GETTING VALUE FROM TRANSFORMER SFRA

By G. Matthew Kennedy and Tony McGrail, Doble Engineering Company

INTRODUCTION

Sweep Frequency Response Analysis (SFRA) is a test for mechanical deformation in power transformers. It has grown in usage over the last decade and is now being standardized by both IEEE and CIGRE. Doble Engineering has pioneered use of the SFRA test over that time and has gathered a great deal of experience and value from the test. This article looks at how you can gain value from SFRA through a simple approach: Control-Context-Conclusion.

SFRA – Keep it simple

SFRA provides a fingerprint of a winding: a signal injected at one end is measured at the other end of the winding. Repeat this at many frequencies and we have a simple response plot which we can analyze, as shown in Figure 1.

The first thing to note is that the responses shown are typical for a winding. The 'picture' which has been taken should not vary significantly in future for the winding – and variation should be investigated as one possible cause that winding deformation may have occurred. (As a note – impulse systems do not measure the frequency response, they estimate or infer it from impulses, assumptions and Fourier Transformer calculations; they are inherently less repeatable in practice).

Gaining CONTROL

Experience has taught us at Doble that keeping the measurement simple is the best way to ensure that value may be extracted from it. The Doble M5200 and M5300 test sets automatically check for ground loop continuity, for example, as that is a key component of the high frequency response. The Doble test leads are simple one-piece design to avoid losing pieces or incorrectly applying them.

Control of the SFRA measurement is key to gaining good results. We stress the need for training and support as we know

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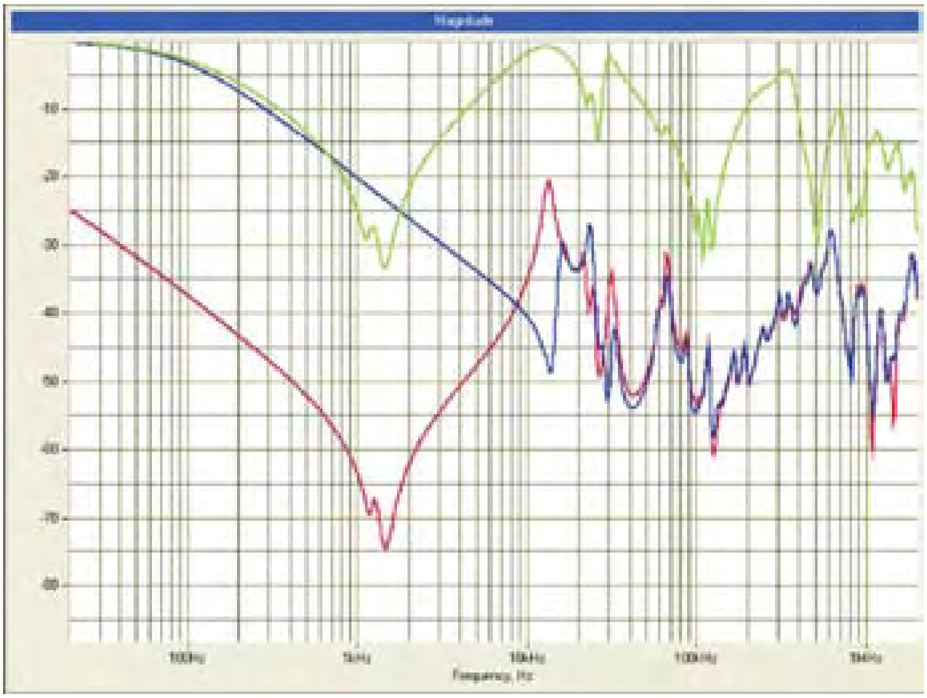

Figure 1 HV, LV and Short Circuit Responses for a single winding

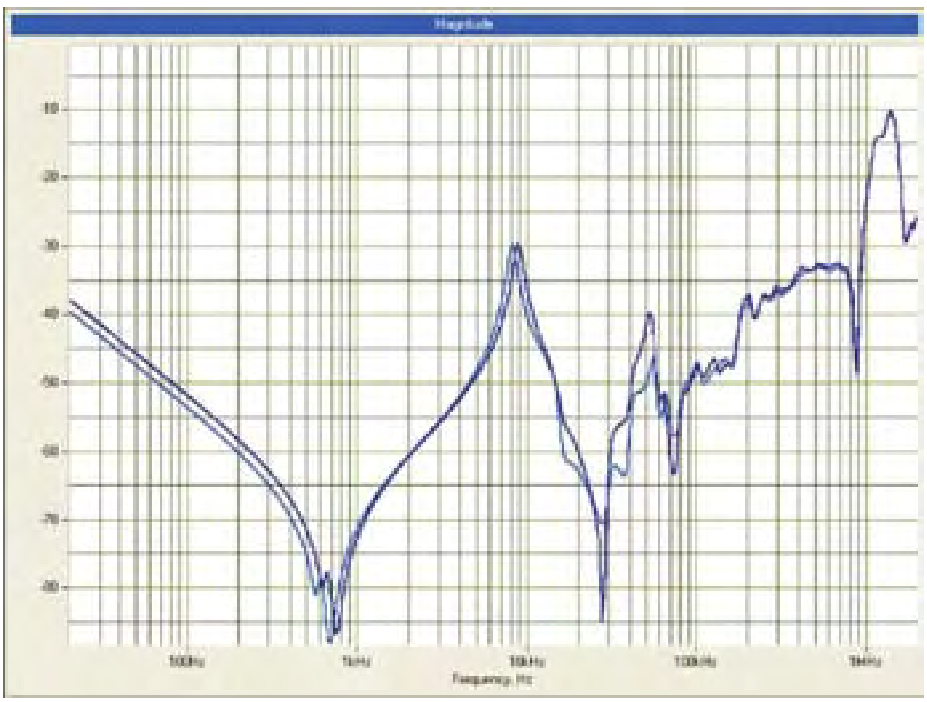

Figure 2 What went wrong?

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that it can be quite a challenge to start taking SFRA measurements without proper education and back up. We understand the common pitfalls that are encountered.

Overall – it is necessary to keep it simple and do it right. For example, Figure 2, shows two successive SFRA results for one winding of one transformer. The results are different – does this mean that the transformer is bad?

In fact, the source of the difference in this case can be traced to a change in DETC (de-energized tap changer) position between the measurements. A small thing, but a key element of control.

Good training and good understanding of parameters which can affect the results help produce valid data which can be used for decision support.

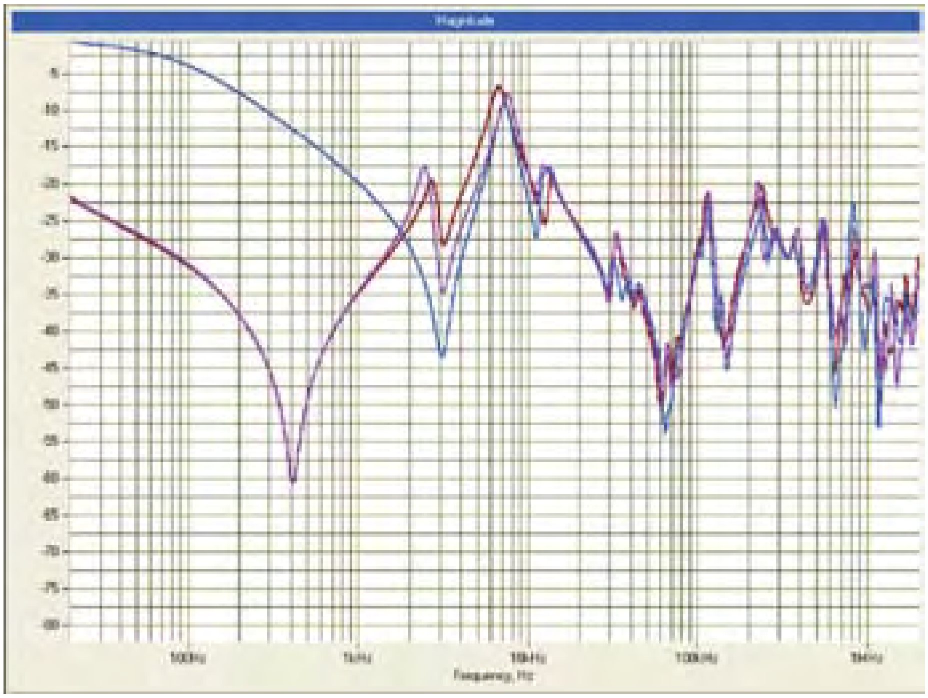

Figure 4 Data as supplied by a Doble Client

Understanding CONTEXT

Assuming that we have exerted good controls and made a valid set of SFRA measurements, the next question is: What does it mean?

If all the results look good, and we are fortunate enough to have reference (baseline) results and they match, then we have strong evidence that nothing has changed in the transformer. If, however, there are some variations compared to baseline, or we have no reference results, what are we to do?

First we should note that SFRA is not the only tool in the bag. Powerful though it is, we should relate SFRA results to other results. Figure 3 shows how SFRA open and short circuit measurements relates to other key electrical tests: DC winding resistance, power factor/capacitance, Leakage impedance (also called leakage reactance) and Exciting currents:

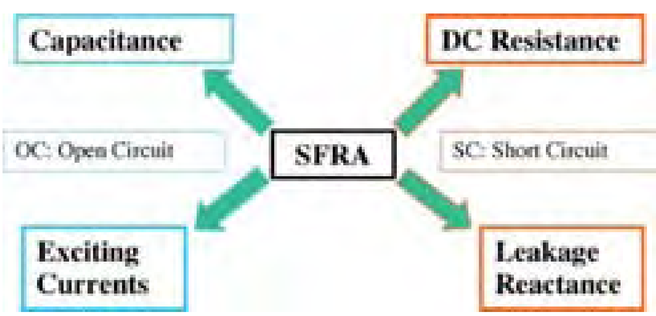

Figure 3 SFRA as part of an Integrated Test Suite

When faced with data which may be anomalous, we need to look at the whole picture. That includes the motivational question: why am I here?

If the test results were generated as part of routine maintenance, then it is almost certain that the transformer is going back in service. I can think of only a couple of instances over the last ten years where a transformer has not been put back in service after routine maintenance as a result of SFRA tests. And even then, further testing was recommended to ensure the decision was a good one!

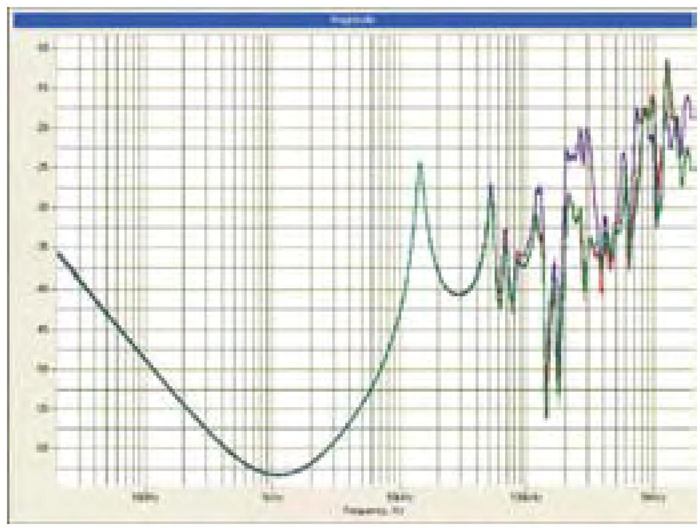

Figure 5 Three in service single phase units

If the transformer trips out of service then we have far greater grounds for being critical. But we must ask which phases were at fault, was it an internal fault or a through fault? What do the DGAs (should we have them) look like?

Drawing CONCLUSIONS

Understanding the context allows us to draw appropriate conclusions. For illustration we have some simple examples.

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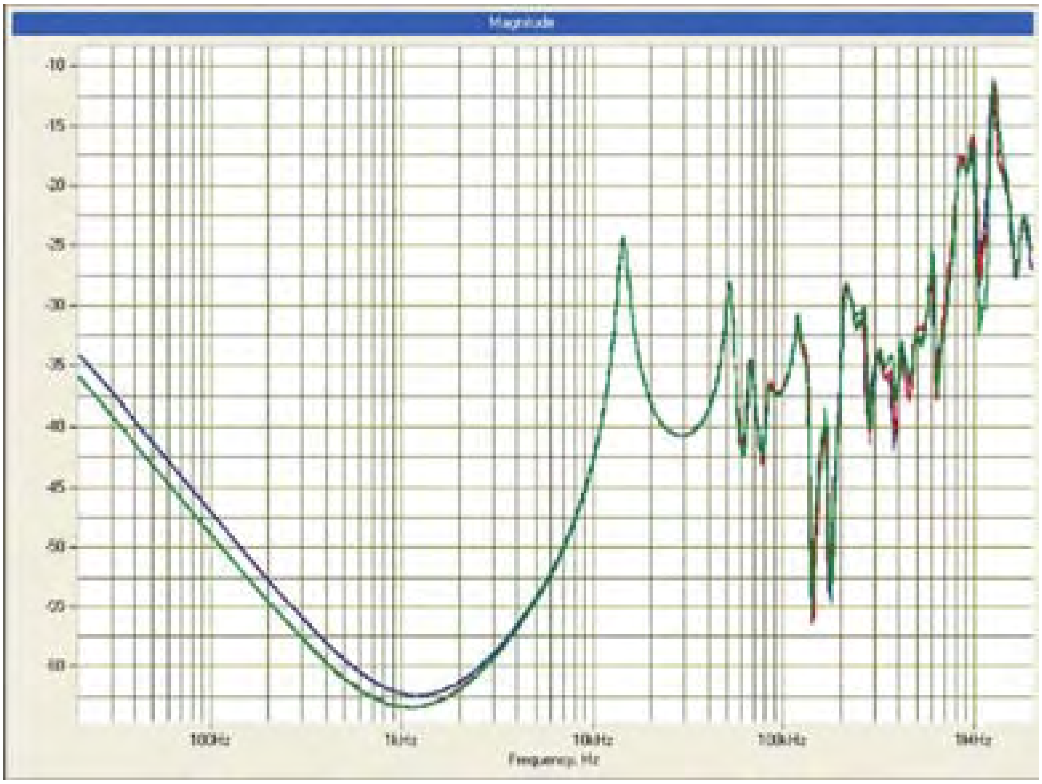

Figure 6 Three single phase units post repair

CASE 1: SHORTED TURN

One of the easiest situations to identify with SFRA is a shorted turn in a winding. The effect is to make what is an open circuit measurement look like a short circuit measurement.

The data in Figure 4 was supplied by a Doble client who was able to recognize good data and understand that the phase-to-phase variation he was seeing was not normal and was not a result of poor set up or site procedure.

Even without reference results, it is possible to say that one winding result is acting as if there is a short circuit on that phase; a more subtle aproach is to try and investigate the possible level of damage to the windings. However, given the nature of the problem, it is unlikely to be a field repair, though such things have been possible in some cases.

In this case the shorted phase was diagnosed, the transformer removed from service and repair effected.

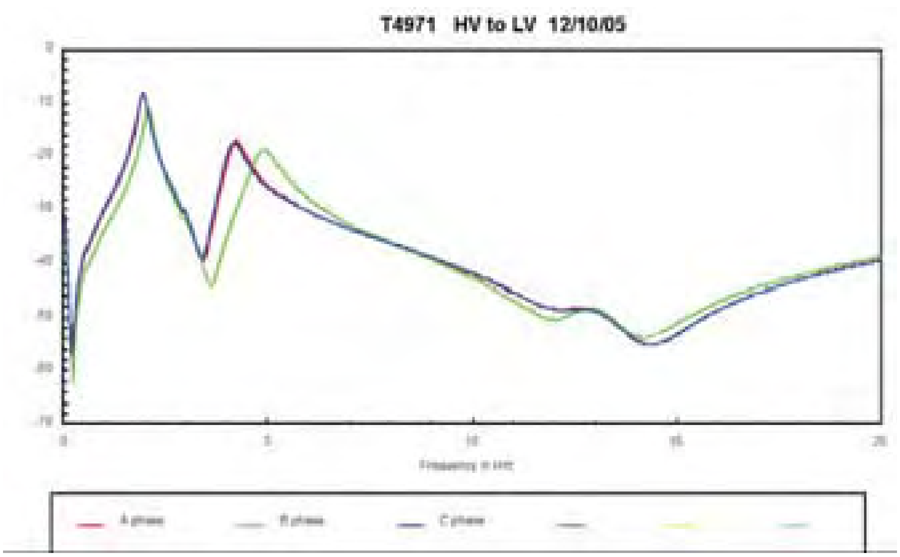

Figure 7 HV-LV for Suspect Transformer

CASE 2: SISTER UNIT REFERENCE

Results from four single-phase units were used to identify a problem with one unit. Three Westinghouse 7-million series units were in service; the fourth was a spare. Figure 5 shows the results for the three in service units; clearly one phase is different: but why?

The results from the spare unit were similar to those of the 'good' in-service units; variations at higher frequencies were noted and attributed to different grounding regimes on the spare transformer. Detailed analysis of the results for the suspect unit lead to a theory that the underlying capacitances and inductances were unchanged. But there seemed to be an impedance variation and a loose connection was possible within the transformer.

An internal inspection revealed loose connections for the bushing draw leads; these were tightened and the transformer retested. The results in Figure 6 show that the results have 'come together' again as expected.

The low frequency variation is due to remnant core magnetization and is a well understood phenomenon while the higher frequency variations are acceptable – we do expect some degree of variability in results!

CASE 3: RESULTS FROM A GENERAL ASSESSMENT

In this case a transmission auto-transformer of 750 MVA and 400/275 kV was identified as suspect as a result of routine DGA. SFRA was performed as part of a routine inspection. No previous results were available, but reference results from a sister unit of the same vintage (1965) were on file.

Figure 7 shows a section of the HV-LV results for the suspect transformer; clearly one phase shows significant variation

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in response compared to the other two phases.

But we often see variation in the 20 kHz region for the center phase. Is it normal for this unit?

The same frequency range for a sister unit showed no such variation (Figure 8). This was substantial evidence of significant winding movement and/or deformation – the frequency range indicates that main winding capacitances would be expected to be 'out'.

However, it was known that the transformer had been in service before the tests were carried out, albeit gassing somewhat. Further testing showed that the main winding power factors were acceptable, but the capacitances had changed by more than 5% from the known good unit.

A decision was taken based on the strength of the SFRA and capacitance not to return the transformer to service but to scrap it and make ready a spare unit.

During the tear down of the 'failed' unit significant winding deformation was found on the suspect phase, the center phase, as predicted.

At Doble we receive SFRA results every day from around the world – we have SFRA practitioners in over 40 countries at present. The majority of results are acceptable; occasionally they show some poor field practice leading us to suggest retraining or a refresher course for the field guys. Occasionally we get an example of results which make it into the Doble Conference – they are not just results to be added to the thousands in the Doble data base, but examples where the whole user base can learn – both the experts at HQ and the guys in the field.

If you have SFRA results and are interested in what they really mean – we'd love to hear from you!

Figure 9 Winding showing significant buckling

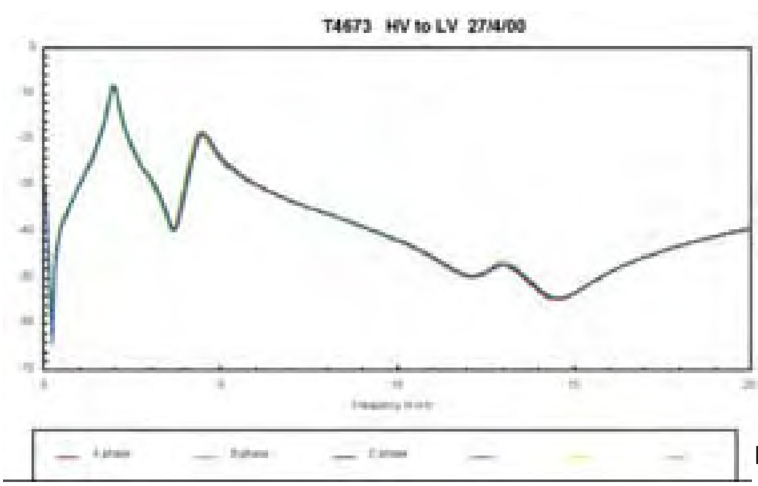

Figure 8 HV-LV for Known Good Transformer

CONCLUSIONS

SFRA is an easy measurement to make, and with proper training and good support anyone can get good value from their SFRA investment. The three Cs of SFRA: Control-Context-Conclusion show the thought process that needs to be applied to SFRA.