Transformers

SPECIAL EDITION: DRY-TYPE TRANSFORMERS 2021 MAGAZINE

ARTICLES:

Solid insulation distribution transformer

On-site PD of cast-resin transformer

Failures in offshore transformers

Development in dry-type technology

ISSN 1849-7268 (Digital)

Temperature monitoring ▪ GEAFOL® cast-resin transformers

The future is SMART ▪ Dry-type transformer for wind turbine application

When primary station equipment trips out, it is often the substation maintenance engineers who must review the situation, get the data needed to make an informed decision, and then 'make the call'

"Is it safe?"

By Tony McGrail, Solutions Director: Asset Management and Monitoring Technology at Doble Engineering

There is always pressure to re-energize a power transformer after a fault trips it out – but to do so comes with risks that need to be understood and addressed.

1. Introduction

When primary station equipment trips out, it is often the substation maintenance engineers who must review the situation, get the data needed to make an informed decision, and then 'make the call'. There is often 'pressure' to re-energize a large power transformer after a fault, especially when the cause of the fault is 'clearly' evident. In the story here, taken from a technical paper presented at the Doble Client Conference in 2012 by Mike Wolf of National Grid USA (now at First Energy) [1], two faults occurred in quick succession, tripping a large power transformer on a site where construction work was being undertaken to expand the station with the transformer adjacent to the site access road.

In this case, a support insulator broke on an incoming overhead, causing a grounded conductor to fall on two 34.5 kV circuits, which produced two successive faults, one on each line

2. Initial faults

The transformer in question, a 1969 Westinghouse unit, rated at 30/40/50 MVA at 115–34.5 kV providing power to residential and commercial customers. A support insulator broke on an incoming overhead, causing a grounded conductor to fall on two 34.5 kV circuits, which produced two successive faults, one on each line.

The initial 115 and 34.5 kV CTs which make up the differential protection, showed B-phase currents 180° out of phase, and thus a fault external to the transformer as the current is seen going through the transformer, with the fault cleared after 5 cycles. This overhead line-locked out on overcurrent.

The subsequent fault on a different line was also on the B-phase, which initially showed a 180° out of phase pattern, which quickly moved to 132°, which represents a fault inside the transformer's differential zone taking some current to the ground. The associated line-locked out on overcurrent protection, but the transformer B-phase currents come into phase, as the internal fault dominates, with the trans-

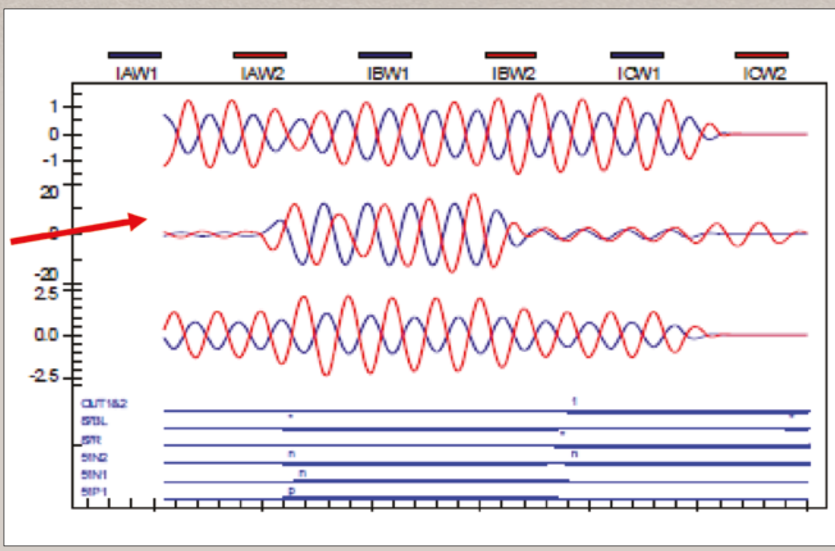


Figure 1. Transformer differential CTs, second fault
B phase is identified with the red arrow. The currents start out 180° out of phase but slowly become in phase, showing an external fault becoming an internal fault.

> **It was decided to perform basic electrical tests on the unit, serving as a quick means to detect and diagnose any serious problems as a result of the internal fault, and to perform a rapid DGA with a portable unit**

former's differential protection operating, locking out the transformer.

With the source of the faults clearly evident, transmission operators were pressing for a rapid re-energization. However, with construction activity at the site, there was a great deal of staff and contractor movement about the station, increasing the risk should there be a subsequent transformer failure. How quickly could the local engineers respond? After reviewing the protection data, it was decided to perform basic electrical tests on the unit, serving as a quick means to detect and diagnose any serious problems as a result of the internal fault, and to perform a rapid DGA with a portable unit.

3. Headspace and dissolved gas analyses tests

The headspace results were acceptable, at 0.5 %, but close to the limit of what may be a combustible headspace. The portable DGA results using an IR device were inconclusive: the data in Table 1 shows two previous laboratory DGA results from 2010 and 2011, and two site results.

Expecting an accuracy from the portable DGA in the region of +/- 25 %, the discrepancies were unsettling: CO not present where previously there was over 200 ppm, CO_2 significantly less than earlier lab results, H_2 also low, and no acetylene, which was a surprise after an internal fault. The inconsistencies seemed 'strange' and a cause for concern: in effect, the portable DGA results were not trusted. Urgent lab tests were required, and thus a super-rush syringe sample was taken and sent to Doble oil labs. While the sample was transported and processed, initial electrical diagnostic tests were performed on the transformer. As you can imagine, the pressure to return the unit to service was growing, especially after what appeared to be a favorable DGA result.

4. Basic electrical tests

Several different tests were performed to gather data on the viability of the unit:

- Excitation current tests followed the expected high-low-high pattern and were in line with most recent maintenance test results indicating no short circuits or severe winding deformation.
- Transformer turns ratios were within 0.5 % of expected values, as required.
- Power factor tests seemed 'unremarkable' and generally close to previous results. CL, however, was up by 6 %, but this was given a low weighting in review as CH and CHL were acceptable.
- Bushing C1 and C2 tests were acceptable.
- Winding resistance data showed nothing of concern – good data in line with expectations.

At this point, there is little evidence that would show the transformer is still at fault, an anomalous CL value being the main indicator of a possible problem, while there is much data to support re-energization: especially with operations and management being keen to see a return to service.

Imagine you are in the position of the substation maintenance engineer responsible for the decision: would you authorize re-energization?

With lab sample results not yet available, a decision was made to perform extra – 'advanced' testing: that is, tests that would not normally be performed. Based on the

Table 1. Portable DGA results

DGA											
	H_2	O_2	N_2	CH_4	CO	C_2H_6	CO_2	C_2H_4	C_2H_2	C_2H_4/ C_2H_2	H_2O
Portable Again	<5			7	<1	10	1237	7	<0.5	0	76
Portable DGA	<5			8	<1	14	1052	15	<0.5	0	74
Lab DGA 02/28/2011	10			22	199	17	4062		0	0	
Lab DGA 09/30/2010	11			23	247	19	6763	12	0	0	

Low concentrations of dissolved gas seem strange.

elevated CL, there was an indication there could be some geometrical changes within the transformer – winding movement – and possibly damage to other equipment within the differential zone. Thus, Leakage Reactance (LR) and Sweep Frequency Response Analysis (SFRA) tests were performed.

There is little evidence that would show the transformer is still at fault, an anomalous CL value being the main indicator of a possible problem, while there is much data to support re-energization

M4100—High Voltage Apparatus Tester

The M4100 is the industry standard for power apparatus and insulation testing. Its unique combination of test capabilities and artificial intelligence analysis software makes it the power industry's most trusted power factor / tan-delta instrument.

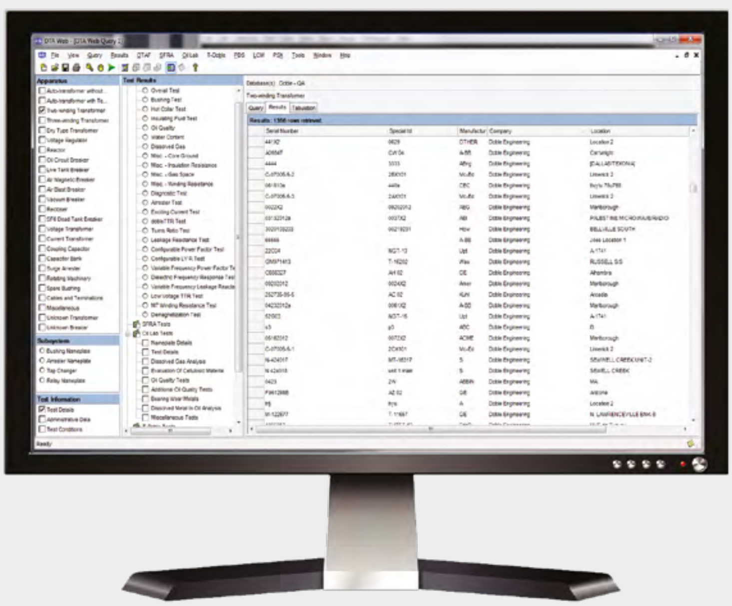
Learn more:
doble.com/m4100

M7100 Analyzer—High-Voltage Asset Analyzer

The Doble M7100 High-Voltage (HV) Asset Analyzer is your complete solution for high and low voltage testing. The only test set featuring two dual-function high-voltage leads for source and measurement delivers the fastest, complete set of measurements. Compared to a single-lead system, this patented design dramatically improves technician safety by reducing ladder trips by as much as two-thirds and simplifying lead placement.

The M7100 automates multiple tests previously performed by several pieces of equipment, cutting down the testing time from seven hours to one and a half hours. Reduced testing time means technicians can safely perform more commissioning, scheduled maintenance and diagnostic activities.

Learn more:
doble.com/m7100



Doble Test Assistant (DTA) Software

Doble Test Assistant (DTA) software is a comprehensive software tool for the collection, analysis and management of test results for the Doble M-Series family of instruments.

DTA software seamlessly integrates with Doble Database. The DTAWeb client interface software allows users to upload and download data to private remote data storage while leveraging over 60 million worldwide test results for analytic comparison.

Learn more:
doble.com/dta

Table 2. Laboratory DGA results compared to portable tests

DGA											
	H_2	O_2	N_2	CH_4	CO	C_2H_6	CO_2	C_2H_4	C_2H_2	C_2H_4/ C_2H_2	H_2O
Doble Rush 1	64	816	83400	38	291	11	5130	31	21	1.48	12
Portable Again	<5			7	<1	10	1237	7	<0.5	0	76
Portable DGA	<5			8	<1	14	1052	15	<0.5	0	74

Laboratory tests showed internal arcing.

5. Further tests and inspections

In addition to further tests, an inspection of the equipment surrounding the transformer was undertaken to rule out the potential of a flashover occurring outside the transformer but within the differential zone. No damage was found on bus support insulators or disconnect switches. The oil circuit breaker was tested for time-travel and power factor, with acceptable results. The breaker tank was 'dropped' for a visual inspection – no damage was found to CTs or the breaker.

When the Doble lab DGA results came in – a lab technician called and asked the question: "Are you sure these are not from an LTC?" This is possibly the worst thing to hear when hoping to re-energize, as it means there is evidence of arcing within the transformer. The laboratory tests were clearly indicative of a flashover within the main tank – elevated key gases as shown in 'Doble Rush 1' in Table 2 – very much in contrast with the portable IR results. A second rush sample was sent for confirmation.

SFRA and LR are not always performed during routine outages – they can be very useful, providing both quantitative and qualitative analyses which complement each other.

The SFRA tests were performed on the unit for the first time, making interpretation of the results more difficult with no prior data for comparison. The results showed no obvious issues, but a consultation with Doble's Client Service Engineer identified some B-phase variations in the 100-150 kHz range. With no comparison

The three-phase equivalent is possibly acceptable, being within the Doble recommended guide of 3 %, but the per-phase equivalent is off from the per phase mean by 6.6 %

Table 3. Leakage reactance data

Leakage reactance tests			
3-phase equivalent	Nameplate impedance, Z % p.u.	Measured impedance, Z % p.u.	Delta, %
	6.60	6.79	2.80
Per-phase tests			
per Phase A		6.60	-2.80
per Phase B		7.24	6.63
per Phase C		6.54	-3.68
Average per phase		6.79	

The tests indicate a major deviation from nameplate impedance.

The fault was not 'visible' with standard electrical tests but was found using 'advanced' tests, and subsequent teardown of the transformer showed significant radial buckling on the B-phase with no shorted turns

data, the variations were treated as 'indicative' rather than diagnostic of a B-phase variation. The technical paper shows the traces obtained (1).

Leakage Reactance showed an obvious discrepancy with nameplate values, as shown in Table 3, for the three-phase equivalent, and a bigger discrepancy for the per phase values.

The three-phase equivalent is possibly acceptable, being within the Doble recommended guide of 3 %, but the per-phase equivalent is off from the per phase mean by 6.6 %; this was supported by the reactance for the B-phase being almost 10 % higher than expected. The message of the leakage reactance is clear – a problem in the geometry between the HV and LV windings. Why then only marginal variation in the SFRA? Possibly owing to the presence of a radial buckle with no shorted turns – this could have caused the change in CL earlier and is less detectable using SFRA alone – hence the application of SFRA and leakage reactance in tandem.

At this point, the second DGA sample results came in from the Doble lab for 'Doble Rush 2' – confirming the first sample with acetylene, hydrogen and ethylene all rising after the faults.

6. Summarising

At this point, there is a range of data available but some clear indications of a problem from:

a) The transformer saw two LV B-phase external faults.
b) The transformer's differential protection operated correctly.
c) The transformer had 21 ppm acetylene – arcing under oil took place.
d) There was a change in CL capacitance – possible LV winding deformation.
e) The leakage reactance was poor on B phase – likely winding deformation in B phase.
f) The SFRA data could be taken as corroborative of the other LV, B-phase winding data.

So: would you be keen to put this transformer back in service with the data available?

Table 4. Laboratory DGA results compared to portable tests

DGA											
	H_2	O_2	N_2	CH_4	CO	C_2H_6	CO_2	C_2H_4	C_2H_2	C_2H_4/ C_2H_2	H_2O
Doble Rush 2	60	458	87300	32	286	11	5270	27	18	1.5	13
Doble Rush 1	64	816	83400	38	291	11	5130	31	21	1.48	12
Portable Again	<5			7	<1	10	1237	7	<0.5	0	76
Portable DGA	<5			8	<1	14	1052	15	<0.5	0	74

Laboratory tests showed internal arcing.

7. Decision

The data could support a scenario where: the second of two close in faults caused a B-phase winding failure; a radial buckle outward into the leakage channel; no shorted turns, thus maintaining the bulk of the insulation integrity; an internal flashover producing raised key gas levels, most notably acetylene.

It was decided that re-energization would be inappropriate, and replacement of the transformer was planned. Further motivating the decision to replace the transformer was the proximity of a spare unit, possible exposure of personnel at the station to a catastrophic failure, the system importance of the transformer, and the high-profile regional construction project ongoing at the station.

8. Confirmation

A subsequent teardown of the transformer showed significant radial buckling on the B-phase – with no shorted turns, as shown in Fig. 2. This explains all the findings. The fault was not 'visible' with standard electrical tests but was found using 'advanced' tests. Deep analysis of all results, taken as a whole and in the context of the location and application of the transformer, gave a credible picture of internal winding deformation of a specific type and location.

Re-energization could have led to a catastrophic failure – an unacceptable risk for a transformer so close to a work zone and the public.

9. Acknowledgment

Mike Wolf's 2012 paper is highly recommended for review as it gives much more detail and discussion and gives a clear impression of the process of analysis while under the stress of 'real time' pressure.

Bibliography

[1] M. Wolf, *50 MVA Transformer failure as experienced by maintenance engineers*, National Grid USA, 79th Annual International Doble Client Conference, Boston, USA, 2012

Figure 2. B-phase winding showing radial buckling damage with no shorted turns