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Learning from Forensic Investigation of Gassing Wind Turbine Transformers (WTTs)

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Outline of the Presentation

1. WTTs are Different from Conventional GSU Transformers !
2. Challenges in DGA Diagnostics of Gassing WTTs
3. Learning from Forensic Investigation of Gassing WTTs
4. Conclusions and Takeaways

1. WTTs are Different from Conventional GSU Transformers

- Significantly lower power ratings (typically <10 MVA in contrast to >100 MVA)
- Significantly lower operating voltages (medium voltage area)
- Significantly lower overvoltage capacity
- Highly fluctuating loads
- Highly vibrations

60076-16 © IEC:2011 – 7 –

POWER TRANSFORMERS –

Part 16: Transformers for wind turbine applications

1 Scope

This part of IEC 60076 applies to dry-type and liquid-immersed transformers for rated power 100 kVA up to 10 000 kVA for wind turbine applications having a winding with highest voltage for equipment up to and including 36 kV and at least one winding operating at a voltage greater than 1,1 kV.

Transformers covered by this standard comply with the relevant requirements prescribed in the IEC 60076 standards.

IEC Standard 60076 -16 : 2011
Transformer for Wind Turbine Applications
Recognises Difference

2. Challenges in DGA Diagnostics of Gassing WTTs

There are uncertainties about diagnosing abnormally high amounts of dissolved hydrogen in WTTs!

Non-WTTs

App Table C.7. CIGRE Gas Concentration Levels above Typical Values, in ppm

Concentration Level	H_2	CH_4	C_2H_4	C_2H_6	C_2H_2	CO	CO_2
Typical	118	85	56	111	5	700	6300
Intermediate 1	200	135	120	210	19	970	11600
Intermediate 2	280	180	200	300	40	1180	16700
Pre-failure (PF)	725	400	800	900	450	2100	50000

WTTs

App Table D.1. 90% percentiles of gas concentrations in ppm

Source		H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	CO_2
Iberdrola[29]	Spain	1026	184	-	-	-	555	2825
Acciona[21]	Spain	5400	788	145	8	0	789	1794
Alliant[30]	US	5660	344	53	15	1	521	1592
SDMyers[34]	US	2352	593	162	47	5	977	5173

CIGRE TB771:2019

Table A.4 – Examples of 90 % typical concentration values observed on individual networks

Values in microlitres per litre

Transformer subtype	H_2	CO	CO_2	CH_4	C_2H_6	C_2H_4	C_2H_2
Furnace	200	800	6 000	150	150	200	a
Distribution	100	200	5 000	50	50	50	5
Submersible	86	628	6 295	21	4	6	$< S$ b

NOTE The values listed above were obtained from one particular network. Values on other networks can differ.

a The data are influenced by the design and assembly of the on-load tap-changer. For this reason, no statistically significant value can be proposed for acetylene.

b $< S$ means less than the detection limit.

Table A.5 – Ranges of 90 % typical concentration values observed in WTTs

Values in microlitres per litre

Transformer subtype	H_2 c	CO	CO_2	CH_4	C_2H_6	C_2H_4	C_2H_2
WTT a	1 026 to 5 600	521 to 977	1 592 to 5 173	184 to 788	53 to 162	8 to 47	$< S$ b to 5

a 90 % typical values in WTTs above have been reported in CIGRE TB 771 [2] in 2019, based on very large numbers of DGA values (thousands +). The ranges reported here were observed in WTTs from four electrical networks (in Europe and North America). For hydrogen, for example, one network reported a typical value of 1 026 µl/l, another one 5 600 µl/l and the two other reported values between 1 026 µl/l and 5 600 µl/l. In the reported ranges, values of distribution-type transformers are usually lower than values of padmount-type transformers. Owing to the wide variability of observed 90 % typical concentrations, it is highly recommended to each utility to calculate its own values, considering the homogeneity of the population and the observed failure rate.

b $< S$ means less than the detection limit.

c Hydrogen values obtained statistically can be due to the high electrical stress (transients and harmonics) to which those units are exposed. For this reason, the values for hydrogen can be considered "typical" for statistical purposes, but they could not be inherently attributable to fault absence. Available experience worldwide on wind turbine units is not sufficiently large, yet, to define which statistical values can be considered as fault-free.

IEC 60599:2022

2. Challenges in DGA Diagnostics of Gassing WTTs

There are uncertainties about diagnosing abnormally high amounts of dissolved hydrogen in WTTs!

Notes of Table A.5. of IEC 60599:2022:

"Hydrogen values obtained statistically can be due to the high electrical stress (transients and harmonics) to which those units are exposed. For this reason, the values for hydrogen can be considered "typical" for statistical purposes, but they could not be inherently attributed to fault absence. Available experience worldwide on wind turbine units is not sufficiently large, yet, to define which statistical value can be considered as fault-free."

3 Learning from Forensic Investigation of Gassing WTT

Main Features of Gassing WTT

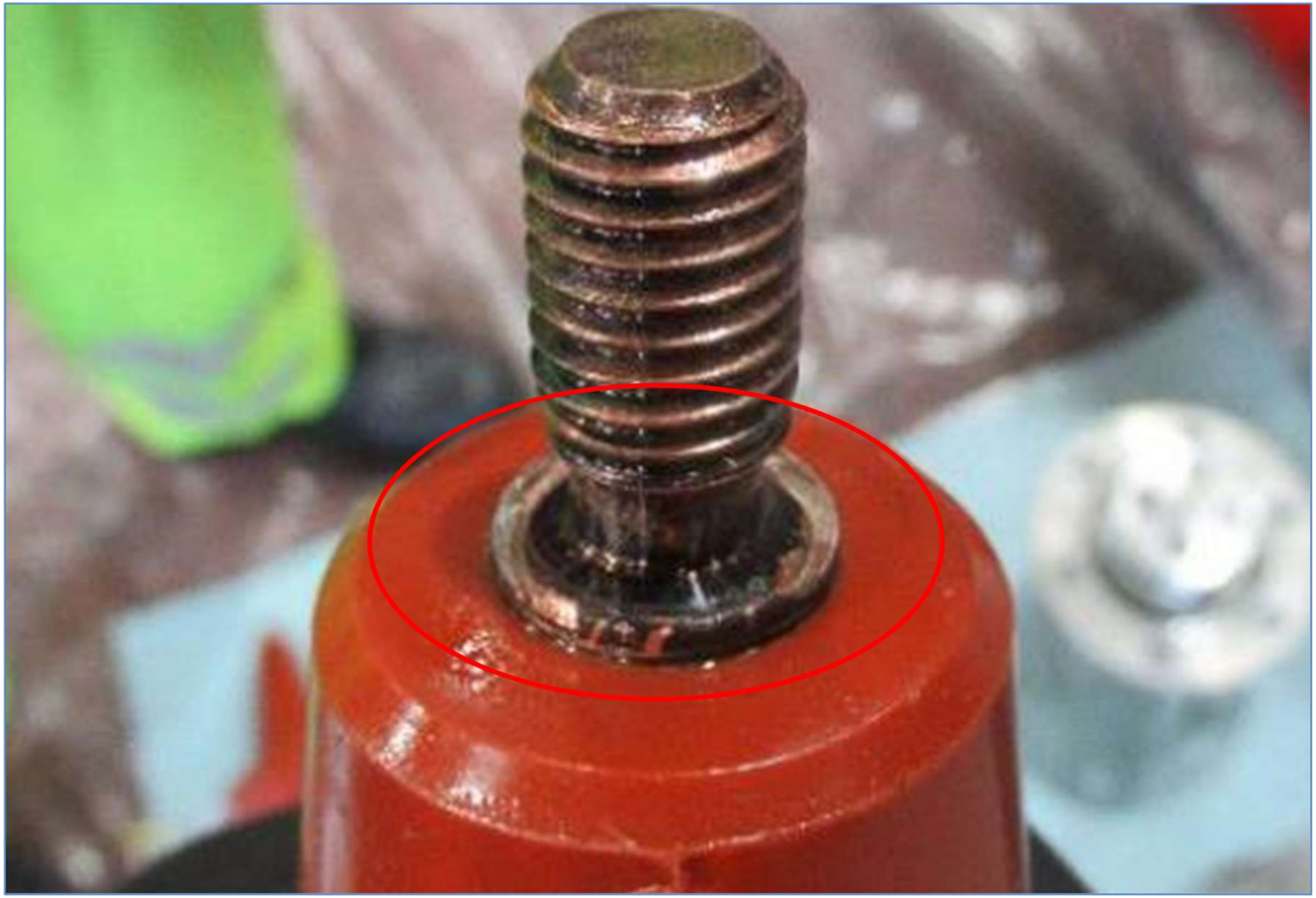
- 2600kVA 33/0.69kV mineral oil filled WTT - ONAN
- 10 years' service
- **Decommissioned in 2022 due to increasing gassing (hydrogen 10,416ppm, methane 3,924ppm, and appearance of acetylene)**

Prior to being removed from the system, several tests were conducted but inconclusive. Internal inspection was also inconclusive. Finally, a decision was made to carry out forensic teardown examination with aim to establish the cause of abnormally high amounts of dissolved gases, especially extremely high levels of hydrogen.

Problem (1) - Corrosion on Lid and at Bolted Lid Holes

3 Learning from Forensic Investigation of Gassing WTT

Problem (2) - Blackening and Overheating at Phase 'B' HV Bushing Bottom End Terminal



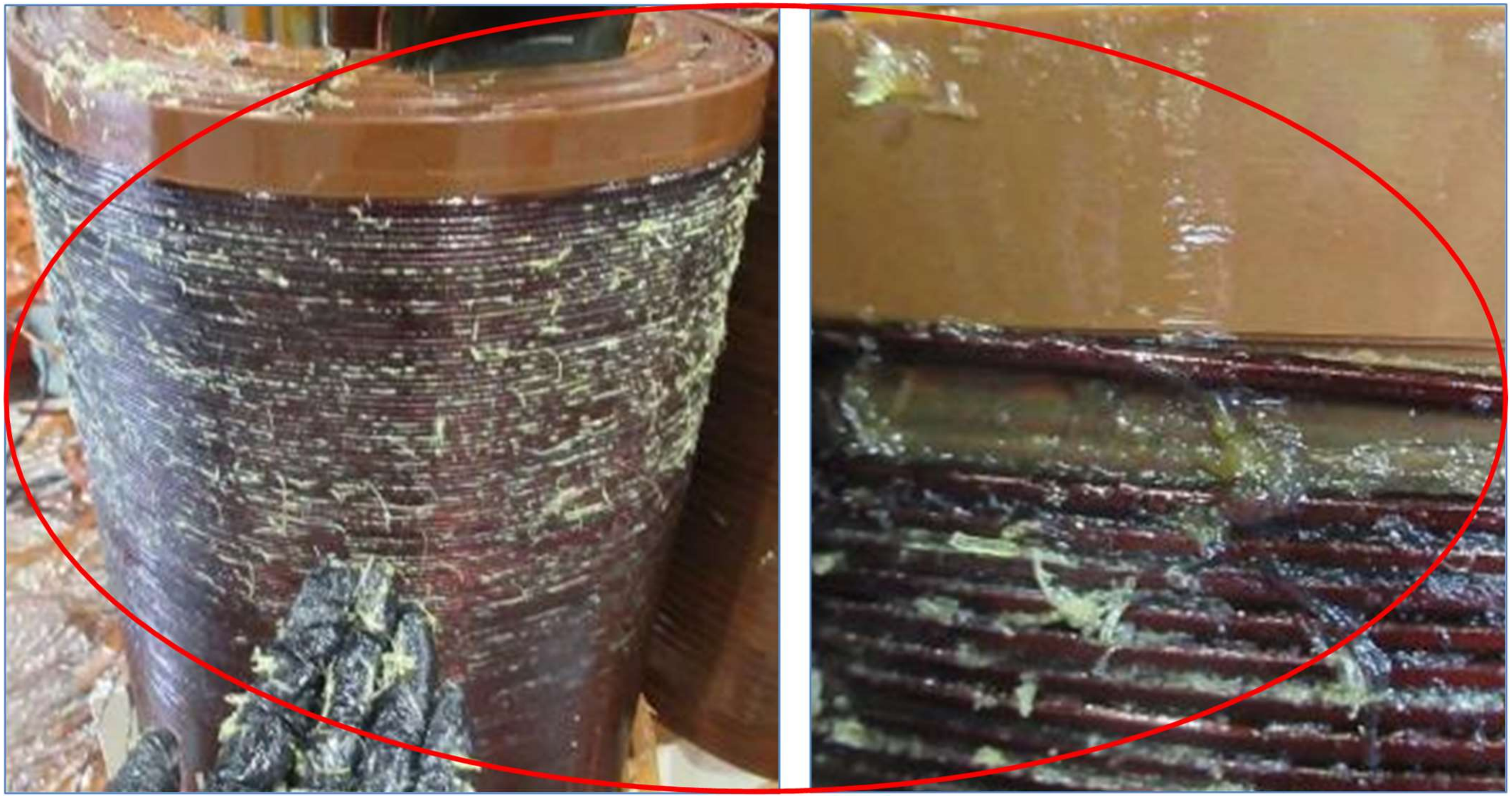
Problem (3) - Carbonised Oil Emission from Security Bolts at Each End of Top Yoke Frame

3 Learning from Forensic Investigation of Gassing WTT

Problem (4) - Carbonised Oil Marks on Top Yoke Frame, Package Insulation, and Core Laminations

Problem (5) - Heavy X-Wax Contamination in Phase ‘C’

HV/HV Tap Winding

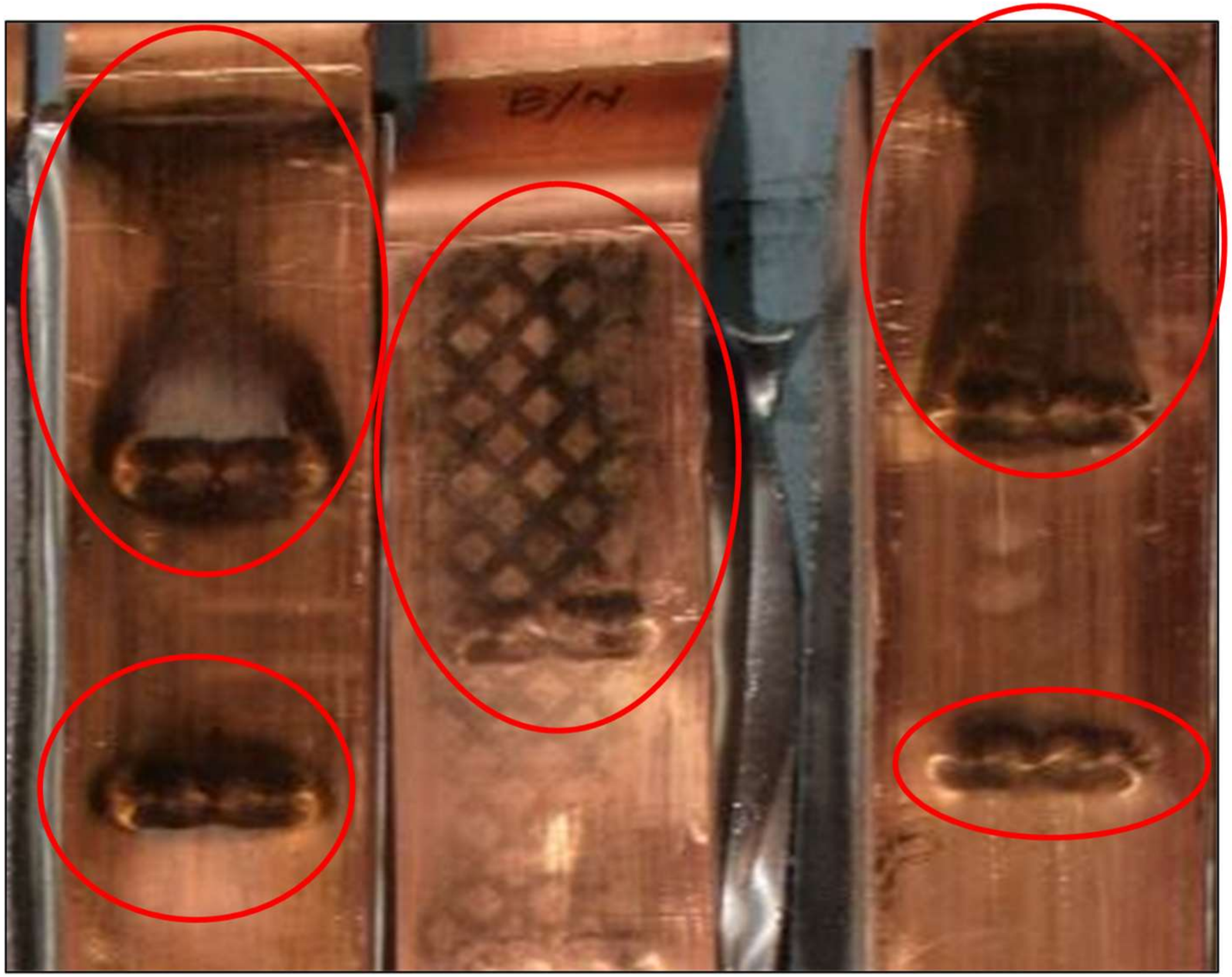


Problem (6) - Carbonised Marks on Phase ‘C’ HV Winding Inter-Layer Insulation

Problem (7) - White Marks on Phase 'C' LV Winding

Aluminium Sheet

Problem (8) - Local Overheating on All Copper Lead Plates at Indentation Points



3 Learning from Forensic Investigation of Gassing WTT

Correlation between Forensic Evidence and High Levels of Dissolved Gases in Gassing WTT

Key and significant forensic evidence in identifying the gassing mechanisms are

- **Heavy X-wax contamination in Phase 'C' HV/HV Tap winding** – confirming that the observed abnormal high amounts of dissolved hydrogen originated primarily from partial discharge in the HV winding.
- **Local overheating on all copper lead plates at indentation points** – confirming weakness in the manufacturing and that the observed abnormal high amounts of dissolved methane and ethane originated primarily from low-temperature overheating of copper lead plates.

4 Conclusions and Takeaways

- The observed abnormal high amounts of dissolved hydrogen in gassing WTT originates *primarily* from partial discharge in the HV winding.

- The observed abnormal high amounts of dissolved methane and ethane in gassing WTT originated *primarily* from low-temperature overheating of copper lead plates.

- Knowledge from forensics are of vital importance in understanding DGA results of WTTs , and an in-depth understanding the life-limiting factors enable better interpretation of DGA results. Utilizing this practical experience allows asset engineers to manage the risk of unexpected WTT failures.