EFFECTIVE TRANSFORMER CONDITION ASSESSMENT

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Doble Engineering Africa
Introduction

This transformer has clearly reached its end of life

What about this one?
When will it fail?
Million Rand Question
## Introduction

**What do we know?**

- The life expectancy of a transformer can vary from a few cycles (ms) to more than 50 years.

*Interesting, but not very useful.*

<table>
<thead>
<tr>
<th>Component</th>
<th>CIGRE</th>
<th>DOBLE all designs</th>
<th>DOBLE one design</th>
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<tbody>
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</table>

What does it tell you about your transformer?
Introduction

What we need to know?

✓ The life expectancy of a particular transformer in the network

Interesting, and very useful.

This is the essence of CONDITION ASSESSMENT
Condition Assessment

Condition assessment is the process used to determine the asset health.

There is no standard procedure for carrying out condition assessment and asset health reviews.

What is appropriate depends on:
✓ Amount of information already available.
✓ Criticality of the units in the population.
✓ Number of transformers in population.
We know that condition assessment is not:

- TESTING AND REPRODUCING THE TEST RESULTS
- DIAGNOSING A CAUSE AFTER A TRANSFORMER HAS FAILED

“A comprehensive assessment of the condition of a transformer taking into account all relevant information eg. Design information, service history, operational problems, results of condition monitoring and other chemical and electrical tests”

Cigre Working Group on Life Management Techniques for Power Transformers.
Condition Assessment

• So what happens to utilities that has little to no information?
• Is effective condition assessment possible without the basic knowledge?

Yes it is!

• But how?
• By using a simple yet novel two phase approach introduced by Doble
The Doble Condition Assessment Approach

We have a two phase approach

• **Phase 1 - all units**
  – On line assessment (no outage required)
  – Review of existing data

• **Phase 2 – selected units**
  – The focus here is on high risk transformer identified in phase 1
  – Offline tests are performed (outage required)
Doble Phase One

• **Step 1**
  – Basic nameplate information of transformer and tapchanger
    • Capture manufacturer, vintage, serial number and design
    • Ratings, BIL, fault level, impedance, cooling system, etc
  – Transformers can be grouped into **Family**, **Make**, **Model**, **Application** and **Age**.
  – From this you can Identify
    • Design related issues with transformers
    • Service advisories from manufacturers
    • Reports of failure on similar designs
    • Pattern of failure on similar designs
  – The above can be obtained from Doble’s database with test results (25 million results) and equipment failure data collected for over 30 years.
Doble Phase One

• Step 2

  – External visual inspection
    Conducted on:
    • Plinth
    • Tank
    • Cooling system
    • Temperature reading
    • Marshalling kiosk
    • Bushing
    • Tapchanger
    • Surge Arrester

  – Identify observe problem that will accelerate transformer aging
Doble Phase One

• **Step 3**
  – **Documentation**
    • **Factory test report**
      – Used to compare with current test results
    • **Purchasing specification**
      – Used to compare to current manufacturing standards
    • **Tests results – electrical and oil**
      – Current data can be compare to Doble database for industry norms
    • **Failure reports**
      – Indicates the rate of aging, availability and performance
    • **Maintenance practices**
      – What are you doing?
    • **Major modifications or rebuild**
      – Indicates the rate of aging generally expected
    • **Substation fault level**
      – Changes in fault rating
    • **Loading**
      – Used to calculate loss of life
Doble Phase One

• **Step 4**
  – Consult with staff
    • General problems
    • Information that is not documented
### Doble Phase One

- Once Steps 1 to Step 4 is completed
- The information needs to be presented in an easily accessible format.
- Best solution is usually a spreadsheet.

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<th>C</th>
<th>D</th>
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Clearly identify all equipment

All equipment is identified by:
- Location
- Serial number.
Could add other categories here if required.
Doble Phase One

Add rated characteristics

All equipment is identified by:
- Ratio
- Rated power
- Impedance
- Tap range
- Type of cooling
- Vector group
- Any other information
Add information about the manufacturer

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</table>
Add information about the design

Designs are identified using a short code. Designs are rated after review of Doble database. A “traffic light” system is used to identify poor to good designs.
• **Step 5**
  – Additional online tests
    • Oil tests (main tank)
      – Check oil quality – condition – sludge - electrical etc
    • Dissolved gases (main tank)
      – Incipient faults and Furans for paper degradation
      – Doble DGA scoring system
    • UHF and IR scans
      – Discharges and overheating
Doble Phase One

Oil quality and DGA

A sample would be taken and analyzed with the standard methods.

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<tr>
<th>Dissolved Gas (DGA)</th>
<th>Detection of incepted faults – IEEE, IEC etc</th>
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<tbody>
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<td>Furfuraldehyde (FFA)</td>
<td>Paper insulation degradation – Chendong relation to DP</td>
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<td>Moisture in oil</td>
<td>Insulation dryness</td>
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<tr>
<td>Breakdown Voltage</td>
<td>Dielectric integrity</td>
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<td>Acidity</td>
<td>Ageing and sludge</td>
</tr>
<tr>
<td>Interfacial Tension</td>
<td>Ageing, sludge and contamination</td>
</tr>
</tbody>
</table>
Doble DGA Scoring System

It uses key gas response and gives a single number to track the change in pattern.

It illustrates the clear difference that exists between ‘normal’ and ‘abnormal’ results.

- **Normal** < 60
  
  All normal results can be ignored.

- **Suspect** > 60
  
  Only suspect results need to be investigated.

- **Serious** > 100
  
  Winding and dielectric faults can be discounted.
A – Core bolt fault
B – Core and frame to earth circulating currents
C – Winding inter-stand fault
D – Winding shorted turns
E – Winding phase to earth fault
F – Winding tracking fault
G – Winding clamping bolt sparking fault
Infra Red Scan

Routine IR scans are a useful method for picking up overheating problems in the tank (circulating or image currents, stray flux heating). They are also useful for finding hot joints in the external connections.

Routine IR scans are not effective for problems buried deep inside the tank.

Routine IR scans are also cheap and quick to carry out, and can be made without removing the transformer from service.
Example of a frame circulating current, found using an IR scan.
Doble Phase One

- Bushing connections
- Unequal rad flow
- Fan not operational
Doble Phase One

PD Detection UHF (RFI) surveys
Corona up to a few 10s of MHz,
Surface discharge 200MHz.
Internal partial discharge 1GHz.
Once step 5 has been completed:

- Oil quality;
- DGA
- Doble Scoring System
- IR scanning
- UHF scanning

The transformer can be assessed in terms of its dielectric and thermal condition.
Transformers condition is divided in dielectric and thermal and scored to the Doble condition classification.
## Condition Classification

<table>
<thead>
<tr>
<th>CONDITION</th>
<th>DEFINITION</th>
<th>SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>As New</td>
<td>no damage and accelerated deterioration</td>
<td>1</td>
</tr>
<tr>
<td>Normal ageing/performance</td>
<td>Reasonable for age- no actions required</td>
<td>3</td>
</tr>
<tr>
<td>Aged/ some Issues with performance</td>
<td>Some ageing, - in need of some monitoring- but not urgent</td>
<td>10</td>
</tr>
<tr>
<td>Suspect/ Major issues Performance</td>
<td>Identified ageing, significant risk for failure, safety. Plan for rectification</td>
<td>30</td>
</tr>
<tr>
<td>Unacceptable</td>
<td>Unacceptable ageing deficiencies- need fix now.</td>
<td>100</td>
</tr>
</tbody>
</table>
Doble Phase One

Outcome of Phase One

• Establishment of an asset register
• Design weakness
• Identifies:
  • High risk transformers in terms of the dielectric and thermal condition
  • High risk transformers in terms of the environment, staff and third parties

• Identification of units for further investigation in phase 2
Schedule outages for investigation

Use standard off-line techniques to investigate problems, where possible:

- Capacitance and tan δ - windings and bushings
- Dielectric response of winding
- Sweep Frequency Response Analysis
- Leakage Reactance
- Exciting Currents
- Turns Ratio
- Insulation Resistance
- Winding resistance
Doble Phase Two

Once the off-line tests are performed you can then **rescore** the transformer condition. A far more accurate assessment of the transformer.
Doble Phase Two

What do we know now!

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Identi</th>
<th>Serial</th>
<th>Ratio</th>
<th>Rating</th>
<th>Condition</th>
<th>Overall</th>
<th>Dielectric</th>
<th>Thermal</th>
<th>Mechanical</th>
<th>Report</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Church Road</td>
<td>SDT1</td>
<td>1001</td>
<td>110/20 kV</td>
<td>25 MVA</td>
<td>Fault</td>
<td>12</td>
<td>10</td>
<td>T</td>
<td></td>
<td>04-1</td>
<td></td>
</tr>
<tr>
<td>Church Road</td>
<td>SDT2</td>
<td>1002</td>
<td>110/20 kV</td>
<td>25 MVA</td>
<td>OK</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Church Road</td>
<td>SDT3</td>
<td>1003</td>
<td>110/20 kV</td>
<td>25 MVA</td>
<td>OK</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Church Road</td>
<td>SDT4</td>
<td>1004</td>
<td>110/20 kV</td>
<td>25 MVA</td>
<td>OK</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Street</td>
<td>SDT1</td>
<td>1010</td>
<td>110/20 kV</td>
<td>40 MVA</td>
<td>OK</td>
<td>13</td>
<td>3</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Street</td>
<td>SDT2</td>
<td>1011</td>
<td>110/20 kV</td>
<td>40 MVA</td>
<td>OK</td>
<td>13</td>
<td>3</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Station</td>
<td>GT1</td>
<td>1100</td>
<td>15/120 kV</td>
<td>120 MVA</td>
<td>Aging</td>
<td>34</td>
<td>3</td>
<td>30</td>
<td></td>
<td>02-2</td>
<td></td>
</tr>
<tr>
<td>Power Station</td>
<td>GT2</td>
<td>1110</td>
<td>15/120 kV</td>
<td>120 MVA</td>
<td>OK</td>
<td>7</td>
<td>3</td>
<td>3</td>
<td></td>
<td>03-1</td>
<td></td>
</tr>
<tr>
<td>Power Station</td>
<td>UT1</td>
<td>1102</td>
<td>15/20 kV</td>
<td>5 MVA</td>
<td>OK</td>
<td>11</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Station</td>
<td>UT2</td>
<td>1103</td>
<td>15/20 kV</td>
<td>5 MVA</td>
<td>OK</td>
<td>11</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Station</td>
<td>ST1</td>
<td>1104</td>
<td>110/20 kV</td>
<td>5 MVA</td>
<td>OK</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Railway Sidings</td>
<td>TT1</td>
<td>1020</td>
<td>110/25 kV</td>
<td>10 MVA</td>
<td>Suspect</td>
<td>10</td>
<td>3</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Railway Sidings</td>
<td>TT2</td>
<td>1021</td>
<td>110/25 kV</td>
<td>10 MVA</td>
<td>Fault</td>
<td>100</td>
<td>100</td>
<td>10</td>
<td></td>
<td>02-1</td>
<td></td>
</tr>
<tr>
<td>Upper Farm</td>
<td>SDT1</td>
<td>1012</td>
<td>110/20 kV</td>
<td>25 MVA</td>
<td>OK</td>
<td>13</td>
<td>3</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Farm</td>
<td>SDT2</td>
<td>1013</td>
<td>110/20 kV</td>
<td>25 MVA</td>
<td>OK</td>
<td>7</td>
<td>3</td>
<td>3</td>
<td></td>
<td>03-2</td>
<td></td>
</tr>
</tbody>
</table>
No need for action plans for most of the population.

The faulty transformer needs to be replaced. The sister transformer needs to be tested.

The other two need further monitoring before a firm decision is made.
Doble Phase Two

Phase Two Outcomes

• Identifies high risk transformers in terms of the dielectric, thermal and mechanical condition.
• More accurate overall condition as a result of the off line tests
• An action plan in terms of units that require replacement, repair and monitor
• The transformers risk can be calculated
Conclusion

Transformer condition assessment program can be effectively introduced by using this two phase approach. This method of condition assessment can be implemented irrespective of the amount of information.

It allows utilities to finally have answers to the following situations:
- When to have maintenance outages
- How to respond to a protection trip
- To know capability to increase transformer rating
- To know when to replace (5, 10, 15 years) transformers

An added advantage is that this method forces the utilities to make the bold move to condition based maintenance. A further advantage is the risk assessment and residual life can finally be achieved through sound engineering principles.
Doble Electrical Tests

**Tan δ**
Performed on winding and bushings at 10 kV AC

- Moisture
- Carbonisation of insulation
- Contamination of oil
- Improperly grounded core

![Diagram of electrical circuit](image)
Case Study - Tanδ

- Spare transformer stood on plinth for 2 years
- 45 MVA; 132/11 kV; Free breather
- High tanδ and moisture
- Required purification

<table>
<thead>
<tr>
<th>Date</th>
<th>HV Winding</th>
<th>Between HV and LV windings</th>
<th>LV Winding</th>
<th>Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007-04-18</td>
<td>0.54</td>
<td>0.68</td>
<td>1.39</td>
<td>15ppm</td>
</tr>
</tbody>
</table>
Case Study - Tanδ

- After first purification
- Not happy with LV winding value!
- HV winding - moisture decreased
- Request further purification

<table>
<thead>
<tr>
<th>Date</th>
<th>HV Winding</th>
<th>Between HV and LV windings</th>
<th>LV Winding</th>
<th>Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007-04-18</td>
<td>0.54</td>
<td>0.68</td>
<td>1.39</td>
<td>15ppm</td>
</tr>
<tr>
<td>2007-05-06</td>
<td>0.43</td>
<td>0.53</td>
<td>1.39</td>
<td>8ppm</td>
</tr>
</tbody>
</table>

After first purification
Case Study - Tanδ

- After second purification
- Complete increase in all tanδ values
- HUGE PROBLEMS

<table>
<thead>
<tr>
<th>Date</th>
<th>HV Winding</th>
<th>Between HV and LV windings</th>
<th>LV Winding</th>
<th>Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007-04-18</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After first purification</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007-05-06</td>
<td>0.43</td>
<td>0.53</td>
<td>1.39</td>
<td>8ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After second purification</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007-05-24</td>
<td>1.42</td>
<td>1.46</td>
<td>1.58</td>
<td>8ppm</td>
</tr>
</tbody>
</table>
Case Study - Tanδ

- Performed TIP-UP test
- Steady increase in tan δ as the voltage increases

<table>
<thead>
<tr>
<th>Date</th>
<th>Voltage (kV)</th>
<th>HV winding</th>
<th>LV winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007-05-24</td>
<td>1</td>
<td></td>
<td>1,47</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1,38</td>
<td>1,49</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td>1,50</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1,39</td>
<td>1,55</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
<td>1,58</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1,40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1,41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1,42</td>
<td></td>
</tr>
</tbody>
</table>
Case Study - Tanδ

- After hot flush, vacuum for 24 hours and further purification

<table>
<thead>
<tr>
<th>Date</th>
<th>Tan δ (%)</th>
<th>Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Winding</td>
<td>Between HV and LV windings</td>
</tr>
<tr>
<td>2007-04-18</td>
<td>0.54</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>After first purification</td>
<td></td>
</tr>
<tr>
<td>2007-05-06</td>
<td>0.43</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>After second purification</td>
<td></td>
</tr>
<tr>
<td>2007-05-24</td>
<td>1.42</td>
<td>1.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>After third purification</td>
<td></td>
</tr>
<tr>
<td>2007-05-30</td>
<td>0.36</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Exciting currents**

Performed at 10 kV AC. The focus is on the magnetic circuit

- Core related problems
- Laminate issue
- Abnormal ground
- Shorted turns
- Tap changer problem

**Ratio Test**

Performed at 10 kV AC with a capacitor.

- Confirm ratios are within 0.5% of nameplate data;
- Detect shorted turn-to-turn;
- Detect open circuit windings; and
- Confirm tap lead connections.
Sweep Frequency Response Analysis (SFRA)
Detects core displacement and winding deformation that arises from:
Transportation – Large forces from fault currents – winding shrinkage
Doble Electrical Tests

• These changes in the RLC network is detected by SFRA.

• How does it work?
  – A low voltage signal with varying frequencies are applied to the transformer.
  – The input and output signal is measured.
  – The ratio of the two signal gives the frequency response of the transformer.
  – This ratio is called the transfer function from which the magnitude and phase can be obtained.

• This technique is not new it started in late 1960’s and was refined in the late 1980’s and 1990’s.
• Number of papers are published on FRA – AMEU 2006
Doble Electrical Tests
Case Study 1

• Tripped on differential protection
• Suspected and internal fault

• Performed:
  • SFRA
  • Exciting Current
  • Leakage Reactance
  • Ratio
  • Winding and bushing insulation (tan delta and capacitance)
  • Oil analysis
Case Study 1

10 kV Ratio Test
Correct ratios on tap 1, 2 and 6
Incorrect ratio on tap 3-5, and 7-17 on blue phase

Oil Analysis
No areas of concern – normal aging
Case Study 1

What do we know?

- Oil analysis: No internal problems

Ratio Test
- Turn to turn failure?

Where to look first?

- Exciting current: No turn to turn failure but problems with tap 9 and 10?

- SFRA: Supports exciting currents no winding movement

Strong Indicators of tapchanger problems
Case Study 1
After Repair

The tapchanger was repaired and retested.

Exciting Current after Repair

Transformer returned to service with confidence.
Case Study 2

The problem:

- GEC, 1982, 275/132/22 Auto, 350 MVA
- South African customer
- Protection operation:
  - Tapchanger pressure
  - Transformer differential
  - MAIN TANK PRESSURE
Case Study 2

- Ratio and exciting current – problem with blue phase
- Clearly tapchanger problems
- Little to no change in capacitance

- SFRA – possible winding problem on blue phase
Case Study 2

HV to MV winding

AMEU Convention 2007
Case Study 2

HV winding SC

AMEU Convention 2007
Case Study 2

- Tapchanger inspected
- Inspection of tapchanger revealed a damaged selector and diverter
Case Study 2

Blue phase selector- severe burns due to flashover at: change-over mounting washer, fixed contact no. 2, even collector rings at positions 10 and 8.

Burnt flexible lead which connects metal parts to the common contacts which connect to the take-off terminal on Blue phase diverter switch.
Case Study 2

• However the SFRA indicated possible movement within the transformer
• Doble recommended that the transformer be internally inspected
Case Study 2

Blue Phase tap lead movement with broken cleats
Case Study 2

- Strongly recommended that more intrusive inspections be conducted
- Investigation not completed
Case Study 3

The problem:

• ASEA, 1977, 400/275/22 Auto, 720 MVA
• South African
• Protection operation:
  – Tapchanger pressure
  – Transformer differential
Case Study 3

HV to MV winding response
Case Study 3

Internal inspection revealed tap lead displacement and damage
Case Study 3

Tap winding responses

AMEU Convention 2007
Case Study 3

• Strongly recommended that the tap winding be inspected
• Investigation not completed
The End

End of presentation

Thank you