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DP Incident Data Capturing & Analysis SESSION

Data Capture for Condition Monitoring and Incident Investigation

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Abstract

Industry-wide incident reports provide limited information with respect to power-related incidents. IMCA reports indicate the majority of DP incidents, are a result of human error and redundancy issues that translate to incorrect system configuration for specific operation tasks. These incidents are easy to report and understand as a result.

Power system-related incidents are often characterized by alarm events from multiple systems which may not be synchronised, and do not allow for transient analysis. Transient analysis is vital for identifying complex failure modes such as: earth faults, phase imbalance, excitation/fuel failures, and others.

A number of these incidents recently expose how much the industry would benefit from an onboard, OEM-agnostic centralized monitoring system. The ideal system would aid operators with optimizing equipment configuration for the industrial mission, and provide a high-speed data-centric approach to power system failure investigation.

Abbreviation / Definition

Abbreviation	Definition
AVR	Automated Voltage Regulator
DP	Dynamic Positioning
IAS	Integrated Automation System
MTS	Marine Technology Society
PMS	Power Management System
PQ	Power Quality
RMS	Root Mean Squared
S/s	samples per second
VFD	Variable Frequency Drive
BESS	Battery Energy Storage System

Introduction

After an analysis of reported DP incidents, it has been hypothesised that the current methodology for power-related incident investigations can be improved. There are opportunities to improve investigations by implementation of monitoring technologies.

The ideal monitoring technology will

- Reduce carbon footprint,
- Optimise operations, and
- Avoid unnecessary equipment replacements,

by providing crew with insight into the vessel operations. High speed data captured from fault events and maintained in the same, familiar interface used for condition and emissions monitoring and will ease the usability burden and provide rapid insight into undesirable events.

Call to action

If better information was available, the expenses associated with mobilising service technicians and ineffective equipment swaps could be reduced. Further, disruptions to operations may be reduced, and return to service expedited with data-driven evidence of the investigation and rectification validation.

Current Investigation Methods

Most power-related incidents (eg: loss of generator, loss of thruster, AVR failures, partial blackouts) do not provide enough information to properly identify the root causes that led to these failures. The below chart can represent the concept of the methodology currently implemented during an incident investigation:

- Observed Results: eg: partial blackout, generator breaker tripped, loss of thruster, etc
- Alarms Sorting: Time-consuming task that yields limited information and is subject to human error.
- Timeline reconstruction: Description of the root cause events that led to a major incident such as loss of DP. Often the timeline is assembled based on experience, estimation, and possibilities. and does not take into consideration the cascading of transient events, which may lead to inconclusive findings.

Available Data Sources Onboard

Nowadays state-of-the-art software solutions are being implemented onboard DP vessels and offshore installations to help solve industry-wide problems and support operations. A brief description of some of these applications is given below:

- Condition monitoring: helps predict equipment failure and maintenance schedule. Eg of data points are: vibration, temperature, oil composition, among others.
- Production Optimization: AI models take data from the well and predict deviations to help operators make better decisions.
- Emissions Monitoring: helps determine gas or particulate matter concentration or emission rate using pollutant analyzer measurements.[1]

Other systems may offer power data and events. However, these rely on already available data from OEM hardware used in Power Management Systems (PMS) and Integrated Automation Systems (IAS), which is often acquired at a very slow sample rate (eg: 1 sample/sec). These systems are unable to aid in transient analysis, as it is known -based on recent studies[2]- that a minimum of 4000 samples/sec (64 samples per cycle) is advised to properly post process and analyze AC power transient data.

[1] https://www.epa.gov/emc/emc-continuous-emission-monitoring-systems

[2] Voltage Dip Immunity of Equipment and Installations - https://e-cigre.org/publication/412-voltage-dip-immunity-of-equipment-and-installations

Improvement proposal

A better solution for the needs of the industry would be a complete hardware and software solution, which temporarily logs instantaneous power measurements. The high sampling rate does not need to be stored for regular operation. Data may be stored at lower sampling rates for long term analysis, provided the instantaneous capture is retained for all significant variations in the system. A case history of significant variations would then allow investigators to understand the vessel's behaviour and provide insight into the event under investigation.

For the purposes of this paper, "significant variations" would include engines starting/stopping, significant consumers coming online, sudden changes in load profile (ie squalls), bus ties opening/closing, and other activities which happen irregularly (frequency of greater than 24hr between events). This definition may vary depending on the facility, and should be adjusted to suit the risk and operational profiles of the facility.

This system would also support carbon footprint reduction with extra data points to build a more accurate model of engine chemistry. A front-end user interface can be then employed to contextualize stored data and events, aiding and adding accuracy to the identification of root causes.

System Description

Ideally, the system described above would have the technical capabilities given below:

- Steady-state and transient data logging in real-time. True RMS would be logged at a medium rate (5 - 10 S/s). During a transient event, all digital I/O, measured, and calculated values can be sampled at speeds as high as 10 kS/s:
  - Instantaneous phase to phase Voltage and phase Current, and phase angle
  - Calculated values such as: active power (kW), reactive power (kVar), apparent power (kVA), and power factor (PF)
- Integrated events logging,
- Symmetrical components (Zero, Negative, and Positive sequences)
- Circuit breakers status all main switchboard supplies (Generators, Batteries), Bus Ties and Consumers,
- Monitoring functions for grid and generator protection that allows triggering data logging,
- Measurement of grid harmonics up to the 50th (PQ),
- Engine Conditions
  - Fuel input (flow IN-OUT)
  - Exhaust gas composition
  - Temperature
  - Speed
  - Air mass flow (intake and exhaust)
- Onboard server with high storage capacity where event triggered transients would be stored. This server would also allow remote access to the facility's data, which can be used to support trials and troubleshooting remotely.
- Cybersecurity to a suitable level (see note over page)

Cybersecurity
The system described within does not have access over vessel functionality so should present a reduced risk compared to remote systems which do have access to vessel functionality. However, Cybersecurity should be considered with the implementation of any new on-board system as a priority.

The diagram below describes an example of installation topology on a DP2 vessel.

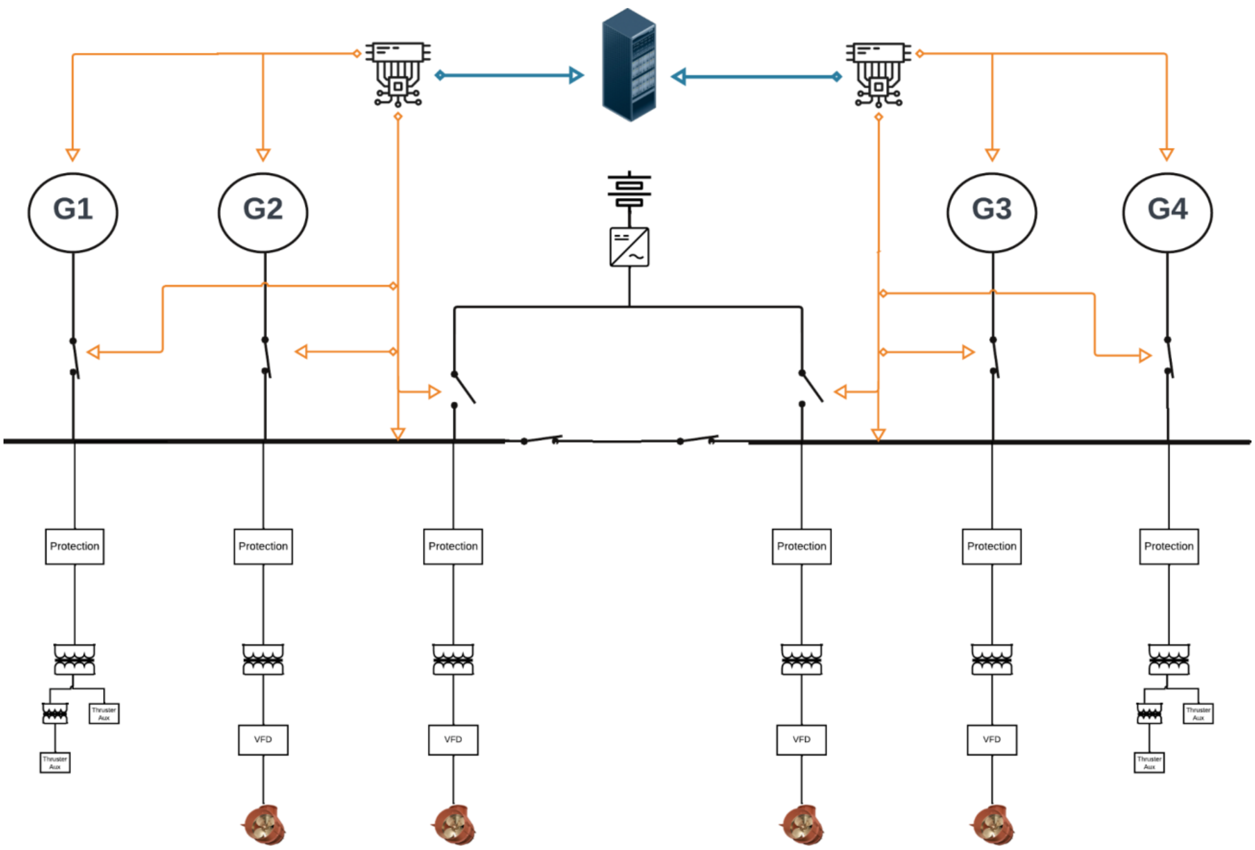

Figure 1: High-speed data capture and emissions monitoring topology for power systems.

Data Contextualization

Having access to high quality data from a power system allows facility's power plant to be represented as a model that can be queried in multiple ways to obtain operational and incident data. This data can add context to incidents, and allow investigations to be streamlined.

Power distribution-related incidents are often a result of cascaded events that originate from a single-point failure. IMCA DPE 03/18 event is an example of this:

> *"The engineer on watch noticed a developing load imbalance across the online engines. DG1 and 3 dropped load quite rapidly, leading to them both being tripped on reverse power protection, leaving only DG2 online. The PMS automatically instigated a standby start of DG4. However, before DG4 was up to speed and synchronised, DG2 tripped on overload, leading to a blackout. DG4 connected to the switchboard as part of the blackout recovery process and the engineers worked to bring DG1 & 3 back online."*
>
> *"An investigation found that the DG2 governor had experienced a mechanical failure, leading to excessive fuel supplied to the engine. The engine therefore 'grabbed' load from the otherwise healthy online machines forcing them to trip on reverse power. The generator protection and power management systems had no way of identifying the faulty machine although the PMS did generate load imbalance alarms prior to blackout." IMCA DPE 03/18*

The IMCA incident report, which is acknowledged as only outlining a small portion of the investigative process, has key clues regarding the investigation, including the statement: "*The generator protection and power management systems had no way of identifying the faulty machine* ***although the PMS did generate load imbalance alarms*** *prior to blackout.*" (Emphasis added)

Finding the root cause of these styles of incidents becomes an overwhelming task when investigators have to review alarm logs and contextualize events with the help of operators' observations and experience. The conclusion the IMCA investigators have arrived at seems reasonable and robust with the information available, however the method lacks data-backed evidence and the investigation can be misled, particularly when attempting to identify and remediate the root cause.

If the incident had occurred on a vessel with high-speed power monitoring, the following additional information would be available:

- active power for each generator
- fuel input for each generator
- bus voltage
- generator circuit breaker and busties status
- And a range of other contextual clues which are unrelated to this incident investigation

The above IMCA incident appears relatively simple from a diagnostics perspective, due to the fault style and the investigation summary. More complex scenarios have an even greater need for high-quality power evidence during an investigation. Cascading failures, such as a scenario where a single fault takes advantage of a hidden failure to escalate into a more complex (and catastrophic) failure would greatly benefit from transient data captured in the minute leading up to the event.

The protection systems onboard DP vessels are difficult to analyze and validate, sometimes resulting in improper fault discrimination when certain faults occur. The investigation can yield inconclusive findings. The time and resources used to rectify issues can increase dramatically with time, and still functioning equipment may be replaced, leaving the latent error in situ.

This additional information would be key to help direct troubleshooting, aiding in cost reductions for logistics or operational interruptions: not mobilizing un-needed service technicians or replacing healthy equipment represents a significant cost saving, particularly in under-serviced and remote regions.

Finally, rectification validation can be performed with the in-situ monitoring system. Validation of the immediate fault mechanism, and the rectified protections in more complex failures, can be confirmed with the use of the system as described.

Remote Trials

Remote DP FMEA Trials have been hotly debated in the years since the 2020 pandemic. The Author's are not placed to comment on the efficacy of remote trials, however the data requirements for remote trials would be greatly supported by having a system with fault capture which can be interrogated from the remote location. This system would also greatly decrease the opportunity for maloperation of the tests, and provide opportunities for traceable comparison of year-on-year results.

Carbon Footprint Reduction Applications

The most current methods implemented for emissions monitoring are based on the Environmental Protection Agency (EPA) guidelines, which provide a list of most concerning gases concentrations that must be measured and controlled to ensure compliance with current emissions regulations, such as Nitrogen Oxides (NOx), Carbon Monoxide (CO), non-methane hydrocarbons (NMHC)[3].

Traditional emissions measurement aboard facilities has been based on the data captured during the factory acceptance testing of the engines prior to entering service. This data is then applied to the historical power consumption of the unit, and an estimate of the emissions generated is produced for reporting purposes.

Recent regulatory changes have prompted the industry to upgrade their emissions reporting process, and installation of either fuel monitoring systems or emissions monitoring systems have become widely expected. While fuel monitoring systems may provide additional data to the user, the emissions calculated as a result of fuel monitoring measurement remain subject to the factory acceptance testing data. Ideally, real emissions monitoring should be undertaken.

Measuring gas concentrations will allow facilities to be aware of the operation's emissions levels. However, it does not necessarily provide a full understanding of the engines' chemistry and what could be done to maintain or improve exhaust limits. When power, fuel, and air mass flow data points are added into the mix with exhaust gas concentrations, a more robust model of the engine operating conditions can be obtained. This data would provide a better understanding of fuel usage (kWh/gram) and individual engine efficiency; which would benefit operators to find cost-effective solutions to decrease exhaust gas concentrations. For example:

- The best combination of engines or engines - batteries online could be used depending on the load profile of the system and operations knowing the fuel burn rate and exhaust composition of each engine.
- Inefficient engine tuning,

In addition, there may be value to the operator by having the ability to segregate their emissions between various operating modes (transiting vs stationary) this is only viable with an integrated system of data recording.

[3] 40 CFR Ch. I (7–1–21 Edition) - Subpart B—Emission Standards and Related Requirements - https://www.ecfr.gov/current/title-40/chapter-I/subchapter-U/part-1039#subpart-B

A Case Study: Sailplan

The system showcased in this case study focuses mainly on emissions monitoring to provide clients with contextual information about their vessel operations. Data is recorded continuously and remotely accessible to support onshore management.

The graphs below offer a clear picture of the difference between transit and DP operations for a vessel. It is noticed that during DP operations - at lower vessel speeds (knots) and low engine loads (%) - the Unburnt Hydrocarbons (UHC) concentrations would increase dramatically compared to Carbon dioxide (CO_2). The opposite is true for transit operations, where CO_2 concentration slightly decreases and UHC decreases by ~90%.

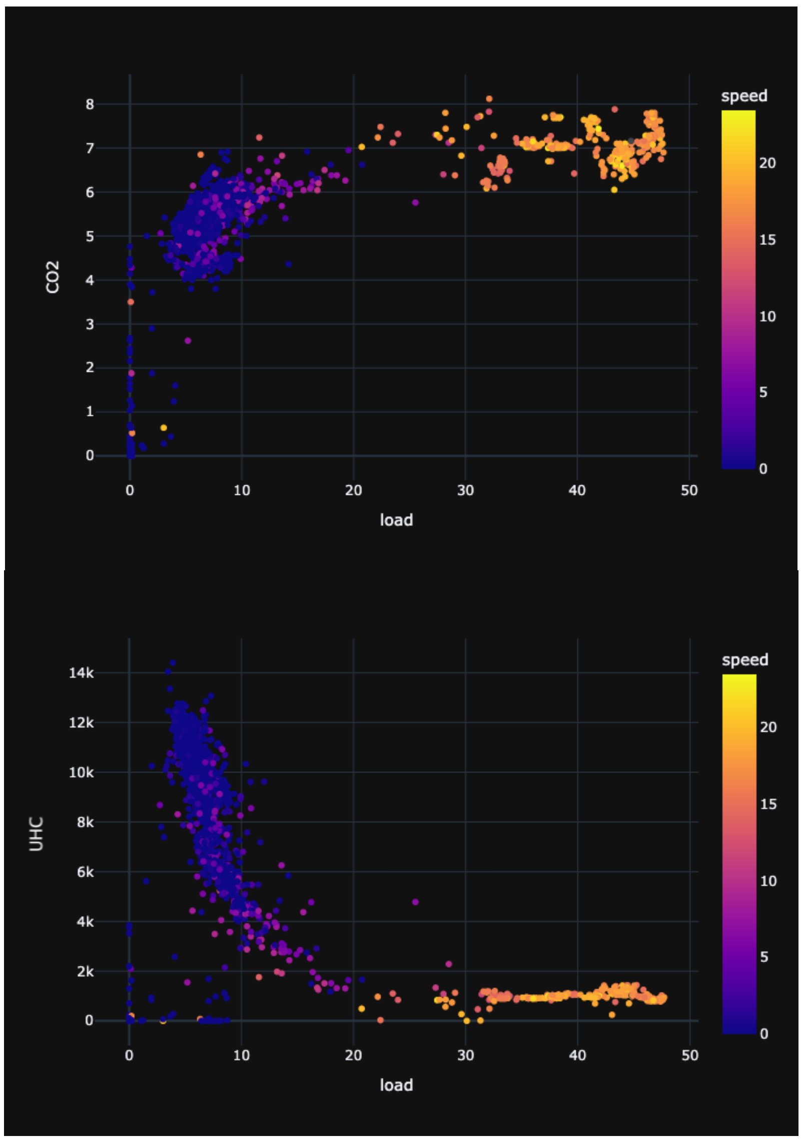

Figure 2: Emissions vs. Engine load vs. Vessel Speed. speed - vessel speed (knots), load - engine(s) load percentage (%), UHC - Unburnt Hydrocarbons (ppm), CO2 - Carbon dioxide percentage (%)

In addition, per engine status, live emissions and power data is available as shown in the images below.

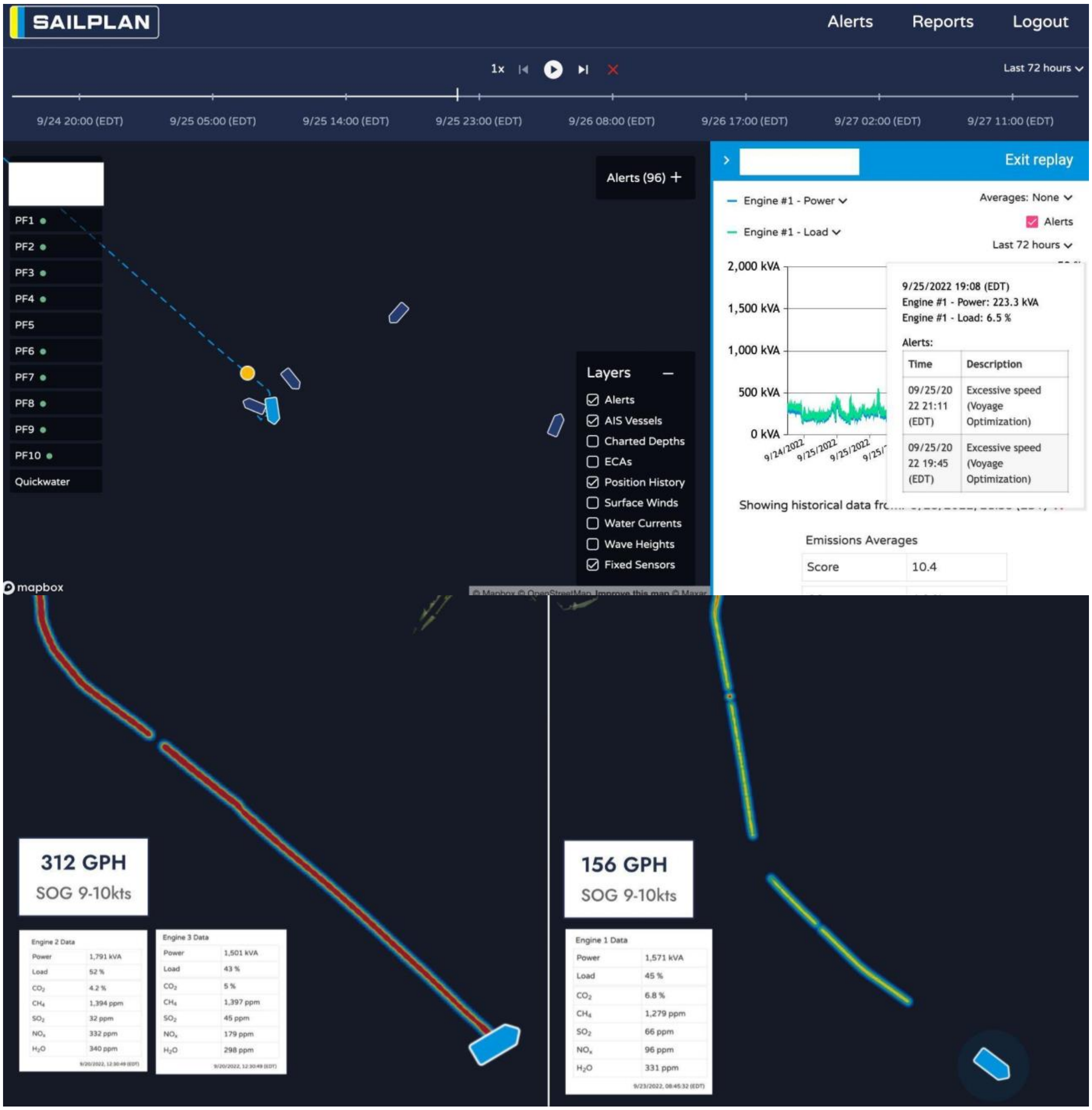

Figure 3: Remote live feed showing engines power and emissions data

Knowing this information allows operators to configure the power plant differently for each operation, aiming to improve emissions, by for instance: discarding engines that have historically shown higher concentrations or decrease the number of engines online as allowable.

High Speed Recording

Additionally, the system installed onboard this vessel has the technical capabilities mentioned in the "Improvement Proposal" section of this paper. Over the short time that this system has been installed, it has been able to detect high harmonic distortion at the generator terminals.

The graphs below represent the instantaneous harmonic distortion per phase and total for voltage (V) and current (I) when there is no thruster load. For this particular case, it can be seen that the Total Harmonic Distortion (THD) is within manageable limits.

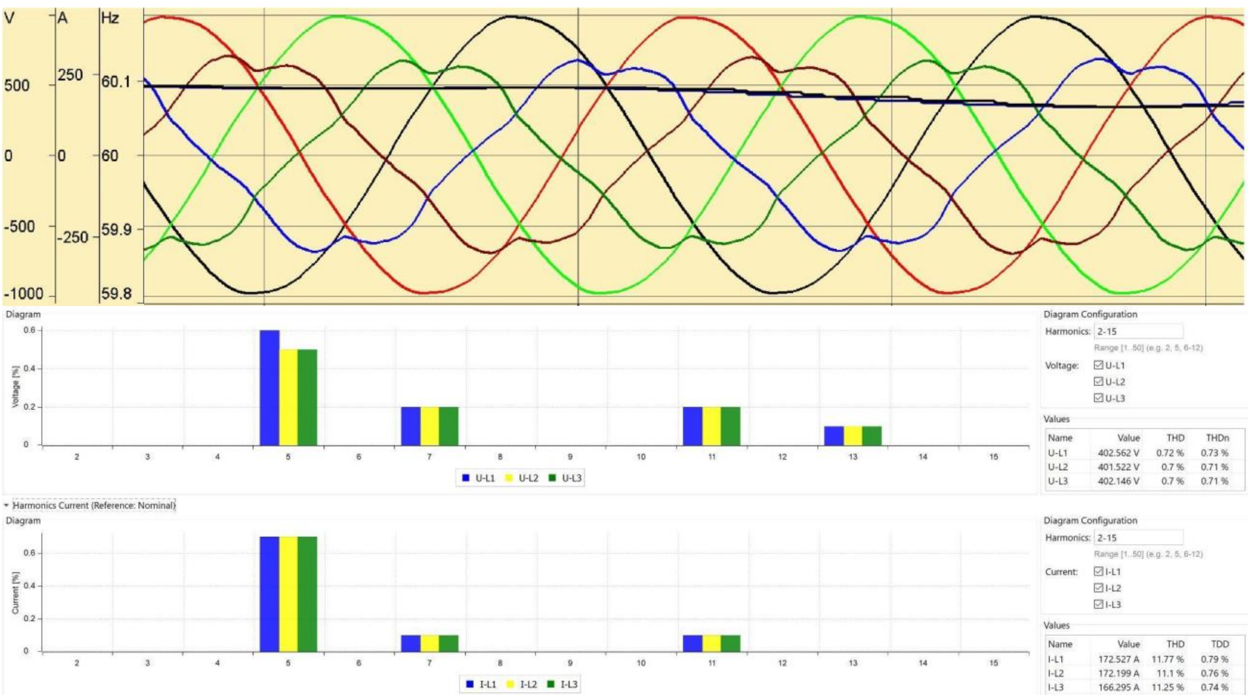

Figure 4: Live generator Voltage (V) and Current (A) waveform and harmonic distortion characterization while lightly loaded.

On the other hand, as expected, when the AC/DC switching components are active, such are propulsion VFDs and BESSs inverters, the current (I) harmonic distortion increases dramatically as characterized by the image below. This clearly shows the benefits of having high speed data capture that can be accessed remotely when troubleshooting power quality issues and related failures such as failed transformers.

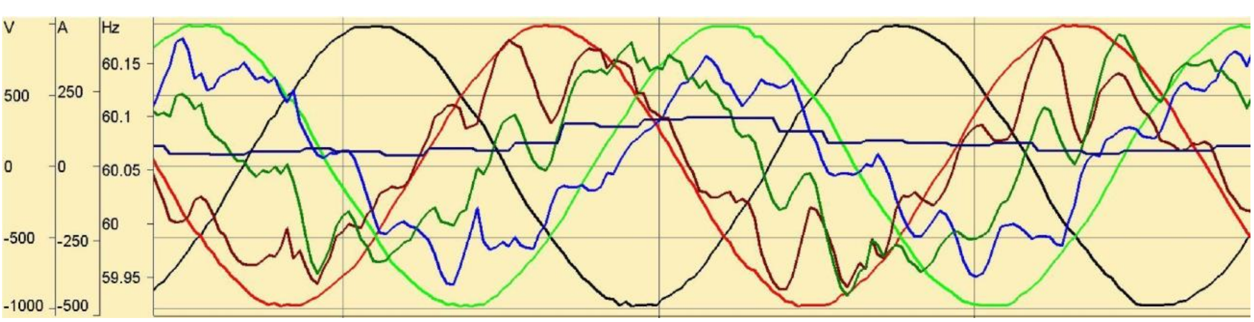

Figure 5: Live generator Voltage (V) and Current (A) waveform while AC/DC switching components are enabled.

Conclusion

While the current methods implemented during power-related incident investigation may be effective most of the time, it is a slow process and may cause longer vessel operation interruption while waiting on a rectification action plan.

Having a comprehensive solution like the one showcased in the case study featuring Sailplan, allows for a smooth investigation process as operators and involved service contractors can access vessel data remotely. Additionally, as demonstrated, power-data can be used to contextualise emissions data, providing operators with a more robust and actionable model of their operations.

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References

Originator	Year	Doc Title	Link
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CIGRE	2010	Voltage Dip Immunity of Equipment and Installations	Accessed: Sep 20, 2022 https://e-cigre.org/publication/412-voltage-dip-immunity-of-equipment-and-installations
EPA	2021	40 CFR Ch. I (7–1–21 Edition) - Subpart B—Emission Standards and Related Requirements	Accessed: Sep 20, 2022 https://www.ecfr.gov/current/title-40/chapter-I/subchapter-U/part-1039