

# **REDUCING HOME ENERGY CONSUMPTION WITH LOAD DISAGGREGATION**

- UNDER THE SUPERVISION OF DR. ABDALKARIM AWAD

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# AGENDA

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- 01** Motivation and Problem Statement
- 02** Methodology
- 03** Load Disaggregation
- 04** Implementation of Deep Learning Approaches: PTP-Net and Conv-BiLSTM
- 05** Results and Comparative Analysis
- 06** Challenges and Future Works



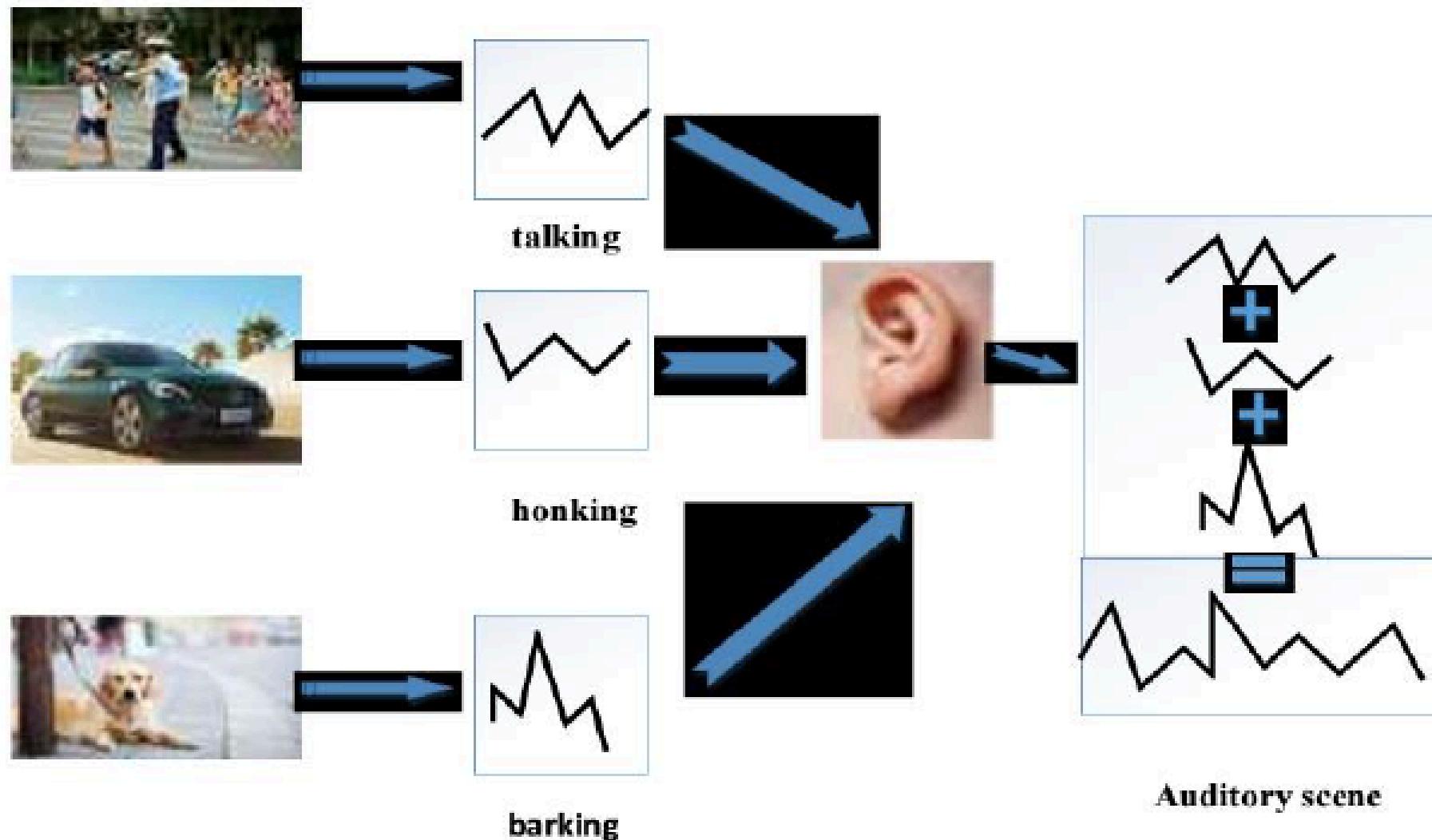
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# MOTIVATION AND PROBLEM STATEMENTS

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# MOTIVATION & PROBLEM STATEMENTS



**Financial Strains**

**Environmental Impact**



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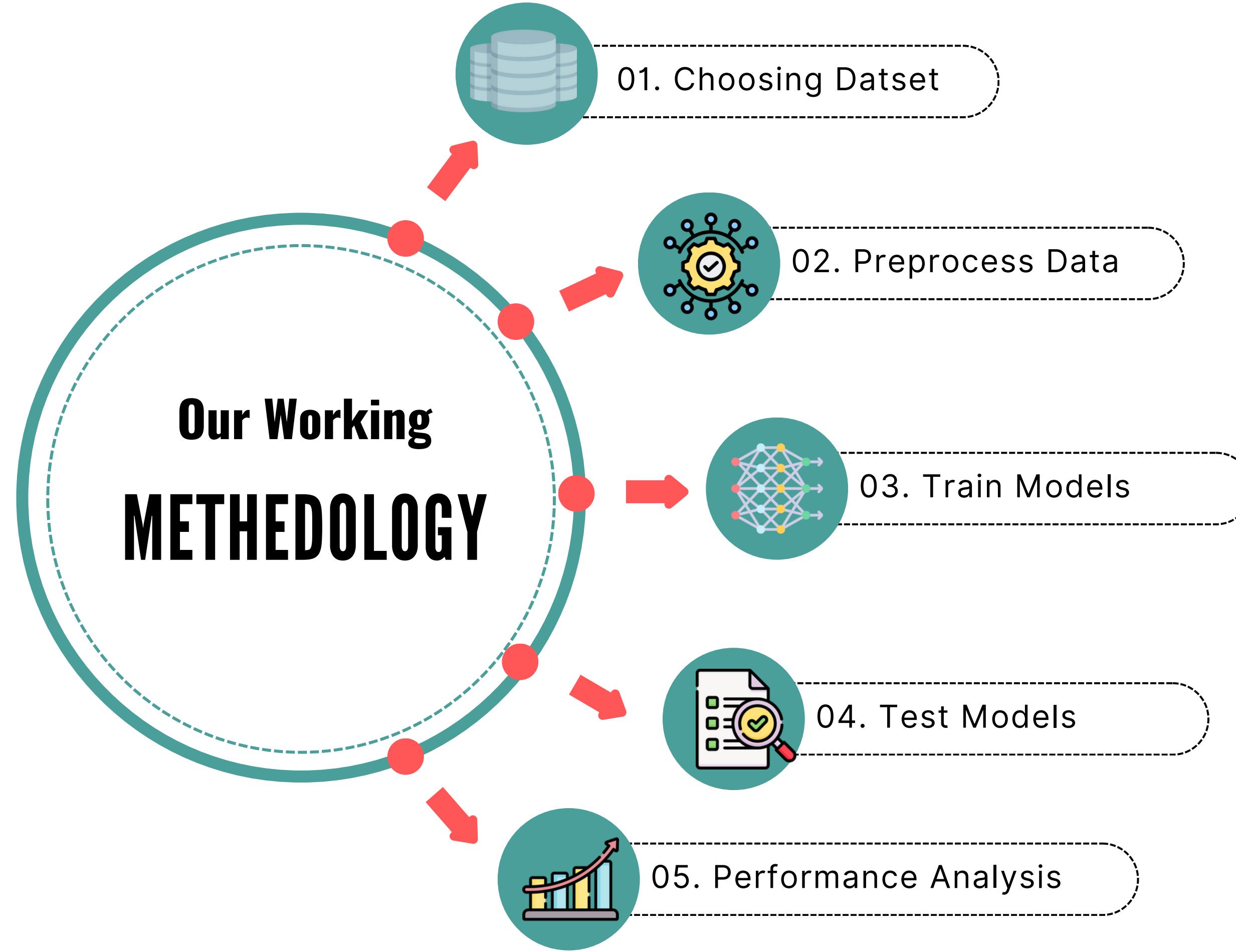
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# METHODOLOGY

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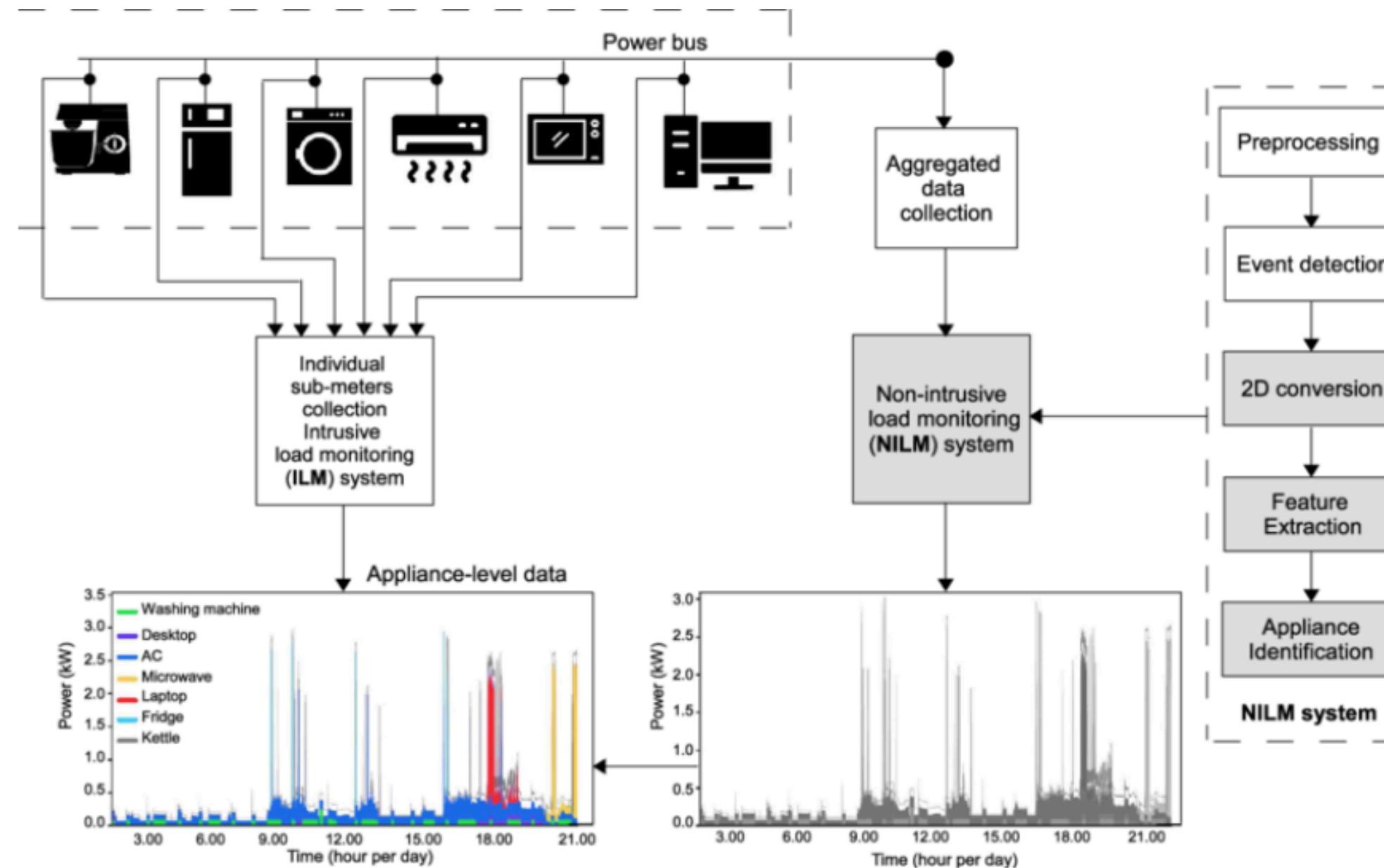
# **LOAD DISAGGREGATION**

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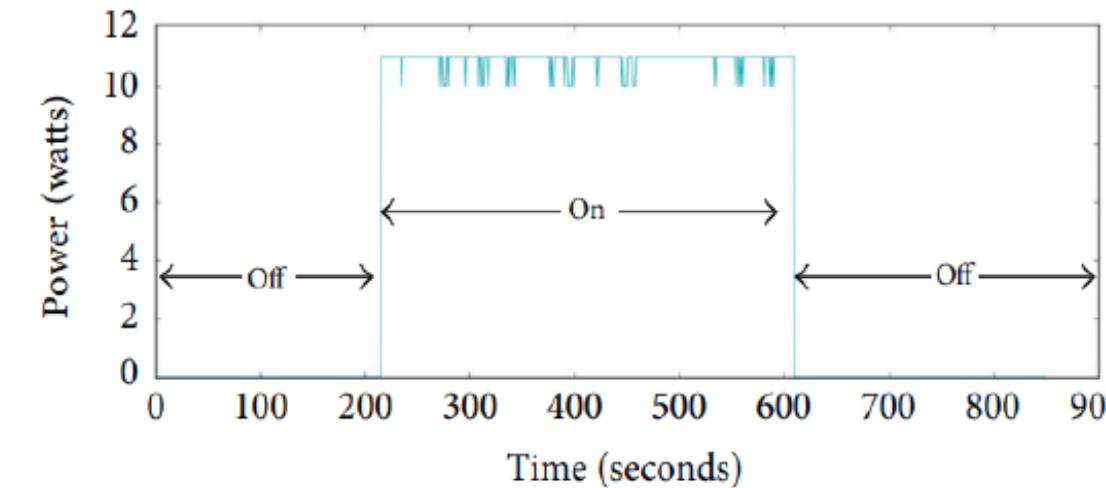
# LOAD DISSAGGREGATION



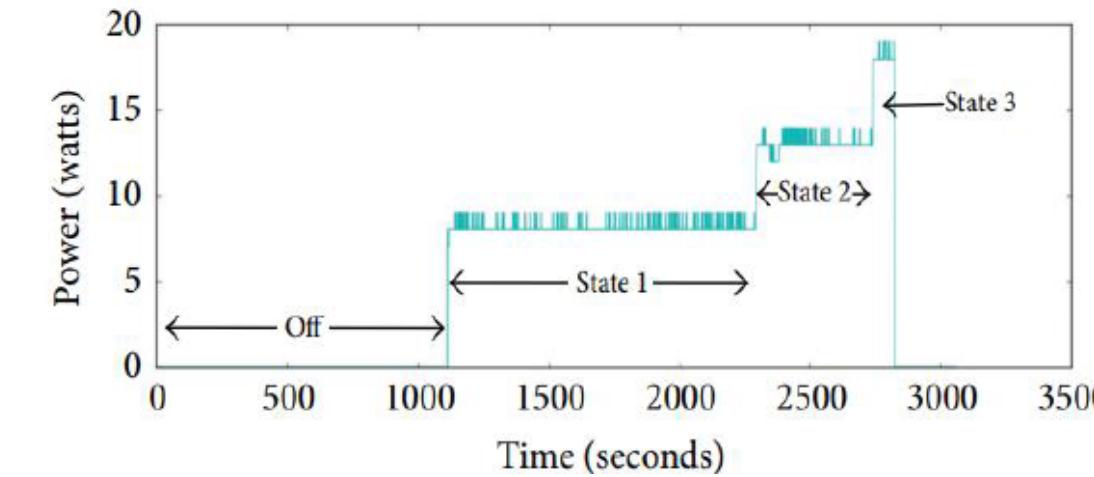
**Load Disaggregation (LD)** is a technique used to disaggregate the total energy consumption of a household into individual appliance-level consumption.



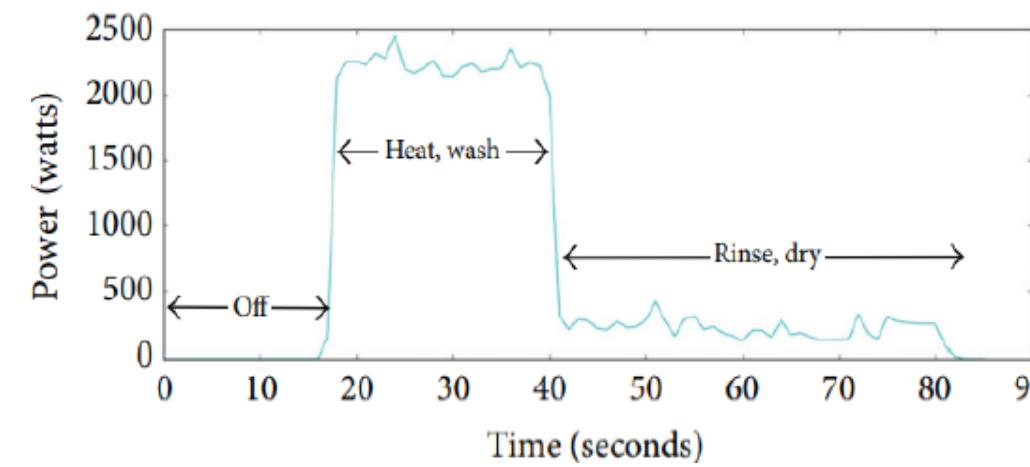
# TYPES OF APPLIANCES



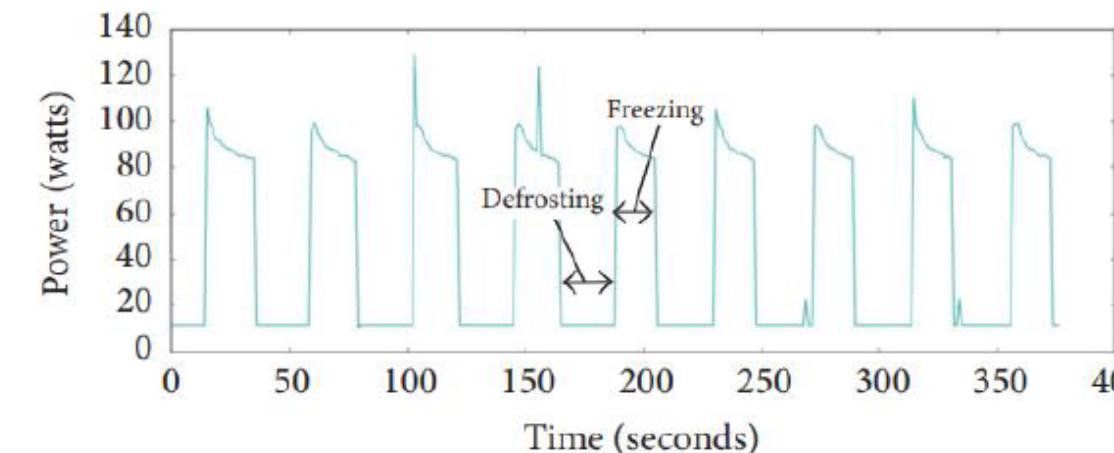
On/Off



Finite State Machine



Continuously Variable



Always On



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# IMPLEMENTATION OF DEEP LEARNING APPROACHES:

*PTP-Net and Cov-BiLSTM*

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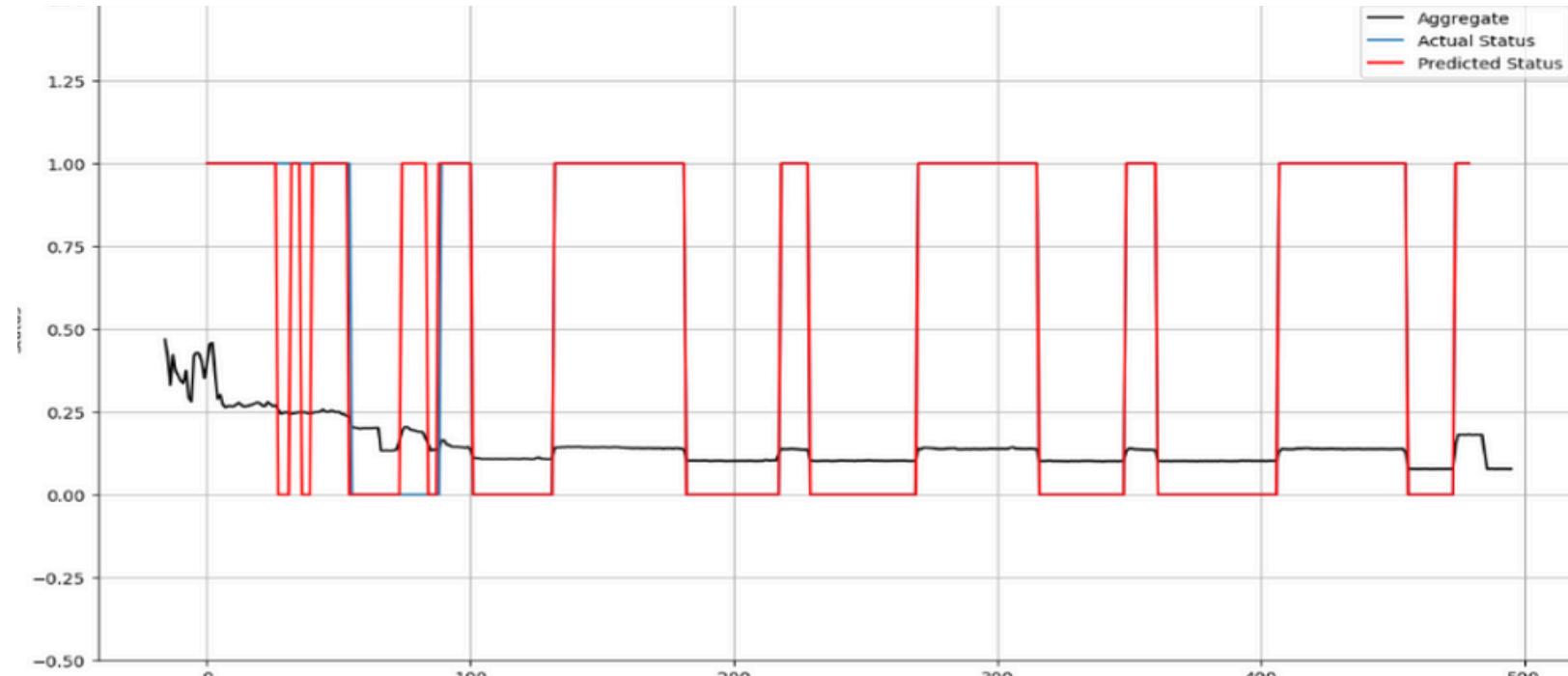


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# CLASSIFICATION AND REGRESSION PROBLEMS

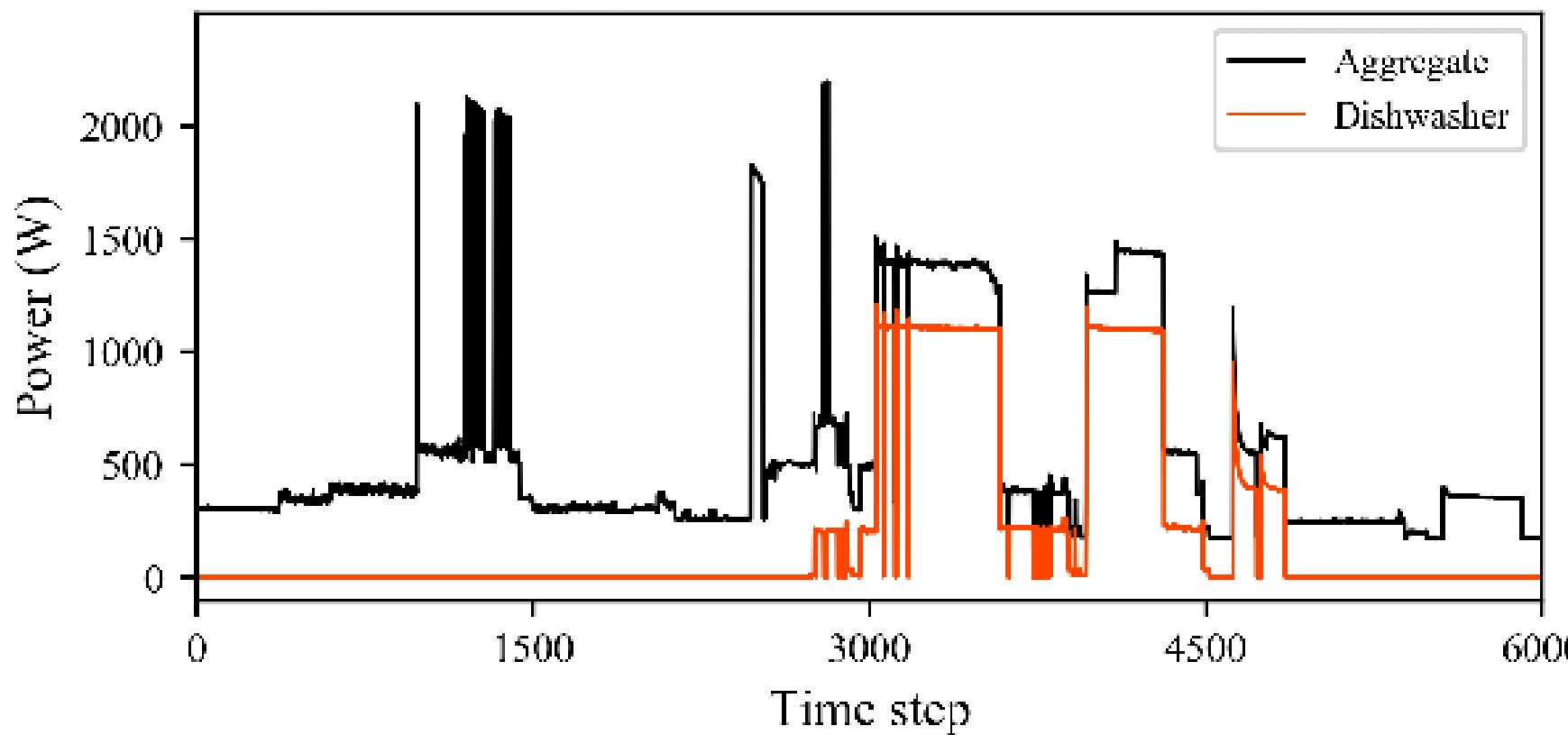
## Classification Task

The classification task focuses on determining whether a specific appliance is in an ON or OFF state.



## Regression Task

The regression task involves predicting the continuous power consumption values for target appliances.



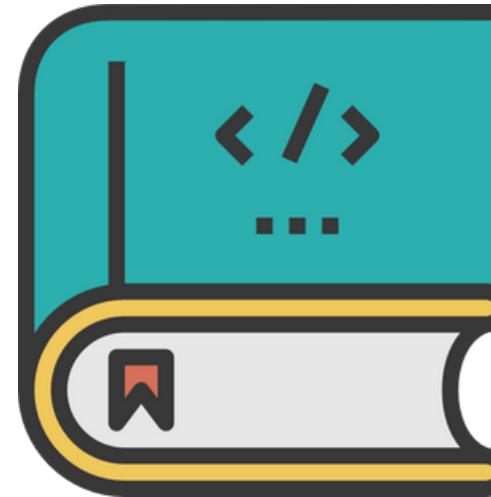
# PYTORCH AND SUPPORTING LIBRARIES

Pytorch

scikit-learn

pandas

matplotlib



# READING THE UKDALE DATASET

Each house from the 5 houses in the UKDALE dataset had a different number of appliances and different data recording periods. In all five houses, the first appliance (numbered 1) represents the total aggregated power used in each house. The aggregated power is apparent power, which is the total power consumed in an electrical system.



**House 1: 52 appliances, data recorded from 2012-11-09 to 2015-01-05.**



**House 2: 18 appliances, data recorded from 2013-02-17 to 2013-10-10.**



**House 3: 4 appliances, data recorded from 2013-02-27 to 2013-04-08.**



**House 4: 5 appliances, data recorded from 2013-03-09 to 2014-11-13.**



**House 5: 24 appliances, data recorded from 2014-06-29 to 2014-11-13.**



# TARGET APPLIANCES

## Reasons for Selection:

- Insufficient data for many other appliances (e.g., iron used only a few times in the first house).
- Selected appliances were present in most households, simplifying testing across different homes.
- Chose a mix of appliances with distinct usage patterns to enhance the model's learning capabilities.

Fridge

Washing Machine

Dish Washer



# PREPROCESSING STEPS

The following steps were followed for data preprocessing:

- Resampling Data.
- Setting Maximum Power Limits.
- Handling Missing Values.
- Normalization.

	Fridge	Dishwasher	Washing Machine
Max. power (W)	300	2500	2500

```
def resample_meter(store=None, building=1, meter=1, period='1min', cutoff=1000.):
    key = '/building{}/elec/meter{}'.format(building,meter)
    m = store[key]
    v = m.values.flatten()
    t = m.index
    s = pd.Series(v, index=t).clip(0.,cutoff)
    s[s<10.] = 0.
    return s.resample('1s').ffill(limit=300).fillna(0.).resample(period).mean().tz_convert('UTC')
```



# PREPARING DATA FOR CLASSIFICATION

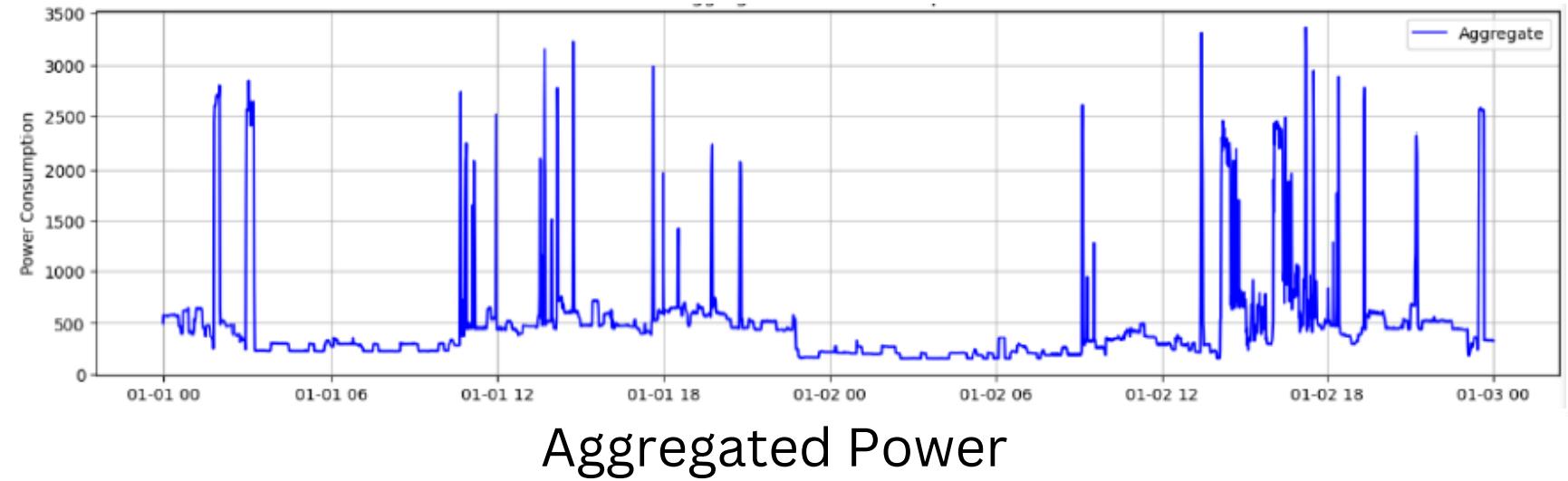
For classification tasks, the output will be **0/1** for the target appliances, while for regression tasks, the output will be continuous power consumption values.

**Thresholding** involves applying specific thresholds to distinguish between ON and OFF states of the appliances based on their power consumption levels.

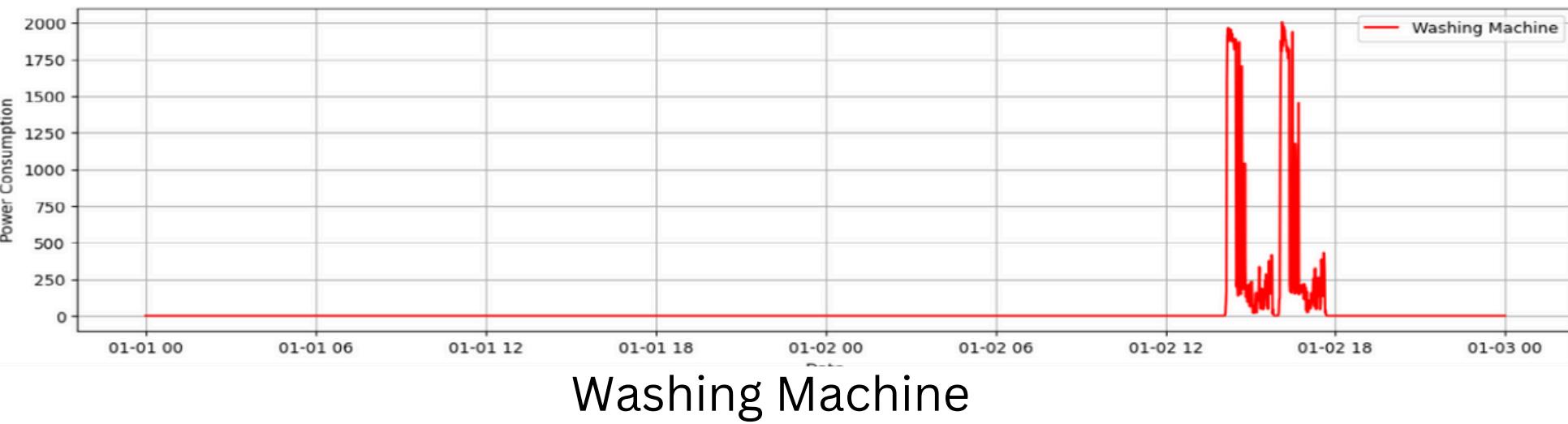
	Fridge	Dishwasher	Washing Machine
Max. power (W)	300	2500	2500
Power threshold (W)	50	10	20
OFF duration (min)	0	3	30
ON duration (min)	1	30	30



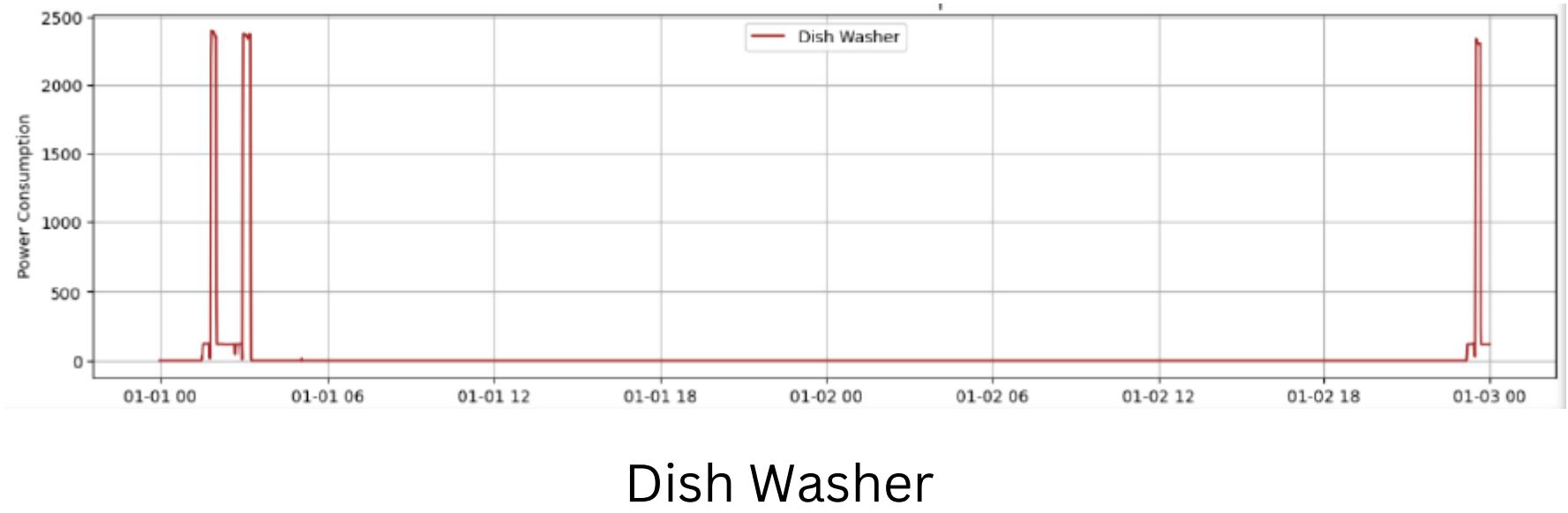
# DATA VISUALIZATION



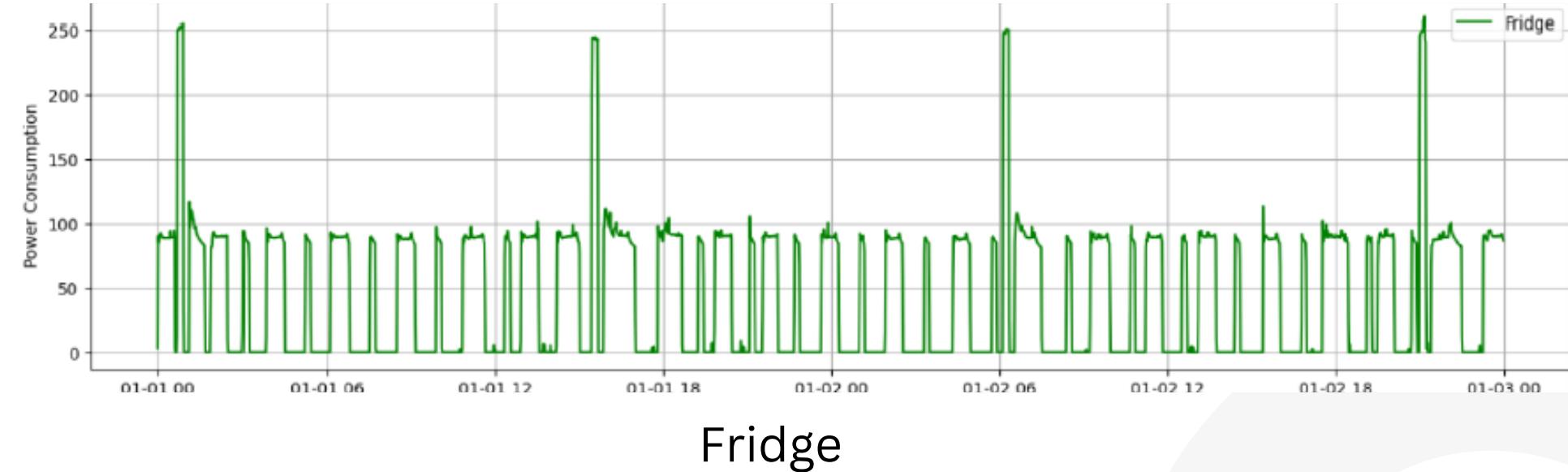
Aggregated Power



Washing Machine



Dish Washer



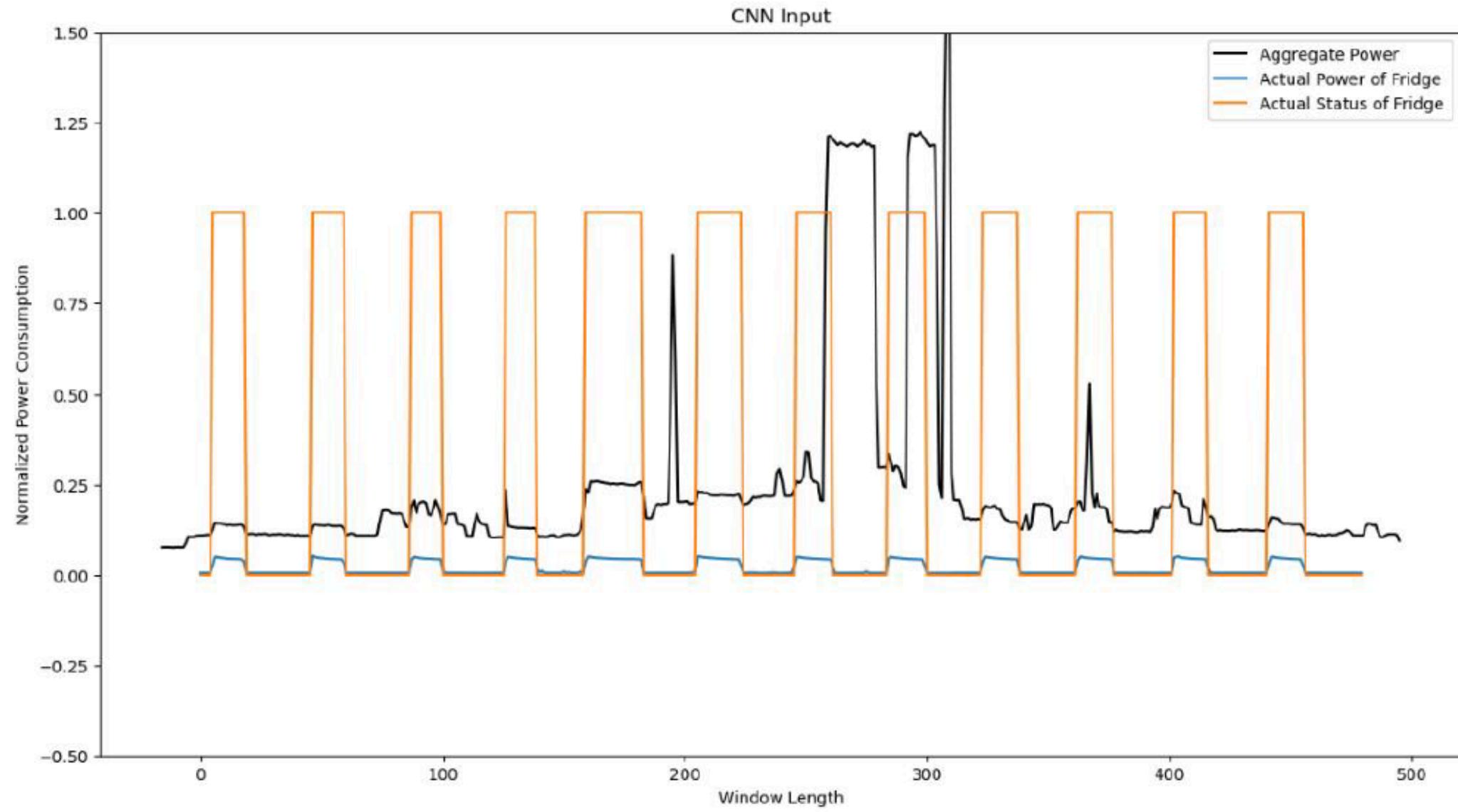
Fridge



# SPLITTING DATASET

The datasets are divided as follows:

- Training dataset: 80% of the total data.
- Validation dataset: the next 10% of the data.
- Testing dataset: the last 10% of the data.



# SEEN AND UNSEEN CASES

we consider two scenarios, the “SEEN” case and the “UNSEEN” case.

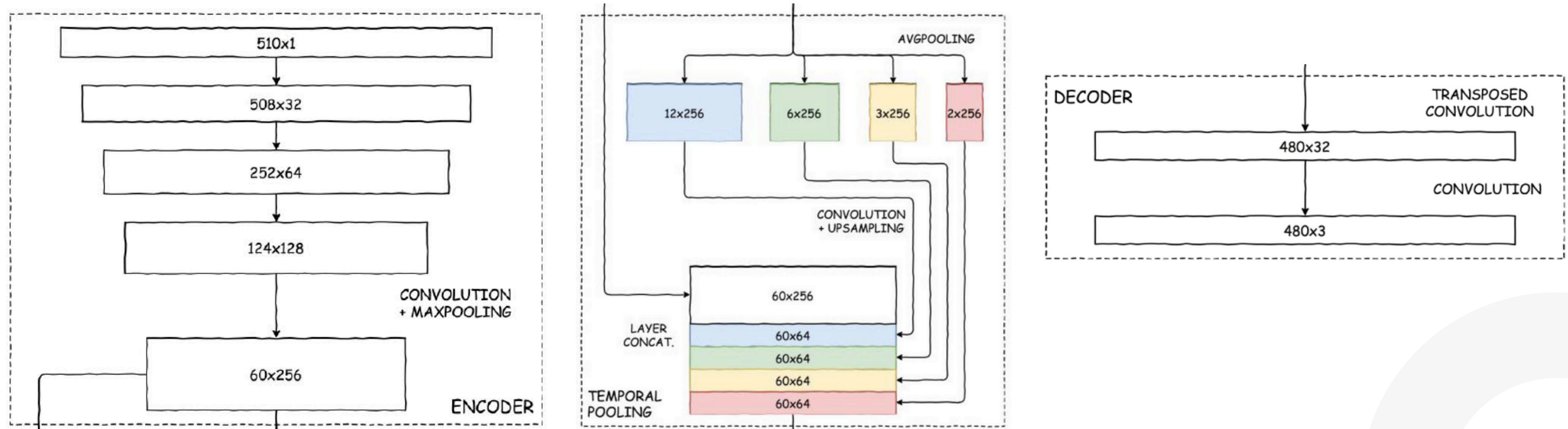
- ***SEEN CASE:*** the model is trained and tested on data from the set of houses that it trained on.
- ***UNSEEN CASE:*** the model will be trained on data from houses and tested on data from different houses. The purpose of this case is to test the generalization ability of our model to predict the appliance’s signatures (the power in the regression task, and the status in the classification task).

Use Case: <i>seen</i>			Use Case: <i>unseen</i>		
Training (%)	Validation (%)	Testing (%)	Training (%)	Validation (%)	Testing (%)
House 1	80	10	10	80	10
House 2	80	-	-	-	100
House 5	80	-	-	80	10



# PTP-NET MODEL ARCHITECTURE

The model architecture consists of Four main components: the **encoder**, **temporal pooling layer**, **attention block**, and **decoder**. It is worth noting that this attention block is exclusively added to the model responsible for power prediction.



# CONV-BILSTM MODEL ARCHITECTURE

Consists of one Conv1D layer, two bidirectional LSTM layers, and two dense layers.

```
def __init__(self, in_channels, out_channels, init_features, seq_len=None):
    super(ConvLSTMModelStatus, self).__init__()

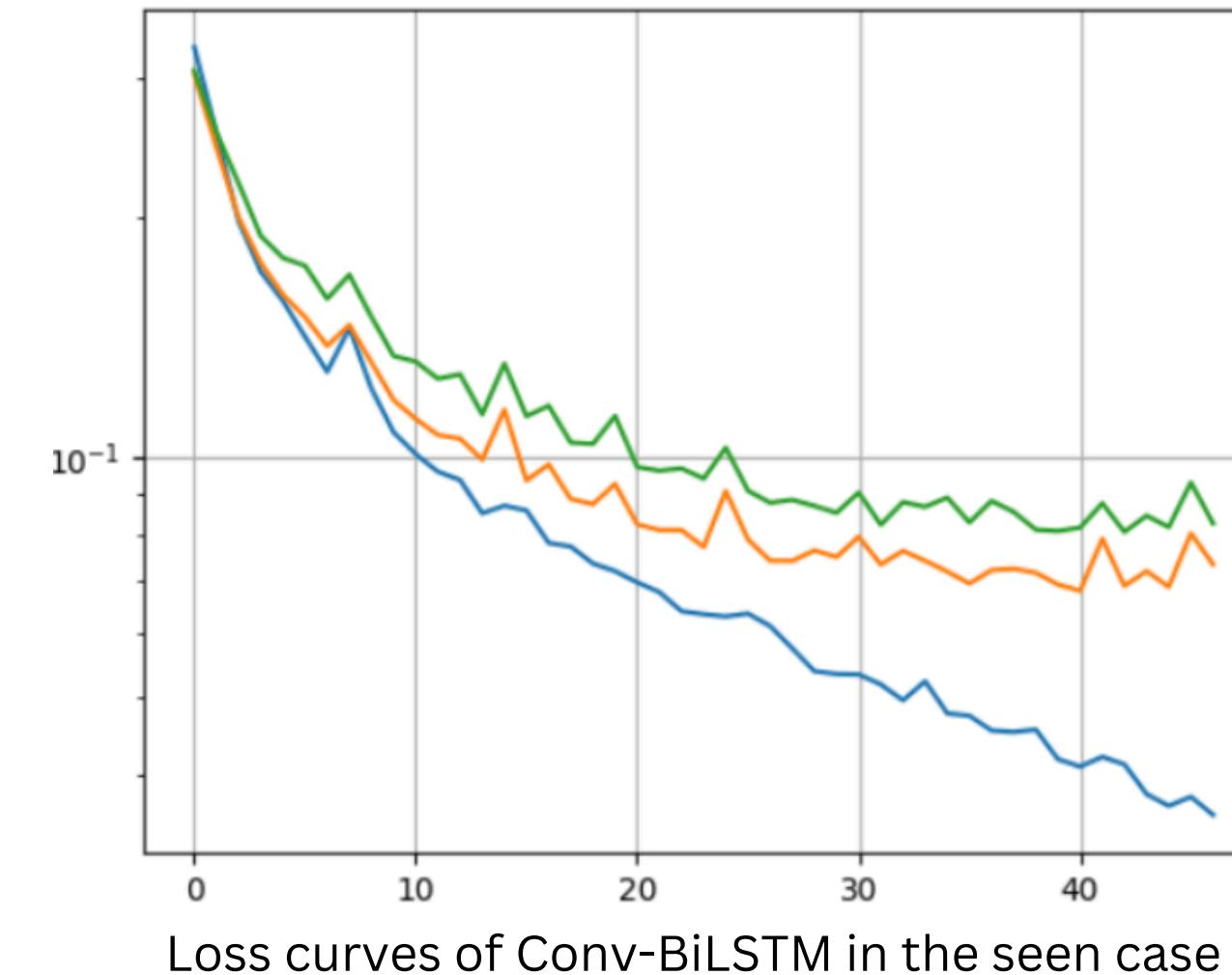
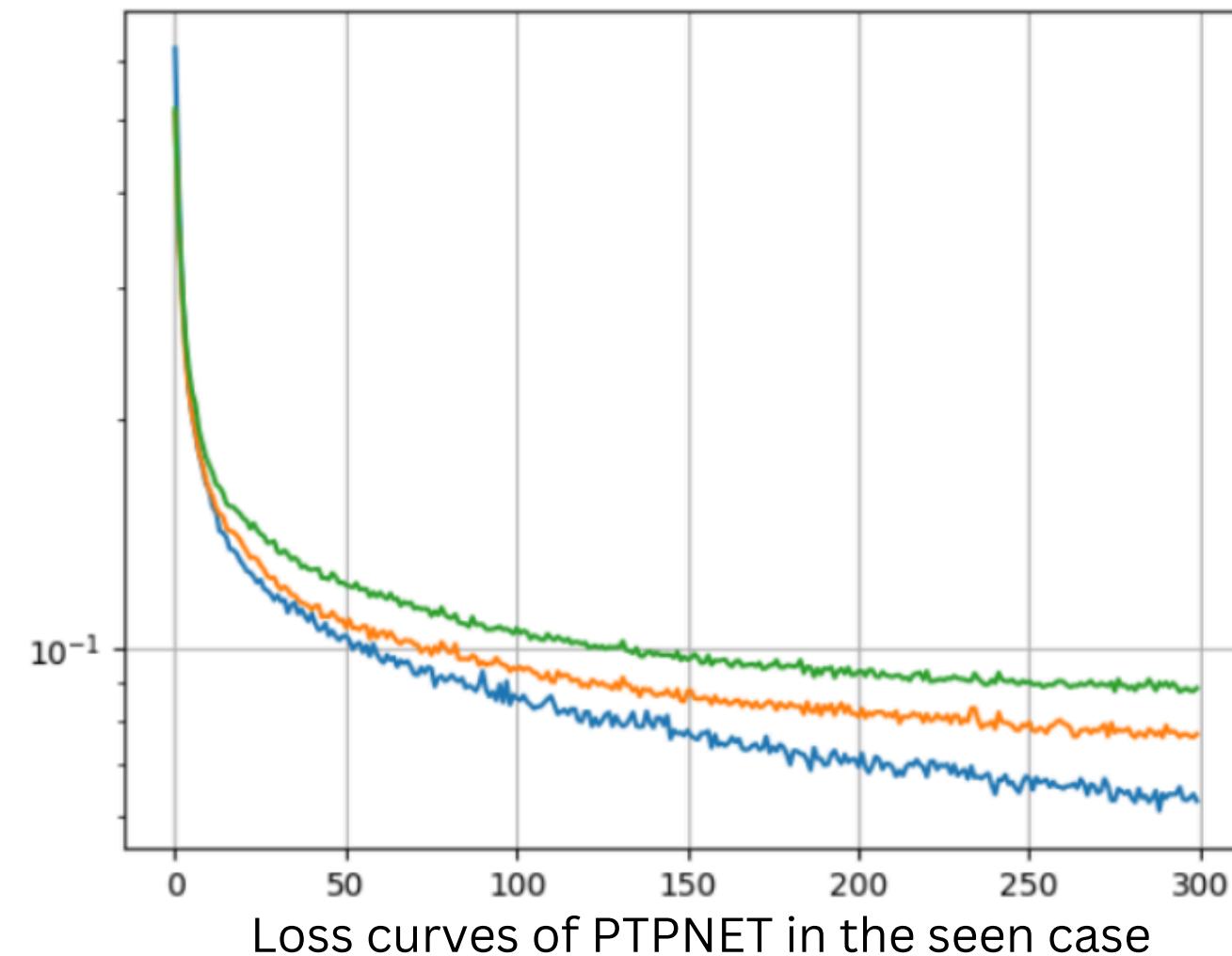
    self.seq_len = seq_len

    self.conv1d = nn.Conv1d(in_channels, init_features, kernel_size=4, padding='same')
    self.lstm1 = nn.LSTM(input_size=init_features, hidden_size=128, num_layers=1, batch_first=True, bidirectional=True)
    self.lstm2 = nn.LSTM(input_size=256, hidden_size=256, num_layers=1, batch_first=True, bidirectional=True)
    self.dense1 = nn.Linear(512, 128)
    self.dense2 = nn.Linear(128, out_channels)
```



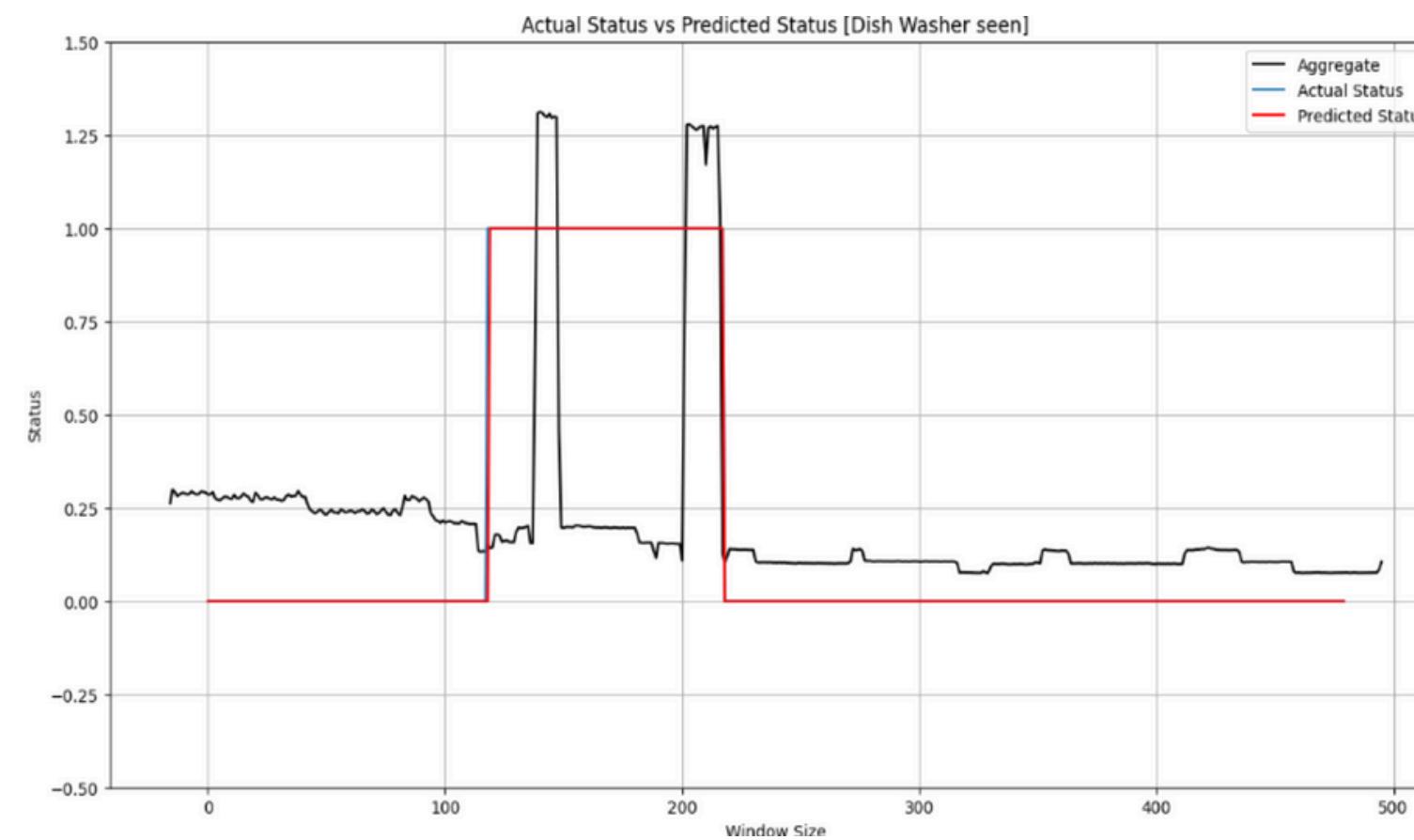
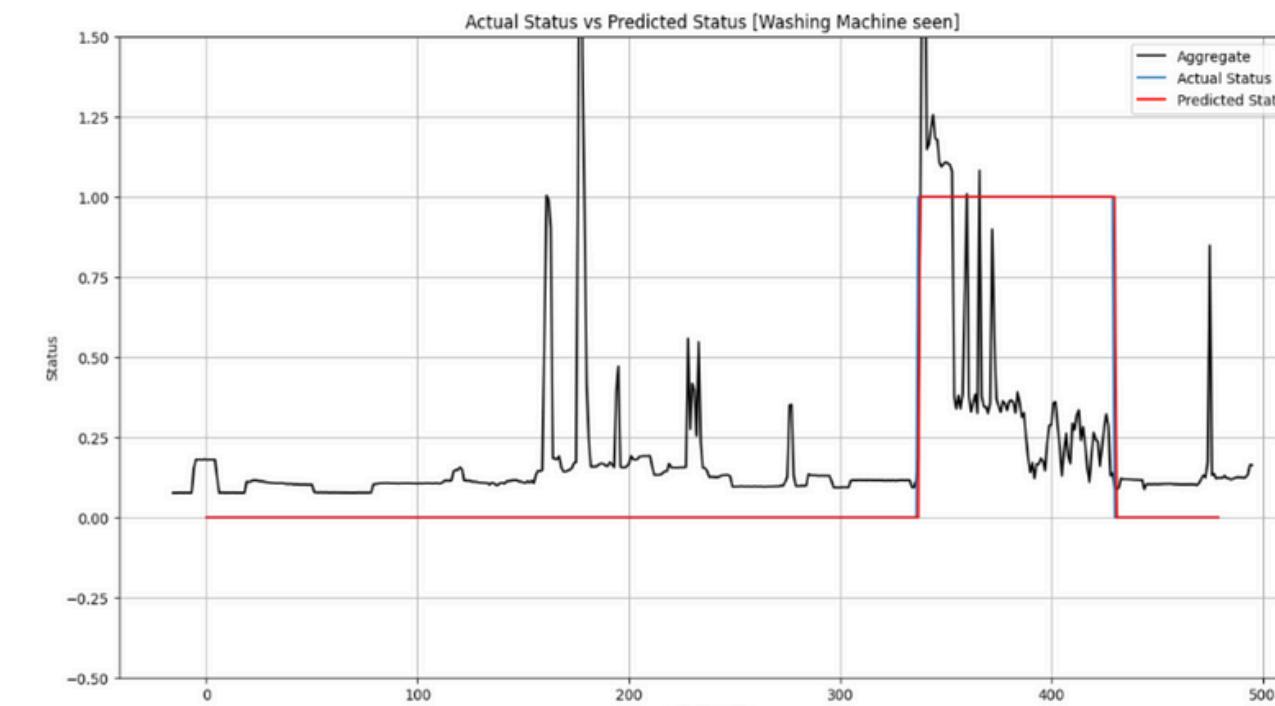
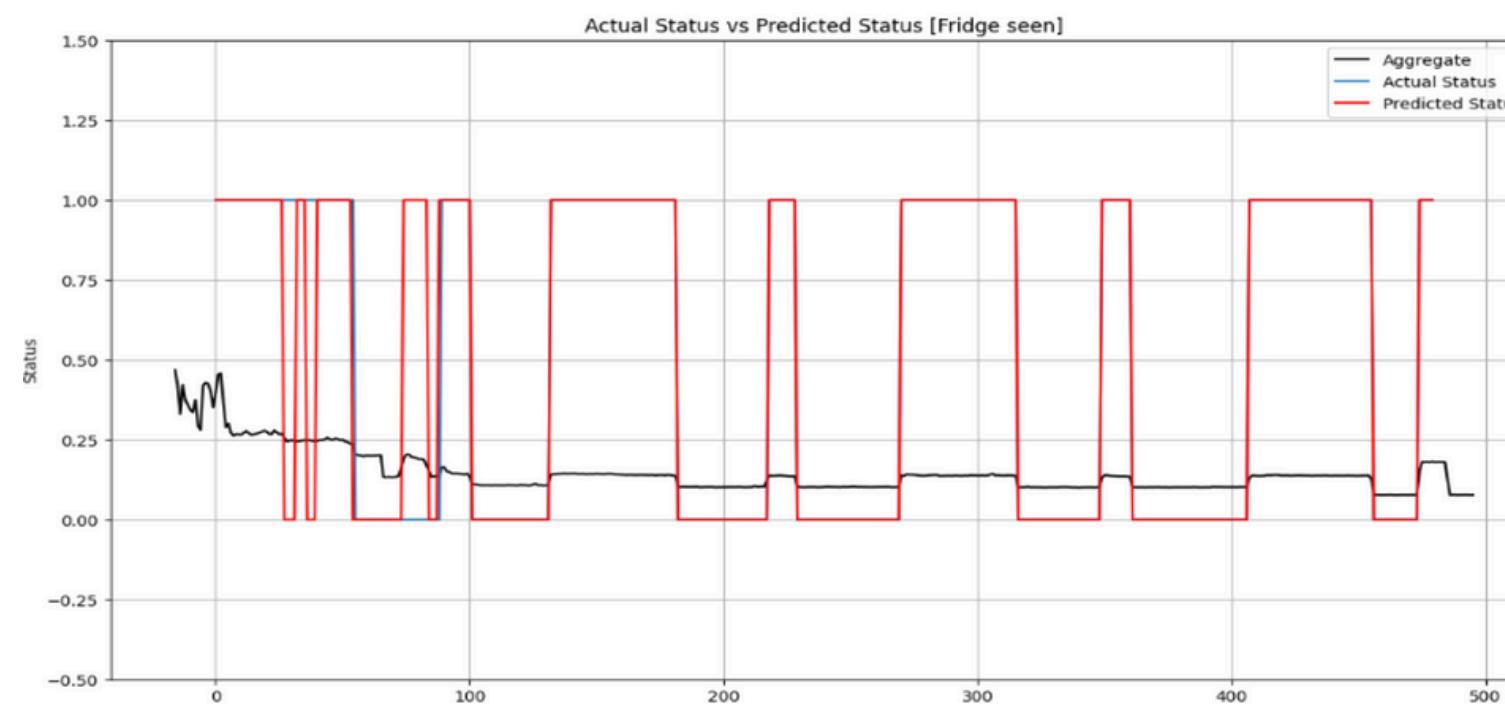
# BINARY CLASSIFICATION TASK (STATUS PREDICTION)

*Seen Case*



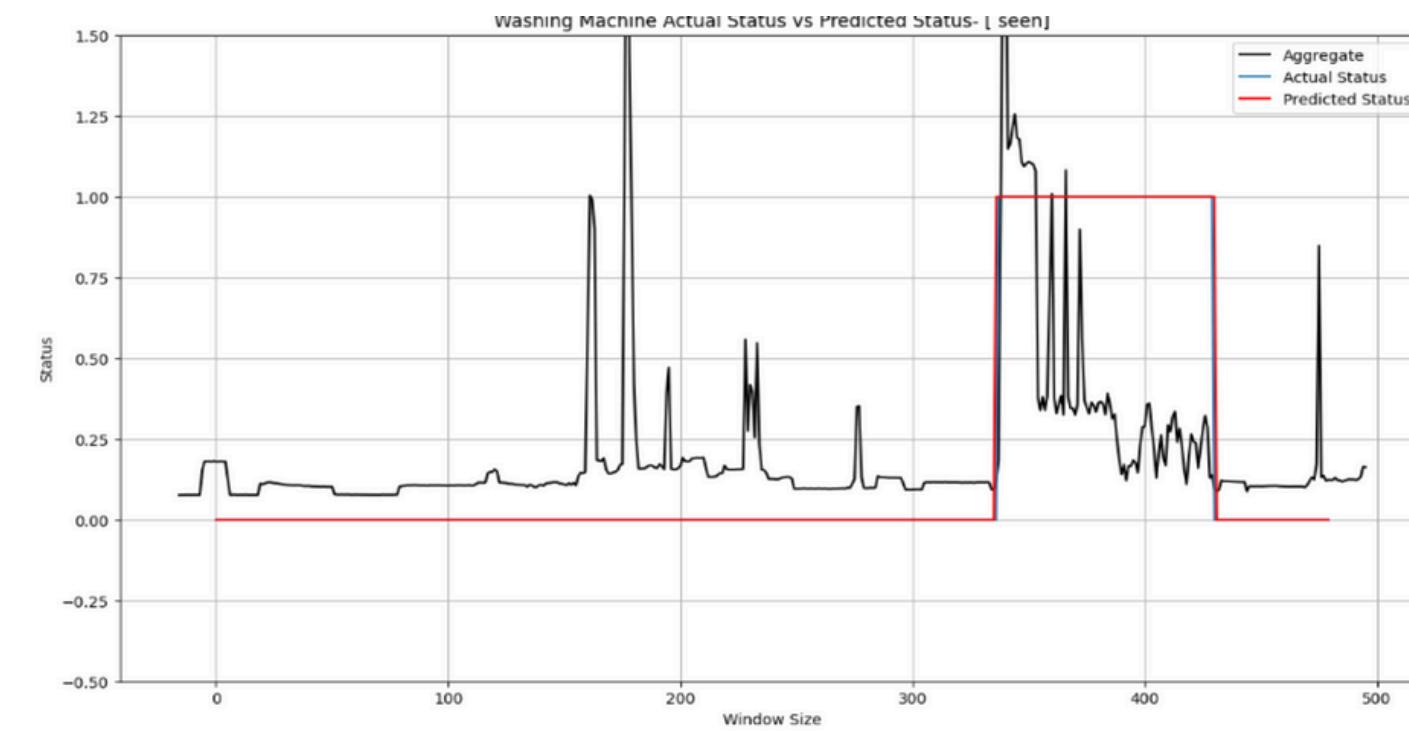
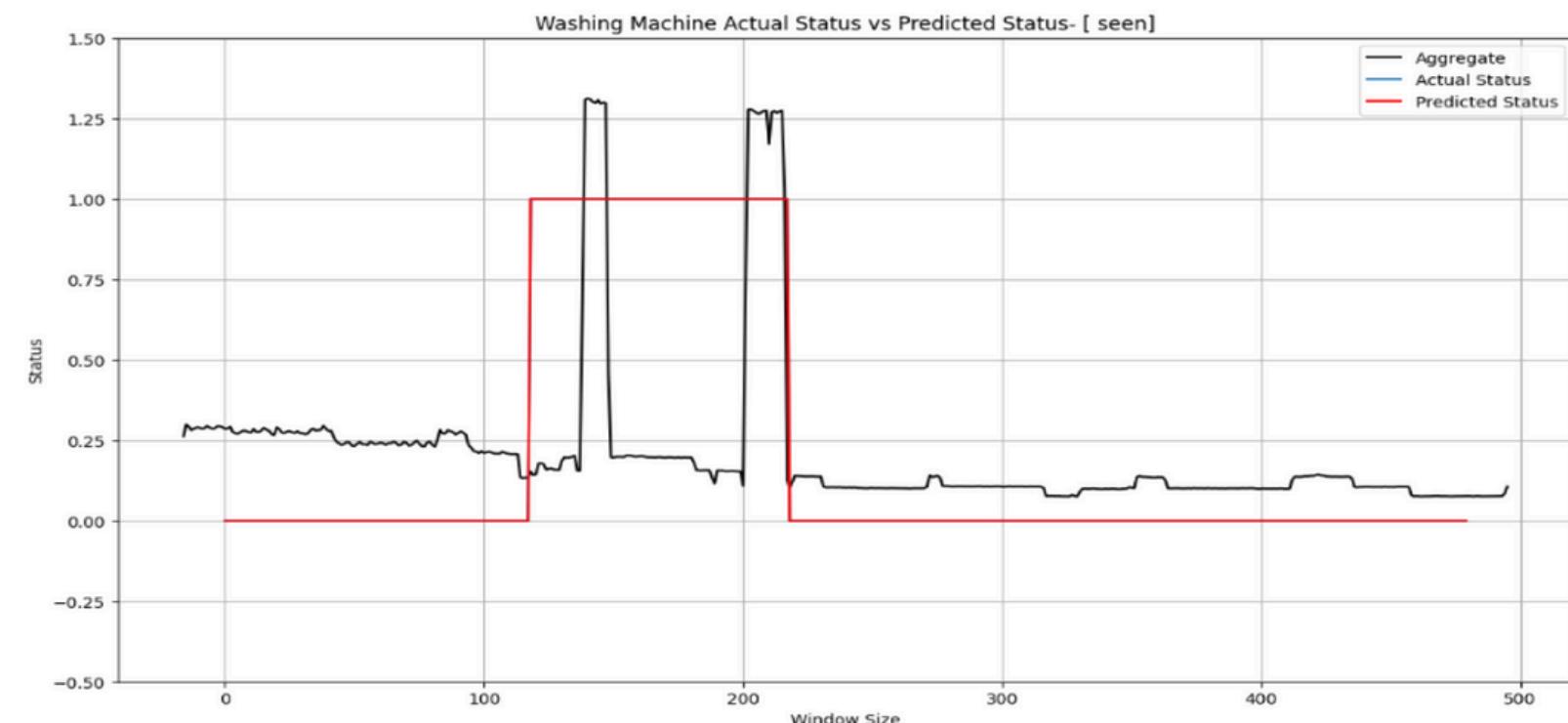
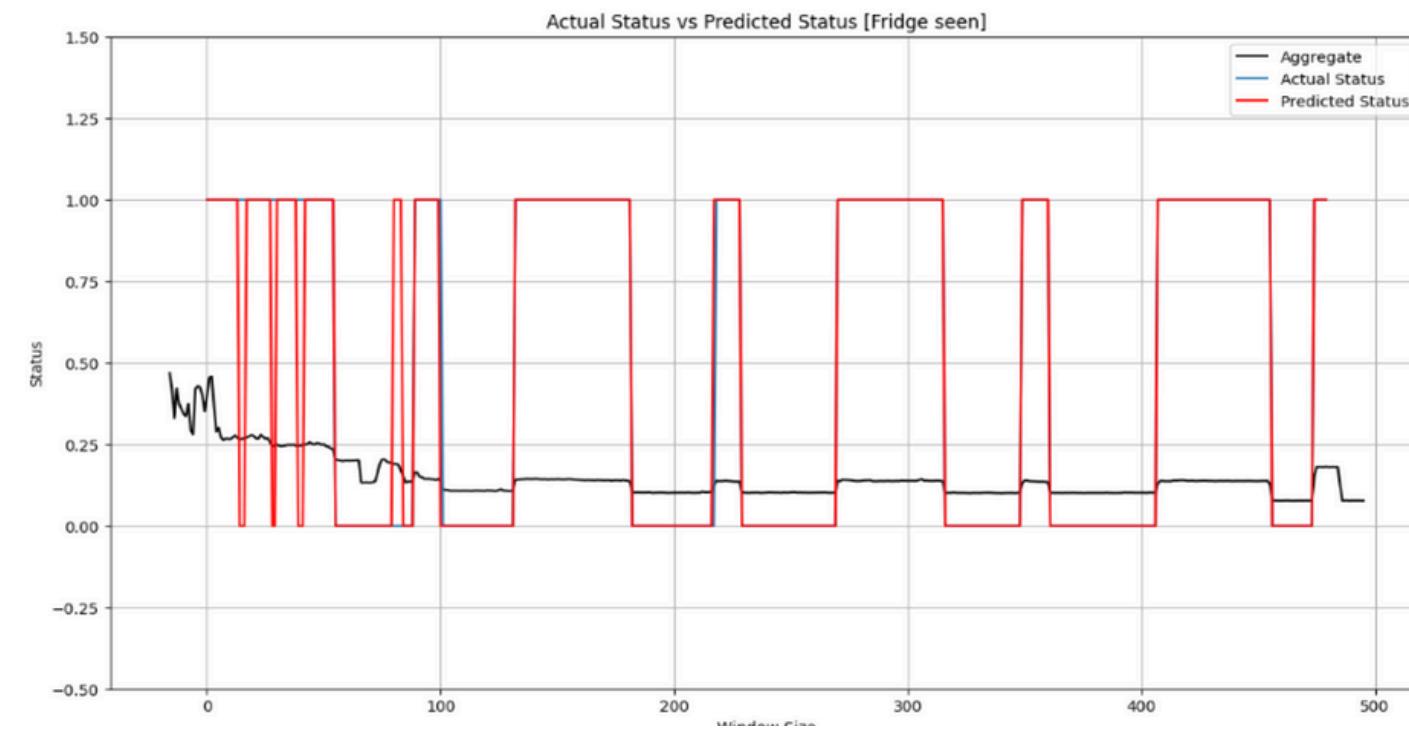
# PTP-Net Target Appliances Activation Results

*Status Prediction in the seen case for PTPNET:*



# Conv-BiLSTM Target Appliances Activation Results

*Status Prediction in the seen case for Conv-BiLSTM:*



## Performance Evaluation of Status Prediction - Seen Case

```
fridge
F1 Score :0.9707112970711297
Precision :0.9789029535864979
Recall :0.9626556016597511
Accuracy :0.9708333333333333
MCC :0.9418005057872556

dish_washer
F1 Score :1.0
Precision :1.0
Recall :1.0
Accuracy :1.0
MCC :1.0

washing_machine
F1 Score :0.9893617021276596
Precision :0.9789473684210527
Recall :1.0
Accuracy :0.9958333333333333
MCC :0.9868577450141074
```

Status Prediction metrics in seen case for CONV-BILSTM

```
fridge
F1 Score :0.9565217391304348
Precision :0.9545454545454546
Recall :0.9585062240663901
Accuracy :0.95625
MCC :0.9125048833338797

dish_washer
F1 Score :0.9949748743718593
Precision :1.0
Recall :0.99
Accuracy :0.9979166666666667
MCC :0.9936808213924376

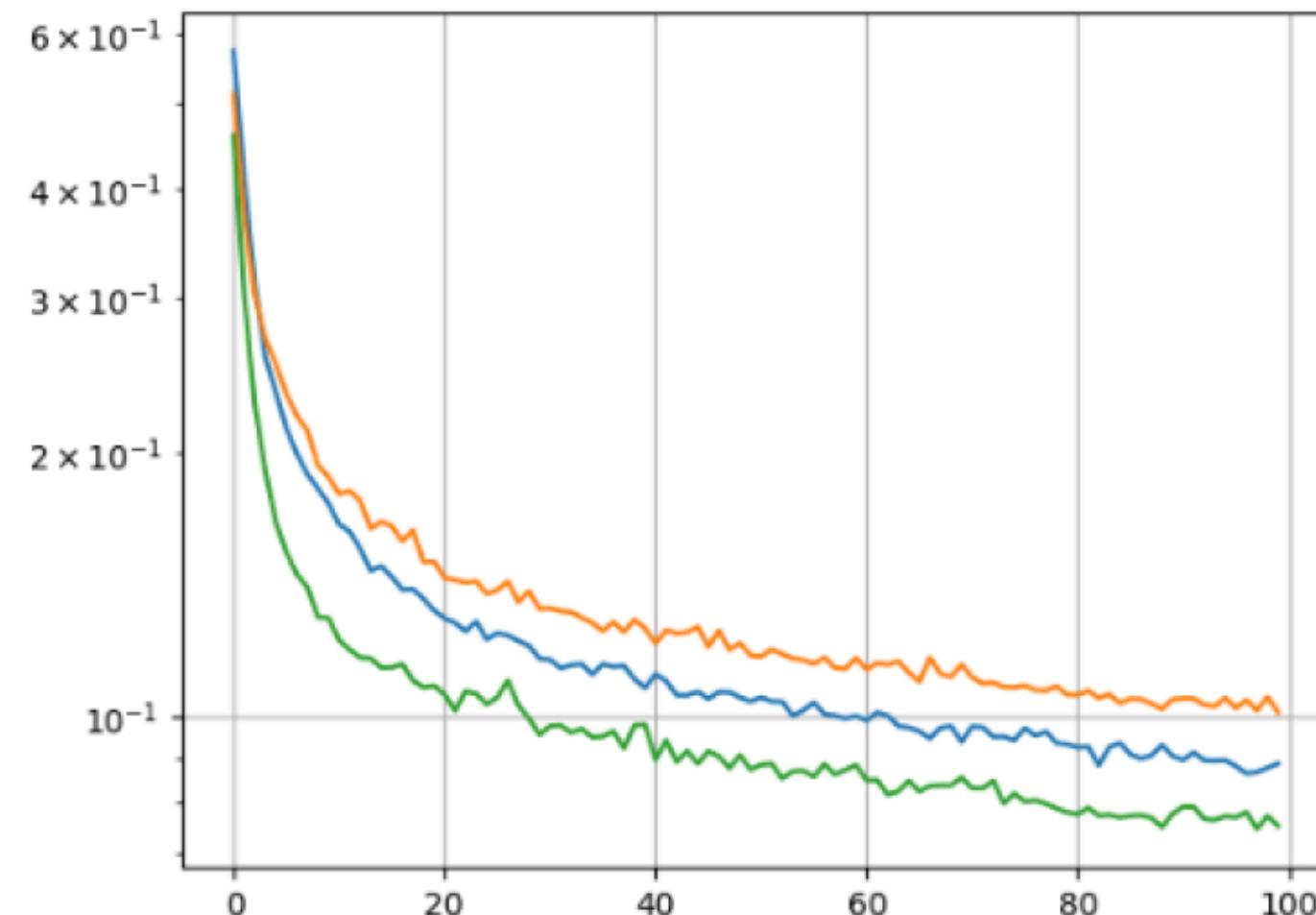
washing_machine
F1 Score :0.989247311827957
Precision :0.989247311827957
Recall :0.989247311827957
Accuracy :0.9958333333333333
MCC :0.9866633324997917
```

Status Prediction metrics in seen case for PTPNET

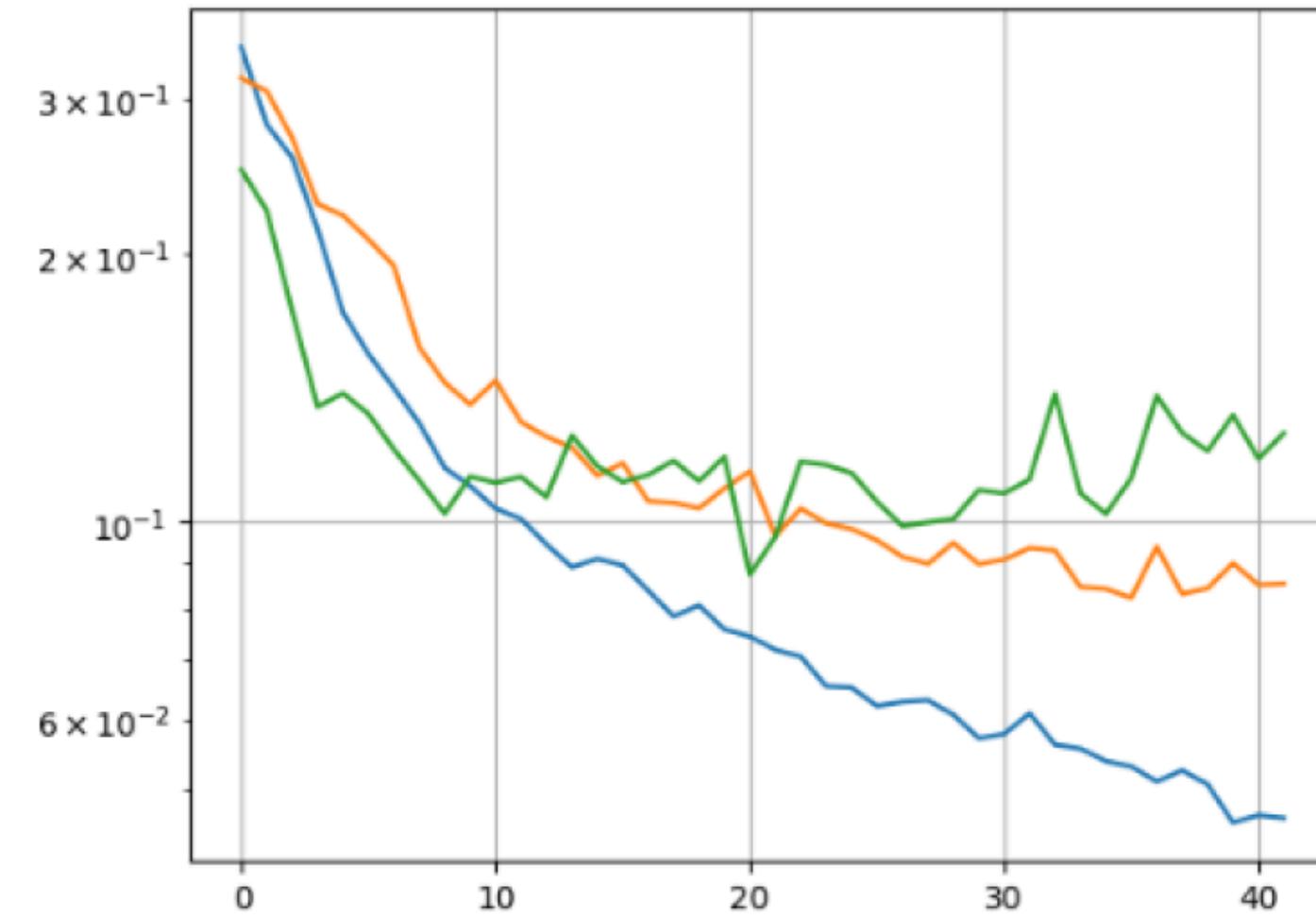


# BINARY CLASSIFICATION TASK (STATUS PREDICTION)

## *Unseen Case*



Loss curves of PTPNET in the unseen case

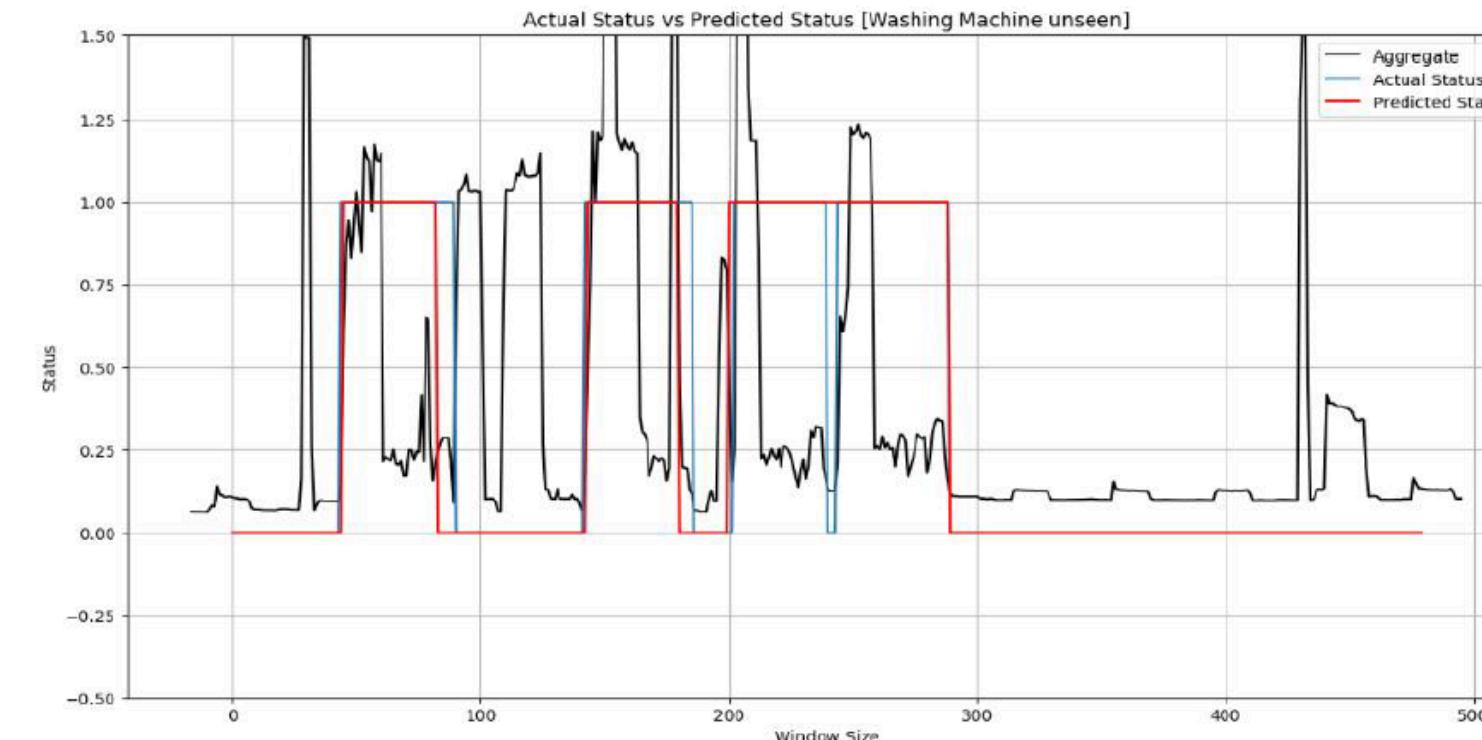
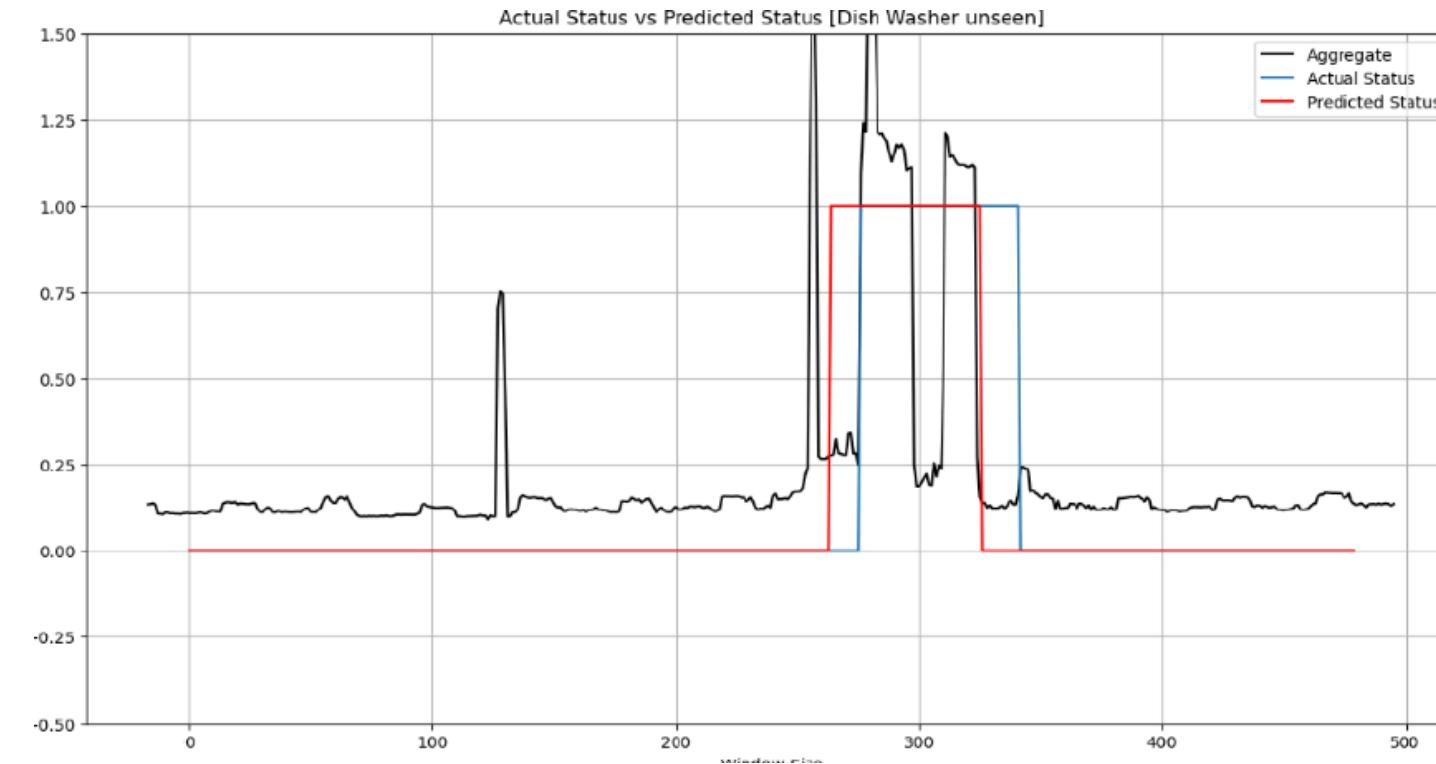
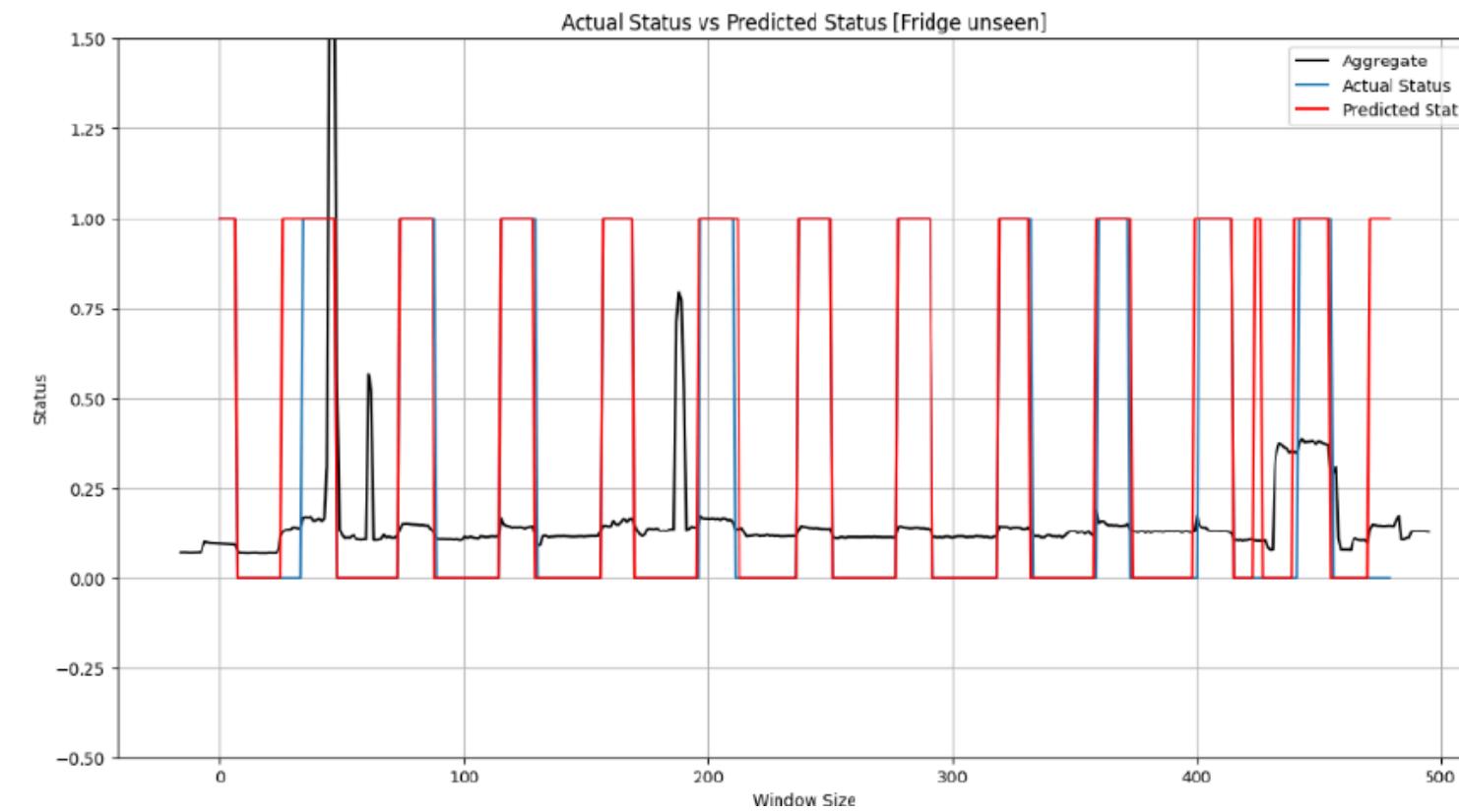


Loss curves of Conv-BiLSTM in the unseen case



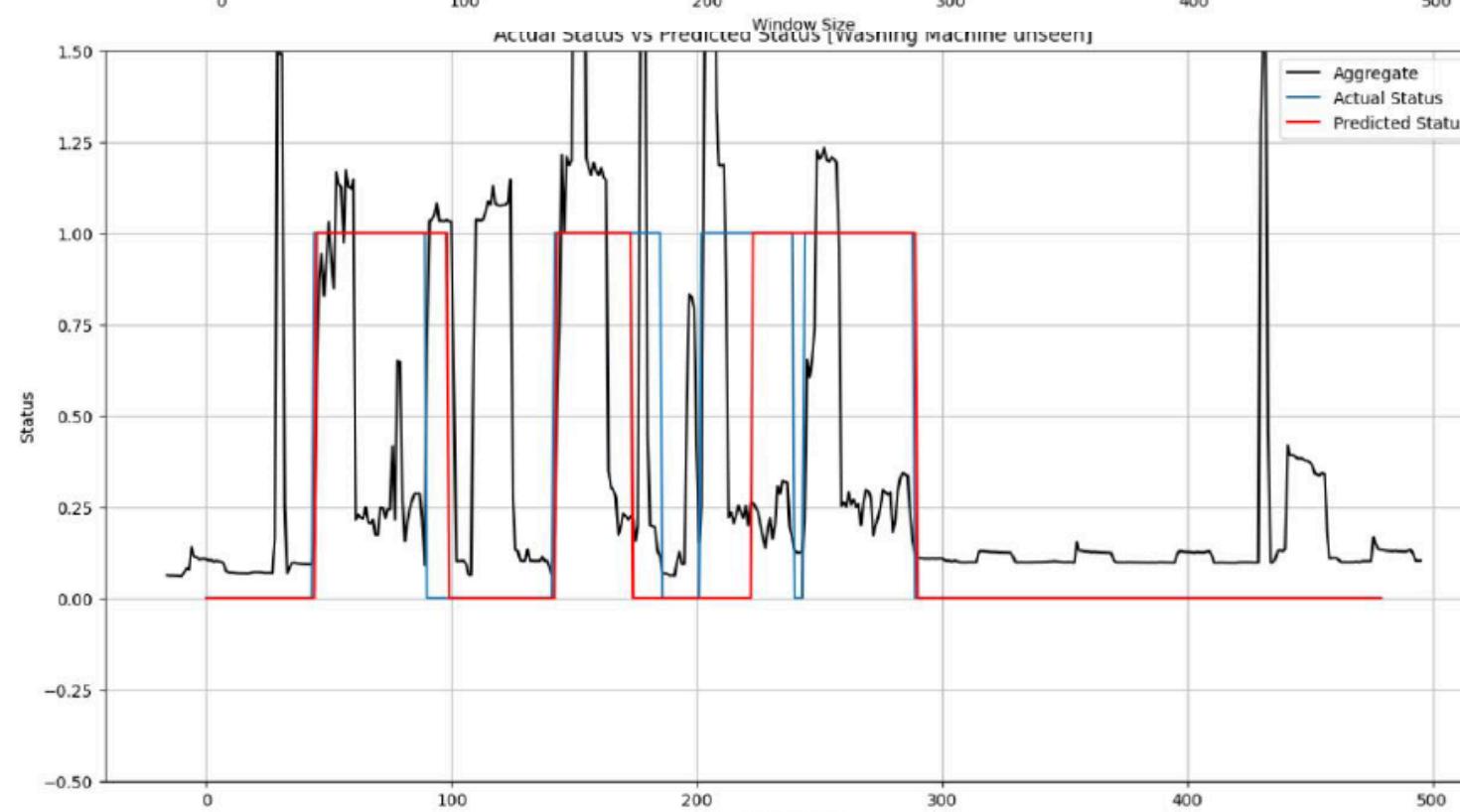
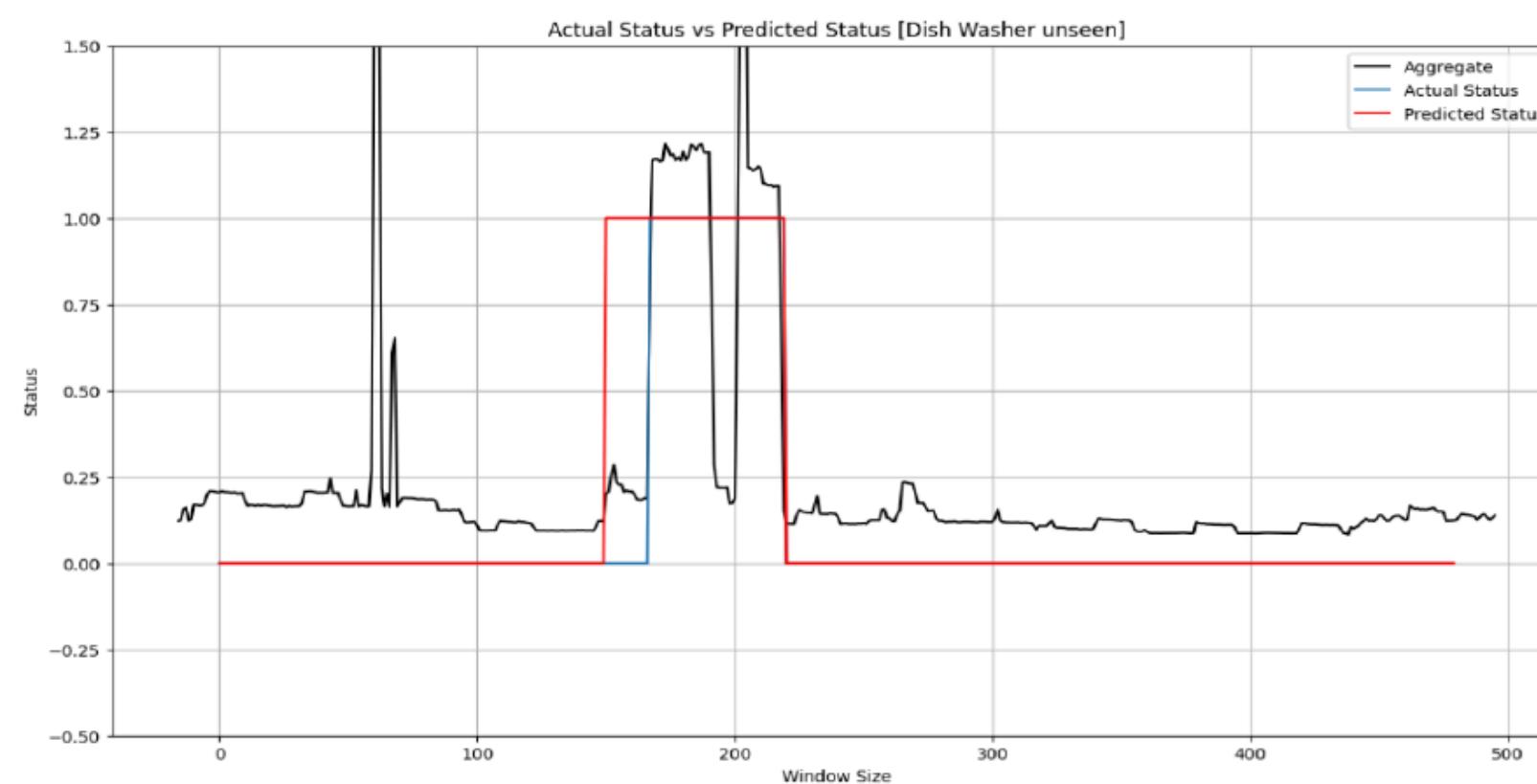
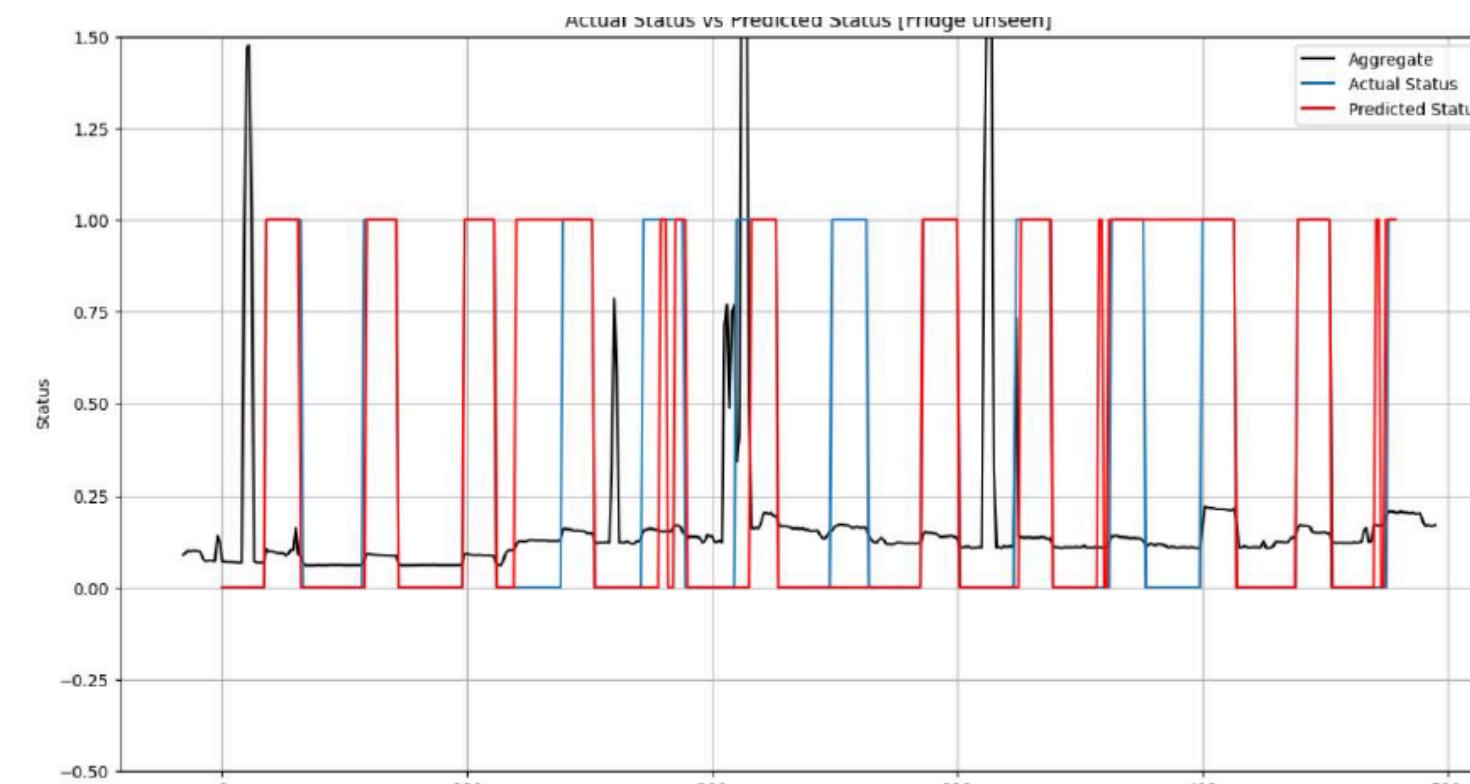
# PTP-Net Target Appliances Activation Results

*Status Prediction in the unseen case for PTPNET:*



# Conv-BiLSTM Target Appliances Activation Results

*Status Prediction in the unseen case for Con-BiLSTM:*



# Performance Evaluation of Status Prediction - Unseen Case



fridge

F1 Score : 0.7754010695187166  
Precision : 0.7474226804123711  
Recall : 0.8055555555555556  
Accuracy : 0.825  
MCC : 0.6335754305211765

dish\_washer

F1 Score : 0.8617886178861789  
Precision : 0.7571428571428571  
Recall : 1.0  
Accuracy : 0.9645833333333333  
MCC : 0.8526423613214625

washing\_machine

F1 Score : 0.8492307692307692  
Precision : 0.9078947368421053  
Recall : 0.7976878612716763  
Accuracy : 0.8979166666666667  
MCC : 0.7762481853292692

Status Prediction metrics in unseen  
case for CONV-BILSTM

fridge

F1 Score : 0.9048991354466858  
Precision : 0.8440860215053764  
Recall : 0.9751552795031055  
Accuracy : 0.93125  
MCC : 0.8569418223967017

dish\_washer

F1 Score : 0.7812499999999999  
Precision : 0.8064516129032258  
Recall : 0.7575757575757576  
Accuracy : 0.9416666666666667  
MCC : 0.7481204184498087

washing\_machine

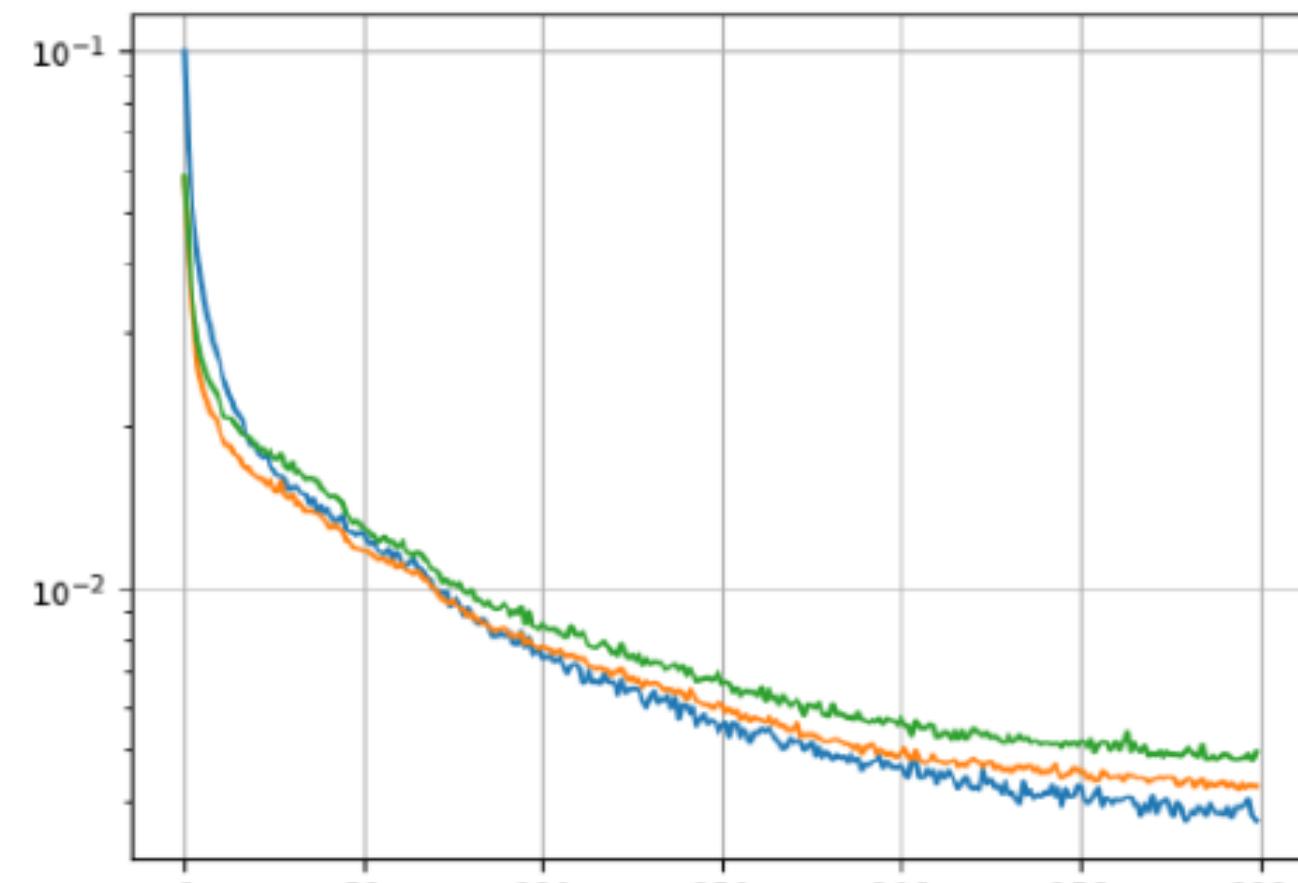
F1 Score : 0.9376854599406528  
Precision : 0.9634146341463414  
Recall : 0.9132947976878613  
Accuracy : 0.95625  
MCC : 0.9047804938235995

Status Prediction metrics in unseen  
case for PTP-Net

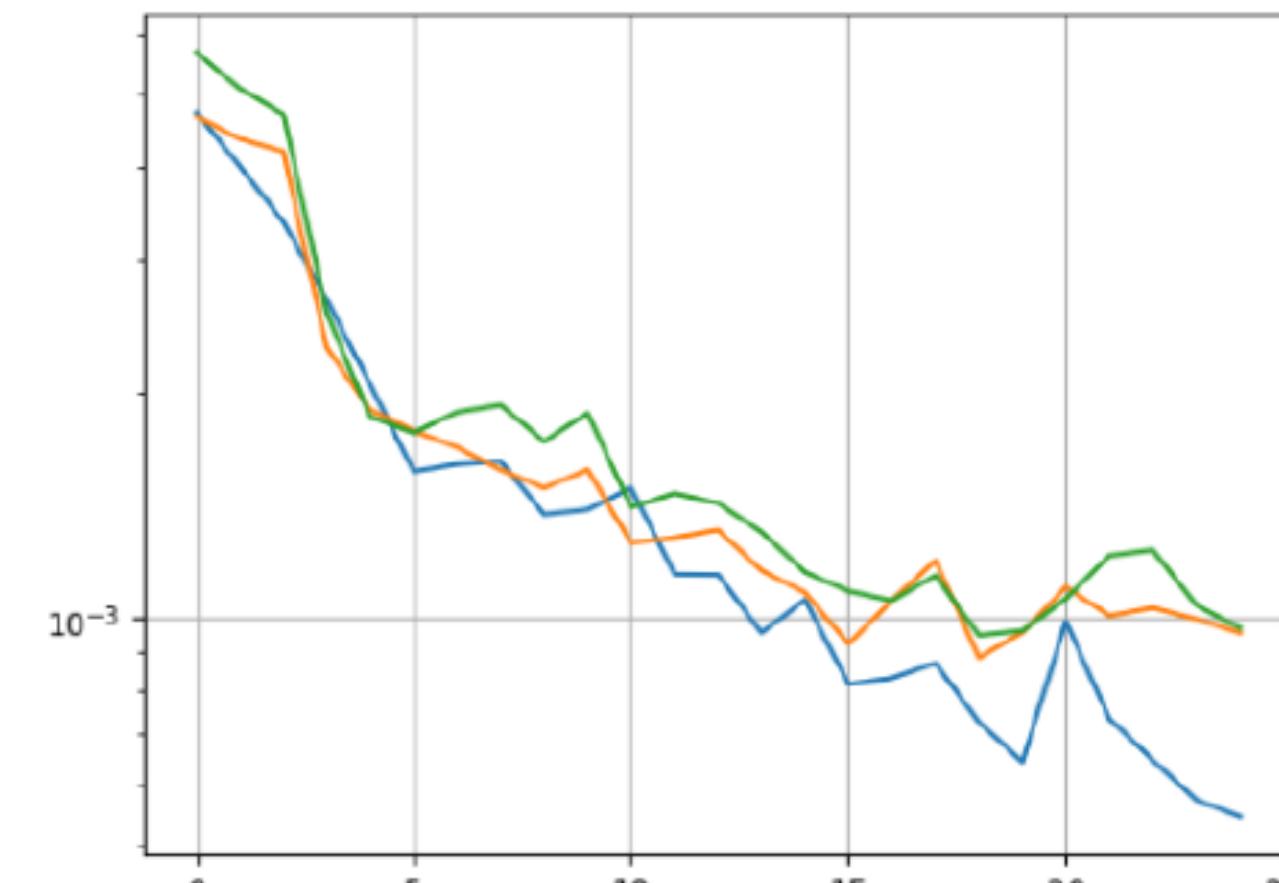


# REGRESSION TASK (POWER PREDICTION)

## Seen Case



Loss curves of PTPNET in the seen case



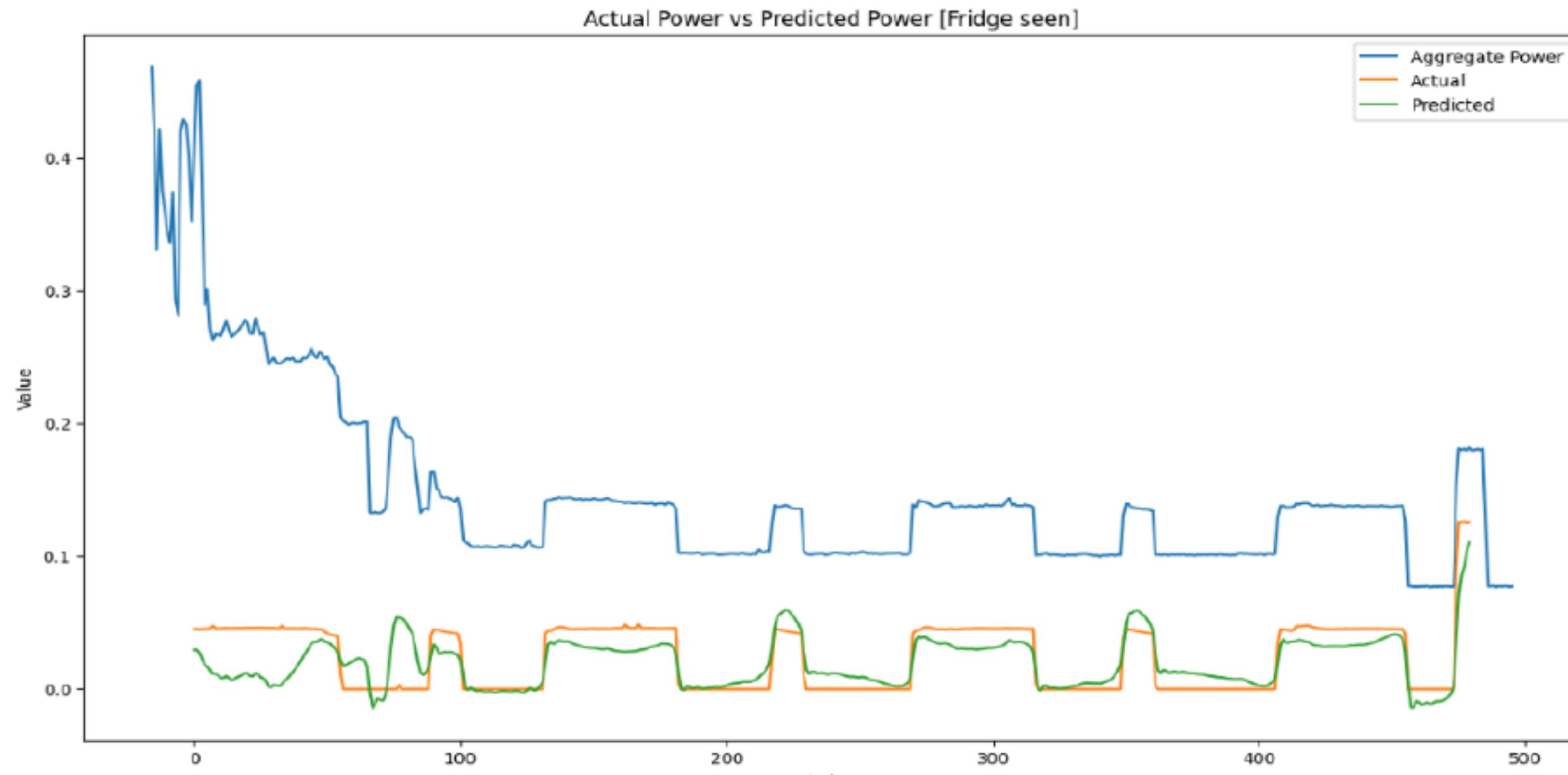
Loss curves of Conv-BiLSTM in the seen case



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## Conv-BiLSTM Target Appliances Power Consumption Results

*Power Consumption Prediction in the seen case for Conv-BiLSTM:*



Total Aggregate Energy is 150.71kw/8h

Actual Energy Consumed by the Fridge is 22.72kw/8h

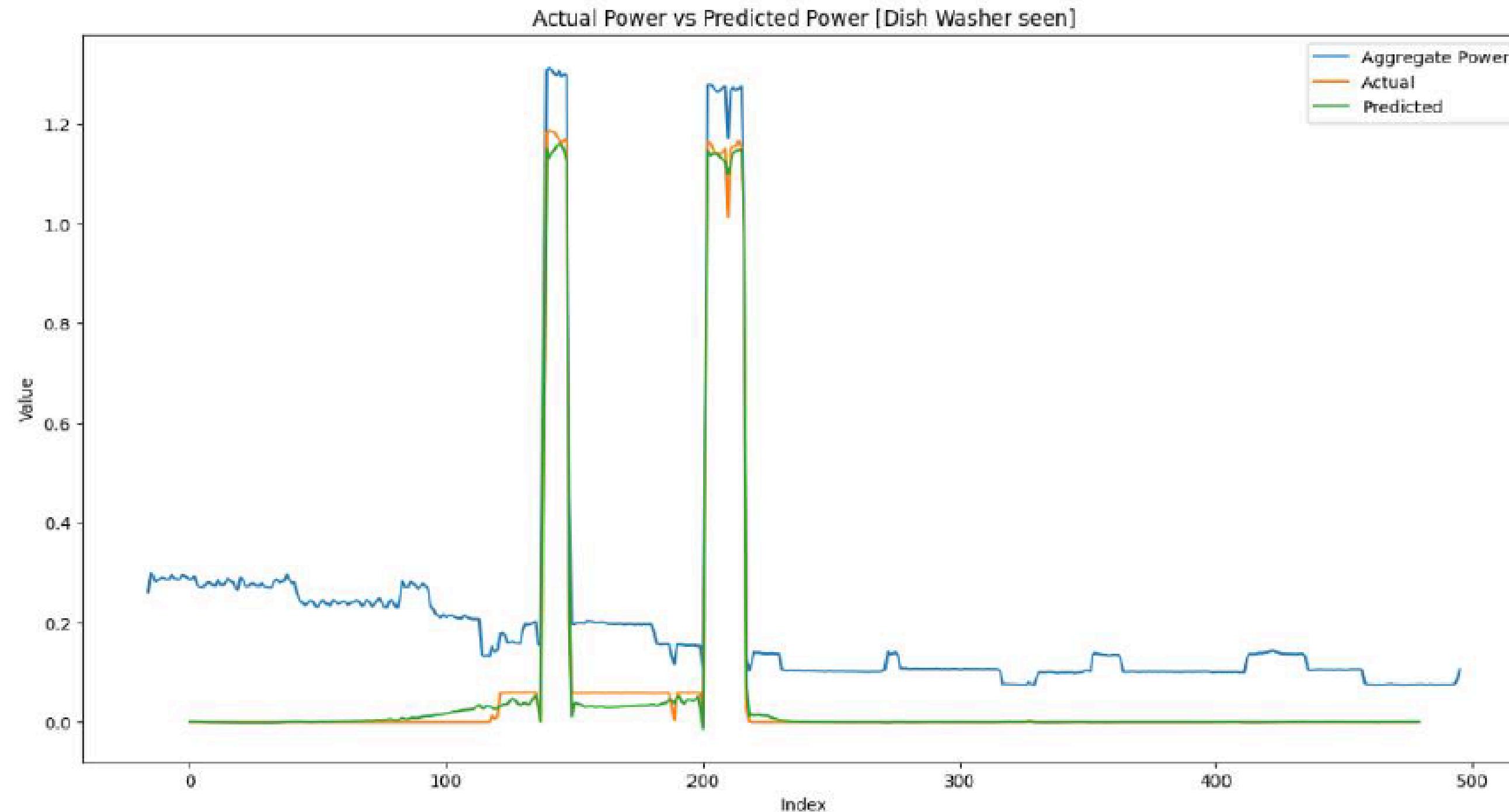
Predicted Energy Consumed by the Fridge is 18.85kw/8h



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# Conv-BiLSTM Target Appliances Power Consumption Results

*Power Consumption Prediction in the seen case for Conv-BiLSTM:*



Total Aggregate Energy is 216.96kw/8h

Actual Energy Consumed by the Dish Washer is 65.71kw/8h

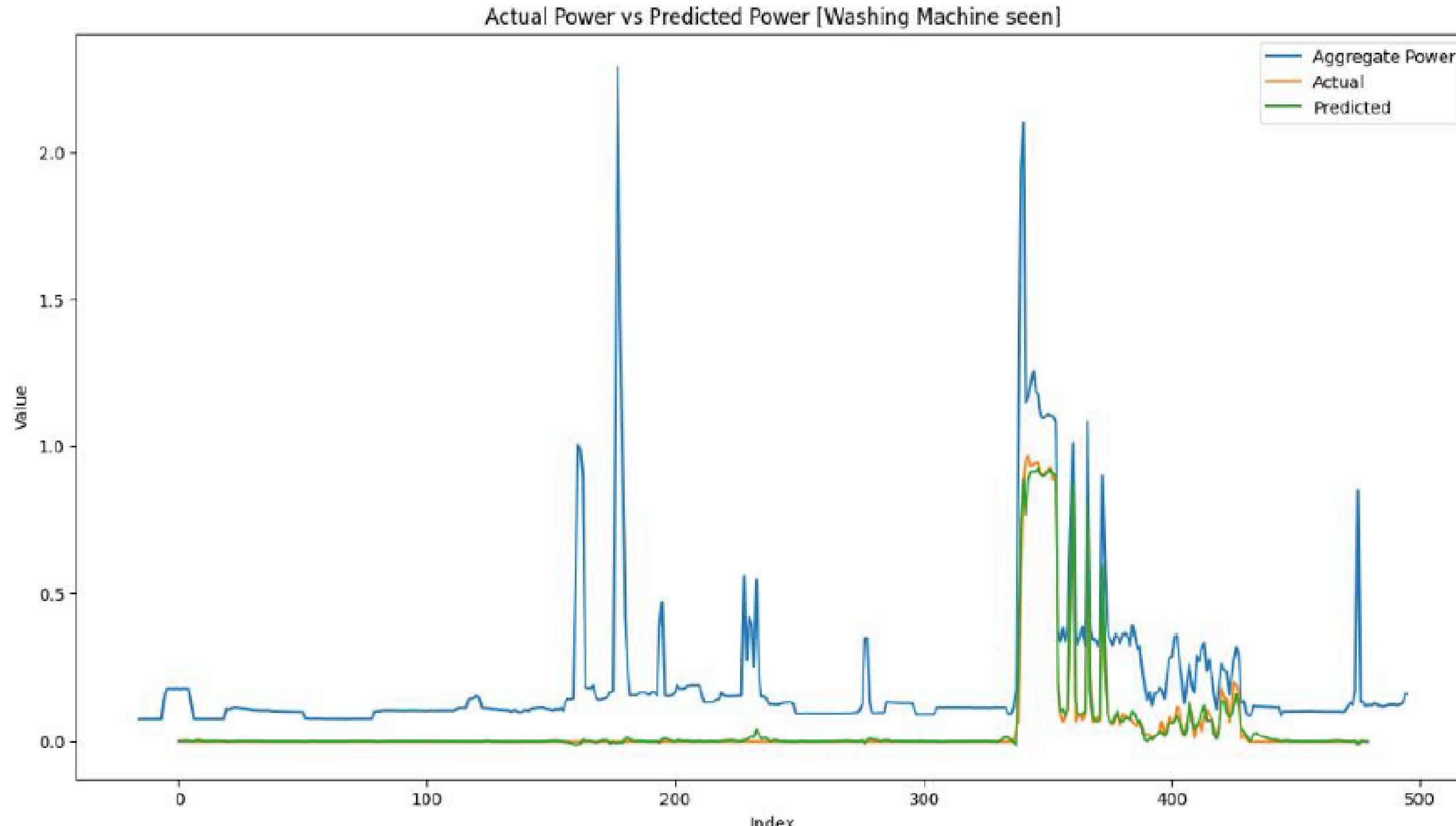
Predicted Energy Consumed by the Dish Washer is 64.56kw/8h



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# Conv-BiLSTM Target Appliances Power Consumption Results

*Power Consumption Prediction in the seen case for Conv-BiLSTM:*



Total Aggregate Energy is 211.14kw/8h

Actual Energy Consumed by the Washing Machine is 43.91kw/8h

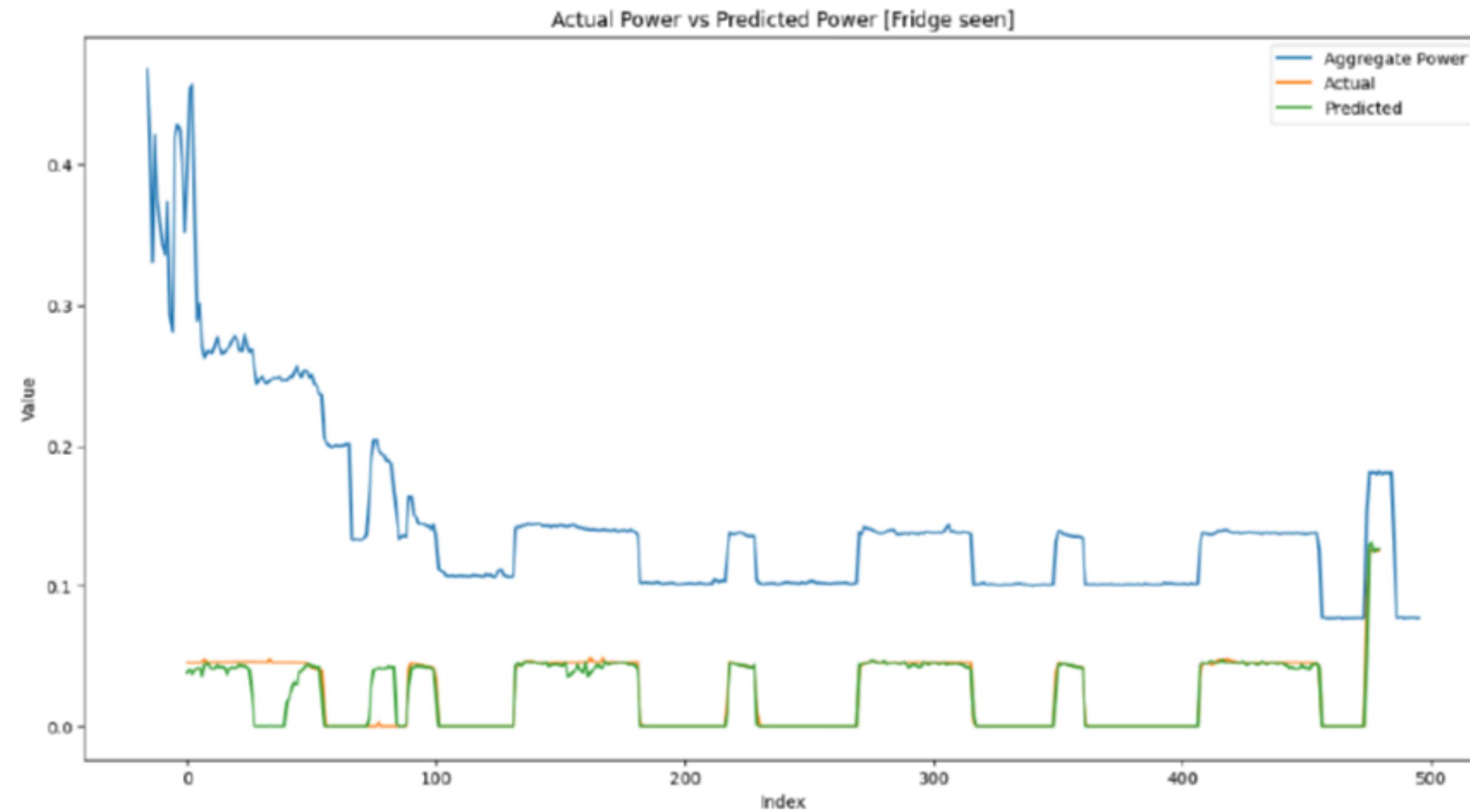
Predicted Energy Consumed by the Washing Machine is 45.78kw/8h



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# PTP-Net Target Appliances Power Consumption Results

*Power Consumption Prediction in the seen case for PTP-Net:*



Total Aggregate Energy is 150.71kw/8h

Actual Energy Consumed by the Fridge is 22.72kw/8h

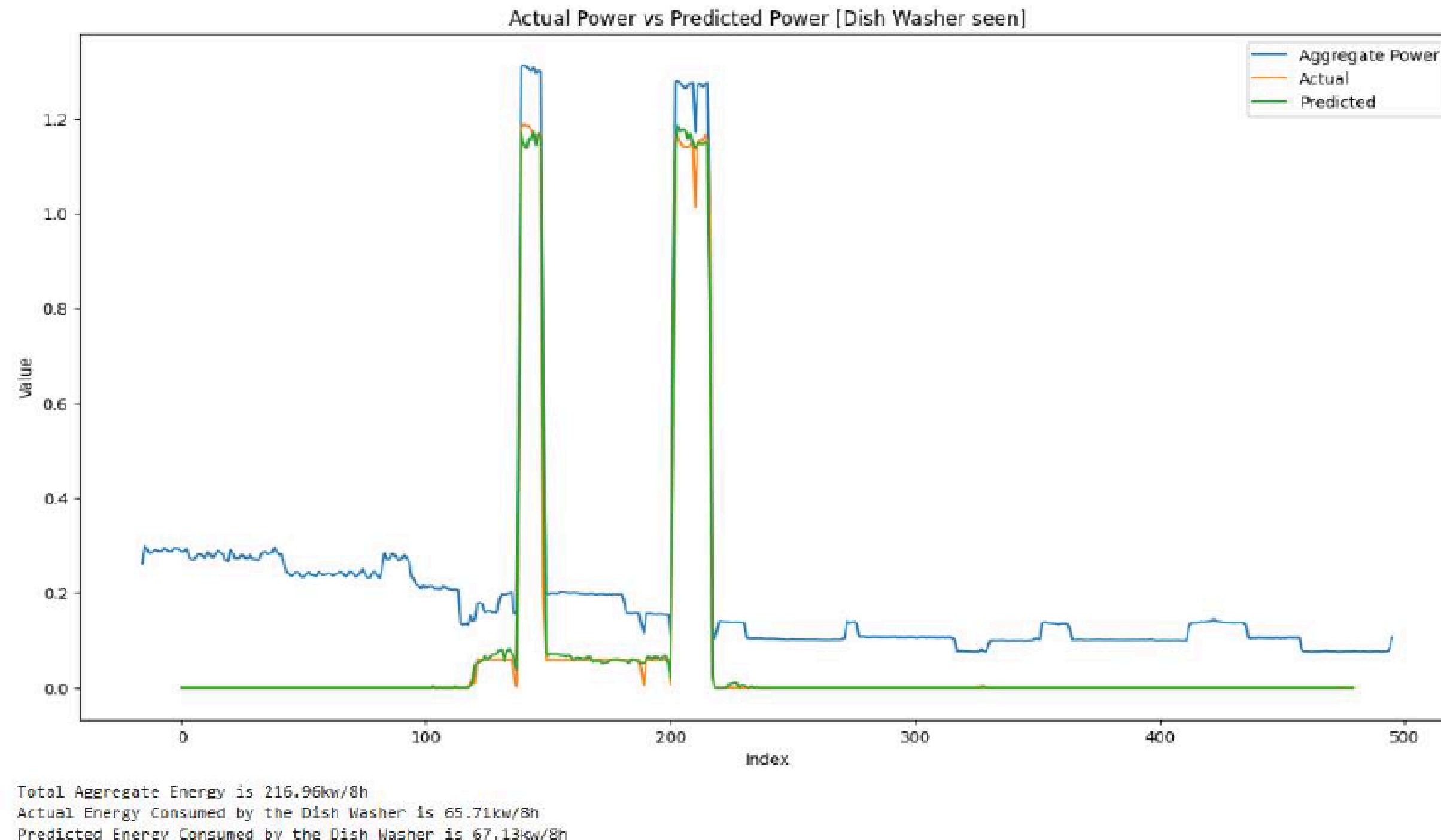
Predicted Energy Consumed by the Fridge is 21.12kw/8h



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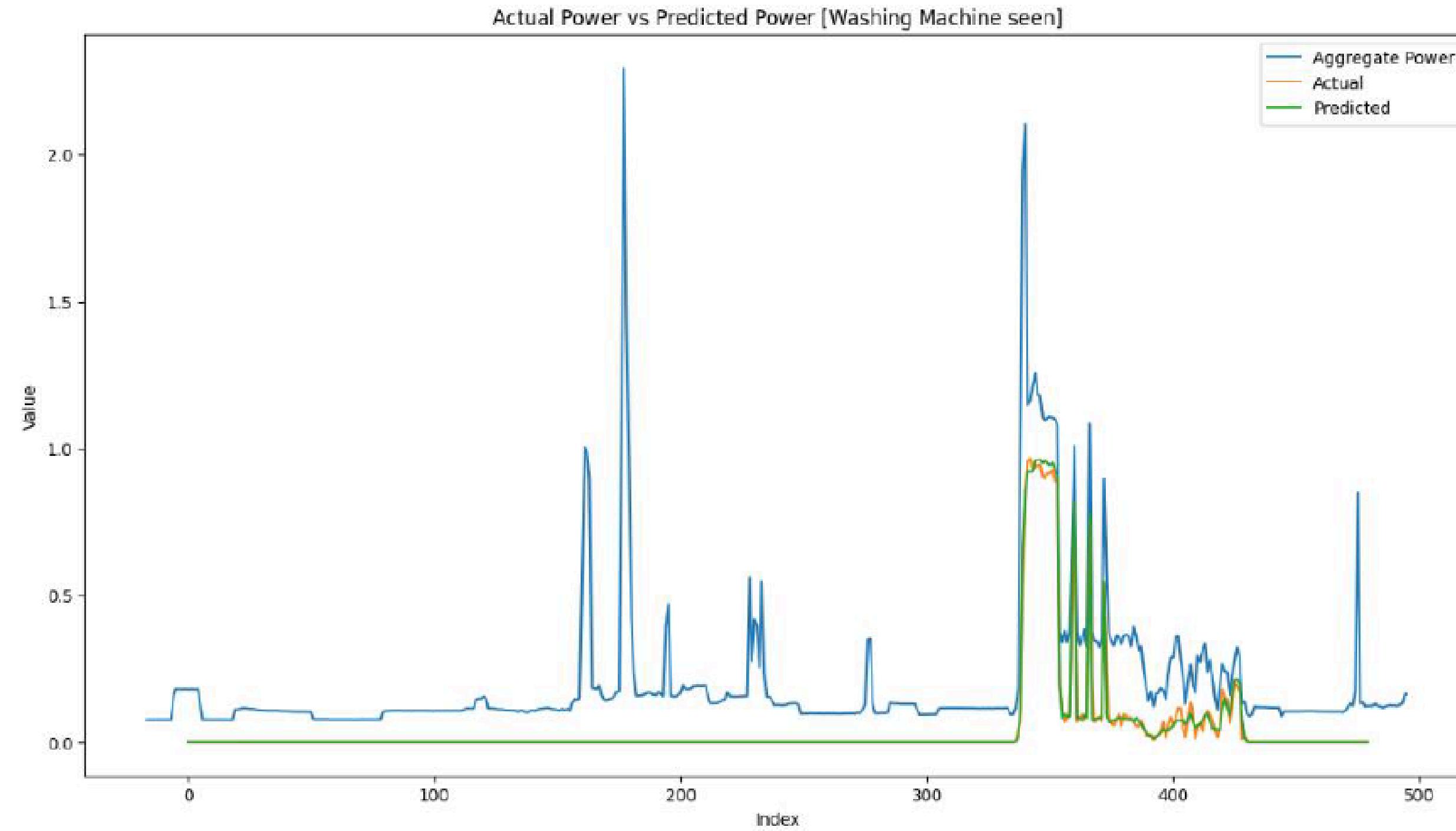
# PTP-Net Target Appliances Power Consumption Results

*Power Consumption Prediction in the seen case for PTP-Net:*



# PTP-Net Target Appliances Power Consumption Results

*Power Consumption Prediction in the seen case for PTP-Net:*



Total Aggregate Energy is 211.14kw/8h

Actual Energy Consumed by the Washing Machine is 43.91kw/8h

Predicted Energy Consumed by the Washing Machine is 44.32kw/8h



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## Performance Evaluation of Power Prediction - Seen Case



```
fridge
MAE : 0.012747319415211678
MSE : 0.0002751215943135321
RMSE : 0.01658678986132145
R Squared : 0.5536022186279297

dish_washer
MAE : 0.007094299886375666
MSE : 0.00018994430138263851
RMSE : 0.01378202810883522
R Squared : 0.9969937014393508

washing_machine
MAE : 0.007470957934856415
MSE : 0.00038617735845036805
RMSE : 0.019651396200060844
R Squared : 0.9863424133509398
```

Power Prediction metrics in the seen case for Conv-BiLSTM.

```
fridge
MAE : 0.003587055951356888
MSE : 0.00010567851859377697
RMSE : 0.010280005633831024
R Squared : 0.8285316228866577

dish_washer
MAE : 0.003578596282750368
MSE : 0.00035551696782931685
RMSE : 0.018855158239603043
R Squared : 0.9943731389939785

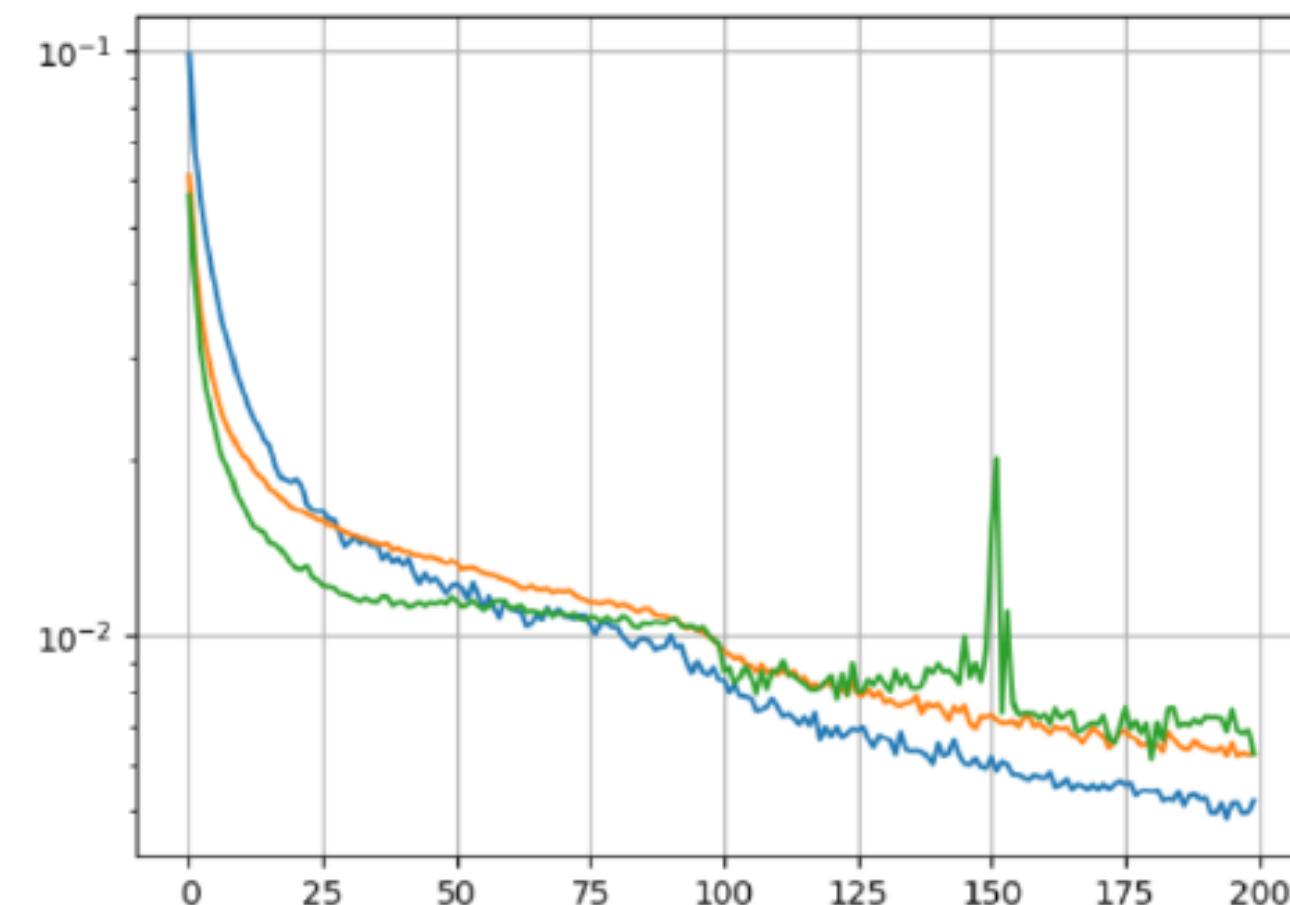
washing_machine
MAE : 0.004715790040791035
MSE : 0.00027398887323215604
RMSE : 0.016552608460187912
R Squared : 0.9903100822120905
```

Power Prediction metrics in the seen case for PTP-Net.

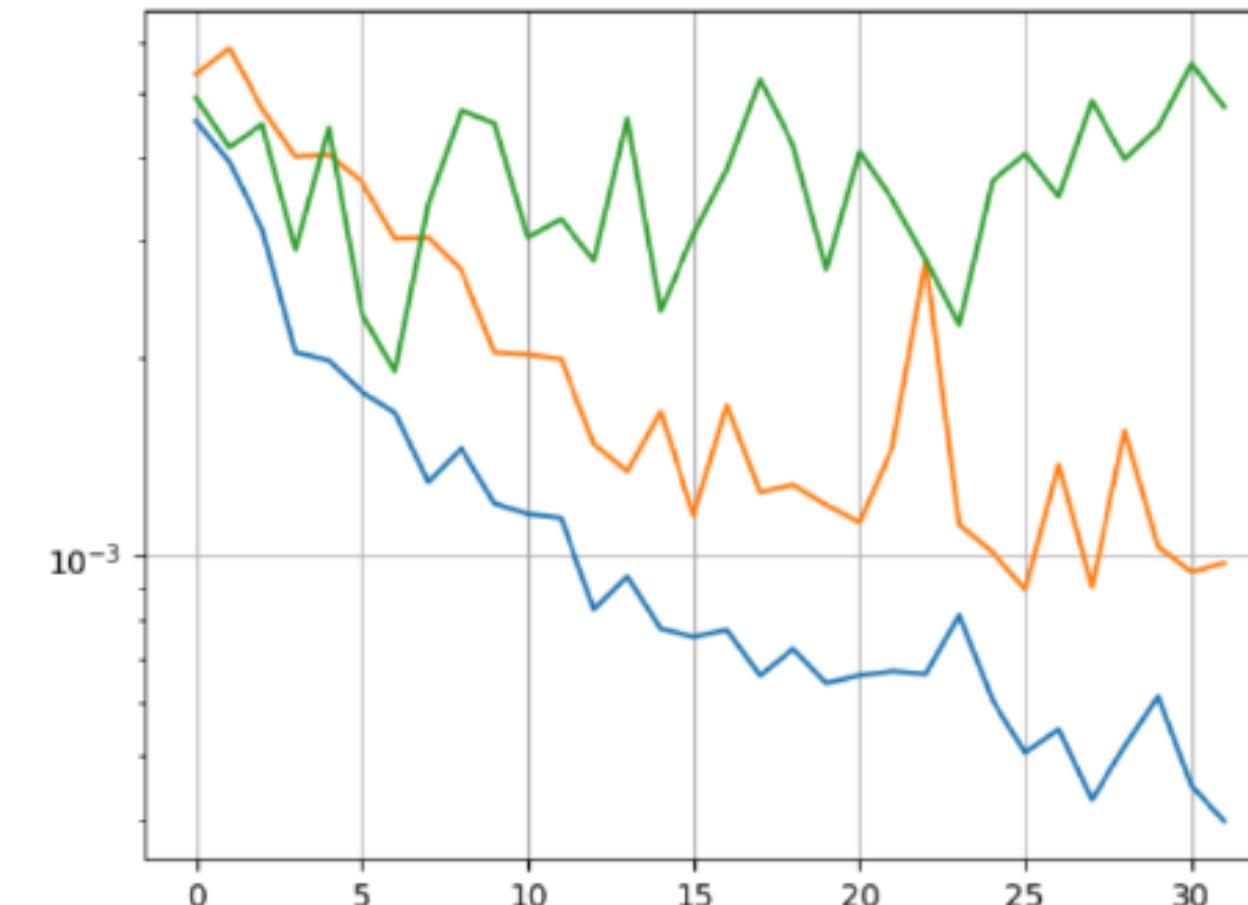


# REGRESSION TASK (POWER PREDICTION)

## *Unseen Case*



Loss curves of PTPNET in the unseen case

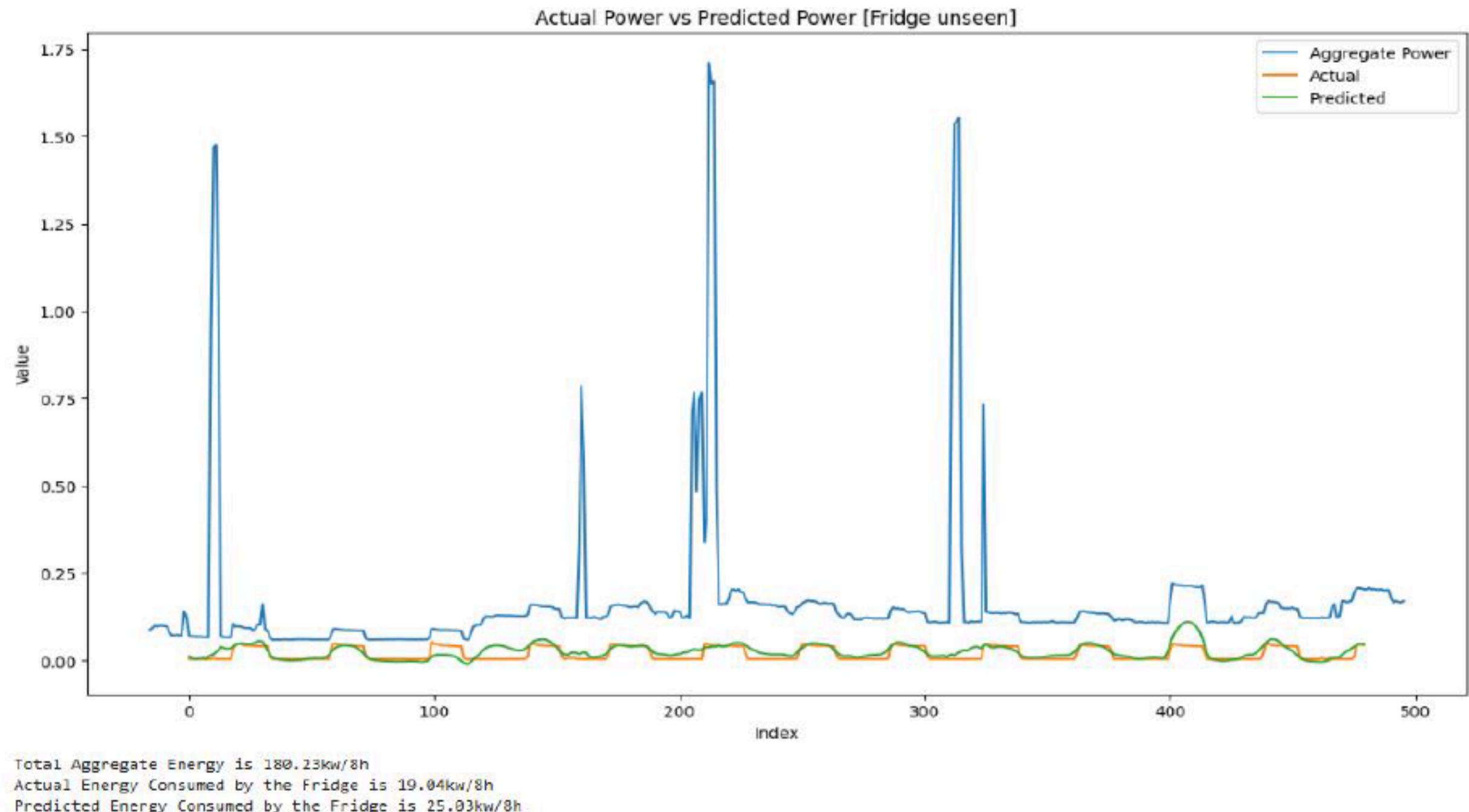


Loss curves of Conv-BiLSTM in the unseen case



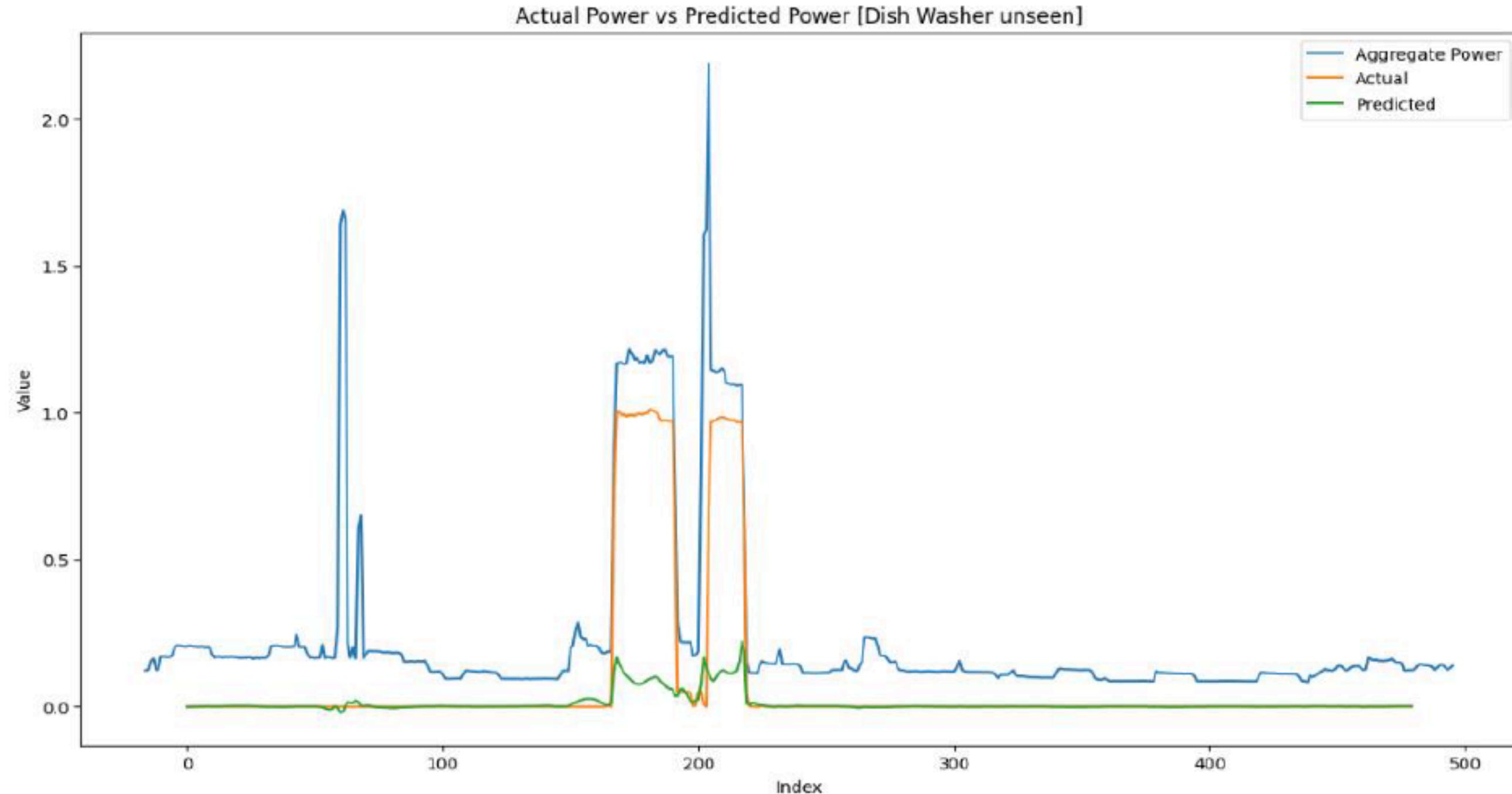
## Conv-BiLSTM Target Appliances Power Consumption Results

*Power Consumption Prediction in the unseen case for Conv-BiLSTM:*



# Conv-BiLSTM Target Appliances Power Consumption Results

*Power Consumption Prediction in the unseen case for Conv-BiLSTM:*



Total Aggregate Energy is 276.04kw/8h

Actual Energy Consumed by the Dish Washer is 77.12kw/8h

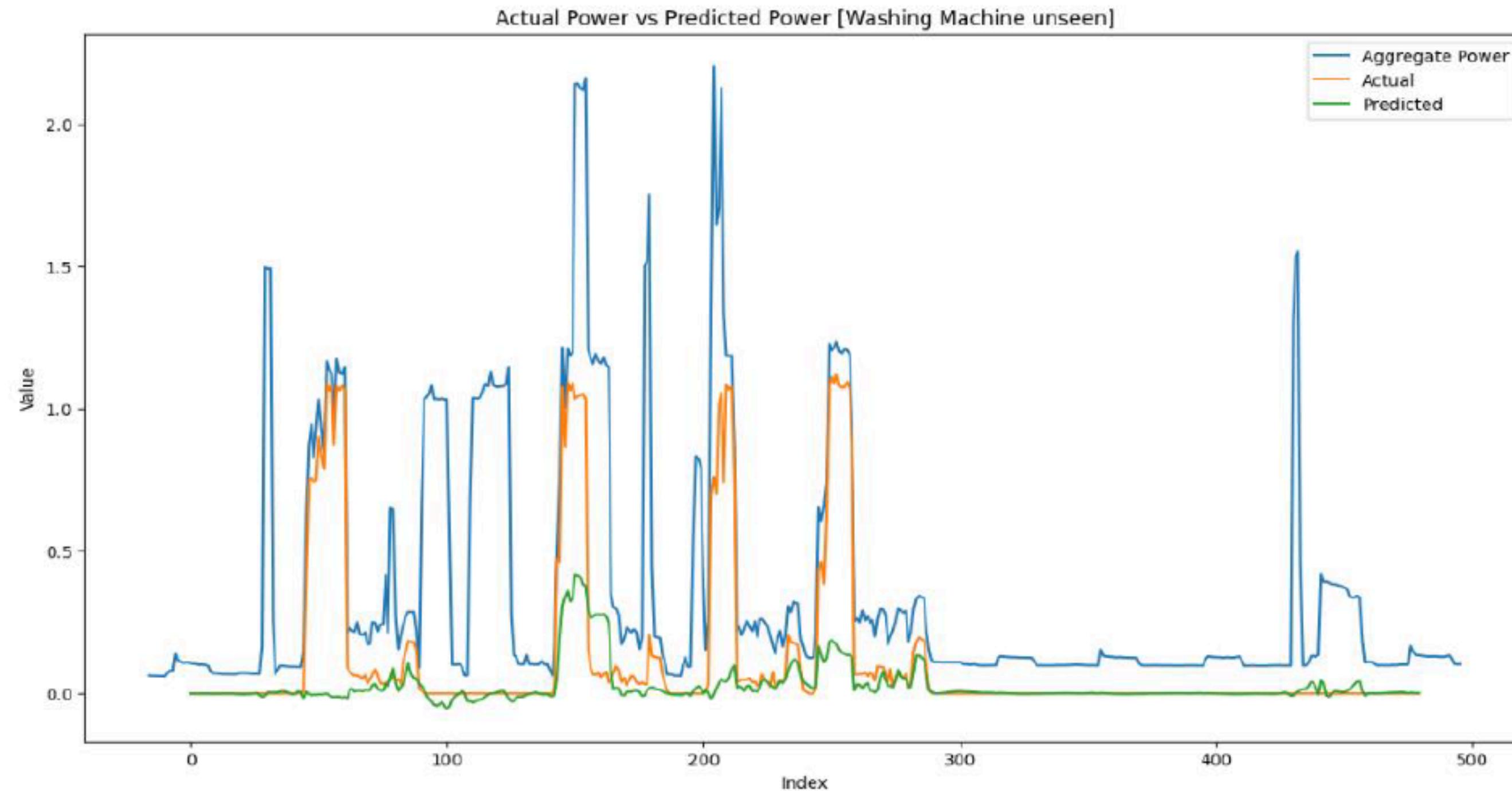
Predicted Energy Consumed by the Dish Washer is 11.03kw/8h



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# Conv-BiLSTM Target Appliances Power Consumption Results

*Power Consumption Prediction in the unseen case for Conv-BiLSTM:*



Total Aggregate Energy is 185.86kw/8h

Actual Energy Consumed by the Washing Machine is 112.36kw/8h

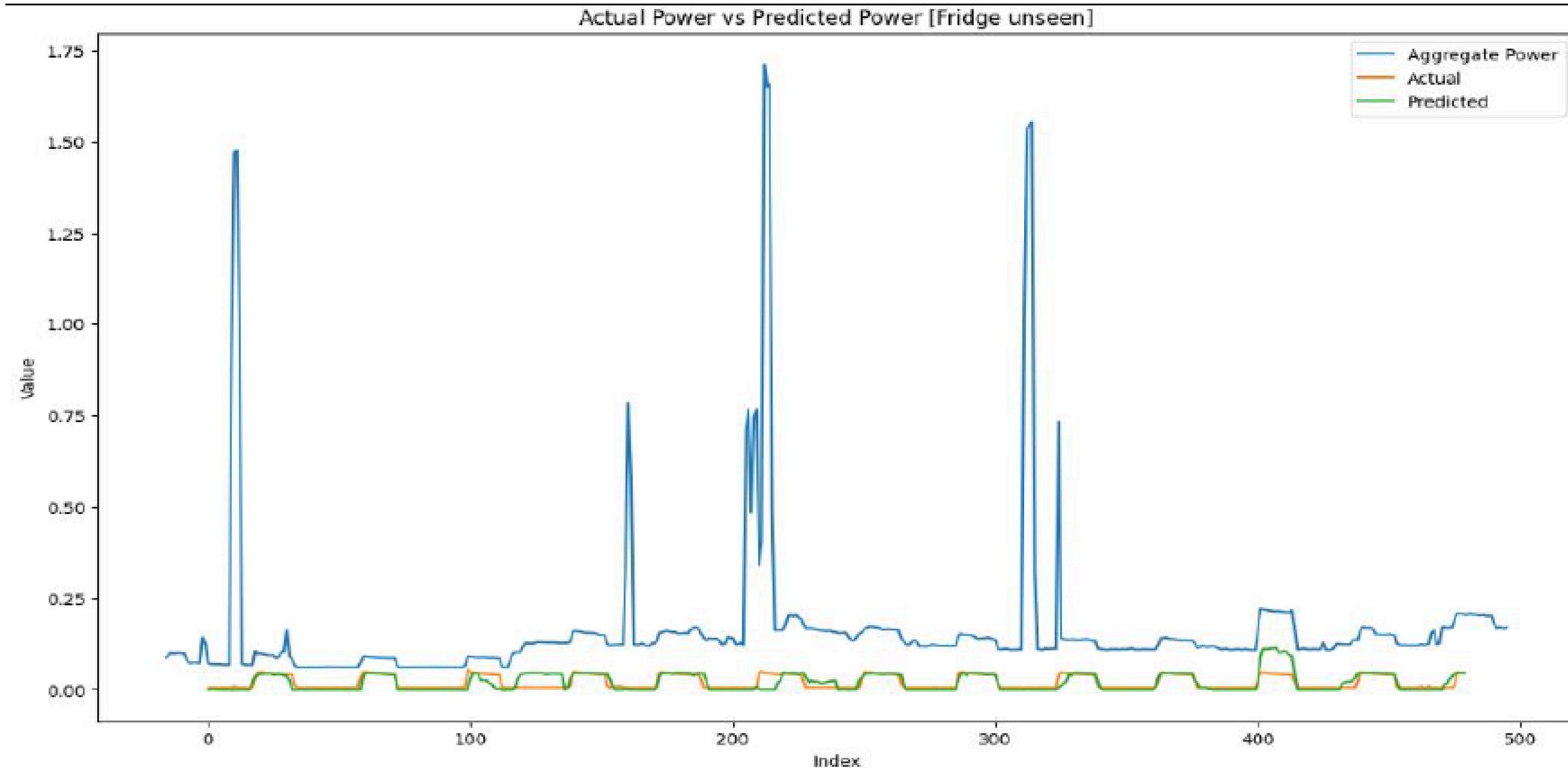
Predicted Energy Consumed by the Washing Machine is 25.13kw/8h



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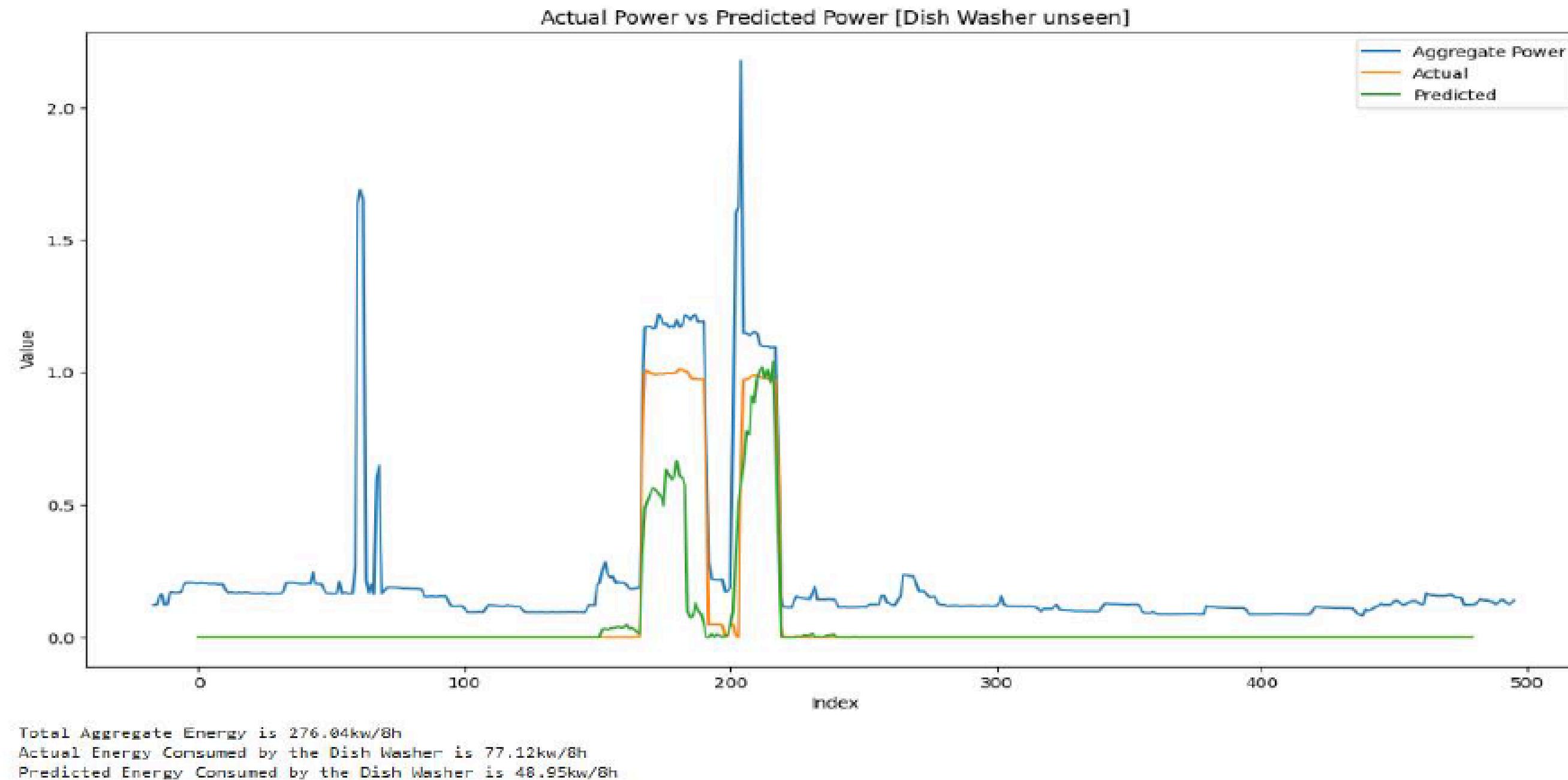
# PTP-Net Target Appliances Power Consumption Results

*Power Consumption Prediction in the unseen case for PTP-Net:*



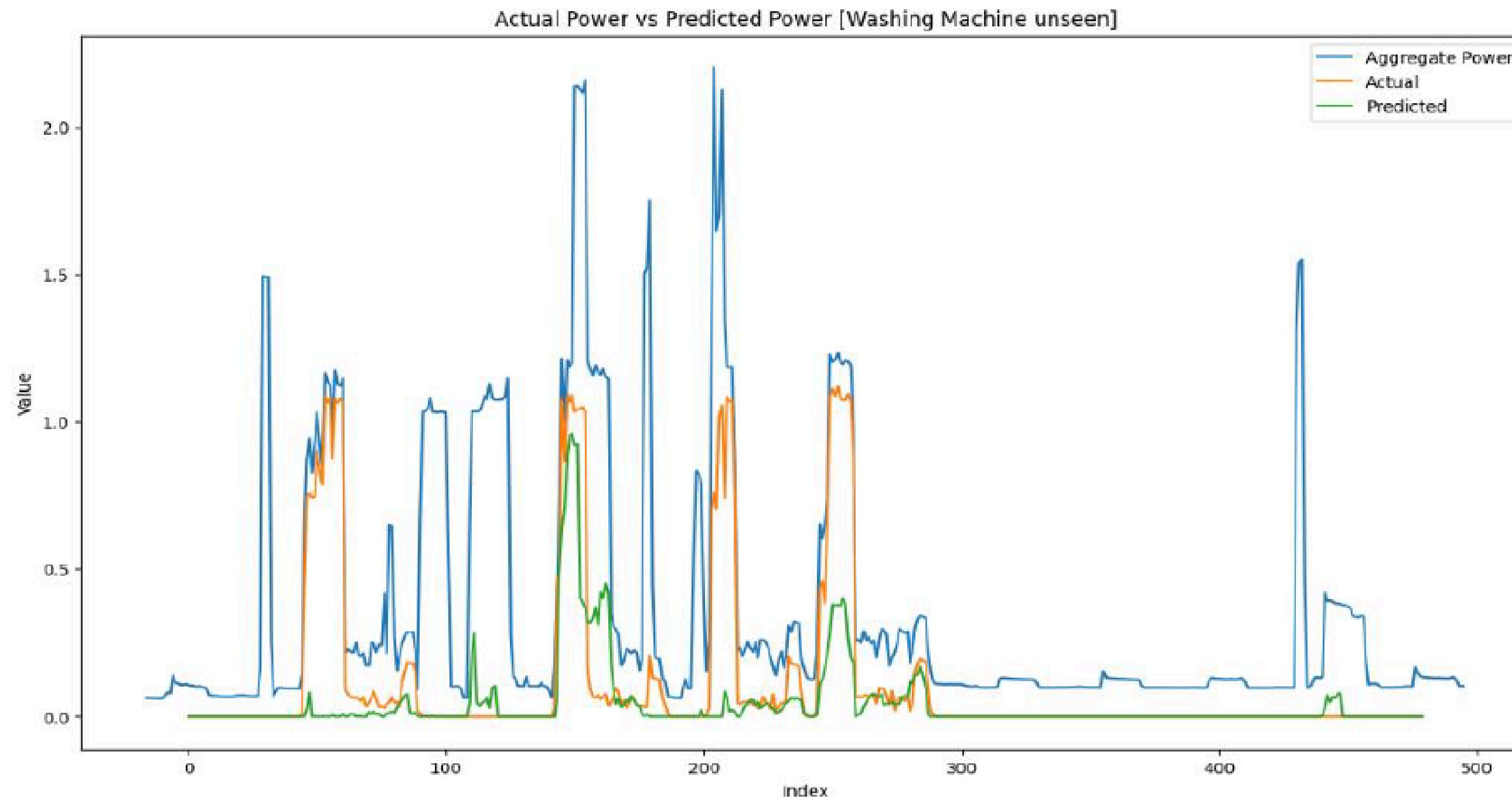
# PTP-Net Target Appliances Power Consumption Results

*Power Consumption Prediction in the unseen case for PTP-Net:*



# PTP-Net Target Appliances Power Consumption Results

*Power Consumption Prediction in the unseen case for PTP-Net:*



## Performance Evaluation of Power Prediction - Unseen Case



```
fridge
MAE  :0.011578688398003578
MSE   :0.00026720258756540716
RMSE   :0.01634633168578148
R Squared :0.20619404315948486

dish_washer
MAE  :0.07359108328819275
MSE   :0.060938797891139984
RMSE   :0.24685785174369812
R Squared :0.12969970703125

washing_machine
MAE  :0.10277135670185089
MSE   :0.07412384450435638
RMSE   :0.2722569406032562
R Squared :0.10540097951889038
```

Power Prediction metrics in the unseen case for Conv-BiLSTM.

```
fridge
MAE  :0.005877479910850525
MSE   :8.059209358179942e-05
RMSE   :0.008977309800684452
R Squared :0.7508131116628647

dish_washer
MAE  :0.026185283437371254
MSE   :0.010289785452187061
RMSE   :0.10143858194351196
R Squared :0.8449403047561646

washing_machine
MAE  :0.09319838136434555
MSE   :0.06351472437381744
RMSE   :0.25202128291130066
R Squared :0.23344218730926514
```

Power Prediction metrics in the unseen case for PTPNET.



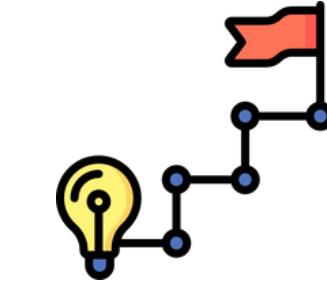
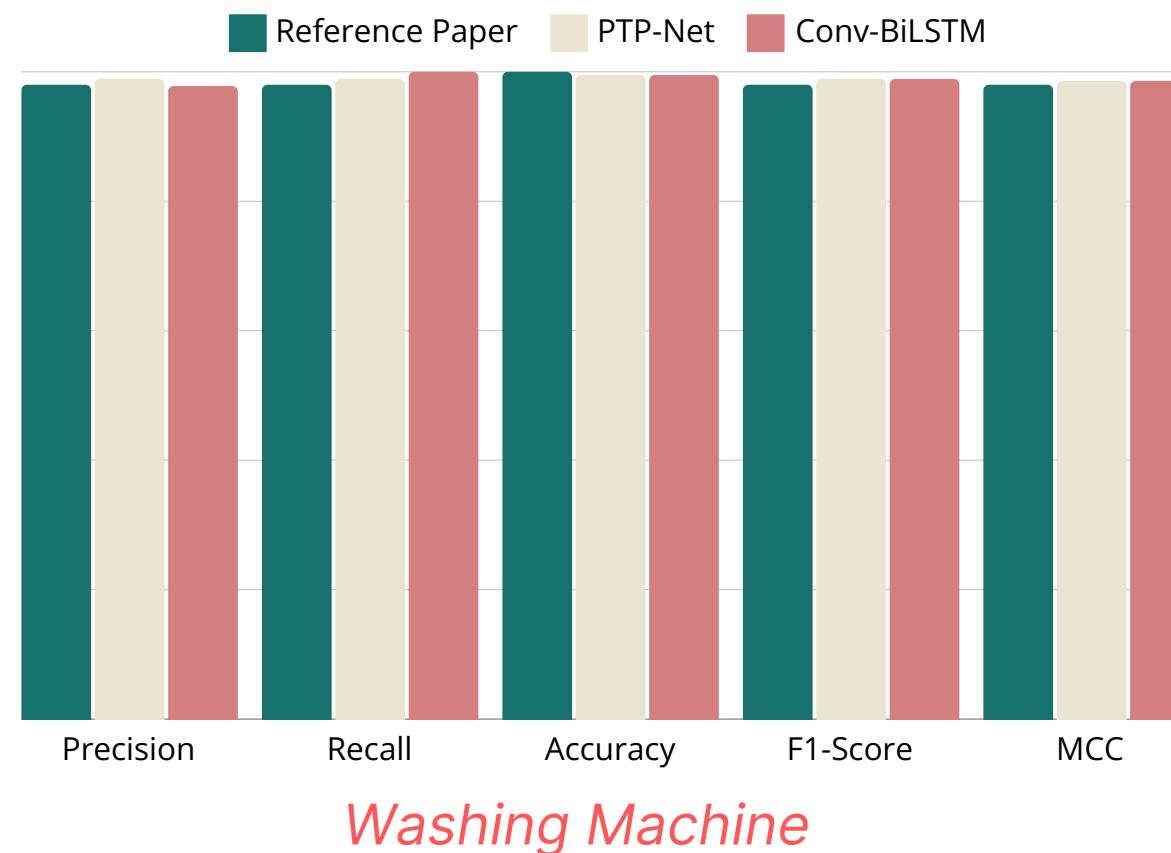
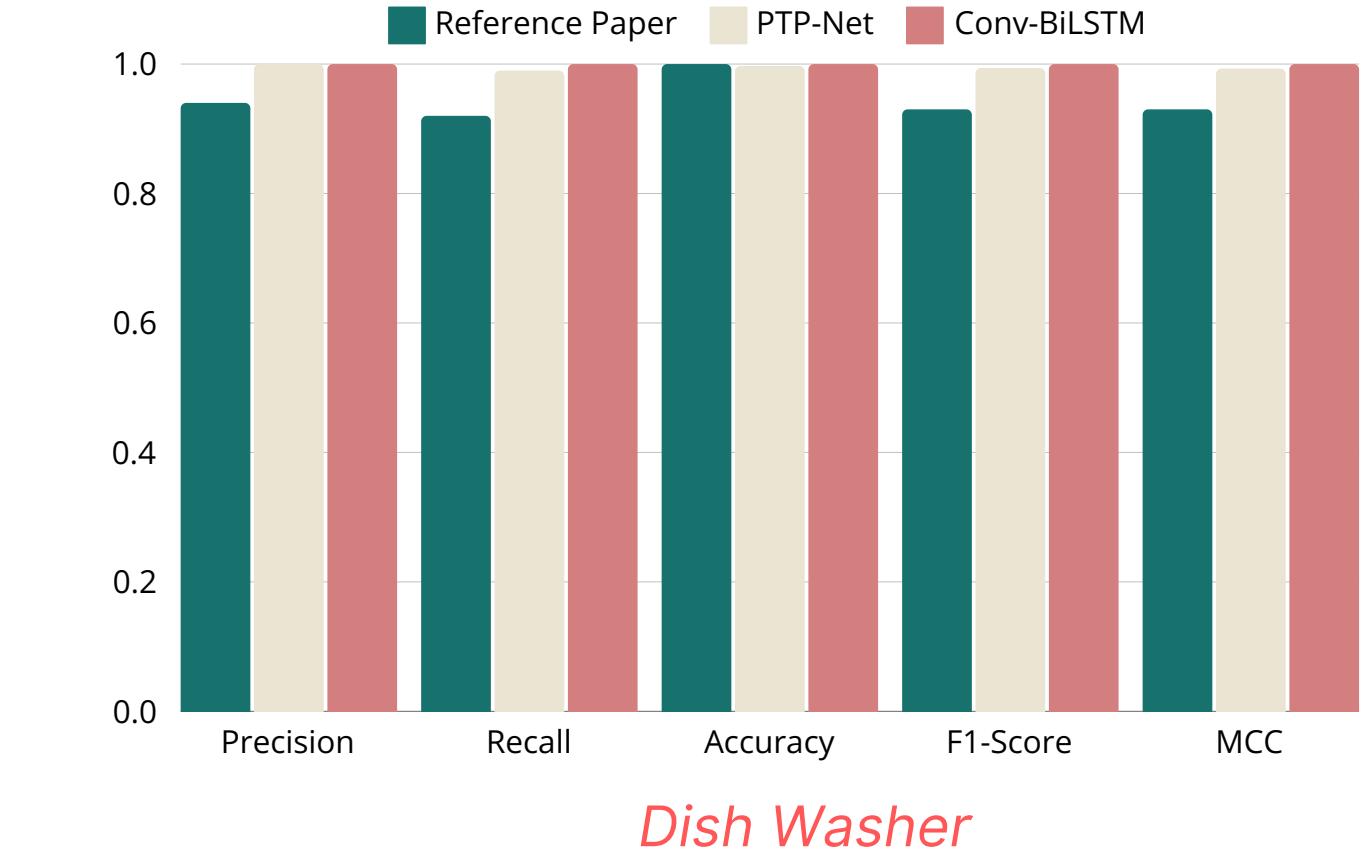
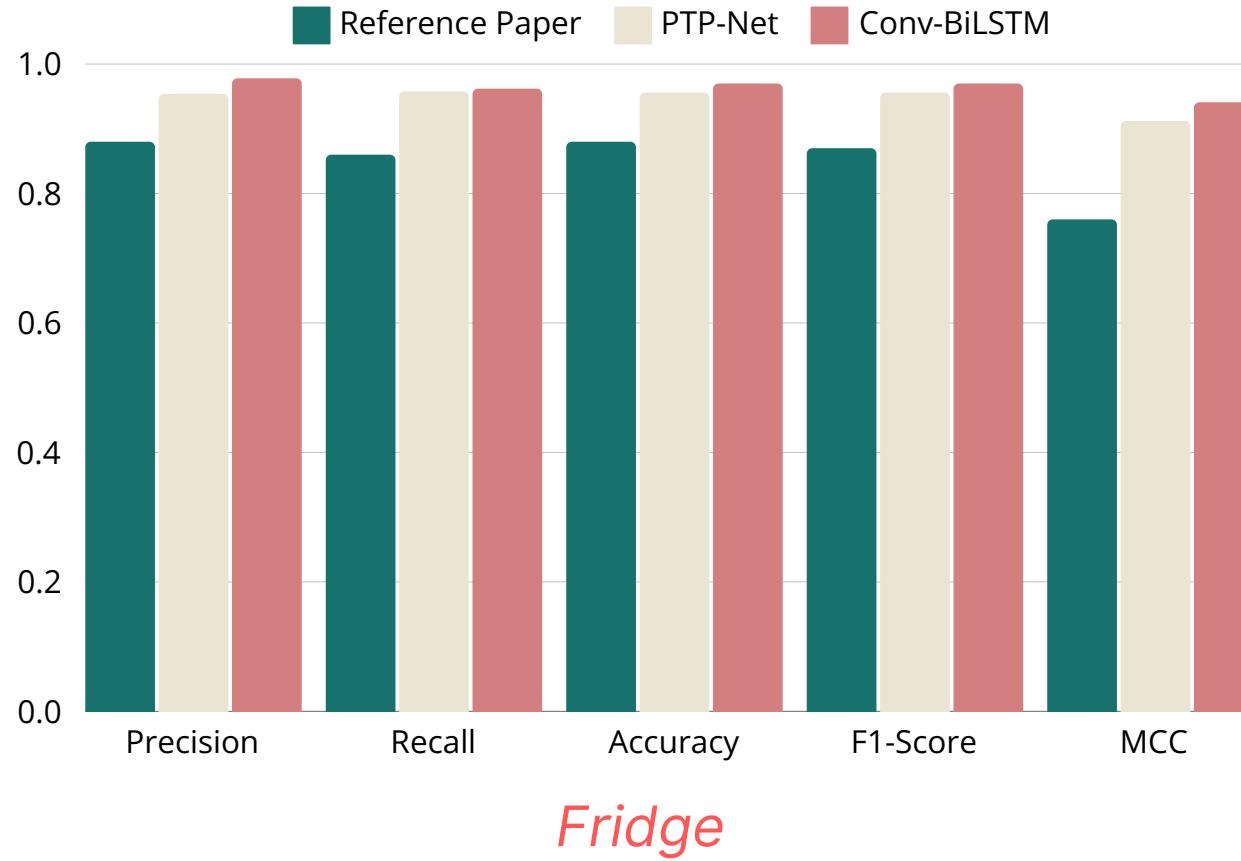
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# **RESULTS AND COMPARATIVE ANALYSIS**

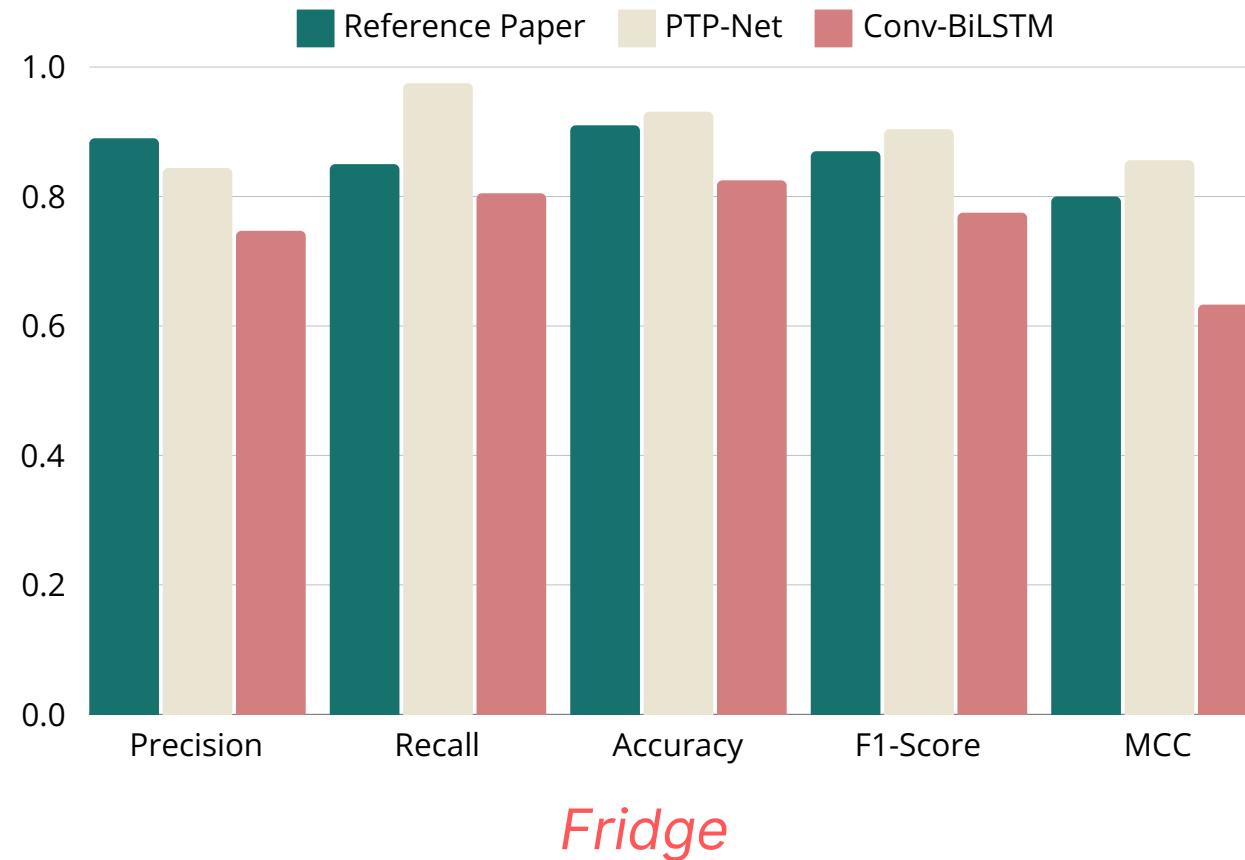
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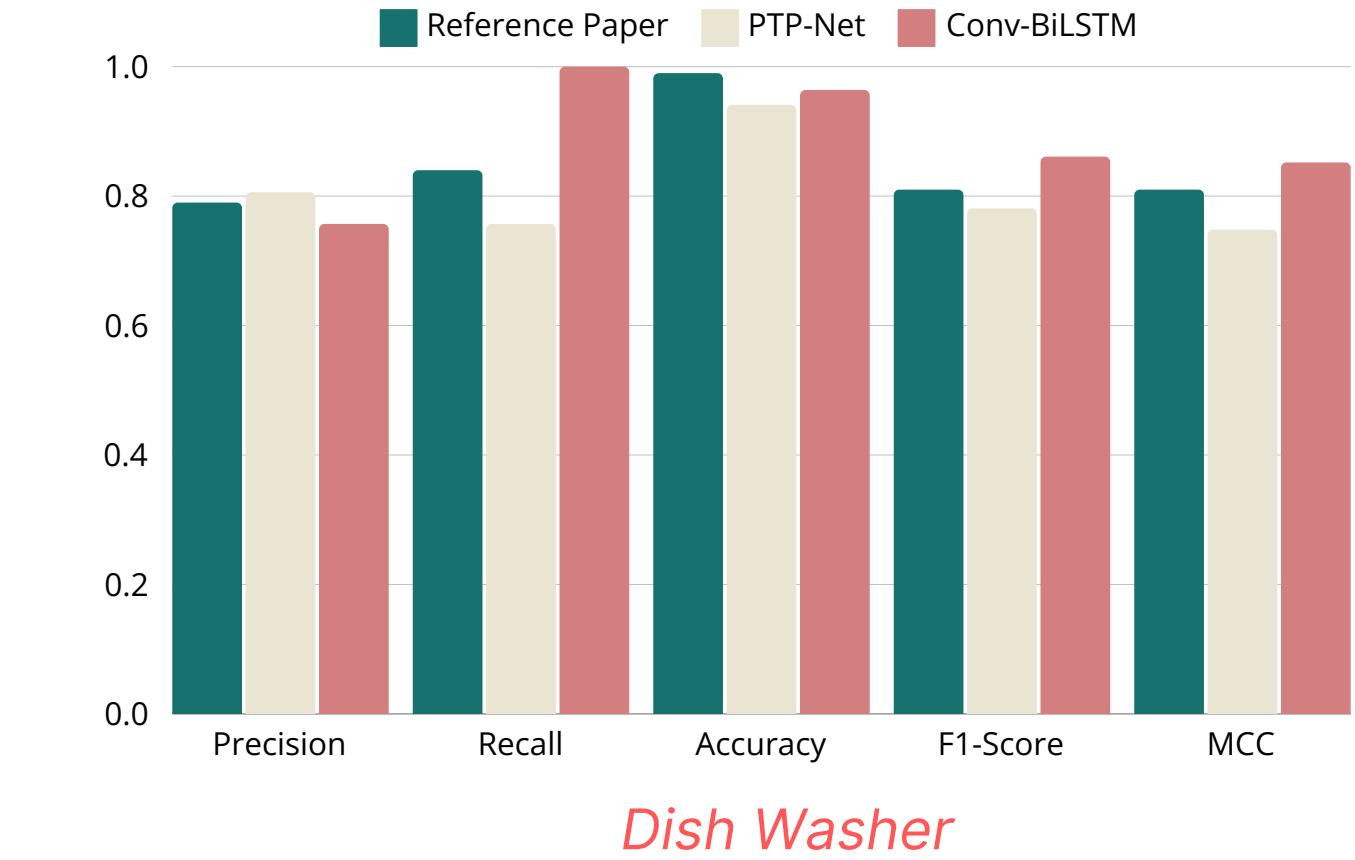
# Comparative Analysis of Appliance Status Prediction Models - SEEN CASE



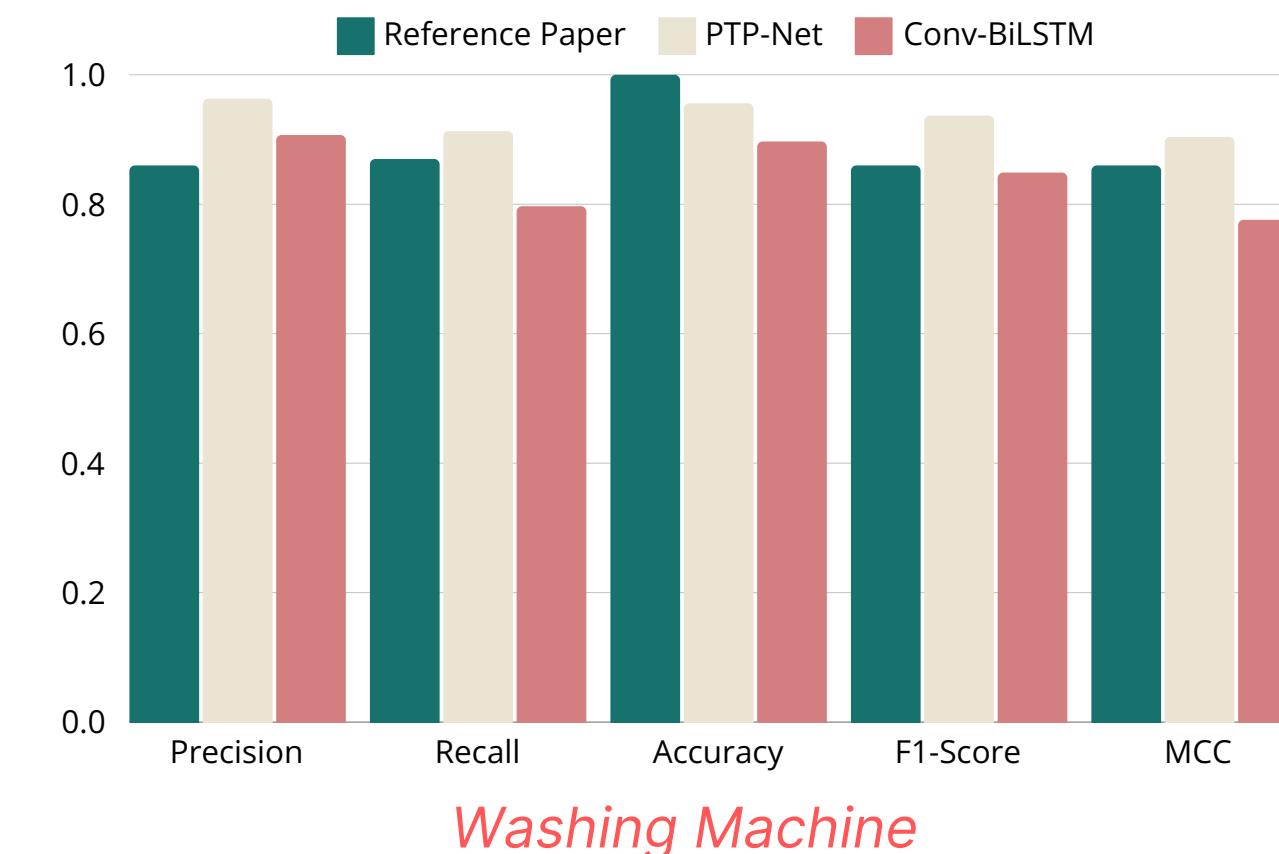
# Comparative Analysis of Appliance Status Prediction Models - UNSEEN CASE



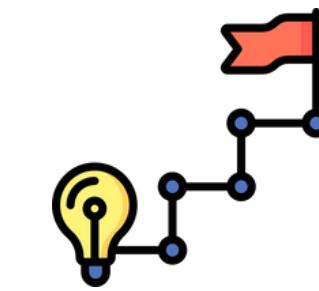
*Fridge*



*Dish Washer*



*Washing Machine*





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# CHALLENGES AND FUTURE WORKS

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# CONCLUSION

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# THANK YOU

FOR YOUR NICE ATTENTION



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