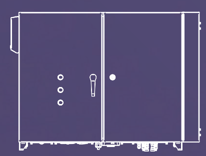


CONNECTING DATA TO DECISIONS

Case Studies

Linking Total Transformer Monitoring & Actionable Information
to Drive Business Value for Utilities

camlin energy

CONTENTS

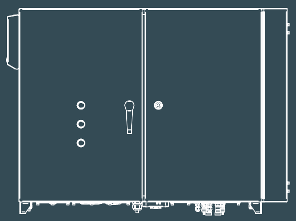
TRANSFORMING DATA TO DRIVE DECISION MAKING

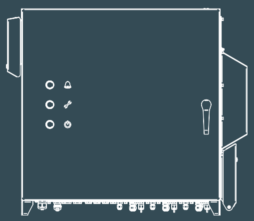
Power transformers are integral to the flow of energy and dynamic communication and could be viewed as the nerve centre in the era of digitalization of energy systems. However, environmental and operational factors can affect the health of an aged transformer fleet and reduce the capabilities and readiness for the technological change.

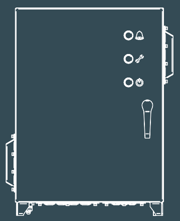
The use of a more holistic and integrated approach to transformer monitoring can significantly help to optimize maintenance and mitigate risk. Holistic means the treatment of the whole transformer, taking into account operational data, environmental data, external factors and previous experiences, rather than just a single diagnostic parameter such as DGA. The chances of identifying the failure mode or defect can dramatically increase, allowing asset owners to understand their risk and ultimately make prompt and better-informed decisions.

The following case studies demonstrate successful examples when the utility was able to plan preventive actions and maintenance thanks to the study of the correlation of two or more parameters.

TOTUS MONITORING


TOTUS G9


TOTUS G5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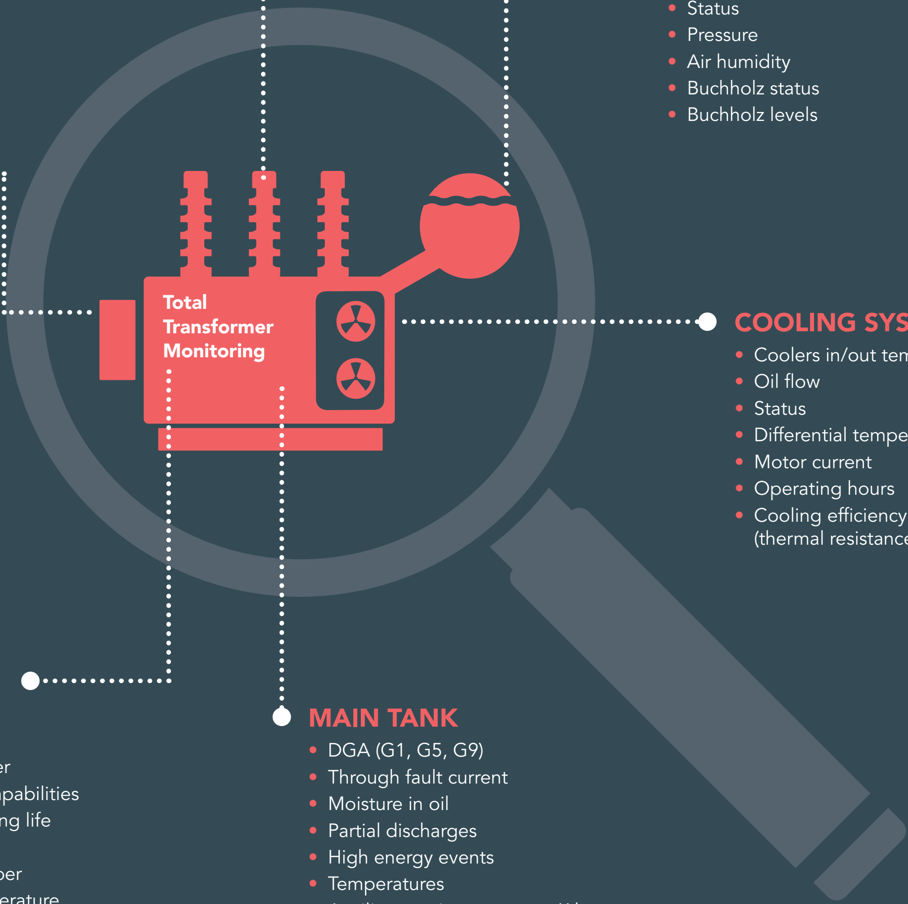
A holistic transformer monitoring approach

BUSHINGS
- Capacitance
- TanDelta / Power factor
- Partial discharges
- High energy events
- Voltage

CONSERVATOR AND OIL PROTECTION
- Oil levels
- Status
- Pressure
- Air humidity
- Buchholz status
- Buchholz levels

OLTC
- Tap position
- Differential temperature
- Status
- DGA
- Motor current
- Number of operations
- Acoustic emissions*



COOLING SYSTEM
- Coolers in/out temperature
- Oil flow
- Status
- Differential temperature
- Motor current
- Operating hours
- Cooling efficiency (thermal resistance)

ANALYTICS
- Load/Voltage
- Hot spots
- Apparent power
- Overloading capabilities
- Aging/Remaining life
- Losses
- Moisture in paper
- Bubbling temperature
- Transformer condition

MAIN TANK
- DGA (G1, G5, G9)
- Through fault current
- Moisture in oil
- Partial discharges
- High energy events
- Temperatures
- Auxiliary equipment status/Alarms
- Fiber optic direct hot spots
- GIC

* Focus area for future development

Only when monitoring all the key components and parameters, in synergy, can the factors of health, risk and reliability be better understood.

SOUTH KOREAN TRANSMISSION COMPANY REPLACES BUSHINGS DUE TO ONLINE MONITORING

Details
South Korean Transmission Company successfully replaces 345 kV bushing.

Evidence
Online monitoring showing capacitance increase and high energy events.

Bushing and partial discharge monitoring was installed in 2015 on a single-phase transformer bank in Ulsan, South Korea. The installed device was continuously monitoring the currents from the bushings and the partial discharges from both the main tank and bushings using properly designed tap adaptors installed at the bushing test taps. The acquisition was continuous (not scheduled) and simultaneous in all phases with the results summarized every hour. The bushings, from NGK, were 30 years old, OIP, 345 kV, around 430 pF of capacitance.

On February 2015, a sudden step increase of the capacitance (C1) in bushing A was detected by the monitoring system, estimating a capacitance change in the order of 1.7% which corresponds to a rough increase of 7 pF. Such a small change could have been caused by a partial short circuit between two layers in the condenser core, considering >60 control layers for 345 kV bushings. South Korean Transmission Company planned an offline test to confirm the online readings, but the results proved difficult to interpret. Indeed, the absolute value
of bushing A capacitance had not changed significantly from the previous measurements, as shown in Table 1.

Table 1. Offline results before (2012, 2014) and after (2015) the online alarm.

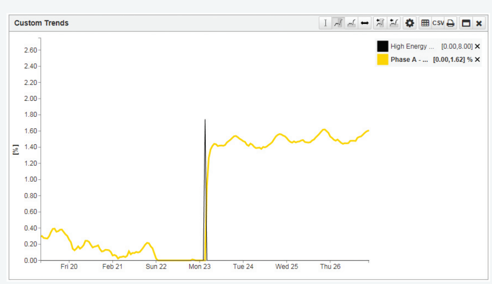
345 kV NGK Bushing OFFLINE Capacitance C1 (pF)				
	2012	2014	2015	Increase since 2012
Bushing A	435	429	438	0.60%
Bushing B	433	430	426	-1.60%
Bushing C	432	NA	430	0.46%

345 kV NGK Bushing OFFLINE Capacitance C1 (pF)				
	2012	2014	2015	Increase since 2012
Bushing A	435	429	438	0.60%
Bushing B	433	430	426	-1.60%
Bushing A-B	+2 pF	-1 pF	+12 pF	2.7%

However, it was noticed that while the increase of capacitance in bushing A was quite small, both bushings B and C were showing a decrease of capacitance. This led to the assumption that the test setup was different when readings were taken. In order to take this into consideration, the relative difference between capacitance A and B was analysed over time. It was then possible to spot that this difference was quite constant in 2012 and 2014 (below 2 pF), while it was significantly high in 2015, exceeding 12 pF (roughly equal to 2.7% of capacitance increase).

This offline test was not conclusive but led to further investigation of the online data.

Figure 1. Capacitance increase in bushing A1 and high energy event recorded at the same time.

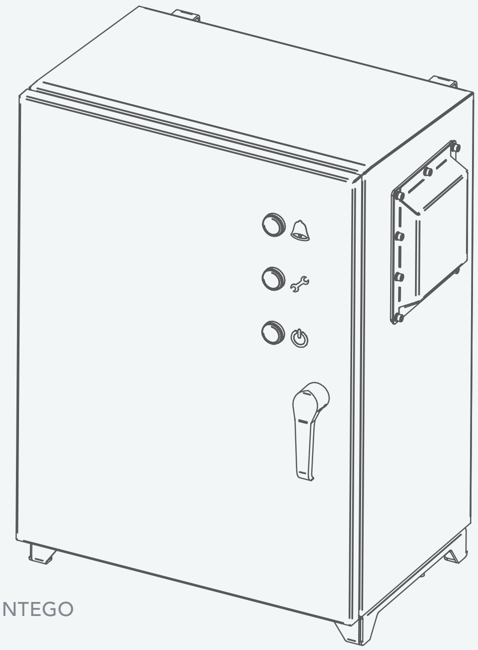


It was then found that at the precise moment of the bushing capacitance increase, a high energy event (partial discharge activity with significantly high magnitude, generally equal or higher than 20 V peak-peak [6]) was recorded in the same phase (from same sensor) by the online monitoring system. In this case, the recorded event had just 8 pulses per second and it happened just once. The fact that this event was recorded in conjunction with the capacitance increase was an important detail that prompted an additional offline test: oil sampling from the bushing and Dissolved Gas Analysis (DGA). Table 2 reports the results of the DGA analysis for bushings A and C.
It can be clearly seen that the amount of acetylene in bushing A is well above the tolerance values, being 76 ppm; while level of acetylene in bushing C was zero, as expected.

Table 2. Offline DGA results for bushings A and C

OFFLINE DGA results for Phase A and C bushings		
	Phase A	Phase C
H_2	17	28
CH_4	40	39
C_2H_2	76	0
C_2H_4	44	1
C_2H_6	32	62
CO	71	53
CO_2	564	789
N_2	150.862	156.665
O_2	10.280	4.337

Following the results shown in Table 2, South Korean Transmission Company promptly planned and executed the bushing replacement within a few months, thus saving the bushing from a potentially catastrophic incident. It must be noted that both the capacitance change and the repetition rate of the high energy event were quite small in terms of absolute magnitude. But being able to detect both these phenomena online and see that they occurred in the same moment provided crucial information enabling South Korean Transmission Company to take a very successful action.



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South Korean Transmission Company was able to take a very successful action thanks to the correlation of online data showing small variations of capacitance and partial discharges.

345 KV BUSHING REPLACED IN NORTH AMERICA

Details
The correlation of partial discharges and bushing monitoring data was successful in identifying the problem at a very early stage, ultimately saving the transformer.

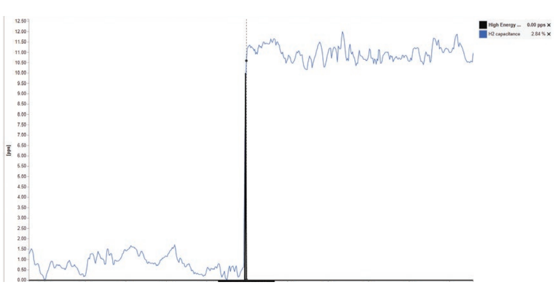
Evidence
High energy event was recorded in conjunction with a capacitance increase in the same phase.

Bushing and partial discharge monitoring was installed in 2018 on 504 MVA three-phase transformer in North America. The installed device had the same characteristics of the asset in Case #1 and was installed on a voltage tap on Westinghouse 1979 OIP bushings.

Similarly, to Case #1, a sudden step increase of the capacitance (C1) in bushing H2 was detected by the monitoring system, estimating a capacitance change in the order of 2.9%, which can correspond to a short circuit between two layers.

By looking at the data it was observed, once again, that a high energy event was recorded in conjunction with the capacitance increase in the same phase. Figure 1 shows the recorded data (not averaged, published every hour) and the partial discharge pattern. The event was characterized by impulses with significant magnitude (60 V peak-peak) and very small repetition rate (just 6 pulses per second), almost describing a sudden arcing activity. Recognizing the same correlation pattern (capacitance change + high energy event) seen in the KEPCO case, it was then suggested to the utility to take an oil sample of the bushings.

Figure 1. Capacitance increase in bushing H2 and high energy event recorded at the same time



The correlation of partial discharges and bushing monitoring data, along with proper offline tests, was successful in identifying the problem at a very early stage, optimizing the maintenance and ultimately saving the transformer.

Figure 2. Bushing tap adaptor for partial discharge and bushing monitoring

Table 1. Offline DGA results for bushings H1 and H2

OFFLINE DGA results for H1 and H2 bushings		
	2012	2014
H_2	20	85
CH_4	8	167
C_2H_2	<2	21
C_2H4	<2	645
C_2H_6	14	65
CO	75	714
CO_2	1.460	2.790
N_2	51.800	84.300
O_2	7.490	29.600
TDCG	117	1697
TDG%	6,07	11,79

Table 1 reports the comparison between the DGA from bushing H2 and H1, showing the acetylene concentration exceeding 20 ppm in the bushing where the capacitance change and high energy events have been detected, confirming the online analysis and enabling the utility to immediately plan the bushing replacement. The correlation of partial discharges and bushing monitoring data, along with proper offline tests, was successful in identifying the problem at a very early stage, optimizing the maintenance (in this case truly condition-based) and ultimately saving the transformer.

Most important:

- The absolute intensity of the capacitance increases, and the partial discharges were so small that if they were only considered individually and separately they would cause little concern.
- The combination of the two small deviations/anomalies occurring at the same time, plus the experience from previous similar cases, suggested the choice of the DGA oil sampling as confirmation test.
- It must be noted that DGA on bushings is not a routine testfor the utility's policy and it is carried out only in very exceptional cases.

EUROPEAN HYDRO PLANT INVESTIGATION

Details
25 MvA GSu with unknown defect under investigation.

Evidence
Investigate through holistic monitoring of DGA, partial discharge, and temperature and bushings.

A 25 MVA GSU transformer was installed in 1986 in a hydro plant in Europe. In 2018 the transformer underwent regular maintenance with the OEM who carried out the following actions:

- Oil degassing. The transformer had a history of abnormal but stable levels of hot gases due to a thermal issue such ethylene and methane. The fact that the gases were stable for a long time indicated that the defect was likely not active anymore.

- Replacement of the glass inspection window in the bushings. The transformer was originally not equipped with any monitoring system. After the maintenance, an oil sample was taken which showed abnormal levels of H2 in the range of a few hundred ppm. The OEM speculated that this could have been related to the same defect that generated the ethylene increase previously and was likely to be associated with hot spots.

Figure 1. Online holistic monitoring system installed in 25 MVA GSU

Since the new gas pattern was not actually showing "hot metal" gases and considering that the H2 increase was significant and coincidently occurring right after the maintenance, the generation company suspected that the defect was somehow related to the latest maintenance. The utility equipped the transformer with a comprehensive transformer monitoring system that included a five-gas monitor and modules for monitoring moisture, partial discharges, and bushings, as well as analytics capabilities and temperature readings.

After two months of results the following results were observed:

- After a first H2 increase of about 4 ppm/day, the subsequent two months showed that the H2 was still increasing but with a lower rate, at about 1.6 ppm/day, reaching an absolute ppm level of roughly 700 ppm. All other gases had normal concentrations. There was clearly an active defect.
- The partial discharge module immediately detected a persistent active partial discharge source in phase A. This activity had two components, likely indicating two different defects:
- The first is always present and constant in amplitude and repetition rate (5000 pps) with indirect polarity and typical for defects inside the main tank (including the bushing turrets, i.e. whatever is outside the bushing core). This activity has no cross coupling with the other phases which means that the source is far from the other two phases or very close to the partial discharge sensor.
- The second is sporadic, with smaller repetition rate (in the range of 1000-2000 pps) and with direct polarity indicating that it could be inside or very close to bushing A.The overall partial discharge activity was increasing over time in terms of repetition rate, indicating that the active defect was in phase A.
- From the phase-resolved partial discharge (PRPD) pattern it was difficult to identify the partial discharge source, however similar shapes of the pattern had been recorded when the oil treatment was not conducted properly leaving small air bubbles trapped, or when small puncturing activities were present in the paper insulation on the top of the winding column (e.g. in the stress ring).
- Looking at all the data collected by the holistic monitoring system, it is possible to see that there is almost no correlation to load temperature or humidity. The gas generation and partial discharge activity are not influenced by the load, nor by temperatures and humidity.

The first speculative analysis, after having looked at the online data, was leading towards the possibility that the defect was likely to be due to the last oil filling process that apparently had not been carried out under vacuum (due to the fact that gaskets are not suitable for the vacuum process).

The use of the total transformer monitoring not only aims at optimizing and deferring the maintenance to the best possible moment (generator annual stop) but is also a means to resolve the controversy between the OEM, responsible for the maintenance and oil process, and the transformer owner.

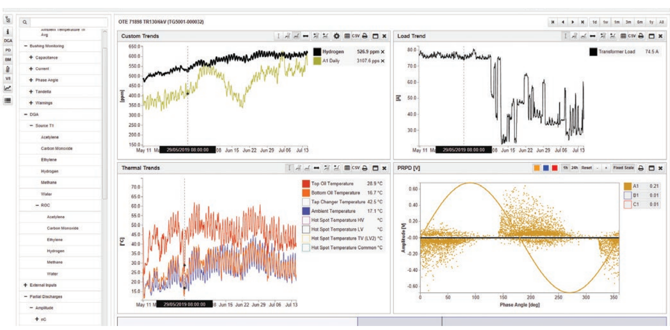


Figure 2. Online results synchronized and visualized in a way to enable further investigation on the possible correlation

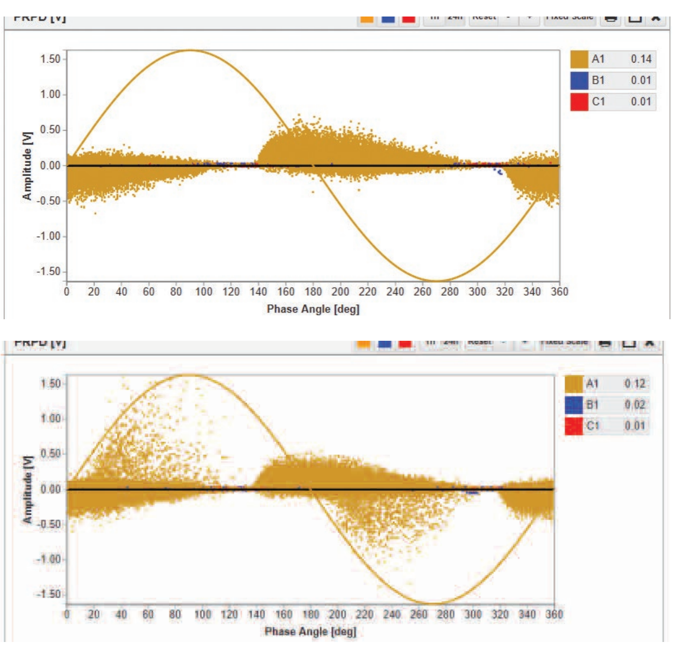


Figure 3. PRPD pattern of the stable partial discharge activity in Phase A1 (left) and the sporadic activity overlap (right)

Due to an absence of hot and arcing gases, the perfect condition of the bushings (in terms of capacitance and TanDelta) as well as the absence of a clear correlation with load or temperature, the utility decided to:

- Keep the transformer monitored and under control in order to analyse the gas and partial discharge development during the next few months.
- Plan the gasket replacements in order to perform a proper oil treatment and refilling under vacuum to remove any possible trapped bubble.
- Agree that maintenance was to be planned. However, this could be deferred to the next stop of the generator considering that:

– the overall picture provided by the online monitor indicated that the transformer was not in a critical condition, and

– the transformer was continuously monitored so any unexpected change in the condition would promptly notify the Subject Matter Expert.

In this case (which still under investigation at the time of publication) the use of the total transformer monitoring not only aims at optimizing and deferring the maintenance to the best possible moment (generator annual stop) but is also a means to resolve the controversy between the OEM, responsible for the maintenance and oil process, and the transformer owner.

Camlin Power Inc
1765 N. Elston Ave. Unit 105, Chicago, IL 60642
Email: mail@camlingroup.com
Tel: +1 773-598-4126

Camlin
31 Ferguson Drive, Lisburn, BT28 2EX,
Northern Ireland
Email: mail@camlingroup.com
Tel: +44(0) 2892 626 989

camlingroup.com

camlin energy