Real-time Machine Monitoring using Edge Analytics to Determine Operation and Condition Prediction

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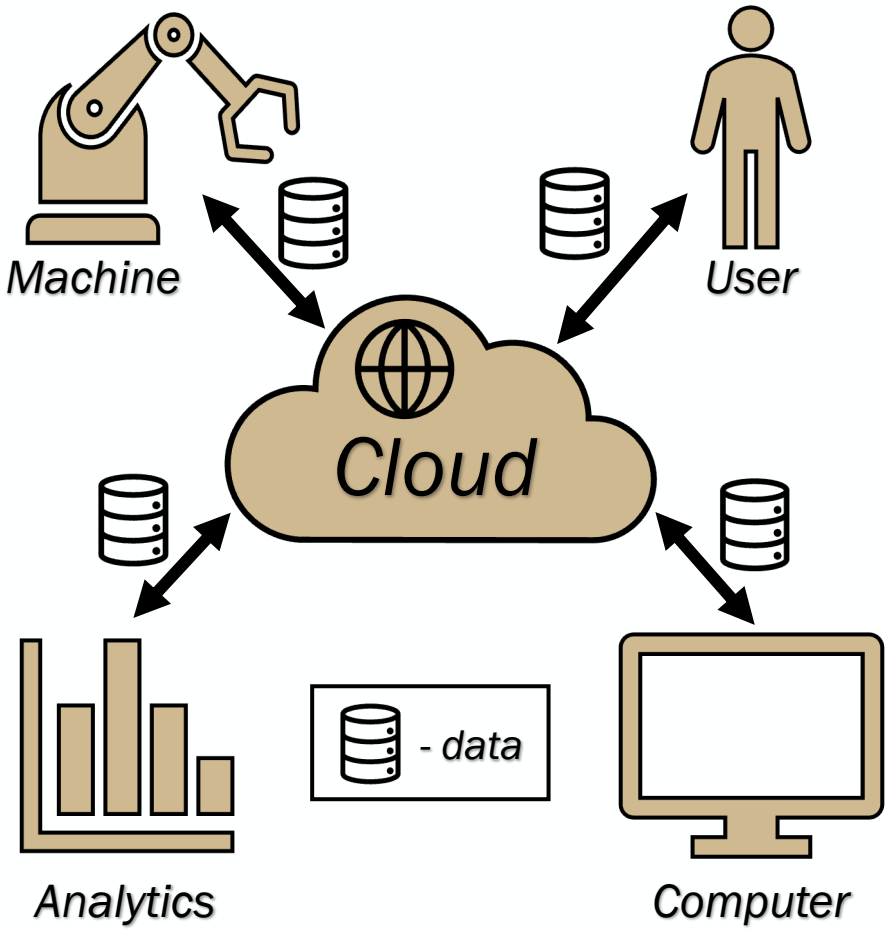
Industrial Internet of Things



Internet of Things (IoT): an ecosystem of devices/machines that can transfer and exchange data by means of internet

- Allows ***remote monitoring*** of machines

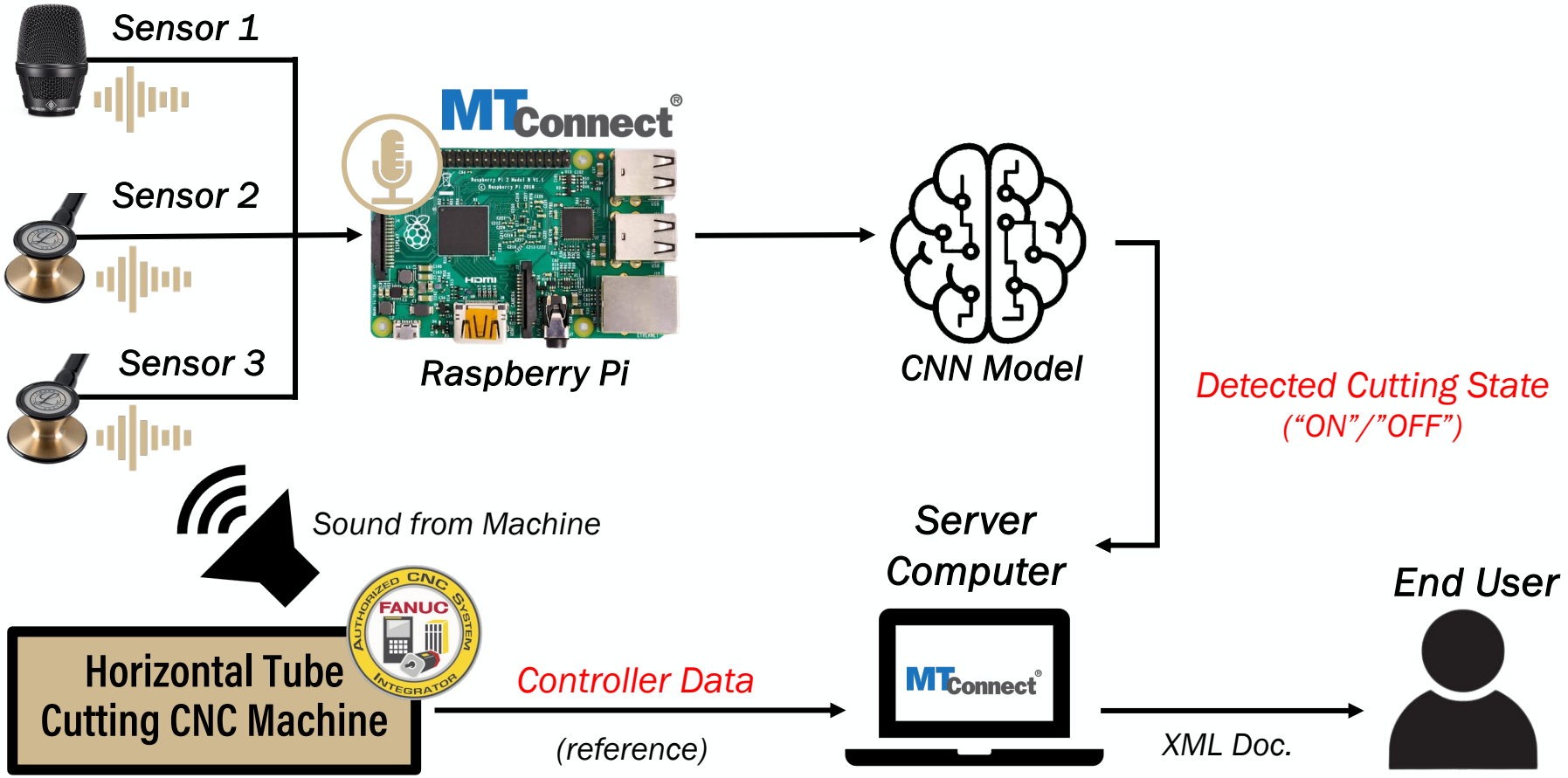
Conventional IoT downfalls

- Bandwidth
- Latency
- Economics
- Privacy
- Reliability

Edge Computing: reduces the proximity of computing to be closer to the target machine/device (where data is generated)

Prior Work

*Evaluated use of **real-time smart machine monitoring** by means of **sound recognition***



Data Pipeline

- Data Collection
- Database & Visualization
- Machine Learning

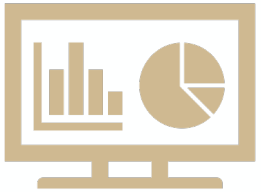
Objectives

Can we implement real-time machine monitoring using current data?

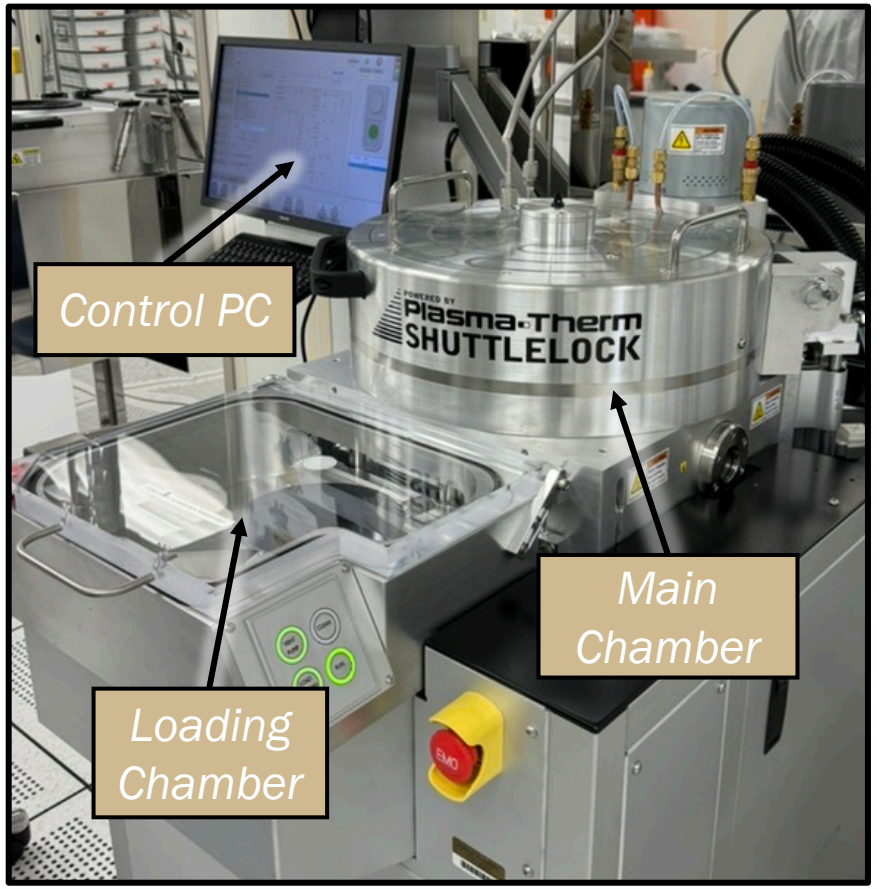
- Collect ***electrical current consumption data in non-invasive method*** from Birck Nanotechnology Center (BNC) plasma etching machine

- Analyze current data to ***determine significant trends*** indicative of machine operation/condition

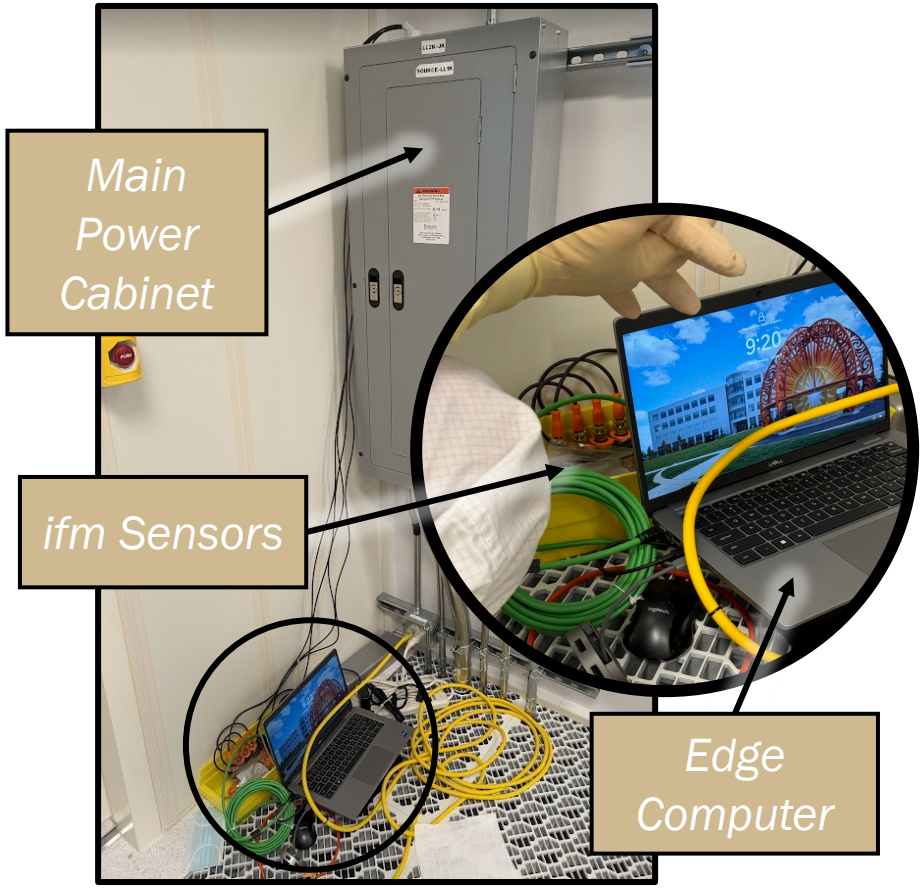
- ***Implement web dashboard and edge computing methods*** for real-time machine monitoring



Data Collection



PlasmaTherm Apex Machine



Circuit Breaker

Data Pipeline

Data Collection

↓

Database & Visualization

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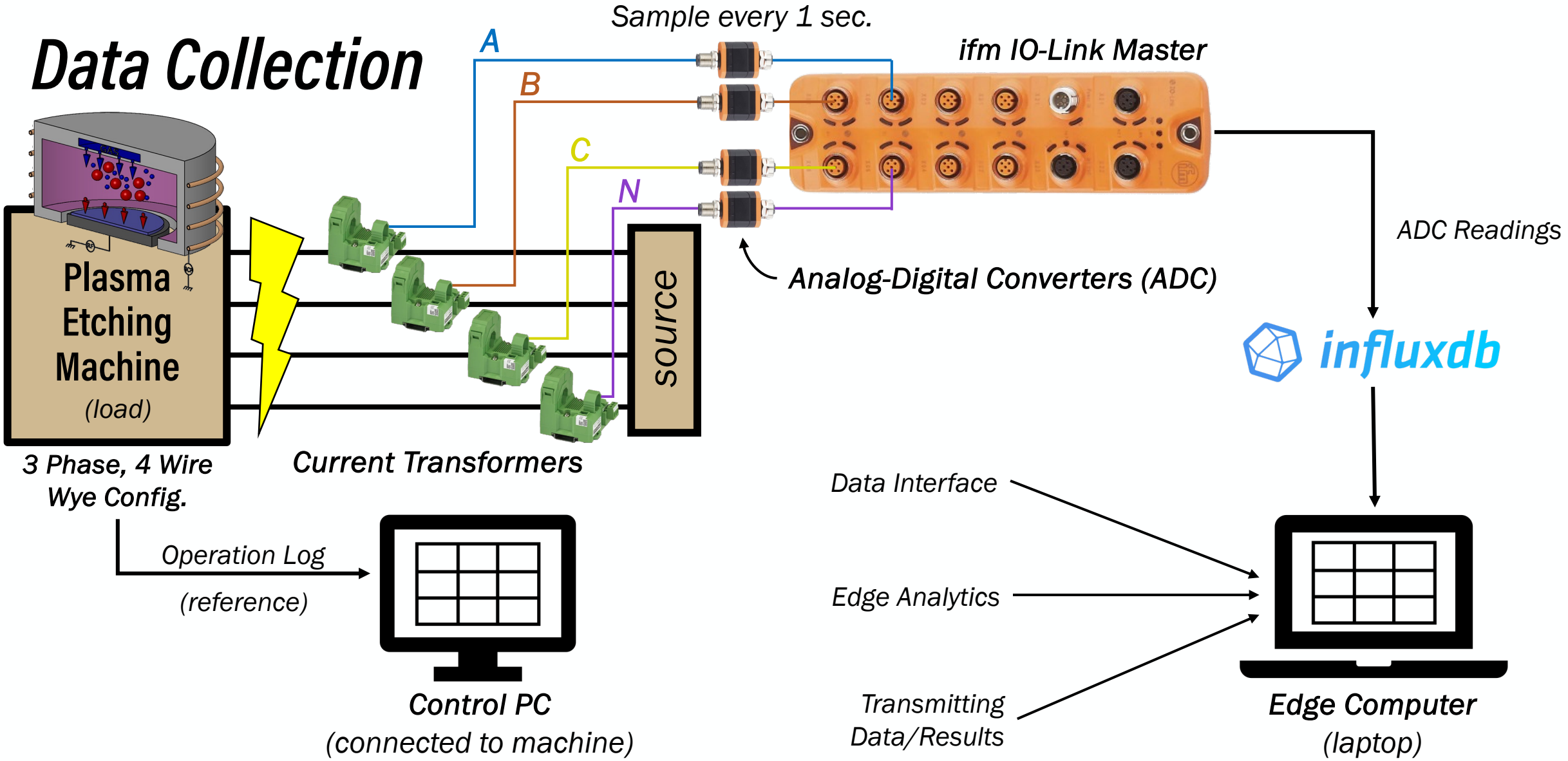
Machine Learning

Data Collection



Database & Visualization

Python – *Raw Current Data*
- Cleaning, formatting, and merging current data information
- Converting ADC readings to actual current values
- ***Calculating total power consumption over time based on current data***

Microsoft Excel – *Operation Status Log*
- Manually converting photos of operation status log into CSV file
- Adjusting timestamps
- Conducting statistics of recipe and status occurrences and elapsed time

MATLAB – *Visualization*
- Visualizing each phase of raw current data
- Visualizing total power consumption

Data Pipeline

Data Collection

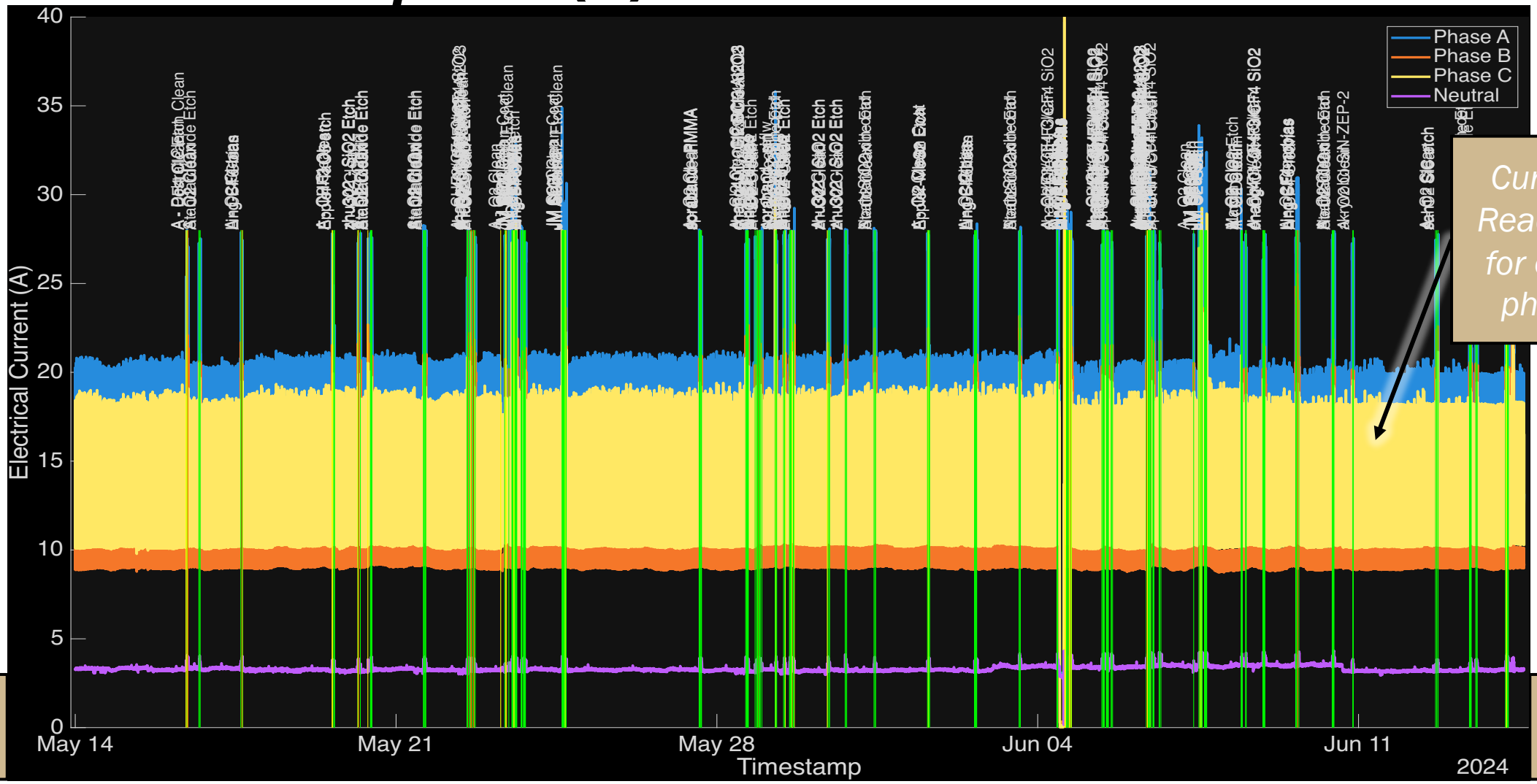
↓

Database & Visualization

↓

Machine Learning

Current Consumption (A)

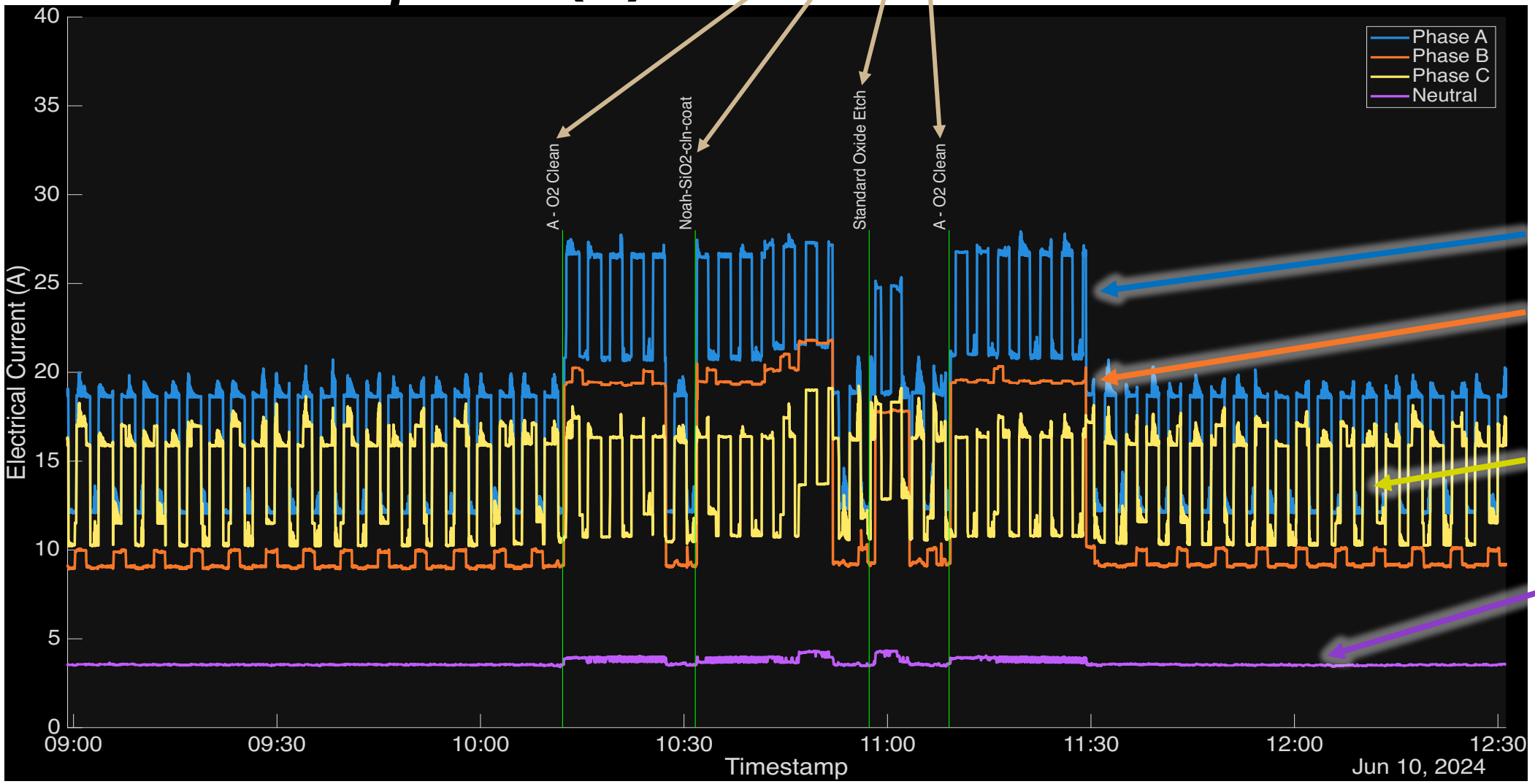


START: May 14

END: June 16

Current Consumption (A)

Status Log Operation Data



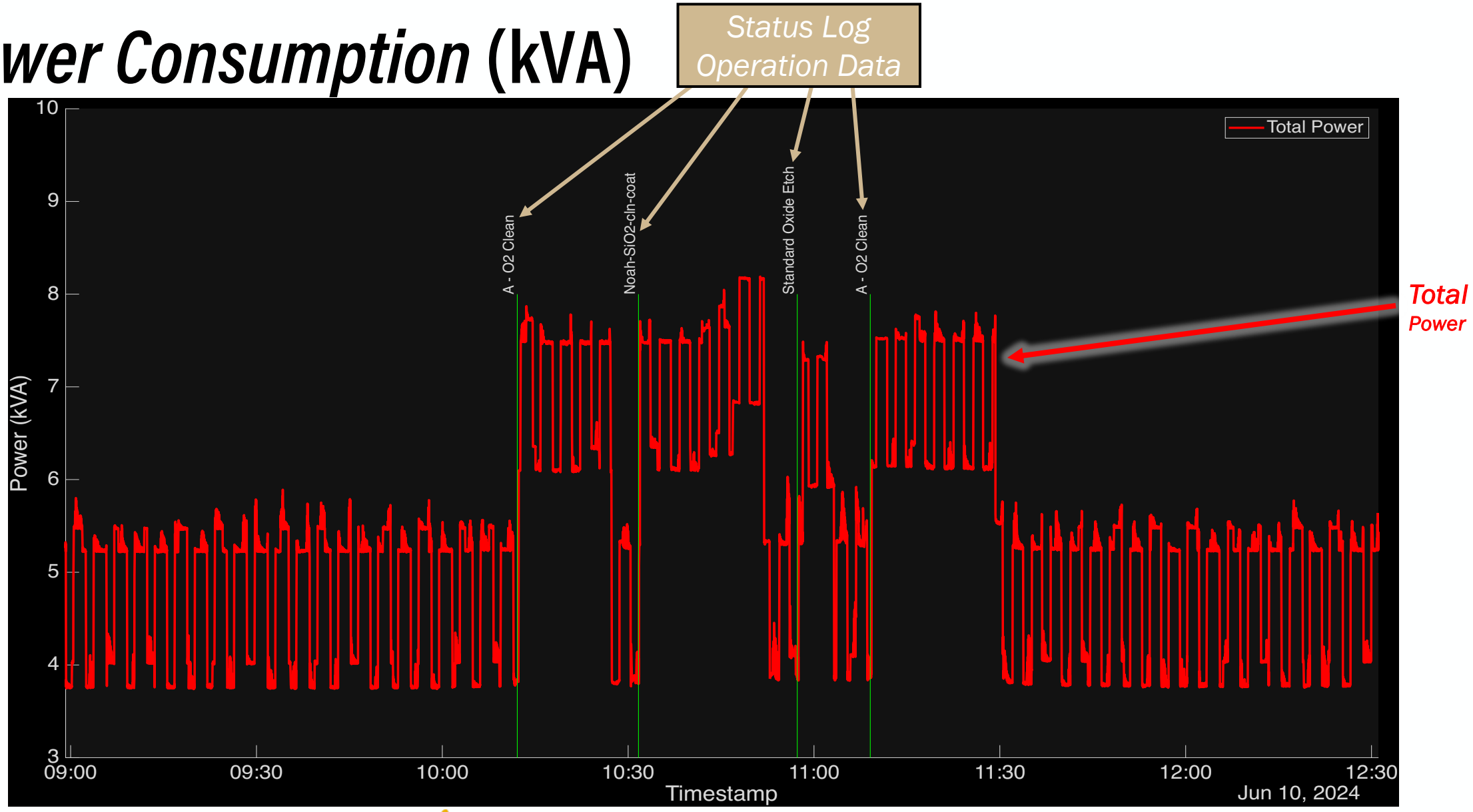
Phase A Current

Phase B Current

Phase C Current

Neutral Current

Power Consumption (kVA)



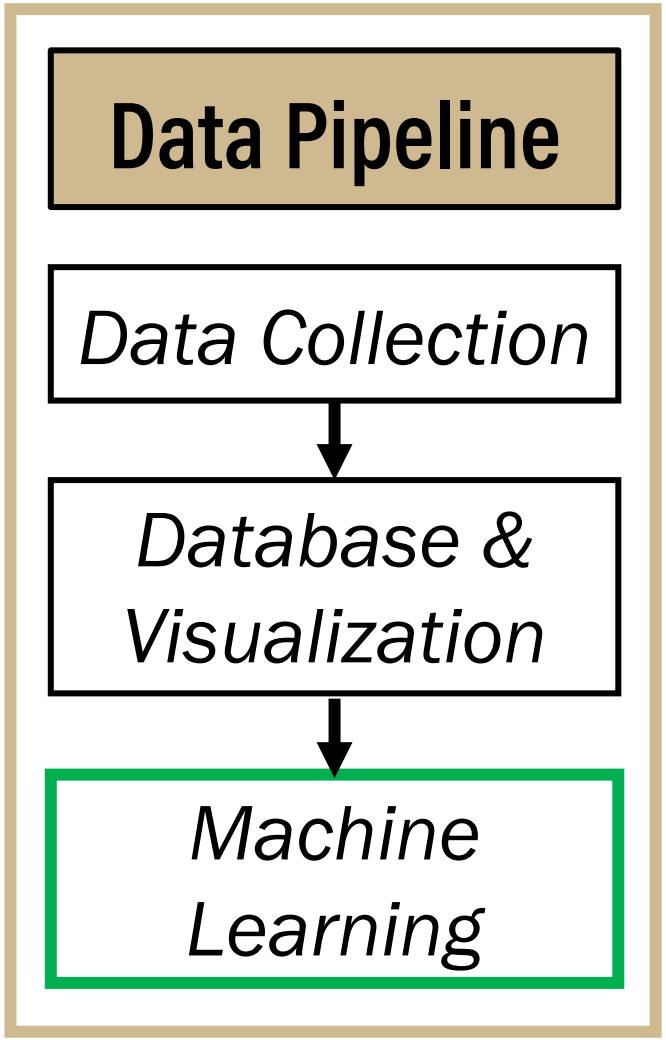
Machine Learning Pipeline

3-Step Fingerprinting Algorithm

Operation State
(Rule-based on power consumption threshold)

Time-Series Feature Analysis
(Statistically determining features of recipe data)

Anomaly Detection
(Machine Learning based on unsupervised clustering)



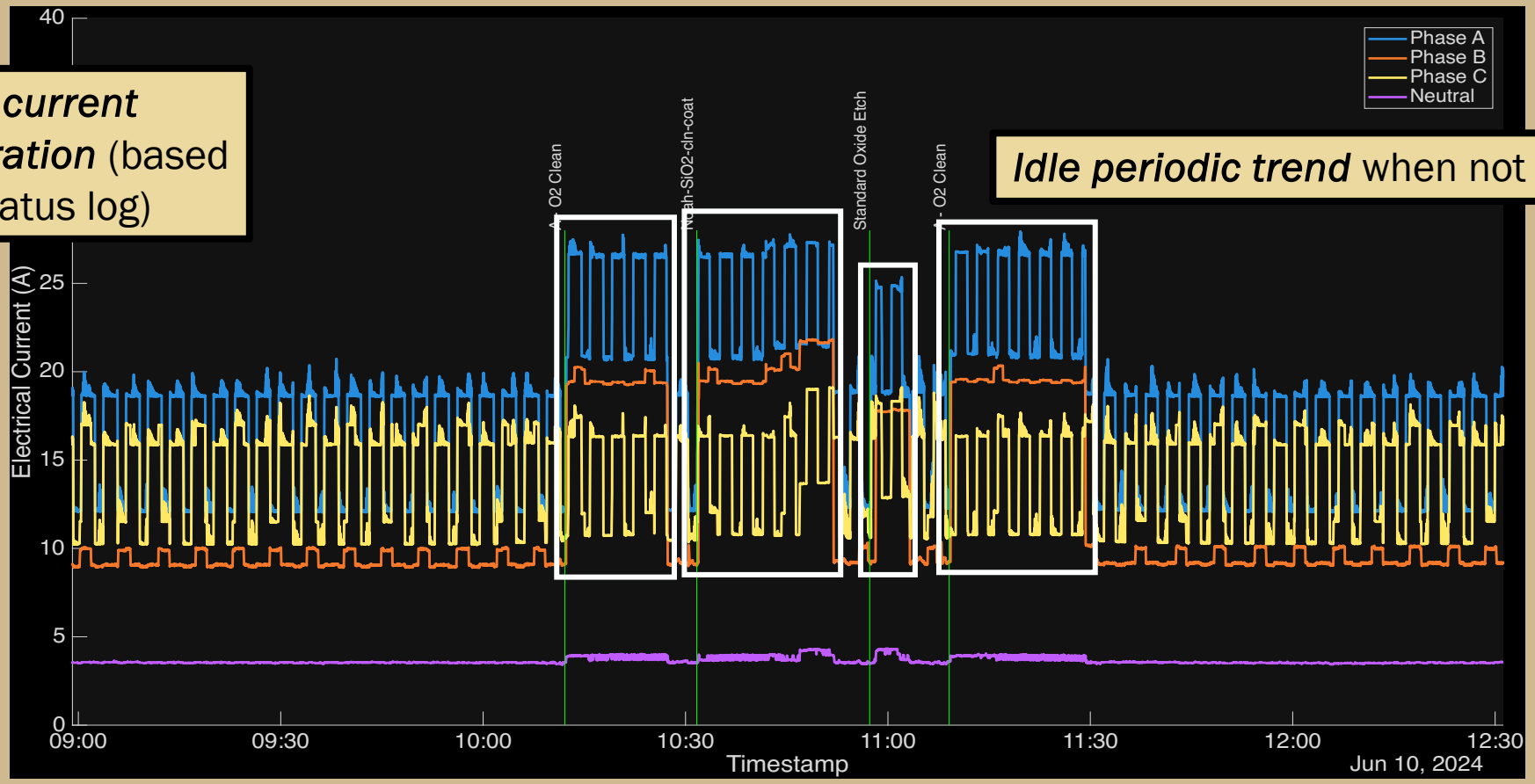
Operation State Detection

Rule-based on power consumption threshold

Based on ***magnitude increase/decrease*** of ***Phase B***

Noticeable ***spikes in current consumption during operation*** (based on start times from status log)

Idle periodic trend when not operating



Magnitude Change

Phase A – ***major change***

Phase B – ***major change***

Phase C – minor change

Neutral – minor change

Periodicity

Phase A – periodic

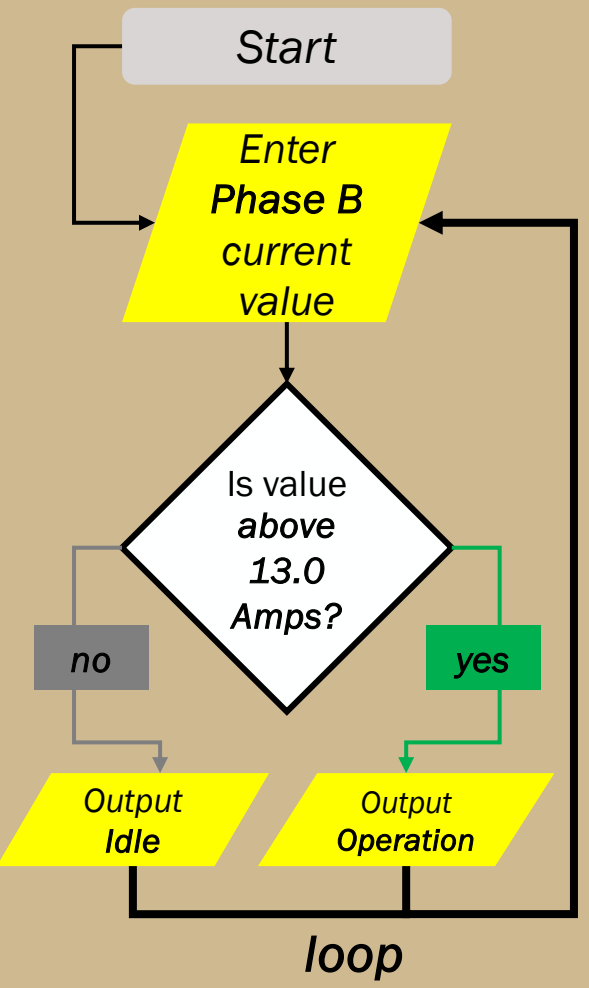
Phase B – ***not periodic***

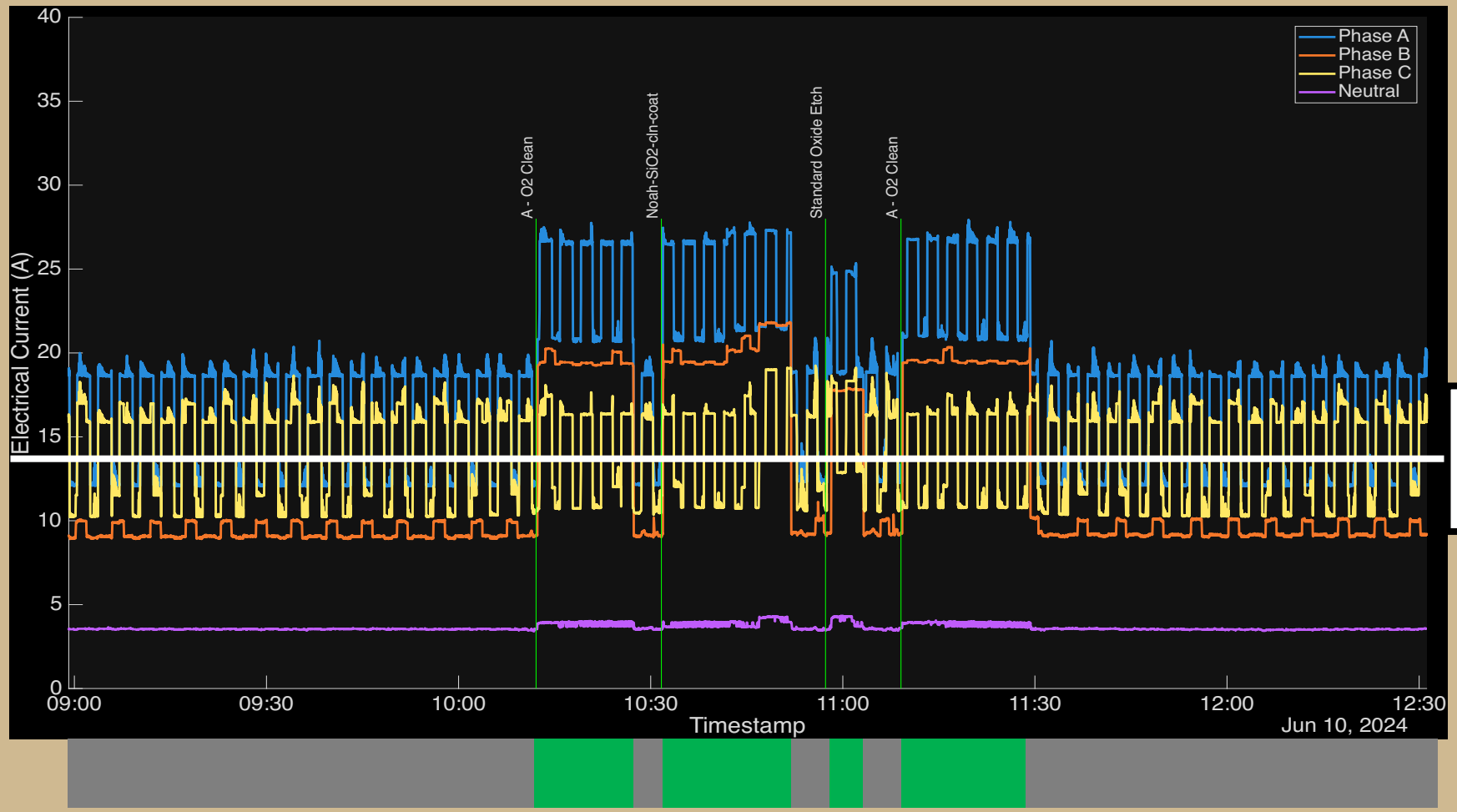
Phase C – periodic

Neutral – ***not periodic***

Operation State Detection

Rule-based on power consumption threshold





Indicates operation

Operation Threshold *(13 Amps)*

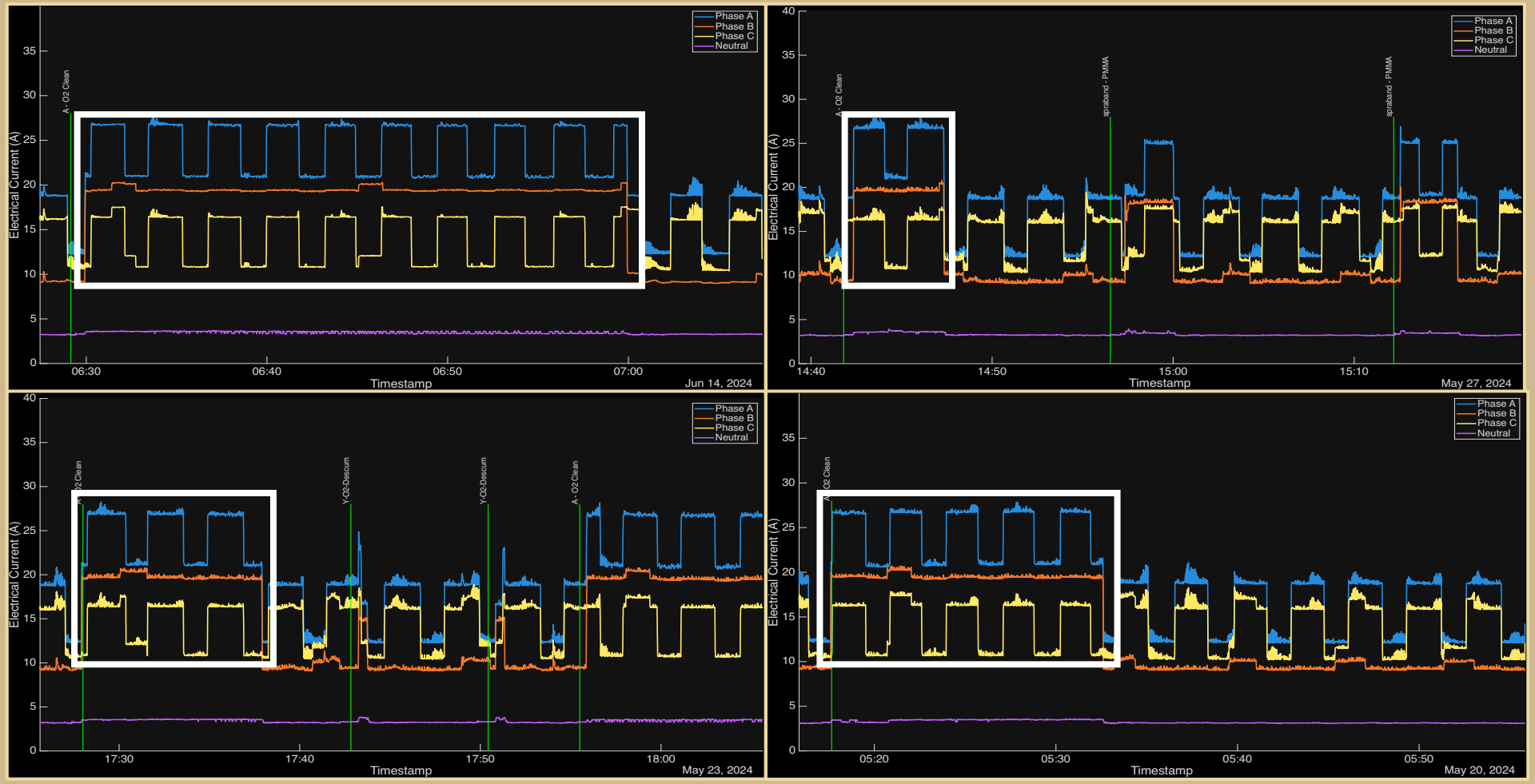
No operation

Time-Series Feature Analysis

Statistically determining features of recipe data

All "*O2 Clean*" Recipe Occurrences

- ***Principal Component Analysis***
  (recipe features)
- *Mean*
- *Root Mean Square*
- *Standard Deviation*
- *Maximum*
- *Minimum*
- *Skewness*
- *Kurtosis*

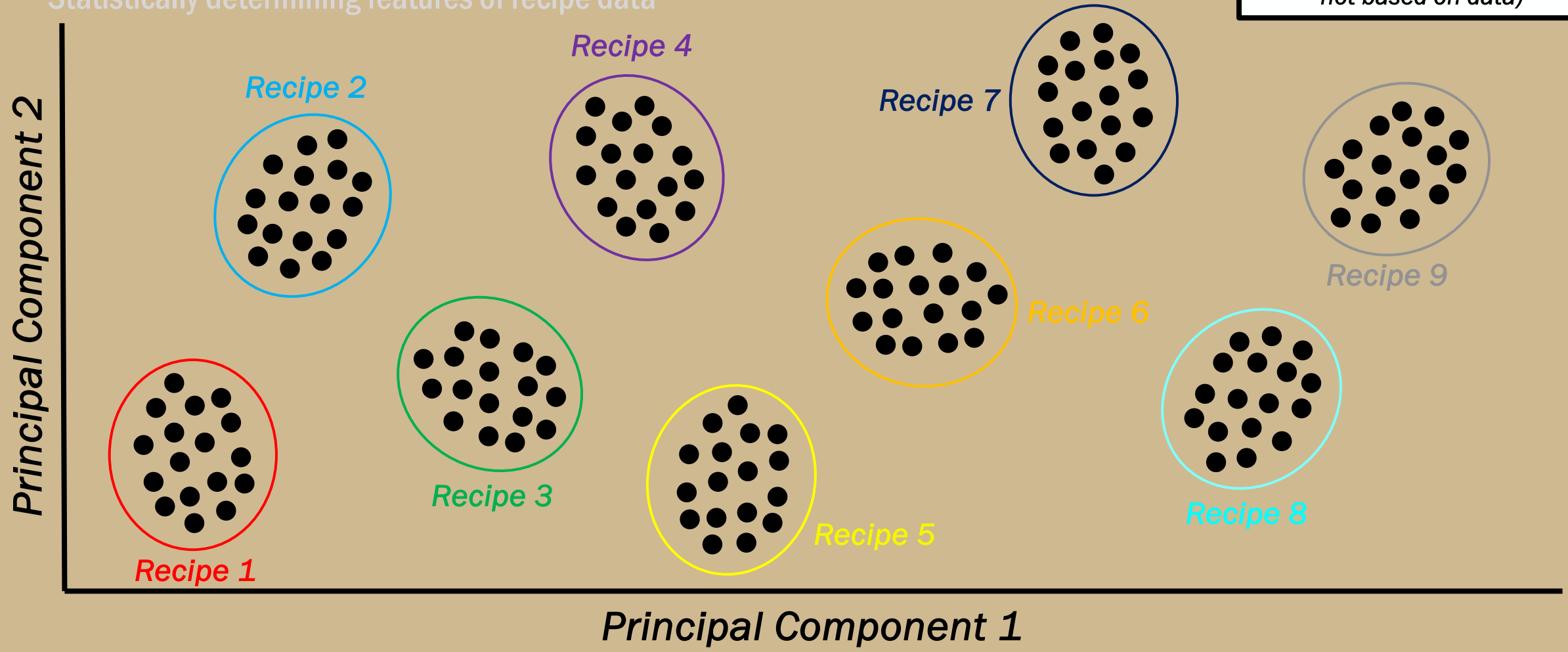


Time-Series Feature Analysis

Statistically determining features of recipe data

Unsupervised Data Clustering

(visualization purposes only, not based on data)

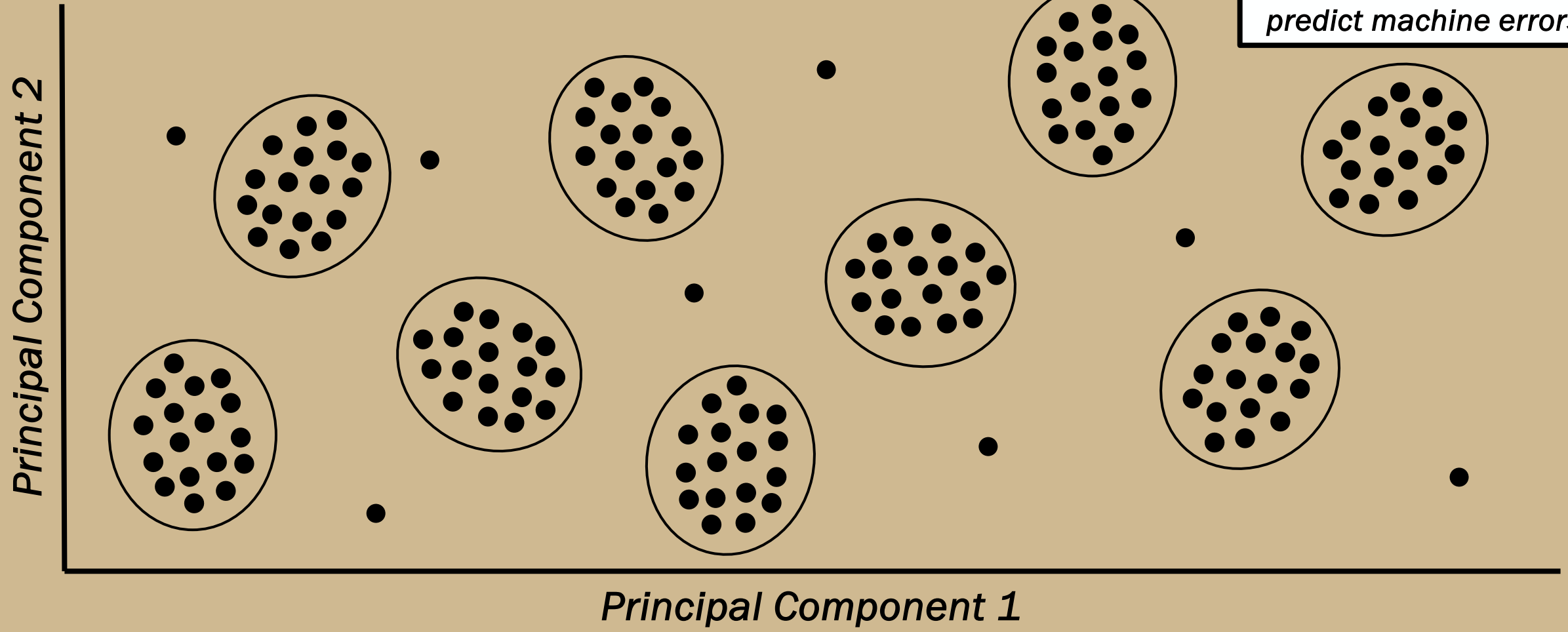


Anomaly Detection

Machine Learning based on unsupervised clustering

Anomalies detectable by identifying outlier data

Anomaly detection can ***predict machine errors***



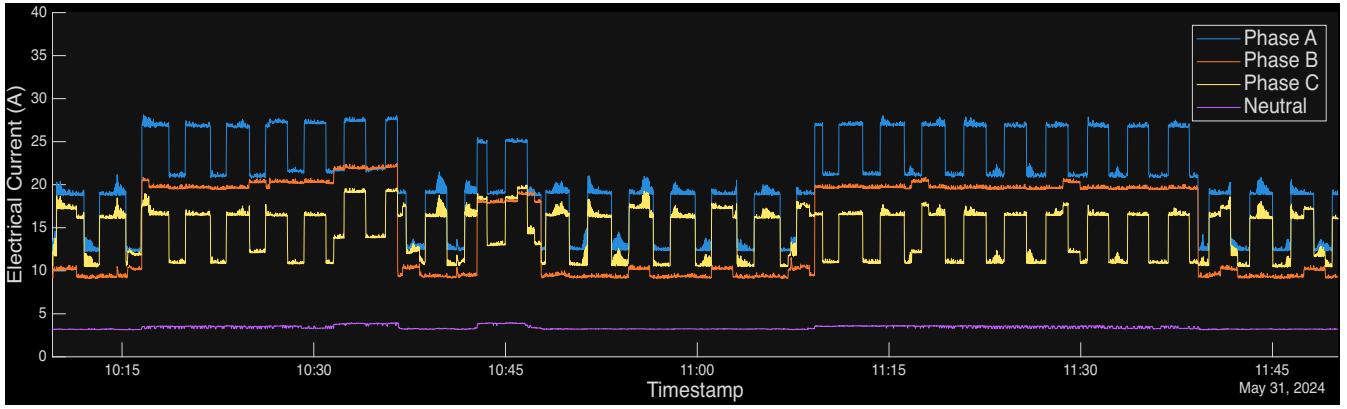
Future Web Dashboard

For visualization purposes only, tentative to change

Live Power Consumption Data

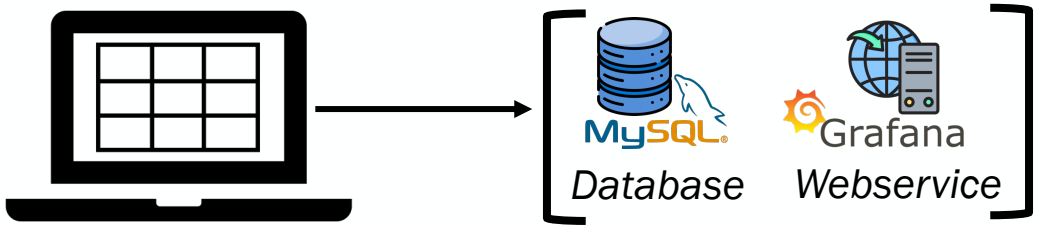
Total Power Consumption: 9.47 kVA

Live Current Consumption Visualization



Operation State

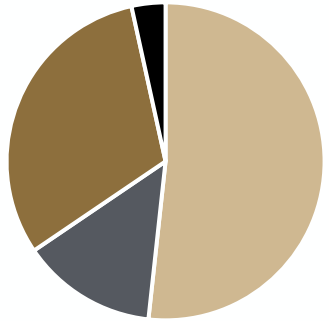
*Provides **real-time insight of machine analytics** to operators*



Edge Computer

Purdue SENSE Server

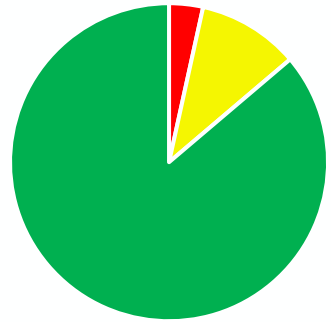
Recipe Occurrences



Recipe1 Recipe2 Recipe3 Recipe4

Per-recipe number of occurrences

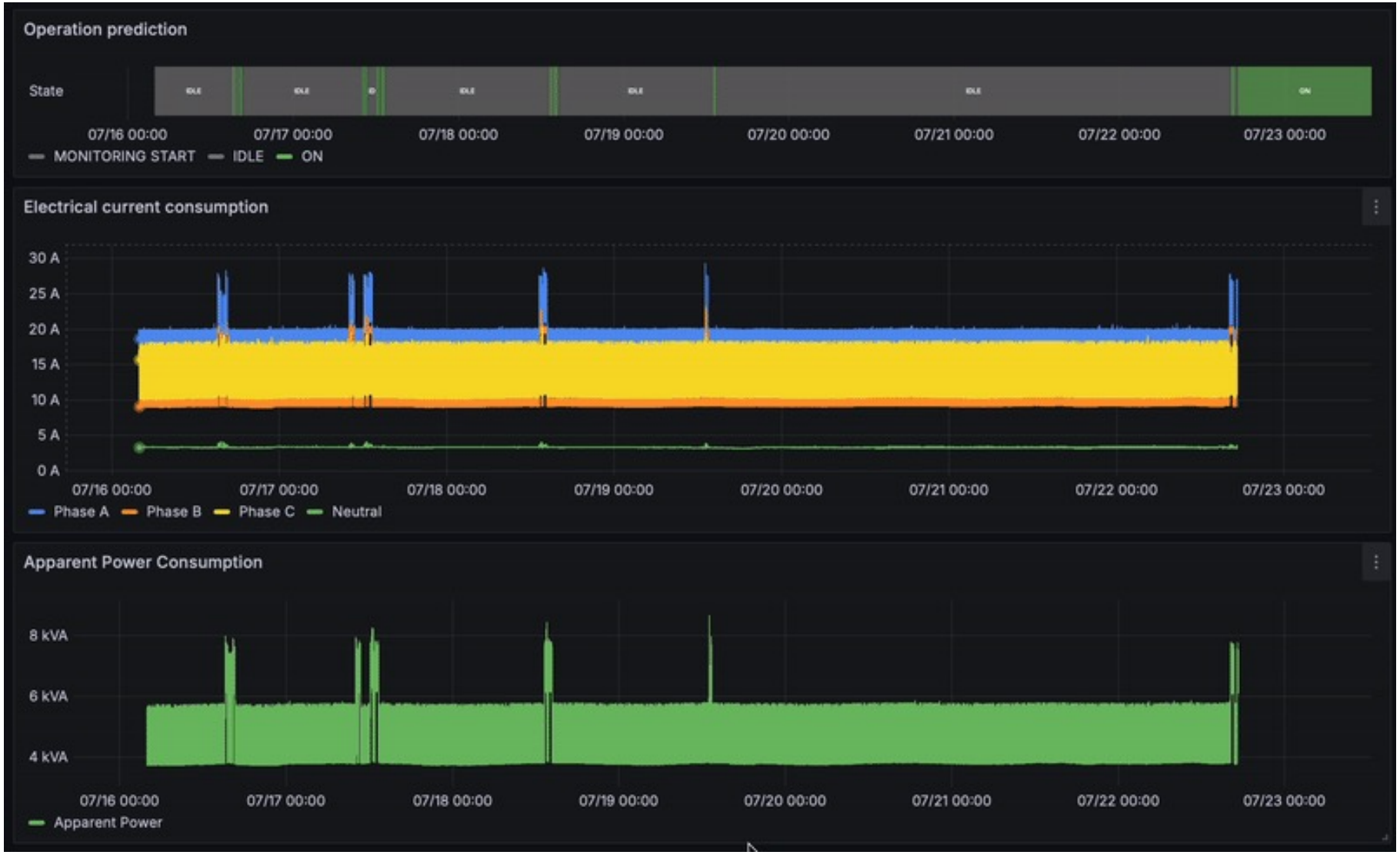
Anomaly Rate



Red Yellow Green

Overall status tracking

Zooming of Live Web Dashboard (Grafana) – July 22, 2024



Conclusions

Machine operation and condition information can be ***monitored from analytics on non-invasively collected current consumption data.***

IIoT and AI, combined with edge analytics, can be used for ***effective real-time remote machine monitoring***.

Electrical current fingerprinting for manufacturing equipment plays an important role in ***predicting operation conditions and detecting anomalies***.

Thank You!

> ***Drs. Ali Shakouri** and **Eunseob Kim** -* allowing me to engage in this enlightening research experience and supporting me through this pursuit of knowledge.

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