Remote Transformer Monitoring: One Size Does Not Fit All

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SERIOUS TRANSFORMER RELIABILITY

Executive Summary

As an industrial reliability and maintenance professional, it's your responsibility to ensure that any equipment installed to support your electric power system is both the best fit for that system and the **best investment** in terms of capital expenditure and operating cost.

There are several factors to consider when purchasing and installing this equipment on your transformer. Many of these factors will be specific to an individual transformer and application and will be detailed in the purchasing specification. This document supplements those factors with a detailed overview of remote transformer DGA monitoring, focusing on variables that affect any monitor purchase:

- Does the monitor provide an appropriate level of protection for the level of criticality of an individual transformer?
- Is it possible to upgrade this monitor in the future, if needed?
- Is there an alarm management philosophy in place to reduce or eliminate false alarms?
- Does the monitor fit the budget?
- What are the benefits of various sensing technologies?

Overview

The utility market has embraced multi-gas online transformer monitoring because that equipment provides all the insights of Dissolved Gas Analysis (DGA) at an exponentially greater frequency than manual sampling and laboratory-based DGA, allowing for more sophisticated trend analysis using transformer management software.

The increase in frequency means that incipient faults are much more likely to be detected early, and critical transformers are more likely to live longer, healthier, lower-cost lives with a lower risk of premature failure.

In the industrial market, however, that decision is more complex. The industrial world has relied heavily on both manual sampling and single-gas hydrogen

monitoring, in part because single-gas monitoring equipment is significantly less expensive than multi-gas monitoring equipment, but also because the data is much simpler to parse; if there is a significant uptick in hydrogen concentrations, it's time to verify with an inspection, a manual sample, and a complete DGA test to diagnose the issue.

But as the demand for plant productivity reaches closer to the conceptual ideal of 100 percent, the market for multi-gas monitors has grown. Prices have adjusted to reflect this too, and the unit cost of multi-gas monitors is now at point where the nuanced analysis of multi-gas transformer monitoring is now a financially viable option for a large pool of industrial companies.

While multi-gas monitors may have become more affordable, they are still relatively more expensive than their single-gas counterparts, steering the conversation amongst procurement and reliability professionals towards one of **criticality**.

Which technology is the "best fit" for the application? Does a transformer that powers the floodlights of a strip mall need the same level of protection as a transformer that powers an arc furnace? What are the risks versus the rewards in terms of dollars and in terms of safety?

Monitoring alone cannot protect your electric power system. That responsibility falls on the shoulders of the professionals in your organization who are monitoring the data, the consultants and experts used to analyze the data, and the dashboard used to turn that data into meaningful insights.

The choice between monitoring systems, then, is not one of "good/better/best." Rather it is a choice of which monitor fits the specific needs of your equipment, your operation, and your company's mission, and one that should be made on a transformer-by-transformer basis.

SINGLE-GAS MONITORS

Single-gas monitors detect **hydrogen (H2)** levels in transformer oil.

Hydrogen accompanies most known transformer faults, which makes single-gas monitors an excellent indicator that something has gone wrong inside the transformer.

If a single-gas monitor detects a significant spike in H2, the specifics of the fault can then be determined with a full Dissolved Gas Analysis (DGA) profile and, if

necessary, an array of chemical, mechanical, and electrical testing to reveal the specifics of the fault.

There are inherent limitations with single-gas monitoring, however. Some transformer faults only produce trace amounts of H2, and if the trace amounts of H2 are not significant enough to register on the monitor, or the limits are set in such a way as to not trigger regular false alarms, serious (and even catastrophic) faults could remain undetected.

Single-gas monitors provide less value than multi-gas monitors if installed on a transformer that is already gassing. If the transformer is already showing a fault condition, an H2 monitor does not provide the nuance required to trend the worsening condition of that fault.

Single-gas monitoring also presents a practical challenge in setting alert or alarm limits. Setting the sensitivity of alerts and alarms to provide early detection of low temperature faults may result in "false alarms," where natural variation in gas concentration or stray gassing may trigger an alert or alarm when no fault condition exists. Single-gas monitors have an elevated risk of being regarded as a nuisance if alarm set points are not intelligently set and monitored by personnel with DGA and transformer expertise.

This risk is mitigated with **third-party remote monitoring services.** If the device is monitored by transformer management experts, the limits can be set to parameters tailored to the transformer, reducing false alarms and putting all legitimately triggered alarms in the hands of professional analysts first. The reduction in false alarms means that incipient faults are brought to the attention of the transformer owner with advice on what to do next and allows immediate access to technicians who will follow up with a full DGA profile.

Single-gas monitors do not detect conditions that would indicate the slow aging of the cellulose insulation, which can be assessed with the presence of carbon monoxide.

Despite these limitations, single-gas monitors are excellent for improving reliability across a fleet of transformers. They are very reliable, they do not require substantial maintenance, and they are considerably more affordable than multi-gas monitors.

Single Gas Monitor
H_2

PROS

- Lower cost.
- Increased likelihood of detecting more problems across an entire fleet.
- Simpler to understand than multi-gas.
- Require very little maintenance.

CONS

- May not detect small enough amounts of H2 and lead to missed (and potentially catastrophic) faults.
- Do not provide sufficient data for full diagnostics.
- Only suitable for non-gassing transformers.
- Requires a sophisticated alarm philosophy to manage false alarms.

Five-gas Monitor

H_2, CH_4, C_2H_4, C_2H_2, CO

PROS

- Same cost for expert monitoring as single-gas.
- Provides the data required for detecting and diagnosing faults.
- Detects faults that may be missed with single-gas monitors.
- Detects problems in the cellulose insulation.

CONS

- Higher unit cost upfront.
- More complex equipment that requires specialized knowledge to operate and maintain knowledge than single-gas monitor.
- Require more maintenance than single-gas monitors because of moving parts.
- Requires a sophisticated alarm philosophy to manage false alarms.

FIVE-GAS MONITORS

Five-gas monitors detect **hydrogen (H2), methane (CH4), ethylene (C2H4), acetylene (C2H2),** and **carbon monoxide (CO)** in transformer oil.

Hydrogen, the gas that is measured in single-gas transformer monitors, is an essential component of five-gas monitors because hydrogen accompanies most transformer faults. With the addition of **methane, ethylene,** and **acetylene,** however, the data collected becomes much more valuable in terms of diagnostics. These key gases provide additional data points that allow for analysis of what the fault might be, whereas trending results from a single-gas monitor only indicates that one exists.

This means that professional analysts can use those data points with diagnostic tools such as **Roger's Ratio, Duval's Triangle, Duval's Pentagon** or, preferably, a sophisticated **combined analytical approach** to understand the specifics of a fault as it happens. These industry standards allow analysts to precisely diagnose **thermal faults, low- and high-energy discharges, and partial discharges.**

Full descriptions of the causes and potential repercussions of the faults that these analyses can detect are beyond the scope of this document, but it's worth noting that none account for what might be happening in the cellulose insulation—that requires **carbon monoxide** measurements.

Oxidation of the cellulose insulation surrounding transformer windings leads to degradation of this insulator, which weakens the dielectric effect and decreases its ability to effectively insulate the windings. There are many tests that can reveal the degree to which the paper insulation is damaged, and a reliable indicator of paper degradation is **carbon monoxide** levels in the oil. Increases in the levels of carbon monoxide over time suggest that there is an issue with the cellulose insulation, which can be verified with further testing and analysis.

Five-gas monitors are effective at detecting dangerous faults that may be missed with single-gas monitors. Arcing is not only one of the most destructive faults within a transformer, but it is also one of the most hazardous. **Acetylene** accompanies arcing and overheating. Five-gas monitors detect precise levels of acetylene, so it is possible to track thermal faults in a way that is impossible with the trace amounts of hydrogen tracked by single-gas monitors.

NINE-GAS/FULL DGA MONITORS

Nine-gas monitors detect **hydrogen (H2), methane (CH4), ethylene (C2H4), acetylene (C2H2), ethane (C2H6), carbon monoxide (CO), carbon dioxide (CO2), oxygen (O),** and **nitrogen (N)** in transformer oil.

A nine-gas monitor can sample and measure all gases included in manual DGA. There are obvious benefits to this level of sophisticated analysis. DGA tests are often performed on an annual or semi-annual basis, or even more frequently for mission-critical transformers. An online monitor exponentially increases the frequency of these tests, allowing for an almost immediate response when incipient faults conditions are detected.

High levels of **oxygen** can accelerate the oxidation and decomposition of the cellulose insulation, and elevated levels of **carbon monoxide** and **carbon dioxide** can indicate degradation of the insulation.

Unlike single-gas monitors, nine-gas monitors can be installed on a transformer that is already gassing because they provide a complete profile of the gases inside the transformer and allow for that data to be analyzed for trends using **transformer management software**.

Nine-gas monitors offer a significantly more precise and nuanced analysis than five-gas monitors because they:

- Detect faults at a very early stage, which enables the transformer owner to order precise follow-up tests and complete more precise maintenance
- Detect **sub-faults**, which are nuanced subcategories of faults
- Provide a full DGA profile of the equipment that can be trended over time

Nine-gas Monitor

H_2, CH_4, C_2H_4, C_2H_2, CO, C_2H_6, CO_2, O, N

PROS

- Same cost for expert monitoring as single-gas.
- Provides full DGA profile of the transformer, detecting and diagnosing faults and more nuanced sub-faults.
- Detects faults that may be missed with single-gas monitors.
- Detects problems in the cellulose insulation.

CONS

- Higher unit cost upfront.
- Requires more knowledge than single-gas monitor.

SAMPLING TECHNOLOGY

Multi-gas monitors use different types of measurement technology, each with their own limitations and advantages. **Gas Chromatography** is the most accurate technology available on remote monitoring equipment, close to the standards of laboratory testing.

There are concerns, however, that the use of Gas Chromatography in monitors could potentially cause damage to the equipment on which it is installed. There is the possibility of carrier gas leakage into the tank, and there are financial implications of regularly replacing carrier gas tanks, which can be expensive depending on sampling frequency.

With **Infrared Spectroscopy**, there are no consumable gases and no gas cylinders to replace, which means lower long-term maintenance costs for the monitor. Infrared Spectroscopy does not measure hydrogen, oxygen, or nitrogen in transformer oil, so multi-gas monitors that rely on Infrared Spectroscopy technology must also include additional sensors to collect that data. With this in mind, modular technologies that allow for individual components to be swapped out are preferred because maintenance on those units are simpler and less expensive.

REMOTE ACCESS AND COMMUNICATION

All three types of monitor typically share the same secure cellular communication protocols. The North American Electric Reliability Corporation (NERC) regulates data transfers between utility providers, electrical asset owners, and third parties as part of the Critical Infrastructure Plan (CIP). The CIP was created as an industry standard to protect electrical utility equipment from malicious attacks. In industrial contexts, these monitors do not fall within the purview of the NIRC CIP regulations due to the nature of the data transfer involved—data is transmitted directly between the monitor and the client server via a Virtual Public Network (VPN), rather than via the asset owner's own server.

The three monitors described utilize a specialized industrial cellular modem with built-in VPN technology to provide and encrypted and secure connection between transformer and server; as such, malicious attacks and equipment theft cannot be used to steal data. In fact, by using an encrypted VPN, data transfer is considered more secure than baseline NERC CIP requirements for similar data types.

In short, the communication method used for each monitor is very secure and very reliable.

INTERPRETING RESULTS FROM MULTI-GAS MONITORS

Hydrogen monitors provide a binary solution to monitoring. If levels are normal or consistent, an alarm is not triggered. If they are elevated or increasing, additional testing and/or maintenance will be performed to determine the fault. The first test performed will probably be a complete DGA.

Interpreting these results correctly is a challenging task that should be entrusted to a transformer expert. The IEEE standard C57.104 strongly

recommends that a transformer expert with DGA interpretation experience should be involved in the process. DGA testing is an incredibly powerful diagnostic tool. There are several methods for interpreting DGA results (including Duval's Triangle and Roger's Ratio, to name two of the most commonly used), each with their own parameters for accuracy and precision. While these diagnostic tools inform the interpretation of the data, they are not the only metrics used for diagnosis.

Herein lies the benefit of using transformer experts: in addition to reading the gas levels, they interpret results based on a large number of variables, such as equipment type, liquid type, past history and trending, the historical specifics of that model and the manufacturer, the age of the transformer, its rating, voltage, gallon capacity, breather type, oil temperature, and service history, among others.

The combination of this expertise with transformer management software allows transformer owners to fully leverage the equipment they use to monitor their electric power assets.

CONCLUSION

Single-gas, five-gas, and nine-gas monitors offer varying degrees of insight into what is happening inside a transformer. Single-gas monitors provide a single data point that can provide an early warning for many kinds of incipient fault. Five-gas monitors provide the data required to remotely diagnose faults. Nine-gas monitors are capable of providing a complete DGA profile of the transformer, which allows even more detailed and precise information on fault conditions at an early stage.

• **Monitoring is not a substitute for more precise case-by-case testing.** Gas monitors are tools for measuring changes in the dissolved gases present within transformer oil, so it is possible to detect faults early and perform further tests.

• **Without analysis, the data has no value.** Monitors are a tool used by engineers, transformer specialists, and maintenance professionals to determine whether further testing is required, whether maintenance is required, and the level of urgency with which they should be performed.

• **Specialized transformer management software is not optional.** Data from all monitors should be analyzed for trending. Although a full DGA profile of a transformer is an excellent indicator of its health, the real benefit of these technologies is their ability to detect fluctuations in the levels of key gases in transformer oil by tracking those changes over time.

• **Monitors should be selected based on application.** Decisions on which approach to take are a balance of criticality (how important the transformer is), budget (how much is available to spend on keeping the transformer healthy), and condition (whether or not the transformer is exhibiting a fault condition already). A transformer that is quick to replace, or is part of a double-ended substation, or can shut down and be replaced without significant damages or loss of production time, for example, may not require the same attention as a transformer that powers the operating rooms of a critical care hospital ward.

The Guardian Monitoring service from SDMyers allows you to monitor the health of your equipment with exponentially more data than standard routine oil testing. When connected with Transformer Dashboard®, you get the trend analysis and graphing capabilities you need to help you plan your maintenance and prevent transformer failure.

With more than 55 years of experience, SDMyers is the industry leader in Intelligent Transformer Management, a maintenance philosophy that ensures measurable and sustainable transformer reliability. With the largest transformer oil testing facility in the world and a deep understanding of the chemical, electrical, and mechanical requirements of transformer reliability, we are an authority in transformer management.

Speak to an SDMyers Guardian Monitoring specialist to help you determine your needs.

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