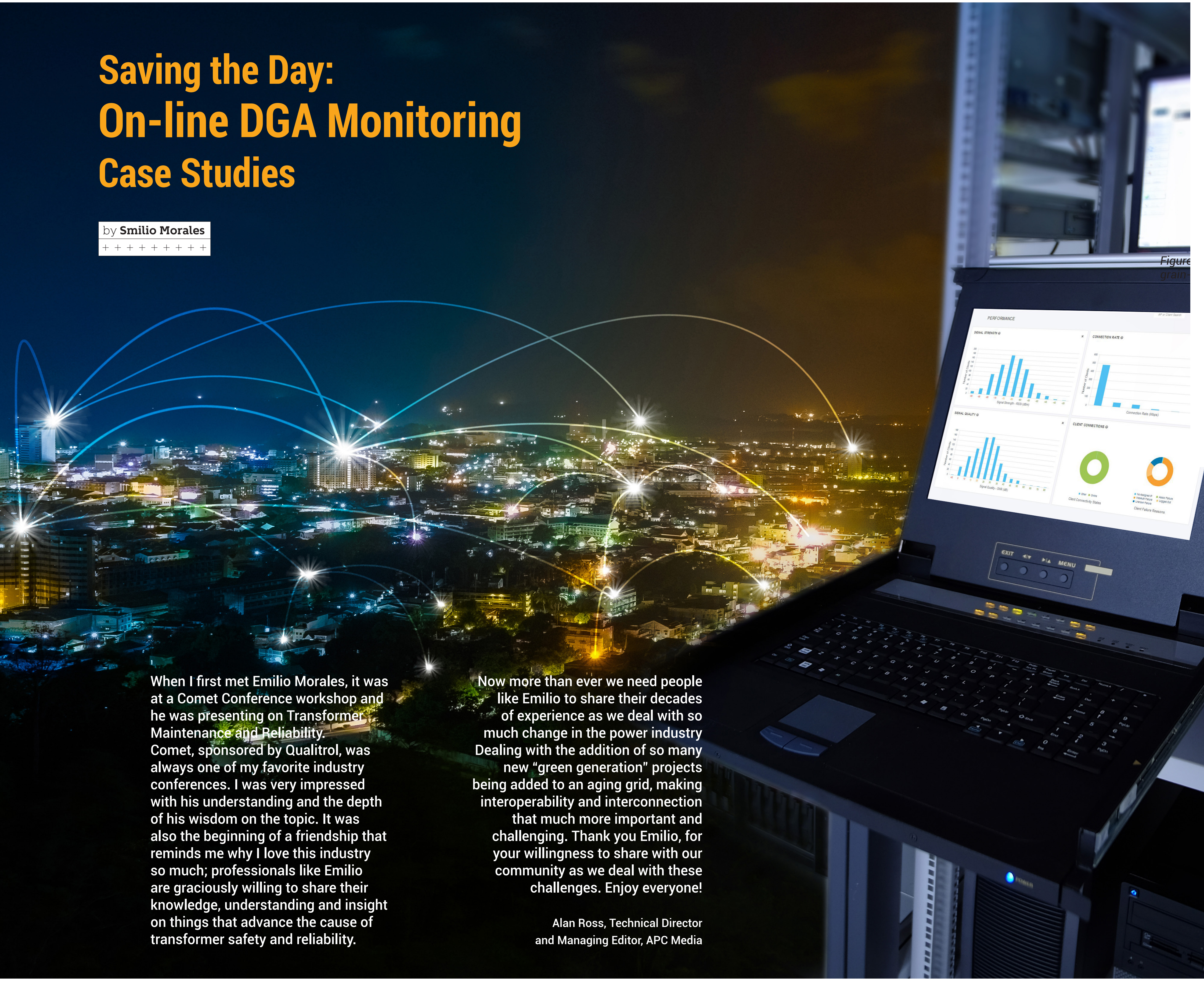


Saving the Day: On-line DGA Monitoring Case Studies

by **Smilio Morales**

When I first met Emilio Morales, it was at a Comet Conference workshop and he was presenting on Transformer Maintenance and Reliability. Comet, sponsored by Qualitrol, was always one of my favorite industry conferences. I was very impressed with his understanding and the depth of his wisdom on the topic. It was also the beginning of a friendship that reminds me why I love this industry so much; professionals like Emilio are graciously willing to share their knowledge, understanding and insight on things that advance the cause of transformer safety and reliability.

Now more than ever we need people like Emilio to share their decades of experience as we deal with so much change in the power industry. Dealing with the addition of so many new "green generation" projects being added to an aging grid, making interoperability and interconnection that much more important and challenging. Thank you Emilio, for your willingness to share with our community as we deal with these challenges. Enjoy everyone!

Alan Ross, Technical Director
and Managing Editor, APC Media

Photo: Shutterstock

Emilio Morales attended Nuevo Leon State University in Mexico, receiving his bachelor's degree in Electromechanical Engineering in 1980. He has over 30 years of experience in power transformer design which includes transformers up to 500 MVA and 500 kV, furnace and rectifier transformers and reactors. He is member of the IEEE/PES Transformer Committee, IEC and CIGRE. He previously worked with GE-Prolec, Ohio Transformer, Sunbelt Transformer and Efacec. He joined Qualitrol in June 2012 as a Technical Application Specialist in transformer applications. His focus is to support solutions in comprehensive monitoring for transformer applications.

On-line DGA have the unique ability to continuously trend transformer fault gases and correlate them with other key parameters such as transformer load, oil and ambient temperatures, as well as customer specified sensor inputs. This capability enables users to relate gassing to external events, a key to determine the existence or type of a fault. A study has also shown that some on-line DGA tools offer better accuracy and repeatability than laboratory DGA. Specifically, those with on-board automated calibration verification that ensures performance to specification throughout the entire operating life of the monitor. This can improve the transformer asset manager's decision timeliness and confidence when incipient faults are detected.

The ability to automatically populate traditional DGA diagnostic tools with on-line DGA data offers users of on-line DGA monitors unprecedented insight into the nature and identification of developing faults. The tools are typically ratio-based, and the on-line data set enables trending of fault gas ratios over time rather than the traditional static snapshots. Diagnostic outcomes can now be determined quickly and with more certainty than in the past. The use of on-line DGA monitoring has allowed the detection of developing faults in transformers in a timely manner. On-line DGA monitoring has produced multiple case studies that document the development of critical faults, which could cause catastrophic transformer failure if left undetected, in timeframes from a few days to a few weeks, where there was a low probability of capturing these rapidly developing fault conditions with a laboratory or portable-based transformer DGA testing program. This article presents some of those cases.

The use of on-line DGA monitoring has allowed the detection of developing faults in transformers in a timely manner.

Case 1: It's important to measure Oxygen in DGA

BACKGROUND

An 8 gas monitor is monitoring an old (30+ years) 3-phase 230kV shell-form nitrogen (N_2) blanketed GSU. At midday on Nov 16th, the monitor alarmed for increasing concentration of Oxygen (O_2), which had been stable at 130ppm for an extended period. Over the course of the following 3 days O_2 concentration continued to increase, peaking at 2,150ppm before gradually declining back to a stable 200ppm.

Reviewing the data around the time of the sudden increase in O_2 concentrations using proprietary data management system, no fault is detected using any of the established diagnostic methods.

OUTCOME

The sudden O_2 increase, with no associated change in any other gas indicated that the O_2 originated from the atmosphere. The supporting vendor experts suggested that the transformer may have had an atmospheric air injection and requested the operator to investigate. Upon a physical examination of the transformer, it was noticed that there was a leaky manhole cover gasket and that the pressure of the nitrogen blanket was close to atmosphere. It was determined that a partial vacuum occurred in the transformer during a cool down that resulted in atmospheric air being sucked into the transformer.

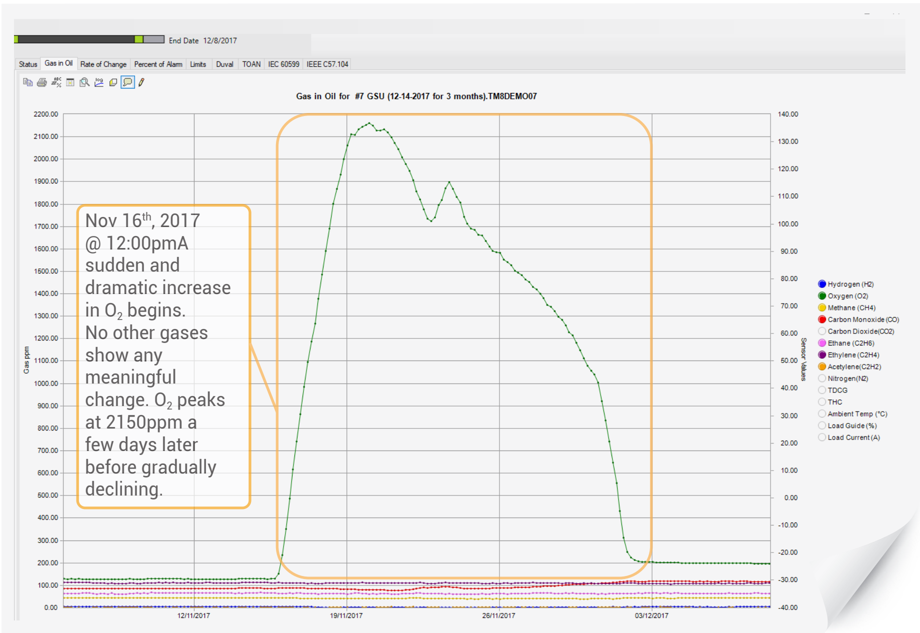
O_2 can facilitate oxidation in the transformer and thus shorten the life of the paper. However, the big concern with a transformer sucking atmospheric air in is that inevitably, it also brings moisture into the transformer.

While none of the modern diagnosis methods explained this sudden increase in O_2 it was possible to detect this incident with online DGA, deduce the cause and implement corrective action. If O_2 was not monitored this process could have occurred many times over without being detected, drawing a lot of moisture into the transformer.

N_2 pressure does not prevent entrance of water — only a good gasket seal does.

NOTE

While this incident occurred on a N_2 blanketed transformer the same vacuum conditions can occur within an operational constant oil preservation system (COPS) transformer. This can occur during cool-down if breather piping to the atmospheric is too narrow or is restricted and air cannot enter fast enough to avoid a vacuum in the main tank. A vacuum can then suck air past a gasket that does not show an oil leak. Another obscure fact is that degassed oil is effectively a vacuum to the atmosphere and in a sealed system can create a vacuum in the gas phase. It's important to give the oil time to reach equilibrium with the N_2 blanket to avoid this situation.



> **N_2 pressure does not prevent entrance of water — only a good gasket seal does.**

Case 2: Hour by hour changes catch a developing fault

BACKGROUND

Once again an 8-gas monitor is used on a single-phase 336 MVA, 500/230 kV autotransformer. The transformer was placed into service in 1979. This transformer is known to have gassed in the past and base levels of hydrocarbons are as high as 100ppm. At 1:00am on June 23rd, the monitor alarmed for Rate of Change increases in concentration of Ethylene(C_2H_6) and Methane (CH_4) both of which had been elevated but stable for several months. Over the next 5 days the operator kept the transformer under load for operational purposes and carefully monitored all gases. When Acetylene (C_2H_2) climbed to an actionable level (10ppm) the transformer was taken off load.

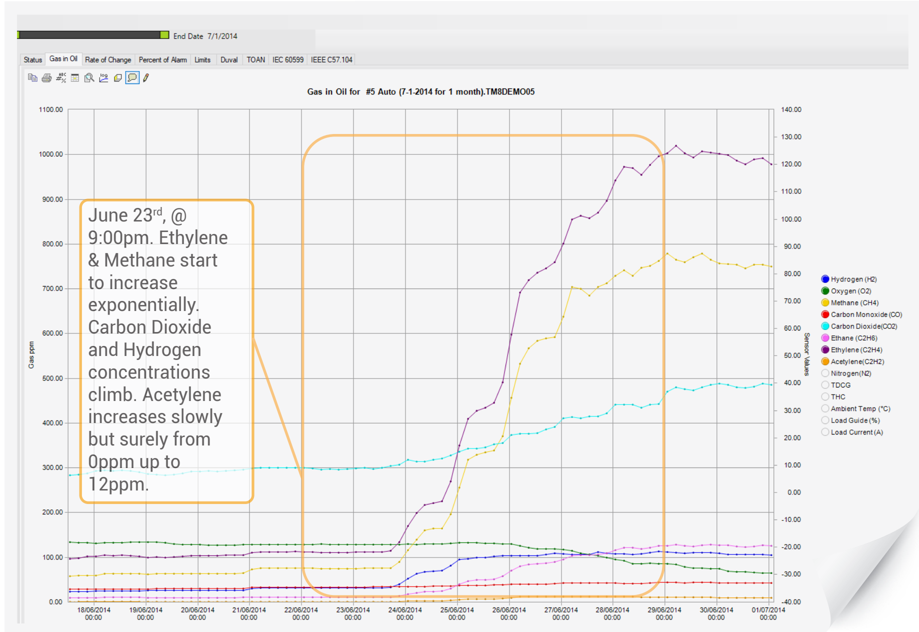
Reviewing the load data around the time of the increasing gas generation rate it was observed that the transformer had been heavily loaded at the time and that increasing load correlated well with increasing gas production. Reviewing the DGA data, Duval Triangle 1 indicated High temperature overheating while Triangle 5 indicated Medium to High temperature hot spots.

However, this diagnosis would have been the same before the exponential increase in gases occurred as can also be seen from the Duval diagnosis. The key to managing this situation was that the user could see the gas levels increasing dramatically over a very short period of time and knew when to take the transformer offline before runaway conditions developed. This is something that periodic offline testing would not provide for.

OUTCOME

The transformer was taken to a repair shop where maintenance personnel found carbon deposits in damaged insulation that is used to isolate the core and coil assembly form the tank. Repairs were undertaken and the transformer was put back into service. Despite the repairs the transformer continues to gas at a slow rate and is scheduled for replacement over the next few years.

In this case the transformer was known to have gassing issues but was needed for operational purposes. Despite its known issues it was used safely because its gassing could be monitored on an hour-by-hour basis. This transformer will continue to be available as a spare together with online DGA until it can be replaced.



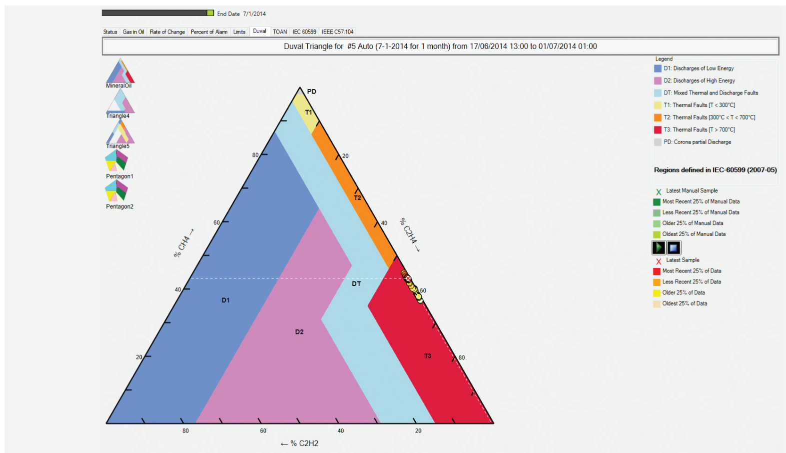


Figure 1: TRIANGLE 1. Thermal Fault >700°C

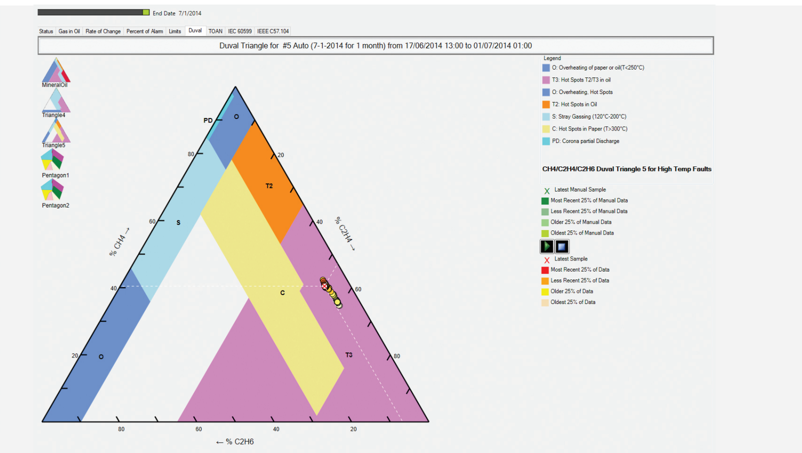


Figure 2: TRIANGLE 5 Hot Spots T2/T3 in oil

Case 3: Runaway fault detected by 8-gas monitor resulting in action to prevent a catastrophic failure

BACKGROUND

An 8-gas DGA monitor was being used to monitor a 3-phase, 1100 MVA, 345 kV GSU transformer. While gas concentration for all gases were relatively high and stable there was a sudden exponential increase on Aug 28th, 2016, at midday. While not recorded in the chart the transformer load was reduced by 50% after 48 hours of gassing and was reduced to zero load 8 hours later when it became obvious that the fault was not manageable by managing load.

Reviewing the DGA data resulted in the following indications at the point in time when the transformer load was reduced to Zero.

All diagnosis systems point to a thermal fault >300°C with some suggestion that there was paper involved. While the ratios of gases before this gas generation event occurred would have indicated the same diagnosis it was the rapid change in gas concentration, as alarmed by the Rate of Change alarming function in the monitor that drove the reduction in load and eventual full shedding of load.

OUTCOME

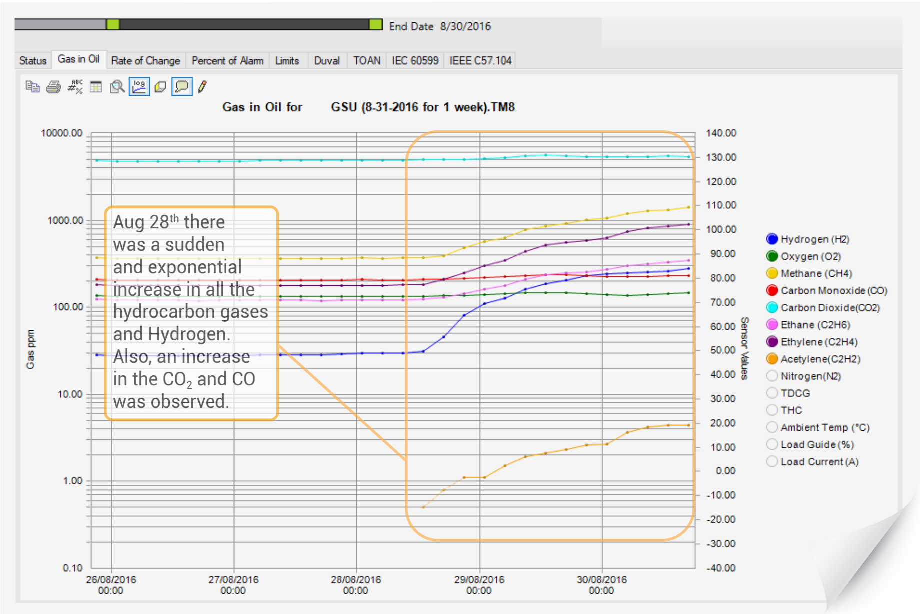
Upon physical inspection it was revealed that localized burning of

Diagnostic System	Result
Duval Tringle 1	Thermal Faults [300°C < T < 700°C]
Duval Triangle 5	Border of Hot Spots in Paper and Hot Spots in oil
Duval Pentagon 1	Thermal Faults [300°C < T < 700°C]
Duval Pentagon 2	Thermal Fault with carbonisation
TOAN	Overheated Oil: Immediate attention required, consider removal from service. (See Figure 2)
IEC 60599	Condition 2: Thermal Faults [300°C < T < 700°C]
Doernenburg Ratios	Thermal Faults [300°C < T < 700°C]
IEEE C57.104-2008	Condition 4. Immediate action required

paper had occurred. With paper stripped back from the crimped ends of the LV connection there was evidence of hot metal damage. Thus, it was concluded this was the site of the gas production.

The conclusion in this case was that the root cause was a combination of high eddy losses in the crimps, overheating because of over-insulation of the LV crimped connections and poor oil circulation in the crimped bundle areas. Remedial work was undertaken, and the transformer was subsequently put back into service.

In this case the transformer was known to have had historic gassing issues but was stable. After a period under full load the transformer suddenly started to produce large increase in gases which was notified to the user by a "rate of change" alarm on the monitor. Only Online DGA would provide this level of resolution in data, and it was this detailed insight that allowed the transformer operator to take the transformer offline before a catastrophic even occurred.



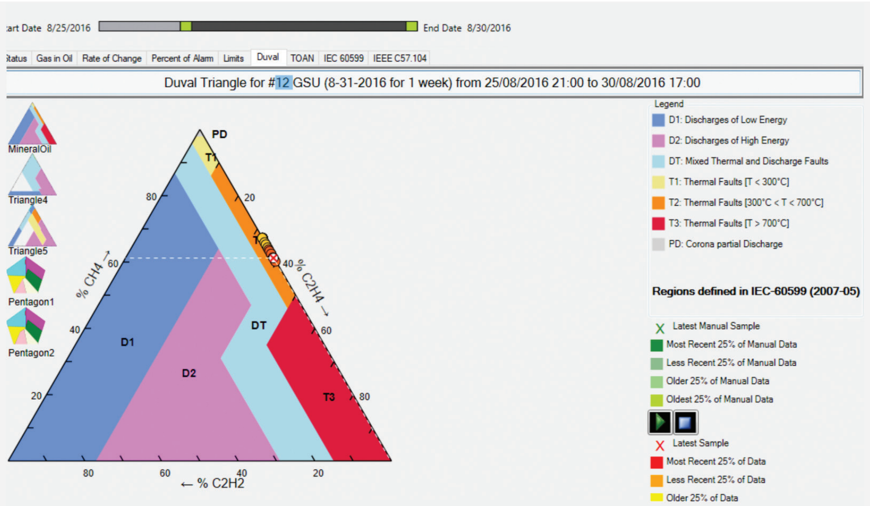


Figure 3: TRIANGLE 1. Thermal Fault 300°C – 700°C

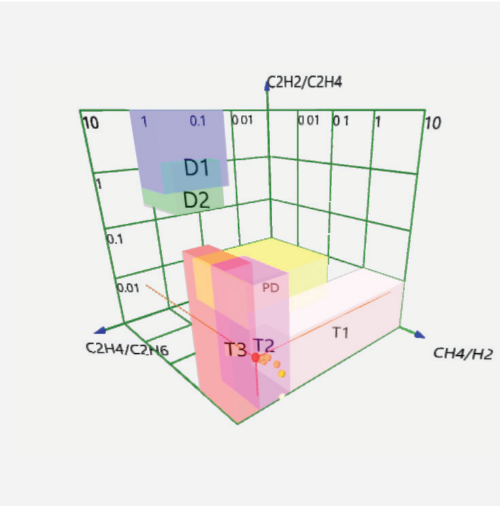


Figure 4: Rodgers Ratio indicating condition T3: Thermal Fault 300°C – 700°C

On-line DGA undoubtedly saves another transformer from catastrophic failure.

Photo: Qualitrol

Case 4: Gradual increase in gases detect a transformer design flaw

BACKGROUND

An 8-gas monitor was monitoring a three-phase 700 MVA, 400kV GSU transformer at a power plant in North America. This online DGA monitor was installed when the operator noticed year-over-year DGA lab data indicating increased levels of hot metal gases and a sustained growth in Carbon Monoxide. Unsure as to the nature of where and when these gases were being generated, a monitor was employed to provide hour by hour tracking of gas generation (Figure 5). Reviewing the DGA data with vendor software resulted in the following fault indications.

Table below represents Results of reviewing the DGA data on a range of common diagnostic systems. This is all performed automatically. All diagnosis systems pointed to a thermal fault >300°C with some suggestion that there was paper involved in the fault.

Diagnostic System	Result
Duval Tringle 1	Thermal Faults [300°C < T < 700°C]
Duval Triangle 5	Hot Spots in Paper >300oC
Duval Pentagon 1	Thermal Faults [300°C < T < 700°C]
Duval Pentagon 2	Thermal Fault with carbonisation
TOAN	Overheated Oil: Immediate attention required, consider removal from service. (See Figure 2)
IEC 60599	Condition 2: Thermal Faults [300°C < T < 700°C]
Doernenburg Ratios	Thermal Faults [300°C < T < 700°C]
IEEE C57.104-2008	Condition 4. Immediate action required

DGA lab data indicating increased levels of hot metal gases and a sustained growth in Carbon Monoxide.

OUTCOME

Physical inspection revealed evidence of significant overheating at the site of a brazed connection at the bottom end of the LV winding lead (Figure 6).

In addition to the discoloration of the metal associated with overheating (the source of the ethane (C_2H_6), methane (CH_4) and ethylene (C_2H_6)) there was also charred / burned paper which would have created CO and CO_2.

This transformer was repaired, together with appropriate design changes, the leads were retaped where the paper was significantly damaged and put back into service.

The four cases above show that On-line DGA provides the capabilities to track gradual increases in gases, facilitating predictive maintenance of an expensive and critical assets, and identify incremental changes in important gases in the presence of high accumulated PPMs of gases, which it is not possible with periodic lab DGA.

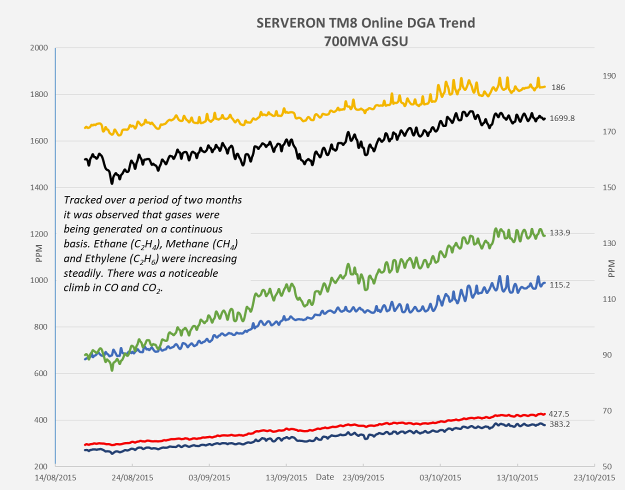


Figure 5. A gradual climb in 6 key gases was noted. There was no acetylene (C_2H_2), meaning this fault had not yet advanced to include any arching. The continuously increasing gas levels were a significant concern.

Figure 6: Overheated brazed connections at the bottom end of the LV winding lead.

Dates, times, and other details may have been changed to maintain the anonymity of the owner / operator in these case studies. All DGA data, timelines and technical specification are factually accurate.