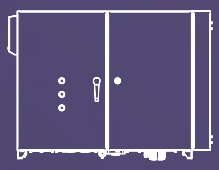


CONNECTING DATA TO DECISIONS

Case Studies - Volume 3

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

camlin energy

CONTENTS

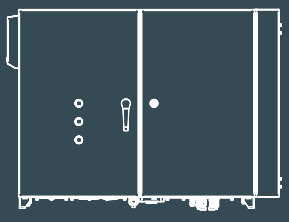
TRANSFORMING DATA TO DRIVE DECISION MAKING

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.

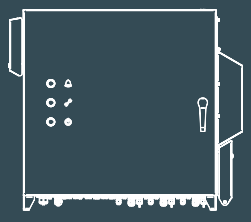
The use of a more holistic and integrated approach to transformer monitoring can significantly help to optimize maintenance and mitigate risk. Holistic means the treatment of the whole transformer, taking into account operational data, environmental data, external factors and previous experiences, rather 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.

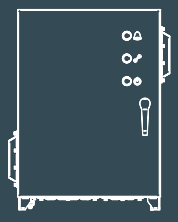
TOTUS MONITORING



TOTUS G9

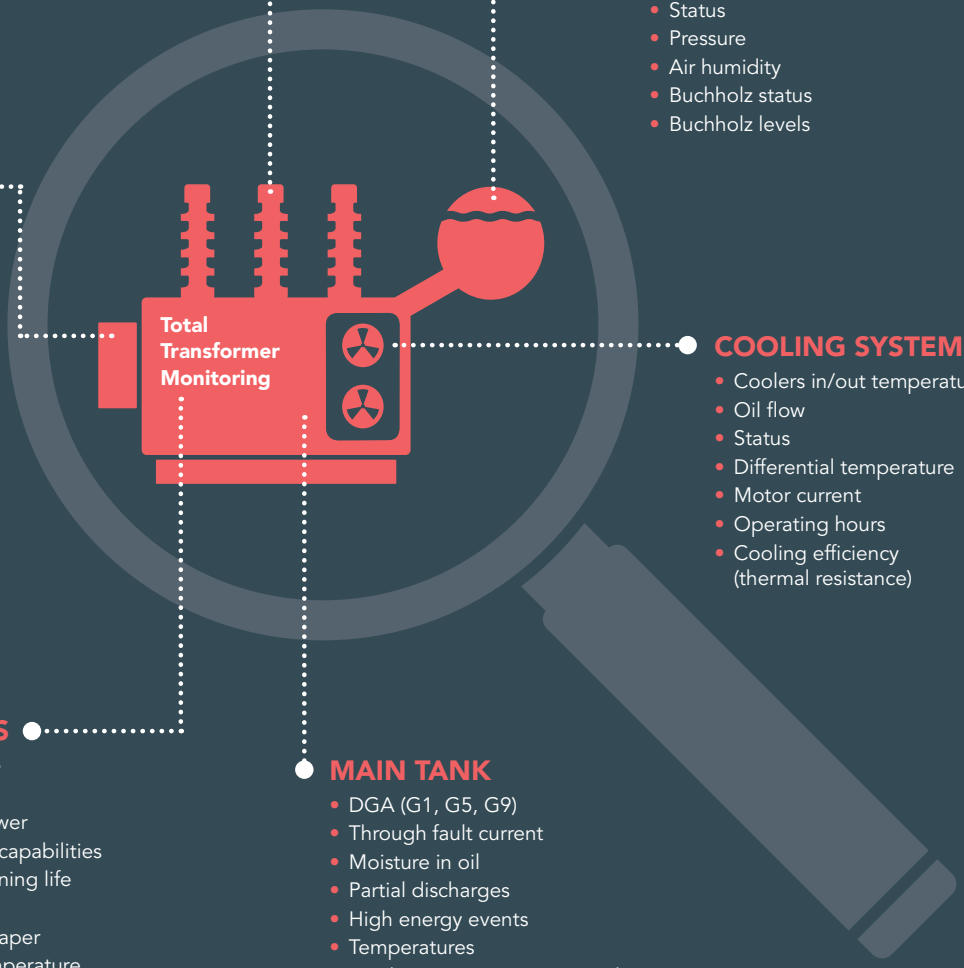


TOTUS G5



INTEGO

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.

US DISTRIBUTION COMPANY

Details
Bushing monitoring, reliable surveillance device.

Evidence
During the periodic substation visual inspection, the utility operator spotted the alarm led switched on. according to the agreed action plan, the operator triggered for an asset manager data analysis highlighting a genuine TanDelta increase.

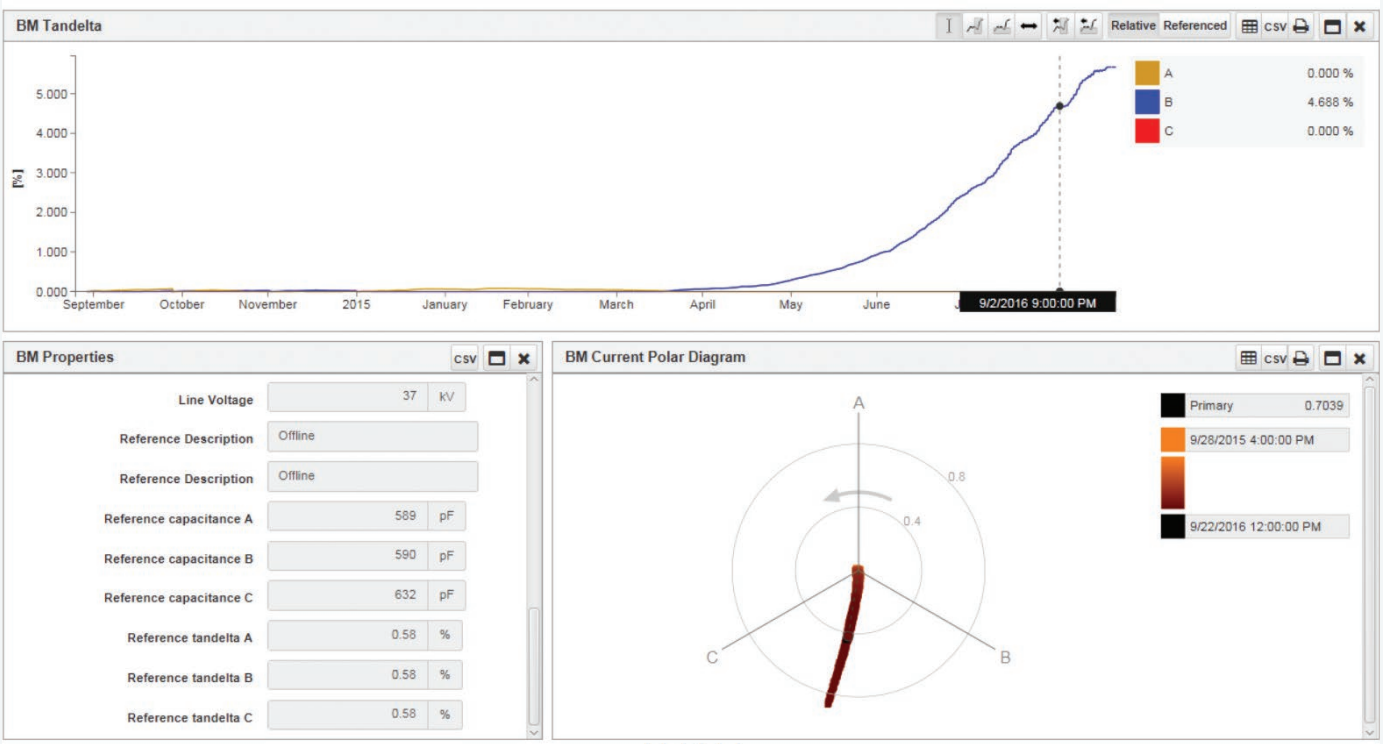
The TOTUS monitoring unit was installed in September 2015 on a 45/60/75 MVA transformer located into an unmanned substation de-centered from an urban location. The utility planned to conduct a periodic visual inspection over the installed monitoring devices to record any change in the diagnostic status.

During the inspection in August 2016 the TOTUS alarm LED was found ACTIVE, and, according to the agreed action plan, a deep data analysis was conducted by the Asset Management Team.

Historical Bushing Monitoring data highlighted a genuine TanDelta increase on the B-phase Bushing. Considering the substantial deviation for the B-Phase Bushing, follow-up action to resolve the case was a bushing replacement.

The TOTUS monitoring system was installed to track the bushing properties and enable the recognition of developing faults. This enabled the utility to prevent the bushing failure and keep the transformer in service enabling an effective Asset life extension with minimal economic effort.

Figure 1: Bushing Monitoring Behaviour from Installation date.



CHINESE TRANSMISSION COMPANY

Details

Evidence

Acetylene deviation recorded by TOTUS and confirmed by laboratory GC results. monitoring devices had a strategic role for the recognition and the troubleshooting for a converter transformer.

In June 2017, a project for 10 Single Phase Converter Transformer commenced including an overall installation of 30 DGA monitoring systems. One TOTUS was installed on each tank and the installation took place together with the asset installation in the substation.

In October 2017, one of the TOTUS started to record an Acetylene deviation and Figure 1 report the historical SCADA summary.

数据表 - 1 - :

采样时间	二氧化碳CO2含量(μL/L)	氢气H2含量(μL/L)	一氧化碳CO含量(μL/L)	甲烷CH4含量(μL/L)	乙炔C2H2含量(μL/L)	乙烷C2H4含量(μL/L)
2018-01-11 08:00:00	98.60	12.40	23.60	1.00	0.40	0.50
2018-01-11 04:00:00	99.80	12.30	23.50	1.00	0.40	0.50
2018-01-11 00:00:00	99.70	12.10	23.70	0.90	0.40	0.60
2018-01-10 20:00:00	101.00	12.00	23.70	0.90	0.40	0.50
2018-01-10 16:00:00	102.60	11.90	23.80	0.90	0.40	0.60
2018-01-10 12:00:00	103.70	11.80	23.90	0.90	0.40	0.50
2018-01-10 08:00:00	104.00	11.60	23.90	0.90	0.40	0.50
2018-01-10 04:00:00	104.20	11.40	24.00	0.90	0.40	0.50
2018-01-10 00:00:00	103.60	11.30	24.10	0.90	0.40	0.50
2018-01-09 20:00:00	103.60	11.20	24.50	0.80	0.40	0.40
2018-01-09 16:00:00	103.70	11.10	24.60	0.80	0.40	0.50
2018-01-09 12:00:00	104.50	10.90	24.70	0.80	0.40	0.50
2018-01-09 08:00:00	107.10	10.80	24.70	0.70	0.40	0.40
2018-01-09 04:00:00	111.10	10.50	24.70	0.70	0.40	0.50
2018-01-09 00:00:00	113.20	10.20	24.80	0.70	0.40	0.50
2018-01-08 20:00:00	114.40	10.00	25.10	0.80	0.40	0.40
2018-01-08 16:00:00	114.90	9.90	25.50	1.00	0.50	0.40
2018-01-08 12:00:00	113.10	9.90	25.70	1.00	0.50	0.40
2018-01-08 08:00:00	111.50	9.90	25.70	1.00	0.40	0.40
2018-01-08 04:00:00	110.70	9.90	25.50	0.90	0.50	0.50
2018-01-08 00:00:00	108.90	9.90	25.30	0.80	0.50	0.50
2018-01-07 20:00:00	108.70	10.00	25.20	0.80	0.40	0.50
2018-01-07 16:00:00	107.70	10.00	25.00	0.80	0.40	0.50
2018-01-07 12:00:00	106.20	10.10	24.90	0.80	0.40	0.50
2018-01-07 08:00:00	105.50	10.10	24.80	0.70	0.30	0.40
2018-01-07 04:00:00	103.50	10.10	24.40	0.60	0.30	0.40
2018-01-07 00:00:00	101.80	10.00	24.40	0.60	0.30	0.40
2018-01-06 20:00:00	103.50	9.90	24.40	0.60	0.30	0.40
2018-01-06 16:00:00	104.90	9.70	24.70	0.70	0.30	0.40
2018-01-06 12:00:00	105.10	9.50	25.00	0.70	0.30	0.40
2018-01-06 08:00:00	107.50	9.50	25.00	0.70	0.30	0.40
2018-01-06 04:00:00	107.60	9.30	24.80	0.70	0.30	0.40
2018-01-06 00:00:00	107.00	9.10	24.90	0.70	0.30	0.40
2018-01-05 20:00:00	107.10	9.00	25.00	0.70	0.20	0.40
2018-01-05 16:00:00	106.00	8.90	25.20	0.70	0.20	0.40
2018-01-05 12:00:00	106.00	8.80	25.20	0.70	0.20	0.30
2018-01-05 08:00:00	105.90	8.60	25.10	0.70	0.20	0.30
2018-01-05 04:00:00	106.30	8.50	24.80	0.60	0.20	0.30
2018-01-05 00:00:00	106.90	8.40	24.70	0.60	0.10	0.20
2018-01-04 20:00:00	106.90	8.30	24.70	0.60	0.10	0.30
2018-01-04 16:00:00	106.60	8.30	25.00	0.70	0.10	0.30
2018-01-04 12:00:00	106.20	8.20	25.00	0.70	0.10	0.30
2018-01-04 08:00:00	106.20	8.10	24.90	0.70	0.10	0.40
2018-01-04 04:00:00	106.90	8.00	24.90	0.60	0.10	0.40
2018-01-04 00:00:00	108.10	7.90	24.90	0.50	0.10	0.40
2018-01-03 20:00:00	107.90	7.70	24.80	0.50	0.10	0.40
2018-01-03 16:00:00	109.60	7.60	24.80	0.50	0.10	0.40
2018-01-03 12:00:00	109.90	7.50	24.80	0.50	0.10	0.40
2018-01-03 08:00:00	109.30	7.40	24.60	0.40	0.10	0.40
2018-01-03 04:00:00	110.00	7.20	24.30	0.30	0.10	0.30
2018-01-03 00:00:00	110.30	7.20	24.30	0.30	0.10	0.30
2018-01-03 04:00:00	110.00	7.20	24.30	0.30	0.10	0.30
2018-01-03 00:00:00	110.30	7.20	24.30	0.30	0.10	0.30
2018-01-02 20:00:00	109.70	7.20	24.50	0.30	0.10	0.30
2018-01-02 16:00:00	107.90	7.40	24.80	0.40	0.10	0.30
2018-01-02 12:00:00	106.80	7.60	25.10	0.60	0.00	0.30
2018-01-02 08:00:00	105.60	7.60	25.10	0.60	0.00	0.30
2018-01-02 04:00:00	104.80	7.50	24.70	0.50	0.00	0.30
2018-01-02 00:00:00	104.40	7.40	24.30	0.40	0.00	0.30
2018-01-01 20:00:00	104.70	7.40	24.20	0.30	0.00	0.30
2018-01-01 16:00:00	105.90	7.30	24.20	0.20	0.00	0.20
2018-01-01 12:00:00	106.50	7.30	24.10	0.30	0.00	0.20
2018-01-01 08:00:00	107.90	7.10	24.10	0.30	0.00	0.20
2018-01-01 04:00:00	108.80	7.00	24.00	0.20	0.00	0.20
2018-01-01 00:00:00	110.90	6.80	24.00	0.20	0.00	0.30

Figure 1: DGA results reported over SCADA.

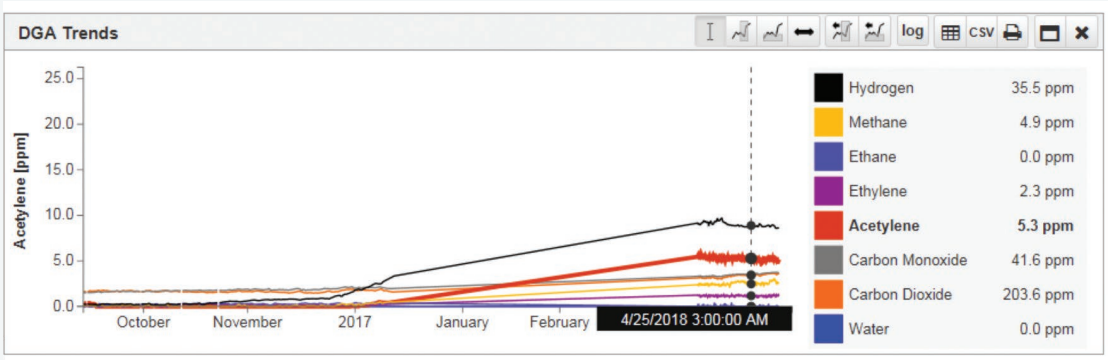
As a result, of the evidence (Acetylene deviation) several manual oil samples for Lab analysis were conducted. Lab analysis used GC method, results are reported in Figure 2.

Table 2. Offline DGA results for bushings A and C

一级单位	二级单位	设备名称	相别	分析时间	甲烷	乙烯	乙烷	乙炔	氢气	一氧化碳	二氧化碳	氧气	氮气	总烃	
换流变	极2高端YD-A	主变1		2018/1/12 8:27	0.7	0	0	0.99	3.44	0	0	0	0	1.69	广固换流站
换流变	极2高端YD-A	主变1		2018/1/12 8:14	0.64	0	0	1.02	3.95	0	0	0	0	1.66	
换流变	极2高端YD-A	主变1		2018/1/11 22:17	0.59	0	0	0.83	3.08	0	0	0	0	1.42	
换流变	极2高端YD-A	主变1		2018/1/11 19:19	0.74	0	0	1.11	3.81	0	0	0	0	1.85	
换流变	极2高端YD-A	主变1		2018/1/11 15:11	1.06	0.5	0	1.46	6.43	0	0	0	0	3.02	
换流变	极2高端YD-A	主变2		2018/1/11 22:29	0.59	0	0	0.71	2.45	0	0	0	0	1.3	
换流变	极2高端YD-A	主变2		2018/1/11 20:00	0.75	0	0	0.87	3.47	0	0	0	0	1.62	
换流变	极2高端YD-A	主变2		2018/1/11 19:51	0.77	0	0	0.8	3.35	0	0	0	0	1.57	
换流变	极2高端YD-A	主变2		2018/1/11 17:53	1.07	0.43	0	1.13	6.49	0	0	0	0	2.63	
换流变	极2高端YD-A	主变2		2018/1/9 17:23	1.09	0.48	0	2.19	0	17.18	255.3	0	0	3.76	
换流变	极2高端YD-A	主变2		2018/1/9 17:31	1.11	0.52	0	2.16	0	17.82	273.93	0	0	3.79	特高压昌乐站
换流变	极2高端YD-A	主变2		2018/1/10 15:06	1.54	0.45	0.127	1.33	5.564	16.695	187.797	0	0	3.447	淄博分部

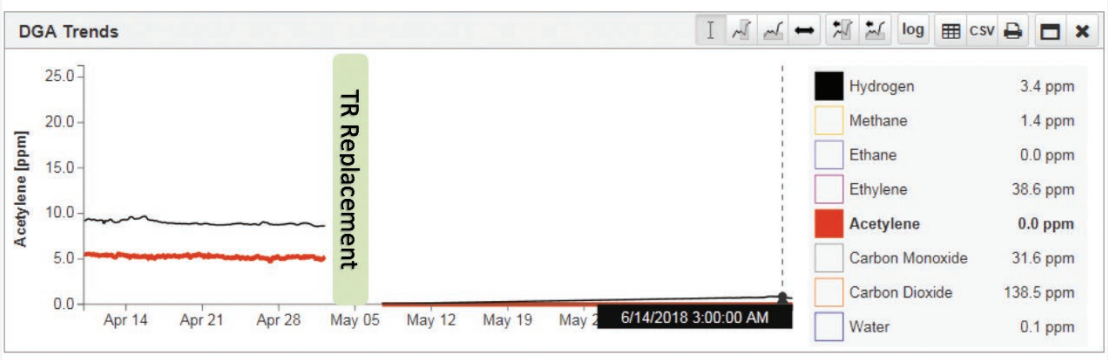
The level of Acetylene in the manual samples showed an increase over the time period. The OEM conducted an inspection and decided to replace the Transformer Tank in April 2018. Within this time frame it was possible to record a stabilization of the Acetylene from the monitoring system up to 5.2 ppm (Figure 3).

Figure 3: DGA Behavior from Installation date to April 2018



After the replacement the monitoring system was recommissioned and left in operation to track future further changes. No further changes were recorded as reported in Figure 4.

Figure 4: DGA Behavior following the OEM intervention.



CHINESE TRANSMISSION COMPANY

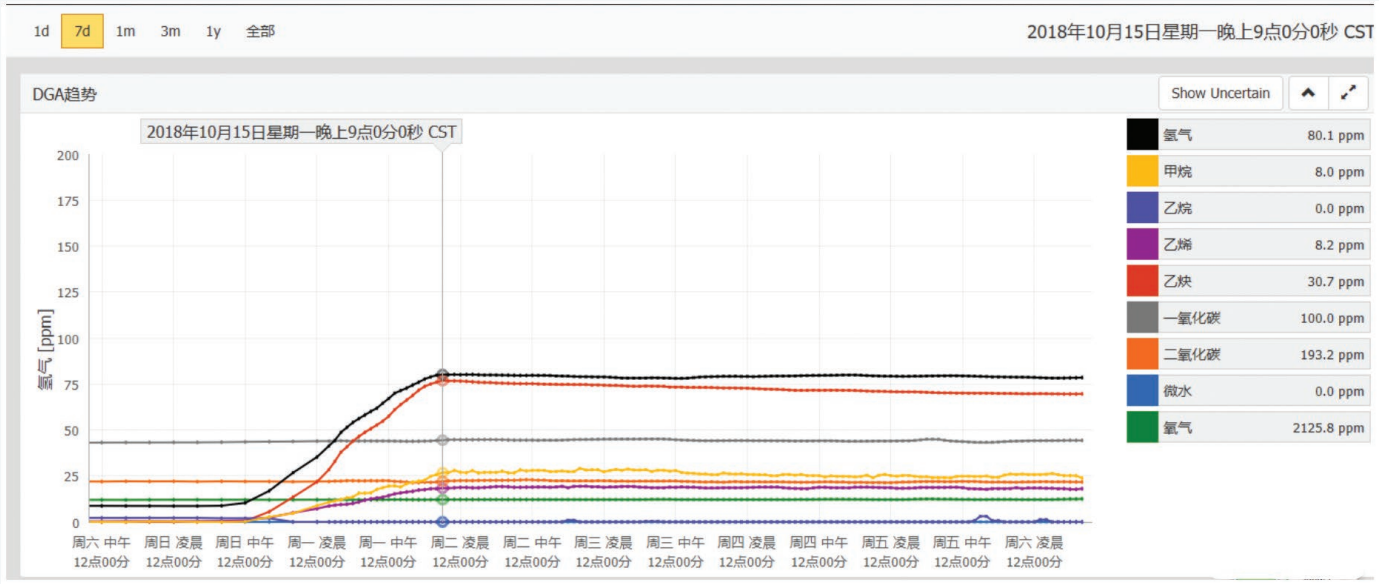
Details
Monitoring as a control system for corrective actions.

Evidence
Sudden acetylene deviation recorded by TOTUS DGA, and confirmed by laboratory GC results. monitoring devices had a strategic role for the recognition and the troubleshooting action for a converter transformer.

In June 2017, a project for 10 Single Phase Converter Transformers commenced including an overall installation of 30 DGA monitoring systems. One TOTUS was installed on each tank and the installation took place together with the asset installation in the substation.

In October 2018, one of the TOTUS started to record an Acetylene deviation together with increases also on other gases: methane, hydrogen and ethylene. Figure 1 shows the Camlin Web User Interface for the monitoring device.

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



Within Picture 1, it must be pointed out that the Acetylene concentration rose from 0 ppm (recorded at 12:00 on 14th of October) to 30.7 ppm (recorded at 21:00 on the 15th of October) within approximately 36 hours.

The TOTUS issued an alarm resulting in maintenance personnel conducting manual oil samples for laboratory testing (GC method used). Several manual oil samples for Lab analysis were conducted. Lab analysis used GC method and results are reported in Figure 2.

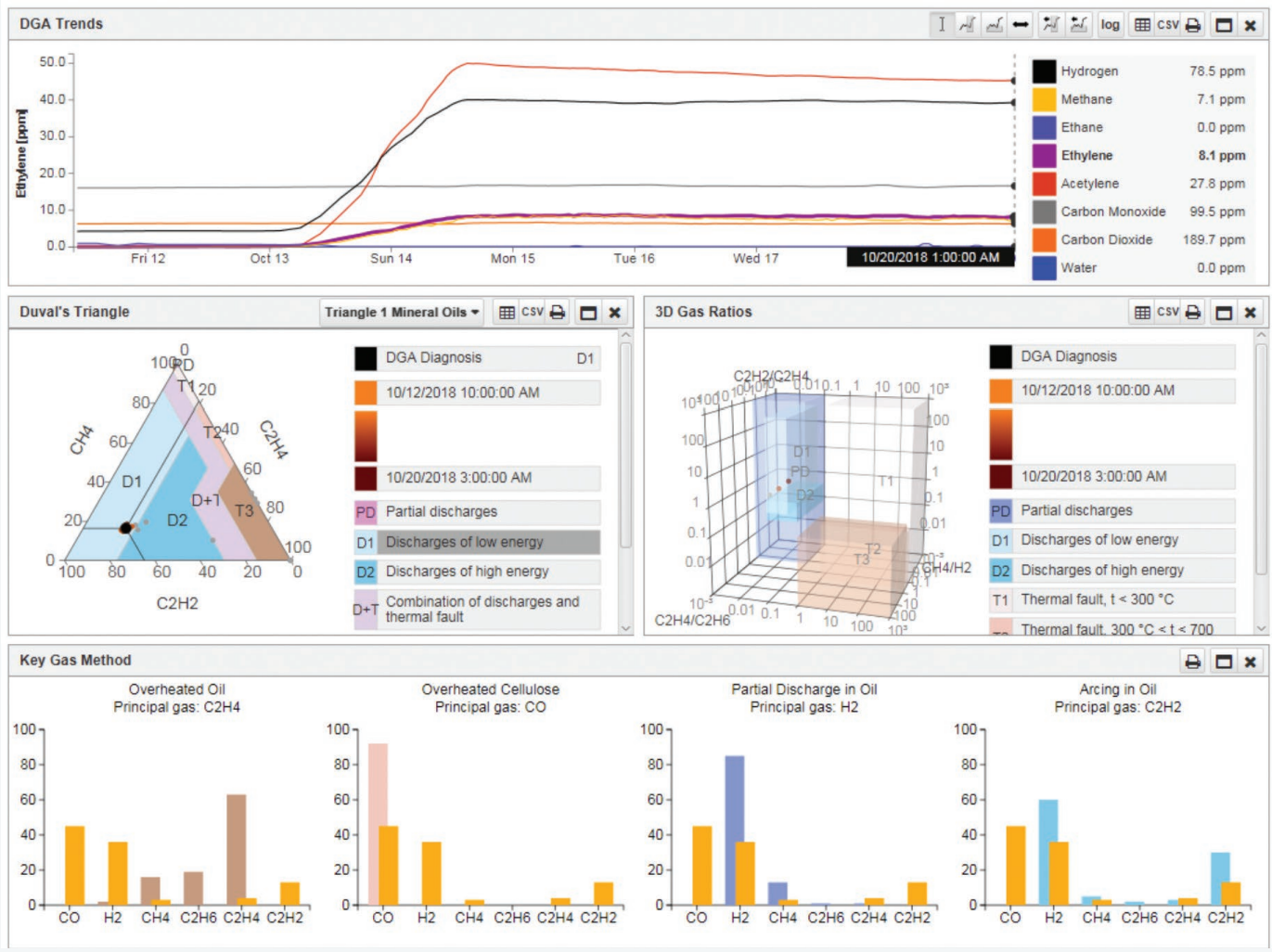
Figure 2: DGA results reported over SCADA.

日期	一级单位	二级单位	设备名称	甲烷	乙烯	乙烷	乙炔	氢气	一氧化碳	二氧化碳	总烃
2018. 10. 16	换流变	极2低端YY-A	本体下部取油口	7. 43	7. 94	1. 63	27. 24	58. 71	85. 09	263. 46	44. 24
2018. 10. 16	换流变	极2低端YY-A	本体下部取油口	7. 61	8. 03	1. 66	27. 37	59. 93	85. 75	276. 79	44. 67
2018. 10. 16	换流变	极2低端YY-A	本体下部取油口	7. 72	8. 2	1. 74	27. 91	58. 46	86. 47	264. 66	45. 57
2018. 10. 17	换流变	极2低端YY-A	网侧套管升高座上阀门	6. 49	6. 54	1. 34	22. 51	52. 42	79. 71	199. 37	36. 88
2018. 10. 17	换流变	极2低端YY-A	网侧套管升高座上阀门	6. 25	6. 48	1. 52	21. 83	55. 23	79. 08	199. 84	36. 08
2018. 10. 17	换流变	极2低端YY-A	网侧套管升高座下阀门	6. 15	6	1. 23	20. 89	52. 21	78. 59	157. 86	34. 27
2018. 10. 17	换流变	极2低端YY-A	网侧套管升高座下阀门	6. 14	6. 13	1. 29	21. 07	50. 97	72. 25	258. 75	34. 63
2018. 10. 17	换流变	极2低端YY-A	有载开关下部取油口	23. 41	4. 1	4. 09	0. 22	66. 46	2. 74	74. 5	31. 82
2018. 10. 17	换流变	极2低端YY-A	有载开关下部取油口	22. 47	3. 95	3. 97	0. 21	64. 86	2. 54	35. 93	30. 6
2018. 10. 18	换流变	极2低端YY-A	网侧套管	1. 57	0. 1	0. 26	0	5. 48	192. 8	408. 32	1. 93
2018. 10. 18	换流变	极2低端YY-A	本体上部取油口	6. 55	6. 39	1. 33	22. 77	51. 52	71. 88	265. 57	37. 04
2018. 10. 18	换流变	极2低端YY-A	本体中部取油口	6. 99	6. 78	1. 43	23. 97	54. 15	74. 25	207. 49	39. 17
2018. 10. 18	换流变	极2低端YY-A	本体下部取油口	6. 83	6. 79	1. 43	23. 95	51. 29	73. 05	277. 6	39

The level of Acetylene in the manual samples showed a high level of Acetylene confirming the findings of the TOTUS and the presence of an issue in the transformer.

The transformer is currently shut down and root cause analysis is still not completed. However, the decision from OEM was to replace the converter transformer.

Figure 3: DGA Diagnostic results



US TRANSMISSION COMPANY

Details
Correlation is the key for diagnosis.

Evidence
Multiple acetylene deviations recorded by TOTUS TTM. the correlation capabilities of the TTM provided a root cause analysis for the asset management strategy.

One of the 6 TOTUS TTM installed in the fleet recorded multiple Acetylene deviations: 3 step changes recorded over 1 year of monitoring data (Figure 1).

Figure 1: DGA results over the monitored period.

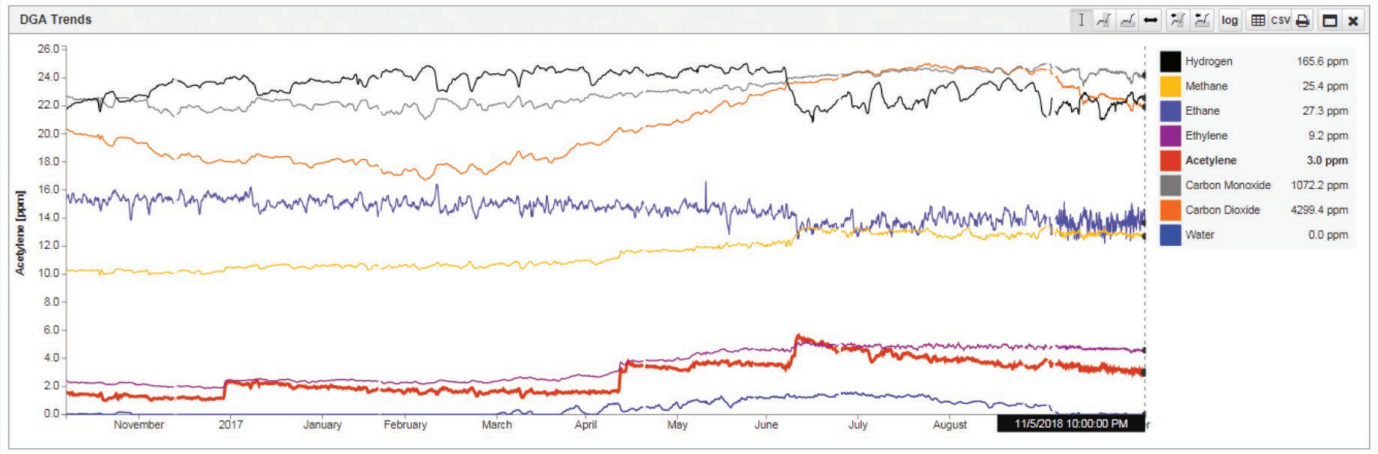


Figure 1 highlights Acetylene concentration increase up to a max of 5.6 ppm (July 2018). TOTUS TTM issued alarms and maintenance personnel conducted manual oil samples to be analyzed in laboratory (GC method used).

According to literature, C2H2 deviations occur as the consequence of arcing or discharges with high energy in the transformer tank. Although the ppm concentrations do not indicate an imminent failure, these events must not be neglected. Furthermore, it is essential to remark that several questions are un-answered in the current status:

- How many windings are affected?
- What is the affected phase? Only one or multiple?
- HV side or LV side?
- Is there anything sustaining the occurrence of arcing or discharges?

Answers to the above questions are the crucial step for an effective resolution plan.

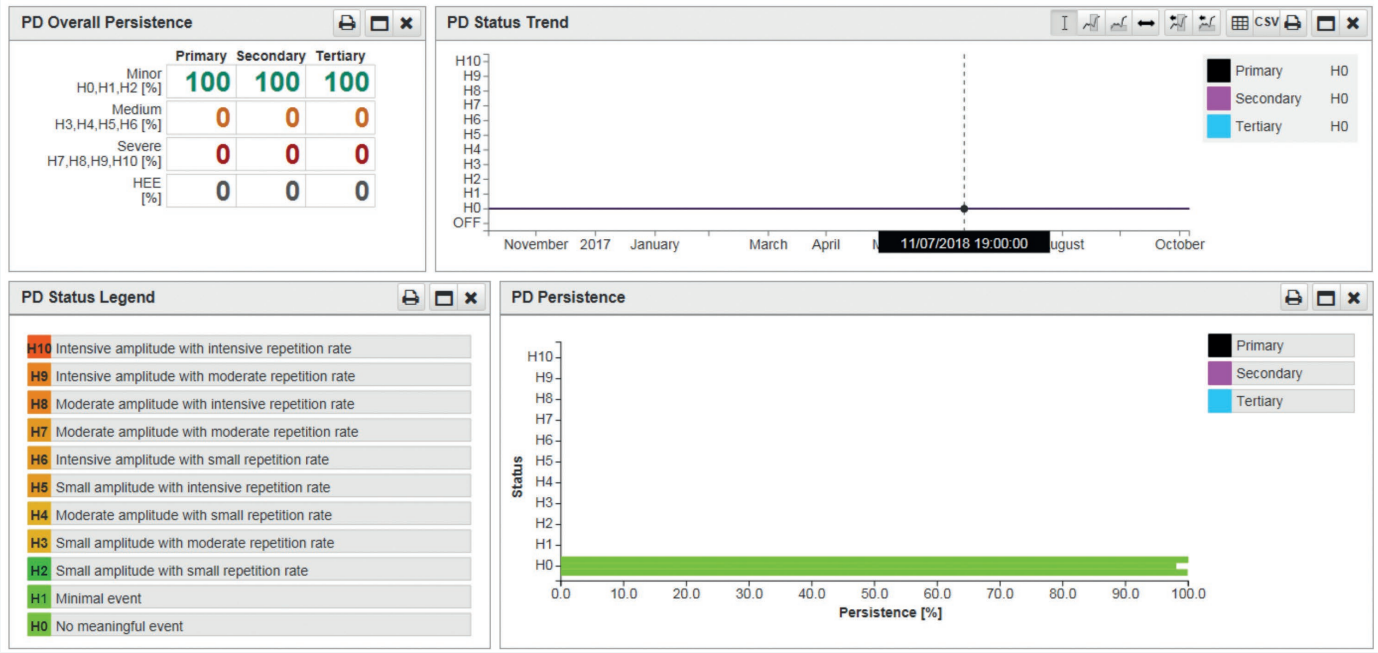
TOTUS TTM is designed to be an all in one monitoring system capable to combine DGA, Partial Discharge, High Energy Events and Bushing Monitoring within the same device together with environmental and operational parameters. The benefit of such a device is the unique capability to combine advanced detection of incipient failure mechanisms with embedded correlation tools.

While the laboratory results confirmed the increases they did add further details to the root cause analysis.

By looking at the data provided by the TOTUS TTM accurate conclusions where identified.

STEP 1: C2H2 increasing suggested the occurrence of arcing activity in the transformer tank, thus, PD and High Energy Events were evaluated.

Figure 2: PD summary over the monitored period.



No persistent PD activity was been recorded within the monitored period. This means that the Acetylene increases were not the consequence of a stable and continuously active PD Phenomenon. The same conclusion can be taken for High Energy Events (in the following HEE).

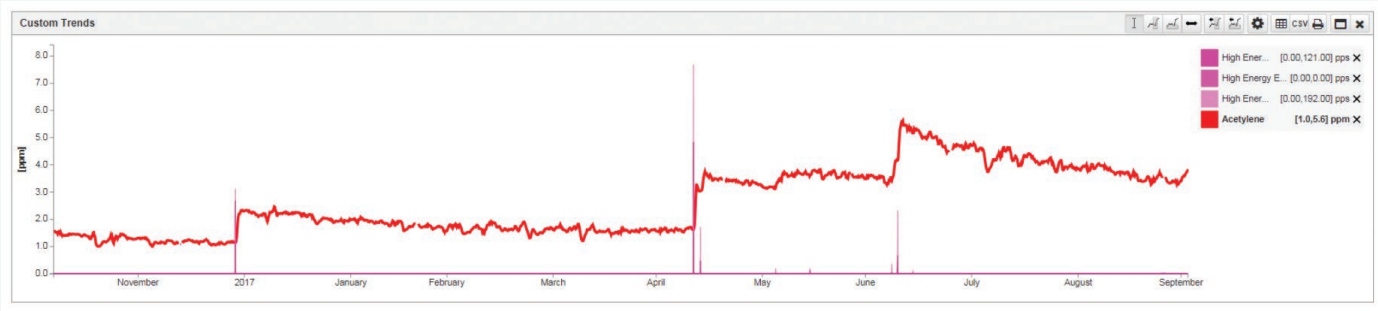
HEE are defined as PD events which have abnormally high amplitude (>10 Volts) and sporadic nature.

Following the investigation stage would be the occurrence of sporadic events to verify whether HEE or PD occurred concurrently with C2H2 step changes.

STEP 2: Cross correlation between C2H2 and HEE through Custom Trends.

Customized trending capability enabled by the TOTUS TTM, allowed for the Acetylene ppm concentrations to be plotted together with HEE from Primary, Secondary and Tertiary windings (Figure 3) showing concurrence between HEE and C2H2 step changes.

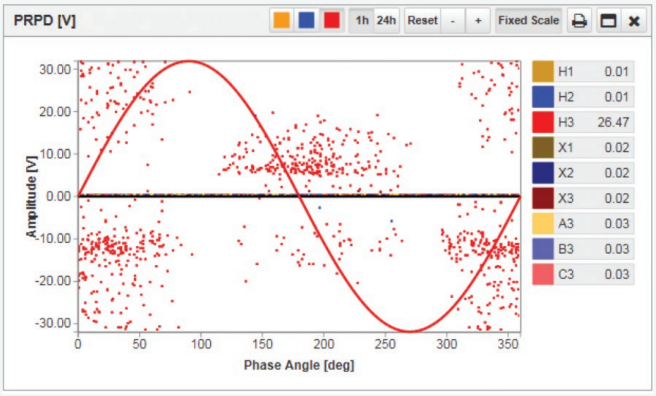
Figure 3: Custom Trend Chart - correlation between C2H2 and HEE.



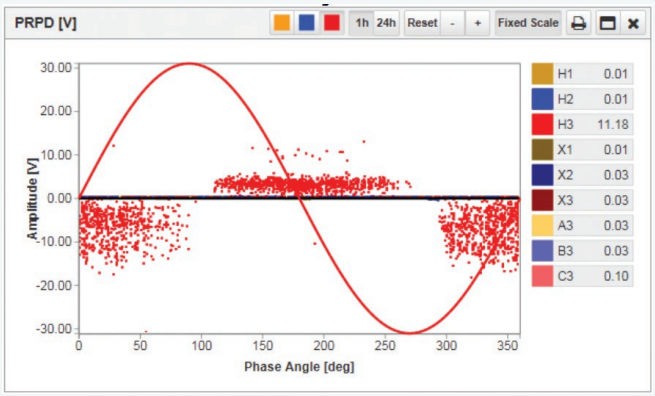
In this case further in-depth investigations must be addressed, Phase Resolved PD patterns can be also evaluated through TOTUS PRO Desktop in order to figure out which phase is the most affected between the three.

Figure 4: PRPD Patterns over the monitored period.

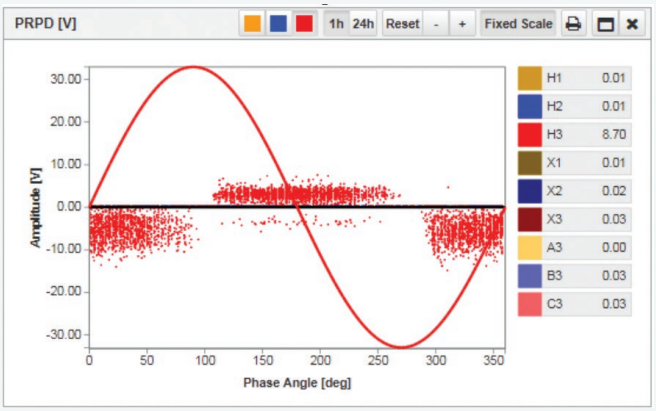
29 December 2017



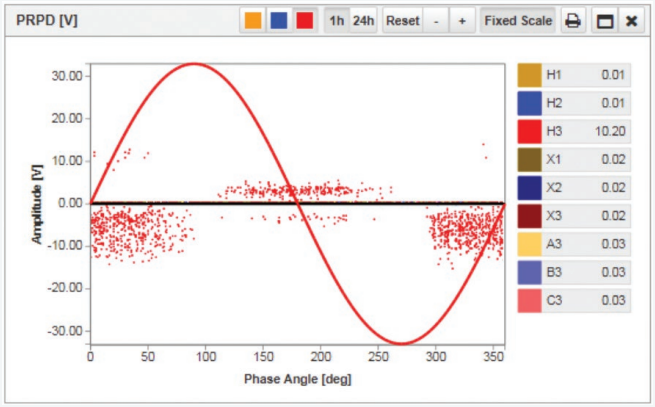
11 May 2018



11 May 2018



7 October 2018



Conclusion is that in the instance of a suspicious sequence of events a step forward can be achieved on diagnosis.

Un-answered questions are now resolved:

- How many windings are affected?
  – One
- What is the affected phase?
  – H3 phase according to the transformer nameplate
- HV side or LV side?
  – HV side according to the wiring procedure and transformer nameplate

The Asset Management Team is now in a position to define the strategy plan in detail:

A. Continue to monitor and properly react with specific and targeted actions (upon the Utility policy) in case of further Acetylene step changes or HEE occurrence.

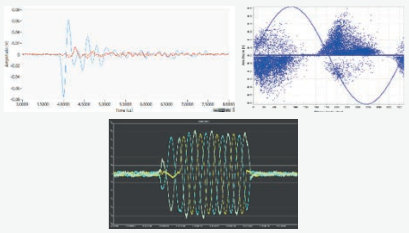
B. Electrical Tests planned anyway as soon as the transformer goes through the next outage to directly investigate the
High Energy Event source in H3 phase.

ACTIONABLE INFORMATION CREATING BUSINESS VALUE

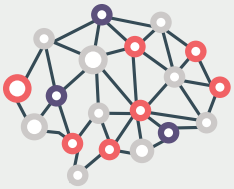
1

Generate the Data

- Detect Anomolies, alarm triggered



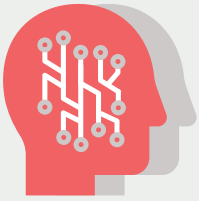
2



Transform Data to Information

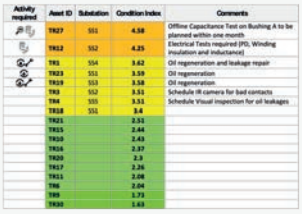
- Correlate the anomilies
- Determine possible failure mode

3



Apply Knowledge to Information

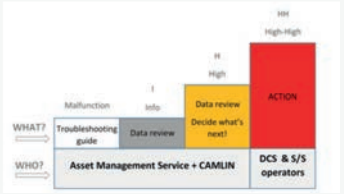
- Combine parameters into condition index to represent transform
- Confirm failure mode to trigger best offline test
- Determine prescriptive actions



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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