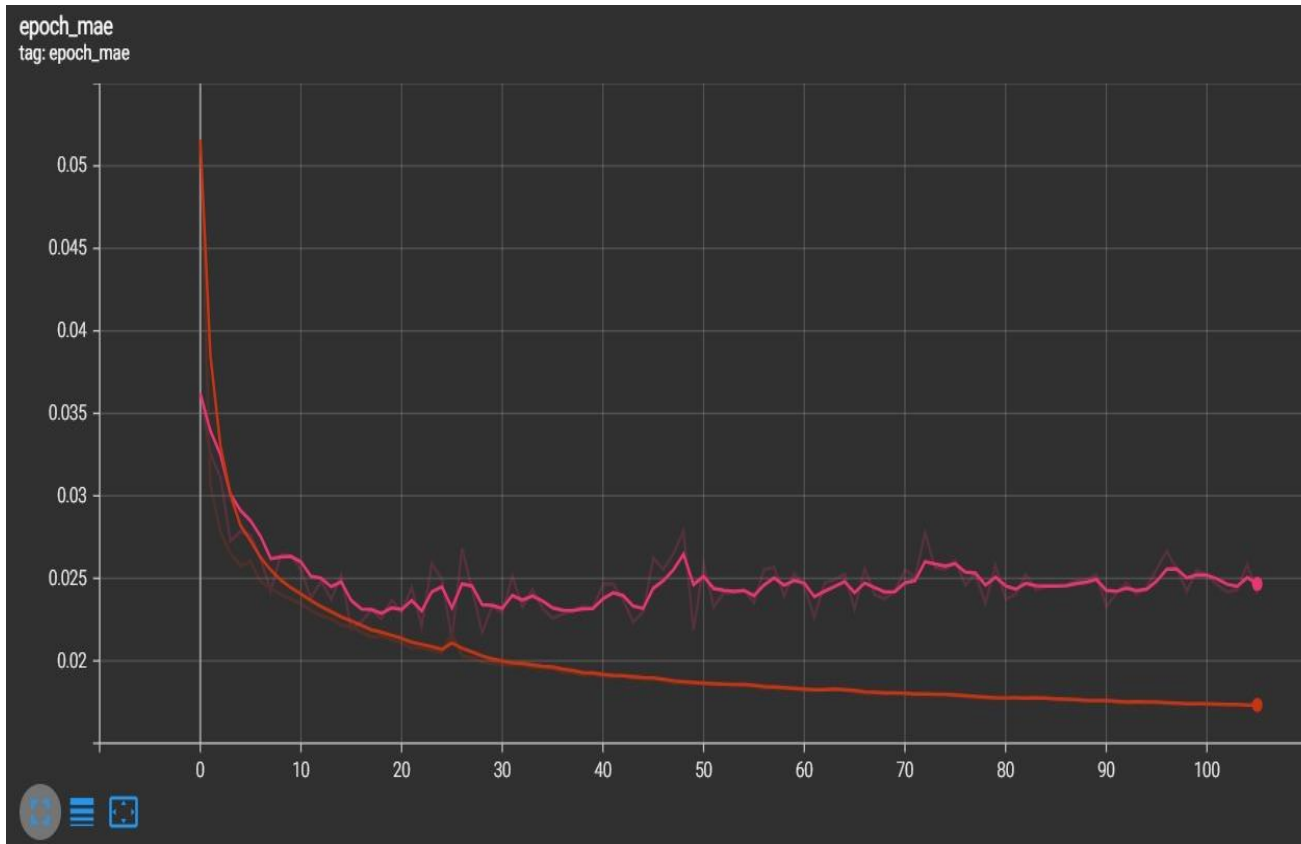
| Model: "Torque_Prediciton_model" |                 |         |
|----------------------------------|-----------------|---------|
| Layer (type)                     | Output Shape    | Param # |
| InputLayer (InputLayer)          | [(None, 4)]     | 0       |
| dense_1 (Dense)                  | (None, 100)     | 500     |
| tf.expand_dims (TFOpLambda)      | (None, 1, 100)  | 0       |
| conv1d (Conv1D)                  | (None, 100, 97) | 500     |
| dropout (Dropout)                | (None, 100, 97) | 0       |
| dense_2 (Dense)                  | (None, 100, 90) | 8820    |
| conv1d_1 (Conv1D)                | (None, 90, 87)  | 36090   |
| dropout_1 (Dropout)              | (None, 90, 87)  | 0       |
| dense_3 (Dense)                  | (None, 90, 80)  | 7040    |
| conv1d_2 (Conv1D)                | (None, 80, 77)  | 28880   |
| dropout_2 (Dropout)              | (None, 80, 77)  | 0       |
| dense_4 (Dense)                  | (None, 80, 70)  | 5460    |
| conv1d_3 (Conv1D)                | (None, 70, 67)  | 22470   |
| dropout_3 (Dropout)              | (None, 70, 67)  | 0       |
| dense_5 (Dense)                  | (None, 70, 60)  | 4080    |
| conv1d_4 (Conv1D)                | (None, 60, 57)  | 16860   |
| dropout_4 (Dropout)              | (None, 60, 57)  | 0       |
| dense_6 (Dense)                  | (None, 60, 50)  | 2900    |
| conv1d_5 (Conv1D)                | (None, 50, 47)  | 12050   |
| dropout_5 (Dropout)              | (None, 50, 47)  | 0       |
| flatten (Flatten)                | (None, 2350)    | 0       |
| dropout_6 (Dropout)              | (None, 2350)    | 0       |
| Output_Layer (Dense)             | (None, 1)       | 2351    |
| =====                            |                 |         |
| Total params: 148,001            |                 |         |
| Trainable params: 148,001        |                 |         |
| Non-trainable params: 0          |                 |         |



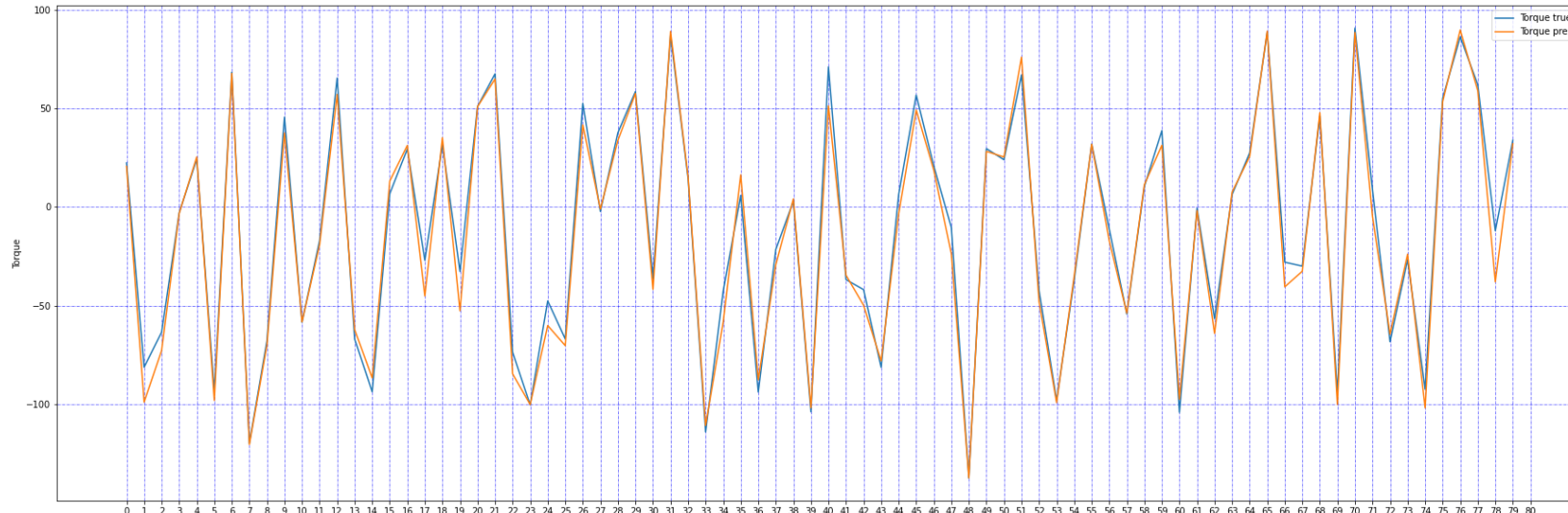
# FINAL MODEL



# FINAL MODEL



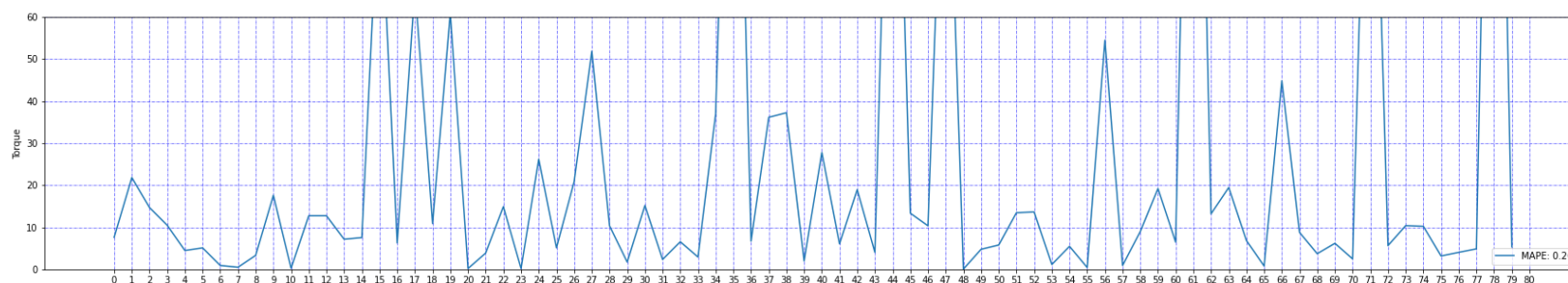
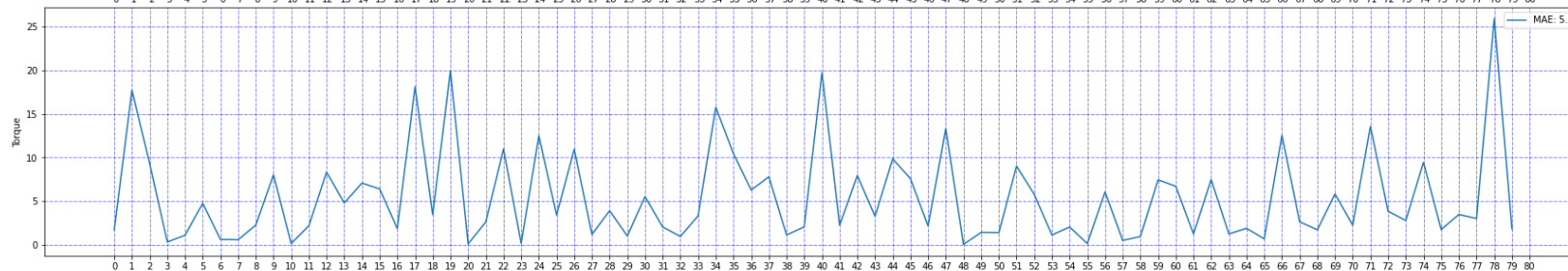
# FINAL MODEL



- **MAE = 5.4**
- **RMSE = 7.66**

Polynomial regression  
(benchmark):

- MAE = 9
- RMSE = 11



# NEXT STEPS

- Check against a simulation of a motor
- Test with a different motor
- Using the speed of the motor for a more precise model
- Real implementation requirements
  - Sampling time
  - Embedded systems
- Looking for more meaningful metrics

$$\text{MASE} = \text{mean} \left( \frac{|e_j|}{\frac{1}{T-1} \sum_{t=2}^T |Y_t - Y_{t-1}|} \right)$$



THANKS FOR LISTENING!