In [1]:

```
import numpy as np
from neural_net.neuralnet import NeuralNet
import neural_net.activation_functions as af
import pandas as pd
from matplotlib import pyplot as plt
import itertools
import json
import csv
from pylab import rcParams
import random
rcParams['figure.figsize'] = 16, 6 # resize figures
plt.style.use('bmh')
```

Preprocessign dat

In [2]:

```
with open('resources/cruzeirodosul2010daily.csv', 'r') as f:
    reader = csv.DictReader(f, delimiter=';')
    avg_temps = np.array([l['AvgTemp'] for l in reader])
    avg_temps = np.array([np.nan if l=='' else l for l in avg_temps], dtype='float64') # replace missing val
with open('resources/cruzeirodosul2010daily.csv', 'r') as f:
    reader = csv.DictReader(f, delimiter=';')
    dates = np.array([l['Date'] for l in reader], dtype='int64') / 100_000 # squish the range of dates
with open('resources/cruzeirodosul2010daily.csv', 'r') as f:
    reader = csv.DictReader(f, delimiter=';')
    inputs = np.array([[l['Precipitation'], l['Insolation'], l['Evaporation'], l['AvgHumidity'], l['WindSpee
    inputs = np.where(inputs == '', np.nan, inputs)
    inputs = np.where(inputs == '#N/A', np.nan, inputs)
    inputs = inputs.astype('float64')

dates[0:5], avg_temps[0:5], inputs
```

Out[2]:

```
(array([0.40179, 0.4018 , 0.40181, 0.40182, 0.40183]),
 array([27.14, 27.7 , 28.68, 26.4 , 24.98]),
 array([[ 0.      ,  9.5     ,  1.7     , 79.25    ,  1.666667],
        [ 0.      ,  8.7     ,  3.5     , 75.25    ,  1.      ],
        [ 0.      ,  8.3     ,  4.1     , 73.      ,  0.      ],
        ...,
        [ 5.8     ,  8.8     ,       nan, 92.      ,  1.02888 ],
        [ 0.      ,  0.2     ,       nan, 93.      ,  0.      ],
        [ 0.      ,  7.1     ,       nan, 97.      ,  0.      ]]))
```

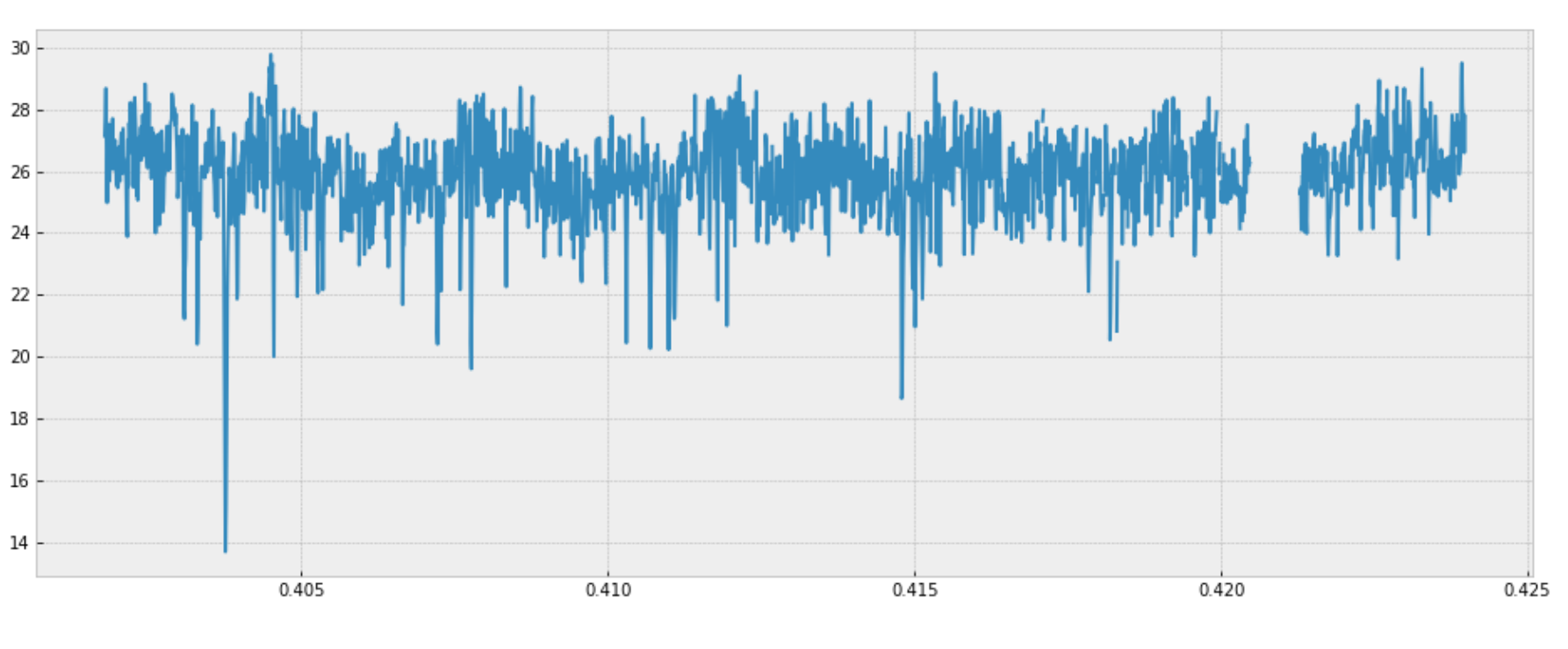
Grafické znázornění časové řady

In [3]:

```
plt.plot(dates, avg_temps)
```

Out[3]:

```
[<matplotlib.lines.Line2D at 0x7f880f832400>]
```



Doplnění chybějících hodnot

Ověření předpokladu, že se jedná o časovou řadu

In [4]:

```
np.all(np.diff(dates) > 0)
```

Out[4]:

```
True
```

Lineární interpolace chybějících dat výstupů, vypočtení popisné statistiky střední hodnota a rozptyl (pro 0 stupňů volnosti)

In [5]:

```
avg_temps_interp = NeuralNet.linear_interpolation(avg_temps)
np.mean(avg_temps_interp), np.var(avg_temps_interp)
```

Out[5]:

```
(25.887502343017804, 1.9603880733830343)
```

In [6]:

```
len(inputs), len(avg_temps_interp)
```

Out[6]:

```
(2134, 2134)
```

Aplikování normalizace, detrendování diferencí I. řádu. Chybějící data doplněna lineární interpolací

In [7]:

```
norm_avg_temps = NeuralNet.normalize(avg_temps_interp)
diff_norm_avg_temps = np.diff(norm_avg_temps)

inputs_interp = NeuralNet.linear_interpolation(inputs)
norm_inputs = NeuralNet.normalize(inputs_interp)
diff_norm_inputs = np.diff(norm_inputs, axis=0)

norm_inputs, diff_norm_inputs
```

Out[7]:

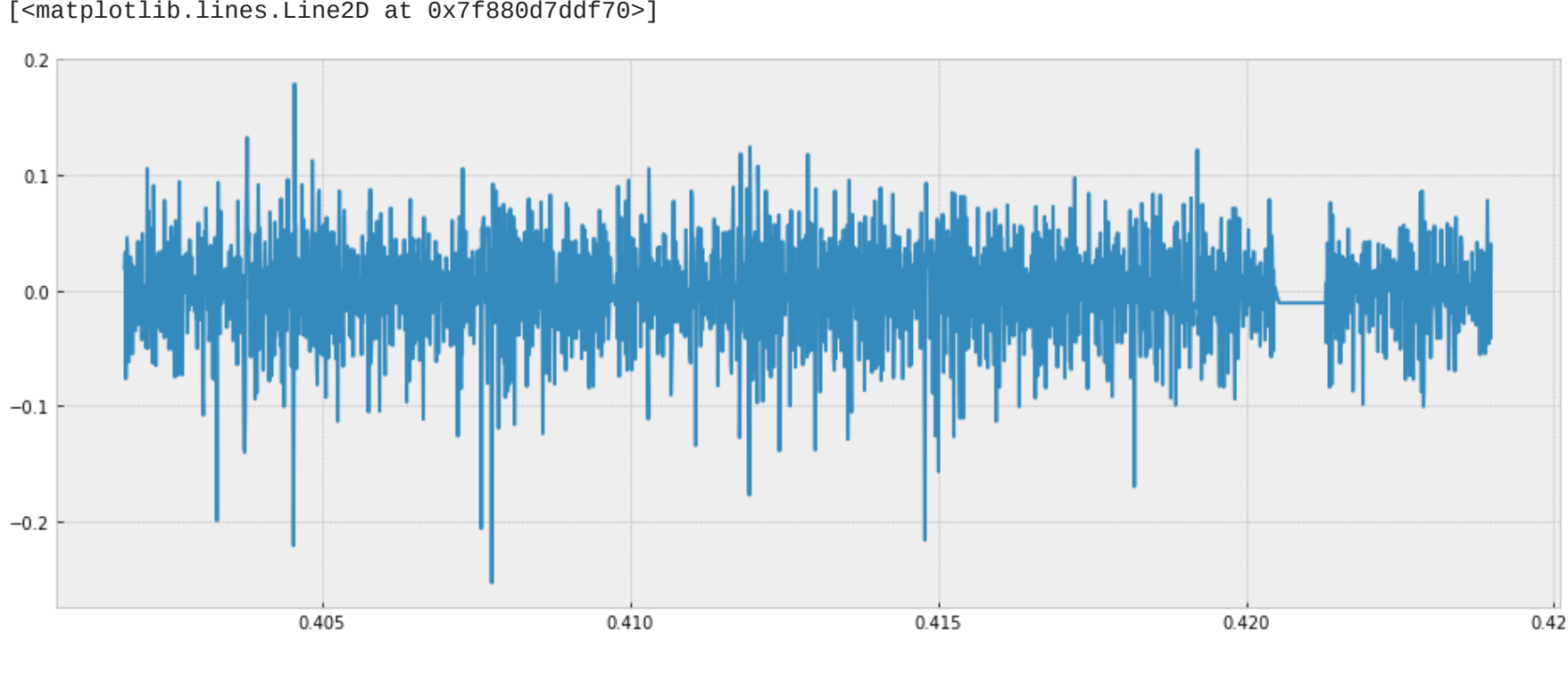
```
(array([[0.        , 0.087236  , 0.01561065, 0.72773186, 0.01530456],
        [0.        , 0.07988981, 0.03213958, 0.69100092, 0.00918274],
        [0.        , 0.07621671, 0.03764922, 0.67033976, 0.        ],
        ...,
        [0.05325987, 0.08080808, 0.00944793, 0.84481175, 0.00944793],
        [0.        , 0.00183655, 0.        , 0.85399449, 0.        ],
        [0.        , 0.06519743, 0.        , 0.89072544, 0.        ]]),
 array([[ 0.        , -0.00734619,  0.01652893, -0.03673095, -0.00612183],
        [ 0.        , -0.00367309,  0.00550964, -0.02066116, -0.00918274],
        [ 0.04224059, -0.06336088, -0.00091827,  0.07805326,  0.00918274],
        ...,
        [ 0.05325987,  0.05785124,  0.00472397,  0.03673095,  0.00472397],
        [-0.05325987, -0.07897153, -0.00944793,  0.00918274, -0.00944793],
        [ 0.        ,  0.06336088,  0.        ,  0.03673095,  0.        ]]))
```

In [8]:

```
plt.plot(dates[1:], diff_norm_avg_temps)
```

Out[8]:

```
[<matplotlib.lines.Line2D at 0x7f880d7ddf70>]
```



Úprava dat pro neuronovou síť

množina byla rozdělena na trénovací a validační v poměru 75%:25%

In [9]:

```
dataset = [(x, np.array([y])) for x, y in zip(diff_norm_inputs, diff_norm_avg_temps)]
random.shuffle(dataset)
dataset[0:5]
```

Out[9]:

```
[(array([ 0.04224059, -0.0174472 , -0.00642792,  0.07116621,  0.        ]),
  array([-0.01813298])),
 (array([-0.11753903, -0.07162534,  0.00472397, -0.04591368,  0.00472397]),
  array([0.00873069])),
 (array([-0.14233242,  0.00183655,  0.        ,  0.84481175,  0.        ]),
  array([-0.03122901])),
 (array([-0.02938476, -0.01469238,  0.00734619,  0.05050505,  0.01836547]),
  array([-0.05104097])),
 (array([ 0.17263545, -0.01469238,  0.        , -0.03673095,  0.        ]),
  array([0.00335796]))]
```

In [10]:

```
training_data, test_data = NeuralNet.ratio_list_split(dataset, 0.75)
len(training_data), len(test_data), len(dataset), training_data[0]
```

Out[10]:

```
(1599,
 534,
 2133,
 (array([ 0.04224059, -0.0174472 , -0.00642792,  0.07116621,  0.        ]),
  array([-0.01813298])))
```

Vypracování

Příprava množiny hyperparametrů

In [11]:

```
neurons = [3, 5, 10, 50]
epochs = [True]
learning_rates = [0.5, 0.1, 0.05, 0.005]
max_epochs = 200
target_test_mse = 0.001
```

In [12]:

```
params = itertools.product(neurons, epochs, learning_rates)
stats = []
for p in params:
    test_mse_list = []
    train_mse_list = []
    nn = NeuralNet([len(dataset[0][0]), p[0], len(dataset[0][1])], a_functions=[af.tanh, af.tanh], a_functio
    print(p)
    for e in nn.gradient_descent_testdata(
            labeled_training_dataset=training_data,
            labeled_test_dataset=test_data,
            no_epochs=p[1],
            mini_batch_size=128,
            learning_rate=p[2]
            ):
        print('epoch: ', e['epoch'], end='\r')
        test_mse_list.append(e['test mse'])
        train_mse_list.append(e['train mse'])
        if e['test mse'] < target_test_mse:
            result = {
                'success': True,
                'neurons input layer': nn.layer_sizes[0],
                'neurons hidden layer': p[0],
                'epochs': e['epoch'] + 1,
                'learning rate': p[2],
                'test mse list' : test_mse_list,
                'train mse list' : train_mse_list,

            }
            stats.append(result)
            print()
            print('TARGET HIT epoch', e['epoch'], '\n test mse', e['test mse'],
                  '\n train mse', e['train mse'])
            print()
            break
        if e['epoch'] > max_epochs - 1: # last epoch
            result = {
                'success': False,
                'neurons input layer': nn.layer_sizes[0],
                'neurons hidden layer': p[0],
                'epochs': e['epoch'] + 1,
                'learning rate': p[2],
                'test mse list' : test_mse_list,
                'train mse list' : train_mse_list,
            }
            stats.append(result)
            print()
            print('TARGET NOT HIT epoch', e['epoch'], '\n test mse', e['test mse'],
                  '\n train mse', e['train mse'])
            print()
            break
stats_json = json.dumps(stats)
with open('resources/stats_avgtemp.json', 'w') as f:
    f.write(stats_json)
```

```
(3, True, 0.5)
epoch:  200
TARGET NOT HIT epoch 200
 test mse 0.0012008097790070613
 train mse 9.362901404400406e-06

(3, True, 0.1)
epoch:  200
TARGET NOT HIT epoch 200
 test mse 0.0020712703270952134
 train mse 1.6075633671463267e-05

(3, True, 0.05)
epoch:  200
TARGET NOT HIT epoch 200
 test mse 0.001995691842135323
 train mse 1.5771027640289893e-05

(3, True, 0.005)
epoch:  200
TARGET NOT HIT epoch 200
 test mse 0.004111418215005452
 train mse 3.0002954369637797e-05

(5, True, 0.5)
epoch:  200102
TARGET NOT HIT epoch 200
 test mse 0.0011864012863707278
 train mse 1.2127206026972974e-05

(5, True, 0.1)
epoch:  200
TARGET NOT HIT epoch 200
 test mse 0.0015116135967505873
 train mse 1.237000057576986e-05

(5, True, 0.05)
epoch:  200118
TARGET NOT HIT epoch 200
 test mse 0.001769603080845378
 train mse 1.4468875444265574e-05

(5, True, 0.005)
epoch:  200
TARGET NOT HIT epoch 200
 test mse 0.0037766321628151943
 train mse 3.86207576447209e-05

(10, True, 0.5)
epoch:  200
TARGET NOT HIT epoch 200
 test mse 0.001015293928698602
 train mse 8.080594245097546e-06

(10, True, 0.1)
epoch:  200
TARGET NOT HIT epoch 200
 test mse 0.0012941817378249695
 train mse 1.044363325126191e-05

(10, True, 0.05)
epoch:  200
TARGET NOT HIT epoch 200
 test mse 0.001972248258661035
 train mse 1.6439216180699284e-05

(10, True, 0.005)
epoch:  2003
TARGET NOT HIT epoch 200
 test mse 0.005722882806281198
 train mse 7.744383884404097e-05

(50, True, 0.5)
epoch:  200
TARGET NOT HIT epoch 200
 test mse 0.0011192374356787623
 train mse 7.40148280684455e-06

(50, True, 0.1)
epoch:  200
TARGET NOT HIT epoch 200
 test mse 0.0019166952471827408
 train mse 1.3740396755756245e-05

(50, True, 0.05)
epoch:  200
TARGET NOT HIT epoch 200
 test mse 0.04182566998471841
 train mse 0.0003674476158181378

(50, True, 0.005)
epoch:  200
TARGET NOT HIT epoch 200
 test mse 0.021456680503832176
 train mse 0.0001534253634078429
```

Citlivostní analýza

tabulka hyperparametrů

In [13]:

```
df = pd.read_json('resources/stats_avgtemp.json')
df[['neurons input layer', 'neurons hidden layer', 'epochs', 'learning rate']]
```

Out[13]:

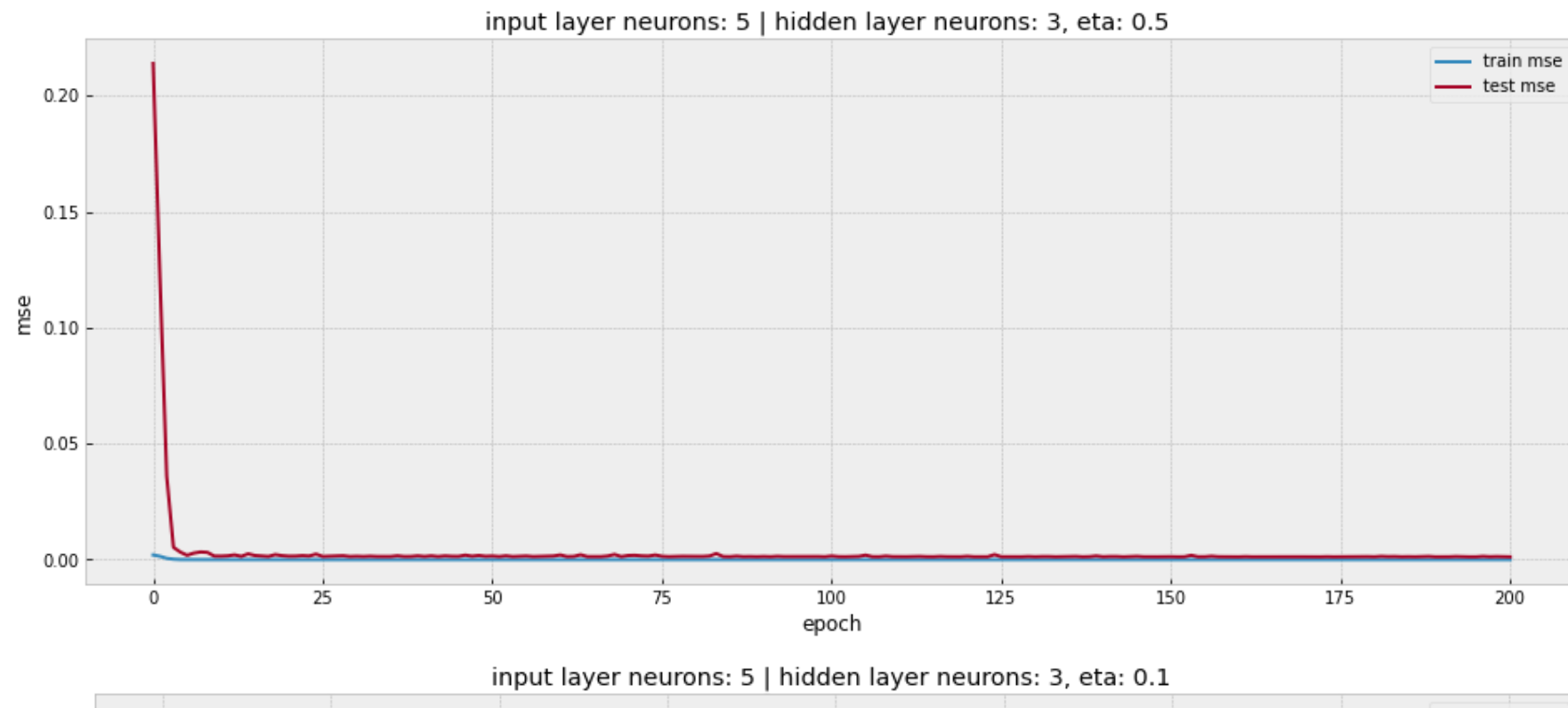
	neurons input layer	neurons hidden layer	epochs	learning rate
0	5	3	201	0.500
1	5	3	201	0.100
2	5	3	201	0.050
3	5	3	201	0.005
4	5	5	201	0.500
5	5	5	201	0.100
6	5	5	201	0.050
7	5	5	201	0.005
8	5	10	201	0.500
9	5	10	201	0.100
10	5	10	201	0.050
11	5	10	201	0.005
12	5	50	201	0.500
13	5	50	201	0.100
14	5	50	201	0.050
15	5	50	201	0.005

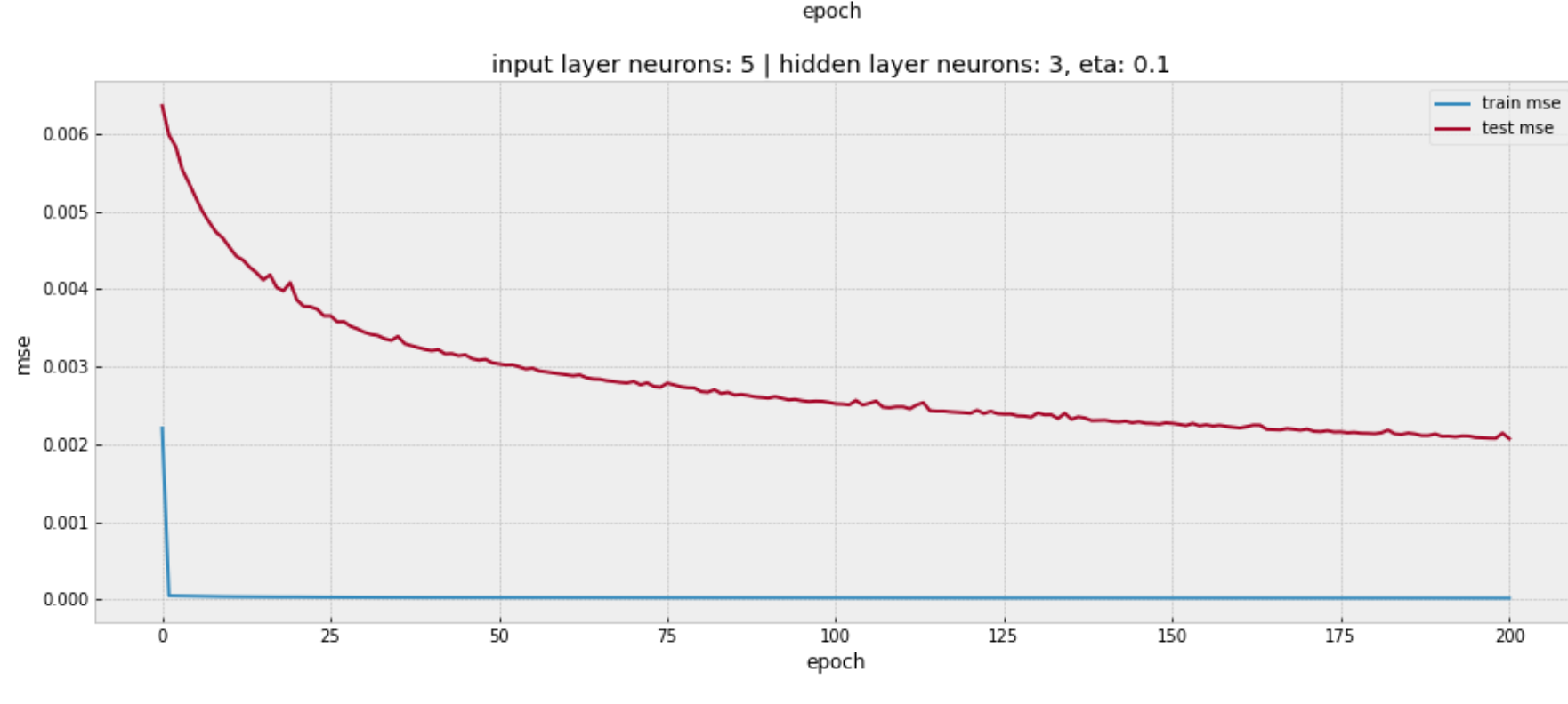
In [14]:

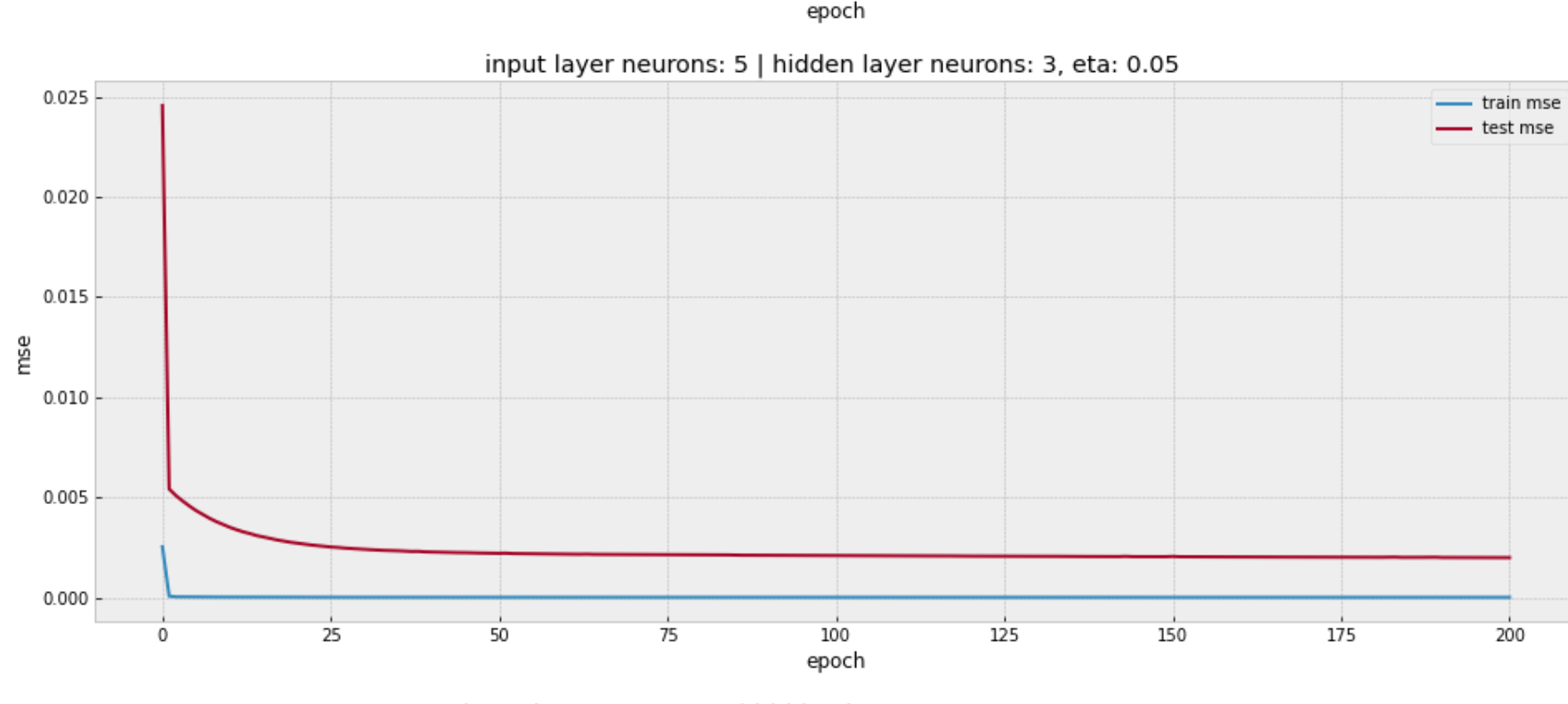
```
# fig.set_xlim([0,200])
# fig.set_ylim([0,0.05])

# plt.plot(df['mse list'], label='mse')
for i in range(15):
    plt.plot(df['train mse list'][i], label='train mse')
    plt.plot(df['test mse list'][i], label='test mse')
    plt.title('input layer neurons: {} | hidden layer neurons: {}, eta: {} '.format(df['neurons input layer'
    plt.xlabel('epoch')
    plt.ylabel('mse')
    plt.legend()
    ax, fig = plt.subplots()
plt.plot(df['train mse list'][15], label='train mse')
plt.plot(df['test mse list'][15], label='test mse')
plt.title('input layer neurons: {} | hidden layer neurons: {}, eta: {} '.format(df['neurons input layer'][15
plt.xlabel('epoch')
plt.ylabel('mse')
plt.legend()
```

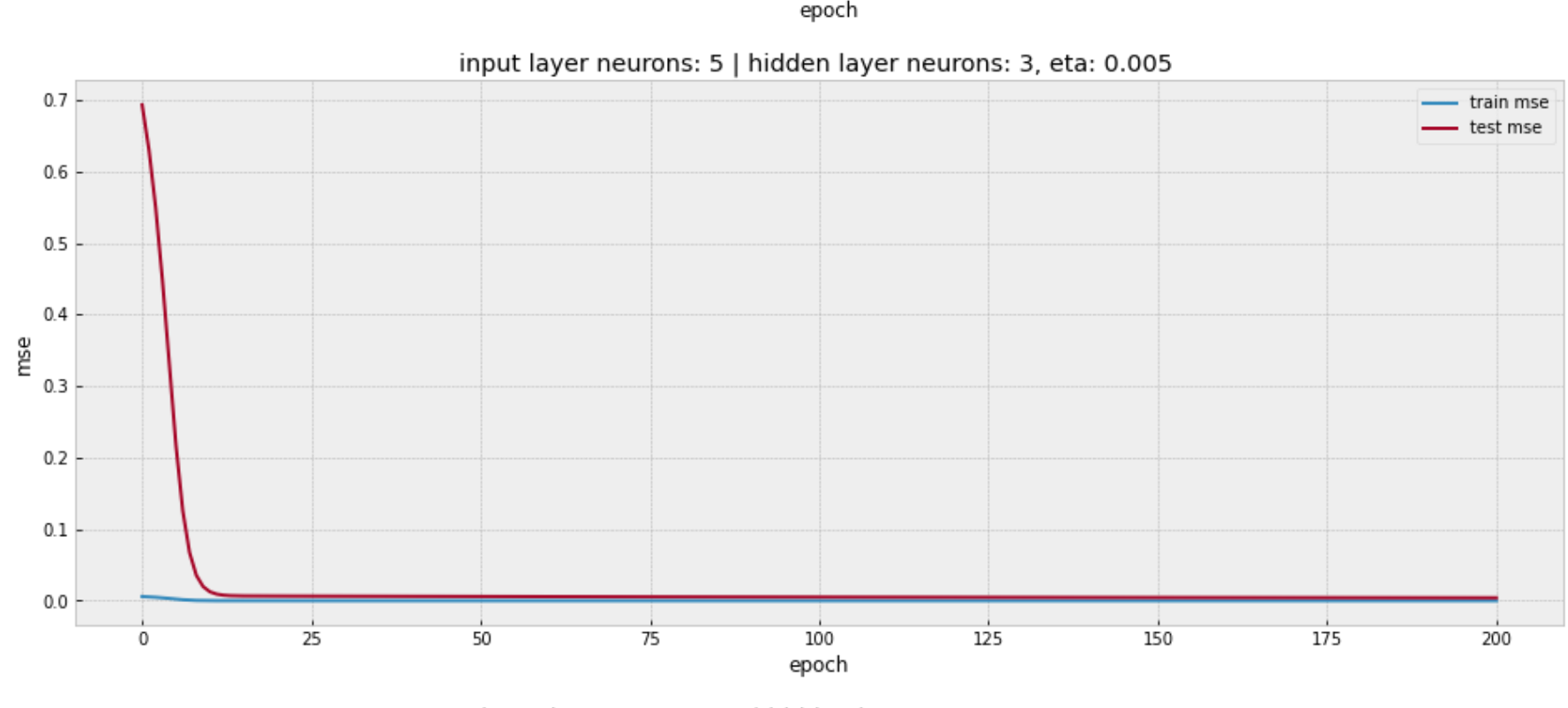
Out[14]:

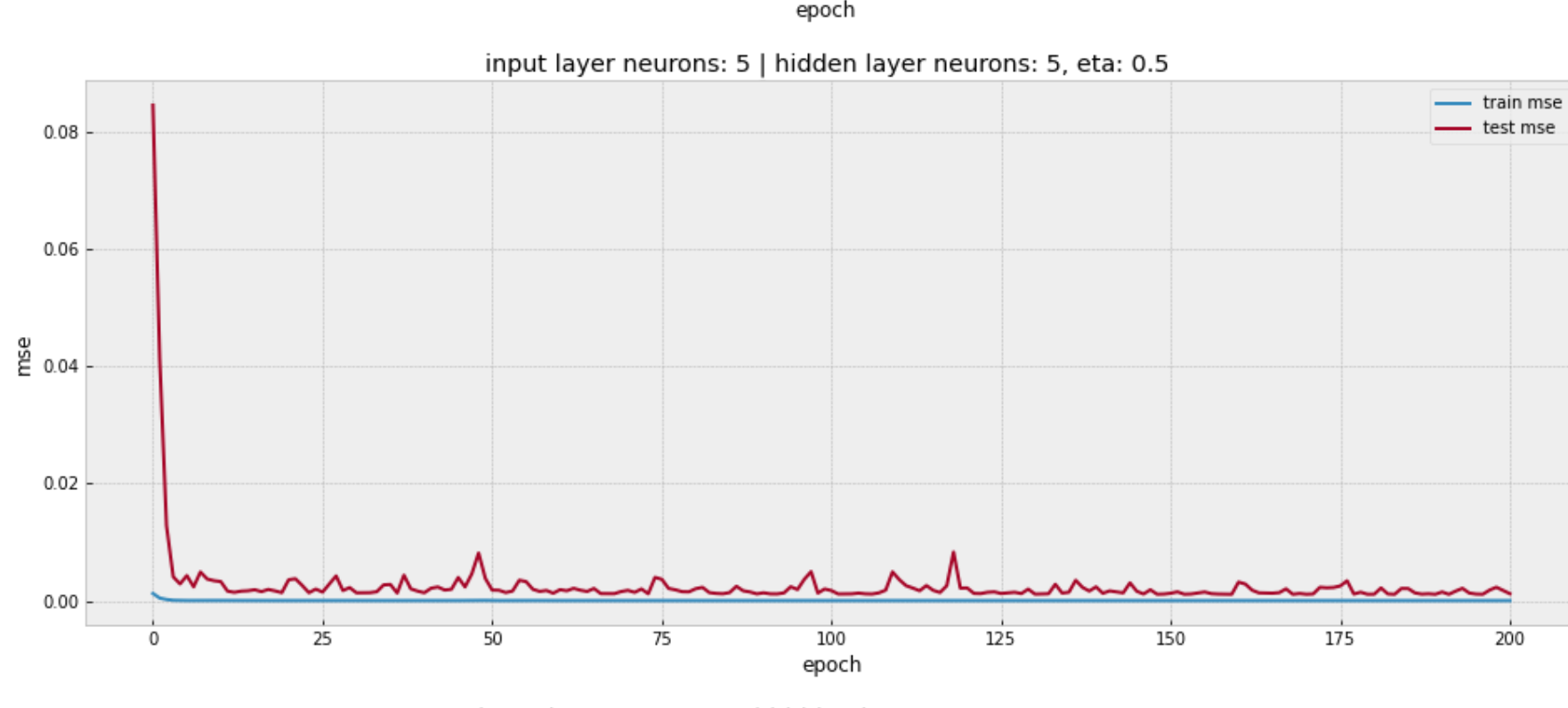
```
<matplotlib.legend.Legend at 0x7fdba427b310>
```

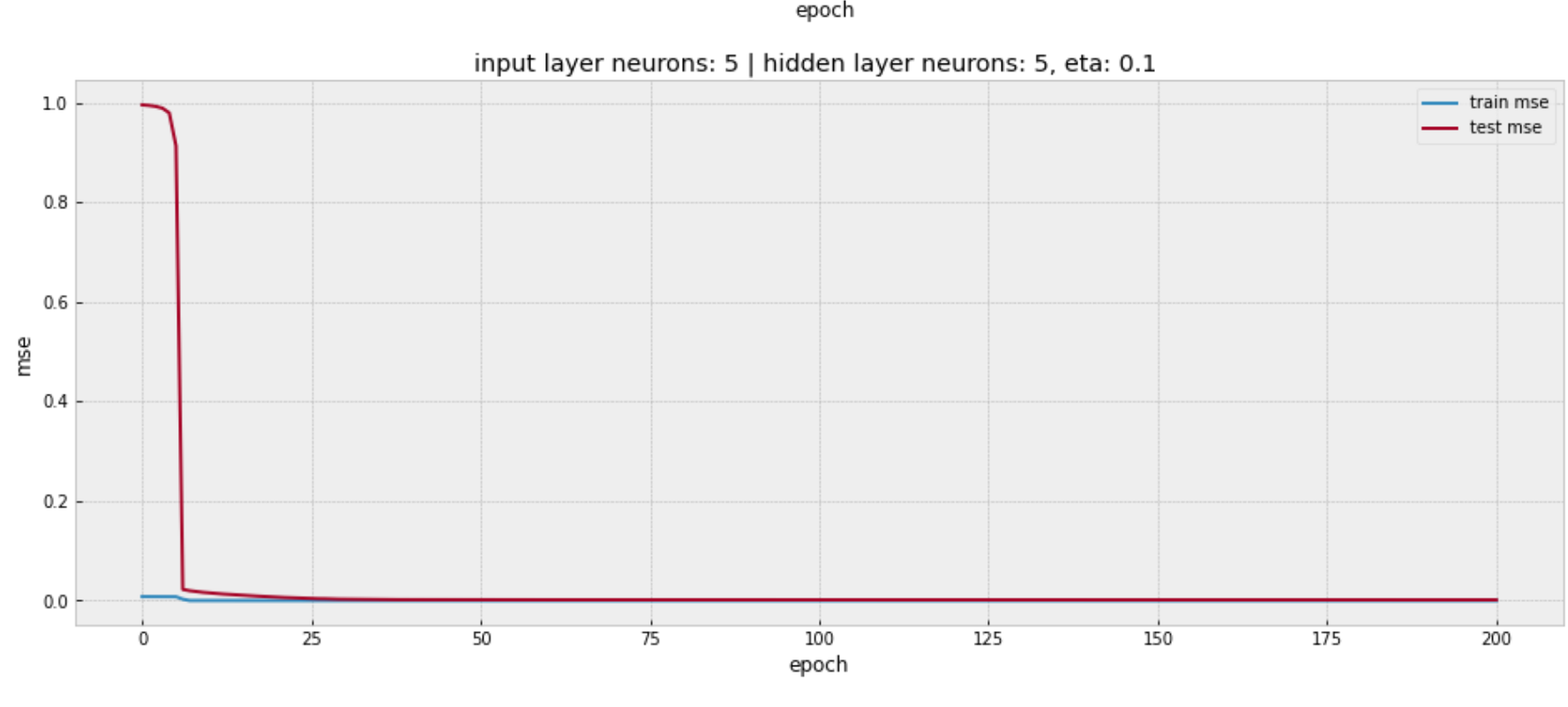

input layer neurons: 5 | hidden layer neurons: 3, eta: 0.5

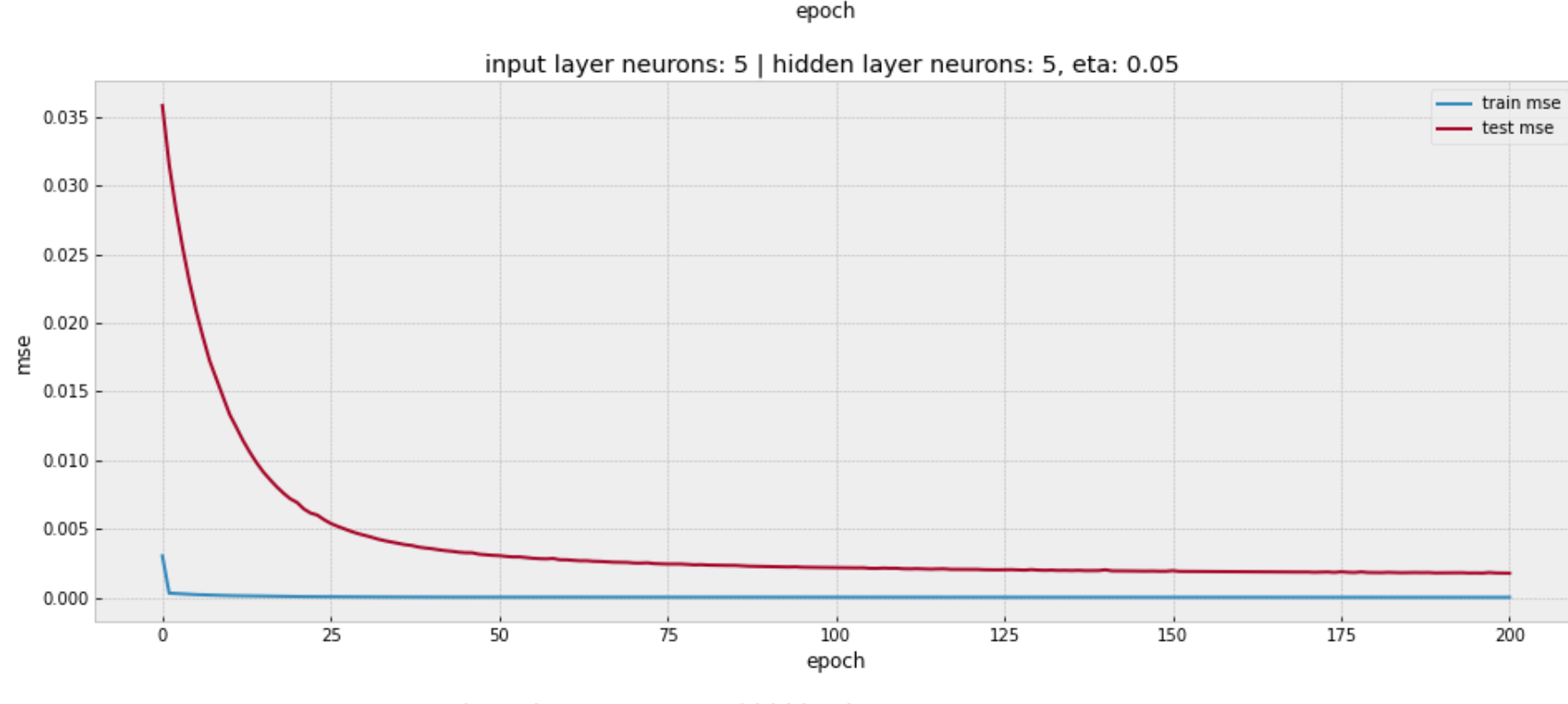

input layer neurons: 5 | hidden layer neurons: 3, eta: 0.1

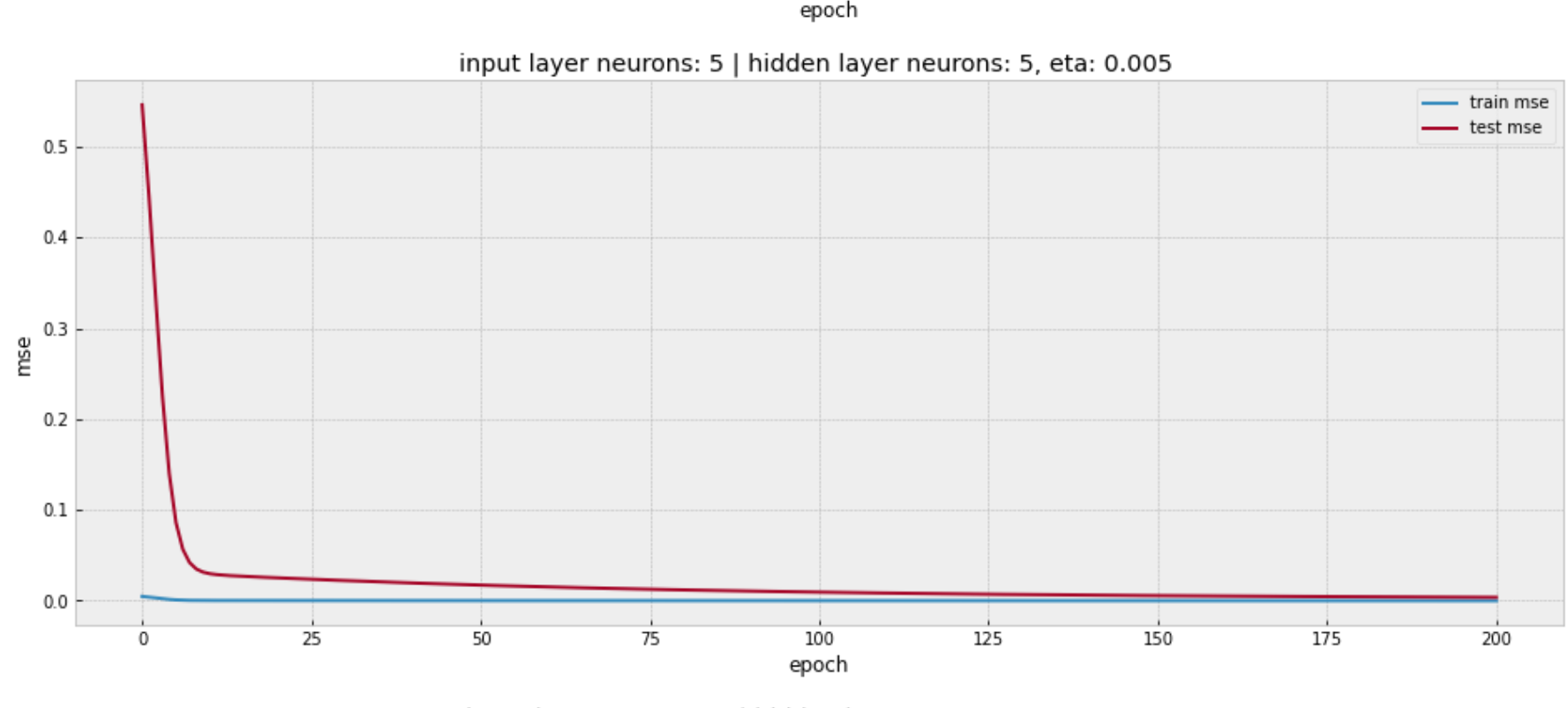

input layer neurons: 5 | hidden layer neurons: 3, eta: 0.05

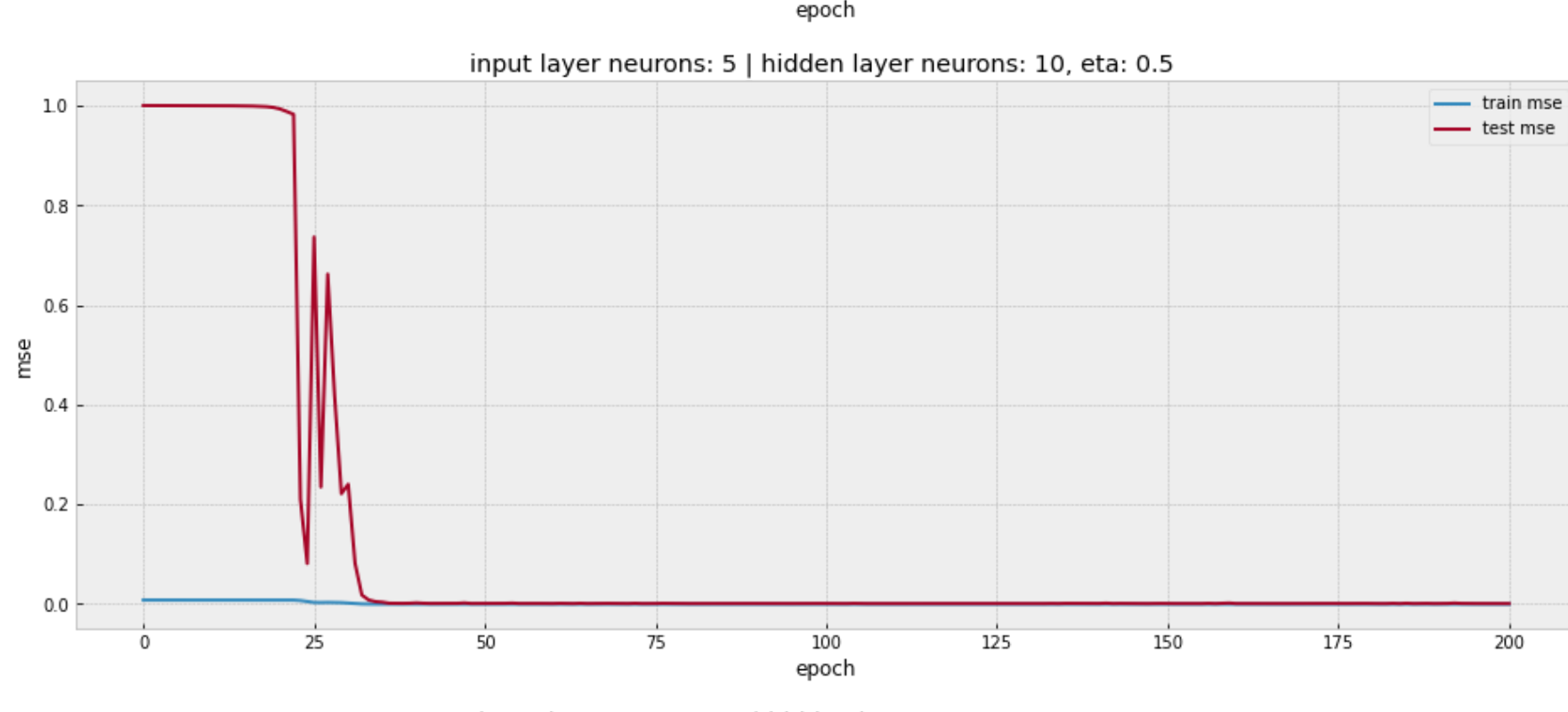

input layer neurons: 5 | hidden layer neurons: 3, eta: 0.005

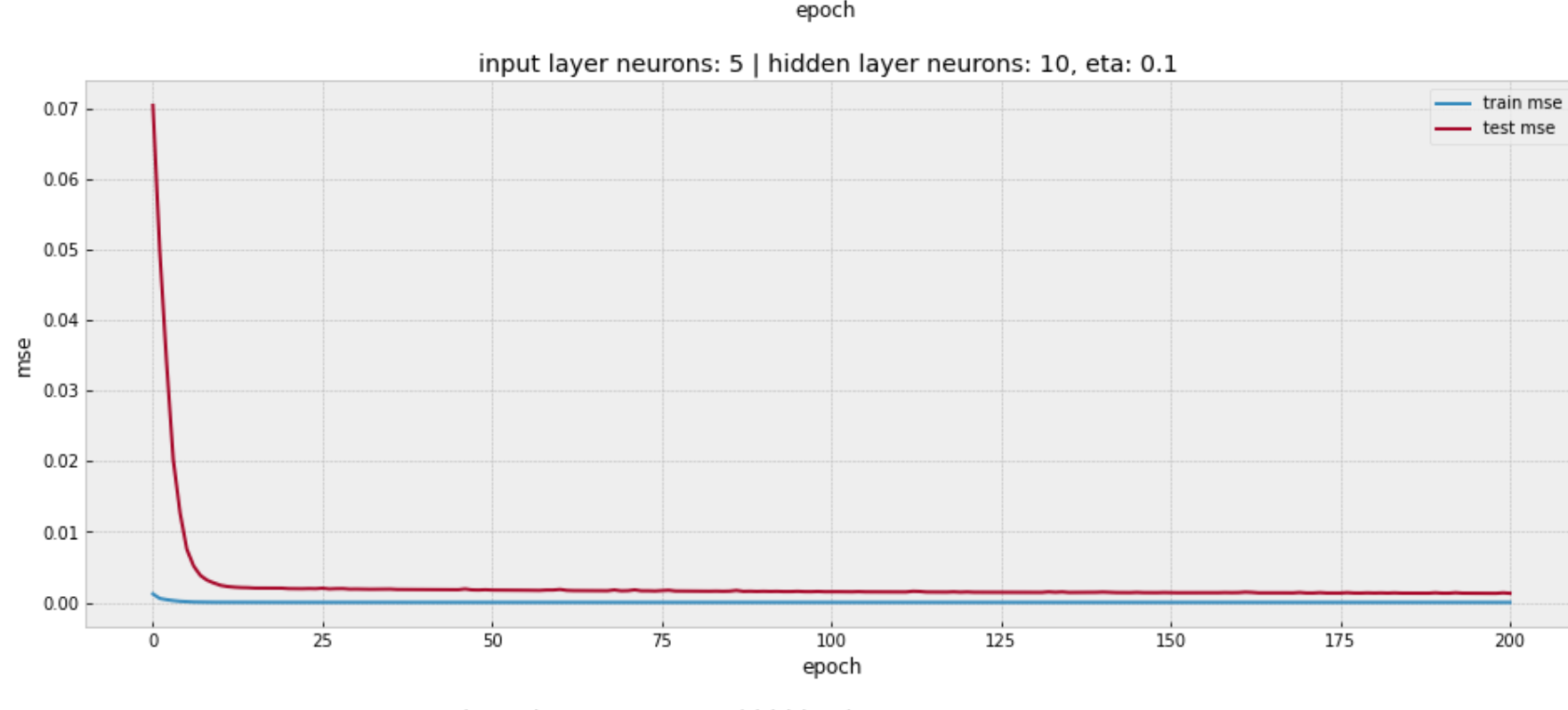

input layer neurons: 5 | hidden layer neurons: 5, eta: 0.5

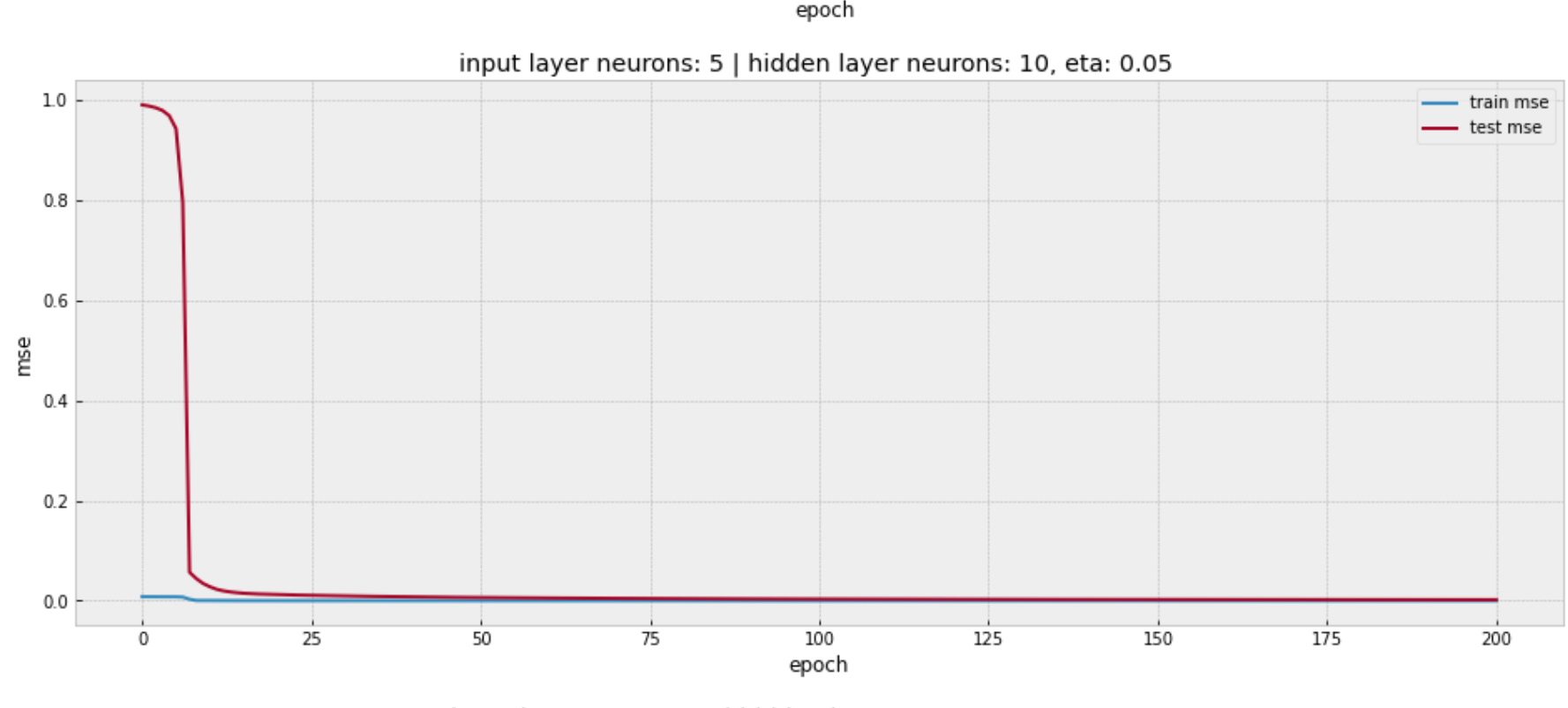

input layer neurons: 5 | hidden layer neurons: 5, eta: 0.1

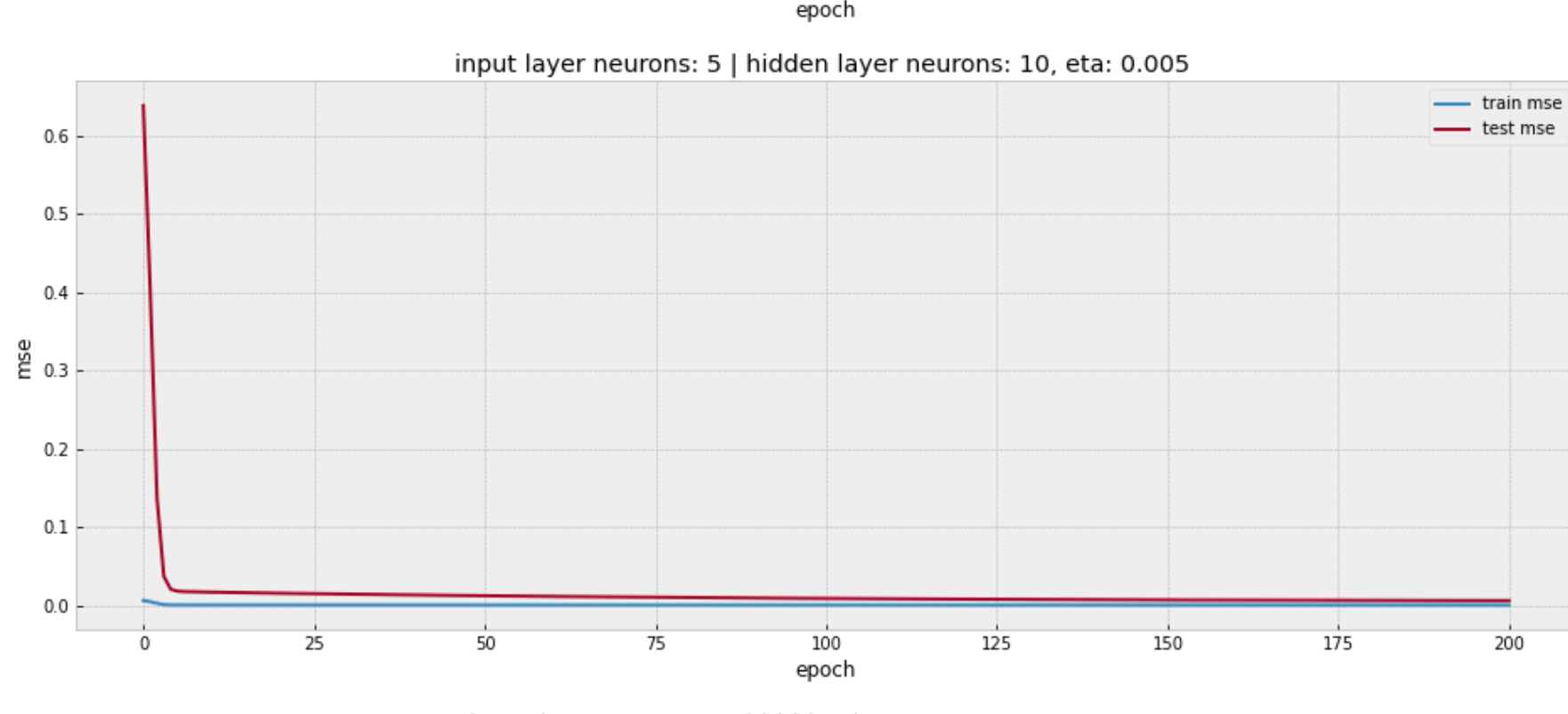

input layer neurons: 5 | hidden layer neurons: 5, eta: 0.05

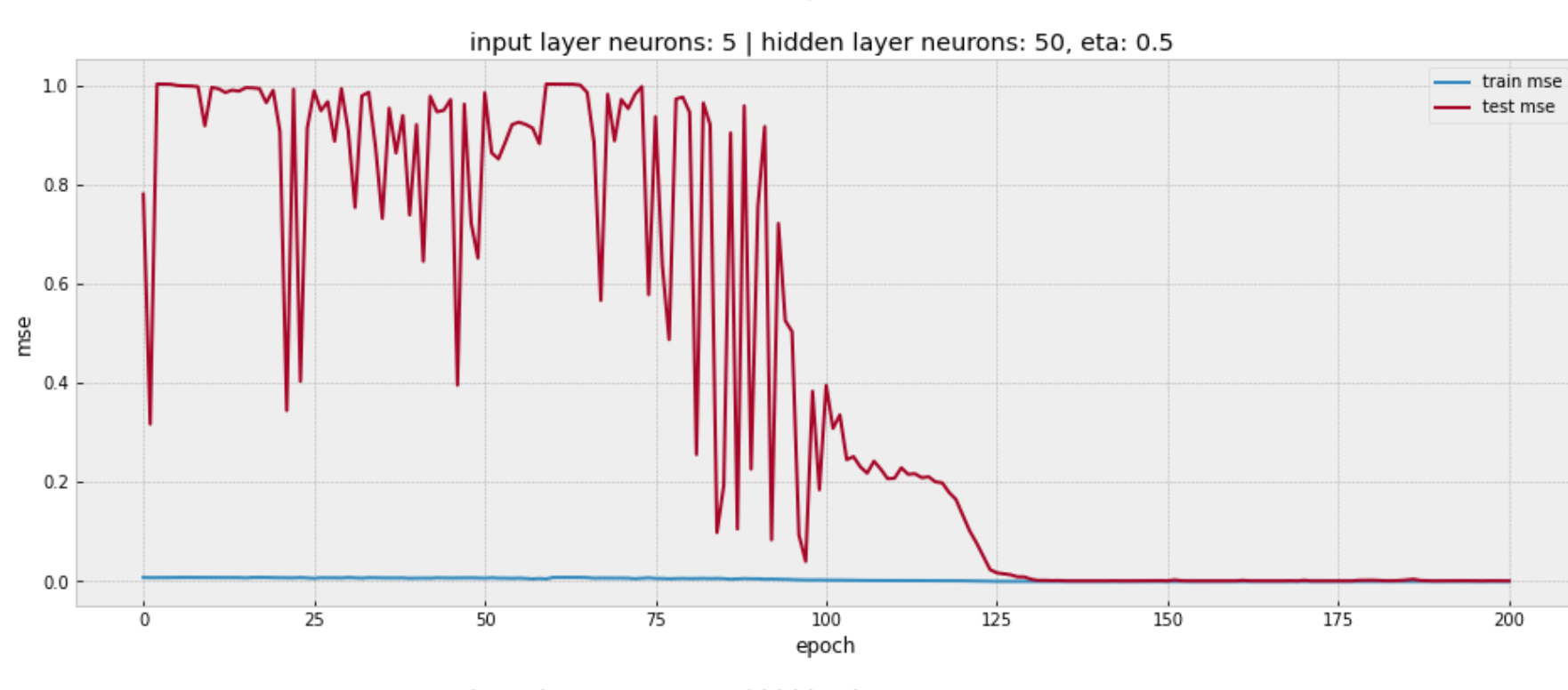

input layer neurons: 5 | hidden layer neurons: 5, eta: 0.005

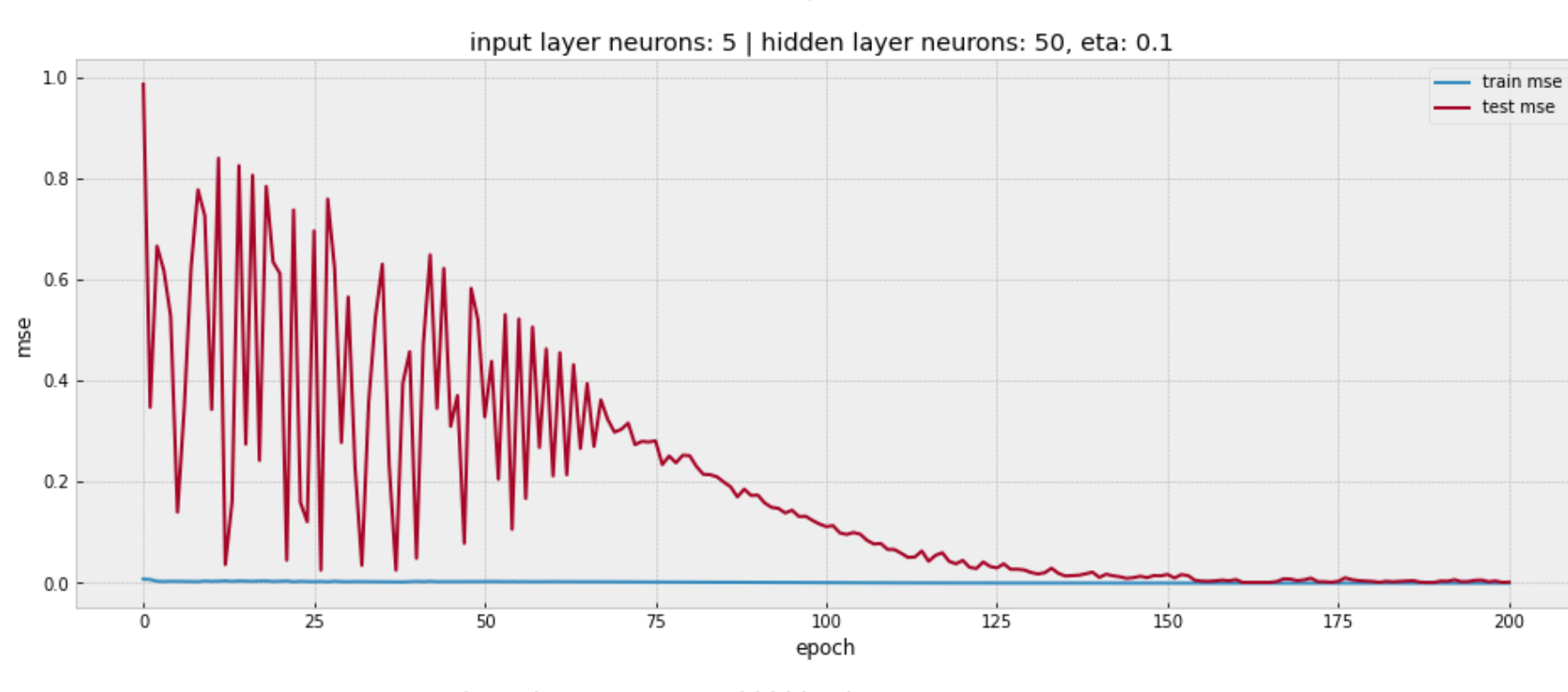

input layer neurons: 5 | hidden layer neurons: 10, eta: 0.5

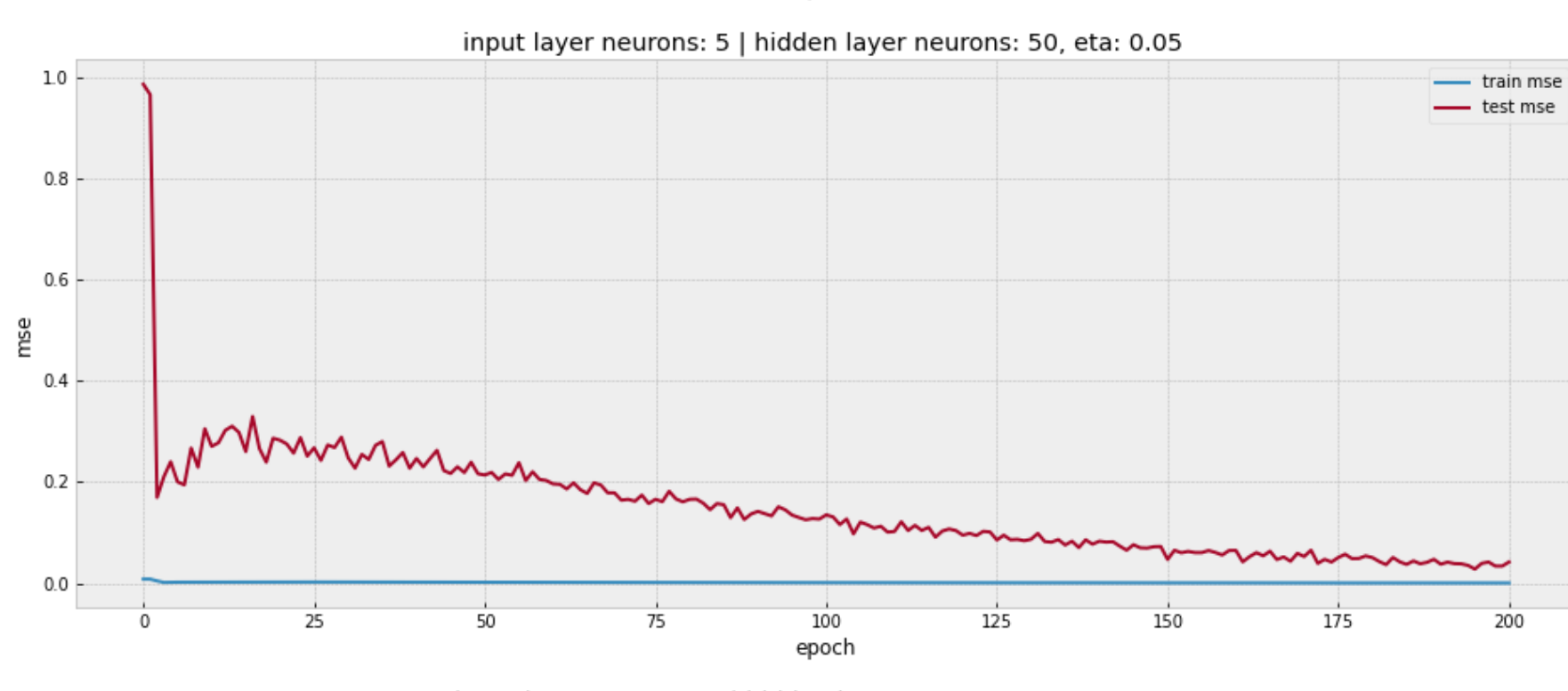

input layer neurons: 5 | hidden layer neurons: 10, eta: 0.1

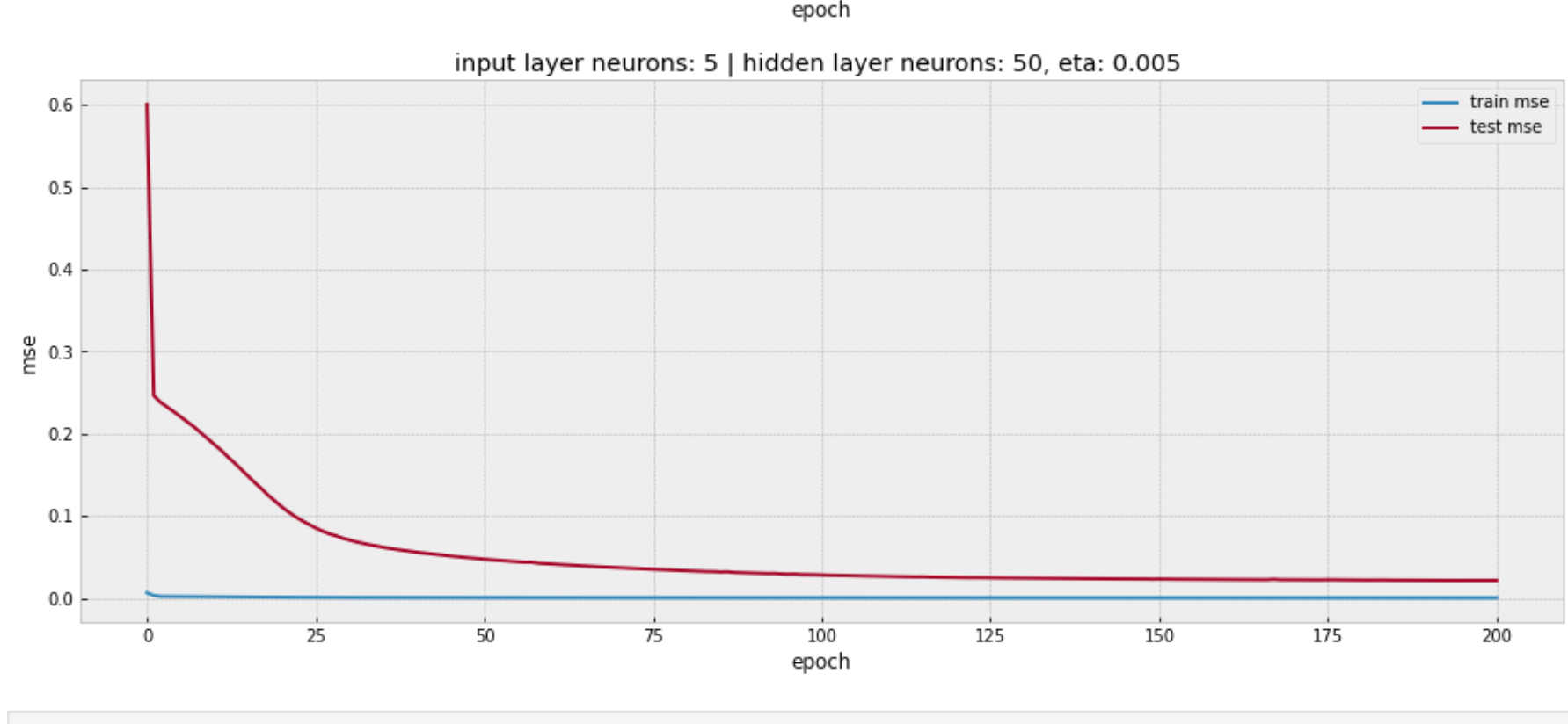

input layer neurons: 5 | hidden layer neurons: 10, eta: 0.05


input layer neurons: 5 | hidden layer neurons: 10, eta: 0.005


input layer neurons: 5 | hidden layer neurons: 50, eta: 0.5


input layer neurons: 5 | hidden layer neurons: 50, eta: 0.1


input layer neurons: 5 | hidden layer neurons: 50, eta: 0.05


input layer neurons: 5 | hidden layer neurons: 50, eta: 0.005

In [11]:

```
neurons = [50]
epochs = [True]
learning_rates = [0.05]
max_epochs = 5000
target_test_mse = 0.01
params = itertools.product(neurons, epochs, learning_rates)
stats = []
for p in params:
    test_mse_list = []
    train_mse_list = []
    nn = NeuralNet([len(dataset[0][0]), p[0], len(dataset[0][1])], a_functions=[af.tanh, af.tanh], a_functio
    print(p)
    for e in nn.gradient_descent_testdata(
            labeled_training_dataset=training_data,
            labeled_test_dataset=test_data,
            no_epochs=p[1],
            mini_batch_size=128,
            learning_rate=p[2]
            ):
        print('epoch: ', e['epoch'], end='\r')
        test_mse_list.append(e['test mse'])
        train_mse_list.append(e['train mse'])
        if e['test mse'] < target_test_mse:
            result = {
                'success': True,
                'neurons input layer': nn.layer_sizes[0],
                'neurons hidden layer': p[0],
                'epochs': e['epoch'] + 1,
                'learning rate': p[2],
                'test mse list' : test_mse_list,
                'train mse list' : train_mse_list,

            }
            stats.append(result)
            print()
            print('TARGET HIT epoch', e['epoch'], '\n test mse', e['test mse'],
                  '\n train mse', e['train mse'])
            print()
            break
        if e['epoch'] > max_epochs - 1: # last epoch
            result = {
                'success': False,
                'neurons input layer': nn.layer_sizes[0],
                'neurons hidden layer': p[0],
                'epochs': e['epoch'] + 1,
                'learning rate': p[2],
                'test mse list' : test_mse_list,
                'train mse list' : train_mse_list,
            }
            stats.append(result)
            print()
            print('TARGET NOT HIT epoch', e['epoch'], '\n test mse', e['test mse'],
                  '\n train mse', e['train mse'])
            print()
            break
        if e['epoch'] % 100 == 0:
            print()
            print('intermediate result: epoch', e['epoch'], '\n test mse', e['test mse'],
                  '\n train mse', e['train mse'])
            print()
stats_json = json.dumps(stats)
with open('resources/stats_avgtemp_bestapprox_targetlower.json', 'w') as f:
    f.write(stats_json)
```

```
(50, True, 0.05)
epoch:  0
intermediate result: epoch 0
 test mse 0.19829807912207578
 train mse 0.0017396422683744622

epoch:  100
intermediate result: epoch 100
 test mse 0.10065167502295176
 train mse 0.0008593879879405362

epoch:  200
intermediate result: epoch 200
 test mse 0.037374844905590586
 train mse 0.00022805611767629137

epoch:  219
TARGET HIT epoch 219
 test mse 0.0065786894433219984
 train mse 0.00015729746513638607
```

Predikce

Pro predikci vybrány hyperparamery:

- počet neuronů vstup: 4
- počet neuronů skrytá vrstva: 50
- learning rate 0.05

In [ ]:

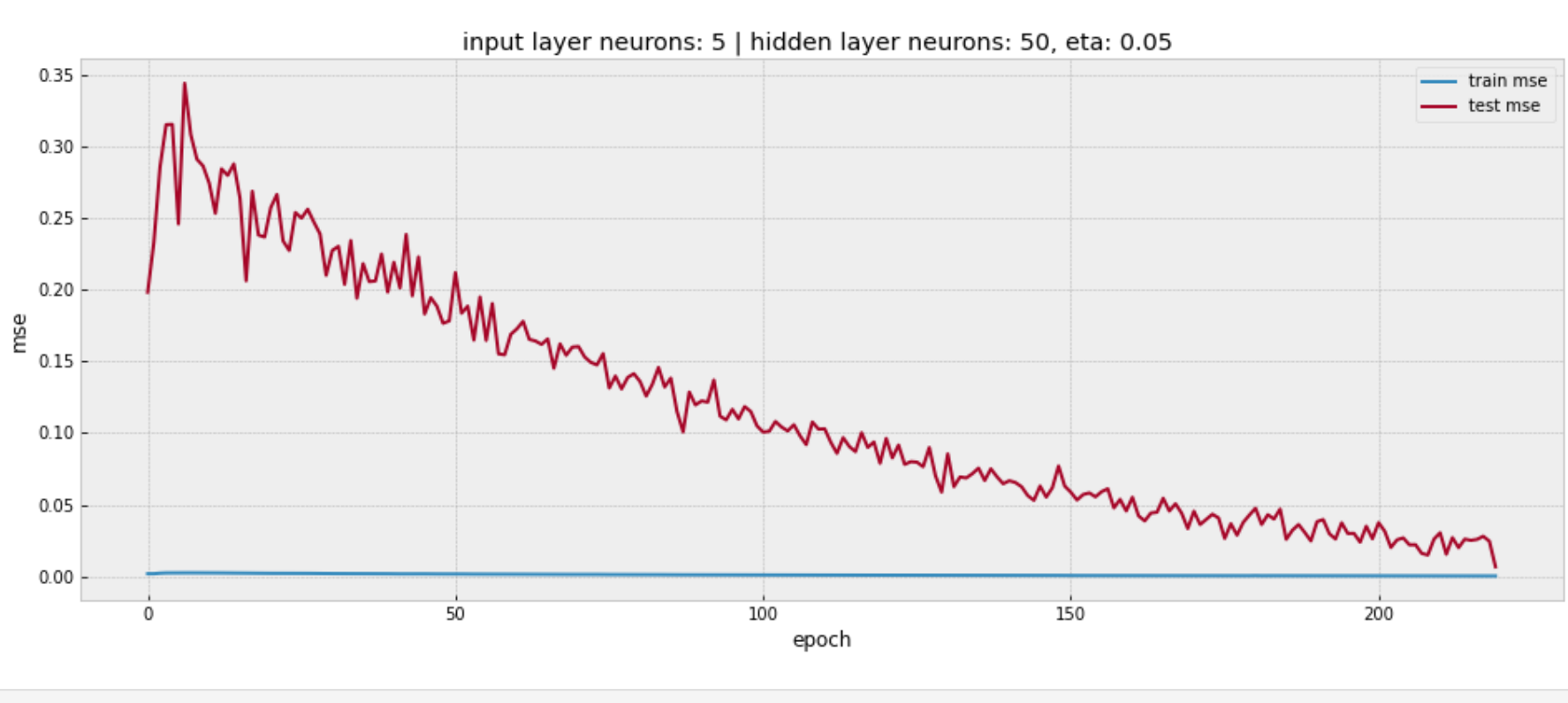
```

```

In [12]:

```
df = pd.read_json('resources/stats_avgtemp_bestapprox_targetlower.json')
ax, fig = plt.subplots()
# fig.set_ylim([0,0.02])
plt.plot(df['train mse list'][0], label='train mse')
plt.plot(df['test mse list'][0], label='test mse')
plt.title('input layer neurons: {} | hidden layer neurons: {}, eta: {} '.format(df['neurons input layer'][0]
plt.xlabel('epoch')
plt.ylabel('mse')
plt.legend()
```

Out[12]:

```
<matplotlib.legend.Legend at 0x7f880d694e20>
```


input layer neurons: 5 | hidden layer neurons: 50, eta: 0.05

In [19]:

```
prediction = [nn.feed_forward(x)['a'] for x in diff_norm_inputs]
prediction = np.array([x[0] for x in prediction])
prediction, len(prediction)
```

Out[19]:

```
(array([-0.0820093 , -0.06500859, -0.12357382, ..., -0.04517385,
        -0.08289188, -0.04136453]),
 2133)
```

In [20]:

```
prediction
```

Out[20]:

```
array([-0.0820093 , -0.06500859, -0.12357382, ..., -0.04517385,
       -0.08289188, -0.04136453])
```

In [25]:

```
prediction_undiff = np.concatenate((np.array([norm_avg_temps[0]]), prediction)).cumsum()
prediction_undiff
```

Out[25]:

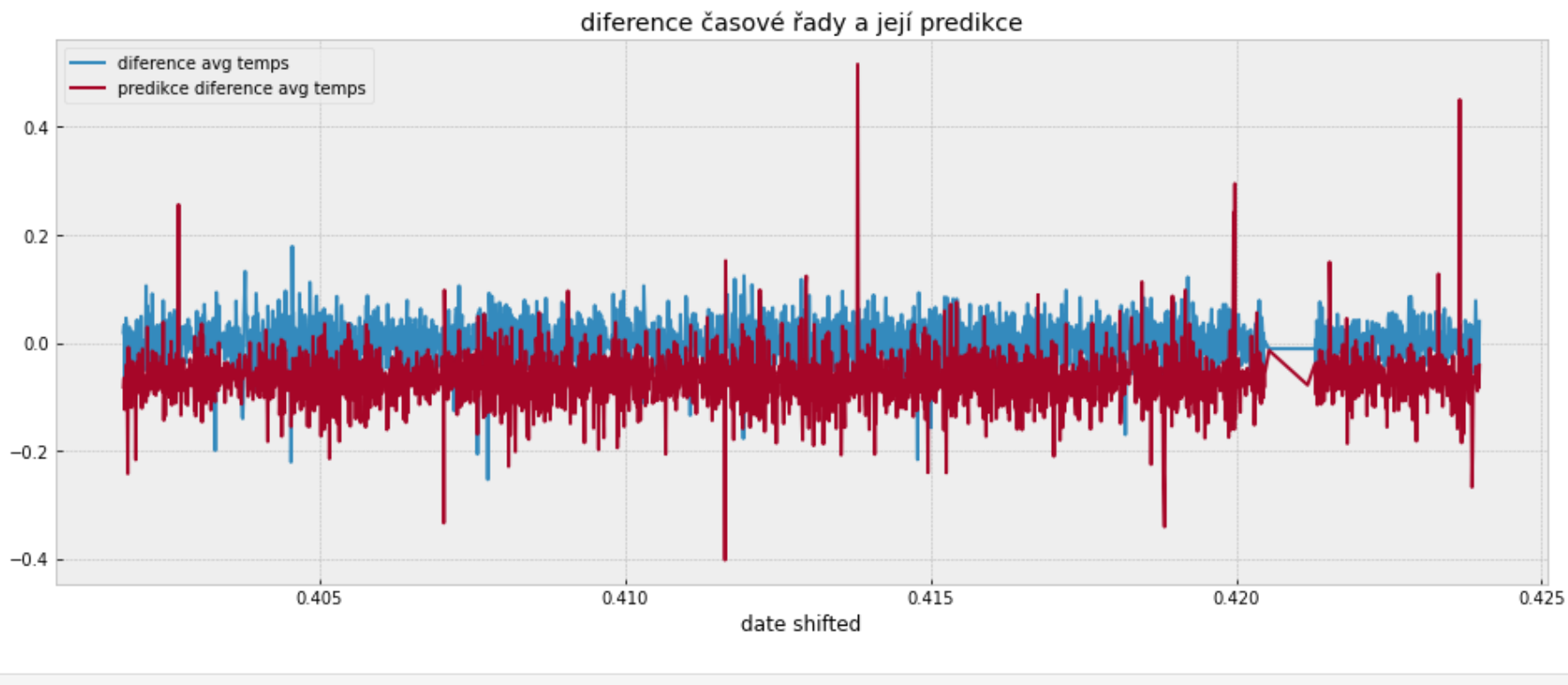
```
array([   0.9113499 ,    0.8293406 ,    0.76433201, ..., -140.77739914,
       -140.86029103, -140.90165556])
```

In [37]:

```
# plt.plot(dates, norm_avg_temps)
plt.plot(dates[1:], diff_norm_avg_temps, label='diference avg temps')
plt.plot(dates[1:], prediction, label='predikce diference avg temps')
plt.xlabel('date shifted')
plt.title("diference časové řady a její predikce")
plt.legend()
```

Out[37]:

```
<matplotlib.legend.Legend at 0x7f880c1a9460>
```



```
In [31]: norm_avg_temps_undiff = np.concatenate((np.array([norm_avg_temps[0]]), diff_norm_avg_temps)).cumsum()
         norm_avg_temps_undiff
```

```
Out[31]: array([0.9113499 , 0.93015447, 0.96306246, ..., 0.93485561, 0.89321692,
                0.93284083])
```

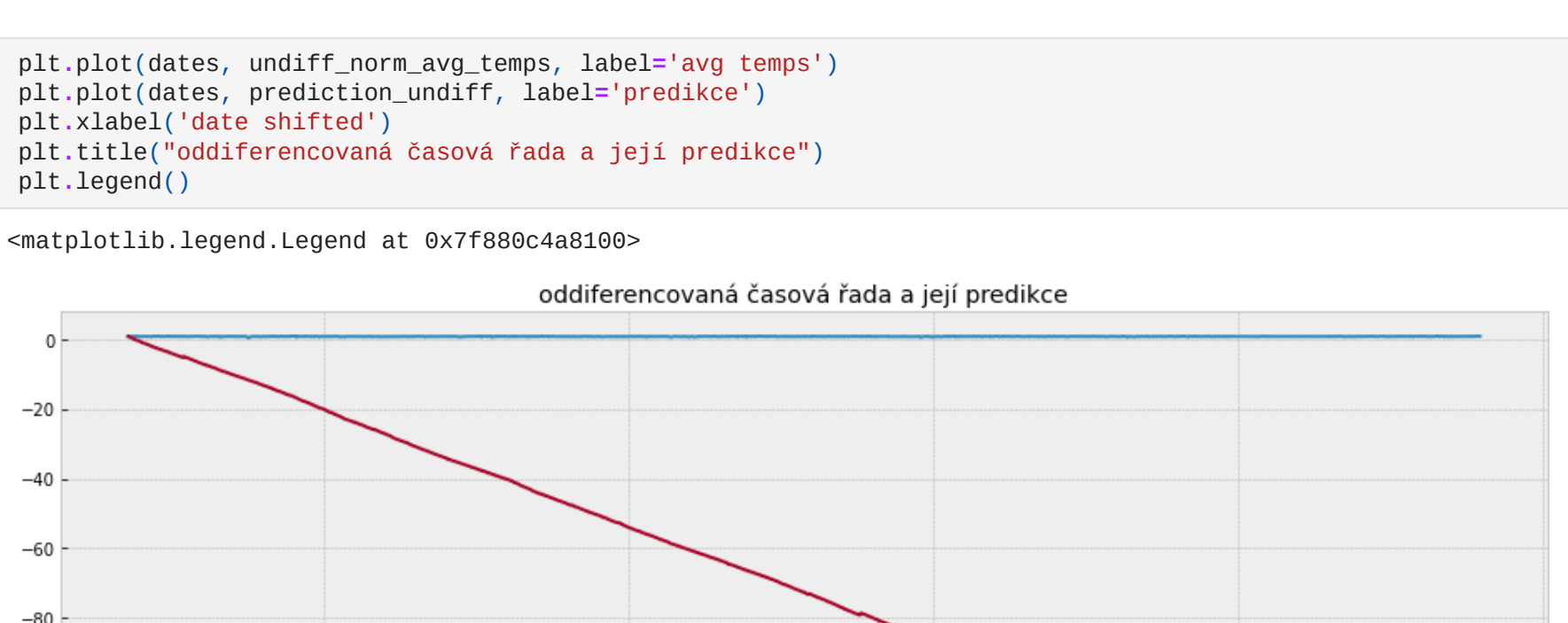
Ověření funkčnosti oddiferencování

```
In [32]: np.array_equal(norm_avg_temps, norm_avg_temps_undiff)
```

```
Out[32]: True
```

```
In [38]: plt.plot(dates, undiff_norm_avg_temps, label='avg temps')
         plt.plot(dates, prediction_undiff, label='predikce')
         plt.xlabel('date shifted')
         plt.title("oddiferencovaná časová řada a její predikce")
         plt.legend()
```

```
Out[38]: <matplotlib.legend.Legend at 0x7f880c4a8100>
```



Závěr

Po vizuální inspekci diference v predikci byl nalezen posun na ose y do záporných hodnot, z čehož vyplývá velký klesající trend při predikci celé časové řady.