# Table of Contents (LSTM Report)



Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

## Purpose:

The Aim of the experiments is to determine the relation between the LSTM window & anomaly trends, and also to distinguish between anomaly in sensor data & sensor faults.

## Methodology:

EV dataset is used in different LSTM window sizes & error patterns are injected into the dataset. Later, the LSTM algorithm is tested on the dataset to see its effectiveness in finding the anomaly as well as sensor faults.

Codebase:
https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Anomaly-Detection

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

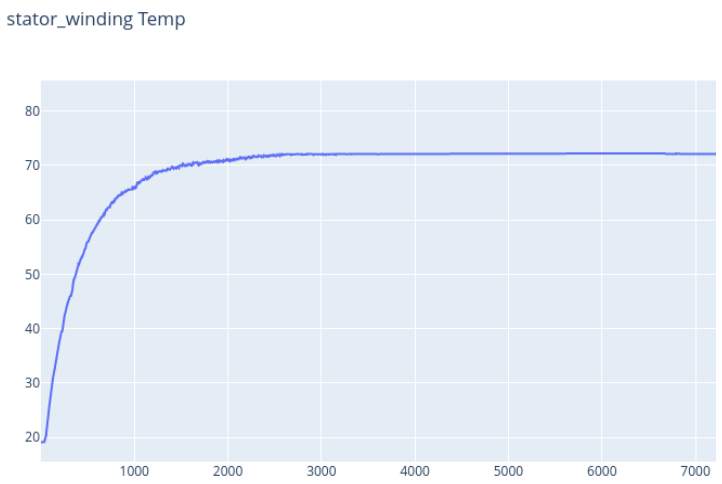
# Part A (LSTM<Error Window)

## 1. Data Vs Anomaly Plots Configuration:

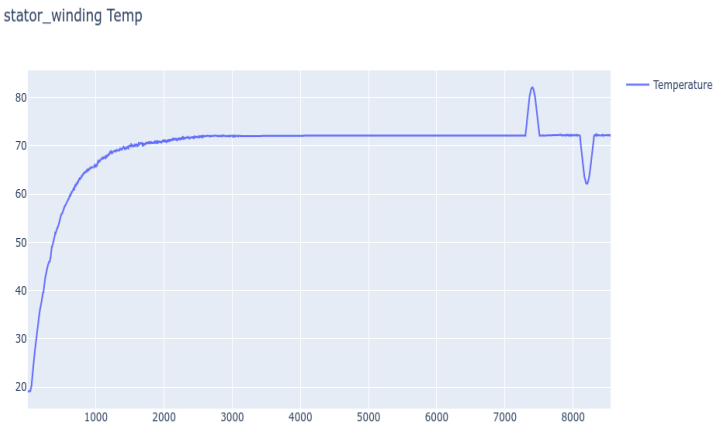
- Dataset: EV stator winding Temp. vs Time (0.5 sec per datapoint)
- LSTM window: 60 data points
- Error window: 200 data points
- Error injected as Sine, Square & Ramp wave
- Error injected as both Positive and Negative values in +Y axis

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

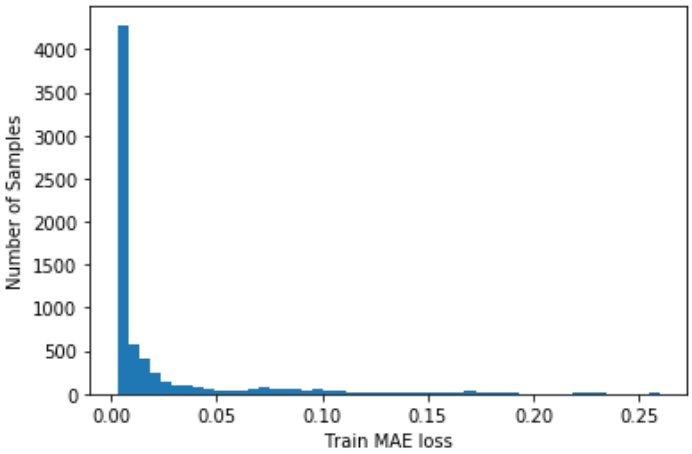
## 1.1 Sine Waveform error



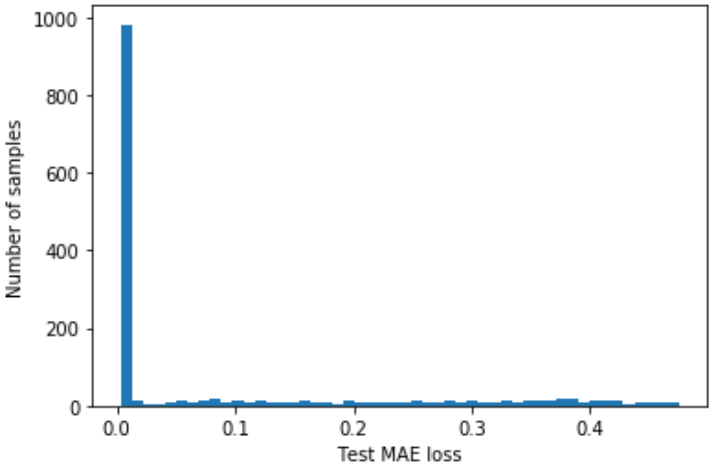

Training Dataset



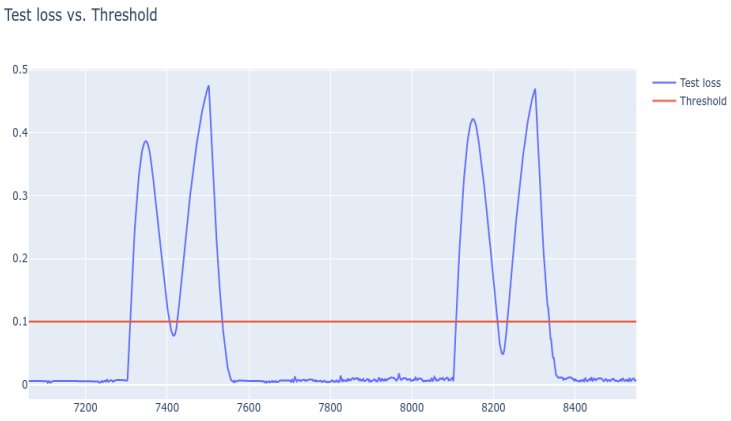

Sine Dataset



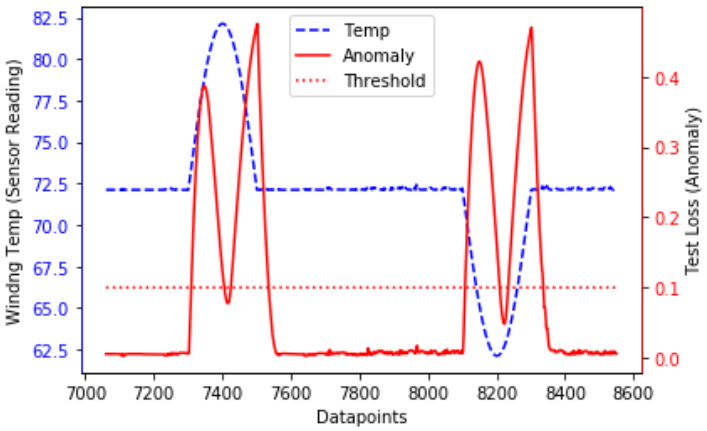

Sine Train MAE loss




Sine Test MAE loss



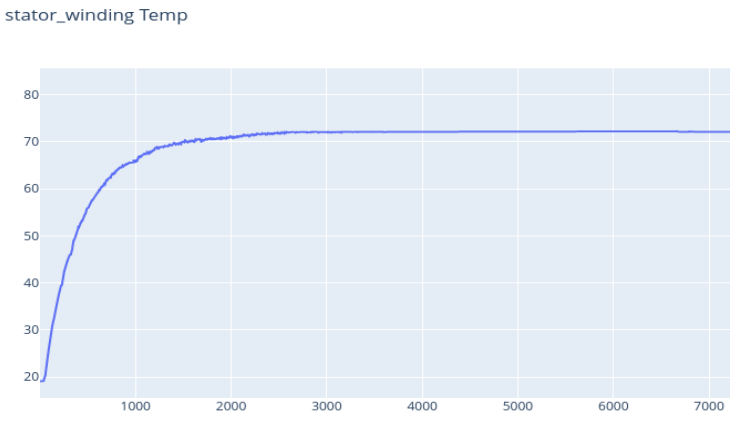

Sine Anomaly vs Threshold



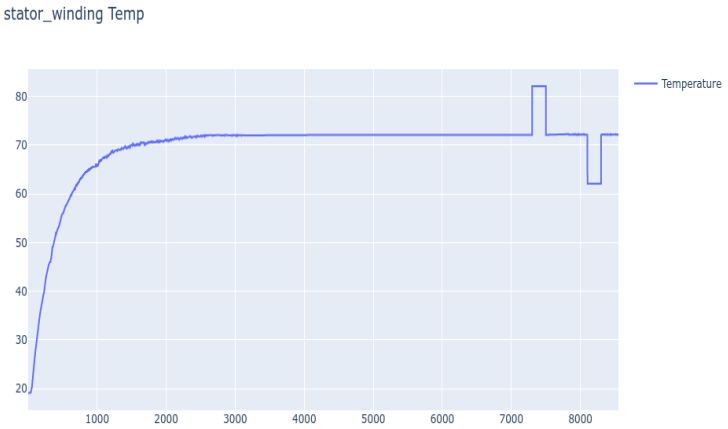

Sine Data vs Anomaly

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

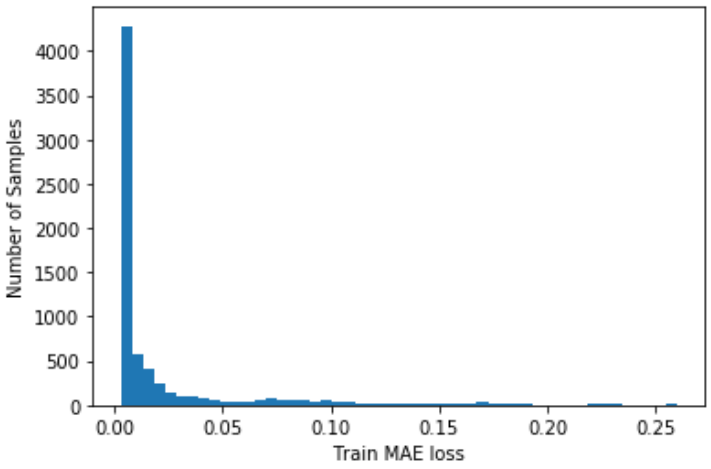
## 1.2 Square Waveform error



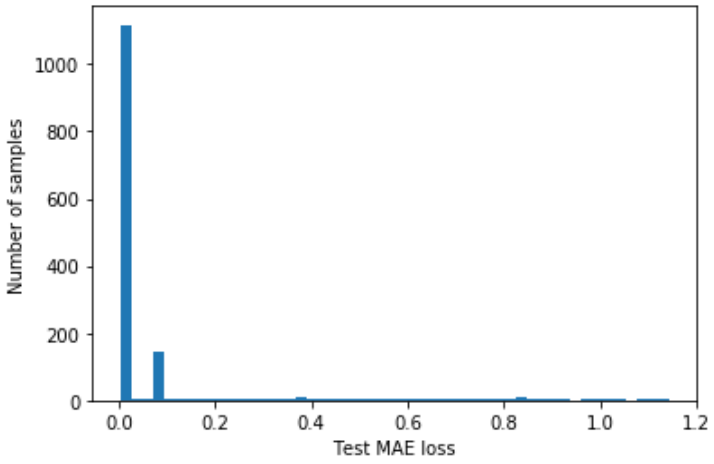

Training Dataset



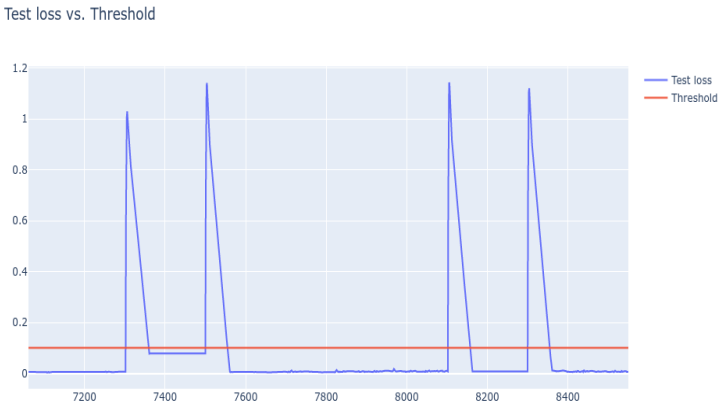

Square Dataset



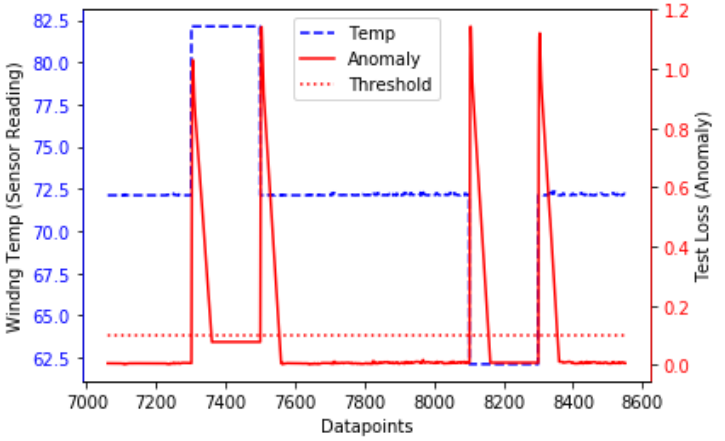

Square Train MAE loss




Square Test MAE loss



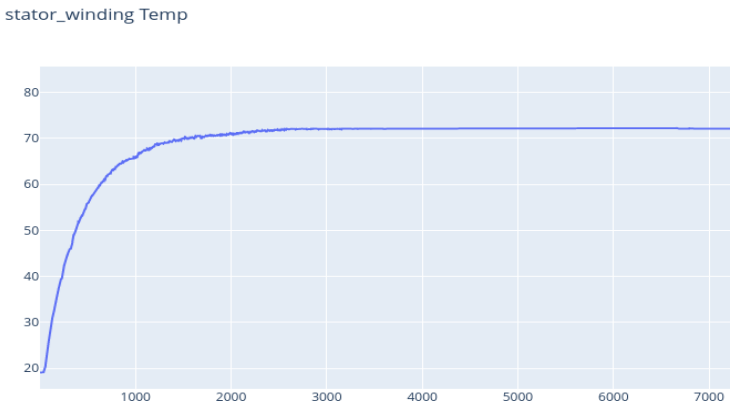

Square Anomaly vs Threshold



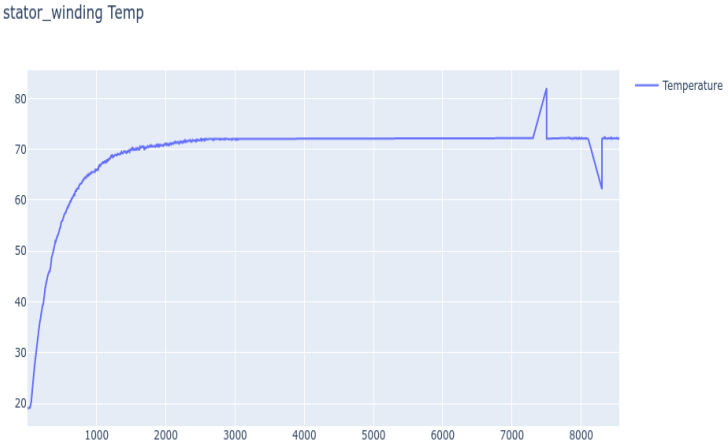

Square Data vs Anomaly

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

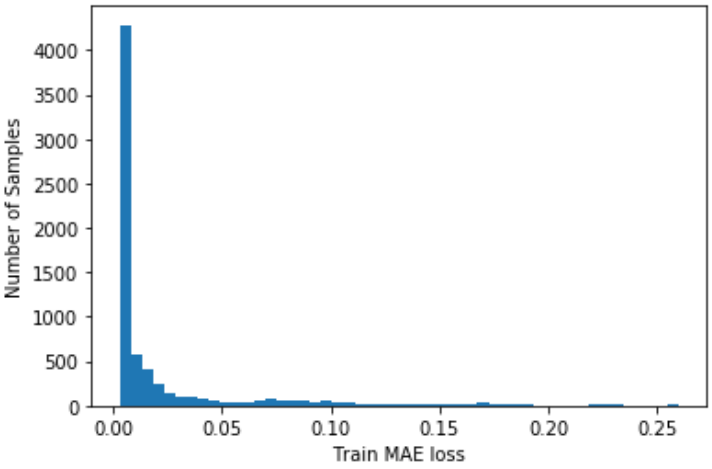
## 1.3 Ramp Waveform error



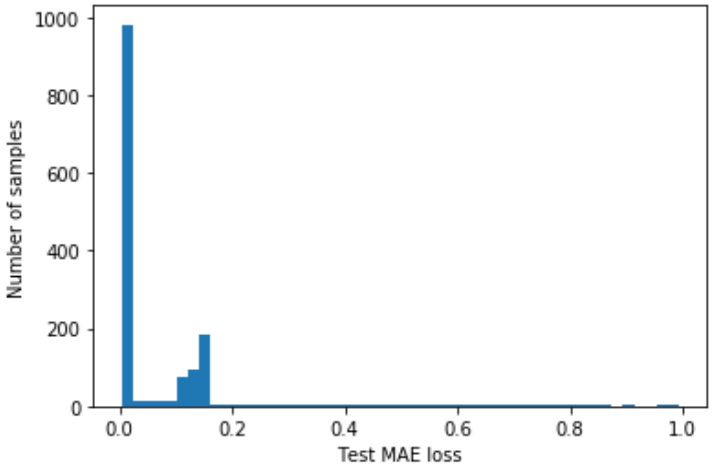

Training Dataset



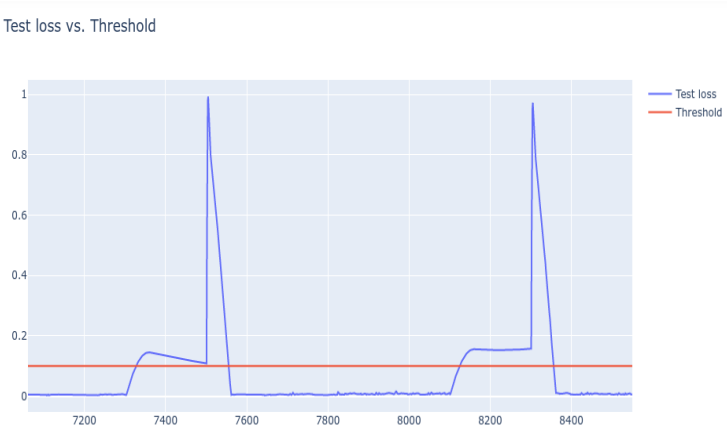

Ramp Dataset



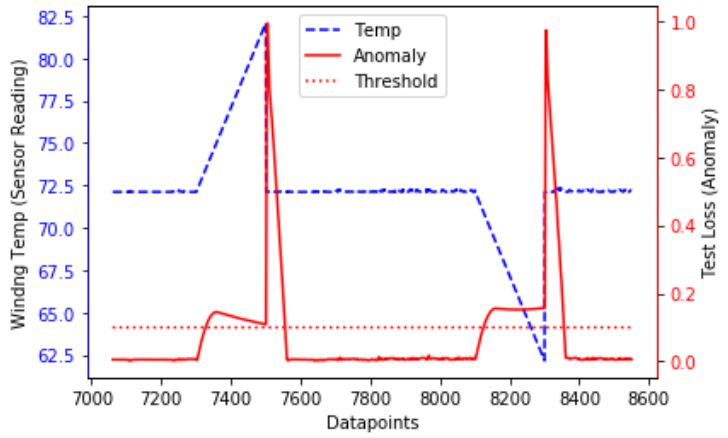

Ramp Train MAE loss




Ramp Test MAE loss




Ramp Anomaly vs Threshold




Ramp Data vs Anomaly

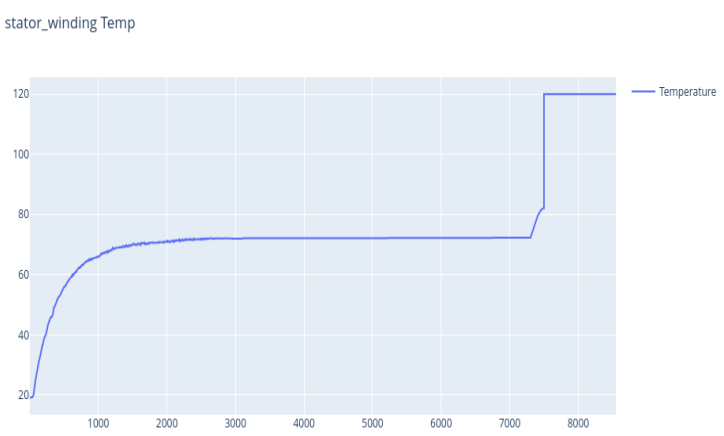
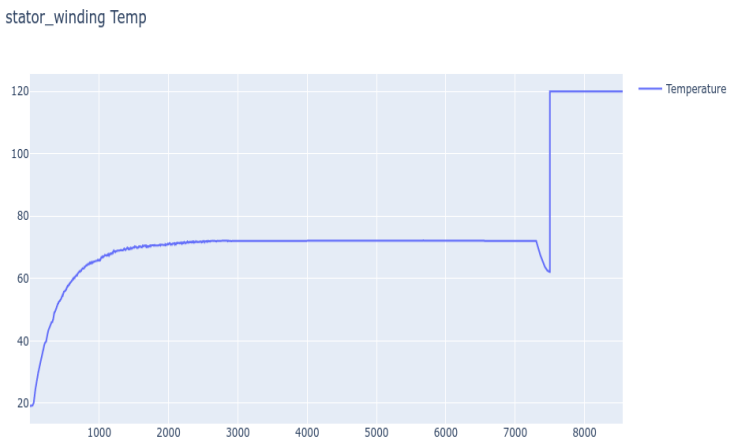
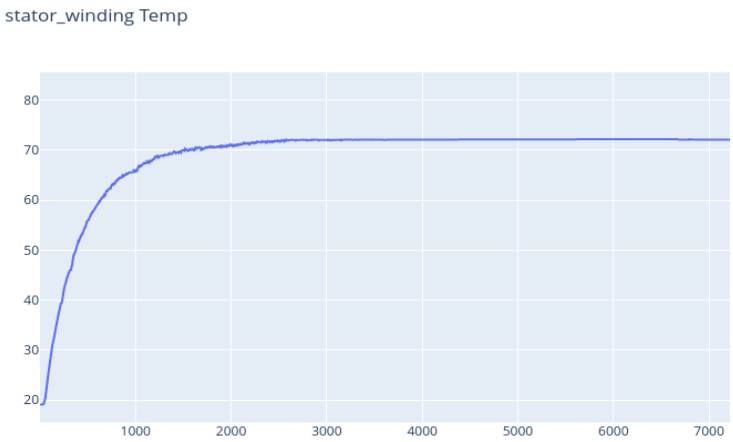
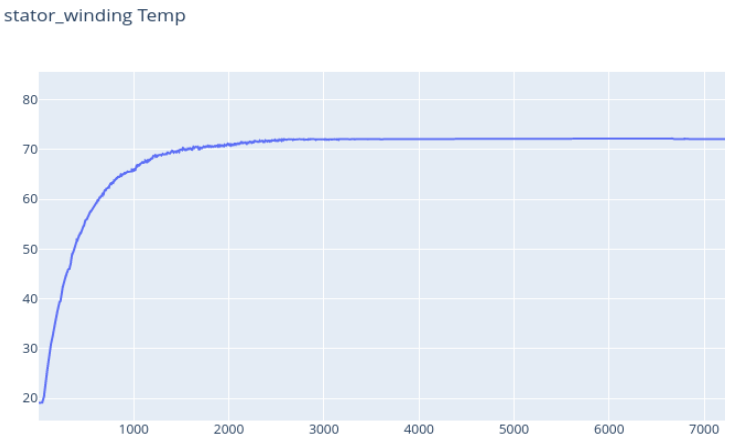
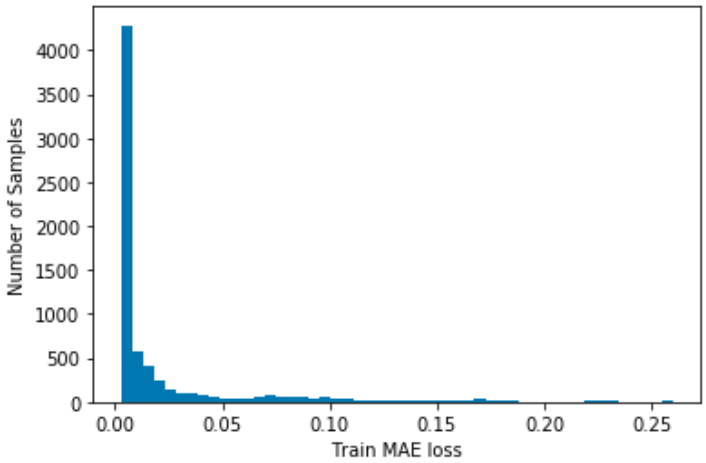
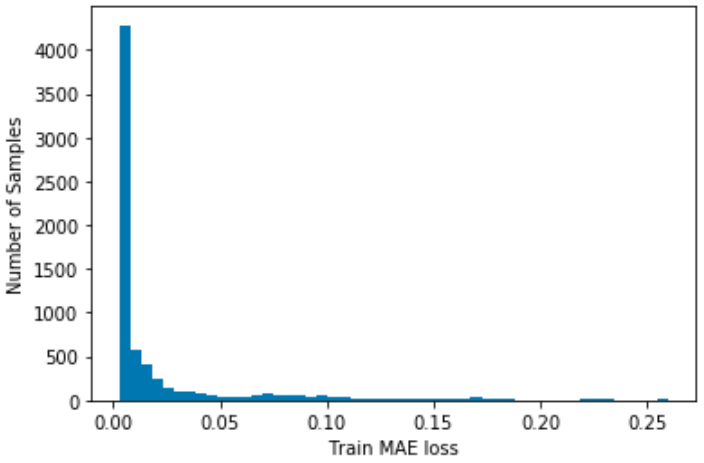
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

## 2. Data Vs Fault Plots

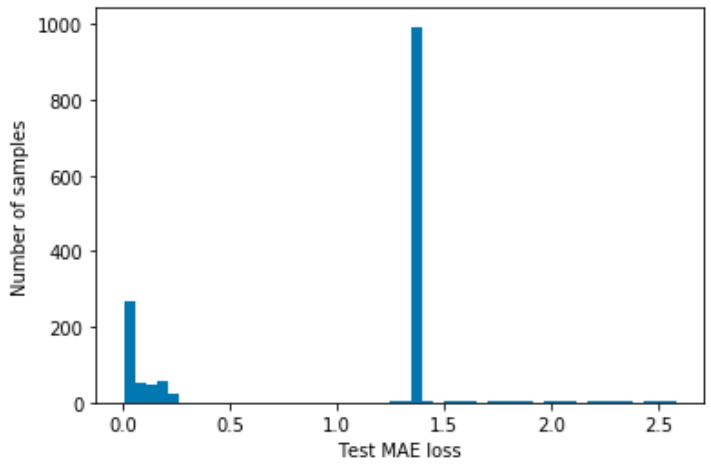
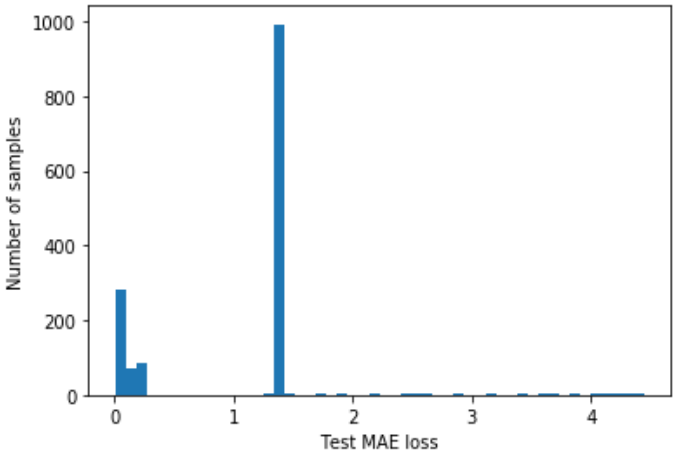
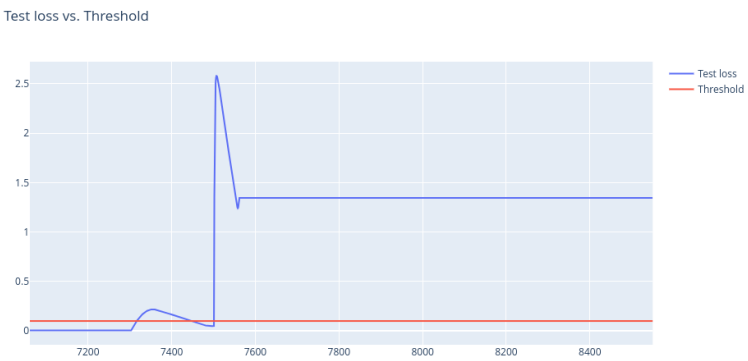
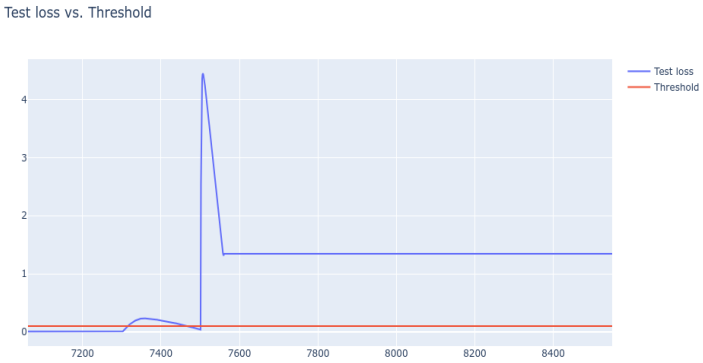
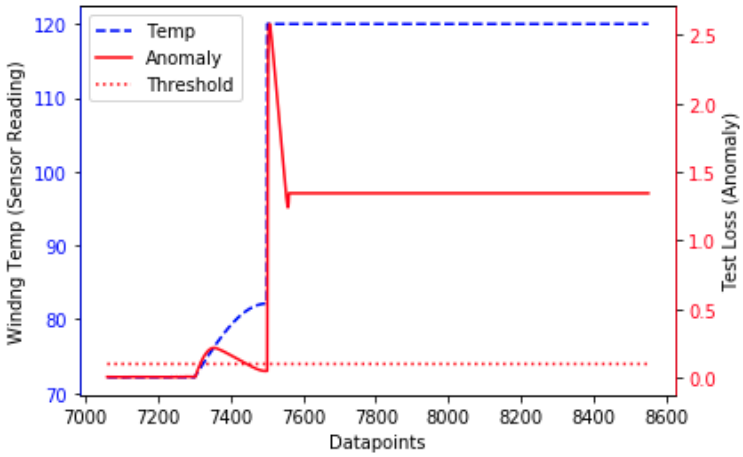
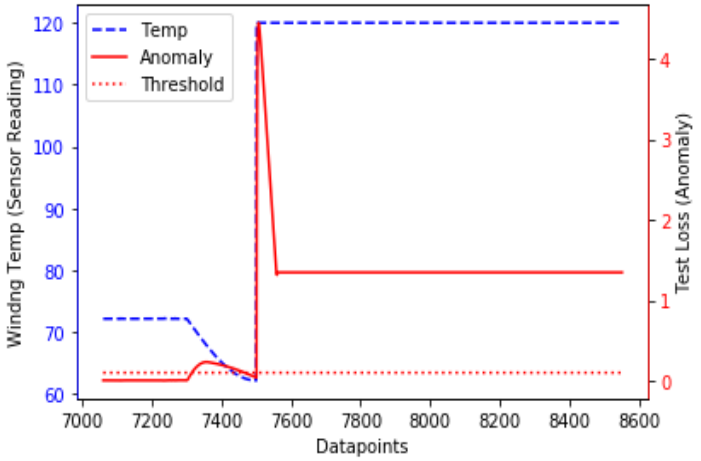
Configuration:

- Dataset: EV stator winding Temp. vs Time (0.5 sec per datapoint)
- LSTM window: 60 data points
- Error window: 200 data points
- Error injected as Sine, Square & Ramp wave
- Error injected as Positive and Negative values in +Y axis separately
- Operating range of the sensor is assumed from 0*C to 100*C,
- When the sensor is faulty, it will send the temp. that is beyond the operating range, i.e. -20*C and 120*C

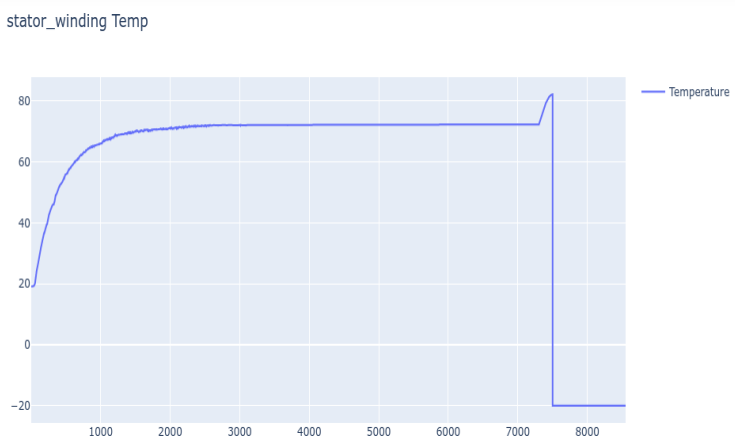
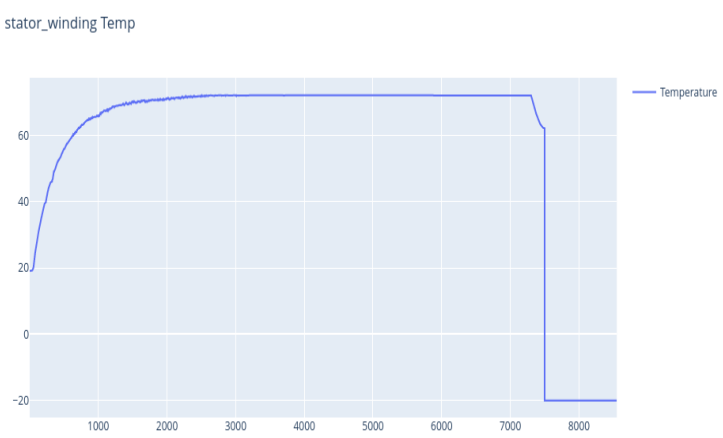
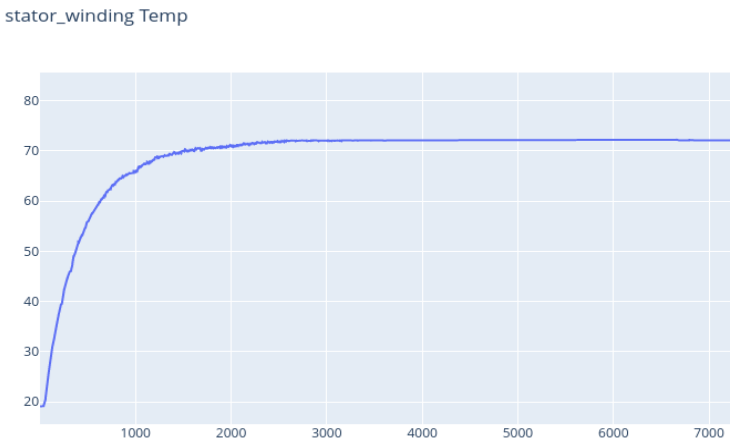
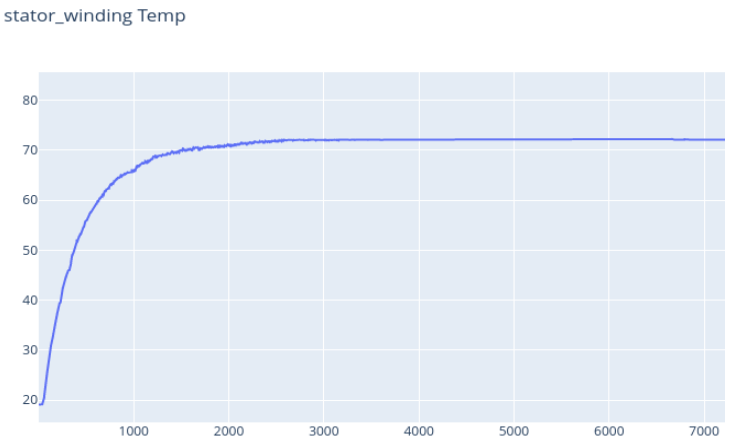
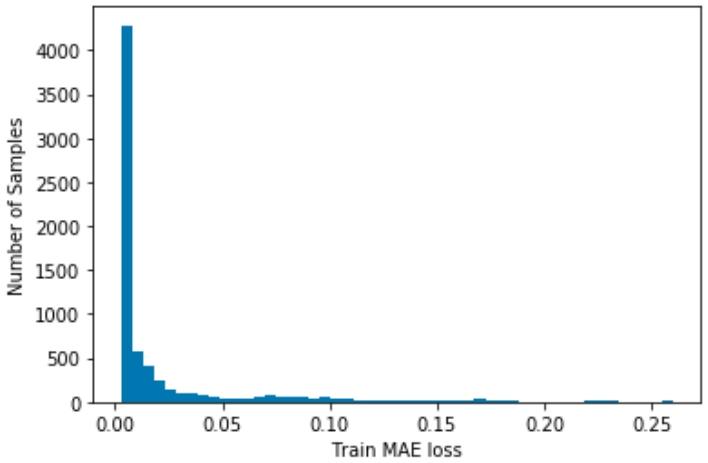
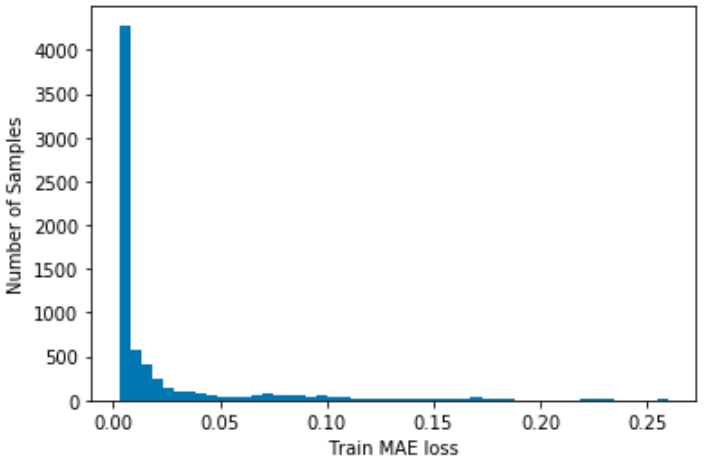
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| 2.1.1 Sine, Fault HIGH | |
|---|---|
| **Sine Error curve: Rising** | **Sine Error curve: Falling** |
|  <br>Sine Dataset |  <br>Sine Dataset |
|  <br>Training Dataset |  <br>Training Dataset |
|  <br>Train MAE loss |  <br>Train MAE loss |

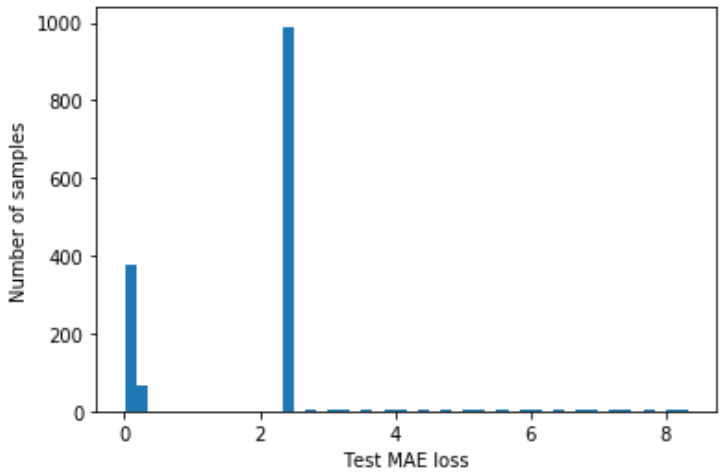
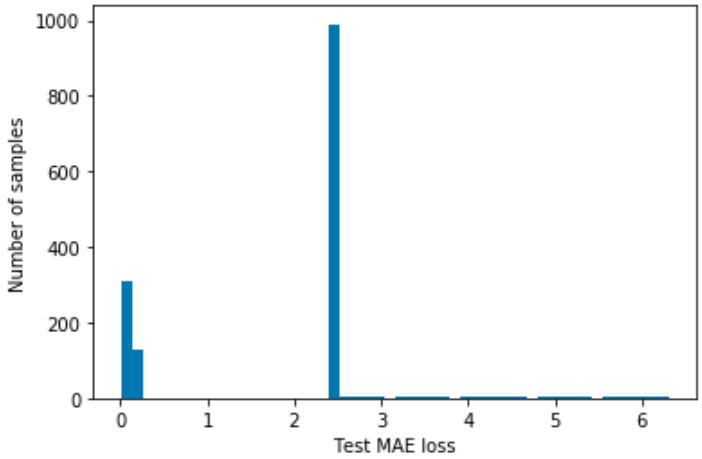
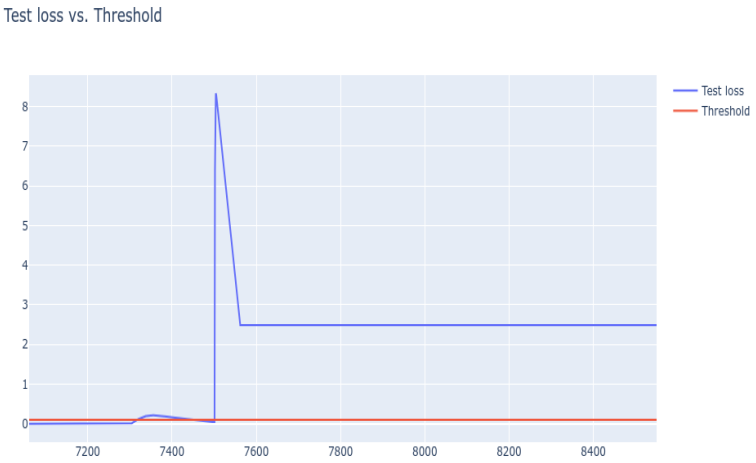
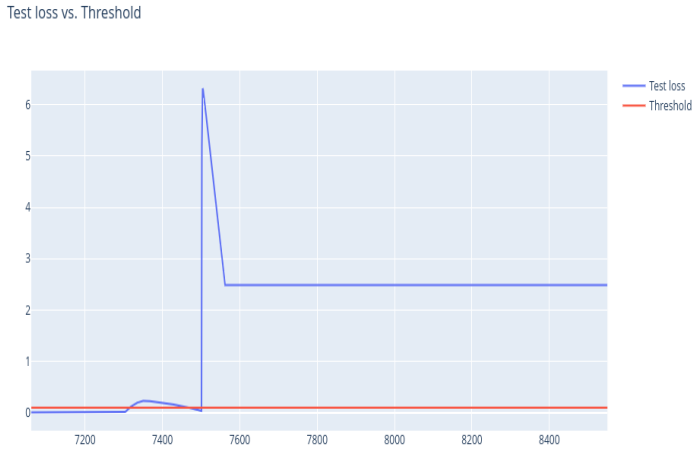
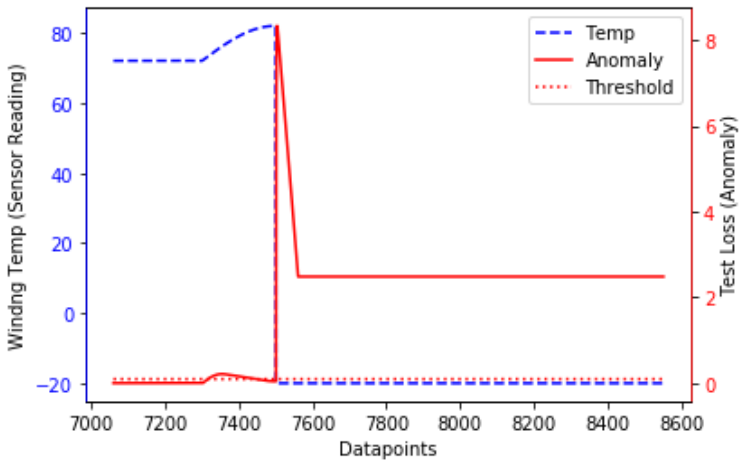
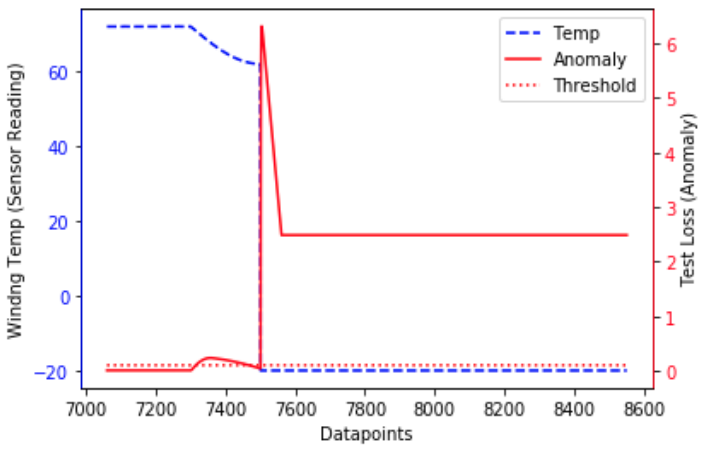
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| Sine Error curve: Rising | Sine Error curve: Falling |
| --- | --- |
|  Sine Test MAE loss |  Sine Test MAE loss |
|  Sine Anomaly vs Fault |  Sine Anomaly vs Fault |
|  Sine Rising Data vs Fault |  Sine Falling Data vs Fault |

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

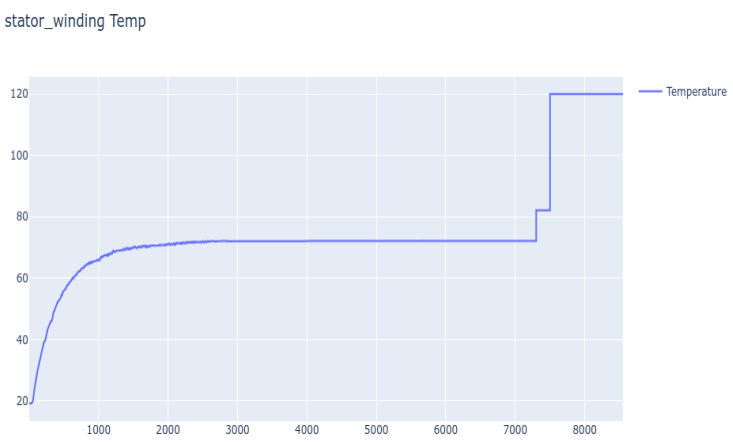
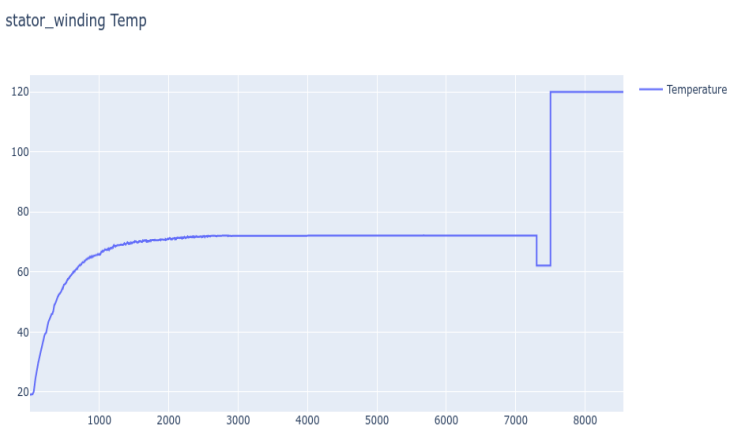
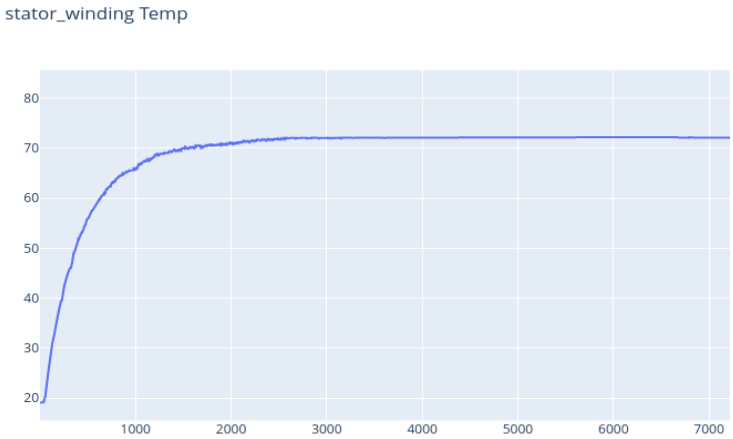
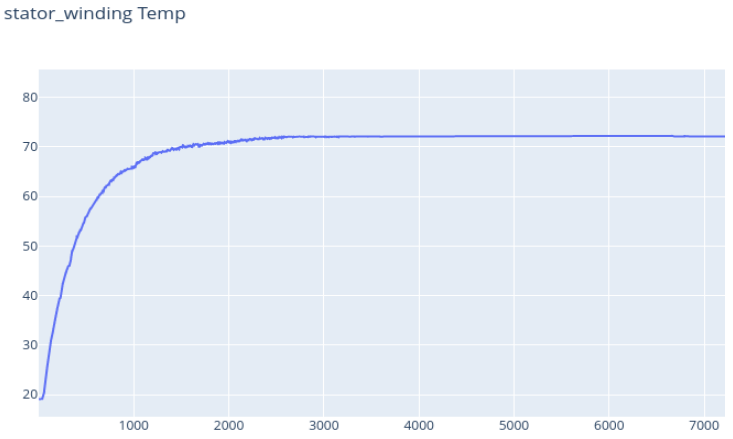
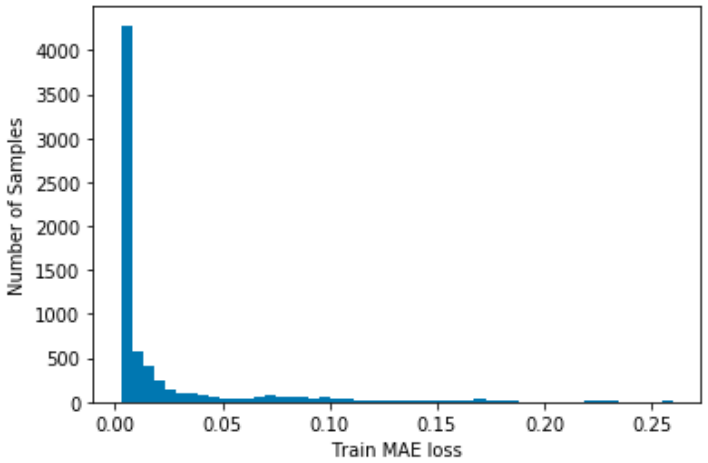
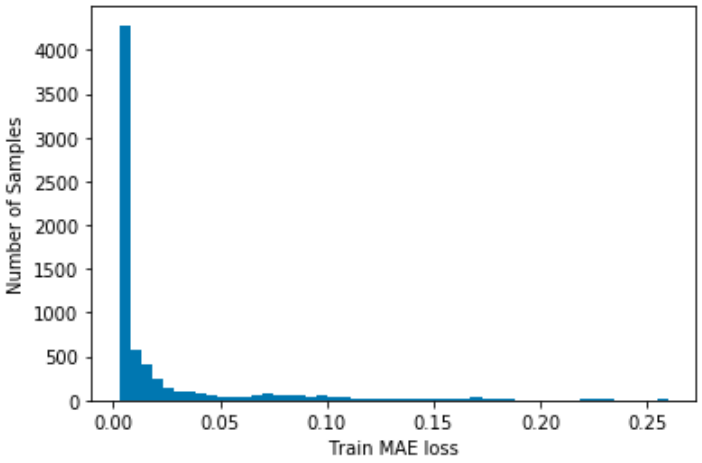
| 2.1.2 Sine, Fault LOW | |
|---|---|
| **Sine Error curve: Rising** | **Sine Error curve: Falling** |
|  Sine Dataset |  Sine Dataset |
|  Training Dataset |  Training Dataset |
|  Train MAE loss |  Train MAE loss |

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

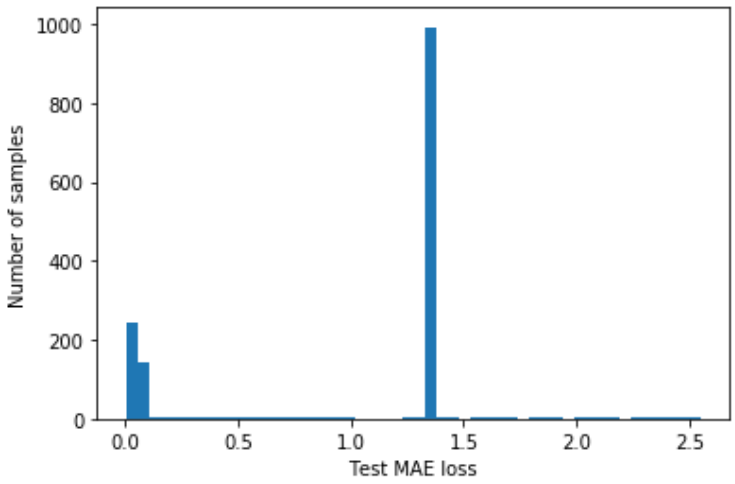
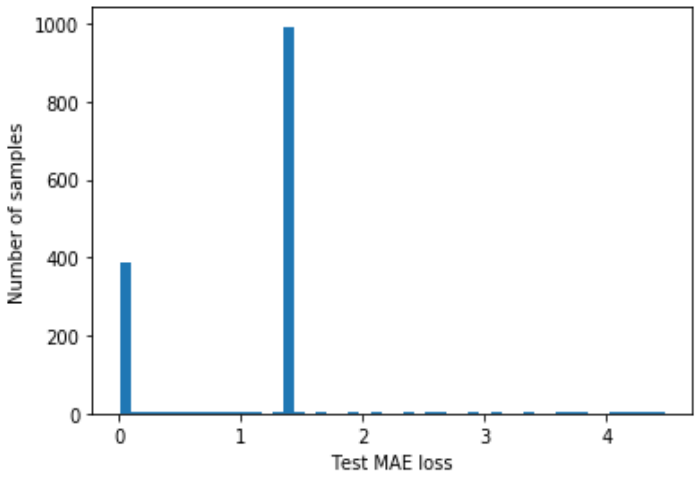
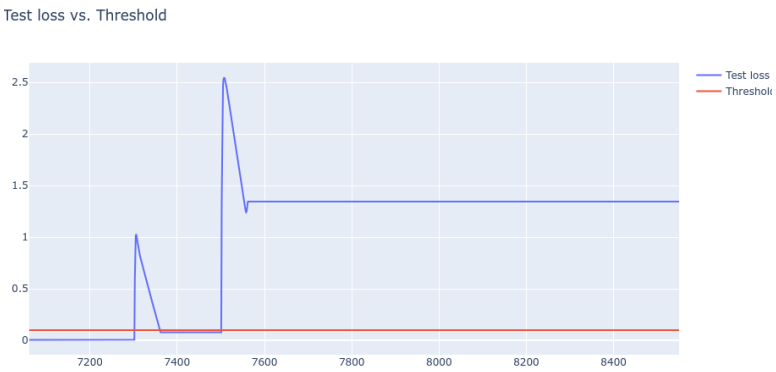
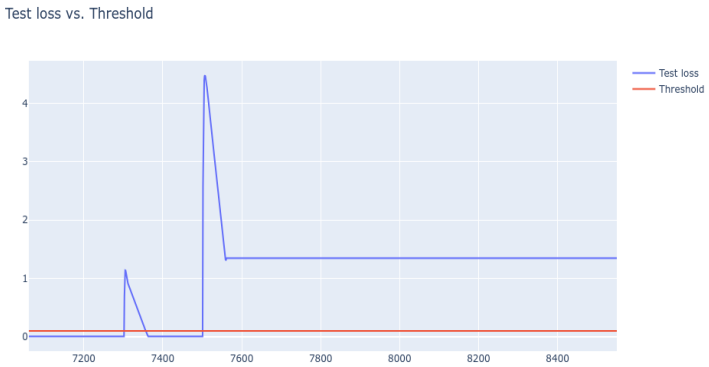
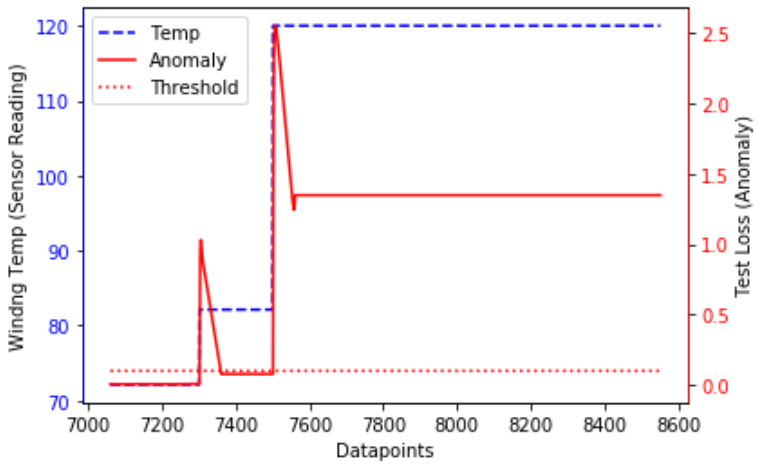
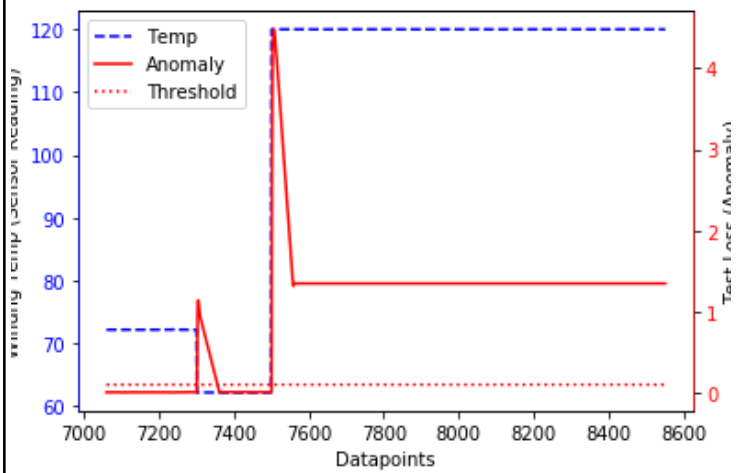
| Sine Error curve: Rising | Sine Error curve: Falling |
| --- | --- |
|  Sine Test MAE loss |  Sine Test MAE loss |
|  Sine Anomaly vs Fault |  Sine Anomaly vs Fault |
|  Sine Rising Data vs Fault |  Sine Falling Data vs Fault |

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

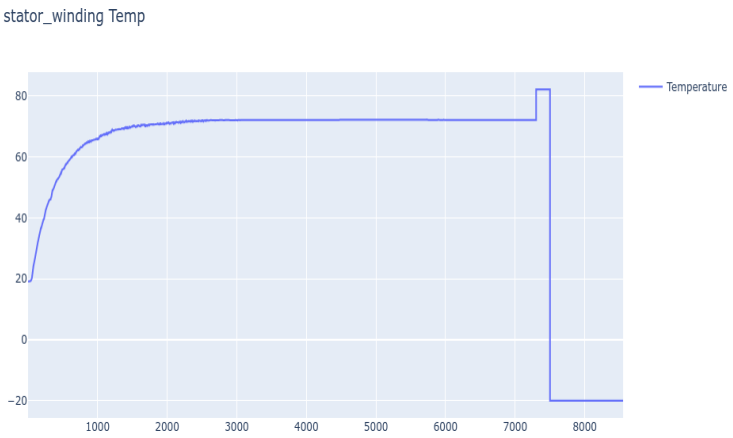
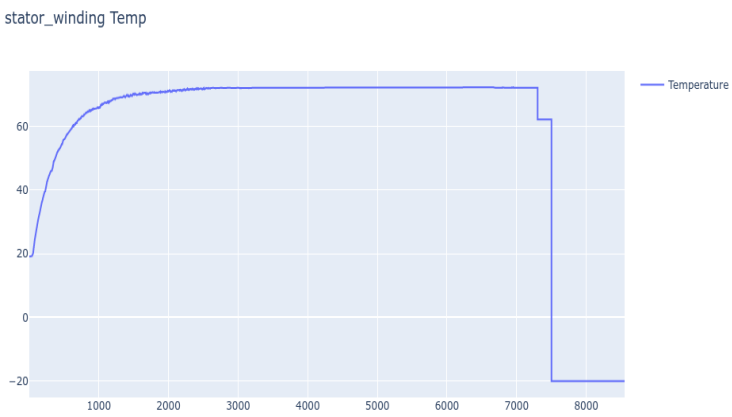
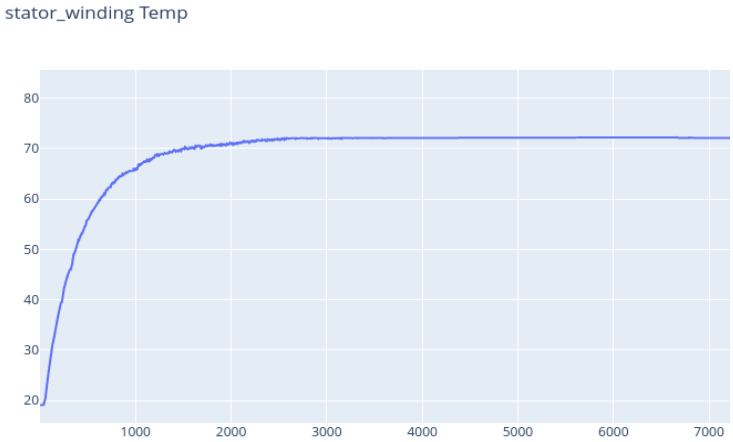
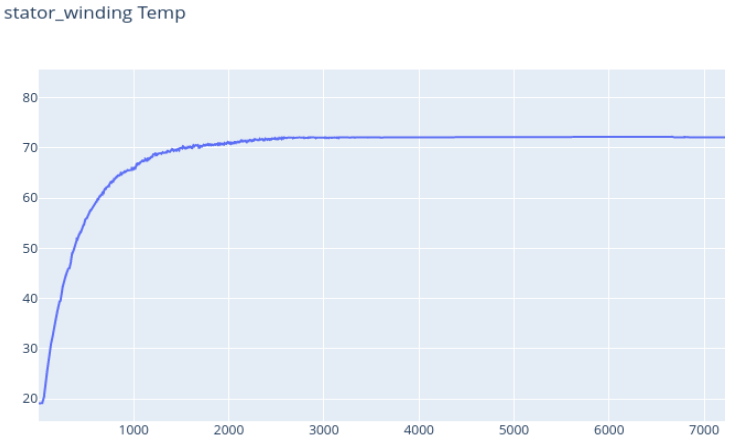
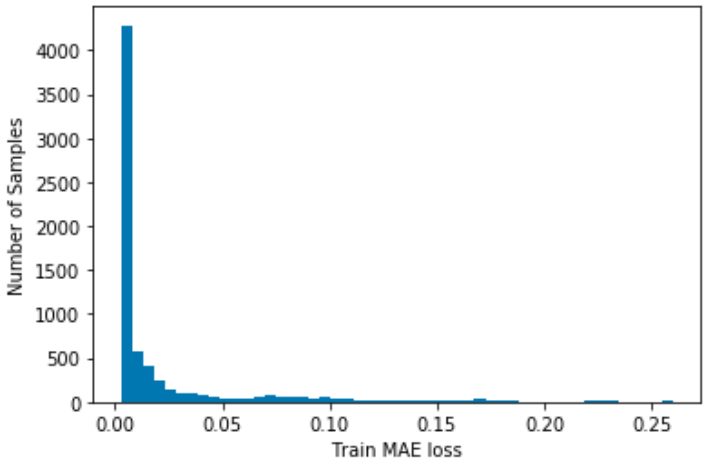
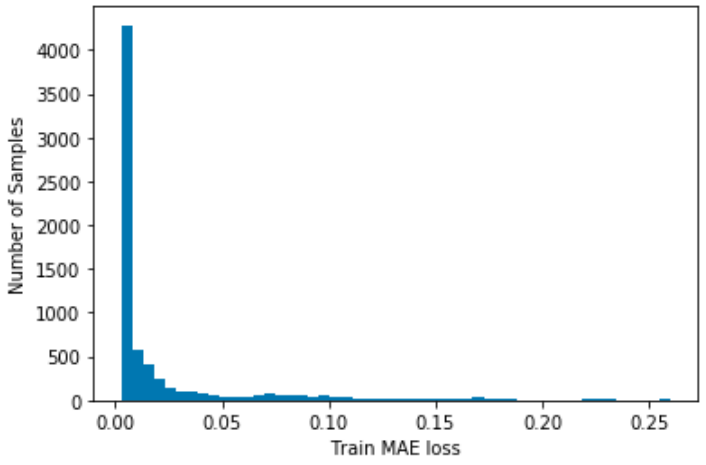
## 2.2.1 Square, Fault HIGH

| Square Error curve: Rising | Square Error curve: Falling |
|---|---|
|  Square Dataset |  Square Dataset |
|  Training Dataset |  Training Dataset |
|  Train MAE loss |  Train MAE loss |

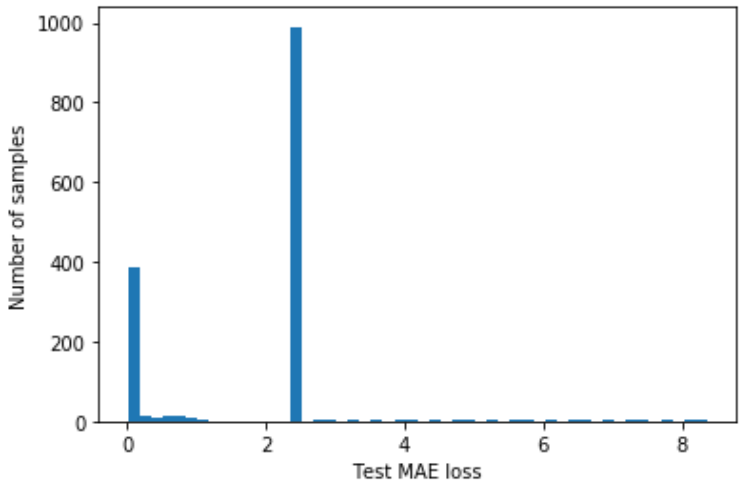
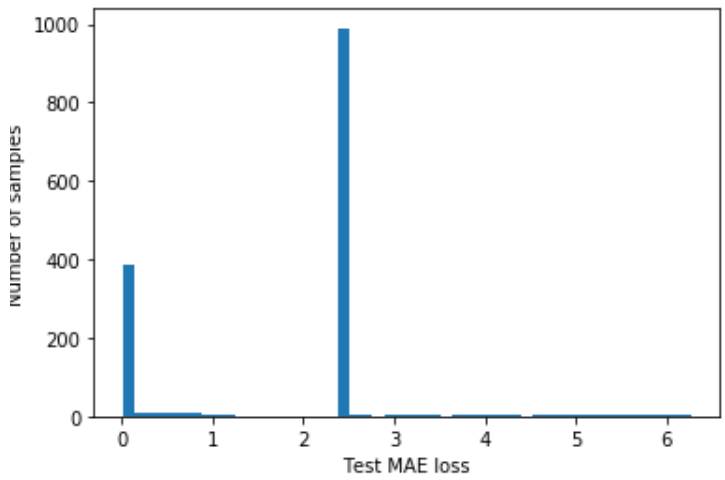
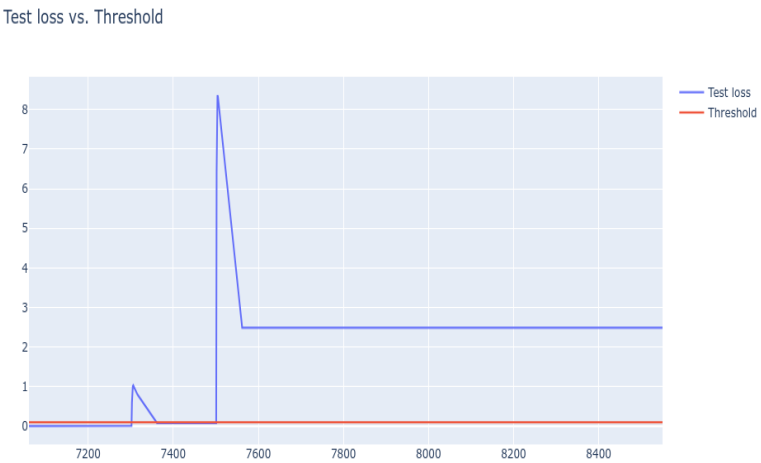
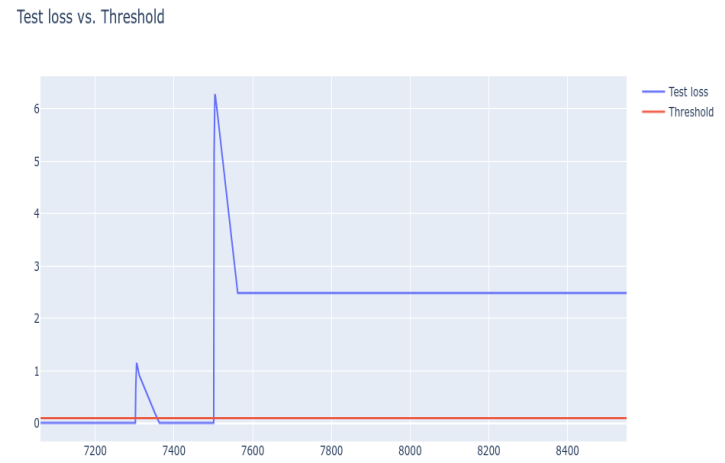
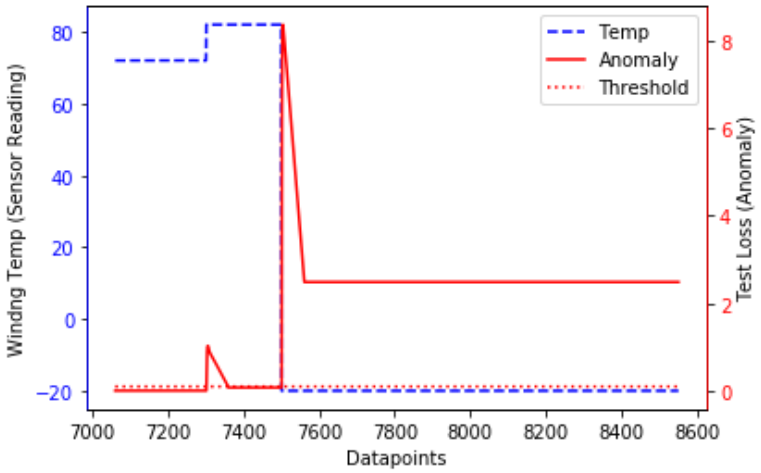
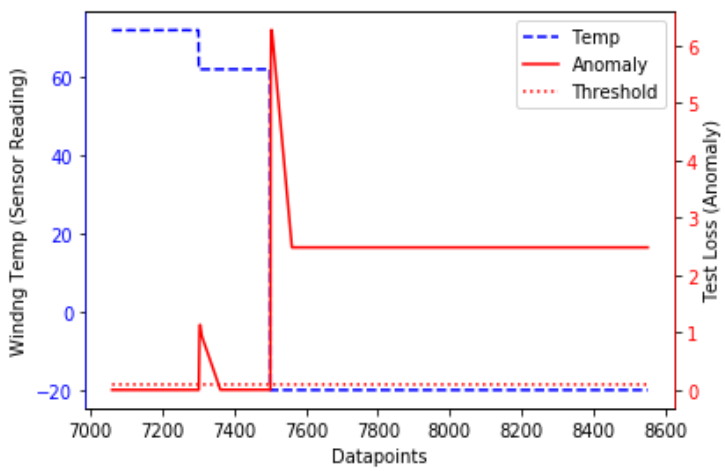
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| Square Error curve: Rising | Square Error curve: Falling |
| --- | --- |
|  Square Test MAE loss |  Square Test MAE loss |
|  Square Anomaly vs Fault |  Square Anomaly vs Fault |
|  Square Rising Data vs Fault |  Square Falling Data vs Fault |

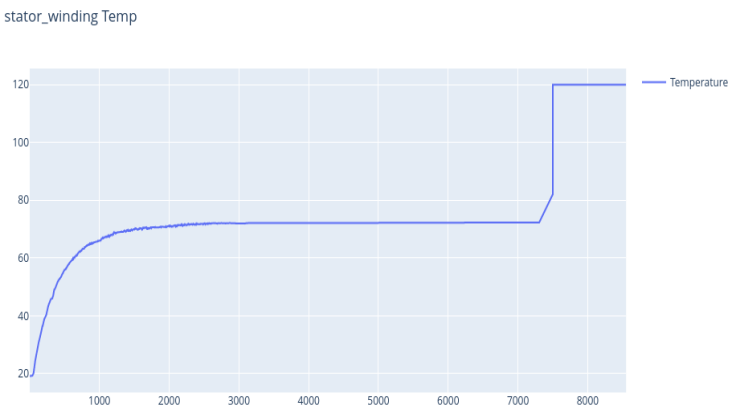
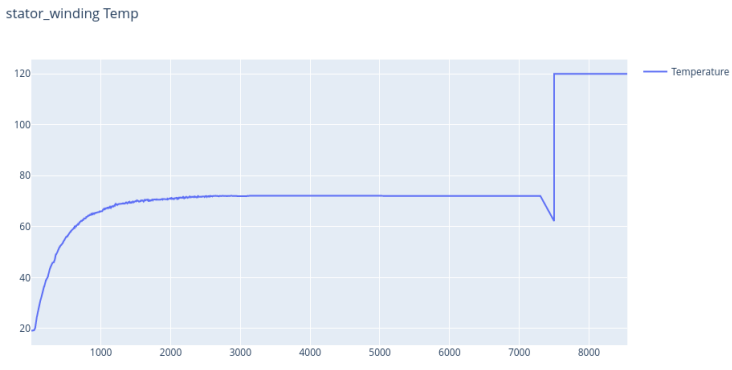
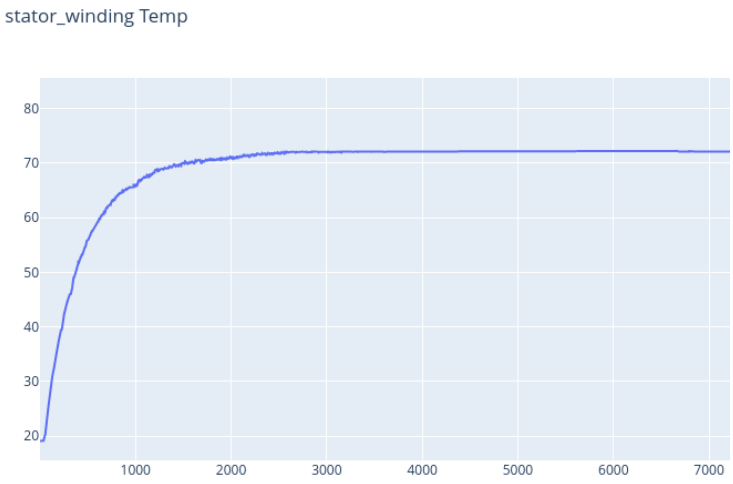
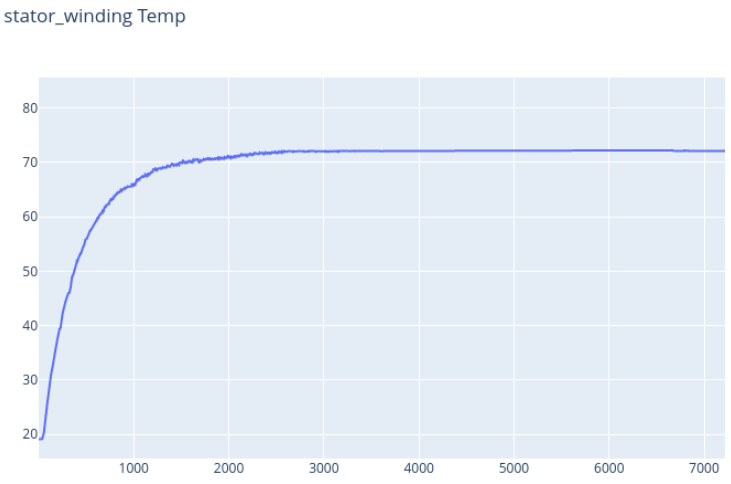
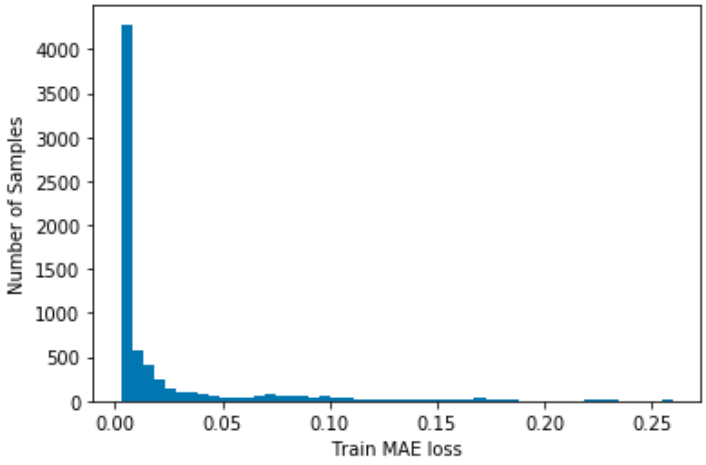
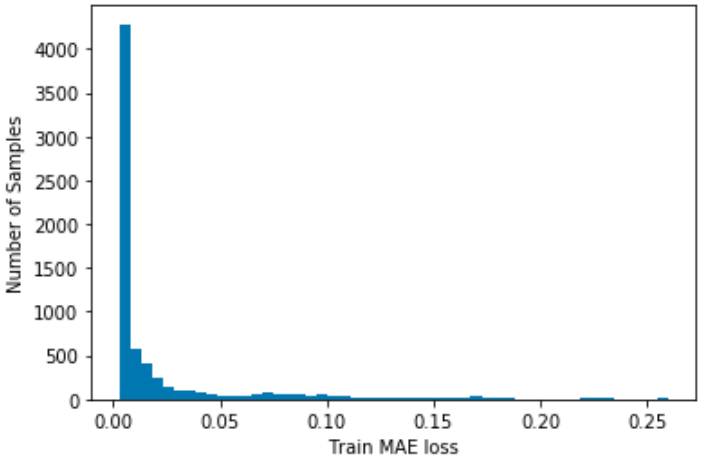
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| 2.2.2 Square, Fault LOW | |
|---|---|
| **Square Error curve: Rising** | **Square Error curve: Falling** |
|  Square Dataset |  Square Dataset |
|  Training Dataset |  Training Dataset |
|  Train MAE loss |  Train MAE loss |

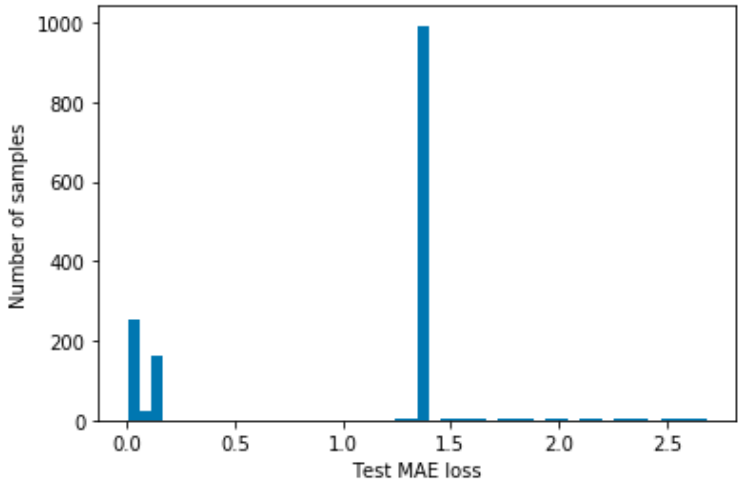
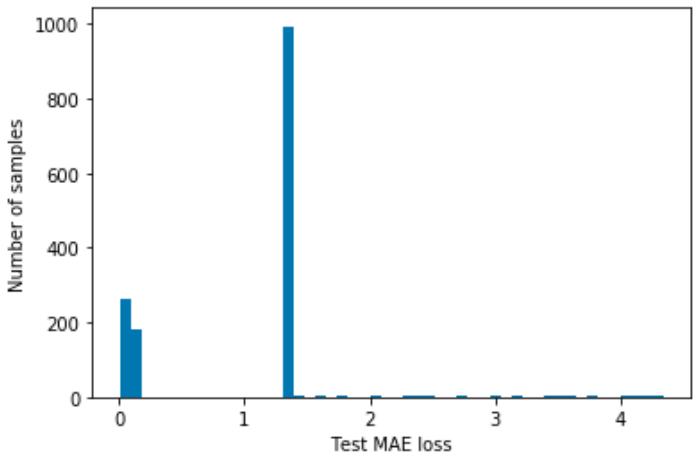
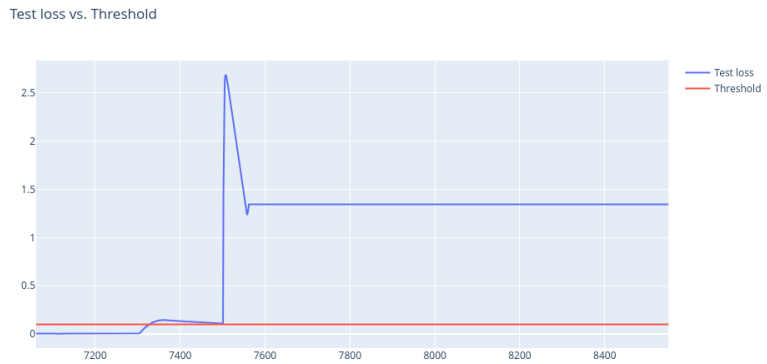
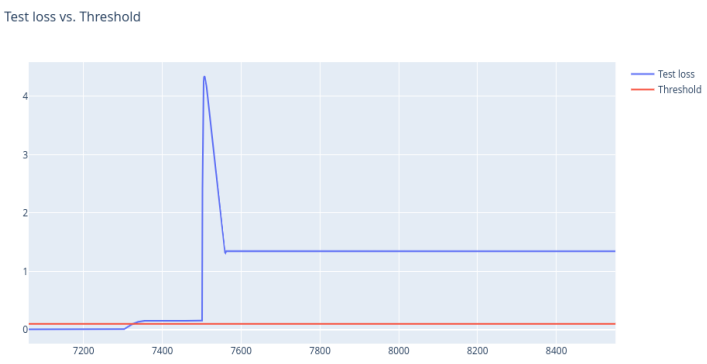
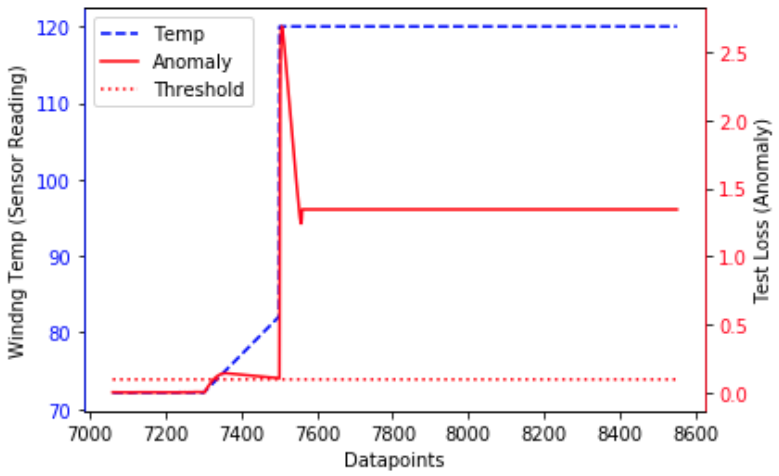
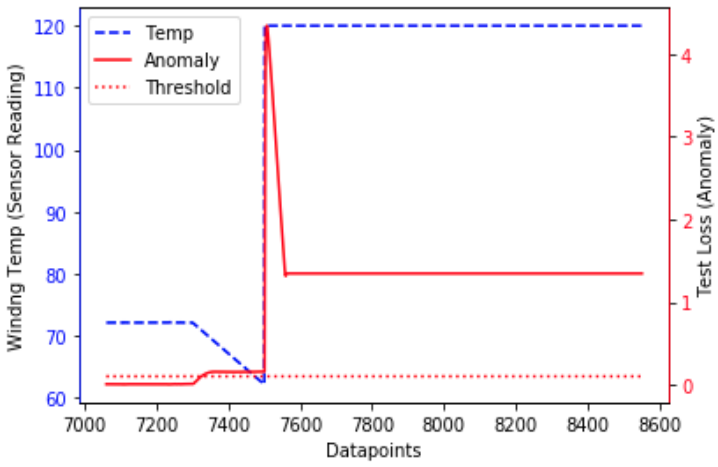
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| Square Error curve: Rising | Square Error curve: Falling |
| --- | --- |
|  Square Test MAE loss |  Square Test MAE loss |
|  Square Anomaly vs Fault |  Square Anomaly vs Fault |
|  Square Rising Data vs Fault |  Square Falling Data vs Fault |

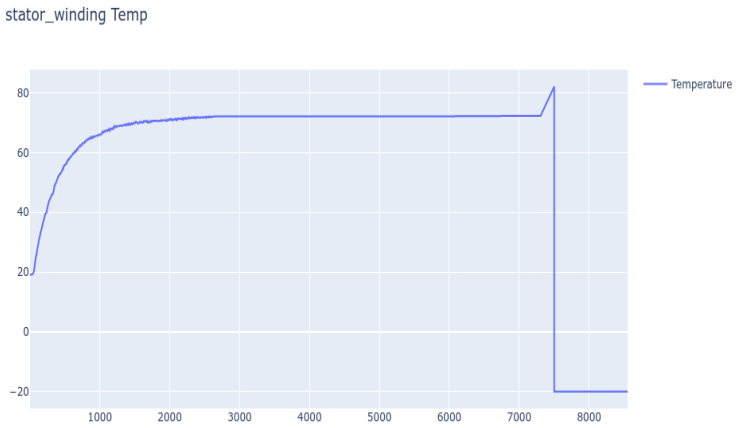
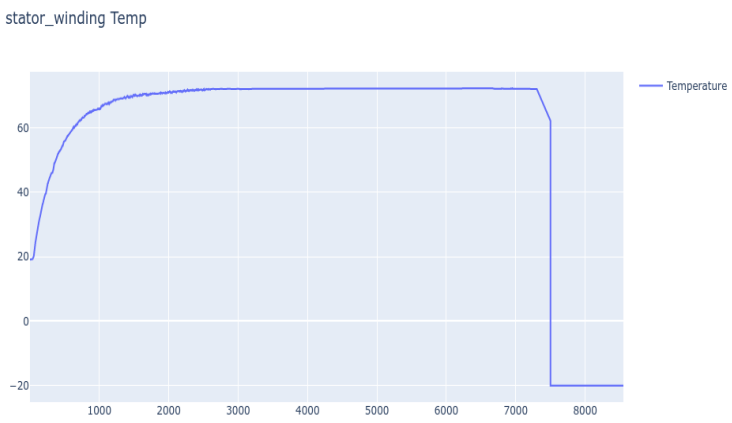
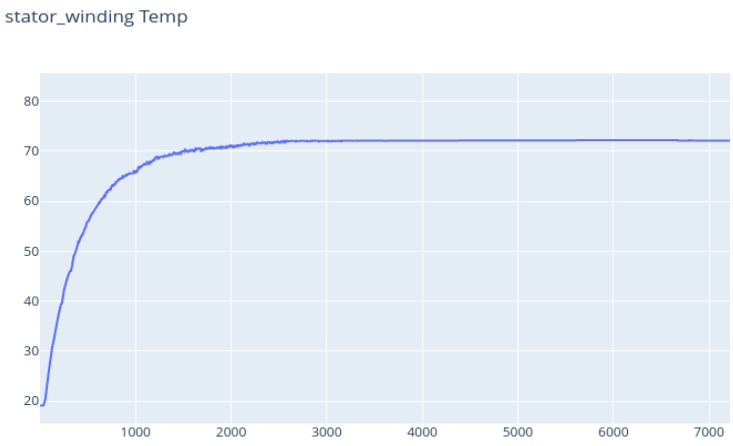
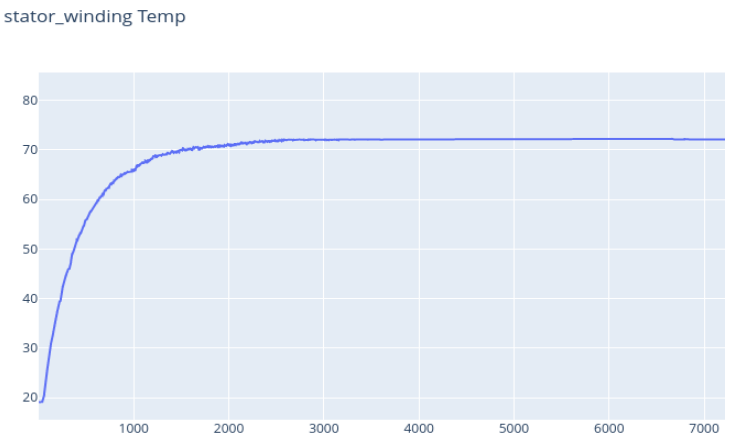
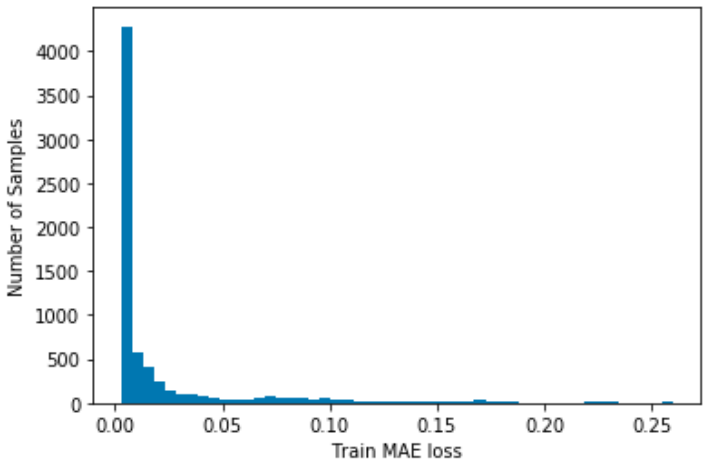
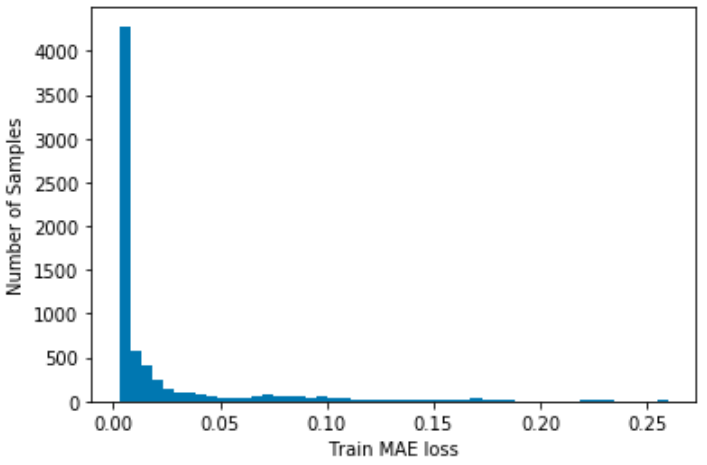
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| 2.3.1 Ramp, Fault HIGH | |
|---|---|
| **Ramp Error curve: Rising** | **Ramp Error curve: Falling** |
|  <br>Ramp Dataset |  <br>Ramp Dataset |
|  <br>Training Dataset |  <br>Training Dataset |
|  <br>Train MAE loss |  <br>Train MAE loss |

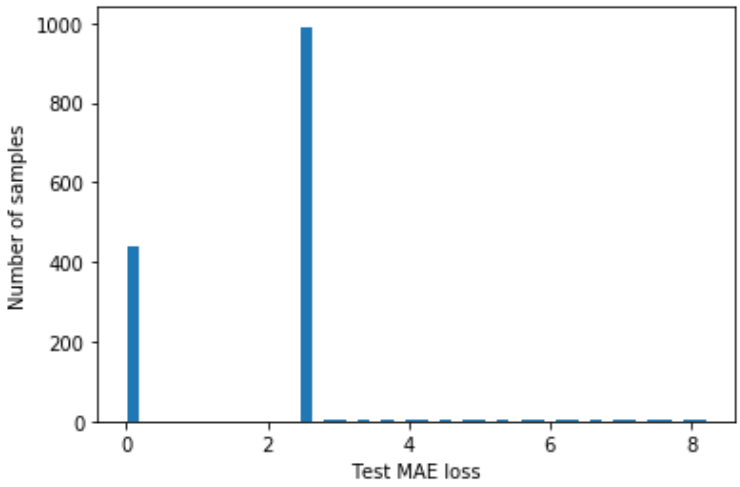
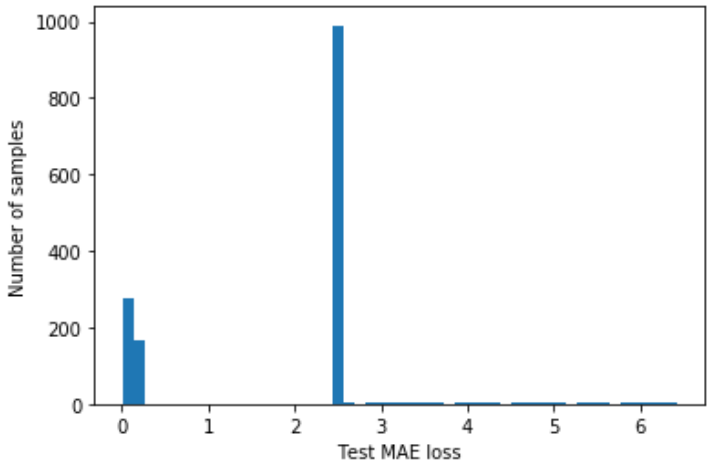
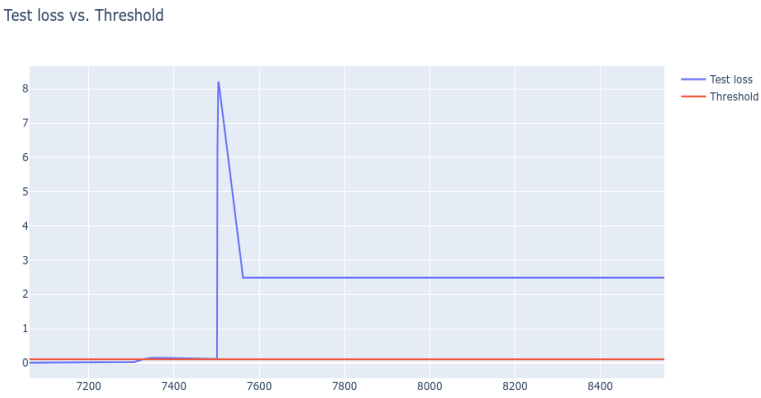
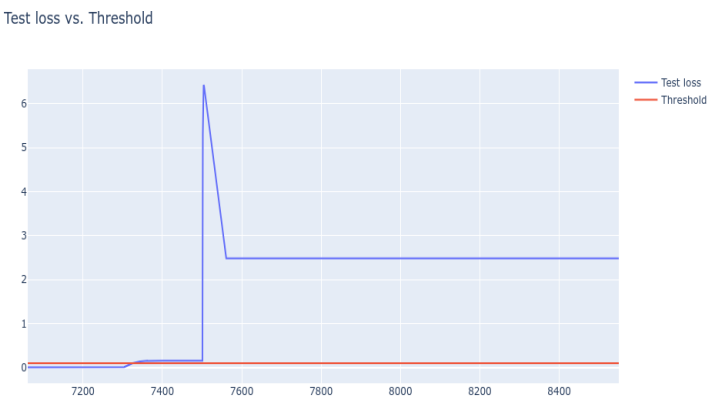
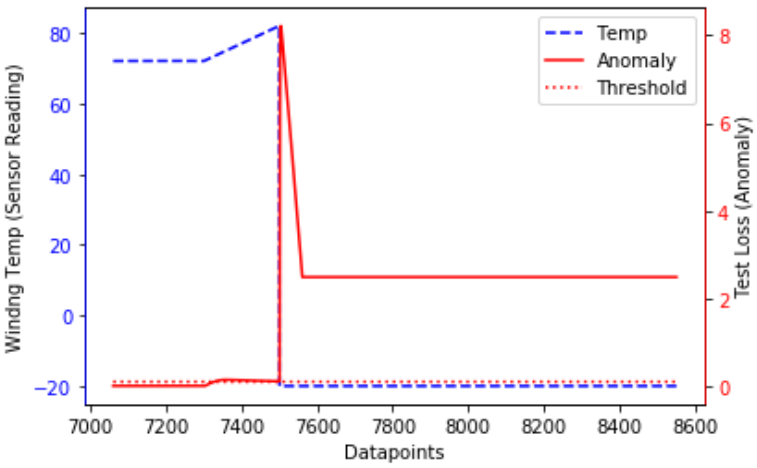
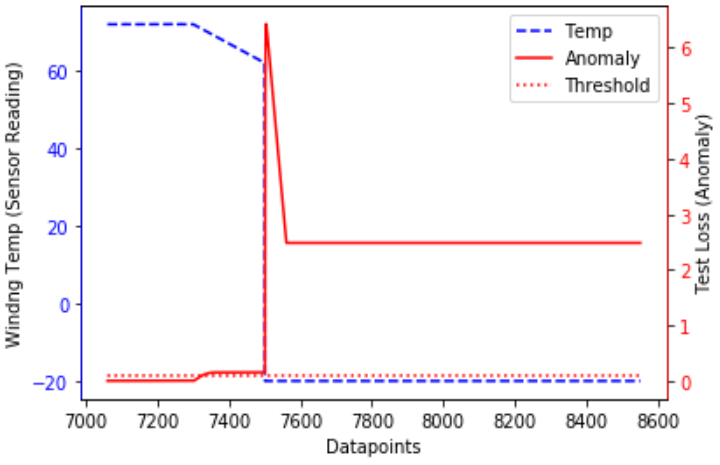
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| Ramp Error curve: Rising | Ramp Error curve: Falling |
|---|---|
|  Ramp Test MAE loss |  Ramp Test MAE loss |
|  Ramp Anomaly vs Fault |  Ramp Anomaly vs Fault |
|  Ramp Rising Data vs Fault |  Ramp Falling Data vs Fault |

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| 2.3.2 Ramp, Fault LOW | |
|---|---|
| **Ramp Error curve: Rising** | **Ramp Error curve: Falling** |
|  <br>Ramp Dataset |  <br>Ramp Dataset |
|  <br>Training Dataset |  <br>Training Dataset |
|  <br>Train MAE loss |  <br>Train MAE loss |

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| Ramp Error curve: Rising | Ramp Error curve: Falling |
|---|---|
|  Ramp Test MAE loss |  Ramp Test MAE loss |
|  Ramp Anomaly vs Fault |  Ramp Anomaly vs Fault |
|  Ramp Rising Data vs Fault |  Ramp Falling Data vs Fault |

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

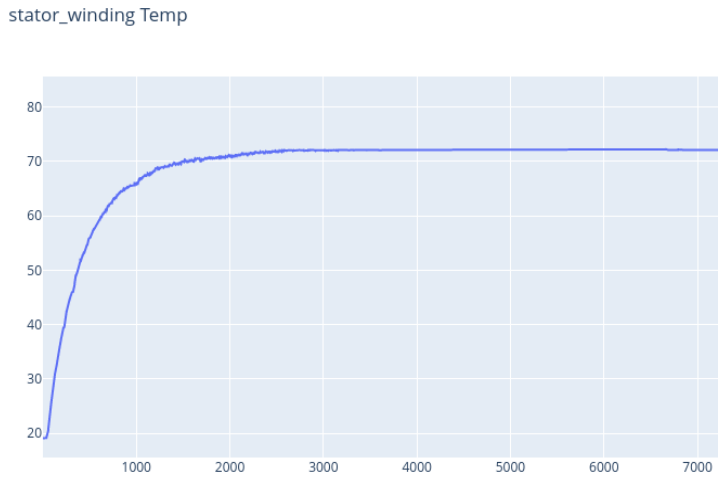
# Part B (LSTM>Error Window)

## 3. Data Vs Anomaly Plots Configuration:

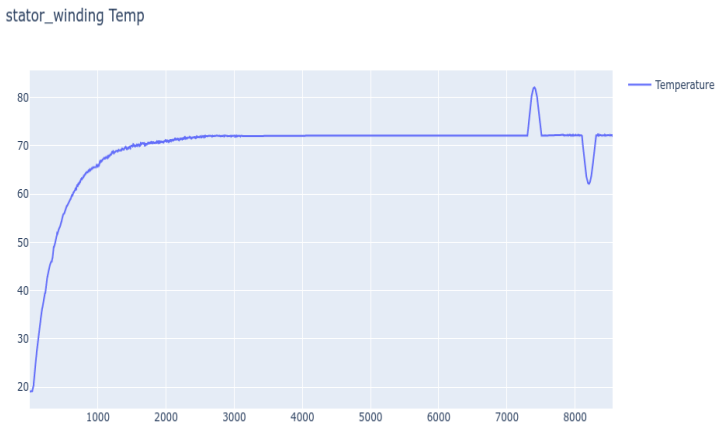
- Dataset: EV stator winding Temp. vs Time (0.5 sec per datapoint)
- LSTM window: 600 data points
- Error window: 200 data points
- Error injected as Sine, Square & Ramp wave
- Error injected as both Positive and Negative values in +Y axis

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

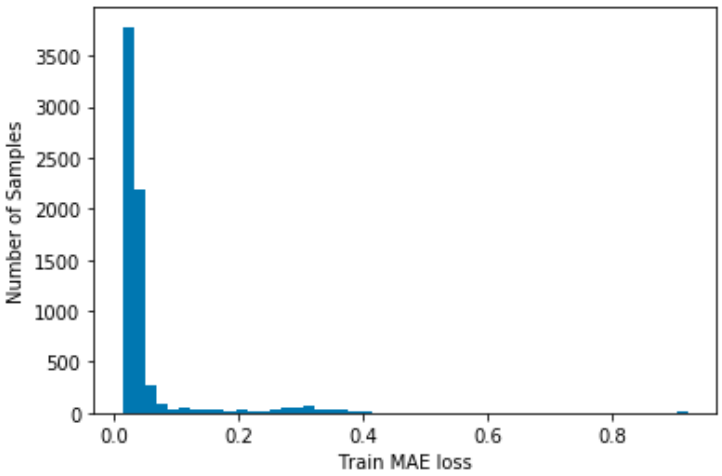
## 3.1 Sine Waveform error



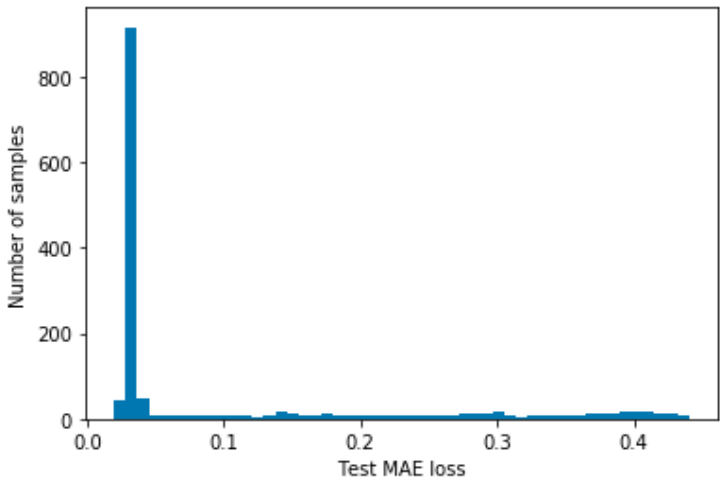

Training Dataset



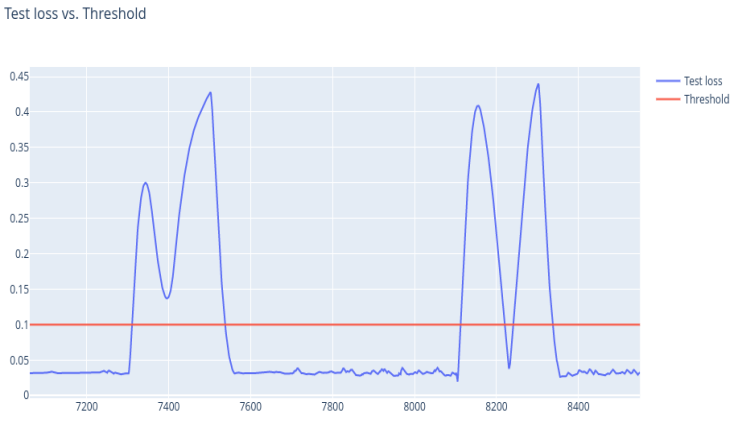

Sine Dataset



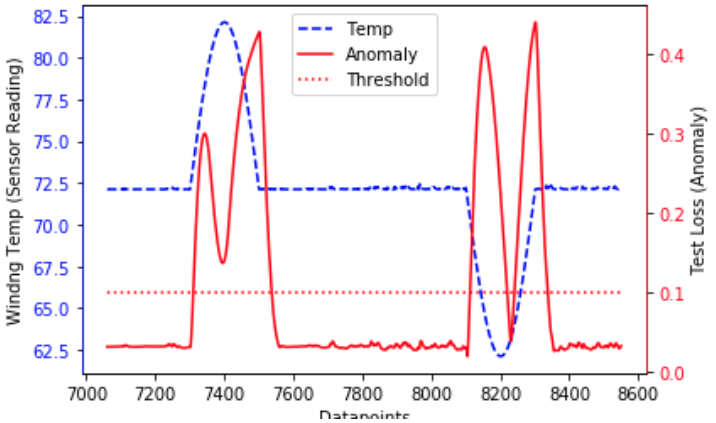

Sine Train MAE loss




Sine Test MAE loss



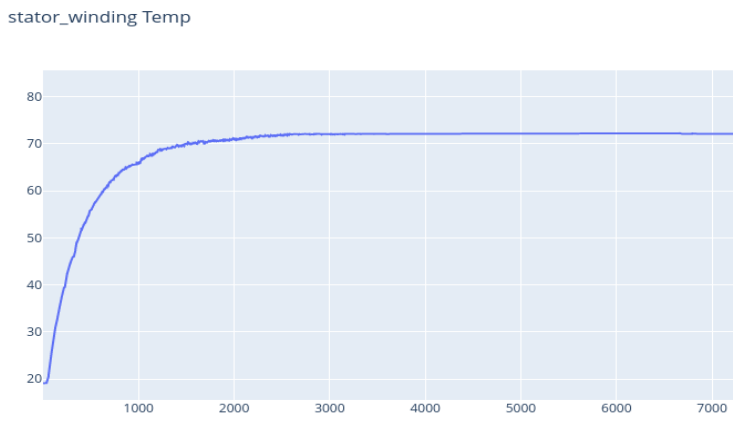

Sine Anomaly vs Threshold



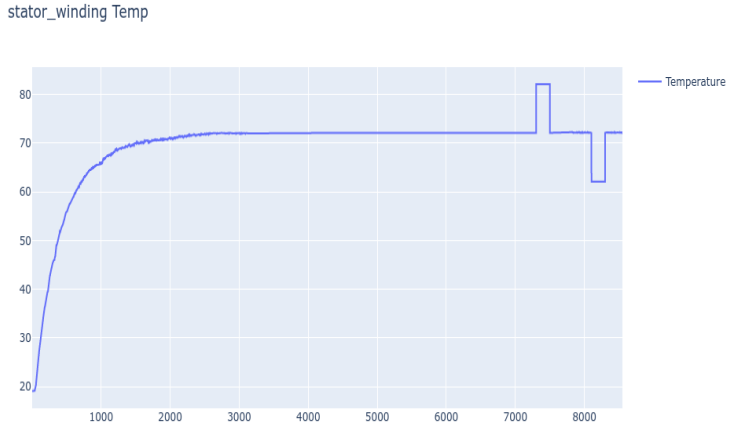

Sine Data vs Anomaly

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

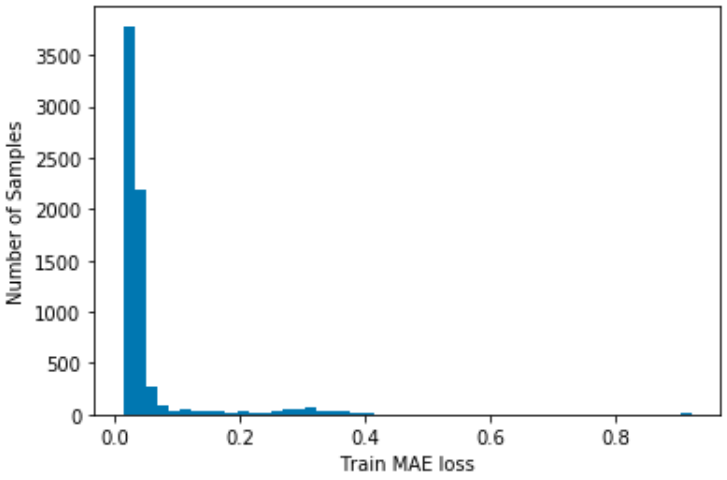
## 3.2 Square Waveform error



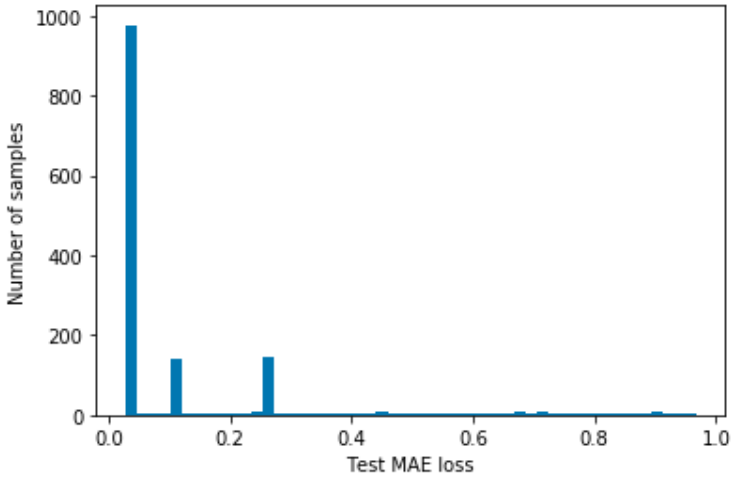

Training Dataset



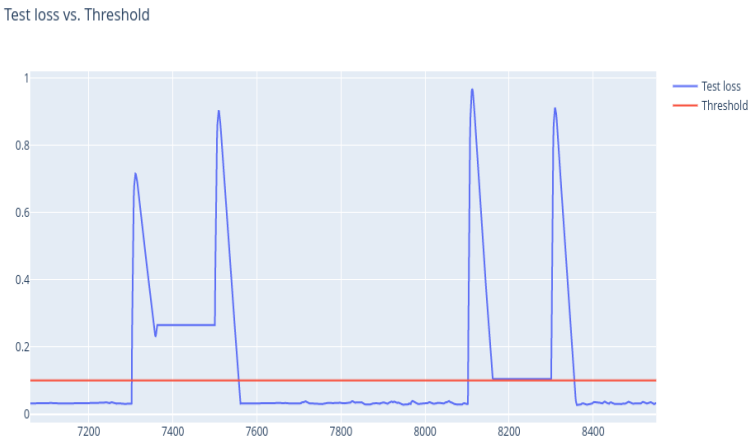

Square Dataset



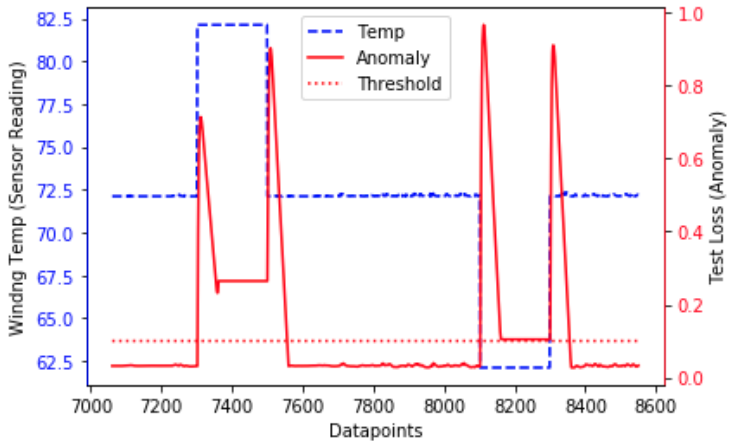

Square Train MAE loss




Square Test MAE loss



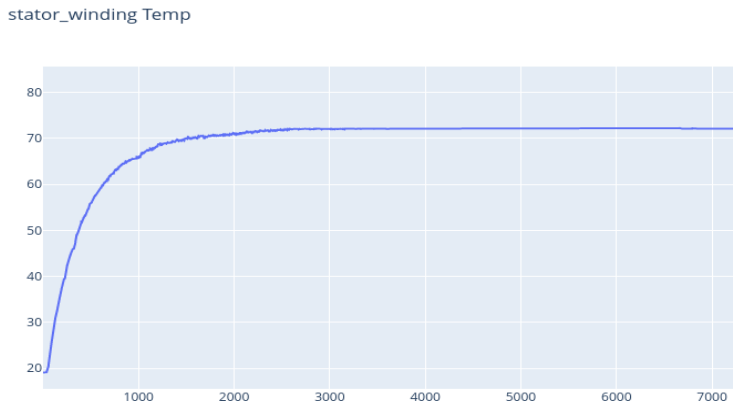

Square Anomaly vs Threshold



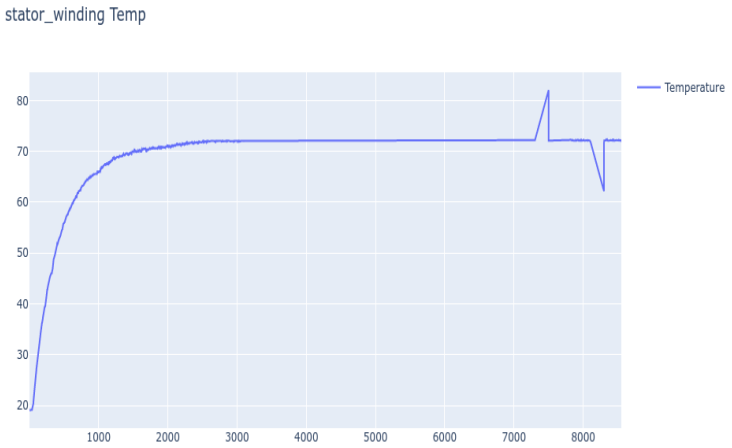

Square Data vs Anomaly

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

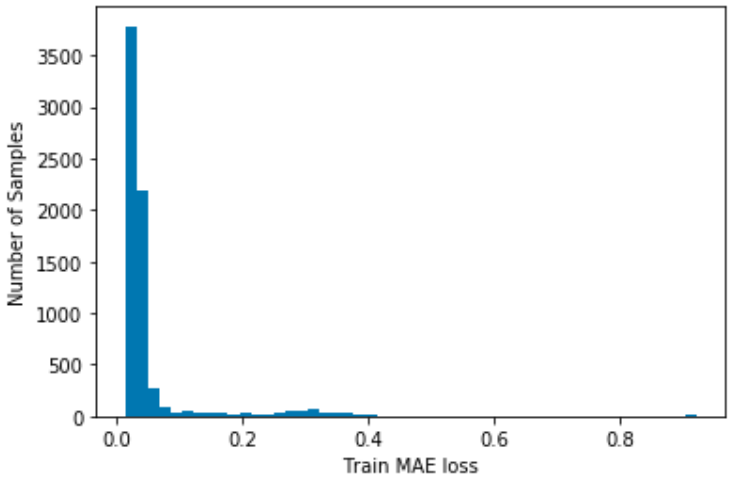
## 3.3 Ramp Waveform error



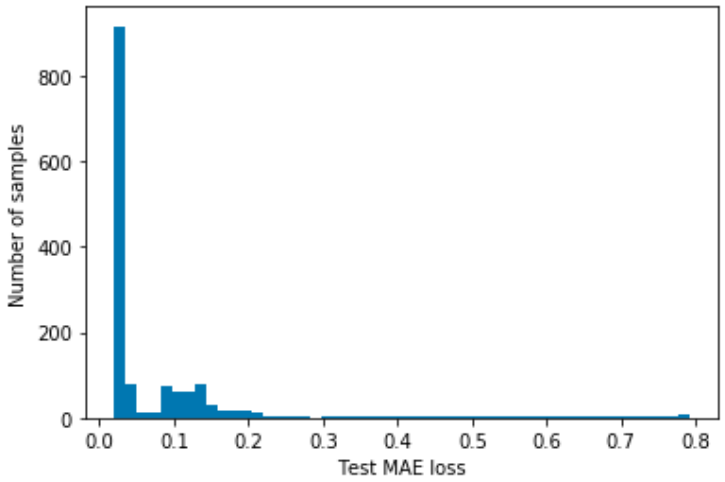

Training Dataset



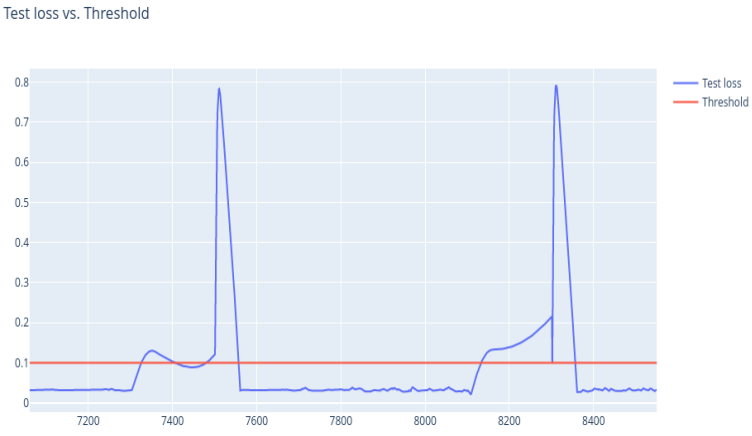

Ramp Dataset



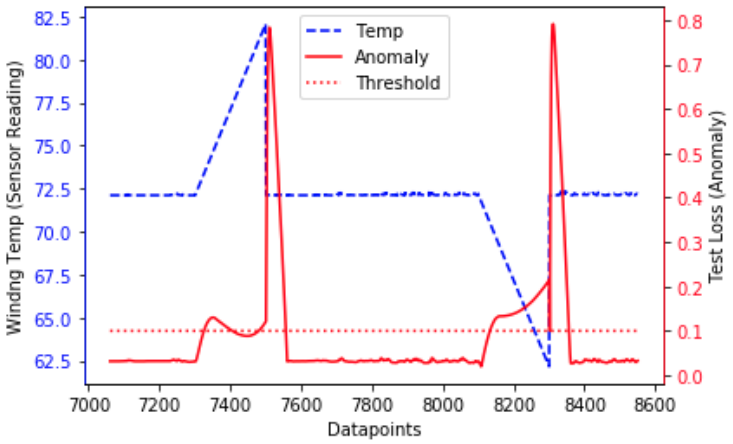

Ramp Train MAE loss




Ramp Test MAE loss




Ramp Anomaly vs Threshold




Ramp Data vs Anomaly

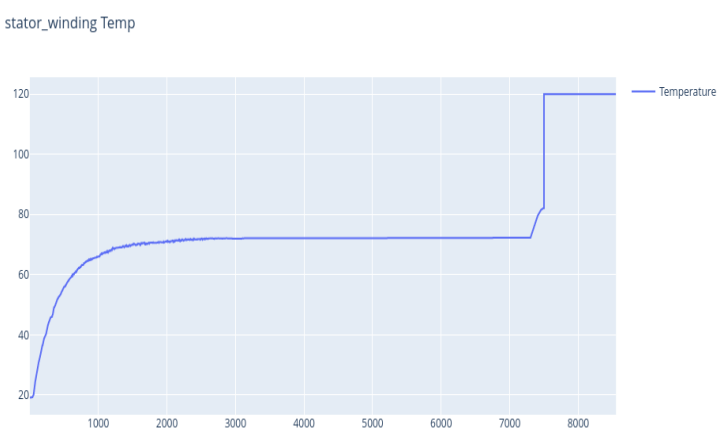
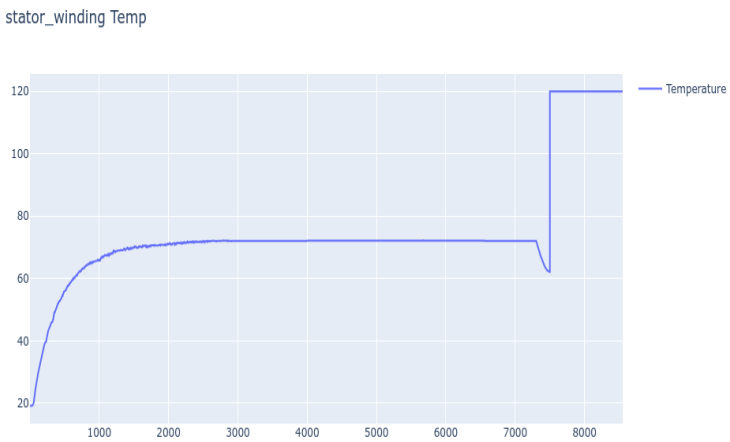
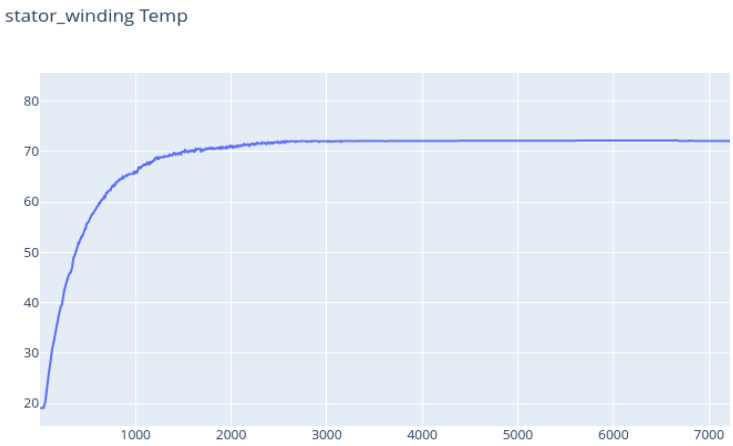
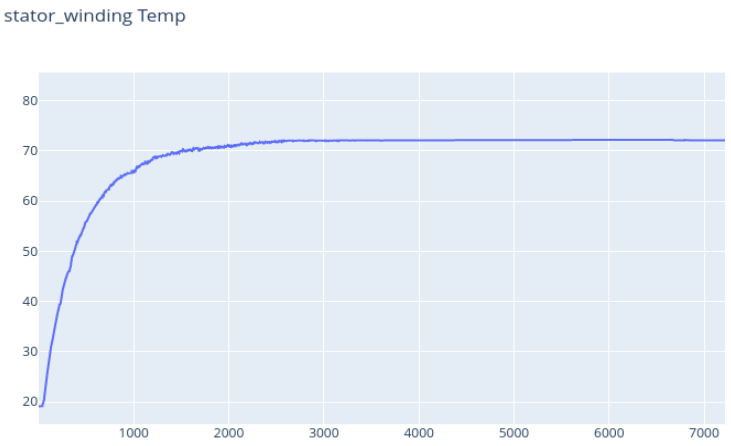
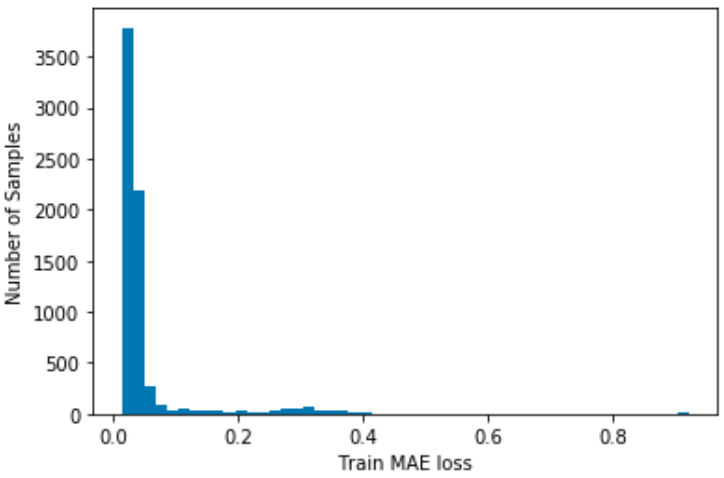
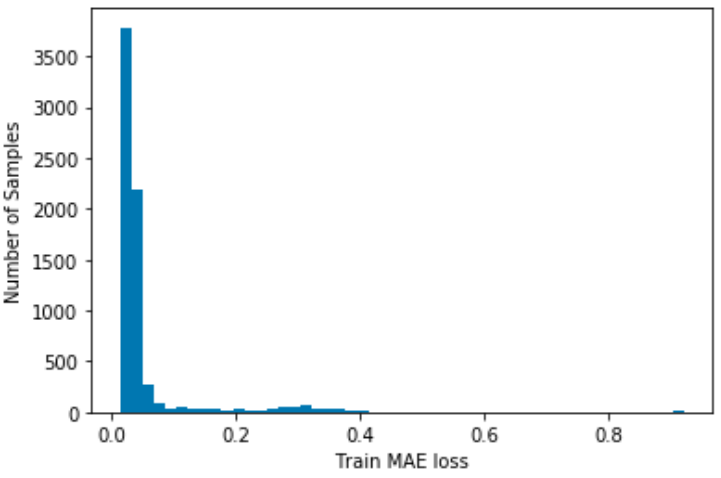
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

## 4. Data Vs Fault Plots

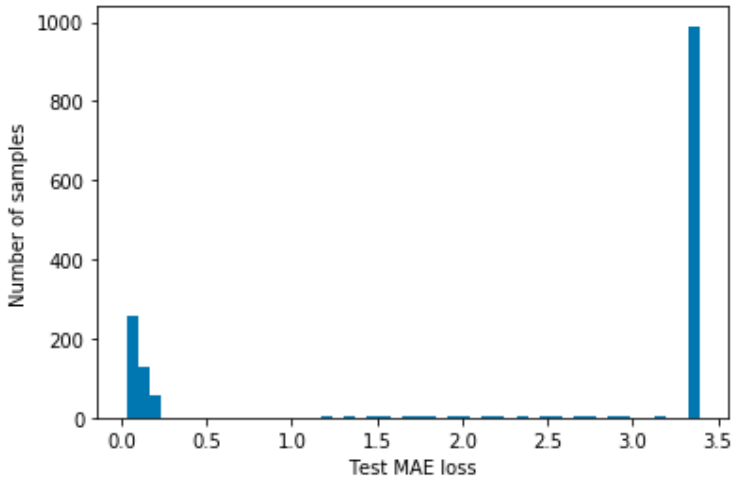
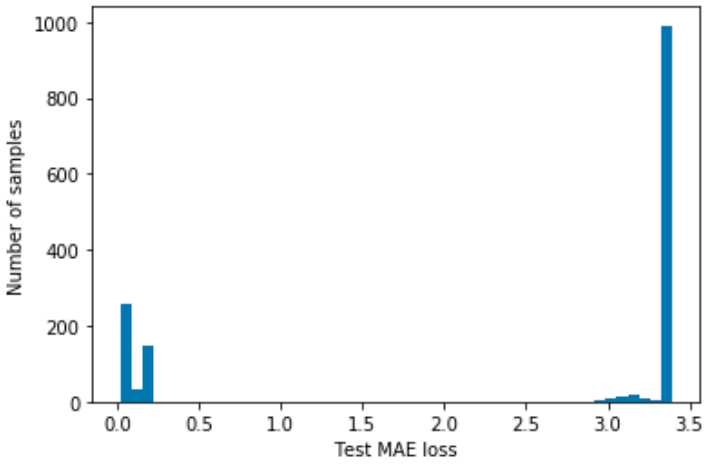
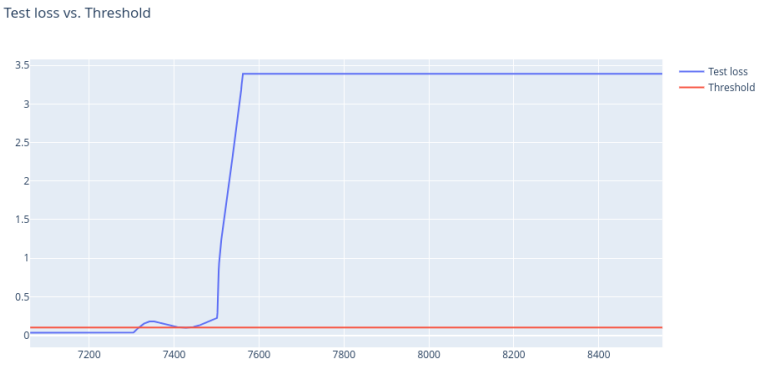
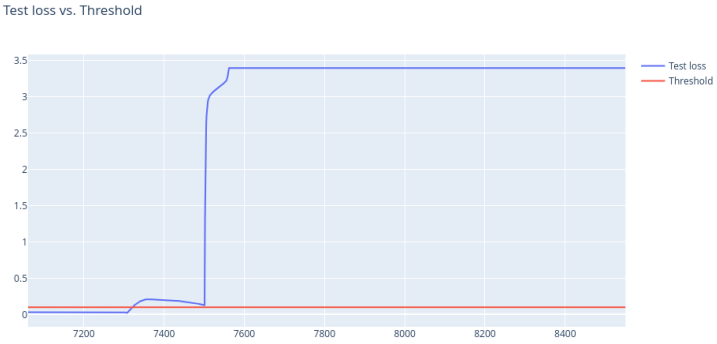
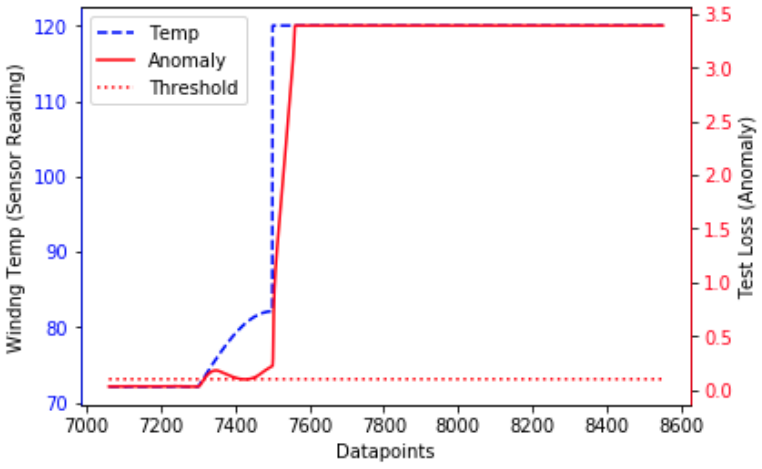
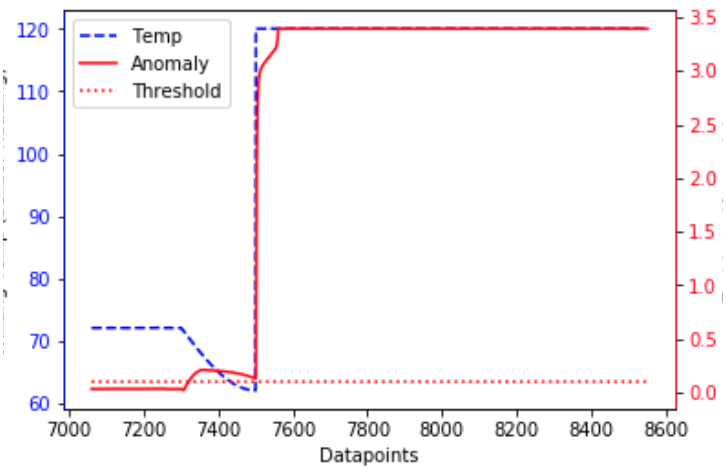
Configuration:

- Dataset: EV stator winding Temp. vs Time (0.5 sec per datapoint)
- LSTM window: 600 data points
- Error window: 200 data points
- Error injected as Sine, Square & Ramp wave
- Error injected as Positive and Negative values in +Y axis separately
- Operating range of the sensor is assumed from 0*C to 100*C,
- When the sensor is faulty, it will send the temp. that is beyond the operating range, i.e. -20*C and 120*C

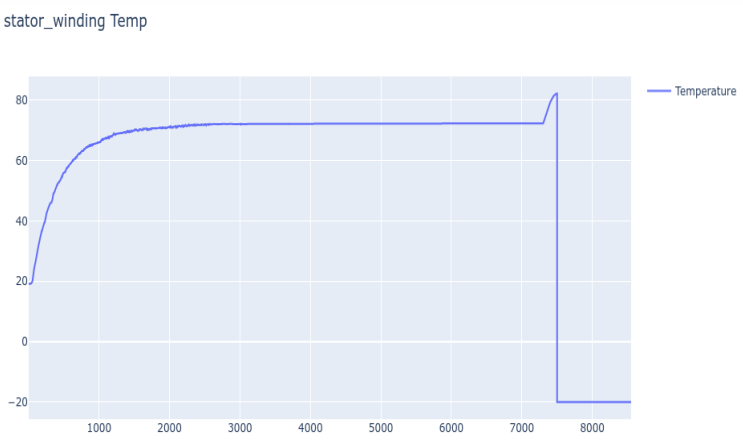
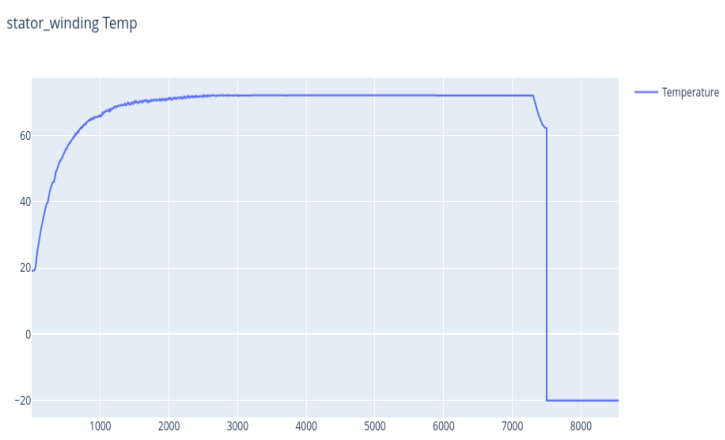
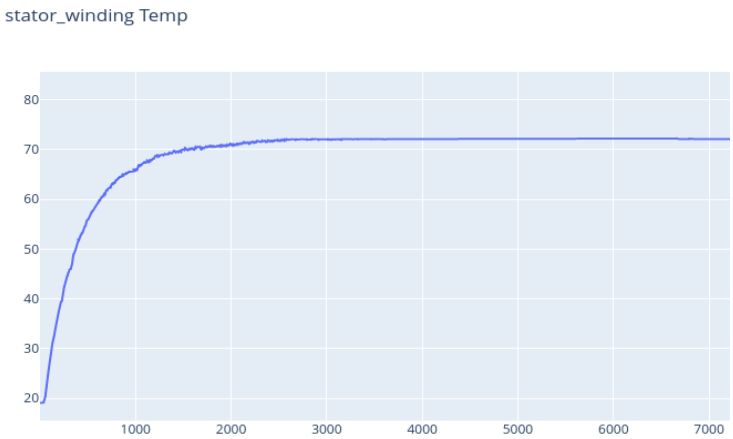
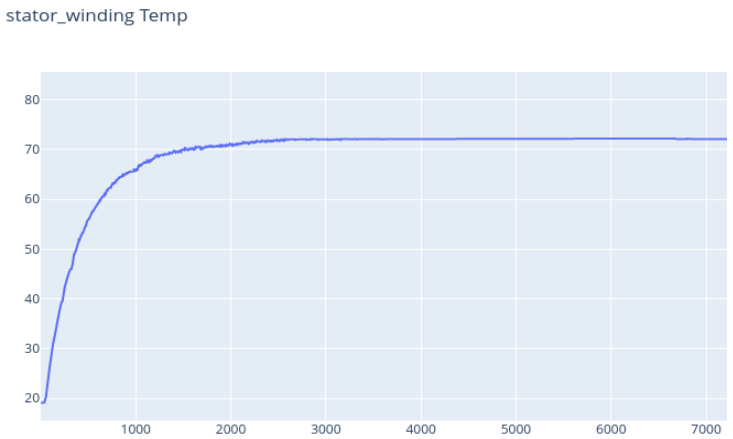
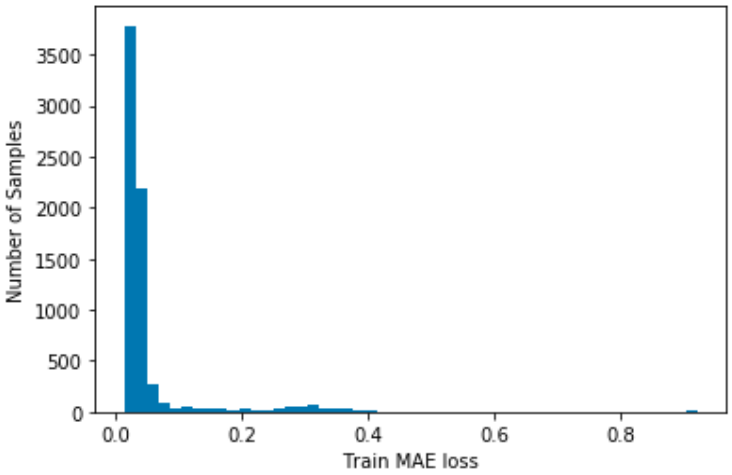
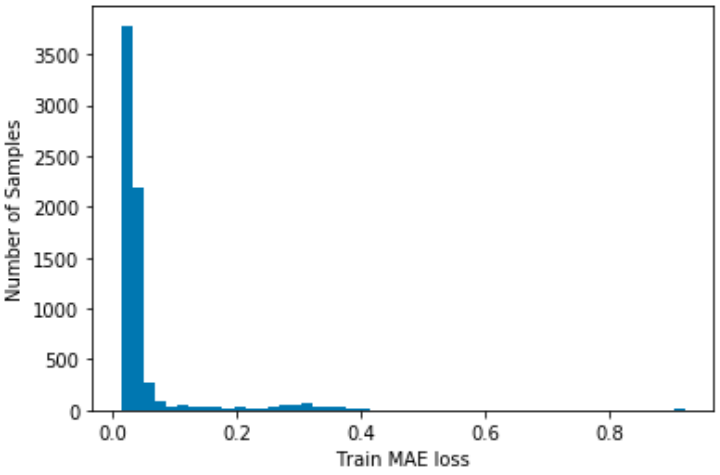
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| 4.1.1 Sine, Fault HIGH | |
|---|---|
| **Sine Error curve: Rising** | **Sine Error curve: Falling** |
|  <br>Sine Dataset |  <br>Sine Dataset |
|  <br>Training Dataset |  <br>Training Dataset |
|  <br>Train MAE loss |  <br>Train MAE loss |

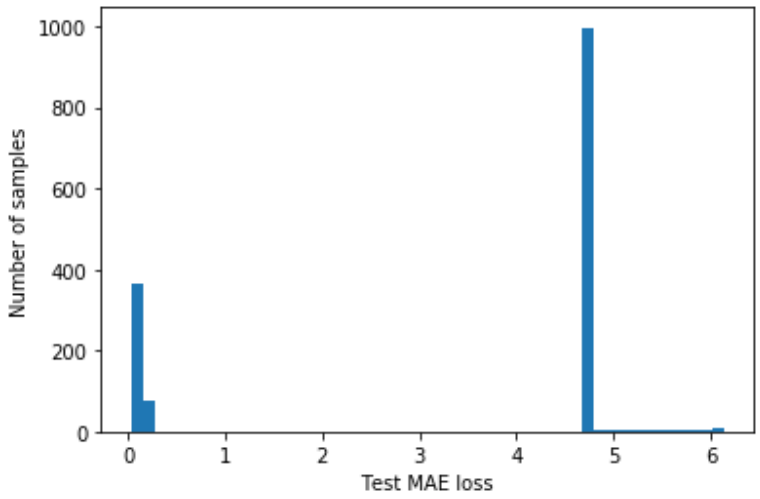
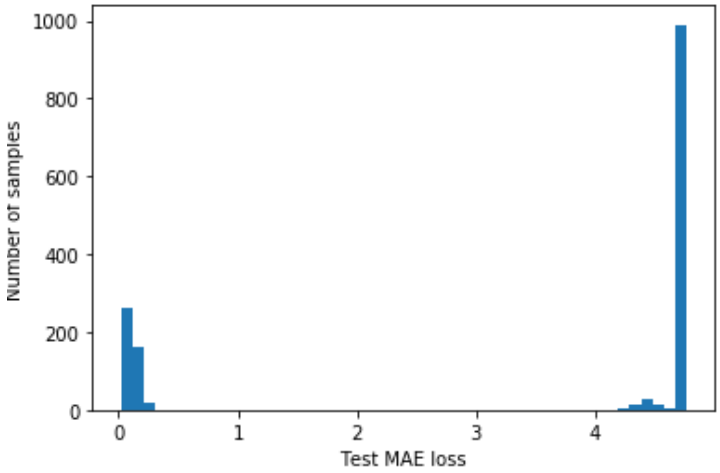
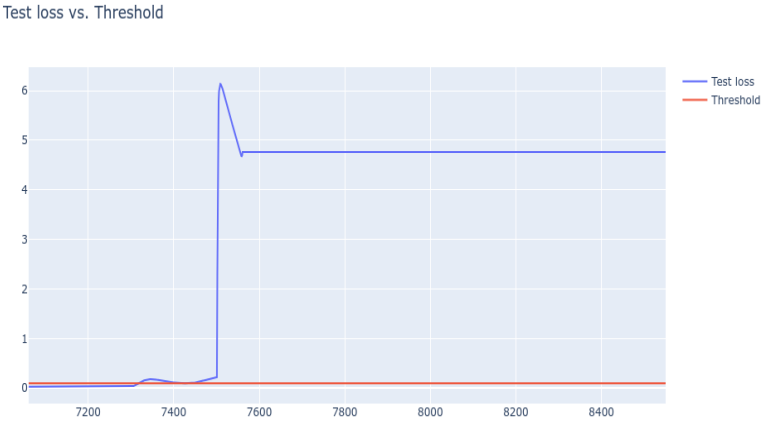
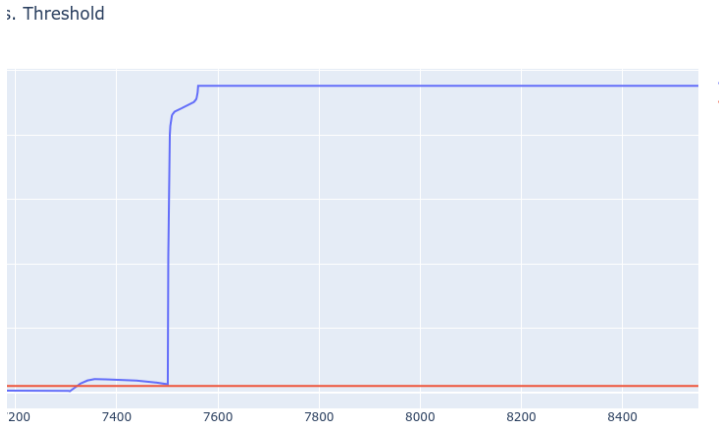
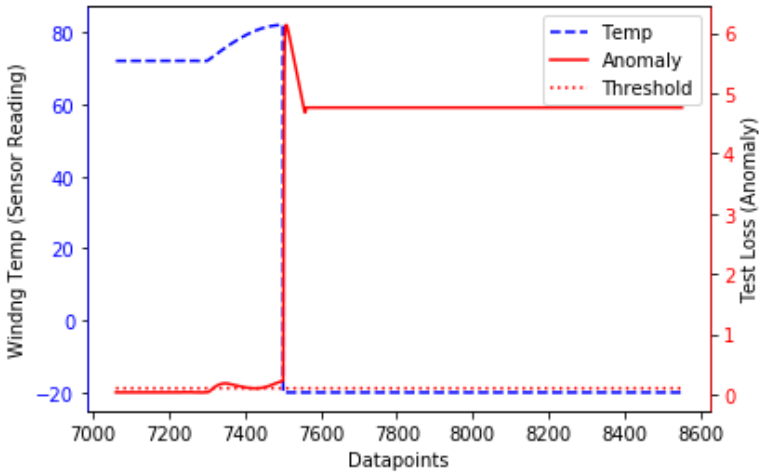
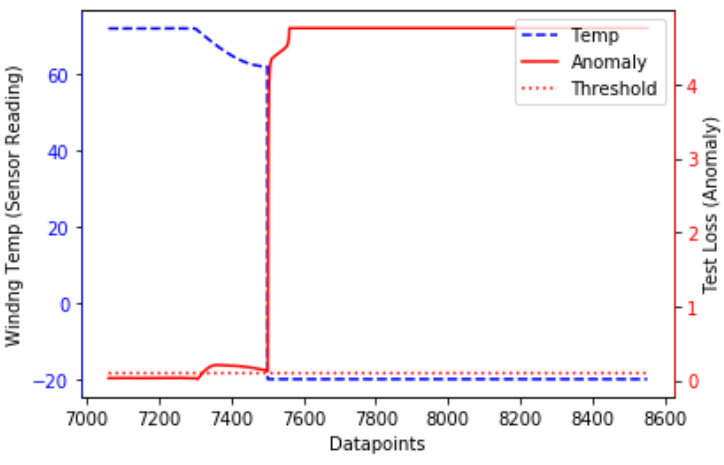
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| Sine Error curve: Rising | Sine Error curve: Falling |
|---|---|
|  Sine Test MAE loss |  Sine Test MAE loss |
|  Sine Anomaly vs Fault |  Sine Anomaly vs Fault |
|  Sine Rising Data vs Fault |  Sine Falling Data vs Fault |

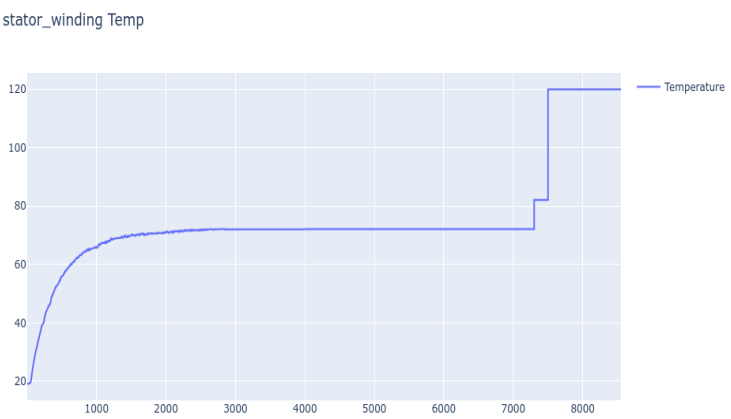
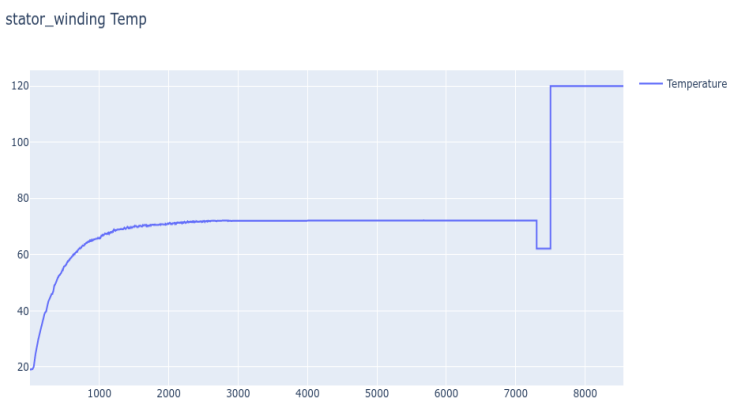
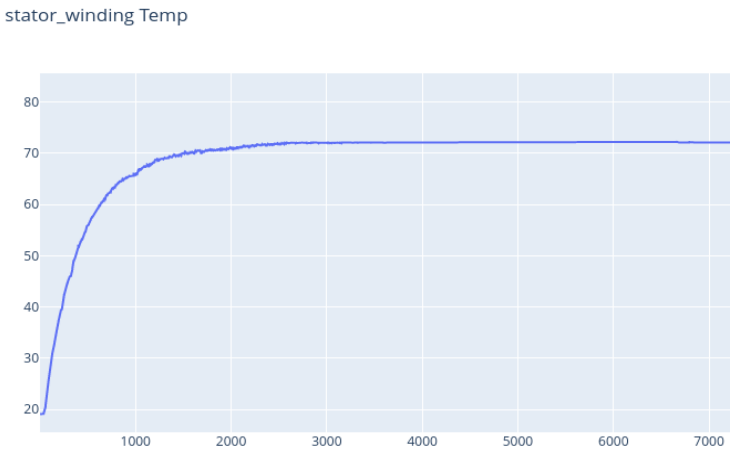
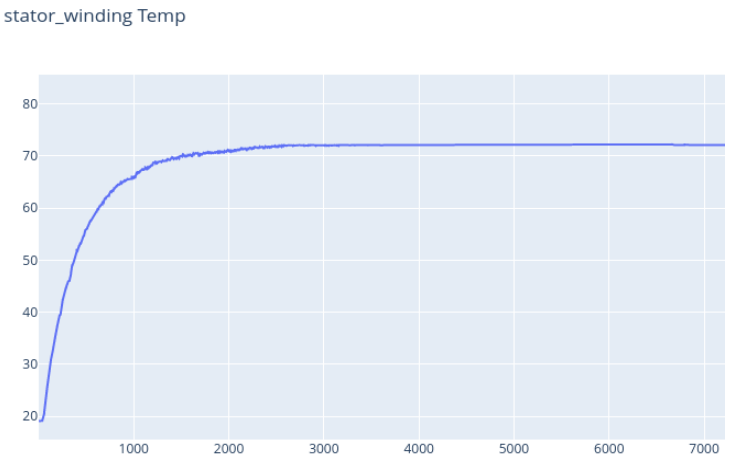
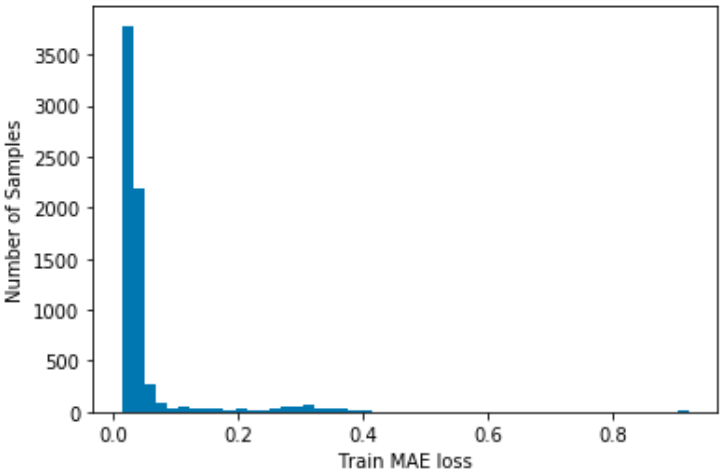
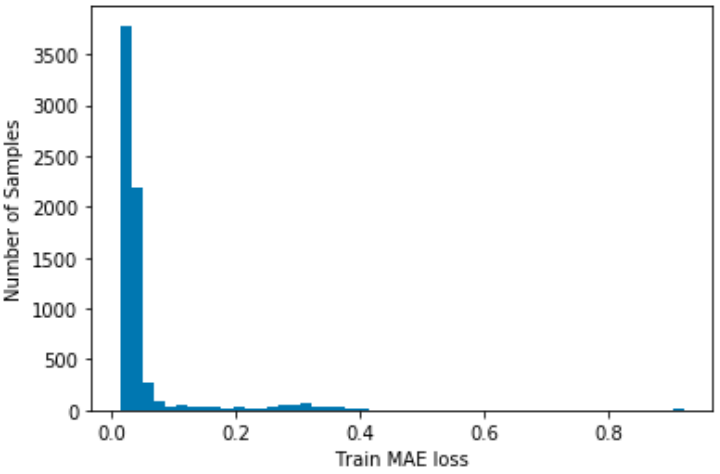
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| 4.1.2 Sine, Fault LOW | |
|---|---|
| **Sine Error curve: Rising** | **Sine Error curve: Falling** |
|  <br>Sine Dataset |  <br>Sine Dataset |
|  <br>Training Dataset |  <br>Training Dataset |
|  <br>Train MAE loss |  <br>Train MAE loss |

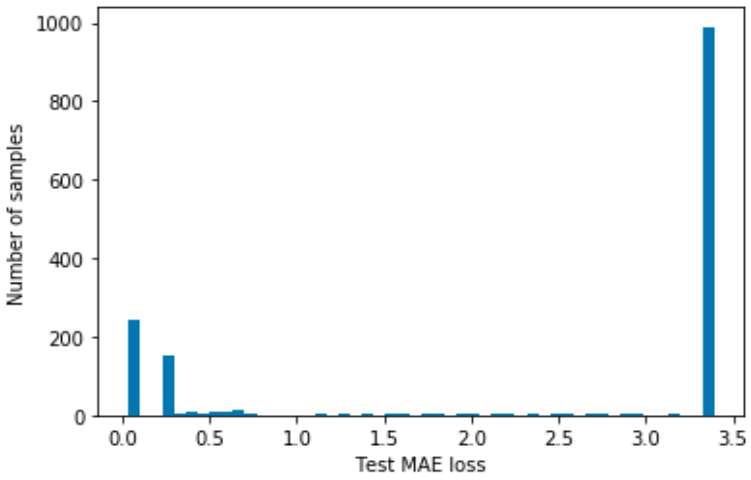
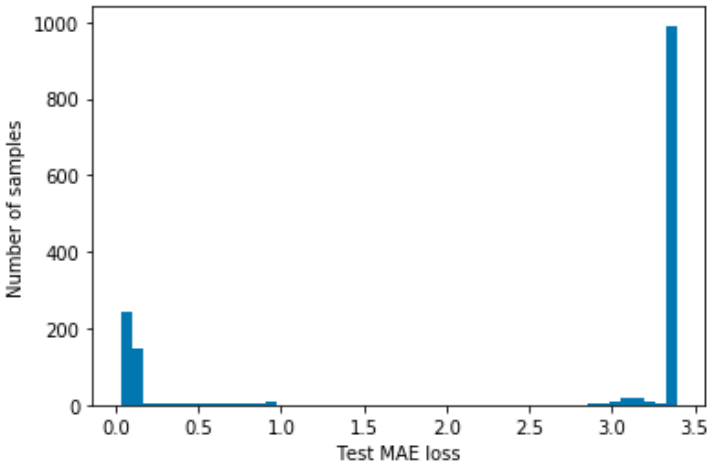
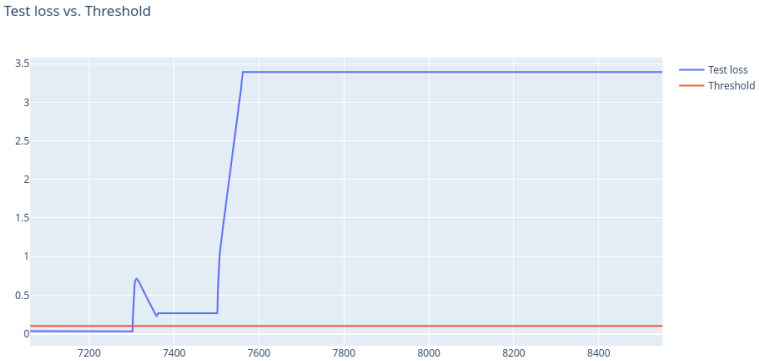
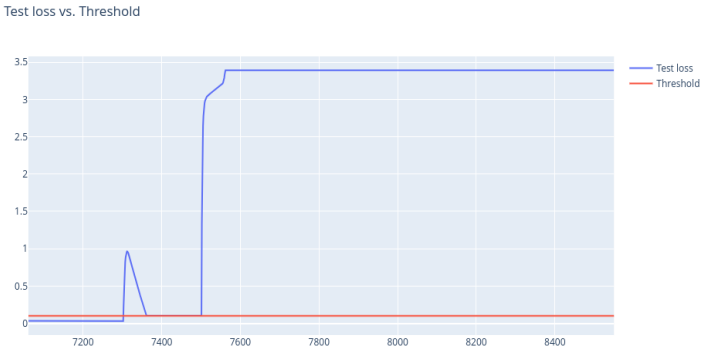
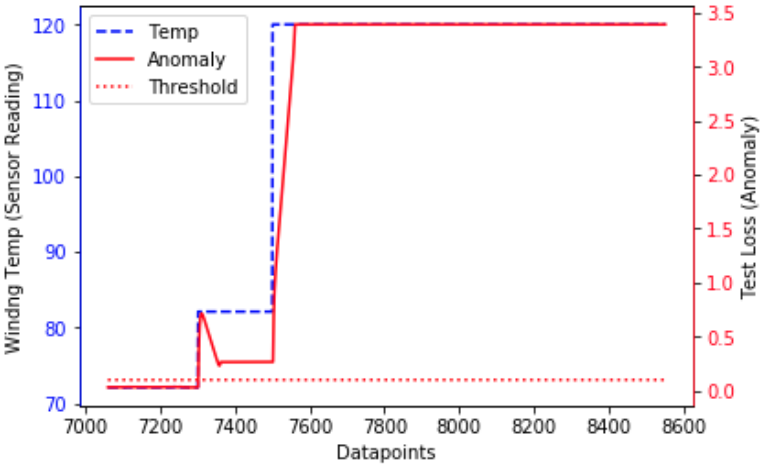
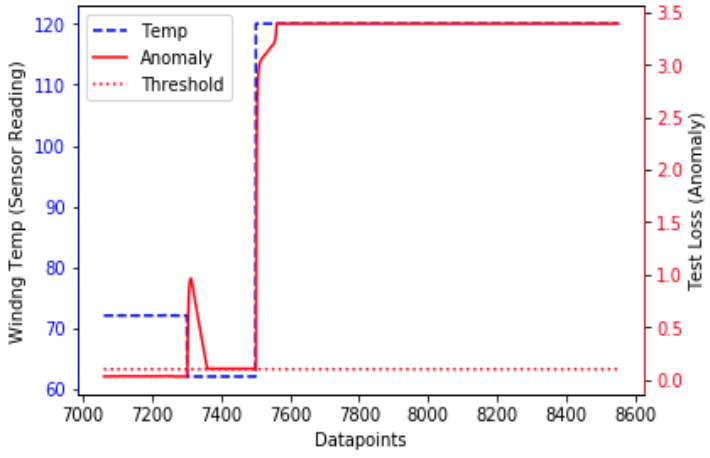
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| Sine Error curve: Rising | Sine Error curve: Falling |
| --- | --- |
|  Sine Test MAE loss |  Sine Test MAE loss |
|  Sine Anomaly vs Fault |  Sine Anomaly vs Fault |
|  Sine Rising Data vs Fault |  Sine Falling Data vs Fault |

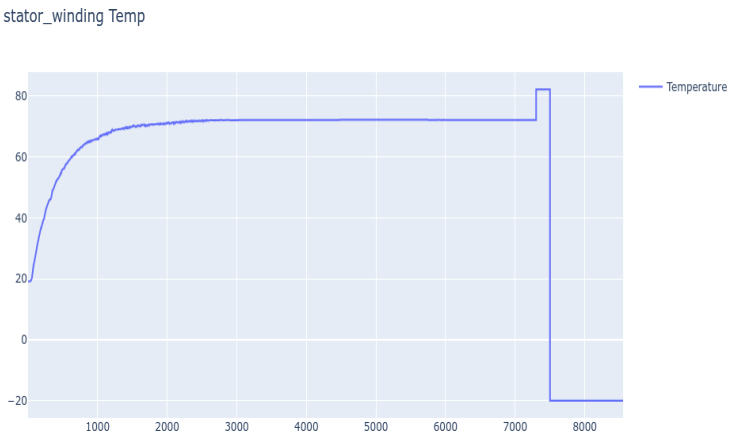
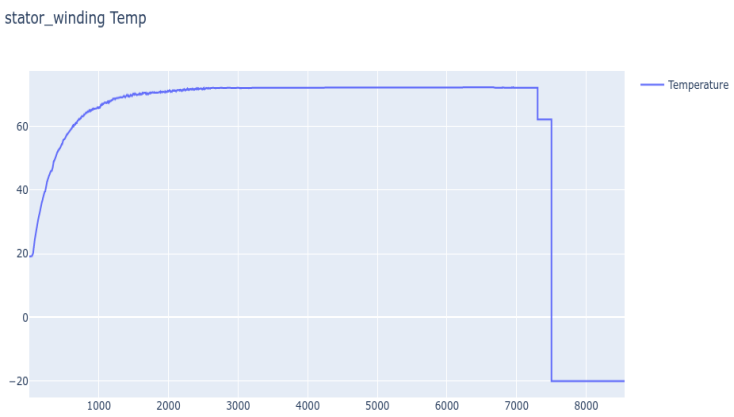
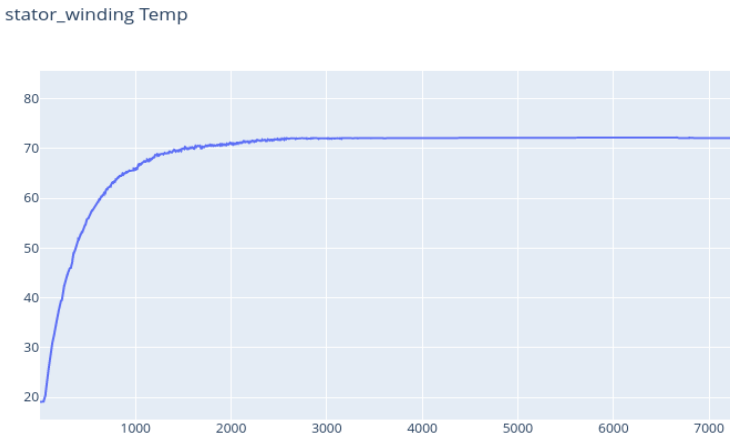
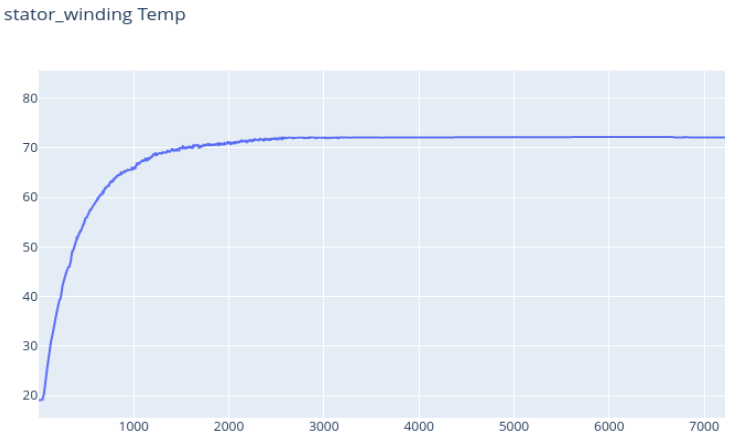
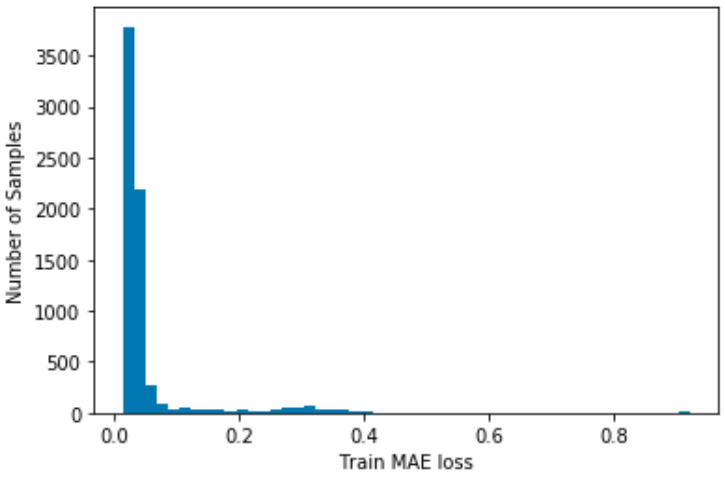
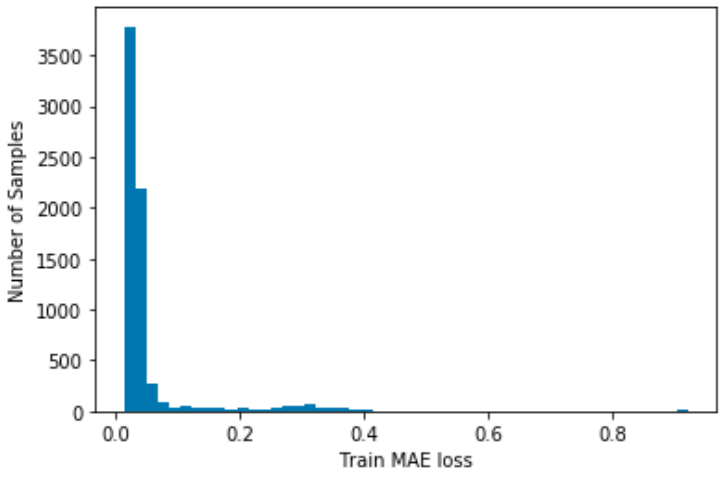
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| 4.2.1 Square, Fault HIGH | |
|---|---|
| **Square Error curve: Rising** | **Square Error curve: Falling** |
|  <br>Square Dataset |  <br>Square Dataset |
|  <br>Training Dataset |  <br>Training Dataset |
|  <br>Train MAE loss |  <br>Train MAE loss |

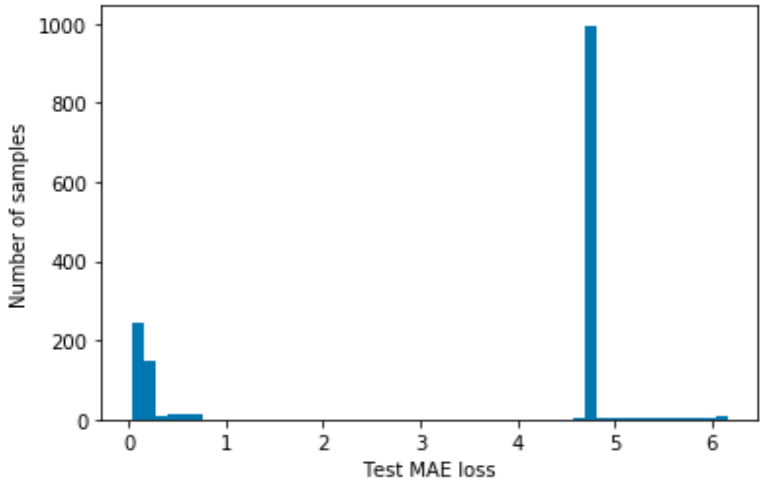
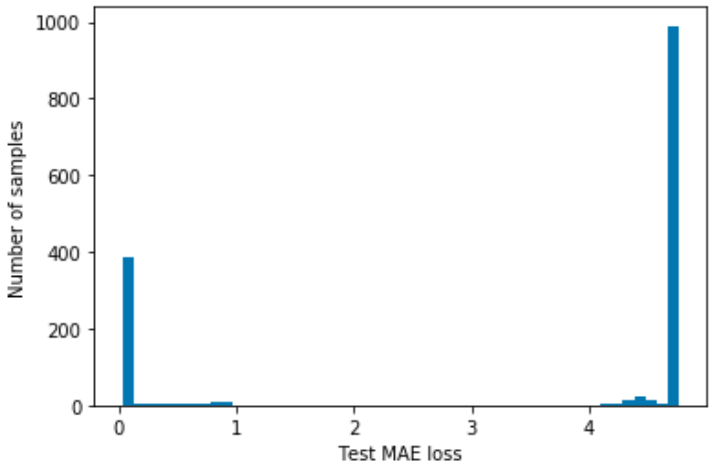
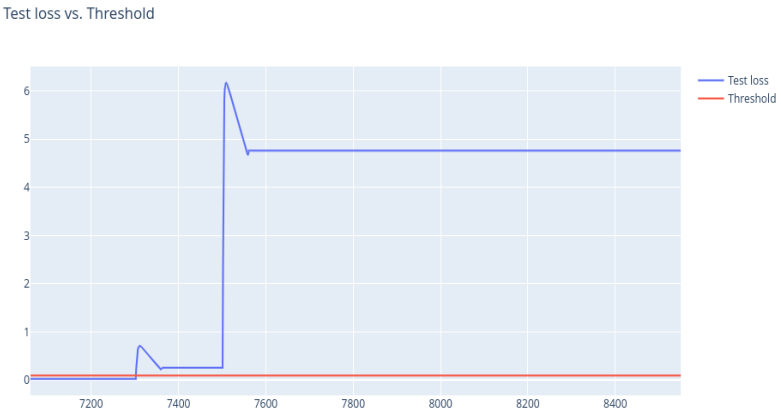
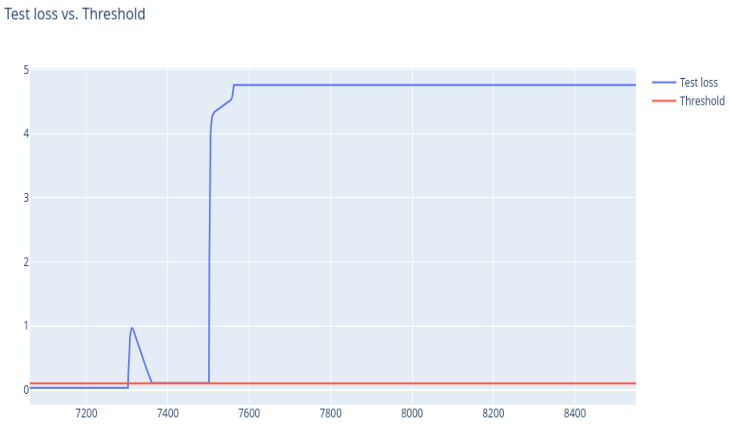
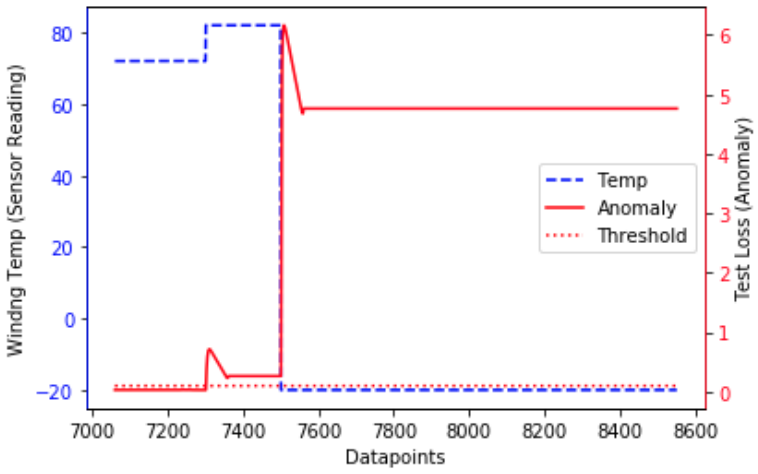
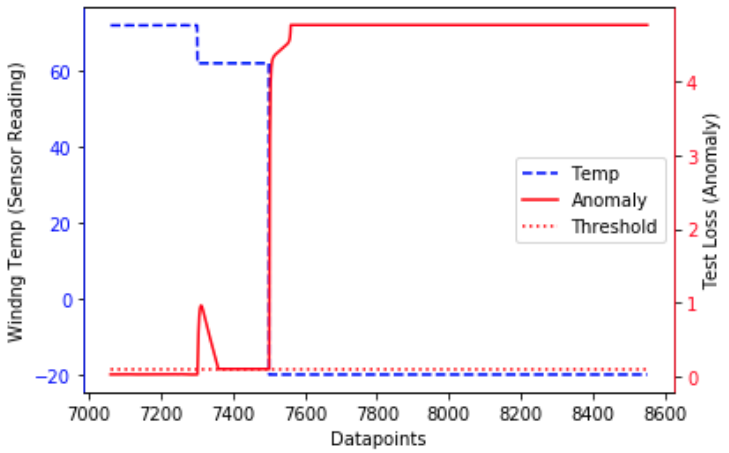
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| Square Error curve: Rising | Square Error curve: Falling |
| --- | --- |
|  Square Test MAE loss |  Square Test MAE loss |
|  Square Anomaly vs Fault |  Square Anomaly vs Fault |
|  Square Rising Data vs Fault |  Square Falling Data vs Fault |

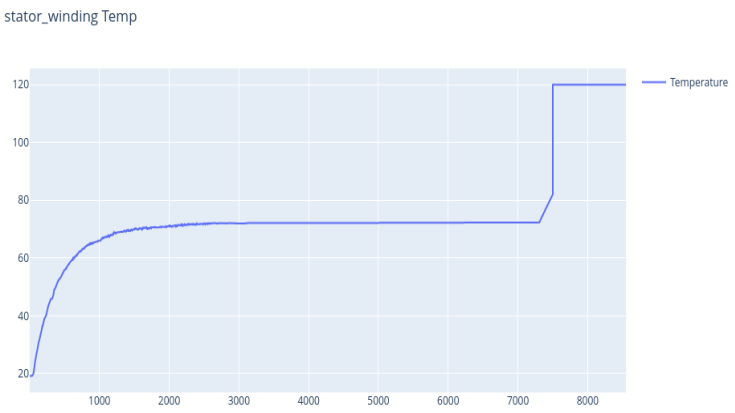
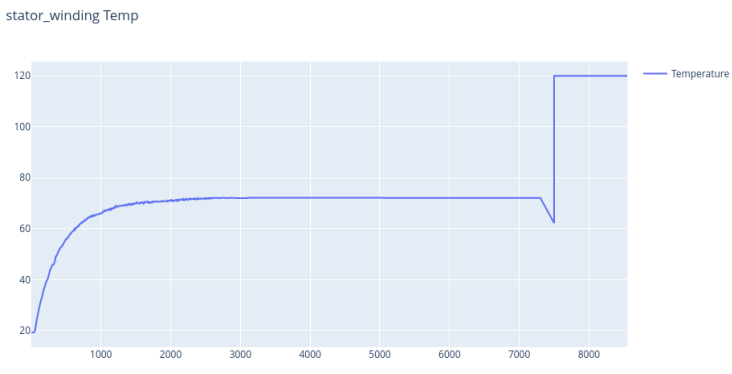
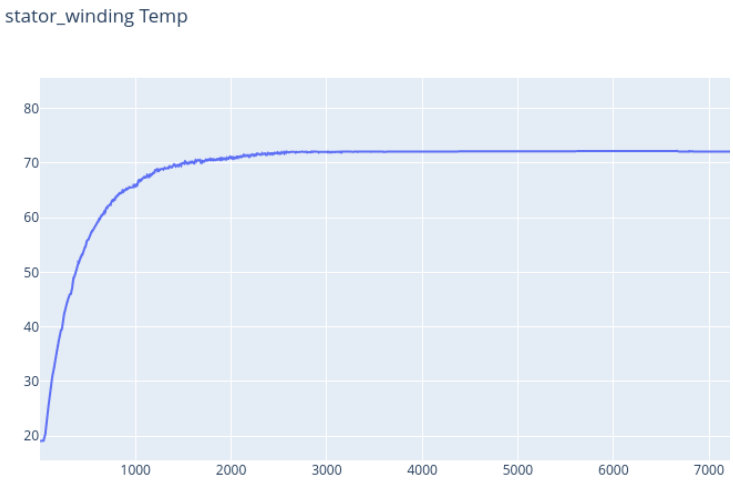
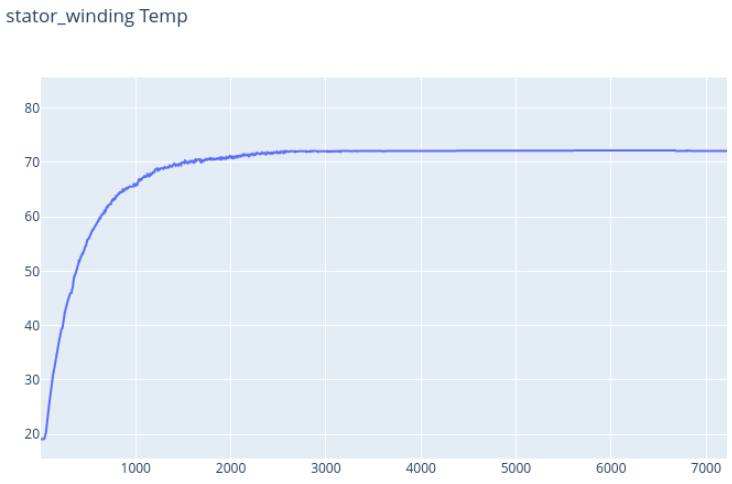
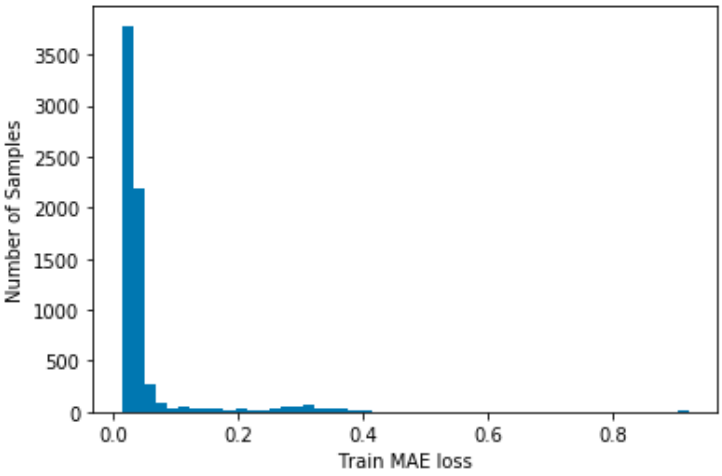
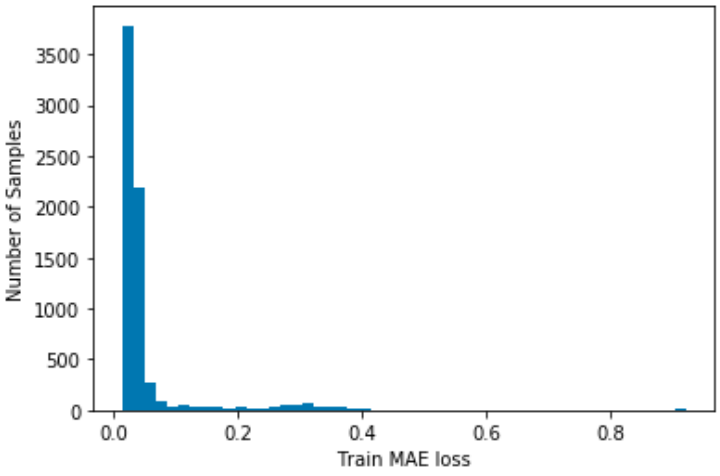
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| 4.2.2 Square, Fault LOW | |
|---|---|
| **Square Error curve: Rising** | **Square Error curve: Falling** |
|  Square Dataset |  Square Dataset |
|  Training Dataset |  Training Dataset |
|  Train MAE loss |  Train MAE loss |

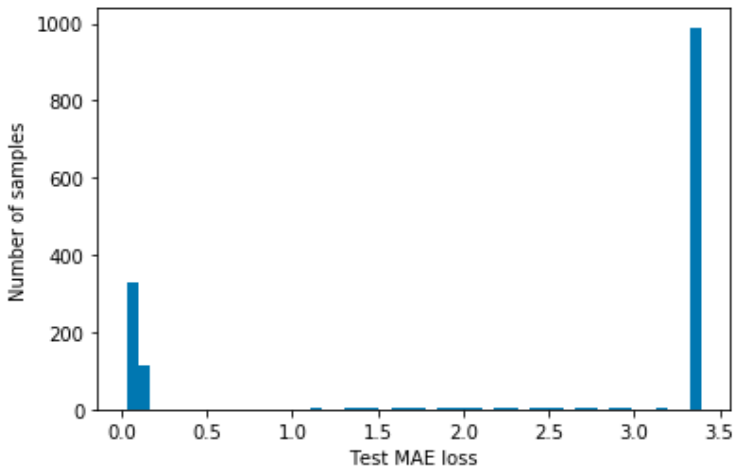
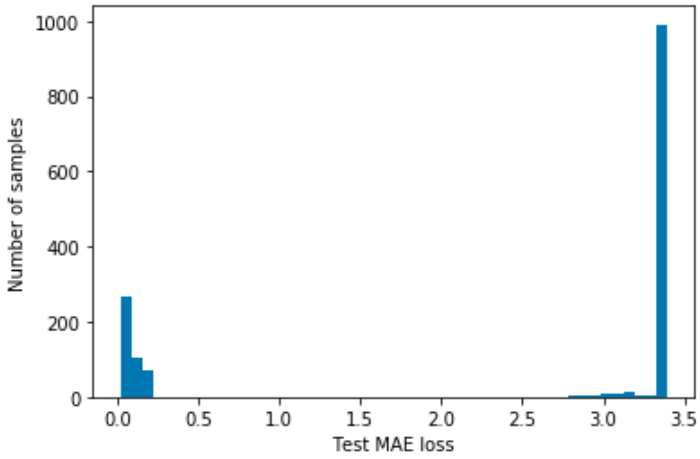
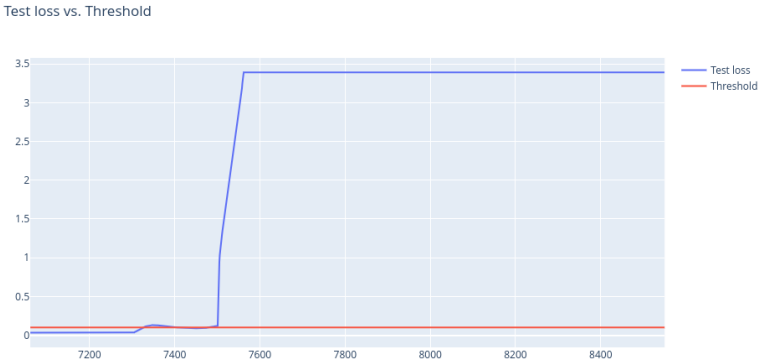
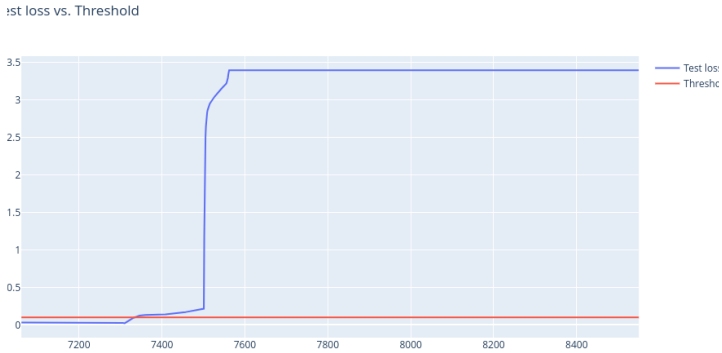
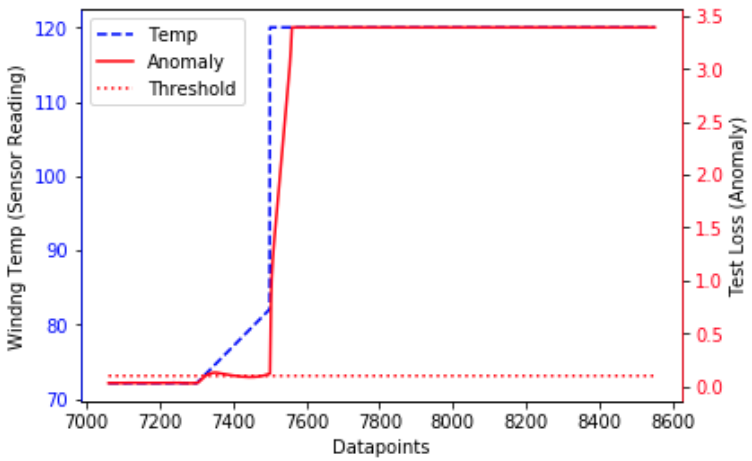
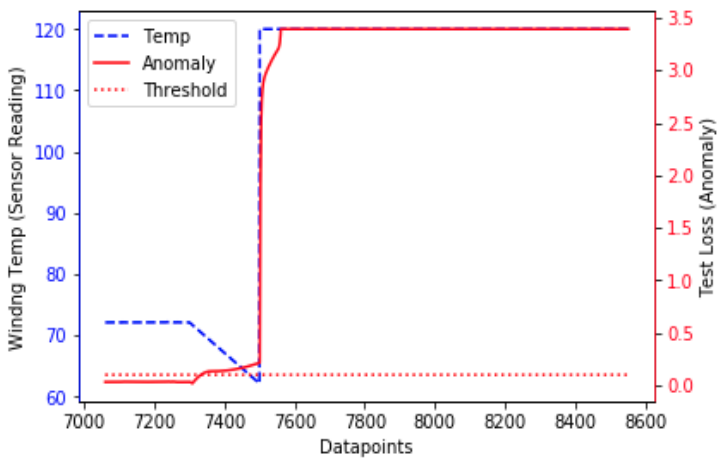
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| Square Error curve: Rising | Square Error curve: Falling |
| --- | --- |
|  Square Test MAE loss |  Square Test MAE loss |
|  Square Anomaly vs Fault |  Square Anomaly vs Fault |
|  Square Rising Data vs Fault |  Square Falling Data vs Fault |

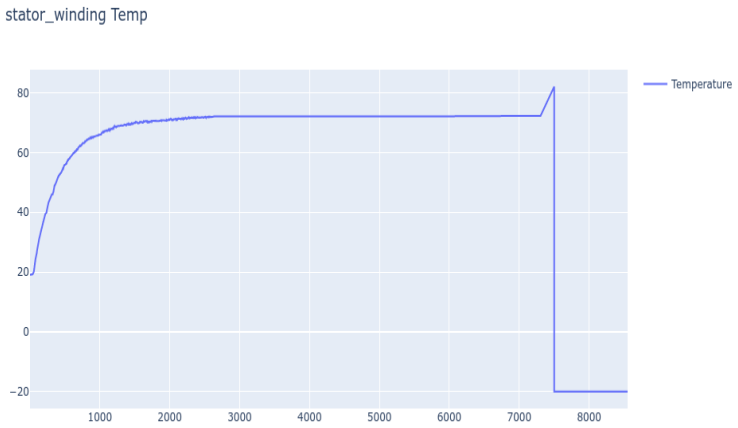
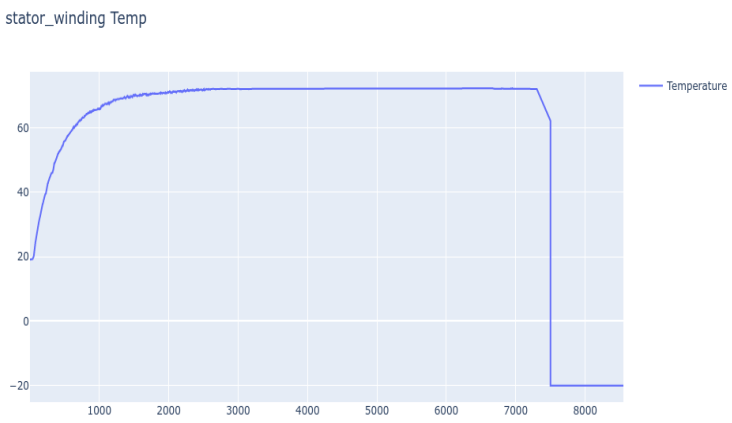
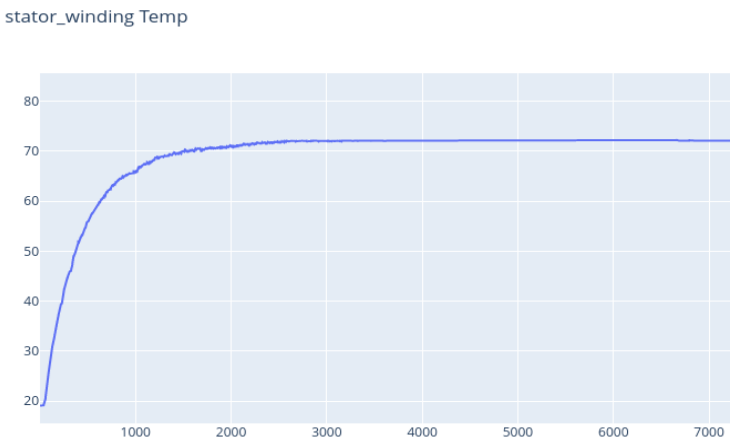
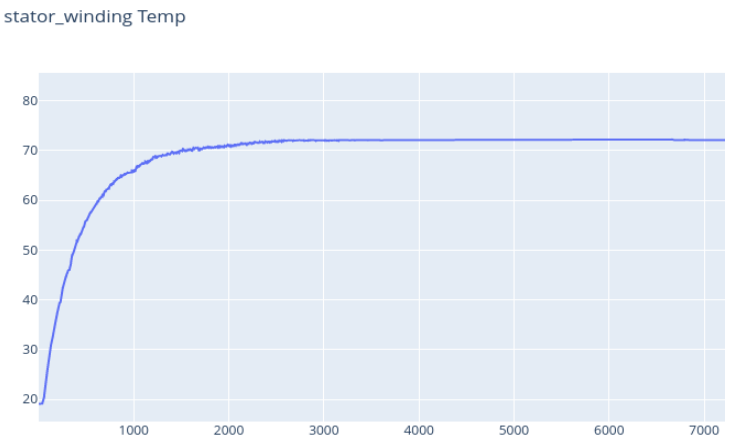
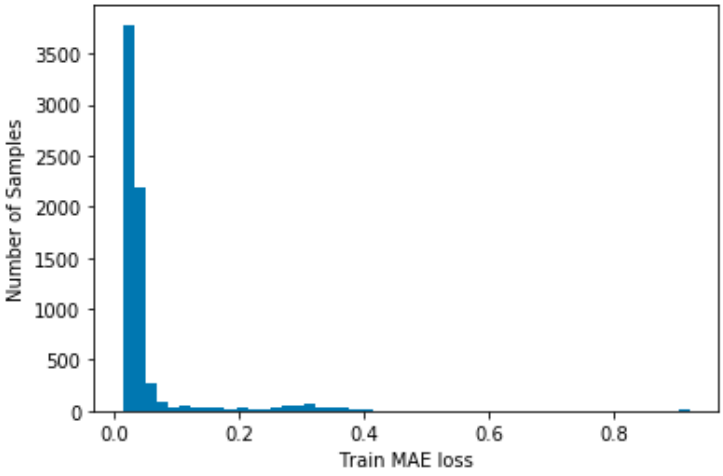
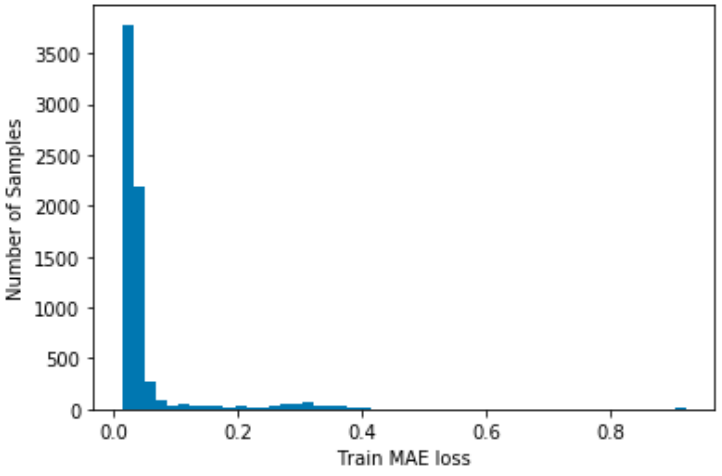
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| 4.3.1 Ramp, Fault HIGH | |
|---|---|
| **Ramp Error curve: Rising** | **Ramp Error curve: Falling** |
|  <br>Ramp Dataset |  <br>Ramp Dataset |
|  <br>Training Dataset |  <br>Training Dataset |
|  <br>Train MAE loss |  <br>Train MAE loss |

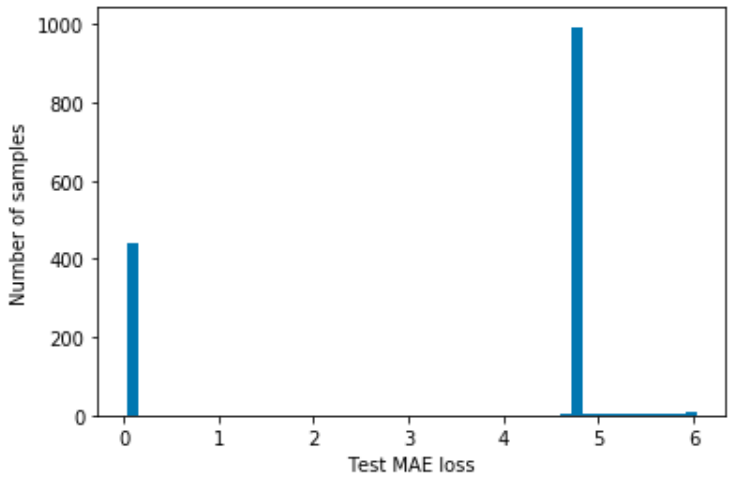
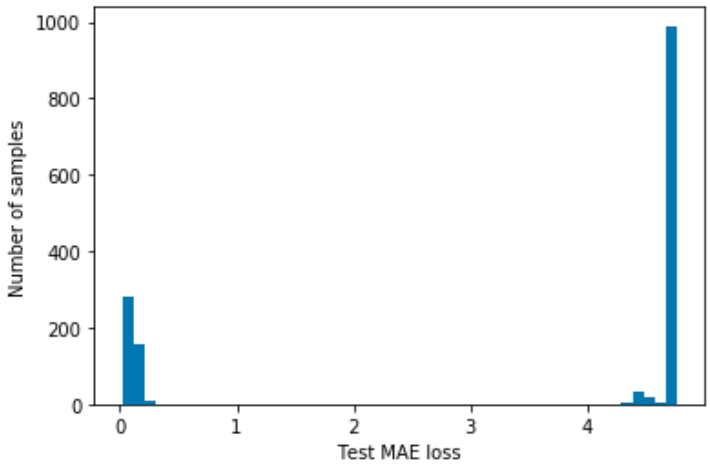
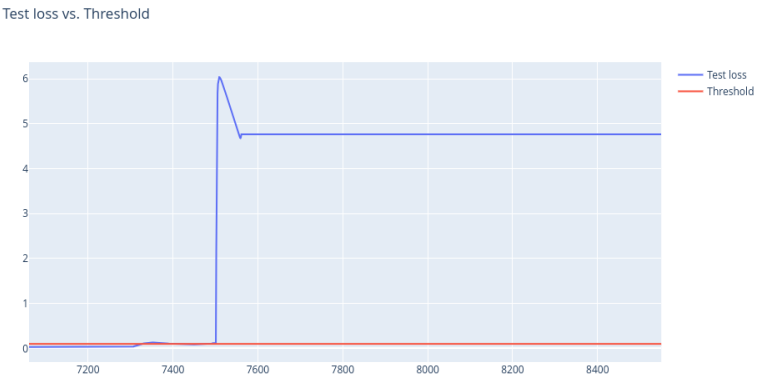
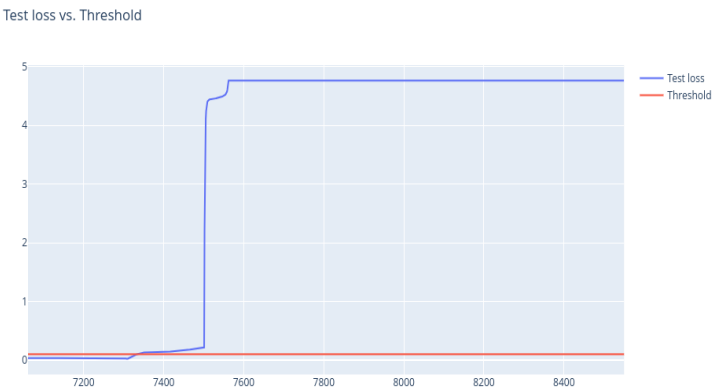
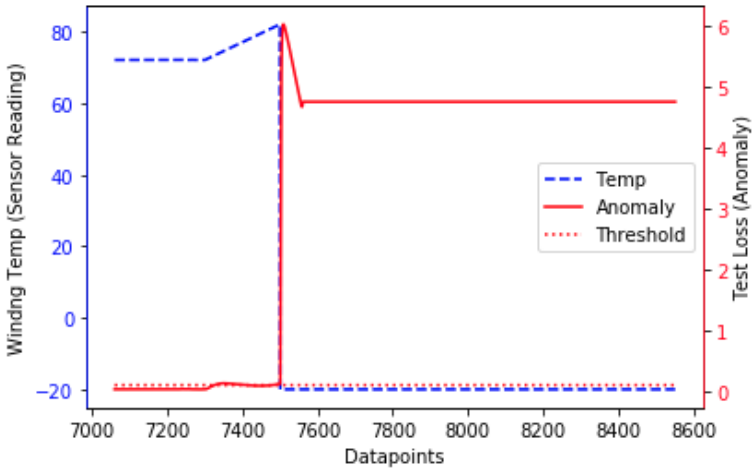
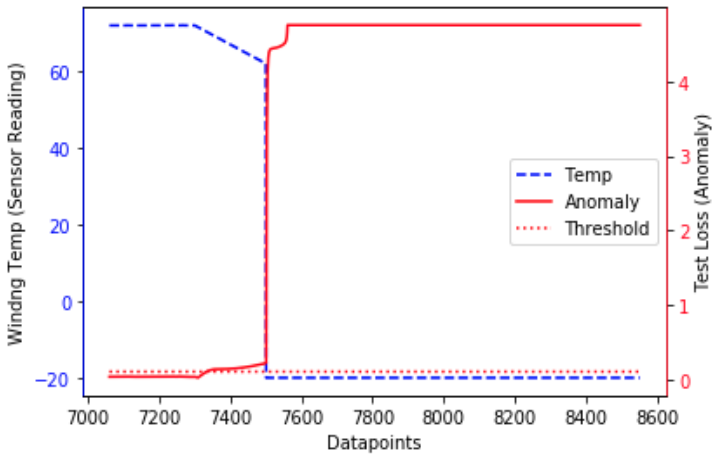
Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| Ramp Error curve: Rising | Ramp Error curve: Falling |
|---|---|
|  Ramp Test MAE loss |  Ramp Test MAE loss |
|  Ramp Anomaly vs Fault |  Ramp Anomaly vs Fault |
|  Ramp Rising Data vs Fault |  Ramp Falling Data vs Fault |

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| 4.3.2 Ramp, Fault LOW | |
|---|---|
| **Ramp Error curve: Rising** | **Ramp Error curve: Falling** |
|  <br>Ramp Dataset |  <br>Ramp Dataset |
|  <br>Training Dataset |  <br>Training Dataset |
|  <br>Train MAE loss |  <br>Train MAE loss |

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

| Ramp Error curve: Rising | Ramp Error curve: Falling |
|---|---|
|  Ramp Test MAE loss |  Ramp Test MAE loss |
|  Ramp Anomaly vs Fault |  Ramp Anomaly vs Fault |
|  Ramp Rising Data vs Fault |  Ramp Falling Data vs Fault |

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images

## Observations:

- Increased LSTM window leads to decreased training time
- Ramp anomaly Notch at datapoint 8302 (table 3.3)
- LSTM window detects the anomaly in the rising or falling trend of the error pattern.
- Most useful for detecting and confirming if there is an anomaly started or stopped
- Not much useful for calculating the degree of anomaly or how severe the anomaly is.
- LSTM window is specially useful & most effective in detecting the peak or sudden reversal of an error pattern while dealing with time series values.

Images: https://github.com/biplabro/Anomaly-Detection-LSTM-AutoEncoder/tree/master/Summary-Images