Gassing of Wind Farm Transformers
Ian Gray
Senior Consultant Wearcheck
South Africa
Transformer Facilities Laboratories
- Cape Town
- Durban
- Gauteng
INTRODUCTION

- The transformer is an engineering marvel with a brief but remarkable history.
- Patented about 100 years ago.
- Modern transformer may represent the most crucial and vulnerable link in today’s total energy chain.
WHAT IS A TRANSFORMER

Chemical Reactor that just happens to Transform Electricity
Siemens : Sensformer

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FUNDAMENTALS OF TRANSFORMER CONDITION ASSESSMENT

• Power transformers are expensive and critical equipment in power systems.

• play a significant role in the transmission and distribution of electricity.

• generally reliable pieces of equipment, failures do occur, and there are many degradation mechanisms operating in components and sub-systems that will ultimately limit the useful operating life.
New Technologies generally conform to the Bath Tube Failure Curve.

**Transformer Failure Curve**

- **Early Failures**
- **Unserviced Units**
- **Poorly Maintained Units**
- **Old Age**

*When should a Transformer be removed from service?*

[Graph showing the Bath Tub Curve - Transformer Failure Rates with axes for Failure Rate vs. Time (years)]
DEFINITION OF MAJOR FAILURE

➢ Any situation which requires the equipment to be removed from service for a period longer than 7 days for investigation, remedial work or replacement is a major failure.

➢ Where repairs are required, these involve major remedial work, often requiring the transformer to be removed from its plinth and returned to the factory.

➢ A major failure would require at least the opening of the tank, including the tap changer tank or an exchange of bushings.

➢ Also a reliable indication that the condition of the transformer prevents a safe operation should be counted as a major failure if remedial work (longer than 7 days) is needed for restoring original service capability (e.g. detection of strong PDs)
Failure Cause

Transformer Reliability Survey – Tutorial of CIGRÉ WG A2.37

- External short-circuit: 11.62%
- Design: 9.96%
- Manufacturing: 9.96%
- Improper repair: 6.02%
- Other reasons: 4.88%
- Material: 3.73%
- Improper maintenance: 3.22%
- Abnormal Deterioration: 2.49%
- Lightning: 2.18%
- Overvoltage: 0.62%
- Overheating: 0.41%
- Pollution: 0.52%
- Damage: 0.31%
- Collateral Damage: 0.31%
- Loss of clamping pressure: 0.21%
- Loss of cooling: 0.21%
- Vandalism: 0.10%
- Corrosive Sulphur: 0.21%
- Improper application: 0.21%
- Repetitive through faults: 0.83%
- Installation on-site: 0.83%
- Unknown: 29.05%

Based on 964 failures
General Risk Model

ESTIMATING CONSEQUENCES OF FAILURE

What are the key risks from failure?

Safety: Public and the staff?
Environment: Are pollution risks too high?
Strategic: System impact?
Financial: Business interruption costs?
Financial: Physical damage?

Courtesy: Ron Moore, Managing Partner, The RM Group, Inc.
### 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

<table>
<thead>
<tr>
<th>Basic Electrical</th>
<th>Advanced Electrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding Ratio</td>
<td>Frequency Response of Stray Losses</td>
</tr>
<tr>
<td>Winding Resistance</td>
<td>Frequency Response Analysis</td>
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<tr>
<td>Magnetisation current</td>
<td>Polarisation/Depolarisation</td>
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<tr>
<td>Capacitance and DF/PF</td>
<td>Frequency Domain Spectroscopy</td>
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<tr>
<td>Leakage Reactance</td>
<td>Recovery Voltage Method</td>
</tr>
<tr>
<td>Insulation Resistance</td>
<td>Electrical Detection of PD</td>
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<tr>
<td>Core Ground Test</td>
<td>Acoustical Detection of PD</td>
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<td></td>
<td>UHF Detection of PD</td>
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</table>

**Dissolved Gas Analysis**
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 but requires expert skill to interpret.*
Dissolved Gas analytical procedure

The Dissolved Gas analytical procedure

With any Analytical Chemistry test there will always be variation, this is referred to as Analytical variation or **Uncertainty of Measurement**

---

**TABLE 7 Interim Precision Statement for Repeatability for One Laboratory**

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<th>Run</th>
<th>H₂</th>
<th>O₂</th>
<th>N₂</th>
<th>CH₄</th>
<th>CO</th>
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<th>C₂H₄</th>
<th>C₂H₆</th>
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</table>

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[Image of laboratory equipment]
Dissolved Gas Measurement

Frequent sampling and analysis will produce variation in results

The sampling procedure
You can’t break the laws of physics. Remembering this can be of help in evaluation of dissolved gas-in-oil data. (P. Griffin Doble Engineering)
In some cases, there have been excessive amounts of hydrogen detected in samples and then suddenly on the next sample, it disappears.

Garbage in-Garbage out

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The Dynamic Behaviour in the Transformers Insulation system
Dissolved Gas concentration varies within the insulating oil due the following:

- Loading
- Absorption
- Diffusion
- Partitioning

Variation of Dissolved Gas measured by an On line Instrument (Gas Chromatograph)

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Comparison of Different DGA Methods

Traditional DGA testing methods are off-line sampling and laboratory techniques.

Modern technology has permitted the development and commercialisation of mobile on-site test and on-line methods.

Is the future of oil testing exclusively in on-line predictive diagnostics?
COMPARISON

In general the DGA tests performed in laboratory environments use far more sensitive equipment when compared to these portable and on line dissolved gas analysers.

- Accredited laboratory (ISO/IEC 17025)
- Client reduces the risk of using or producing a product that does not conform to the required specifications or industry standards
DGA Interpretation History

Several methods introduced in the 1970 & 1980

Statistic threshold
• Rogers
• Halstead
• LCIE
• Laborelec
• GE
• Church
• Dörrenberg

• Potthoff
• Shanks
• Trilinear Plot
• IEC
• Duval
• IEEE C57.104 Key Gas
  – LCIE Sheme
  – Potthoff Scheme
  .... And counting

Advantages and Disadvantages
Today DGA Interpretation Methods

• Since 1970
• Transformer / OLTC / CT / PT / Bushing
• Mineral / Ester / Silicone
• 7 Gases
• 4 Different interpretation methodologies
• More than 100 gas level limits
• More than 20 ratios
• More than 40 faults conditions
• More than 10 rates of rise

TechCon SE Asia, Kuala Lumpur, April 10, 2017
Stray Gassing & Duval Pentagon

Stray Gassing describes the development of gases in an insulating liquid in service under temperatures considered usual for normal operating conditions.

**FAULT ZONES**

| S: Stray Gasing of Oil<200°C |

IEC 60296 Edition 5-Specifies Limits Type A

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method</th>
<th>Limits</th>
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</thead>
<tbody>
<tr>
<td>Stray gassing</td>
<td>Procedure A.4 in the presence of copper</td>
<td>Non stray gassing: &lt; 50 μl/l of hydrogen and &lt; 50 μl/l methane and &lt; 50 μl/l ethane</td>
</tr>
</tbody>
</table>

DGA results identified by visual inspection as due to faults:

- PD
- D1
- D2
- T3
- T2
- T1
- S>200°C
- S=120°C

A.8.1 Stray gassing pattern 1

- Hydrogen, μl/l
- Methane, μl/l
- Ethane, μl/l
- Carbon Monoxide, μl/l

- proc. A (air), without copper
- proc. A (air), with copper
- proc. B (nitrogen), without copper
- proc. B (nitrogen), with copper
To determine asset condition, you need accurate data; you also need effective software to interpret that data.

Integrates data from multiple sources:
- Labs
- Online monitors
- Portable gas analyzers

Analyzes not only current gas levels, but also the change in gas levels and the rate of change (trending) over time.

Validate results using multiple diagnostic methods, such as the Duval Triangle, Rogers Ratios, etc.
Transformers: IR4/IOT - we are still in the infancy stage

CIGRE have just released 761

Main aspect is developing: Transformer Assessment Indices (TAIs) where machine learning can assist in developing the model
Conclusion

Yes, life is complicated!!

However, new software tools exist to make your life simpler and sort out all these possibilities.

Data mining and computer modelling

Experts are there to help you.

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GASSING OF WIND FARM TRANSFORMERS

- Safety Concerns of High Levels of Combustible Gas in Active Transformers

- Wind farm turbine step-up transformers (usually padmount or cabinet style) are not used in the same way as other similar units

- One of the issues they face is the constant changing in the force of the wind. Large swings in load from nearly zero to high percentages of capacity are common
PREMATURE FAILURES OF PADMOUNT TRANSFORMERS IN WIND FARM

Failure modes of padmount transformers when used in WTGSU application are different from standard distribution transformers due to the unique nature of the application that it addresses, and they have to possess special design considerations to improve robustness when used in wind farms

- Over-voltage
- Increased mechanical and electrical stress due to the loading cycles of WTGSU.
- IEC Committee developed new Specification
Premature failures

Increased risk of partial discharge due to gassing

In the electrical design, there are different fast transients, harmonics and non-sinusoidal loadings, and different loading factors that need to be considered.
The IEC provides a worldwide, neutral and independent platform where 20 000 experts from the private and public sectors cooperate to develop state-of-the-art, globally relevant IEC International Standards.
Pad Mount Transformer WTG
Remove from service

Primary Voltage: 660 V Secondary Voltage: 33 kV VA Rating: 2.7 MVA

D2: Discharges of High Energy
Dorper Windfarm Failure Investigation

LV short circuit at the LV bushings due to a rotated bushing
LOERIESFONTEIN WIND FARM-DOORNPN
33 kV : 2.7 MVA Pad Mount Transformer

DGA Fault Diagnosis: Thermal fault of high temperature (>700°C)
Recommendation: Removal from Service

<table>
<thead>
<tr>
<th>IEC 60599 DIAGNOSIS OF GAS SAMPLE DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Examples</td>
</tr>
<tr>
<td>C2H2/C2H4</td>
</tr>
</tbody>
</table>

0 2 2 IEC RangeRatio

Normal C02/C0 Ratio (>3 and <11)
Fault: Thermal fault of high temperature (>700°C)

Fault Codes:
- PD: Partial discharge
- T1: Low-range thermal fault (below 300°C)
- T2: Medium-range thermal fault (300-700°C)
- T3: High-range thermal fault (above 700°C)
- D1: Low-energy electrical discharge
- D2: High-energy electrical discharge
- DT: Indeterminate - thermal fault or electrical discharge.
OEM Inspection: 17th May 2018

Burning connection 33 kV Bus bar link

The 33kV Busbar link from the one set of bushings have not been tightened at all.

Non conforming quality control (factory oversight)
The first nut was not fastened but the 2nd lock-nut was tightly torqued.

This would be the reason why the gas levels increased even though the transformer was de-energised, as the 33kV Links remains energised even when the Isolator is opened in order to power up the rest of the network.
OEM Inspection: 17th May 2018
OEM INSPECTION:
BURNING CONNECTION 33 KV BUS BAR LINK
CORE LOSSES

Eddy currents are generated in the core by the alternating lines of flux as they cut through the metal core.

Hysteresis loss is undesirable in electrical machines as it produces heat and is responsible for the loss of energy thus producing additional temperature rise.
JEFFREYS BAY WIND FARM

WTG Pad Mount Transformer 33 kV : 2.7 MVA

DGA Fault Diagnosis: **Thermal fault of high temperature (>700°C)**

Recommended : Remove from Service
Thermal fault of high temperature (>700°C)

Findings
Thermal fault of high temperature (>700°C)

Findings
Thermal fault of high temperature (>700°C)

Findings
Thermal fault of high temperature (>700°C)

Findings
Partial Discharge Corona (PD)
COST OF NO COMPLIANCE
(QUALITY CONTROL & DESIGN)

- Cost of asset not producing revenue (Share holder value)
- Electrical Outage-Down time
- Reputational Damage
- Warranty issues
- Transport cost to OEM and Return
Harmonics Destroy Transformers?

AMAKHALA EMOYENI WIND FARM (50th Harmonic?)
Transformer Assessment samples 18-27 February 2019

Total Gas Combustibles

Partial Discharge faults (PD) H2 > CH4 > C2H6

Graph showing the distribution of gas combustibles and partial discharge faults across different transformer units.
HILLSIDE ALUMINUM SMELTER
LARGEST ALUMINUM SMELTER IN THE SOUTHERN HEMISPHERE

PREDICTED FAULT ON THE REACTOR TRANSFORMERS

![Graph showing TCG ppm levels across different transformer bays.](image-url)
BAY 22 REACTOR

Internal Inspection and findings

Root cause: not established
Root cause: 5th Harmonic being amplified within the transformer causing it be subjected to 10 times its rated current for a couple of milli-seconds. Design fault involving the power factor correction. (Weakness in design).
TRANSFORMER ASSET REGISTER
Asset Management ISO 55000

All equipment is identified- site/ bay- and once only

And details defined- OEM, factory, date of manufacture
Voltage & Rated power

For transformers the following additional information might be needed:
Ratio
Impedance
Tap range
Type of cooling
Vector group

TCMS web Provides this
CREATE AN ACCURATE ASSET REGISTER
ISO 55000

The first step in any asset management process is to work out what you have and keep the information current. This may not be easy:

- Many sites may be involved.
- Existing asset registers may conflict—different names for the same item.
- Some types of equipment may be over-looked.
- You have to visit and confirm data.

Data hygiene is a big issue.
ALL STAFF AND SERVICE PROVIDES MUST HAVE A DEFINED ROLE

The company officers have to decide on business objectives with stakeholders.

These objectives need to be clearly defined. Then -

Each staff member must have clear definition of his role and one consistent with company business objectives

Assessment is needed for performance and improvement for each staff
The sampling procedure

Competency Training: Certification
Correct techniques & Methods
Correct handling of the samples
Sample Transport to the lab
Documentation: submittal forms
Upskilling information

Note* Pulling on the plunger may result in the formation of bubbles
Structure for reporting Data Quality and Hygiene

Responsibilities for Data Capture

- Report any queries to Asset Manager/Elec Eng. related to transformer sample labels for clarification prior to diagnostic and reporting.

- Coordinated with Asset Manager/Elec Eng to keep the TCMS web data base updated i.e Movement of transformers.
I would like to thank you for the valued input we receive from you and your team.

We are “making history” as we are slowly but surely resolving the transformer gassing issues we are experiencing in the industry at the moment in South Africa.

Please thank your team on our behalf for their level of commitment and service to resolving this issue.

We are off the belief that the latest design we have from Actom, with the input of Dr. Ugo Piovan, will finally resolve this issue. (Perdekraal and Kangnas Wind Farms, will be installed with the latest design units, 109 in total)

The role you and your team played in this process cannot be ignored and I would like to thank you for that.
THE FUTURE WILL BE RENEWABLE-BASED OR THERE WON’T BE A FUTURE
WRAPPING IT ALL UP

How much do you retain from a seminar?
- 10% of what you hear
- 50% of what you see and hear
- 75% of what you see hear and do

Select one or two items to promote when you get back!

- The AM manages Availability
- By ensuring Reliability

We hope you don’t think asset management is just a distraction
Whew!!!!!!!

I am out of here!

THANK YOU

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