Smart Grid Solutions for Transformer Monitoring & Diagnostics

Wajdi Ahmad, Ph.D.
GE Digital Energy
What is Smart grid?

...The integration of two infrastructures...

**Electrical infrastructure**

- Embracing renewables
- Increasing productivity

**Information infrastructure**

- Empowering consumers
- Reducing CO₂ emissions
- Increasing efficiency

Sources: (1) UtilityPoint, by Ethan Cohen 7/18/0 (2) EPRI® Intelligrid
Providing Smart Grid technologies to:

- Monitor assets
- Predict failures
- Proactively manage performance

Move from fearing asset failure to extending useful asset life
Why Transformers?

• Large and expensive assets
• Long lasting, mostly reliable, but approaching the end of their design life
• There are usually no spares readily available
• The lead time for a replacement is very long
• High cost of failure: safety, consequences, environmental, revenue & image.

A chain is only as strong as its weakest link…!
• Transformers are manufacturing ‘tools’
• Failure means …
  – Business interruption
  – Property damage
  – Process stops
• Risk is easy to quantify
The 50-50 risk reality

- 50% of grid assets are at or approaching the end of their design life
- 50% of skilled grid workforce will retire within the next 10 years
Transformer Catastrophic failure
Because you don’t want to gamble

- The best way to avoid unexpected transformer failure is to regularly give it a health check

- A regular transformer tank oil sample sent to a lab for Dissolved Gas Analysis (DGA) is the IEEE recommended way of doing this…

  - How often?
  - How long to get results?
  - Is the main tank the only failure point?
Monitoring:

By comparing the concentration of gases in oil with previous measures, we can detect small changes & developing trends to indicate a possible impending issue.

Diagnostic:

By identifying which gas is increasing or looking at ratios of gases, we can determine the likely nature of the anomaly and start being able to make decisions based on this information, without having to shut down the transformer to determine what is happening.
<table>
<thead>
<tr>
<th>Gaseous Species</th>
<th>Molecular Formula</th>
<th>Key Indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>H₂</td>
<td>Nearly all fault conditions, low energy PD</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>Oil overheating between 200 and 500°C</td>
</tr>
<tr>
<td>Ethane</td>
<td>C₂H₆</td>
<td>Oil overheating between 300 and 500°C</td>
</tr>
<tr>
<td>Ethylene</td>
<td>C₂H₄</td>
<td>Oil overheating over 500°C, possible formation of carbon particles</td>
</tr>
<tr>
<td>Acetylene</td>
<td>C₂H₂</td>
<td>High energy arcing, oil overheating over 800°C, strong formation of carbon particles, metal melting</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>CO</td>
<td>Paper insulation overheating</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>CO₂</td>
<td>Severe oil oxidation, paper degradation</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O₂</td>
<td>Oxidation, leak</td>
</tr>
</tbody>
</table>
Physical vs. on-line

- The main issue with physical oil samples is often the requirement for a physical visit.
- Reducing trips is a key measure of reducing the operating maintenance budget.

Availability of communication methods?
On-line means you can access the data remotely

- Constant monitoring,
- No waiting for results,
- Earliest possible detection,
- Remote diagnostics
- Can take first actions immediately, without the need for a visit
When deciding what type of monitoring & diagnostic is required for each transformer:

1. Cost of the asset
2. Criticality of the asset
3. Known health status
4. History of use/abuse
5. Distance and ease of access
6. Availability of communications
The ‘prescription’ for performance ...

- Smart Grid technologies monitor transformers, predict failures and proactively manage performance
- Reduce risk of transformer-caused outages by up to 80%
DGA Technologies

Photo Acoustic Spectroscopy

Gas Chromatography
Gas Chromatography

- Lab based
- Skilled technicians required
- Prone to contamination / carry over
- Large variances between labs
- Time intensive
- Inflexible

(tap changers Vs main tanks)
Multi-gas PAS DGA

Photo Acoustic Spectroscopy (PAS)

Photoacoustic Spectroscopy

Wavelength Selection (Filter wheel)

Parabolic Mirror

Radiation Source

Chopper Wheel

Analysis Chamber

Sample IN

Microphone

Sample OUT
Why PAS for Dissolved Gas Analysis?

- No regular re-calibrations required.
- Origin of technology is field applications and so ideally suited to this environment.
- Operates in ambient air – no cylinders of gas required.
- Can operate at ambient temperature.
- Accurate and robust over long timeframe.
- Inherently easy to use with no user interaction required to complete results calculation.
- Minimal serviceable parts.
The Transformer - a complex system

- Coils
- Tap changer
- Bushings
- Tank
- Oil
- Core
- Control Cabinet
- Cooling System
Transformer failure modes

Main Tank: Windings failure, Partial Discharge, Excessive H2O, surface contamination, connection failure, screens failure, circulating currents, overloading hazard,

OLTC: contact overheating and coking, desynchronization, excessive number of operations, mechanical damage, neutral switch inactivity

Bushing: moisture penetration, oil leak, Partial Discharge, ‘X’ wax formation,

Cooling System: clogged coolers by pollen or dust, fan/pump failure, sludge, oil leak

Other: External, such as lightning, animal interference, operation error, that are not detectable by on-line monitoring
TMS system overview

Transformer Monitoring System with TRANSFIX Plus showing sensors and oil sample points.
(position of sensors and oil sample points are not representative of the real installation)
Sensors marked with * are not included in GE supply
TMS communications

S/S SCS
TCP/IP Communications Link
IEC 61850

S/S Transformer Monitoring System HMI
GE Perception Server and Commander

SCS/RTU/Gateway Communication Links

Multilink Ethernet Switch *

NCC/ENCC
Remote Access Terminal
GE Perception Commander

TCP/IP Link

* Future

* The Multilink switches may change their number of available ports due to the different number of TMS systems in the various substations

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**LEGEND**
- Ethernet multi mode F.O.
- Ethernet copper
- RS-485
- 4-20 mA

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IEC 61850
Server/Gateway

Modbus TCP

Multinet
ML600 switch

Tapguard 260

Intellix MO150
Intellix BMT 300

Transfix 3x 4-20 mA
All we have seen so far certainly provides you with key data that helps protect transformers from unexpected failure and keeps them operating past their design life. However this brings 2 further problems:

- time to review all the data coming from all the monitored assets
- availability of resources that can understand the data and make decisions
Example: 1 transformer monitored with 6 sensors recorded every 5 minutes….

- 72 records per Hour
- 1,728 records per Day
- 12,096 records per Week
- 628,992 records per Year

… Need to be analysed, interpreted, …
Advance GE proprietary anomaly detection software continually searches data. Detects issues developing even before any alarm level is reached. Greatly increase advance notice.

Exclusive Analytics

Alarm set point i.e. when operator would be notified.
The following example outlines how full 8-Gas DGA can save a transformer from catastrophic failure

- Full range of gas measurements is needed
- High *accuracy* is required
- Other monitoring solutions could probably have resulted in the loss of this transformer
- However, fault was caught at earliest possible opportunity and the situation was managed actively. The customer successfully replaced the transformer, avoiding catastrophic failure.
Initial monitoring identified a thermal problem in the transformer:

- Oxygen content of the oil was decreasing
- Carbon monoxide and carbon dioxide content of the oil was increasing

This combination of gases indicates overheating of the paper insulation in the transformer.
Decrease in $O_2$, increase in CO, CO$_2$.

Thermal degradation of paper.
After a period of low load, the transformer was brought to full load again due to operational requirements. Hydrogen and acetylene began to increase rapidly over a period of 3 days…These gases are indicative of **arching**. Load was reduced, and the gas generation stabilised. When load was again increased the gases began to increase again. The transformer was de-gassed, but after re-energization the hydrogen and acetylene concentrations increased rapidly again.

**Such trend would not have been captured by offline DGA.**
Increasing $H_2$, $C_2H_2$

Oil was degassed but fault was still there.
• Although the transformer was degassed several times, the fault was still active
• The transformer was taken out of service when a replacement became available

Hydrogen and acetylene are highly explosive – if the fault had not been detected, the transformer could have exploded, leading to fire, contamination of the ambient and possible collateral damage
Delivering Important Savings

Reduce Capex – by using life-extending strategies and only replacing assets really needing replacement

Reduce Opex – by reducing on-site visits and moving to condition based maintenance

Increase Revenue - by reducing unplanned outages, avoiding non-generation penalties and enabling controlled transformer overloading.