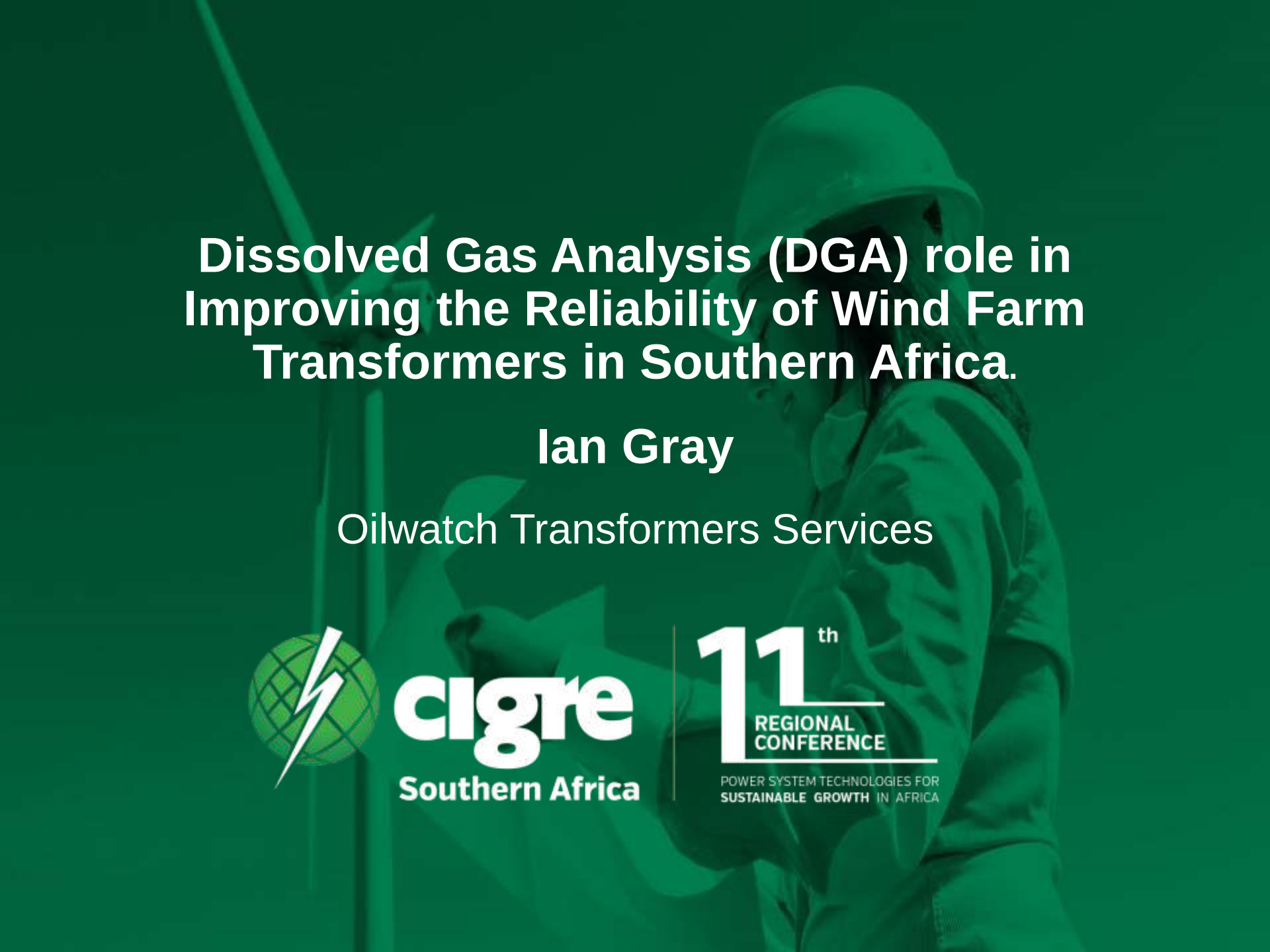
Dissolved Gas Analysis (DGA) role in Improving the Reliability of Wind Farm Transformers in Southern Africa.

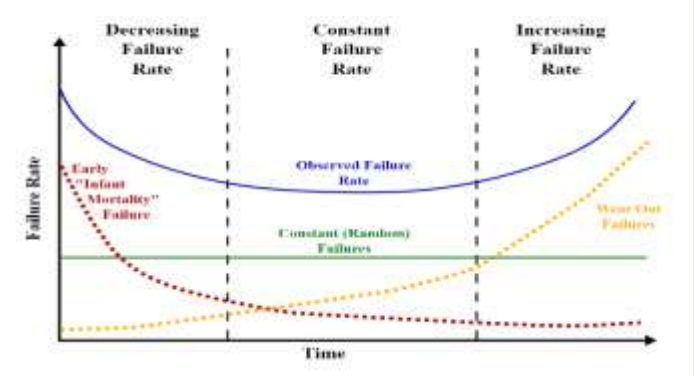
Ian Gray

Oilwatch Transformers Services



Wind turbine step-up transformers

- Play a vital role in ensuring energy security (JET)
- High failure rate. This is not unexpected as transformers follow the Bathtub failure curve (Weibull distribution Curve).
- This trend affects both liquid filled and dry type transformers.
- Most wind projects use pad mount liquid-insulated transformers, and the most common models which have been installed do have their shortcomings.
- Many are designed and rated as distribution transformers rather than generator step-up units, which has created a worldwide issue of a high level of early failures.



Dissolved Gas (DGA)

- DGA is among the most powerful and widely used methods for detecting failures in transformers and for evaluating their condition in service
- requires expert skill to interpret
- Industry experts feel that “Dissolved Gas Analysis (**DGA)** is the most powerful tool in the industry

	Type of Problem	Magnetic Circuit Integrity	Magnetic Circuit Insulation	Winding Geometry	Winding/Bushing/OLTC Continuity	Winding/Bushing Insulation	Winding Turn to Turn Insulation
	Diagnostic Technique						
Basic Electrical	Winding Ratio	•					
	Winding Resistance			•			
	Magnetisation current	•					•
	Capacitance and DF/PF		•		•	•	•
	Leakage Reactance				•		
	Insulation Resistance		•			•	
	Core Ground Test					•	
Advanced Electrical	Frequency Response of Stray Losses			•	•		
	Frequency Response Analysis	•			•	•	•
	Polarisation/Depolarisation		•				
	Frequency Domain Spectroscopy		•				
	Recovery Voltage Method		•				
	Electrical Detection of PD	•	•				
	Acoustical Detection of PD	•	•				
	UHF Detection of PD	•	•				
	Dissolved Gas Analysis	•	•	•		•	•

(CIGRE WG A2.34-Electrical Tests and DGA Diagnostic Matrix)

DGA testing

- laboratory DGA tests are usually the preferred choice, since its low cost, efficiency and capabilities are in most cases superior to the best available DGA portable and online monitors.
- Accredited laboratory(ISO/IEC 17025) is a global standard that recognises the technical competence of a laboratory to perform specified tests.(Legal Standing)
- CIGRE and EPRI working groups
- *DGA monitoring systems*, CIGRE Technical Brochure 783, WG D1/A2.47,201

IMPORTANCE OF ACCURATE DATA FOR IMPROVING ASSET RELIABILITY

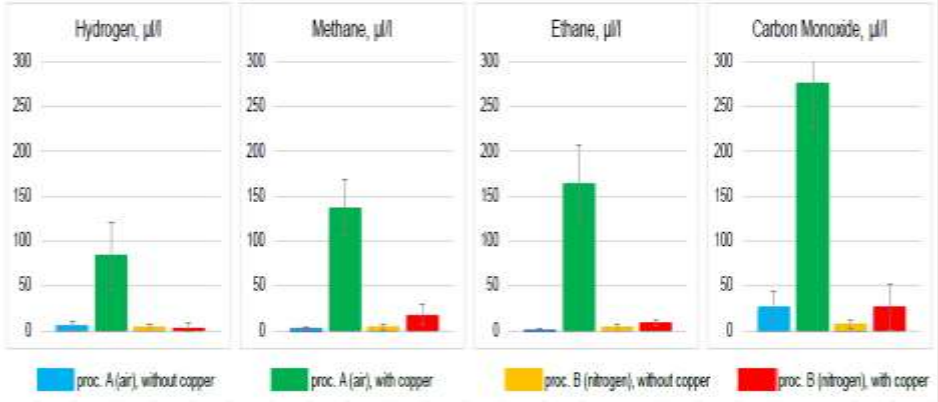
- Data is the most valuable commodity in today's world
- Inaccuracies can quickly aggregate and escalate from a minor niggle into something that compromises all the efforts.
- to obtain a reliable sample plays a critical role.
- Test results are only as good as the sample taken (*Garbage in-Garbage out)*

DGA INTERPERATION

- Since the 1970's numerous diagnostic schemes have been proposed.
- all with advantages and disadvantages
- Stray Gassing (complicate the interpretation further)
- multidisciplinary field
- It would be good to remember the age-old adage" There is no substitute for experience"

Rogers	Potthoff	4 Different interpretation methodologies
Halstead	Shanks	More than 100 gas level limits
LCIE	Trilinear Plot	More than 20 ratios
Laborelec	IEC 60599	More than 40 faults conditions
GE	Duval Triangle &Pentagon	More than 10 rates of rise
Church	IEEE C57.104 Key Gas	
Dörnenberg	LCIE Scheme	
CIGRE	Potthoff Scheme	

A.8.1 Stray gassing pattern 1



IEC 60599 Edition 5 : ?

- **Table A.4a – Ranges of 90% typical concentration values observed in WTTs(wind turbine transformer)**

Transformer sub-type	H_2[c]	CO	CO_2	CH_4	C_2H_6	C_2H_4	C_2H_2
WTT[a]	1026-5600	521-977	1592-5173	184-788	53-162	8-47	<S[b] - 5

[a] 90% typical values in WTTs above have been reported in CIGRE TB # 771 in 2019, based on very large numbers of DGA values (thousands +). The ranges here reported were observed in WTTs from 4 electrical networks (in Europe and North America). For hydrogen, for example, one network reported a typical value of 1026 µl/l, another one 5600 µl/l and the 2 others reported values between 1026 µl/l and 5600 µl/l. In the reported ranges, values of distribution-type transformers are usually lower than values of padmount-type transformers. Due to the wide variability of observed 90% typical concentrations, it highly recommended to each utility to calculate its own values, considering the homogeneity of the population and the observed failure rate.

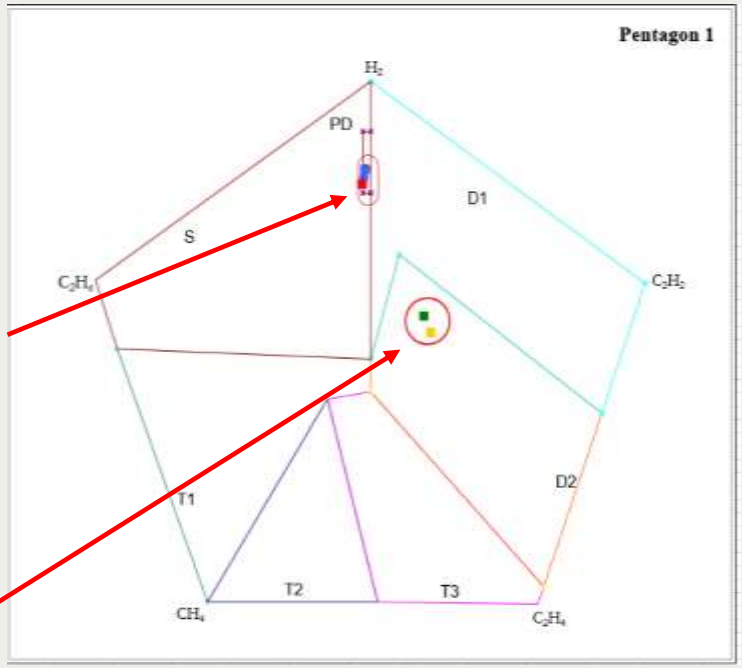
[b] < S means less than the detection limit.

[c] Hydrogen values obtained statistically may be due to the high electrical stress (transients and harmonics) to which those unit 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.

Case Study WTT 2.7 MVA, 33 kV Installed in 2016

- A partial record of the DGA results with the Duval Pentagon plot.
- initially a Partial Discharge fault (PD), but following maintenance in July 2017 the fault type changed to a (D2) Discharge of High Energy

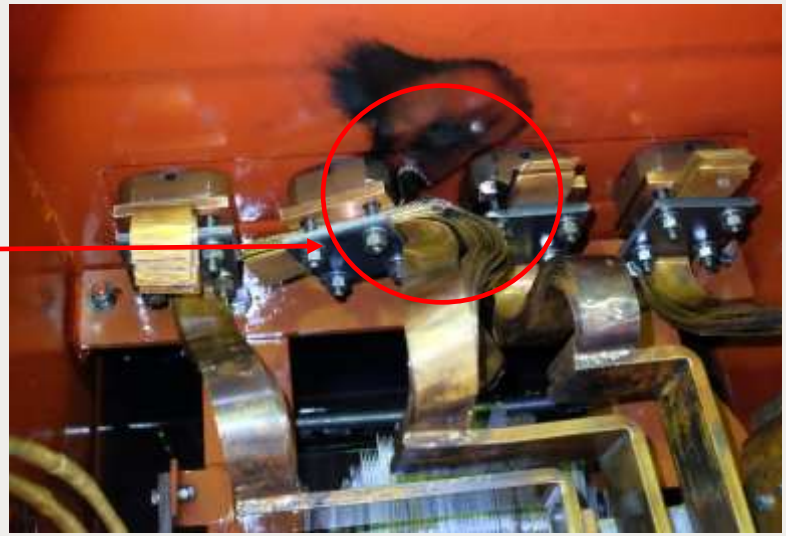
Date	H_2	CH_4	C_2H_2	C_2H_4	C_2H_6
2016/06/07	2942	329	0	6	54
2016/10/12	6857	574	0	6	95
2016/11/02	11908	1232	0	12	276
2016/11/07	12310	1050	0	9	180
2016/11/15	14697	1244	0	13	260
2016/11/23	10710	1329	0	13	276
2017/02/10	13208	1625	0	13	375
2017/06/05	15333	1362	0	8	297
2017/08/14	2463	1047	2256	1569	301
2017/09/01	3169	1063	2237	1566	309



Transformer Assessment Index(TAI) Scoring Matrix (Risk)

Transformer Assessment Index (TAI) Scoring Matrix (Risk)	TAI	Remedial Action
Very Poor condition – high likelihood of failure. Component is near end of life. Repair or replacement as soon as possible is recommended. De-rating or restricted operation of the transformer may be appropriate, and operation under extreme conditions may not be appropriate until replacement is possible.	E	Resample DGA weekly to monitor Gas Rates of Rise-Plan to remove from service for Inspection/Repairs.

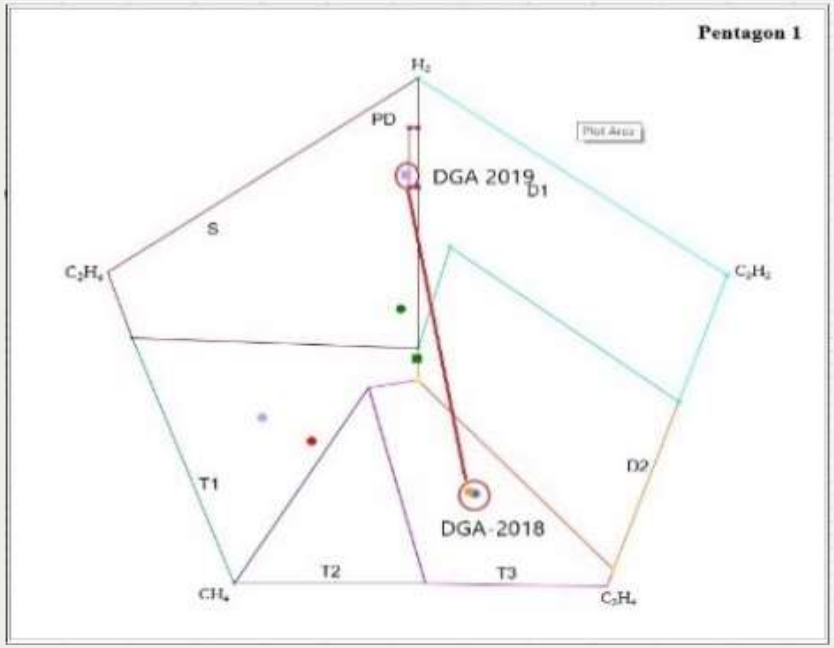
- **Internal Inspection**
- LV short circuit at the LV bushings due to a rotated bushing. It quickly burnt away the touching copper foils which was the cause for the sudden increase in hot metal gasses
- root cause of the rotated bushing was due to improper maintenance



Case Study WTT 2.7 MVA, 33 kV Installed in 2016

- Regular DGA sampling performed from Factory Acceptance Testing (FAT) to site energisation with all results showing normal operation.
- 3 months after Energisation significant Gas rise.
- DGA results shown in Table with Duval Pentagon plot.(T3 Fault)-2018
- 2019-Partial Discharge (PD) fault

Date	H_2	CH_4	C_2H_2	C_2H_4	C_2H_6	Type
2017/06/22	0	3	0	1	5	Prior to energising
2017/12/01	0	4	0	1	4	
2018/01/20	0	4	0	2	3	
2018/04/23	1253	9341	1887	27952	4077	
2018/05/10	2300	12264	2163	33951	4949	
2018/10/08	9	4	1	3	3	Prior to Re-energising
2019/06/10	7737	720	2	87	308	

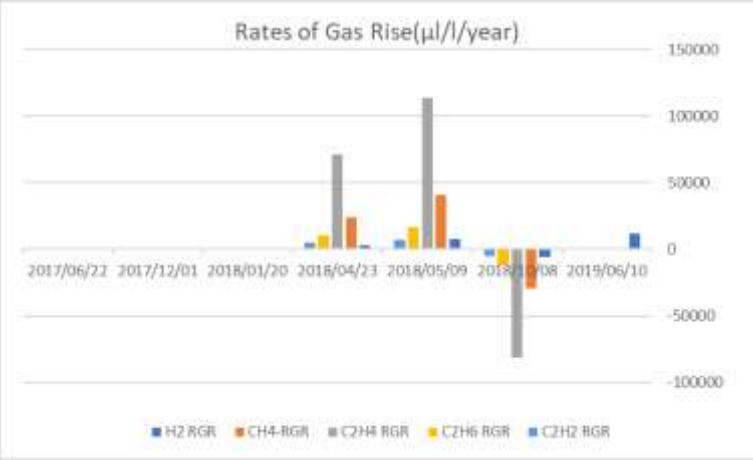


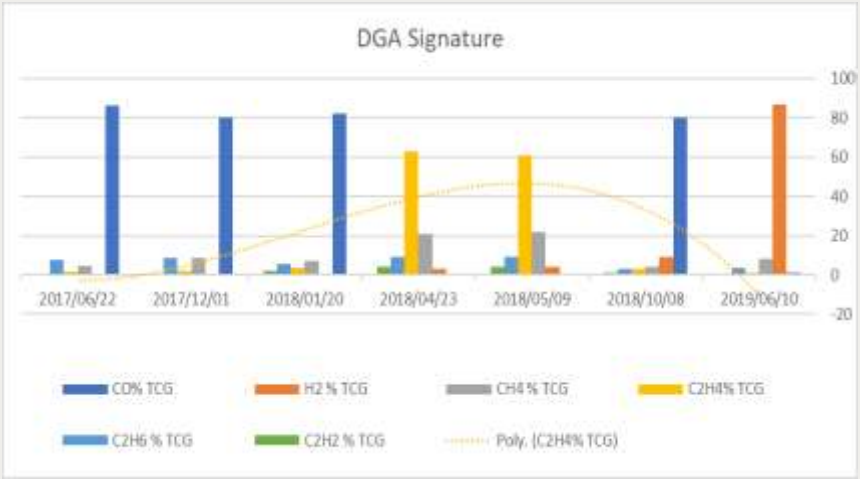
Rates of Gas Rise(RGR)

- between the samples dated 2018/05/10 to 2018/04/23

	H_2	CH_4	C_2H_2	C_2H_4	C_2H_6	CO	CO_2	TCG
ppm /year	4109	11472	1083	23544	3422	110	145	43741
Ranges of 90 % typical rates of gas increase (IEC 60599)	35–132	10–120	0–4	32 – 146	5–90	260–1060	1700-10000	
ppm/day	11,26	31,43	2,97	64,51	9,38	0,30	0,40	119,84

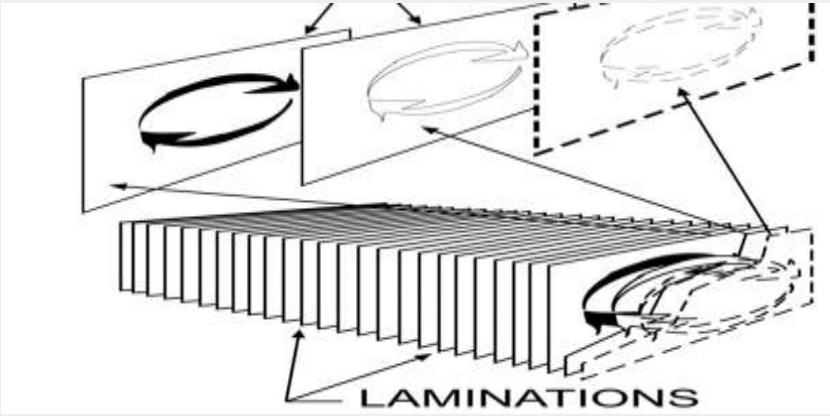
- Note-Despite this enormous interest in wind energy, gas generation in windfarm transformers has not been adequately addressed in international standards.





Internal Inspection (Root cause Investigation).

- In-warranty inspection found a burnt connection on the 33 kV Bus bar link.
- (Non-conforming QC)
- Secondary fault observed on the Core which will contribute to Hysteresis loss and Eddy currents(PD)-DGA 2019

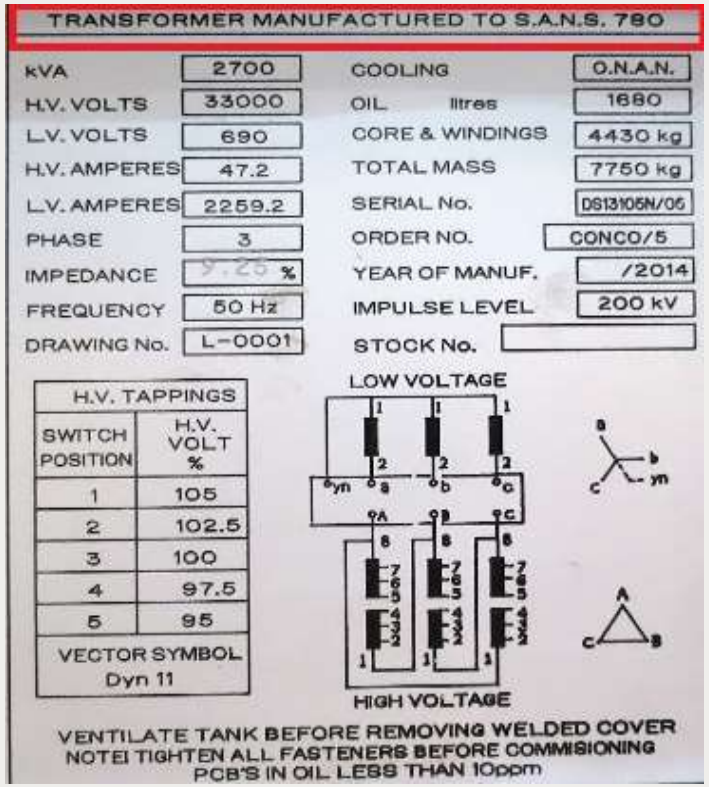


OEM Inspection

- **Burning connection 33 kV Bus bar link**

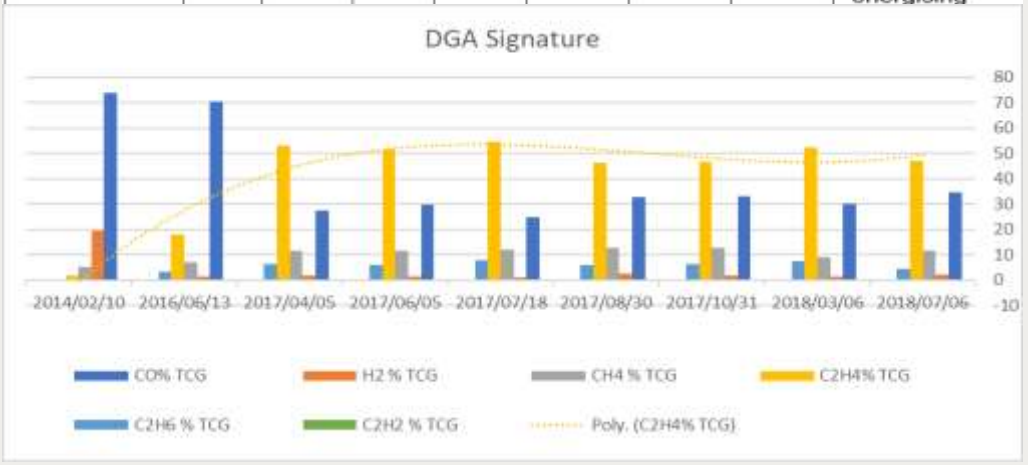
Case Study WTT 2.7 MVA, 33 kV Manufactured in 2014

- The abnormal gassing pattern was evident after Energisation on load, (Warranty issue)
- Nameplate information



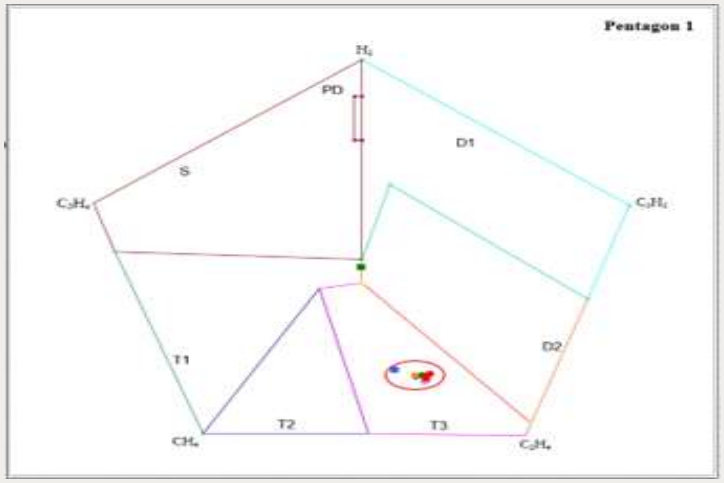
DGA Results and Signature

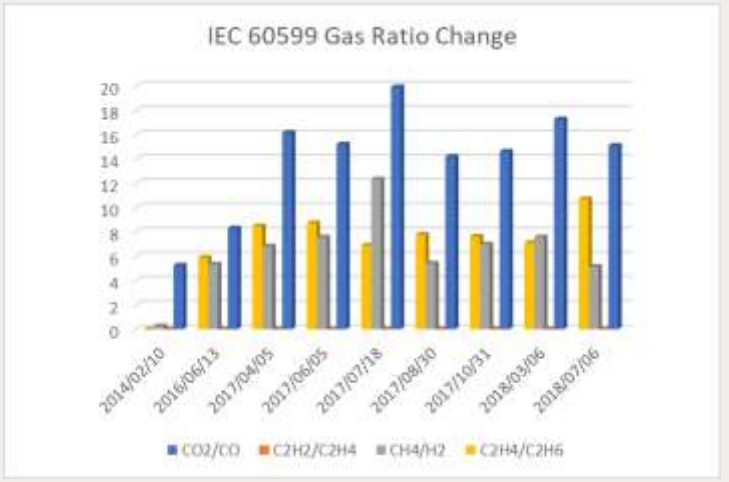
Sample Date	H_2	CH_4	CO	CO_2	C_2H_4	C_2H_6	C_2H_2	Sample Type
2018/07/06	35	181	539	8148	729	68	0	
2018/03/06	12	91	312	5393	542	76	0	
2017/10/31	21	147	383	5604	543	71	0	
2017/08/30	33	179	461	6553	647	83	0	
2017/07/18	9	111	233	4645	511	74	0	
2017/06/05	19	144	370	5635	647	74	0	
2017/04/05	18	123	293	4740	569	67	0	
2016/06/13	17	91	901	7494	230	39	1	
2014/02/10	11	3	42	221	1	0	0	Prior energising

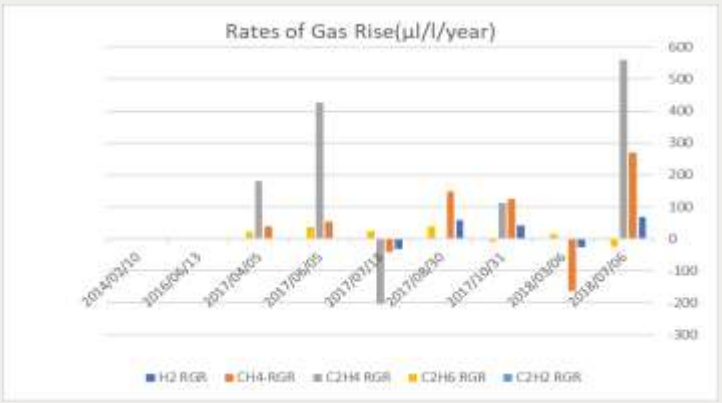


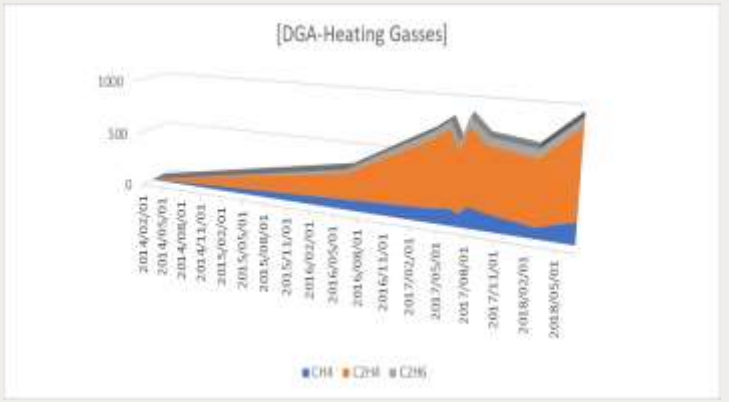
Fault diagnosis
Rates of Gas Rise(RGR)

- Duval Pentagon-Thermal Fault(T3) : IEC Ratio's-T3 t > 700 °C



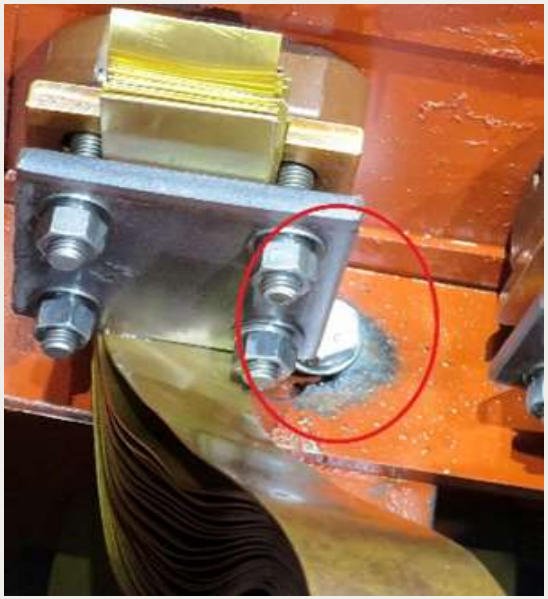






Findings of the Internal Inspection

- The internal inspection revealed a number of quality issue

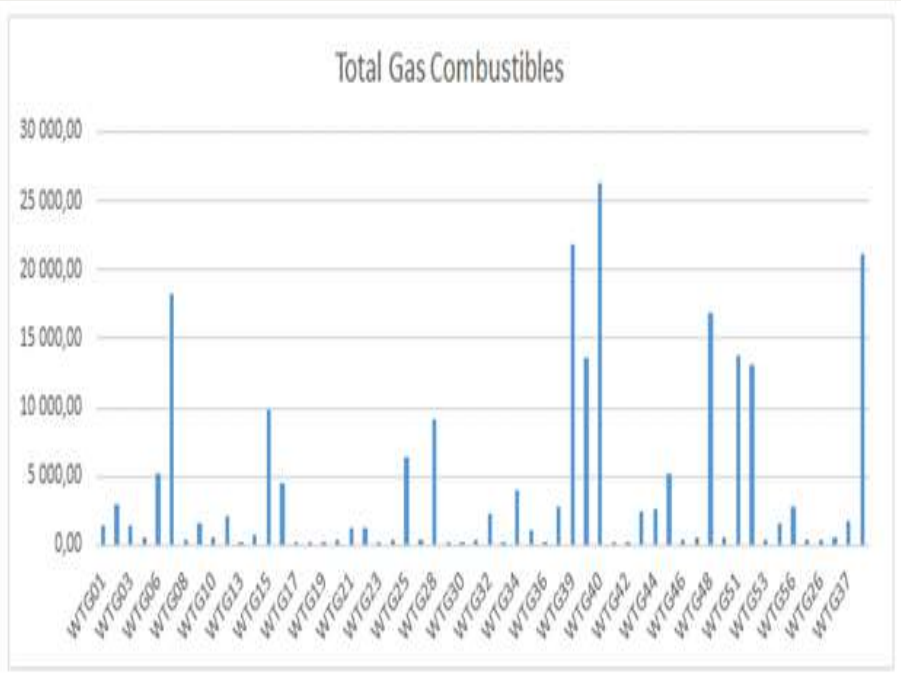


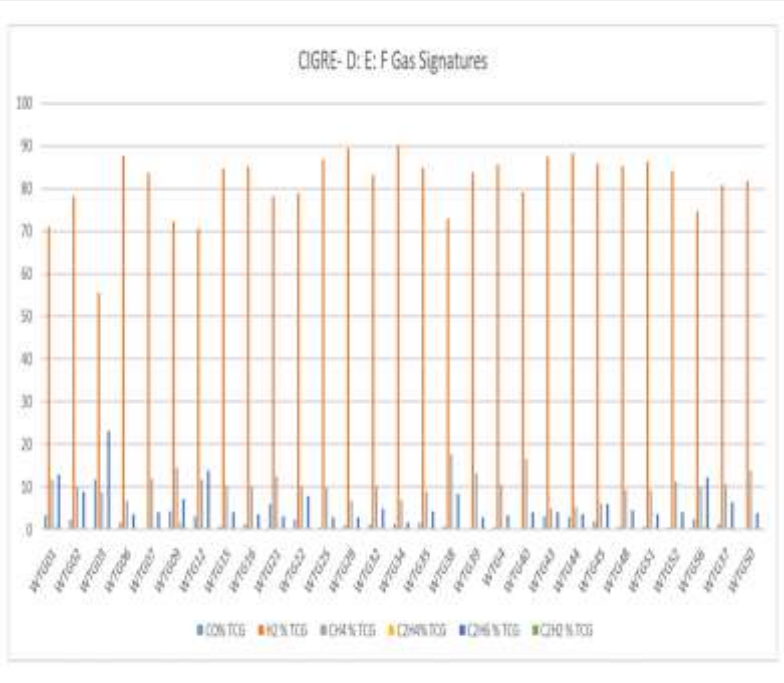
IEC 60599-Typical examples

- Large circulating currents in tank and core
- Minor currents in tank walls created by a high uncompensated magnetic field
- Shorting links in core steel laminations

Case Study of 55 Transformers at a Windfarm(2.7 MVA, 33 kV)

- Dissolved Gas Analysis (DGA), showed a significant number with Abnormal Gas levels when compared to sister Units
- Assessment Index (TAI) results are given in Gas Signatures for Category D: E: F, the fault category in most cases was Partial Discharge activity





Case Study of 55 Transformers

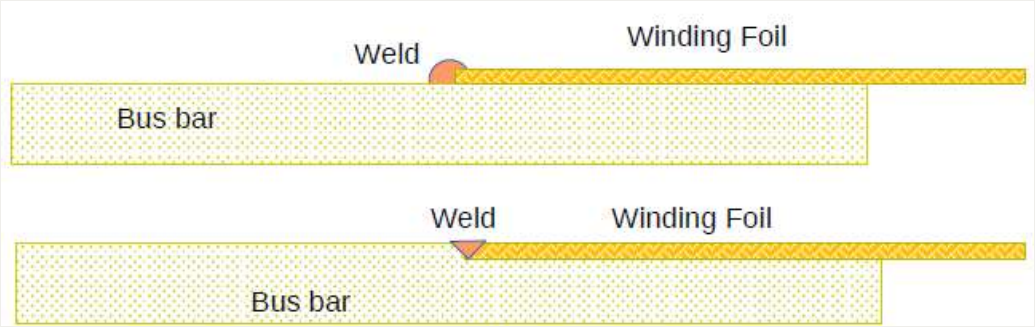
- **CIGRE 761 Assessment Index (TAI) Scoring Matrix (Risk)**

CIGRE (TAI)	Number of Units	% of Total
>3000 ppm H_2(Cigre F)	14	25,45
>1800 ppm H_2(Cigre E)	21	38,18
>700 ppm H_2 (Cigre D)	29	52,73

F	De-energize as soon as possible. Don't return to service until problem is repaired. Component is at end of life.
E	Very Poor condition – high likelihood of failure. Component is near end of life. Repair or replacement as soon as possible is recommended. De-rating or restricted operation of the transformer may be appropriate, and operation under extreme conditions may not be appropriate until replacement is possible.
D	Poor Condition. Repair or replacement should be considered within the short term. Reliable operation may be impaired or compromised. Performance or component may be causing deleterious effects. Consider review of rating and operating condition.

Root Cause Investigation

- PD was identified as sharp edges on the foil windings as well as bad workmanship in the factory exacerbating the PD due to stop-blocks damaging the paper. Harmonics was also a role player.
- One major reason for hydrogen formation due to PD in this transformer type is bad manufacturing procedures.
- Consequently, most transformer manufacturers should be aware that asperities must be avoided even in transformers with low voltage level.

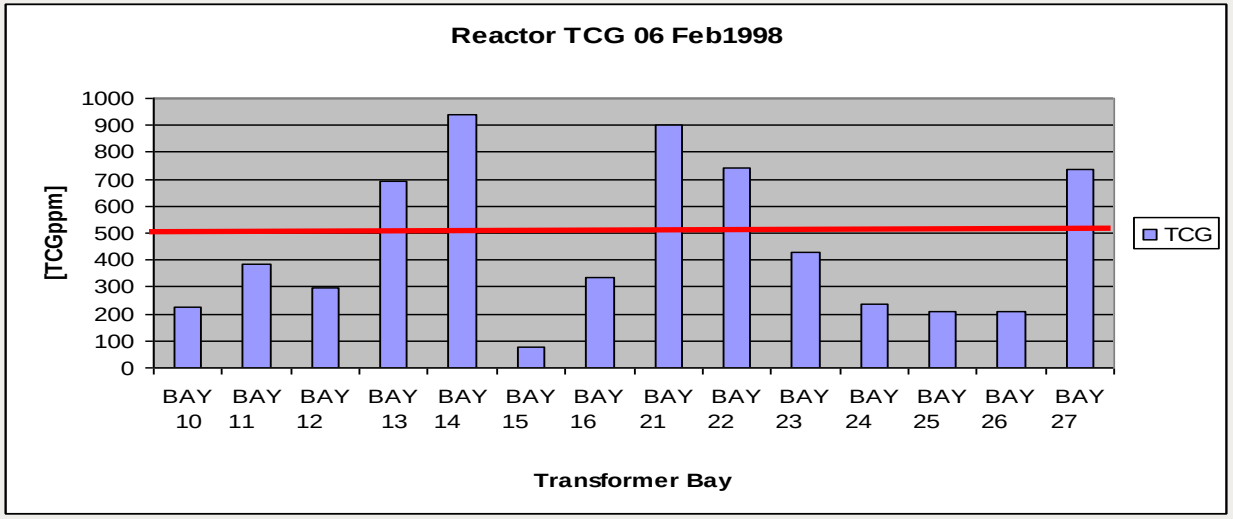


Lower schematic drawing
show a better design, low in asperities and thus causing less PD.

Courtesy: VPdiagnose AB- Lars Arvidsson

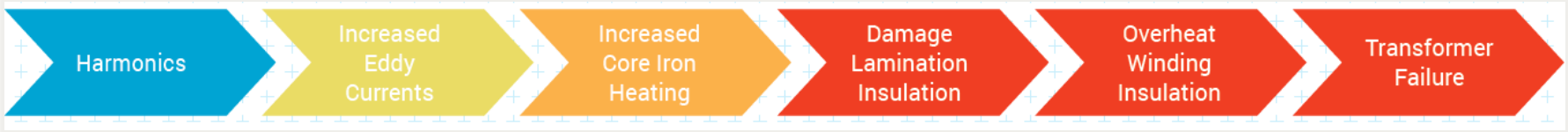
Partial Discharge and Harmonics

- PD and harmonics is complex and extensive
- Compelling evidence of a link to the gassing issues in windfarm transformers.
- Past Experience of Reactors at an Aluminium Smelter

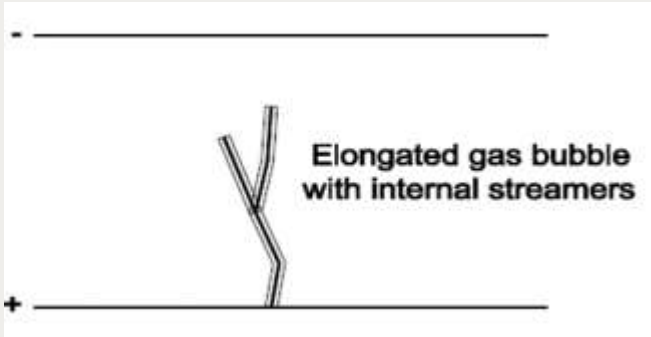


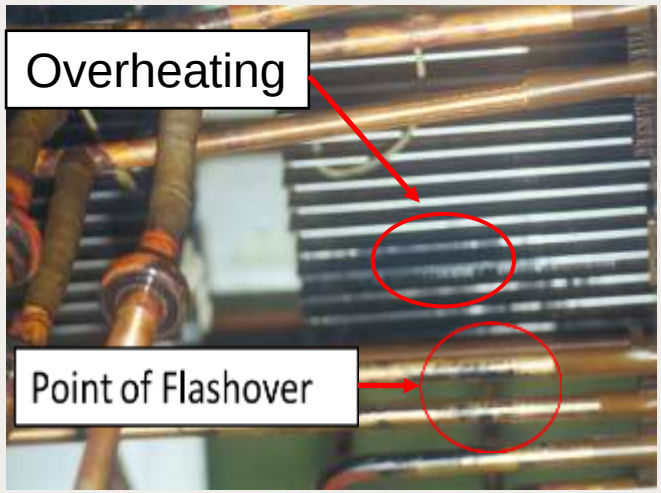
- https://oilwatch.co.za/dissolved-gas-analysis-at-an-aluminium-smelter/

Safety concerns



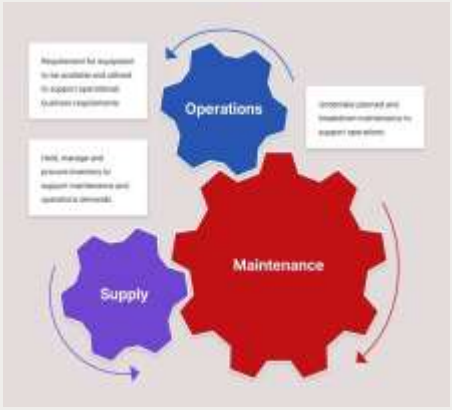
- High Levels of Hydrogen and Hydrocarbons in Active Transformers
- Gas Bubble formation-elongate in the direction of the electric field
- Mechanism of the flash-over-voltage stress caused by gas bubble formation
- Root cause: 5th Harmonic





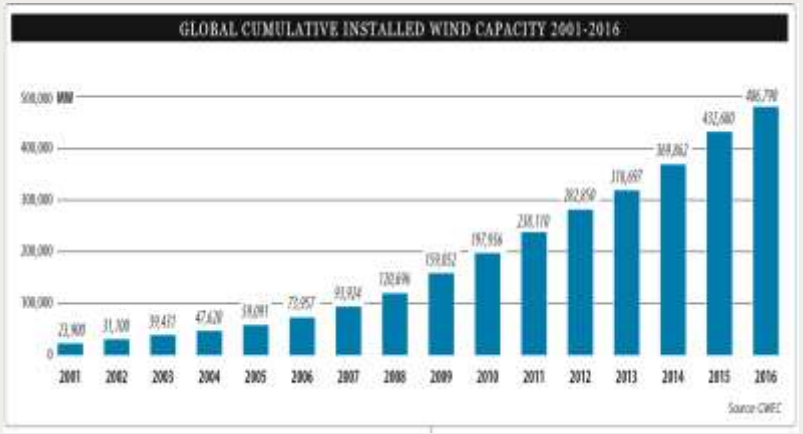
Reliability-is-everybody's-responsibility

- We are fascinated by disasters, yet in our workplaces , mini-disasters occur with monotonous regularity.
- Why should we accept failure is the norm
  - **Design**–a system can only be as reliable as the reliability inherently built into its design.
  - **Operations**–Operating equipment outside its design limitations is a recipe for failure.
  - **Maintenance**–a system needs to be appropriately maintained in order for to remain reliable
  - **Supply**–a key element of the procurement function is to ensure that the items purchased meet the reliability performance standards specified or intended by the designers of the equipment.

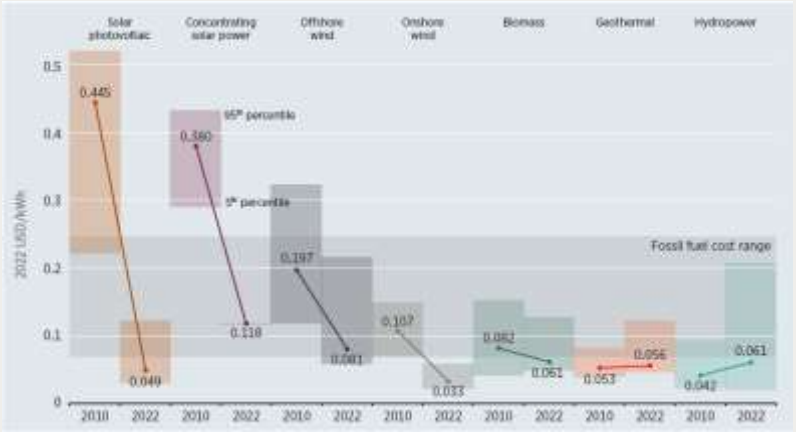


Further considerations

- Knowledge and data sharing among end-users can also help to compensate for unfamiliarity with a specific type of critical component, technology, or supplier.
- The current Non-Disclosure Agreements (NDA) circumvent the ideal of knowledge sharing and should be addressed by the industry
- The future will be Renewable Based or there won't be Future



References : World bank



IRENA 2022

Thank You and Q&A

- Whew!!!!!!!!

I am out of here!