

# CONNECTING DATA TO DECISIONS

Case Studies - Volume 1

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



camlin energy



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Connecting Data to Decisions

## TRANSFORMING DATA TO DRIVE DECISION MAKING

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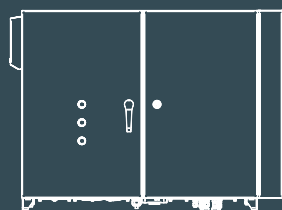
Power transformers are integral to the flow of energy and dynamic communication and could be viewed as the nerve centre in the era of digitalization of energy systems. However, environmental and operational factors can affect the health of an aged transformer fleet and reduce the capabilities and readiness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

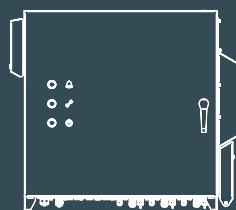
The following case studies demonstrate successful examples when the utility was able to plan preventive actions and maintenance thanks to the study of the correlation of two or more parameters.

## TOTUS MONITORING

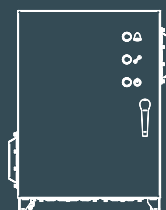
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TOTUS G9

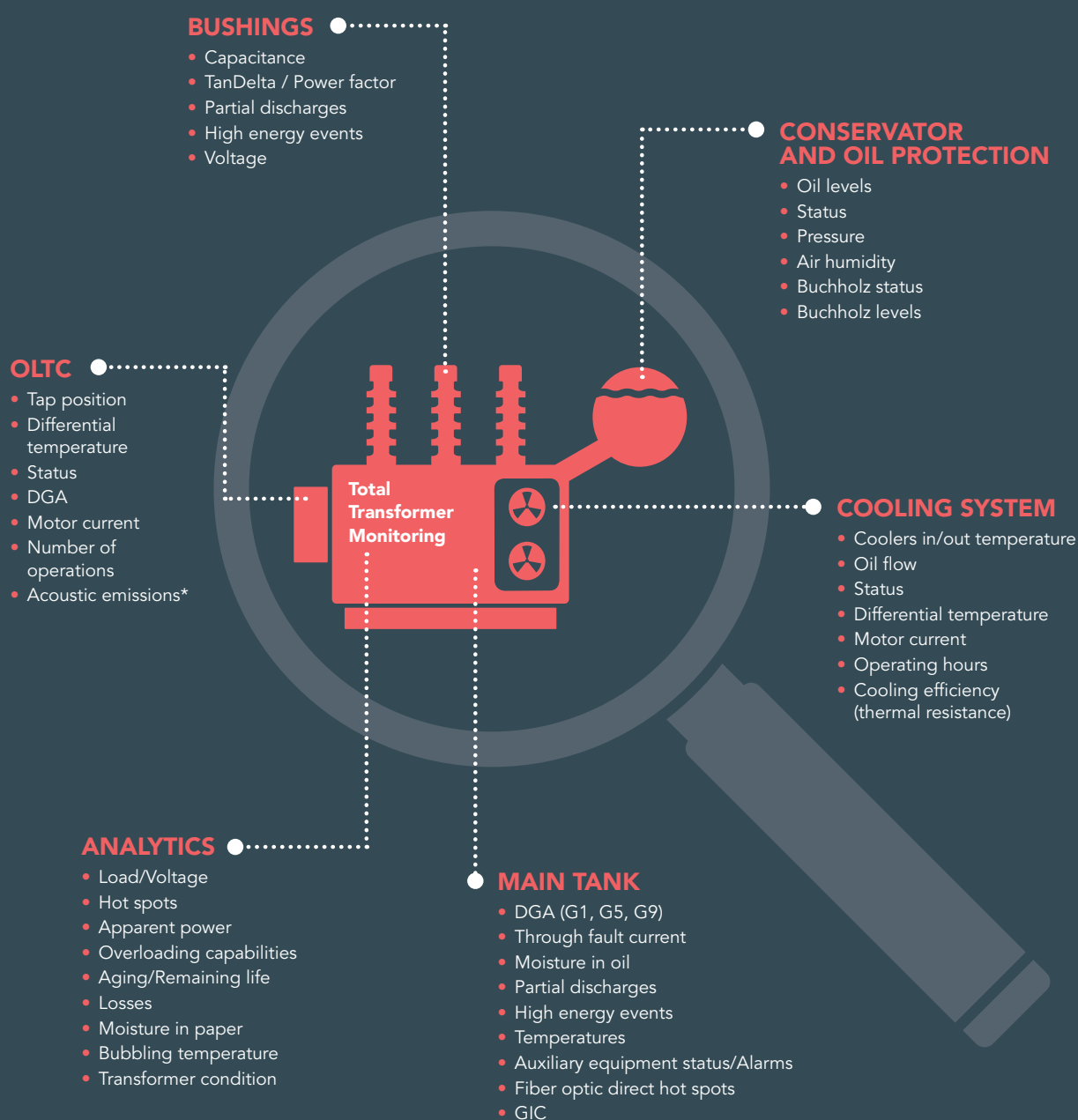


TOTUS G5



INTEGO

## A holistic transformer monitoring approach



\* 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%

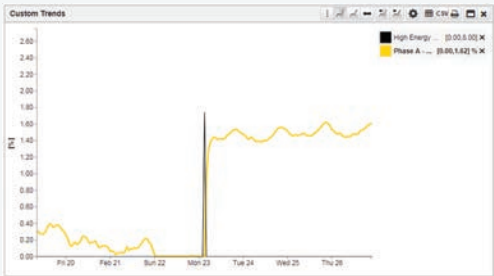
345 kV NGK Bushing OFFLINE Capacitance C1 (pF)				
	2012	2014	2015	Increase since 2012
Bushing A	435	429	438	0.60%
Bushing B	433	430	426	-1.60%
Bushing A-B	+2 pF	-1 pF	+12 pF	2.7%



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.

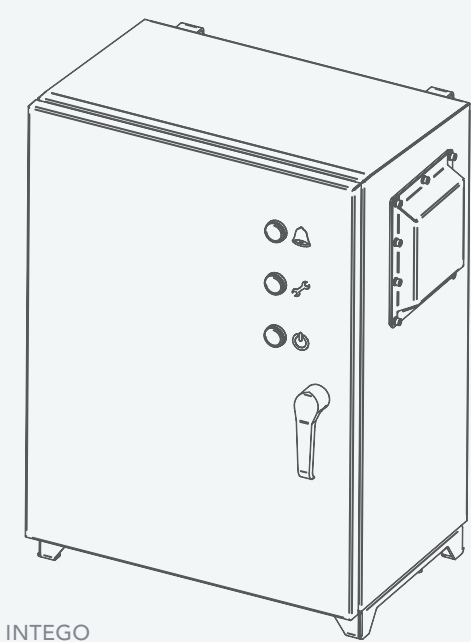


It was then found that at the precise moment of the bushing capacitance increase, a high energy event (partial discharge activity with significantly high magnitude, generally equal or higher than 20 V peak-peak [6]) was recorded in the same phase (from same sensor) by the online monitoring system. In 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 <sub>2</sub>	17	28
CH <sub>4</sub>	40	39
C <sub>2</sub> H <sub>2</sub>	76	0
C <sub>2</sub> H <sub>4</sub>	44	1
C <sub>2</sub> H <sub>6</sub>	32	62
CO	71	53
CO <sub>2</sub>	564	789
N <sub>2</sub>	150.862	156.665
O <sub>2</sub>	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.



INTEGO

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**

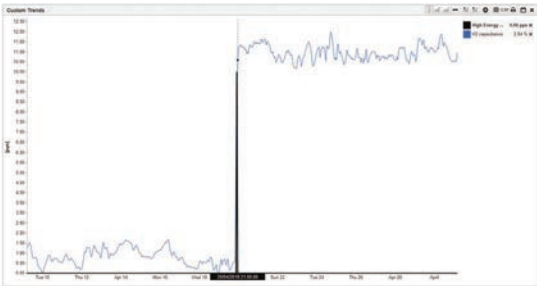
High energy event was recorded in conjunction with a capacitance increase in the same phase.

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 <sub>2</sub>	20	85
CH <sub>4</sub>	8	167
C <sub>2</sub> H <sub>2</sub>	<2	21
C <sub>2</sub> H <sub>4</sub>	<2	645
C <sub>2</sub> H <sub>6</sub>	14	65
CO	75	714
CO <sub>2</sub>	1.460	2.790
N <sub>2</sub>	51.800	84.300
O <sub>2</sub>	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 test for 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 H<sub>2</sub> 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 H<sub>2</sub> increase was significant and coincidentally 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 H<sub>2</sub> increase of about 4 ppm/day, the subsequent two months showed that the H<sub>2</sub> 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.

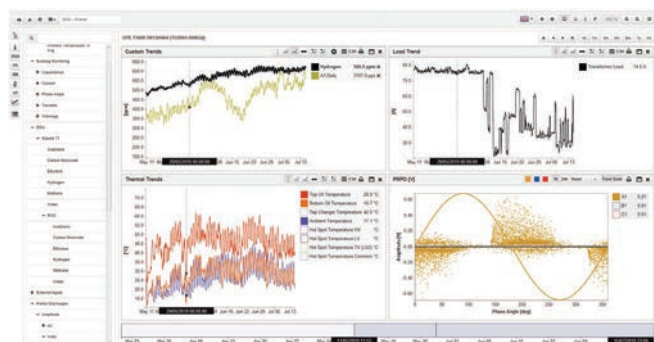


Figure 2. Online results synchronized and visualized in a way to enable further investigation on the possible correlation

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.

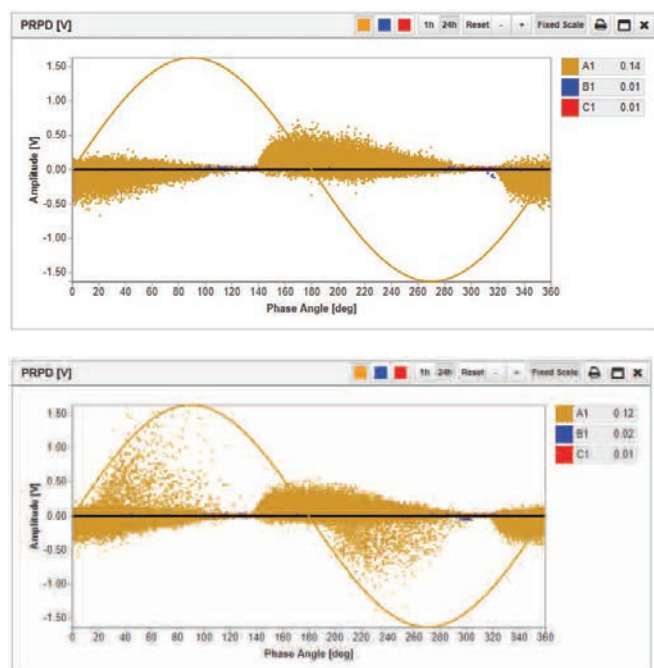




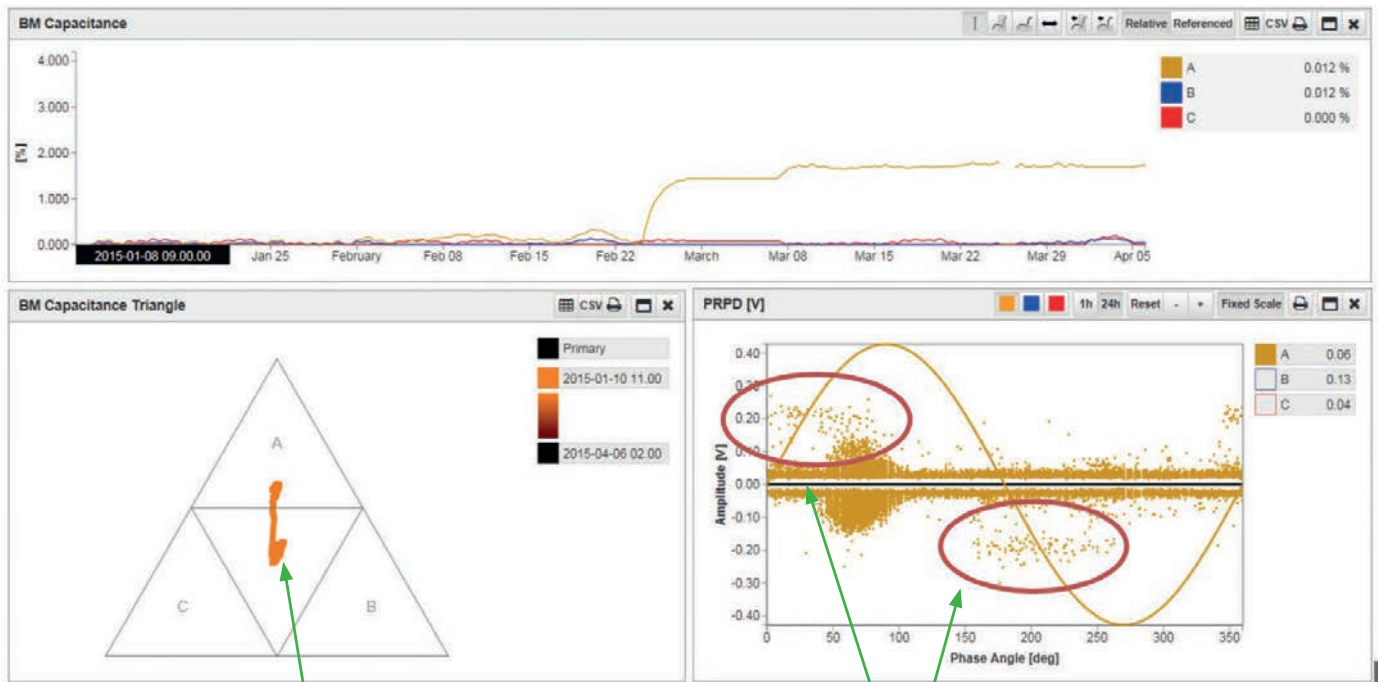
Figure 3. PRPD pattern of the stable partial discharge activity in Phase A1 (left) and the sporadic activity overlap (right)

# FAR EAST TRANSMISSION UTILITY

- **Details**  
Partial breakdown within the bushing control layer.
- **Evidence**  
Online monitoring showing capacitance increase and high energy events.

In 2015 the INTEGRO TM was installed on a unit with 30-year-old bushings. Catastrophic faults had been previously experienced by the utility on same type of bushings. After a certain number of months, the INTEGRO TM detected a change in the capacitance value from HV bushings, PHASE A.

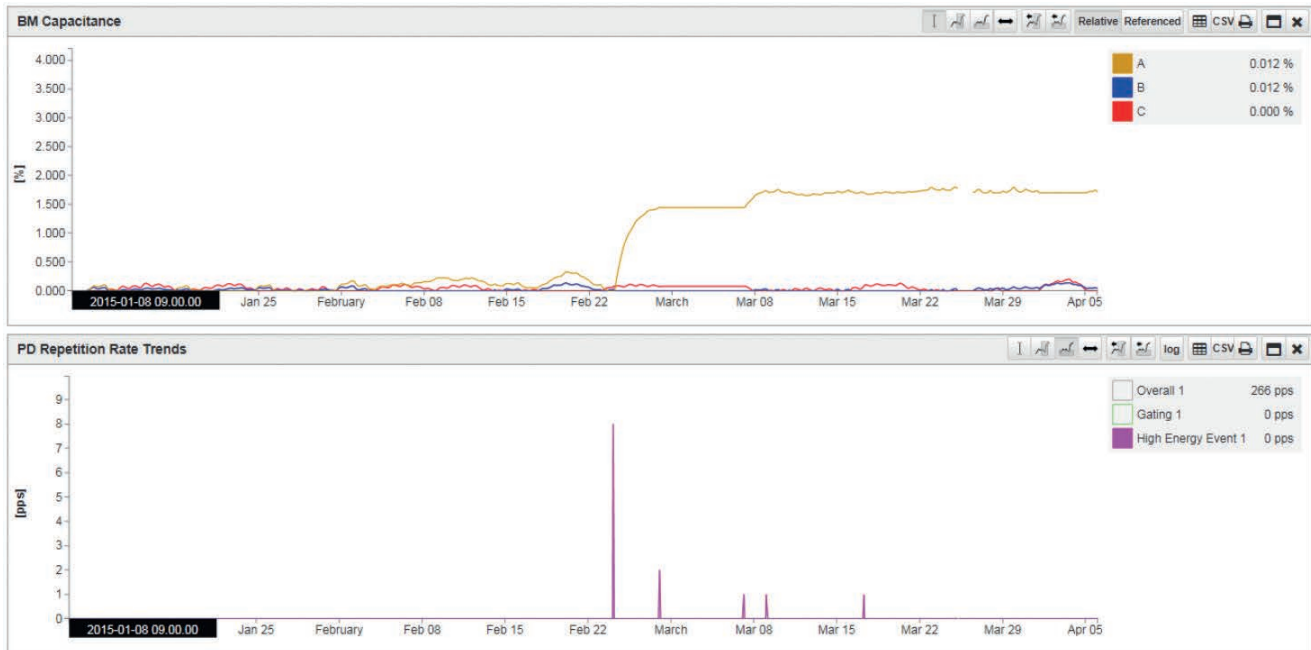
Deviation recorded was minimal (1.5%) but consistent with a short circuit between 2 layers for a 345 kV bushing provided with >50 layers inside the condenser core.



CAMLIN Capacitance Triangle showing Capacitance change in Phase A

PRPD Pattern showing PD in Bushing

In depth analysis over partial discharge records revealed that High Energy Events occurred in correspondence of the sudden capacitance change.



High Energy Event (HEE) is defined as a PD event with very high amplitude (much higher than 10 Vpp and several tens, even hundreds, of nC) which may occur with intermittent behavior. The occurrence of HEE confirmed the increase on the relative Capacitance trend.

Following to the detected capacitance increase Camlin recommended the following actions:

- Bushing Offline Capacitance Test
- Bushing Offline TanDelta Test
- Bushing Oil Dissolved Gas Analysis.

Bushing Capacitance and TD Offline Tests confirmed increasing Capacitance while TD remained substantially unchanged. From an asset management point of view such an increase required further investigation but did not represent an immediate risk factor for the Bushing ( provided that future recordings do not highlight further sudden changes in the Capacitances or TanDelta). As a result, the transformer has been re-energized.

Dissolved Gas Analysis from the Bushing Oil were conducted from a certified Laboratory and results revealed presence of 33ppm of Acetylene in the Oil sample from A phase as reported in Fig. 2, 3 and 4.

This result highlighted and confirm the occurrence of an High Energetic Event occurred within the Bushing causing the formation of Acetylene within A phase Bushing.

This conclusion is fully compliant with INTEGRO TM findings. The result was confirmed also by a second certified Laboratory which has analyzed only A phase Bushing Sample and returned the presence of 76 ppm of Acetylene.

## 2. 분석결과 Result

□ 신울산S/S #2M.Tr 부싱 측정 결과

가스종류	설비명	#2M.Tr A상 1차 #2M.Tr Phase A Primary
H <sub>2</sub>		17
C <sub>2</sub> H <sub>2</sub>		76
C <sub>2</sub> H <sub>4</sub>		44
C <sub>2</sub> H <sub>6</sub>		32
CH <sub>4</sub>		40
C <sub>3</sub> H <sub>8</sub>		21
가연성가스 총량 (T.C.G)		230
CO		71
CO <sub>2</sub>		564
O <sub>2</sub>		10280
N <sub>2</sub>		150862
총 가스량		162,007

Figure 1. Primary Side, Phase A, second Lab result

Figure 2: Primary Side, Phase A

고객명 : 한전 울산전력지사		시험일자 : 2017년 12월 4일		
SERIAL NO. : K7YJ3021		기기 사양 : 신울산S/S #2MTR 1차 A상		
NO.	분석 방법		ASTM D 3612-02(Method "A")	
	단 위		ppm	
	구 분		판 정 기 준	
	가스명		정 상	이 상
1	수 소(H <sub>2</sub> )	140 이하	140 초과	10
2	산 소(O <sub>2</sub> )	참고용		11974
3	질 소(N <sub>2</sub> )	참고용		31050
4	이산화탄소(CO <sub>2</sub> )	3400 이하	3400 초과	63
5	아세틸렌(C <sub>2</sub> H <sub>2</sub> )	2 이하	2 초과	33
6	에틸렌(C <sub>2</sub> H <sub>4</sub> )	30 이하	30 초과	20
7	에탄(C <sub>2</sub> H <sub>6</sub> )	70 이하	70 초과	12
8	메탄(CH <sub>4</sub> )	40 이하	40 초과	34
9	일산화탄소(CO)	1000 이하	1000 초과	43
10	가연성가스총량(T.C.G)			131
11	가스성분총량			43289

Figure 3: Primary Side, Phase B

고객명 : 한전 울산전력지사		시험일자 : 2017년 12월 4일			
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	단위		ppm		
	구분		판정 기준		분석결과치
	가스명		정상	이상	
1	수소( $H_2$ )		140 이하	140 초과	0
2	산소( $O_2$ )		참고용		15688
3	질소( $N_2$ )		참고용		37399
4	이산화탄소( $CO_2$ )		3400 이하	3400 초과	108
5	아세틸렌( $C_2H_2$ )		2 이하	2 초과	0
6	에틸렌( $C_2H_4$ )		30 이하	30 초과	2
7	에탄( $C_2H_6$ )		70 이하	70 초과	8
8	메탄( $CH_4$ )		40 이하	40 초과	7
9	일산화탄소( $CO$ )		1000 이하	1000 초과	13
10	가연성가스총량(T.C.G)				17
11	가스성분총량				53225

Figure 4: Primary Side, Phase C

고객명 : 한전 울산전력지사		시험일자 : 2017년 12월 4일			
SERIAL NO.: K7YJ3023		기기 사양 : 산울산S/S #2MTR 1차 C상			
NO.	분석 방법		ASTM D 3612-02(Method "A")		
	단 위		ppm		
	구 분		판 정 기 준		
	가스명		정 상	이 상	분석결과치
1	수 소( $H_2$ )		140 이하	140 초과	0
2	산 소( $O_2$ )		참고용		23945
3	질 소( $N_2$ )		참고용		35035
4	이산화탄소( $CO_2$ )		3400 이하	3400 초과	95
5	아세틸렌( $C_2H_2$ )		2 이하	2 초과	0
6	에틸렌( $C_2H_4$ )		30 이하	30 초과	1
7	에탄( $C_2H_6$ )		70 이하	70 초과	7
8	메탄( $CH_4$ )		40 이하	40 초과	4
9	일산화탄소( $CO$ )		1000 이하	1000 초과	9
10	가연성가스총량(T.C.G)				12
11	가스성분총량				59096



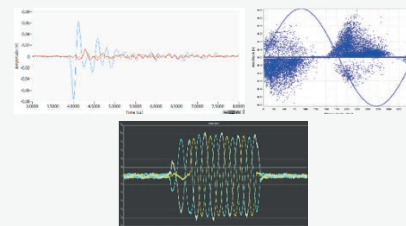
## ACTIONABLE INFORMATION CREATING BUSINESS VALUE

1

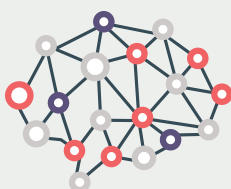


### Generate the Data

- Detect Anomalies, alarm triggered



2

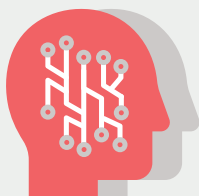


### Transform Data to Information

- Correlate the anomalies
- Determine possible failure mode



3



### Apply Knowledge to Information

- Combine parameters into condition index to represent transform
- Confirm failure mode to trigger best offline test
- Determine prescriptive actions

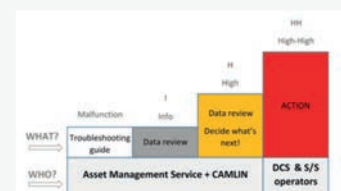
Activity required	Asset ID	Substation	Condition Index	Comments
Oil	18027	101	4.18	Offline Capacitance Test on Building A to be planned within one month.
Oil	18023	102	4.25	Electrical Tests required (PD, Winding insulation and resistance).
Oil	1801	104	3.62	Oil regeneration and leakage repair.
Oil	18023	101	3.59	Oil regeneration.
Oil	18019	101	3.58	Oil regeneration.
Oil	1801	102	3.51	Schedule IR camera for bad contacts.
Oil	1801	105	3.11	Schedule Visual inspection for oil leakage.
Oil	18023	101	3.4	
Oil	18025		3.35	
Oil	18015		2.44	
Oil	18016		2.43	
Oil	18014		2.37	
Oil	18020		2.3	
Oil	18017		2.26	
Oil	18015		2.06	
Oil	1801		2.04	
Oil	1801		1.71	
Oil	18016		1.68	

4



### Apply Wisdom to Drive Decision Making

- Understand risk to operations
- Budgets, environmental issues
- Correlate with external parameters
- Alignment with maintenance planning







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