Data dilemma

ABSTRACT

The transformer under investigation was the Federal Pioneer 230/72kV, 83 MVA autotransformer unit, which was one of two 'merchant' units serving an international tie-line. The SFRA tests were performed, and the results were inconsistent. Careful application of the ABC rule (Assume nothing, Believe nobody, Check everything) eventually solved the problem.

KEYWORDS:

SFRA, ABC rule, problem-solving, on-site measurement, windings

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Overview

What do we do when one test says there seems to be no mechanical deformation in a transformer, and another says there definitely is? What follows is but a brief outline of a case which was both a challenging puzzle in 'real time' and an opportunity to learn.

The case

A transmission autotransformer that had previously seen a number of faults and animal intrusions suffered an LV bushing failure, as shown in Figure 1. The Federal Pioneer 230/72kV, 83 MVA autotransformer unit was one of two 'merchant' units serving an international tie-line. The transformer was carefully cleaned, flushed with hot oil, and inspected after the event.

The X1 and X2 bushings were removed, tested and returned to service, and the X3 bushing was replaced. A 3 cm bulge was observed in the main tank, a bulge which had not previously been noted. With concern for the mechanical integrity of the unit, several electrical tests were performed, including:

- Bushing C1/C2 power factor and capacitance measurements
- Winding power factor and capacitance measurements, as per Table 1
- HV Single phase excitation
- DC winding resistance
- Turns ratio

All results were acceptable and gave no cause for concern.

In addition, both Leakage Reactance (LR) and Sweep Frequency Response Analysis (SFRA) were performed for the first time on the unit in the hope that any mechanical movement within the unit would be reflected in the results. It was not known when the bulge had appeared in the tank, and it may have been there from 'day 1'.

SFRA results for each winding/phase showed no significant variation from expected, with H-X shown in Figure 2; in addition, the short circuit SFRA results were also as expected.

The LR results for single phase measurements from H to L were as expected and

Figure 1. Transformer during test activities

Table 1. Overall power factor and capacitance measurements

Measurement	mA	Watts	Power Factor %	Capacitance pF
CH +CHT	56.174	2.036		14,900.5
CH	26.950	0.894	0.32	7,148.7
CHT (UST)	29.217	1.140	0.38	7,749.9
CHT	29.224	1.142	0.38	7751.8
CT + CHT	84.306	4.017		22,362.6
CT	55.087	2.872	0.5	14,611.7
CHT (UST)	29.217	1.143	0.38	7,749.8
CHT	29.219	1.145	0.38	7,750.9

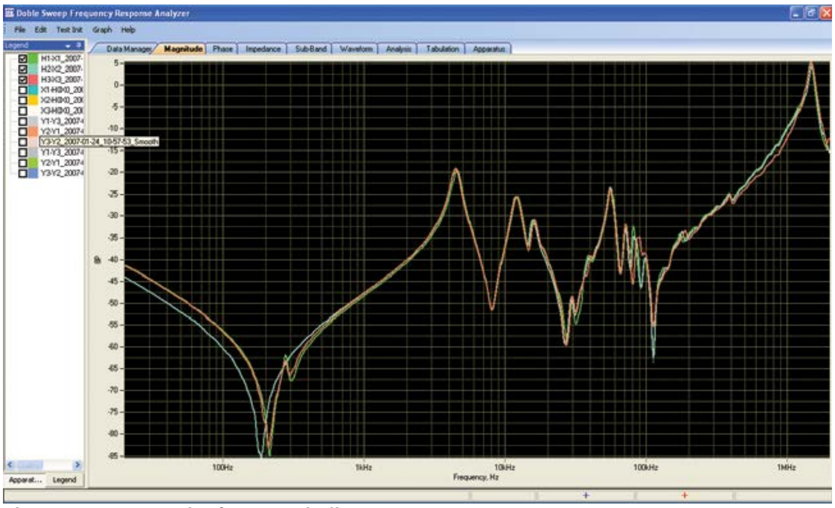

Figure 2. SFRA results for H-X windings

The Leakage Reactance results of the H to T were strongly indicative of a severe problem either on the H1 phase or on both the H2 and H3 phases

acceptable. However, the H to T results were strongly indicative of a severe problem either on the H1 phase or on both the H2 and H3 phases. Given that it was the X3 bushing which failed, there was some surprise that the H1 phase seemed 'different'. In addition, the resistive element of the results looked high for H2 and H3 but only with reference to the tertiary, not the LV.

The results were unexpected: consistently good across tests performed previously; no significant indications of a problem from SFRA; significant indications of a problem with LR. At this, I recall the advice of my colleague Dr. Mark Lachman, a transformer test expert who said: "Many obviously poor test results will be corrected if you pack all of the test equipment away, and then get it out again and repeat the test". So, we did exactly that, and on repeating the LR tests, the results did not vary from the initial results, and nor did variations on the LR test at other voltages and test arrangements. The SFRA results did not change either – everything for both SFRA and all other electrical tests looked acceptable.

So now what? As it happens, the situation is already causing sleepless nights for the engineers and technicians involved as the tie line is an important source of revenue generation, and there is a fear that the remaining transformer may also fail – it has the same bushings and the same operational history.

At which point we get to the dilemma… we really have two choices:

i) put the unit back in service with the hope that there really is no mechanical damage and the transformer does not fail catastrophically, taking out the parallel unit and severing the tie line thus reducing revenue to zero and the costs of replacement and clean-up

ii) extend the outage for further investigation and internal inspection to try to find any likely causes for the test results.

Many obviously poor test results will be corrected if you pack all of the test equipment away, and then get it out again and repeat the test

Table 2. Leakage Reactance Measurements

Leakage Reactance Per Phase H-L								
Phase	**Voltage**	**Current**	**Watts**	**PF**	**Inductance** Henry	**Resistance** Ohms	**Impedance** Ohms	**Resistance** Ohms
H1-H0	234.0	3.517	29.774	3.618	0.176	2.407	66.487	66.443
H2-H0	235.0	3.507	29.639	3.596	0.178	2.409	66.981	66.937
H3-H0	240.0	3.547	27.629	3.245	0.179	2.196	67.630	67.595
Leakage Reactance Per Phase H-T								
Phase	**Voltage**	**Current**	**Watts**	**PF**	**Inductance** Henry	**Resistance** Ohms	**Impedance** Ohms	**Resistance** Ohms
H1-H0	211.0	2.038	16.947	3.941	0.275	4.080	103.679	103.599
H2-H0	245.0	1.999	101.494	20.718	0.318	25.386	122.407	119.746
H3-H0	249.0	2.041	104.601	20.582	0.317	25.109	122.284	119.679

The choice made was to extend the outage: accept the test results as 'inconsistent' and 'unexplained' and perform a more detailed internal inspection

What would you do?

I'm sure some readers will be as mystified as we were on site at the time. And I'm sure some readers will already have an idea what they might do, or would do, and why, but in 'real time' under strong operational pressure, we have to be sure to make a rational decision which we can later justify. The choice made was to extend the outage: accept the test results as 'inconsistent' and 'unexplained' and perform a more detailed internal inspection.

We also started to look more deeply, not just at the results of the tests but also at how those tests were made and what is included in the 'test object'. What is there about the tertiary which might make it 'different'? Nothing obvious, we were thinking, as we looked at the nameplate, Figure 3.

Then, either in a moment of clutching at straws or a moment of inspiration, a question came to mind: what if the CTs aren't shorted?

Then, either in a moment of clutching at straws or a moment of inspiration, a question came to mind: what if the CTs aren't shorted? I checked with the site team, and they noted that all were shorted several years ago when the transformer was installed, commissioned and put into operation. And that was when I had an ABC moment… Assume nothing, Believe nobody, Check everything; and I asked for them to be checked. At that time, the site team informed me almost immediately that two of the tertiary CTs had been left unshortened, which placed a differential burden on those phases and different LR results.

At this point, the LR kit was, once again, taken out and applied, and all results fell neatly into line! With the dilemma removed, the transformer was successfully returned to service later that day. There was no definitive data to connect the bulge in the main tank to the bushing failure, and as the bulge may well have been there for many years, it was left as an unsolved mystery.

Conclusion

The key learning point I took away from the event was a reminder that everything between the test lead attachments to the test object is part of the measurement: in this case, the LR measurement is not just 'looking' at the leakage flux but is also looking at anything connected to the windings such as the CTs. And, of course, the use of ABC can pay dividends.

Acknowledgement

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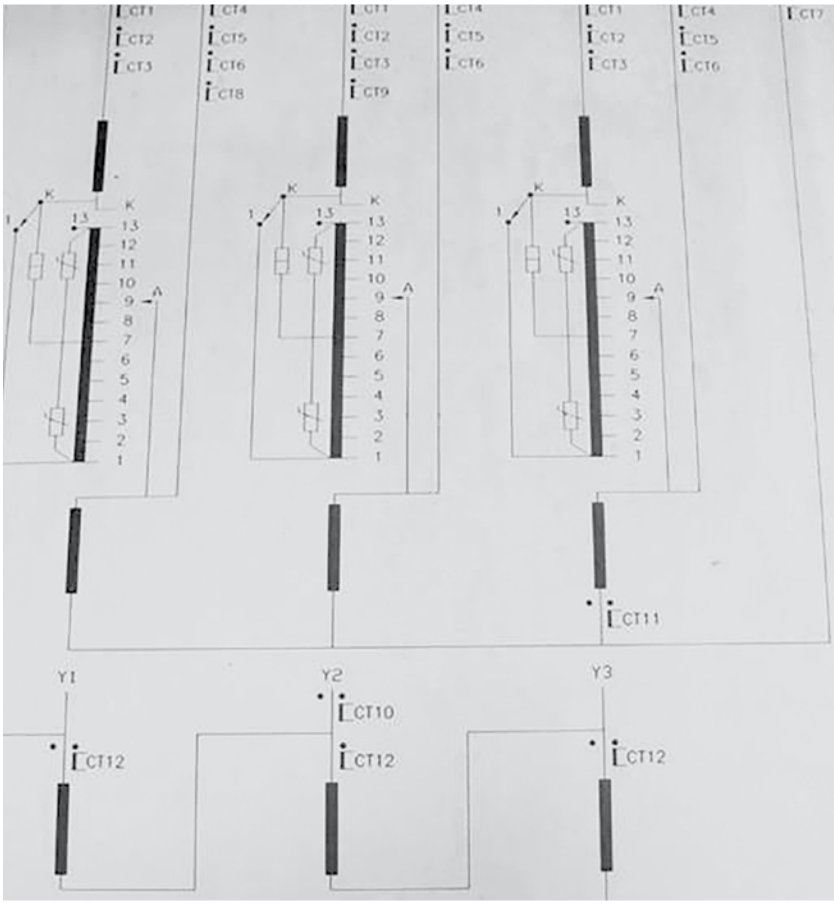

Figure 3. Transformer nameplate detail

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Dr. Tony McGrail is the Doble Engineering Solutions Director for Asset Management and Monitoring Technology. He has several years of experience as a utility substation technical specialist in the UK, focusing on power transformer tests and assessments, and as a T&D substation asset manager in the USA, focusing on system reliability and performance. Tony is a Fellow of the IET and a Member of IEEE, CIGRE, IAM and ASTM. He has a degree in Physics with a subsequent PhD in Applications of AI to Insulation Assessment.