Lessons from Action Planning in Power Transformer Monitoring

J. BEARDSALL[1], T. SALMON[2], S. RHOADS[3], T. MCGRAIL[4], P. BOREHAM[5]
Drax Power[1], Dominion Energy[2], National Grid[3], Doble Engineering[4,5]
USA[1,2,3,4], UK[5]

SUMMARY

This paper reviews cases related to response to condition monitoring alerts, and demonstrates the need to understand the context of the monitor data and to have appropriate response plans in place. In practice, condition monitoring cases are often presented in the literature as a linear progression from data to analysis to alert to action – which is how it is hoped be. However, there are occasions where the data is not as expected, the analyses are somewhat ambiguous, and the actions may need to be reviewed in the light of how the case actually progressed. The cases presented here are 'real' and illustrate the need for forethought in the application of condition monitoring as the consequences of failure may be severe. Case 1 is the appearance of PD on the neutral end of a generator after refurbishment and looks at the monitoring, expectations and resulting actions. Case 2 is the sudden rise in DGA levels on a large transmission transformer while in service, with the ensuing actions putting staff lives at risk. Case 3 is a bushing monitor power factor anomaly – allowing us to review the approach to data-analytics-alerts-actions employed and the need to understand the context of the individual monitoring application to an individual asset. The lessons learned include: the need to identify monitoring expectations and to make sure that data is generated to check expectation; to plan ahead for response as there may be not enough time added to a lack of organizational cohesion to make decisions in 'real time'; audit and review issues and actions so that we can prevent the monitor users going from 'ignorance to negligence'.

KEYWORDS
Power Transformer, Condition Monitoring, Action Planning

tmcgrail@doble.com

INTRODUCTION

Condition monitoring, when applied correctly, is more than just a 'box with lights on', monitoring provides data which can be used to detect incipient failure modes or diagnose specific faults within an asset. To provide value to the asset owner/operator, there needs to be an understanding of what values are expected for the data collected – what is 'normal' – so that variation from the norm can be indicated.

As a parallel, consider a smoke alarm in a domestic setting: the alarm monitors the air and may be designed to generate an alarm when the 'transparency' of the air falls, due to particulates which may be the consequence of combustion. In practice a 'false positive' may be generated by steam from hot water in a shower. Learning that an alarm may be generated in this way is sometimes a surprise – and the alarm has to be considered with reference to activities in the domestic setting.

CASE 1: GENERATOR PD

A 660 MW generator was fitted with PD couplers and monitored on all three phases plus neutral. To track the levels of PD, broadband spectra were taken using high frequency couplers Peak-to-Average-Power-Ratio (PAPR) used as a statistical analysis of the whole spectrum; PAPR indicates the presence of PD in spectral data: a useful PD detector. The B phase results, in Figure 1 show a strong rise in PD levels after the rewind with levels exceeding those previously seen and exceeding values set for 'high' level alerts. The B phase levels were not replicated on other phases or on the neutral
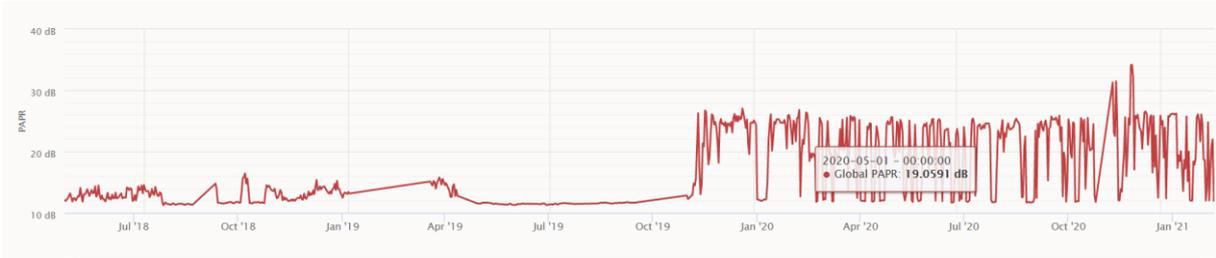

Figure 1 PAPR Values for B Phase Coupler before and after a rewind

The generator had been in service for several years, and was expected to last for several more years. The appearance of PD after the rewind was a surprise and seen as a step change in the unit's characteristics. As a result, detailed investigations were carried out using phase resolved and time resolved diagnostic methods, both individually and in comparison with other sensors on the generator. It was determined that the generator's new levels were 'acceptable' and a new 'normal' had been established. Monitoring continues with new alert levels and more attention paid to the couplers.

CASE 2: SUDDEN DGA CHANGE FOR 280MVA POWER TRANSFORMER

Hydrogen levels for a 500/230 kV 280 MVA McGraw-Edison power auto-transformer, built in 1991, showed consistently low laboratory DGA levels over several years after installation in 1994: hydrogen and hydrocarbons never totalling more than 30ppm in that time. On January 25th, 2018, the online monitor, giving hydrogen and carbon monoxide values, showed a rapid increase in hydrogen levels, as per Figure 2. As is often the case with

DGA Monitoring alarms, a sample is often recommended to be taken for laboratory analysis as a means to confirm the monitor values; such recommendations have appeared in both standards/guidelines publicly available, and in organizational response plans..
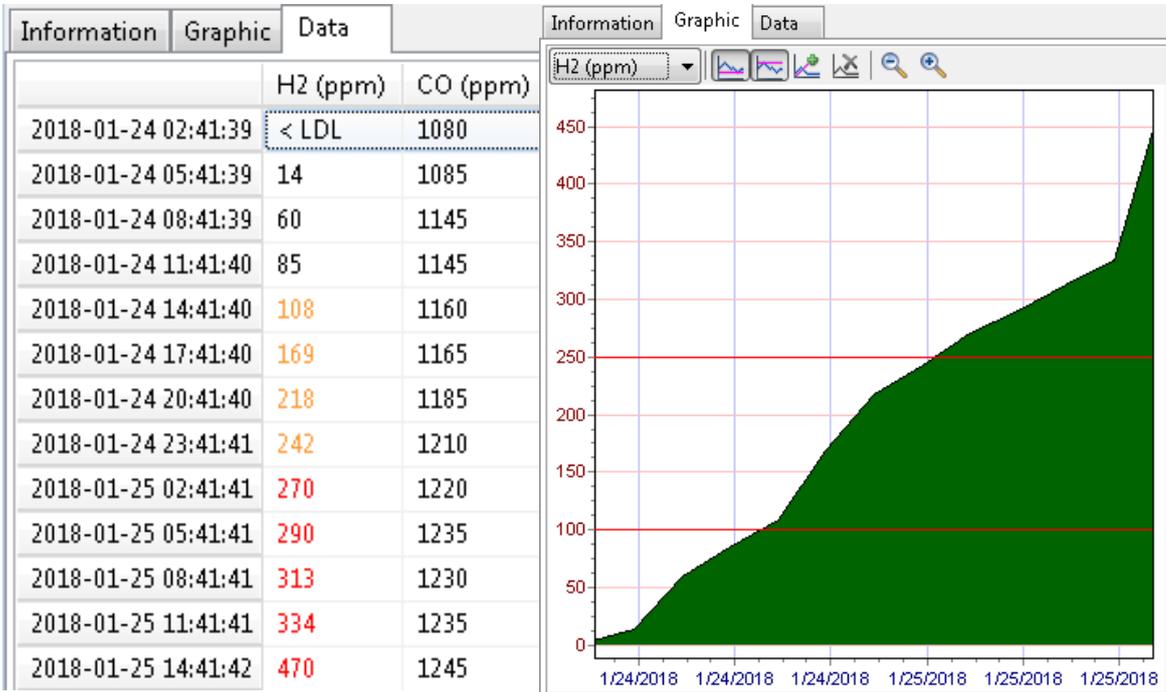

Figure 2: Online DGA results for the Transformer

The oil sample was taken for field evaluation using a high quality portable field test device with the results as per Table 1, which indicated a D2 fault according to the Duval triangle: a 'high-energy electrical discharge'.

Table 1: Portable DGA Results for Confirmation

Gas Name	Gas	ppm	C57.104 Condition
Hydrogen	H2	95	1
Carbon Dioxide	CO2	4788	3
Carbon Monoxide	CO	982	3
Ethylene	C2H4	63	2
Ethane	C2H6	20	1
Methane	CH4	55	1
Acetylene	C2H2	112	4

A second sample was due to be taken for laboratory confirmation when, unfortunately the transformer failed while the sample was being taken. The failure resulted in a main tank rupture, showering field staff with hot oil. However, there was no fire resulting and, fortunately, no fatalities. One question might be: would other organizations have responded in the same way?

As a result of the incident, new response plans were put in place: setting DGA monitor alert levels which would require controlled switching out of the transformer within a specific timescale; taking samples to check the online DGA data only after the transformer has been de-energized; asset management tracking of the levels and tuning responses for individual units.

It is a big step to move from treating monitoring data as an indication of a need to act, to one where monitoring data is trusted *per se*. However, the addition of condition monitoring means we have to be careful to avoid the other step: the one 'from ignorance to negligence'.

CASE 3: ANOMALOUS ONLINE POWER FACTOR

A tertiary bushing on a transmission auto-transformer showed anomalous power factor results, as per Figure 3: the monitor records the raw sinusoid waveforms of the leakage current through the bushing and applied voltage, as measured at an instrument transformer and uses those to calculate the relative and true power factor (RPF & TPF) of each bushing.
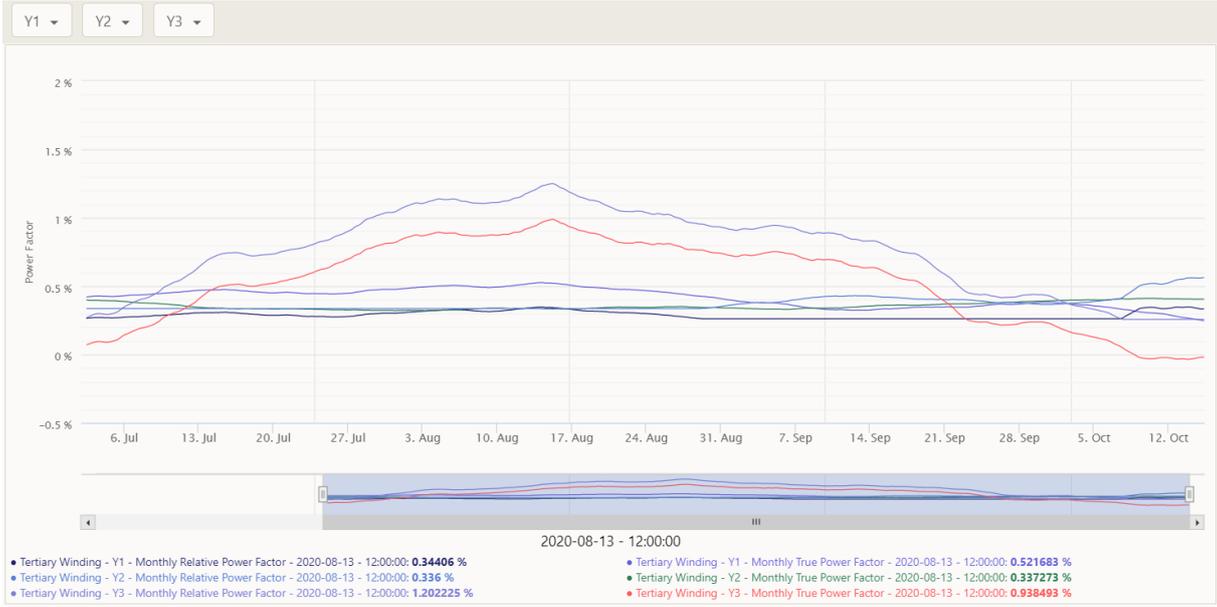

Figure 3: Relative and True Power Factors for three bushings

Figure 3 shows 6 sets of data: 3 RPF and 3 TPF, with the two rising/falling traces being the two associated with the Y3 bushing. These levels rise over a period of about 6 weeks, then fall back to nominal levels, before reducing further. What we need is a way to explain these results – is it possible that the bushing has deteriorated but then improved again? It is unlikely, but we need an alternate explanation!

In practice, offline bushing power factor tests can result in reduced or even negative power factor values: this may be the result of an alternate path to ground for the test current, diverting the current away from the test set and altering the resulting power factor.

In this case, the tertiary bushings have oil fill caps at the top of the bushings – and the Y3 fill cap gasket was cracked completely through at one point. Over time this had allowed water to enter the bushing, slowly increasing the C1 power factor as the oil quality deteriorated; however, as the water continued to infiltrate the bushing, it provided a resistive path to ground, which then reduced the C1 power factor, eventually forcing it negative.

Forensic analysis of the bushing revealed not only the cracked gasket but also the presence of water, sludge and X-wax within the bushing. The ingress of water explains the monitoring data and is used to identify similar failure mode inception with other bushings.

DISCUSSION

The different cases presented here show that condition monitoring is straightforward in theory, but not always straightforward in practice. Managing results from a PD detector, or a DGA diagnostic, or a bushing monitor will often require an understanding of:

- Data context and operational conditions, in terms of what else is going on at the asset
- what counts for 'normal' and what may be 'anomaly'
- standards/guidelines and their implications
- safety, risk and the need to protect staff as well as equipment