

Developments in Online Condition Monitoring of Substation Equipment and the Digital Substation

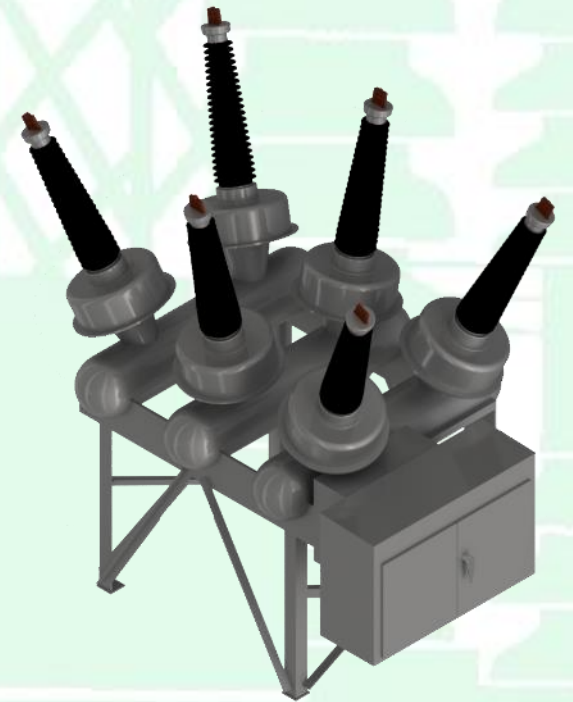
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Introduction / Background

Conventional Perspectives - Role of Online Monitoring

- Improve Reliability / Manage Risk
 - Provide early warning for developing faults
 - Extend Life
- Optimize Availability
 - Implement **Condition Based Maintenance** in place of **Time Based Maintenance**

Introduction / Background

Impact from Digitalization & Decarbonization

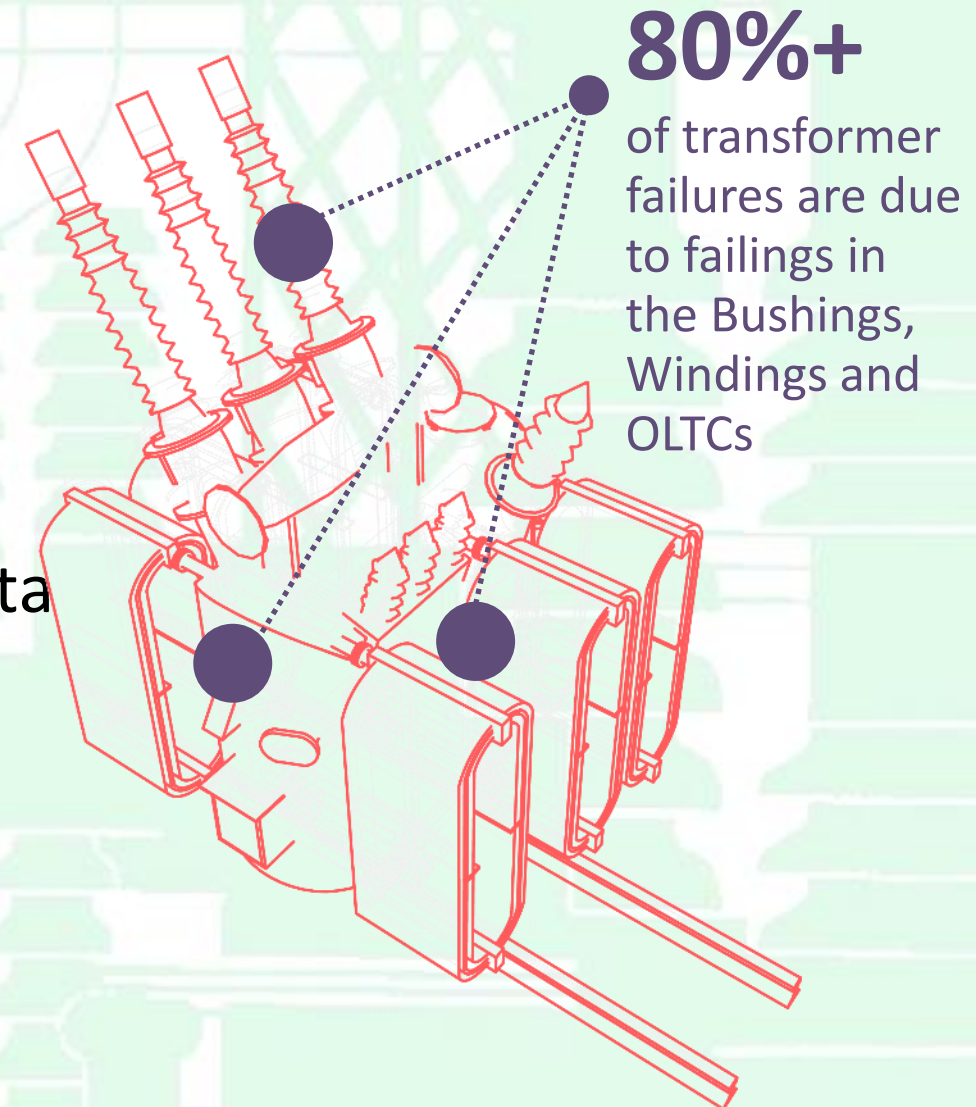
- Larger Role for Asset Online Monitoring in Power Systems
 - Pressures to maximize use of renewables
 - Augment conventional load profiles
 - Periodic overloading
 - Minimize Equipment Downtime
 - **Necessitate improved capabilities for Early Fault Detection**
 - **Predictive Maintenance from Advanced Analytics**

Overview

1. Introduction / Background
2. Holistic Transformer Monitoring / Correlation Analysis – Developments in Transformer Online Monitoring
3. Digital Twins and Analytical Models from Transformer Monitoring
4. Online Monitoring Data Integration for Health Indices & Asset Management
5. Artificial Intelligence & Machine Learning – Transformer and Circuit Breaker Online Monitoring
6. Conclusion

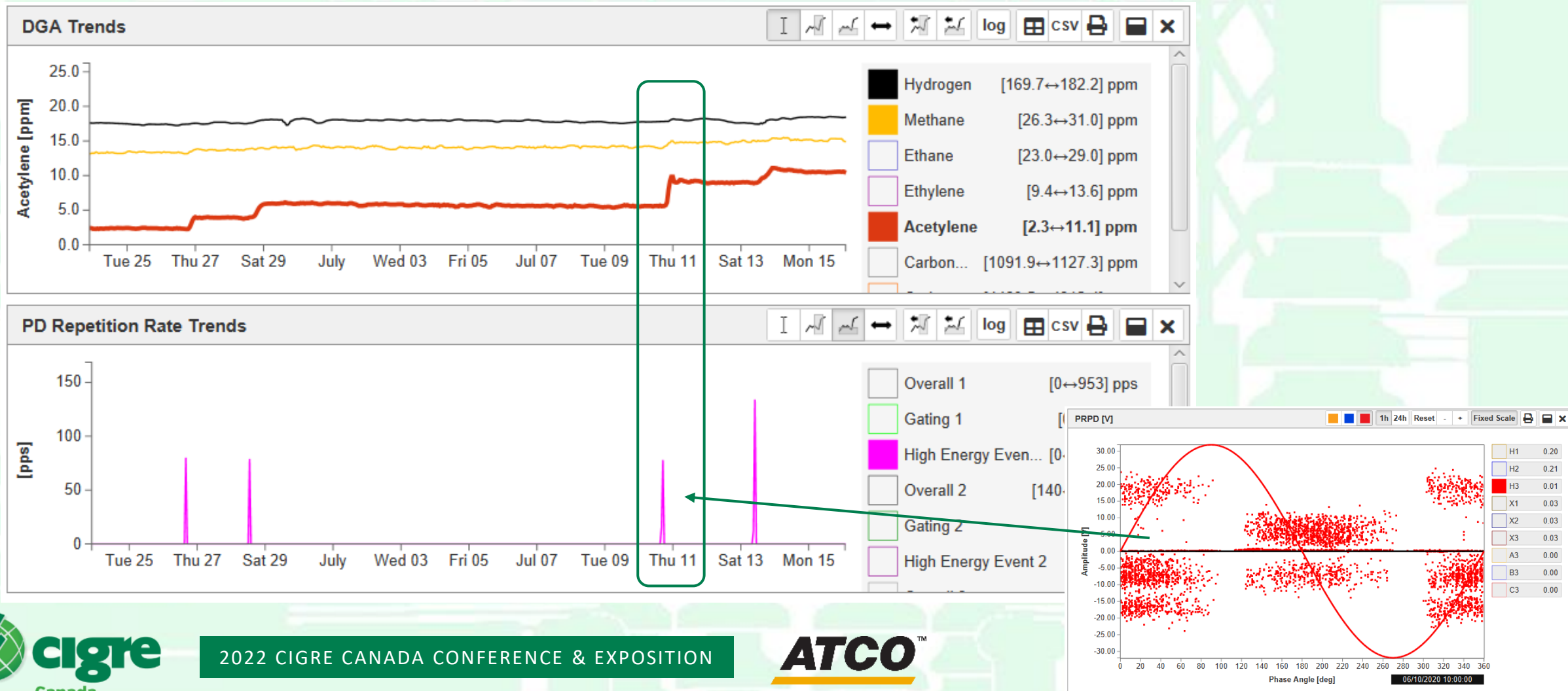
Holistic Transformer Online Monitoring

- According to Cigré 642 – 80% of Transformer failures are attributable to the following:
 - Components in Main Tank (Windings, Core, Leads): ~52%
 - Bushings: ~17%
 - LTC: ~27%
- Effective Online Monitoring should enable **Integration & Correlation** of monitoring data from components
 - DGA + Thermal monitoring of Main Tank & LTC
 - Bushing Monitoring (Capacitance & Tan. Delta)
 - Online Partial Discharge Monitoring



Holistic Transformer Online Monitoring

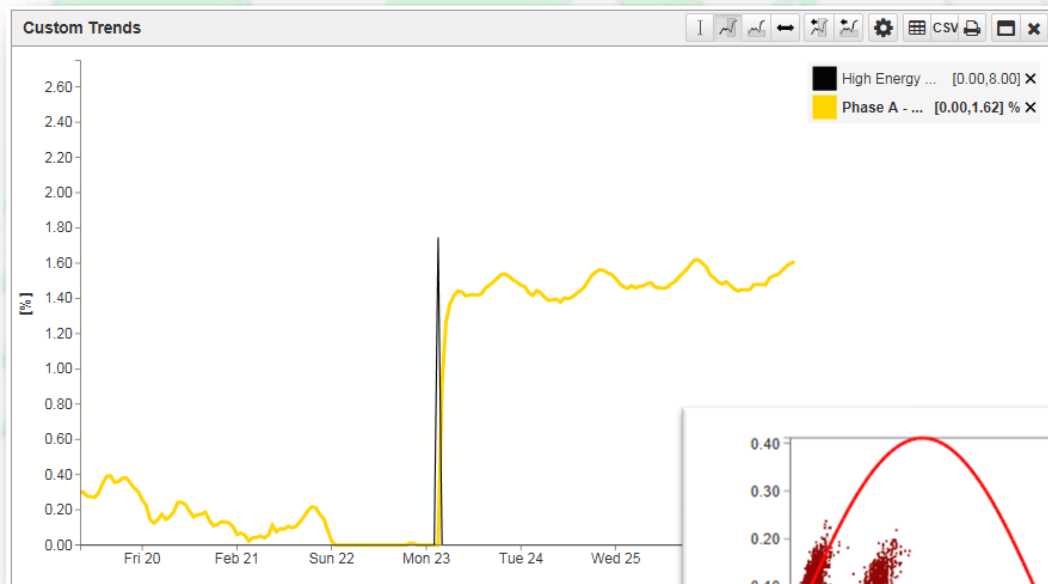
- Example: Correlation Analysis – Online DGA and Continuous PD Monitoring



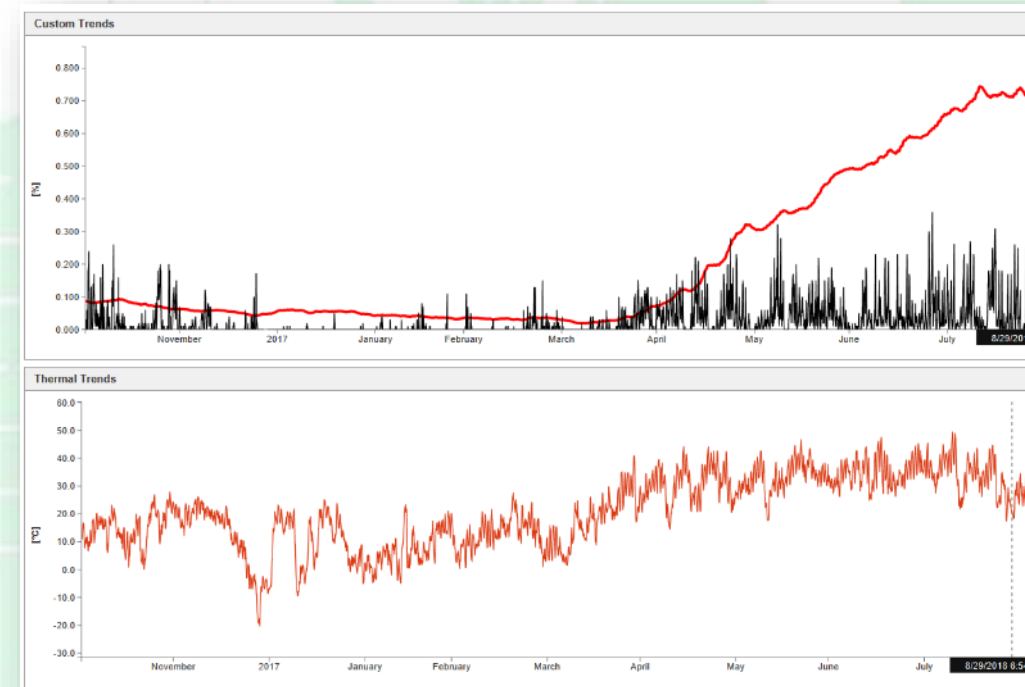
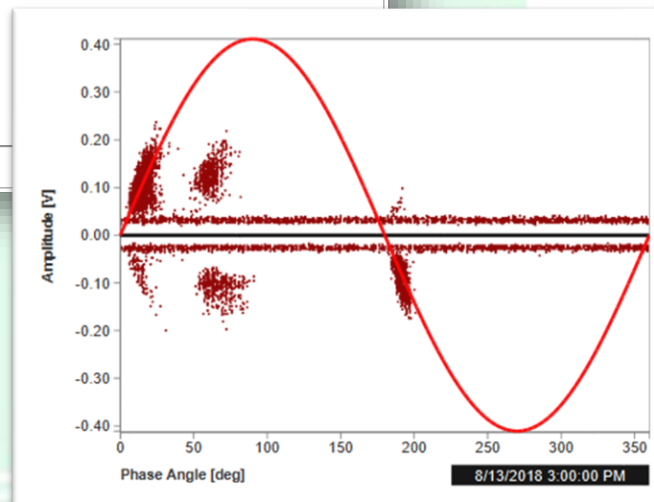


Holistic Transformer Online Monitoring

- Example: Correlation Analysis – Bushing Monitoring (Capacitance/DF) and Continuous PD Monitoring



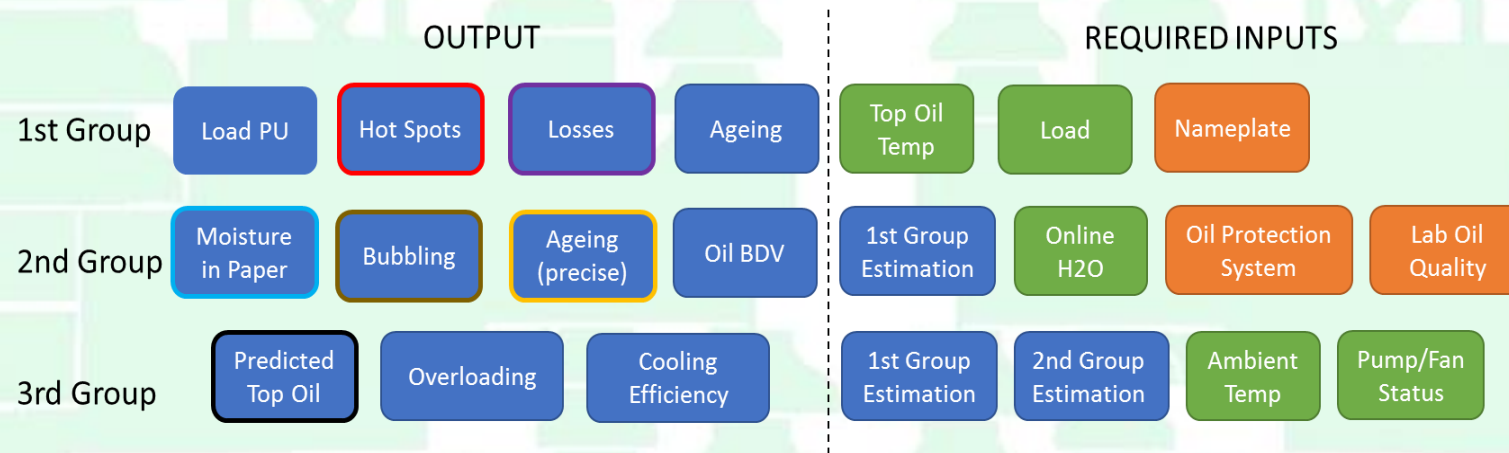
Arcing Events in Bushing
Correlated with Step Change in
Capacitance (Only ~1% Change)



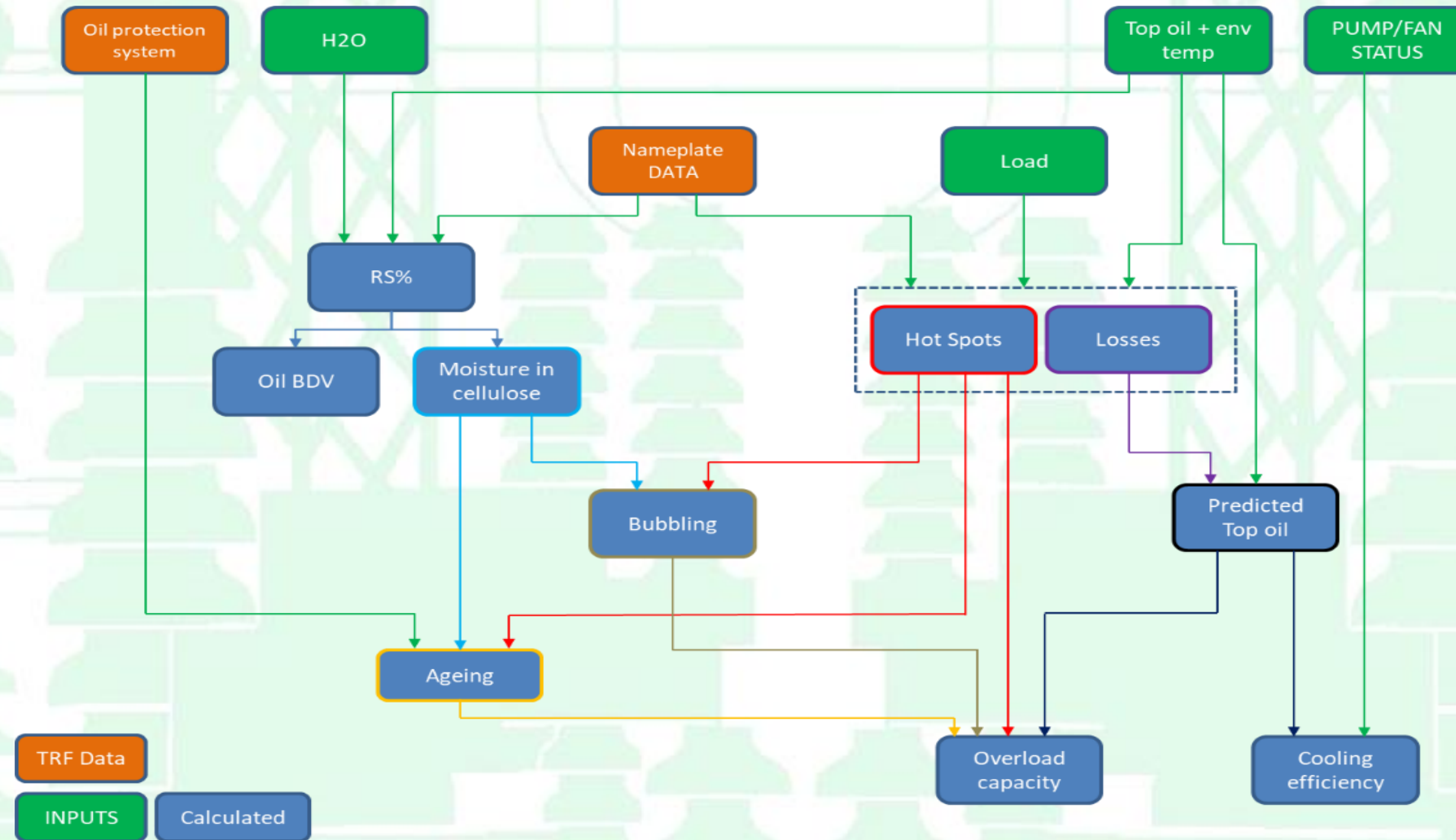
Relative changes in DF show insulation
losses due to contamination –
Correlation with Temperature and PD

Digital Twins and Analytical Models

- Transformer Monitoring parameters useful for Digital Twin and Analytical Models
 - Operational Flexibility** - Controlled Overloading (Dynamic Rating)
 - Diagnostic Benefits** - Oil Breakdown Voltage & Bubbling Temperature
 - Condition Assessment Information** - Estimate of Aging (Remaining Life)



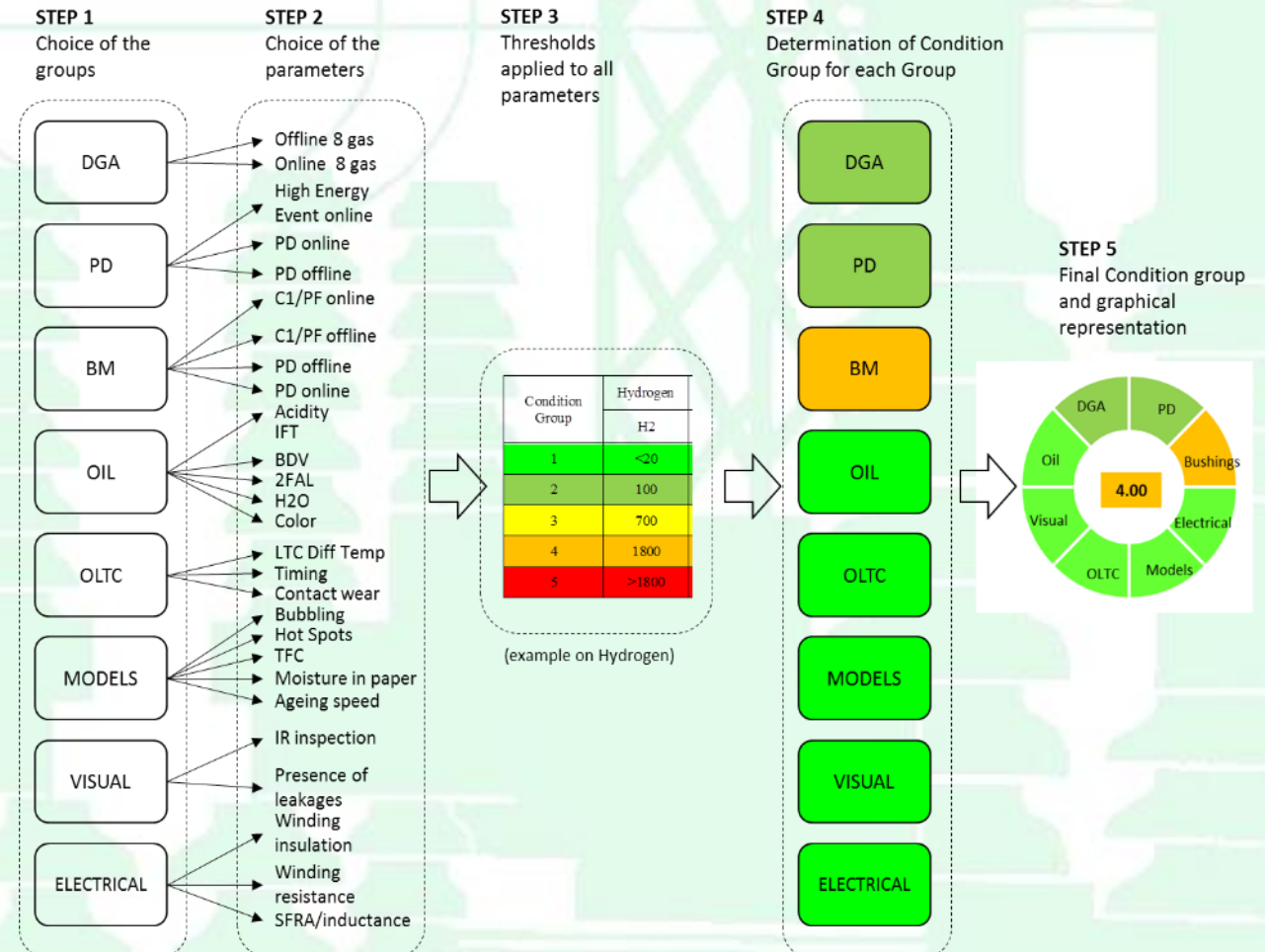
Digital Twins and Analytical Models



Integration of Online Monitoring Data for Health Indices

- Asset Condition Health scores/indices typically based on offline test data or inspections
- Integrating Offline Test Data with Online monitoring can enhance Condition Assessment capabilities:
 - DGA gassing Rate-of-Change
 - Online Partial Discharge
 - Faults which are temperature/load dependent
- Improved Asset Management and Maintenance Planning functions

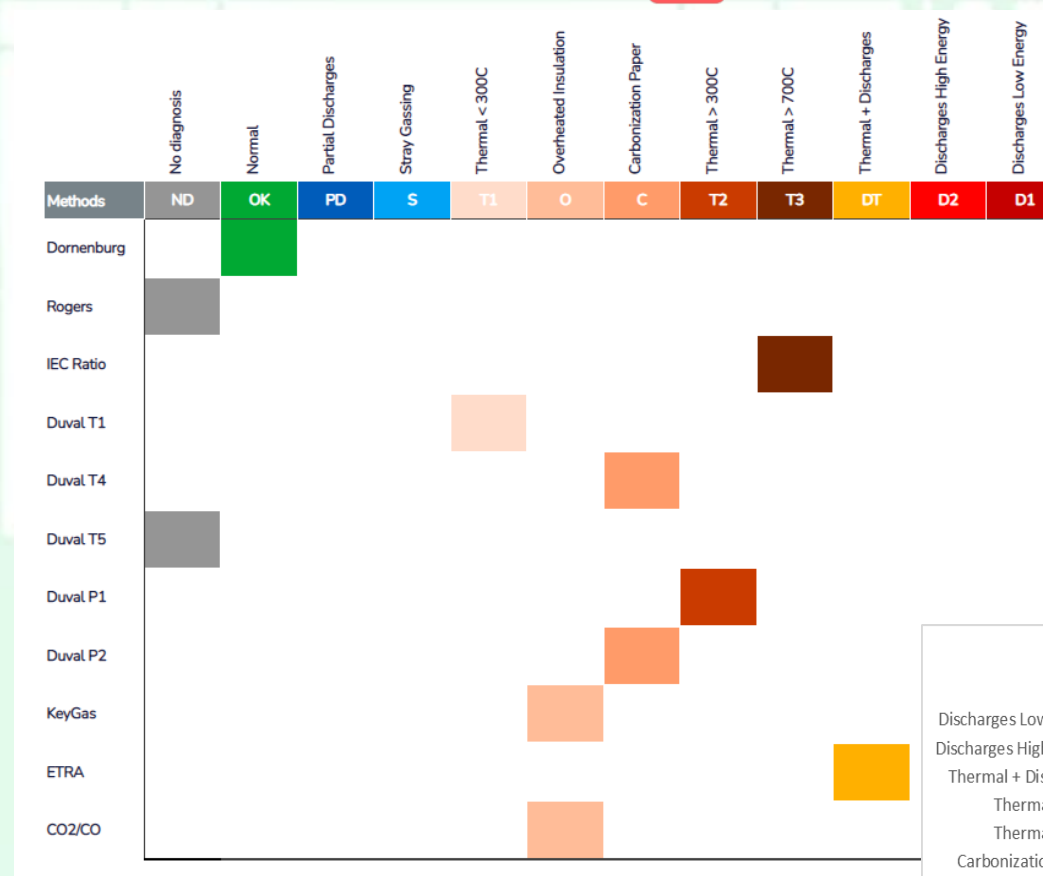
Camlin Condition Index



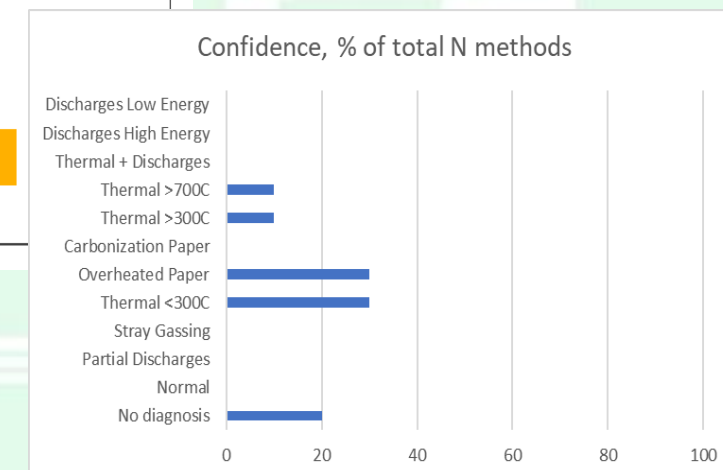
Artificial Intelligence and Machine Learning

Camlin DGA Matrix  camlin energy

- AI and ML methods are well suited for analysis of Online monitoring data
- Application in DGA Diagnostics
 - AI improves Condition Assessment when disagreement among DGA diagnostic methods

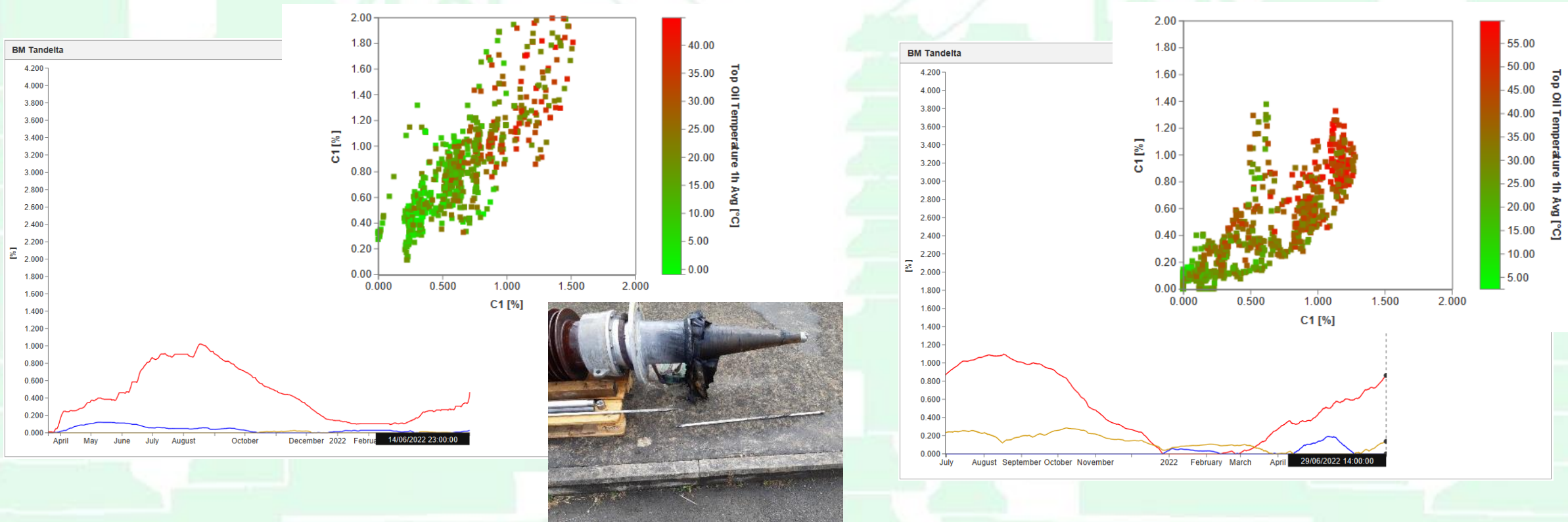


<https://camlingroup.com/dga-dissolved-gas-analysis>



Artificial Intelligence and Machine Learning

- Bushing Monitoring - Temperature Dependent variation with DF
- In-service Failure prevented.

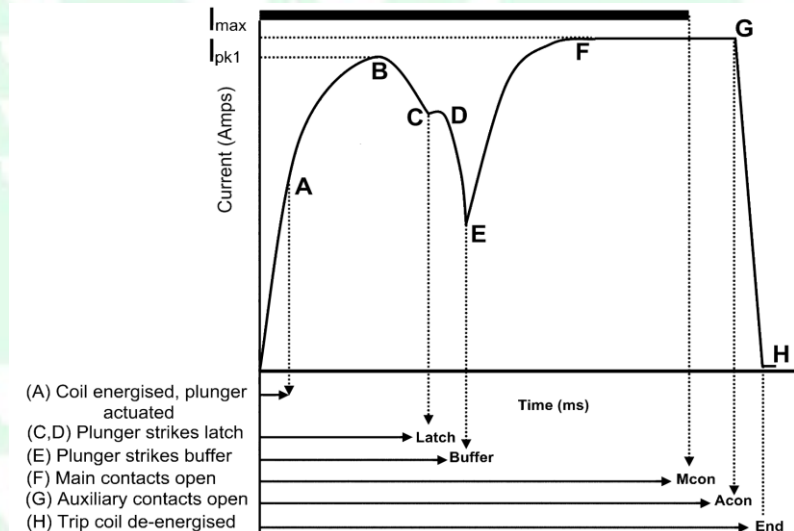


Artificial Intelligence and Machine Learning

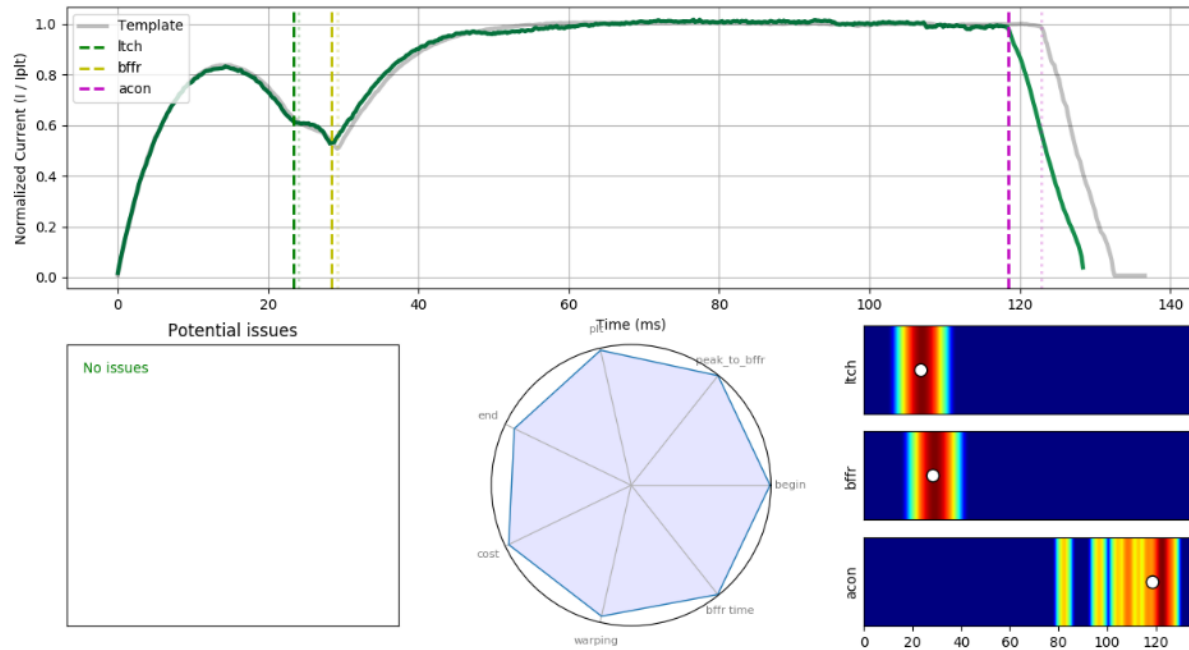
- Application in Circuit Breaker Trip Coil Profiling:
 - Trip coil current has a characteristic waveform during breaker trip operation
 - Effective at diagnosing breaker operations after the breaker has been in a closed position for an extended period
 - Can detect up to 80% of circuit breaker problems
 - Machine Learning methods used to develop Classifier that detects normal operations versus anomalies in the Trip Coil Current waveform



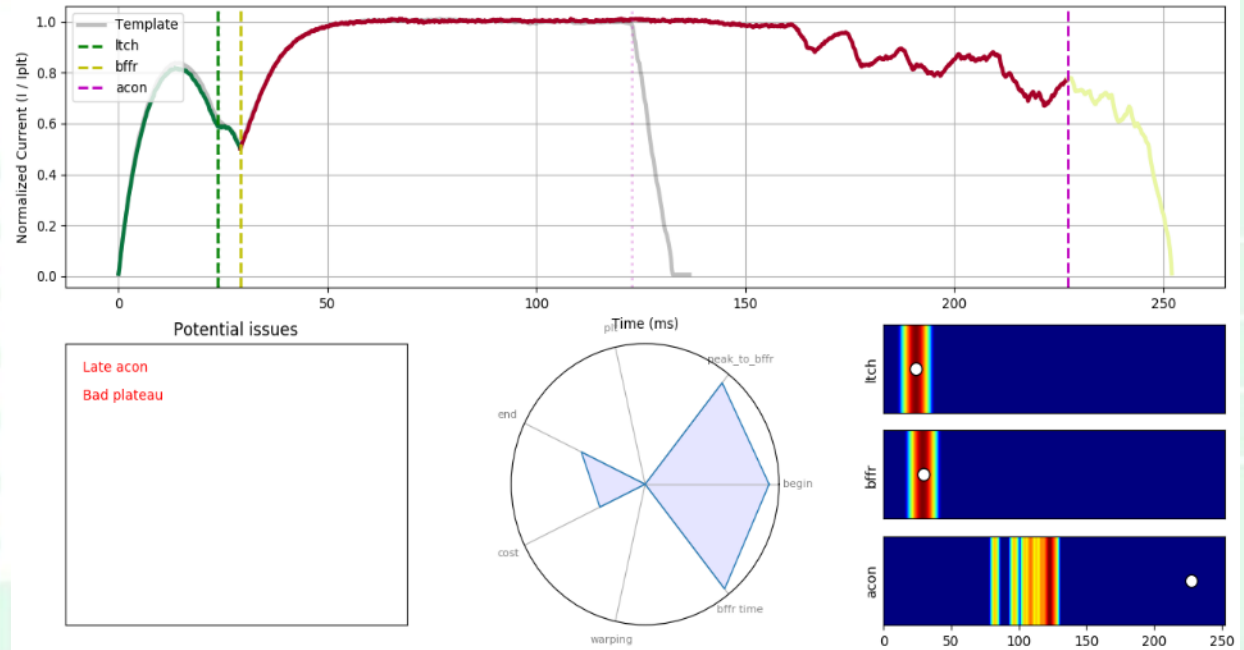
- >99% stationary.
- “Failures” mainly during fault operation.



Artificial Intelligence and Machine Learning



AI diagnostic analysis detected no issues during a normal breaker operation.



AI diagnostic analysis detected issues with the late interruption, and abnormal oscillations in the waveform during an abnormal circuit breaker operation.

Conclusions

- Power System trends/changes with onboarding increased renewable energy and digitalization, will reinforce the need for enhancements in online monitoring
- Modern holistic Online Monitoring systems for Power Transformers enable correlation of data for improved diagnostic capabilities and reliability
- In addition to reliability benefits, Digital Twin and Analytical Models enable controlled overloading and aging estimation
- Online monitoring data may be used for Condition Health Indices and Fleet Asset Management
- AI & ML applications for online monitoring can improve diagnostics, while processing large volumes of data and automate identification of defects