

Use of Mobile Online DGA for Gassing Alarm Response and Analysis

This case study reviews AES Indiana's decision process and the outcomes from the installation of a mobile online gas-in-oil monitor manufactured by Vaisala (the OPT100 Mobile) to provide a tool for real time DGA data for rapid response to lab-based gas results and alarms requiring further analysis. AES needed DGA data that could be compared to other factors in real time, such as load, temperature, and environmental conditions, for a deeper fault evaluation and thereby better maintenance planning. In the end this case study shows the cost and operational benefits found in acquiring an online mobile DGA solution.



Using Mobile Online DGA for Cost Effective Deep Analysis of Questionable Gassing Transformers

AES Indiana has around 350 transformers in its power system but has only 3 fixed online multi-gas DGA devices along with 15 single gas online monitors. The rest of these transformers are sampled and lab tested, either quarterly, bi-annually or annually depending on the perceived need.

This sampling data is fed into an analytical software tool, Transformer Oil Analyst (TOA), which evaluates the health and identifies transformers that may have developing faults.

In particular, AES Indiana identified a 50-year-old transformer showing signs of gassing and potentially degrading health. It was a 1961 step-up transformer, 230-69kV with a 67 MVA rating.

This transformer had historical gassing patterns from lab

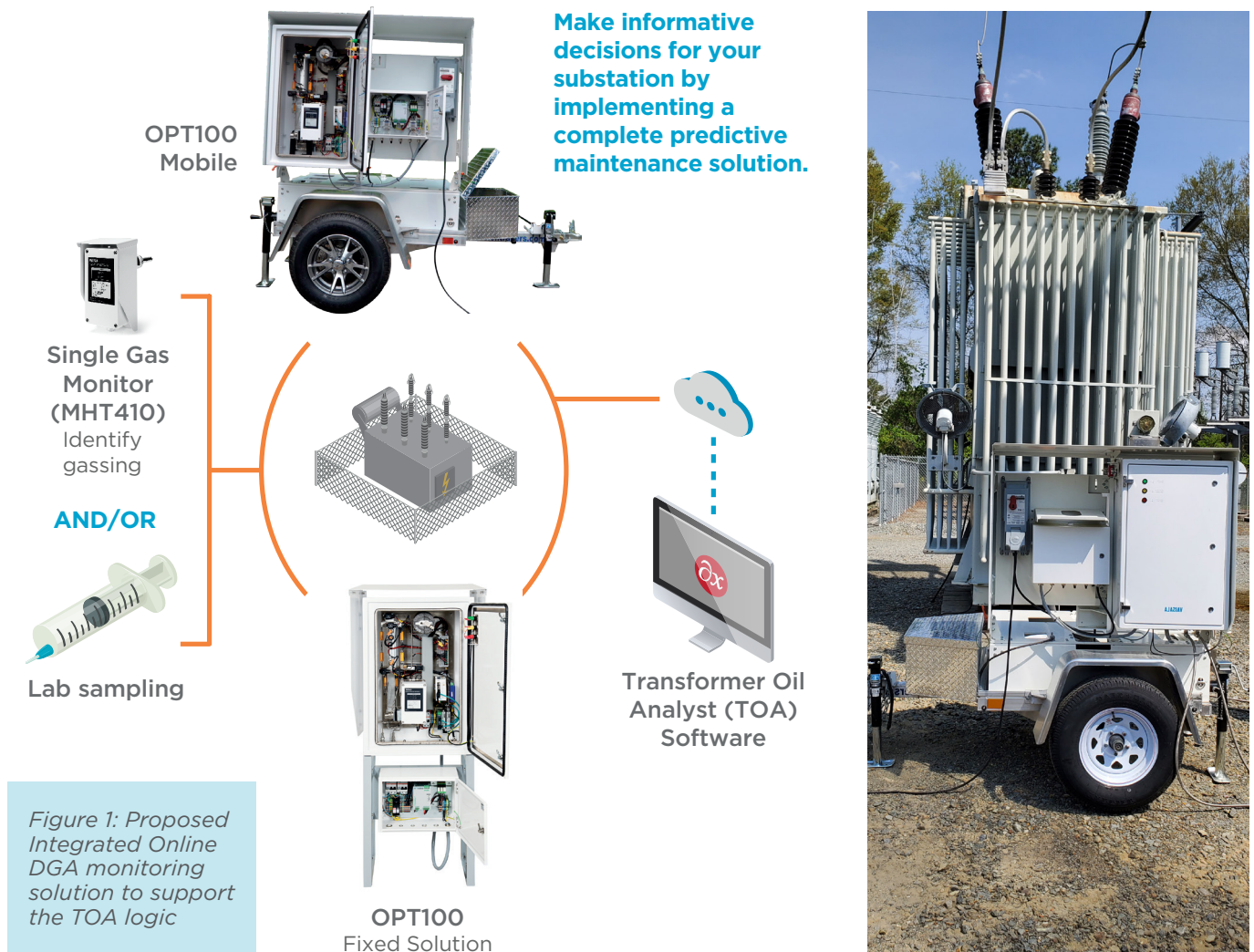
results that TOA identified as questionable and required deeper analysis to determine if the gassing was from a thermal fault that continued to develop or was from other isolated events. On top of that, there was data from the Pi Historian on H₂ trend alarms.

The issue was that sampling was not providing clear data, as the AES maintenance team needed to see how the gases were behaving when compared in real time to other factors, such as load and temperature.

The question for the AES maintenance team was to decide if this was an issue where the transformer had an ongoing fault or was it gassing due to separate isolated events that were not ongoing?

This question highlighted a key missing tool in the maintenance team tool kit. The AES Indiana maintenance team felt they needed an effective way to respond to these lab sample based alerts, as well as the alarms coming from single gas monitors, as higher frequency sampling was not providing real time comparable data for deeper analysis. When the lab results indicated a fault condition arising or when a gas alarm limit came in from the single gas monitors, there was no clear way to acquire real time data for a more in-depth analysis. While the TOA decision support tool was able to give warnings on abnormal conditions, AES decided they needed a tool that would provide real time data to TOA for better analysis of the gassing issues and effectively plan and prepare the next steps to take with a higher level of confidence.

AES Indiana had been evaluating mobile online DGA solutions and decided to purchase an OPT100 Mobile online DGA and moisture monitor from Vaisala. They felt this tool could address the need for a “middleware” solution to gather live data to TOA. (See Figure 1.) The question still remained regarding how easy this type of a system would be to install and move and how reliable the gas measurement results would be, so close attention was paid to the first installation.



As such, a secondary goal for AES was to validate the cost-benefit of mobile online DGA systems and how they would integrate with their existing monitoring solution (TOA).

This case study shows how AES Indiana was able to confirm both the value of a mobile online DGA solution and, just as importantly, better understand the condition of the questionable gassing transformer and make informed decisions about how to proceed with a maintenance plan.

Transformer DGA History

AES Indiana uses TOA from Delta-X Research for assisting with tabulating DGA lab results and ranking transformers for further monitoring or maintenance actions. In particular, the TOA software tool had identified in this 1961 Generator Step Up Transformer concerning gassing events starting in around 2002 that had been continuing to sporadically accumulate in short bursts over time. (See Figure 2.) There was not much DGA data prior to 1995, but it appears to have been stable. Based on an assessment of the current risk and perceived health of this transformer in particular, AES Indiana decided to put the OPT100 Mobile online monitoring device in place to verify the situation and decide what corrective actions may need to be taken.

This decision was supported by the lab tested samples. The TOA software analysis had shown this transformer was having high cumulative energy (NEI¹). Additionally the hydrocarbon and carbon oxides NEI as well as the carbon oxide ratios were showing concerning periods. (See Figure 2.)

But even more concerning was the high hazard factor in event 11. That NEI-CO event – at 1.14%/year indicated a significantly higher risk as compared to background risk (see Figure 3). Based on this analysis and cross referencing the trending to the IEEE C57.104-2019 (Annex F), with both the NEI-HC and NEI-CO increasing along with the CO/CO₂, this would indicate that the paper insulation in the transformer was degrading and that continued oil monitoring should be performed especially as the transformer gassing was trending upward.

GASSING EVENTS:

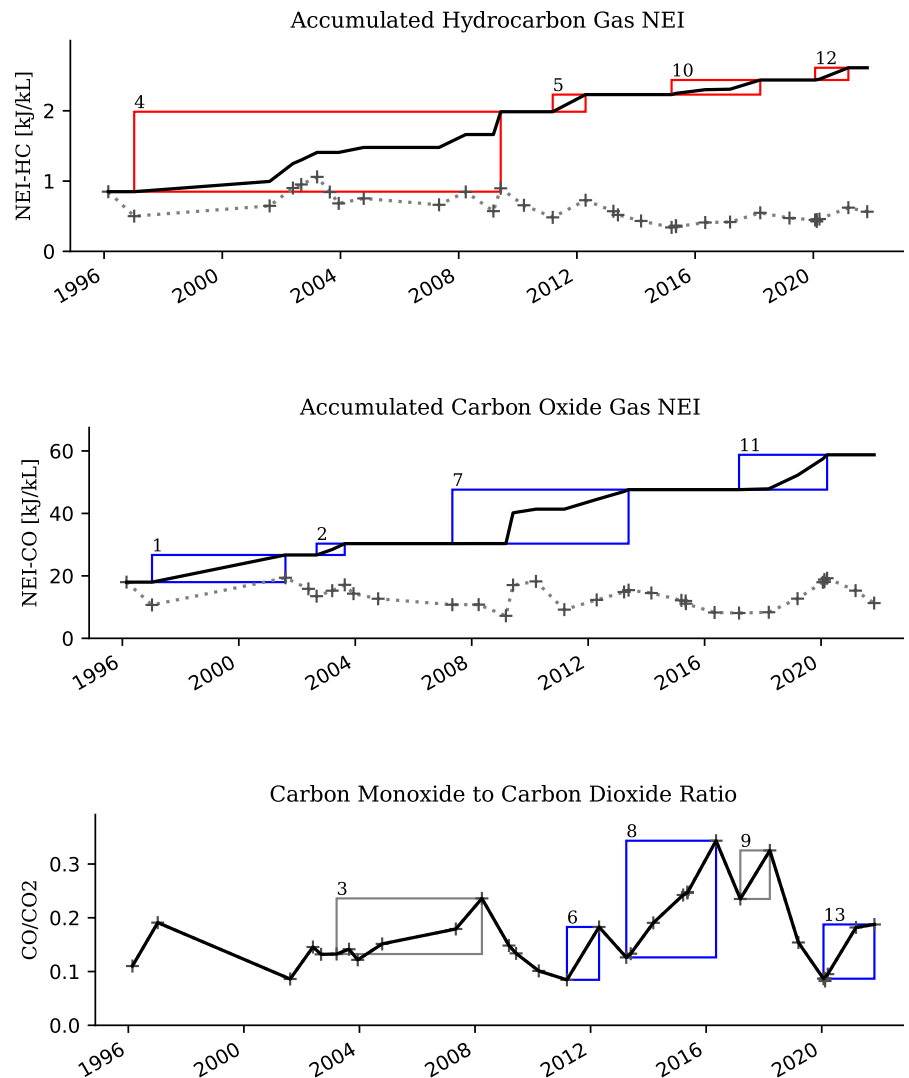


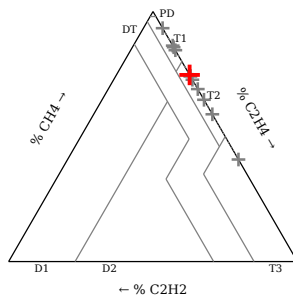
Figure 2: TOA reports on Hydrocarbon and Carbon Oxides Gas Normalize Energy Intensity (NEI) and Carbon Oxide Ratios. 1995 - 2020

Further supporting this theory, the TOA Duval Triangle analysis was showing a potential T2 fault², indicating that there might be a thermal hotspot. Given the NEI-CO was also trending up, it indicated that paper insulation was involved. This raised particular concerns at AES Indiana, as the degree of carbon oxide gassing alone was enough to conclude that the paper had been affected by the previous gassing events (see Figure 2).

¹Normalized energy intensity (NEI) is a fault energy index generated by TOA based on the overall energy released inside the unit from historical gassing. Rather than rely on the gases themselves as indicators, NEI uses the standard heats of formation to calculate how much energy was expended into the oil to create the gases. NEI is then graphed as a single line and shows where gassing events have occurred (where the line ascends, inside the colored boxes). This is done separately for carbon oxide and hydrocarbon gases because they are primarily generated from different insulation systems (paper/oil respectively).

²The TOA uses Duval triangle from the R-DGA report instead of a conventional report, using gas event increments rather than lab concentrations to more accurately diagnose the active fault.

DUVAL TRIANGLE DIAGNOSIS: T2



T2 Low temperature thermal fault (<300°C)

RELIABILITY-BASED DGA SUMMARY:

DGA last date	2020-03-17	Event summary	nei_co+!
DGA samples	30	Cumulative sev liquid %	1.10
Gassing events	11	Cumulative sev paper %	5.97
Event fault type	T1	Gassing status	4
Hazard factor %	1.14		
Figure 3: TOA r-DGA Summary Report. ³			
		DGA result	2/2
		Moisture result	1/1
		FQ result	2/2

As mentioned, this was also concerning because the gassing status was at 4. Gassing status is a short status code similar to IEEE status codes but indicates gassing status. Gassing status 1 is a transformer that has never gassed before. Gassing status 2 is a transformer that has a gassing event in its history but is not actively gassing. Gassing status 3 and 4 is a transformer that is actively gassing. Gassing status 4 is considered higher risk than Gassing status 3. This is because each gassing transformer has an estimated risk of failure from the Hazard factor. The 90th percentile of observed Hazard factors is used to denote 3 vs 4 as high risk. The Hazard factor estimates risk of failure based on an analysis of a large population of transformer failure cases and the transformer's rate of gassing.

So the decision was made by AES Indiana to temporarily install the OPT100 Mobile DGA monitor in order to get real time data and run that through the TOA system for comparative analysis. Again, the goal was to determine if this was an issue that was continuing to produce higher gas levels or was gassing due to an isolated event.

Mobile Online Monitoring Device Installation

The OPT100 Mobile online monitor was installed on the transformer in February of 2020 just south of Indianapolis. The device was left in service for 4 months, gathering DGA data for analysis. During the installation, the transformer was left energized as the connection points were low enough on the transformer to be reached safely and the OPT100 Mobile does not require an outage for installation. The installation and commissioning were completed by 2 people working for a half day, which included setting up the remote comms. No special equipment or connectors were needed, nor was any proprietary software required. Just a laptop and a browser.

The OPT100 Mobile DGA monitor was configured with a Secomea modem running on the Verizon network, which provided the firewall and IT security layer for the wireless communications channel. The OPT100 Mobile was also protected with Username/Password protection. The AES Indiana staff used this connection to access the OPT100 Mobile software with its analytical features, via a web browser.

This OPT100 Mobile device was also connected to and feeding data into the TOA software utilizing the Monitor Watch plug in, which is a real time data aggregation option for TOA. This connection was made through the cellular Ethernet connection. TOA with Monitor Watch conducted a separate analysis on the real time DGA data, analyzing it as monitor data (versus offline lab data) for more accurate interpretation of the results. TOA treats online DGA data differently, as it is higher frequency and trends to higher accuracy.



Figure 4: Vaisala OPT100 Mobile DGA monitor.



OPT100 Mobile ready to be pulled to a transformer site.



OPT100 Mobile Installed on a transformer.

³ The TOA includes Tables 4 and 5 only if certain rules are triggered, which includes checking if H_2 and C_2H_6 are increasing in the time period of the gassing event, which in this case they were not.

DGA Findings from Online Monitoring

Based on the 4 months of real-time data provided by the online DGA monitor, it was determined that while there had been gassing events that had occurred in the past, the situation did not appear to be getting worse and the decision was made to leave the transformer operating with annual sampling. The TOA software did indicate a status 4 gassing pattern during the pilot but there were no clear events. (See Figure 6.) While the gassing was higher than IEEE 2008 guidelines may indicate, the events did not indicate any critical issues.

This was supported by the OPT100 Mobile DGA monitor data, which showed stable measurements (See Figure 7) and unchanged Duval triangle analysis during the online monitoring period. The Duval triangle still indicated a potential T2 fault, but it seemed stable and was not evolving to another fault type. (See Figure 5.)

TRIANGLE DIAGNOSIS:

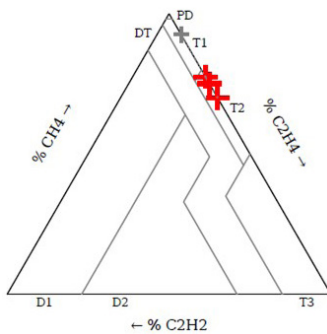


Figure 5: OPT100 Mobile Duval Triangle Analysis which indicated a stable T2 Medium Range temperature thermal fault (300-700°C)

DISSOLVED-GAS DATA:

Lab Report Number	237294-005	236024-002
Sample date	2020-03-17	2020-02-12
Sample temp	34	27
Hydrogen (H2)	273	295
Methane (CH4)	77.5	77.5
Ethane (C2H6)	22.7	21.9
Ethylene (C2H4)	20.6	19.9
Acetylene (C2H2)	0.0	0.0
Carbon Monoxide (CO)	1030	943
Carbon Dioxide (CO2)	10827	10806
Oxygen (O2)	55	316
Nitrogen (N2)	53700	49500
Total heat gas	121	119
Equivalent TCG	2.213	2.340
Total partial press	60.5	57.8
Est. safe handling limit	6.9	6.5
Predicted composite fault gas	459	465
Acetylene/Hydrogen (C2H2/H2)	0.0	0.0
CO/CO2	0.095	0.087
Oxygen/Nitrogen (O2/N2)	0.001	0.006
NEI-HC	0.46	0.45
NEI-CO	19.25	18.83
TCG (headspace or relay)		
Gassing status	4	4

Figure 6: TOA Duval Triangle Diagnosis from the Monitor Watch report and DGA Laboratory Data Summary Table.

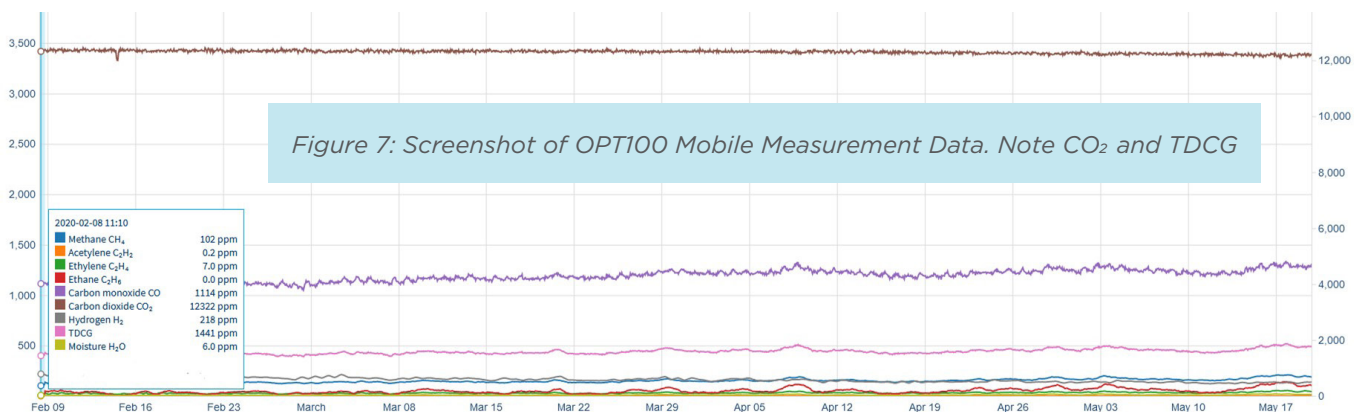


Figure 7: Screenshot of OPT100 Mobile Measurement Data. Note CO₂ and TDCG

Summary

AES was able to use the online mobile DGA device to confirm that there were no ongoing gassing events or faults developing in this transformer based on the real time data gathered. While DGA analysis did indicate that there was an active T2 fault which was worthy of continued monitoring, the added data from the online DGA monitor gave the AES Indiana maintenance team the confidence that the transformer was in a stable and safe condition and could continue to operate.

So both goals were achieved; First, AES confirmed that the T1/T2 fault was not worsening significantly in the transformer and could continue to operate.

- The real time data showed the historical gassing and apparent drifting from T1 to T2 status was not a pressing concern, as there was minimal upward trending (Rate of Change) overall.
- Further supporting this conclusion, the TOA Gassing status has since dropped to Status 2. Transformers that are Gassing status 3 or 4 will naturally de-escalate to a status code 2 and a Hazard Factor of zero, if the gassing stops.

So AES was able to verify that the transformer was safe to operate and the AES Maintenance team could continue to load the transformer safely.

At the time of the writing of this case study the transformer was still in service with no issues.

Just as importantly, the AES maintenance team was able to validate the cost-benefit of having mobile online DGA as a tool for deeper analysis on problem transformers identified through sampling and single gas monitors.

- The AES team validated that the OPT100 Mobile monitor was easy to install and commission, as well as break down and transport to new sites.
- The AES team proved the OPT100 and OPT100 Mobile integrated with TOA seamlessly.
- The AES team confirmed the DGA device measurements tracked well with laboratory data.

At this time, the OPT100 Mobile Online DGA device is still in use, monitoring other critical transformers on the TOA target list.

APPENDIX A

From IEEE C57.104-2019:

Table G.3 - Limit concentrations of dissolved gas

Key gas	Concentrations L1 ($\mu\text{L/L}$ (ppm v/v))
Hydrogen (H_2)	100
Methane (CH_4)	120
Carbon Monoxide (CO)	350
Acetylene (C_2H_2)	1
Ethylene (C_2H_4)	50
Ethane (C_2H_6)	65

APPENDIX B

CIGRE TB771 – Types of faults:

Table 2.1 - Definition of the 10 Types of Faults or Stresses Identifiable by DGA with Triangles 1, 4, 5 and Pentagons 1,2

Fault or Stress	Definition
T3	Thermal $T > 700^\circ\text{C}$
T2	Thermal $300 < T < 700^\circ\text{C}$
T1	Thermal $T > 300^\circ\text{C}$
PD	Partial Discharges of the Corona Type
D1	Discharges of Low Energy
D2	Discharges of High Energy
S	Stray Gassing of Oil $< 200^\circ\text{C}$
O	Overheating $< 250^\circ\text{C}$
C	Possible Carbonization of Paper $> 300^\circ\text{C}$
T3-H	T3 in Oil Only

References

1. "IEEE Guide for the Interpretation of Gases Generated in Mineral Oil Transformers". Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, June 2019. C57.104-2019.
2. "Advances in DGA Interpretation". Cigre, 2019. TB771.

Gas formation patterns vs temperature (energy content) of the fault or stress and vs. type of fault or stress are indicated in Figure 8 (B8). They are the same in all types of equipment (power transformers, air breathing- or sealed-, core- or shell-type, instrument transformer of the current-or voltage-type, bushings, cables).

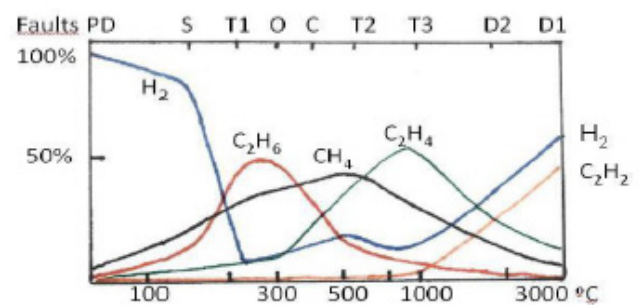


Figure 8: Gas Formation Patterns vs Temperature at Point of Gas Formation

Biographies



GRANT BALDWIN is a Reliability and Performance Engineer at The AES Corporation. During his nearly seven years with AES (FKA Indianapolis Power & Light, IP&L) Grant has collaborated with engineers and field technicians to improve the monitoring and calculation of Asset Health/Risk, drive predictive maintenance programs, and lead multiple Root Cause Analysis investigations into major failure events.

Grant holds a bachelor's degree in Mechanical Engineering from Indiana University-Purdue University Indianapolis and a master's degree in Engineering Management from University of Louisville.



MARK GROSS, Regional Business Manager for the Vaisala Power Solutions group has 25+ years of experience working in the Power Generation, Renewable Energy and Green/Hi Tech industries. From General and Operation Managers roles to Business Development Manager positions, he has held key roles in various companies in the alternative energy and sustainable fuels segments in both the US and Latin America. He has also worked extensively with new markets, market research and market development, looking at new technologies and applications in the Green technology and Energy/Power sectors.

Mark holds a Bachelor's degree from Middlebury College and an MBA from the Olin Graduate School of Business. He is tri-lingual in Spanish, Portuguese, and English.

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