SFRA ratio test on transformers

A simple diagnostic test to identify winding with shorted turns

ABSTRACT

SFRA test is a powerful and sensitive method for assessing the mechanical and electrical integrity of the transformer core/coil assembly. The two most commonly used tests are open- and short-circuit tests. Both are used for testing the complex network of inductances, capacitances and electrical resistances and, frequently, have no difficulties in detecting the presence of an electrical fault with the shorted turn(s). Since windings are electromagnetically coupled, the SFRA trace obtained from one of the windings may be affected by the electrical fault on a different winding. Identifying which winding has the problem is a challenging task. This paper describes the experience with six units, where the faulty winding (if any) was identified by employing an inductive inter-winding SFRA setup. We elected to refer to this test as "SFRA ratio" test.

KEYWORDS

data analysis, detecting fault winding, diagnostics, SFRA ratio, shorted turns

1. Introduction

The objective of a traditional voltage ratio test is to verify the proper number of turns, internal connections and to serve as a benchmark to assess possible future damage, e.g., shorted turn(s). While theoretically, a change in the voltage ratio data should point to the winding with a shorted turn(s), in practice, it may not paint a clear picture. To address that, an inductive inter-winding SFRA (Sweep Frequency Response Analysis) setup was employed. It offers a frequency scanning from low frequency (e.g., < 200 Hz), where the ratio of the induced voltages is closely proportional to the turns ratio. Therefore, the direction of the deviation in the aforementioned SFRA trace segment points to a winding hosting the defect. The following discussion describes the basics of the test, along with the results of several field investigations.

With a simple calculation of the deviation between traces, SFRA Ratio identifies the winding sheltering the shorted turns

2. Basic concept

Fig. 1 shows a basic setup of a SFRA ratio test, which employs connections for the inductive inter-winding SFRA test. In that, the high-voltage winding is excited by the test voltage applied between the red lead and ground, and the secondary voltage is measured between the black lead and ground. Let us recall the expression for the SFRA magnitude in dB:

$$20 \log \left(\frac{V_2}{V_1}\right) = dB \qquad (1)$$

From (1), the ratio of voltages is:

$$SFRA\ Ratio = \frac{V_1}{V_2} = 10^{\frac{dB}{20}} \qquad (2)$$

Obviously, the relevant ratio data can be obtained in a frequency range where the ratio of voltages corresponds to the ratio of turns. To that end, for the units tested, the SFRA ratio remained constant at frequencies < 200 Hz. The difference between the SFRA traces can be useful in detecting / confirming the presence of the defect (3):

$$\Delta_{25\ Hz} = \frac{Max(R_1, R_2, R_3) - Min(R_1, R_2, R_3)}{Average(R_1, R_2, R_3)} \qquad (3)$$

In (3), $\boldsymbol{R_1}$, $\boldsymbol{R_2}$, $\boldsymbol{R_3}$ are SFRA ratio values obtained from the traces of each phase. To identify which winding has a shorted turn, the trace deviation in that segment is examined. If the turn is shorted in the low-voltage winding, the trace segment will move upwards (towards a higher ratio value) and move downwards (towards a lower value) if the shorted turn is located in the high-voltage winding. A comparison can be made either with the previous data or with other phases. Furthermore, the nameplate (NP) voltage ratio can be compared with the SFRA ratio taken near the power frequency to avoid potential interference. The latter allows verifying that the SFRA ratio test setup is correct. Given the wealth of experience gained with traditional voltage ratio tests, it seems practical to continue relying on the traditional voltage ratio test in all situations. The SFRA ratio comes into play when an electrical defect is detected (by any of the tests), and there is a need to identify / confirm the faulty winding. In that, the SFRA ratio test offers a more visible indication of the defective winding.

Combining standard SFRA tests with SFRA ratio enhances diagnostics of shorted turns

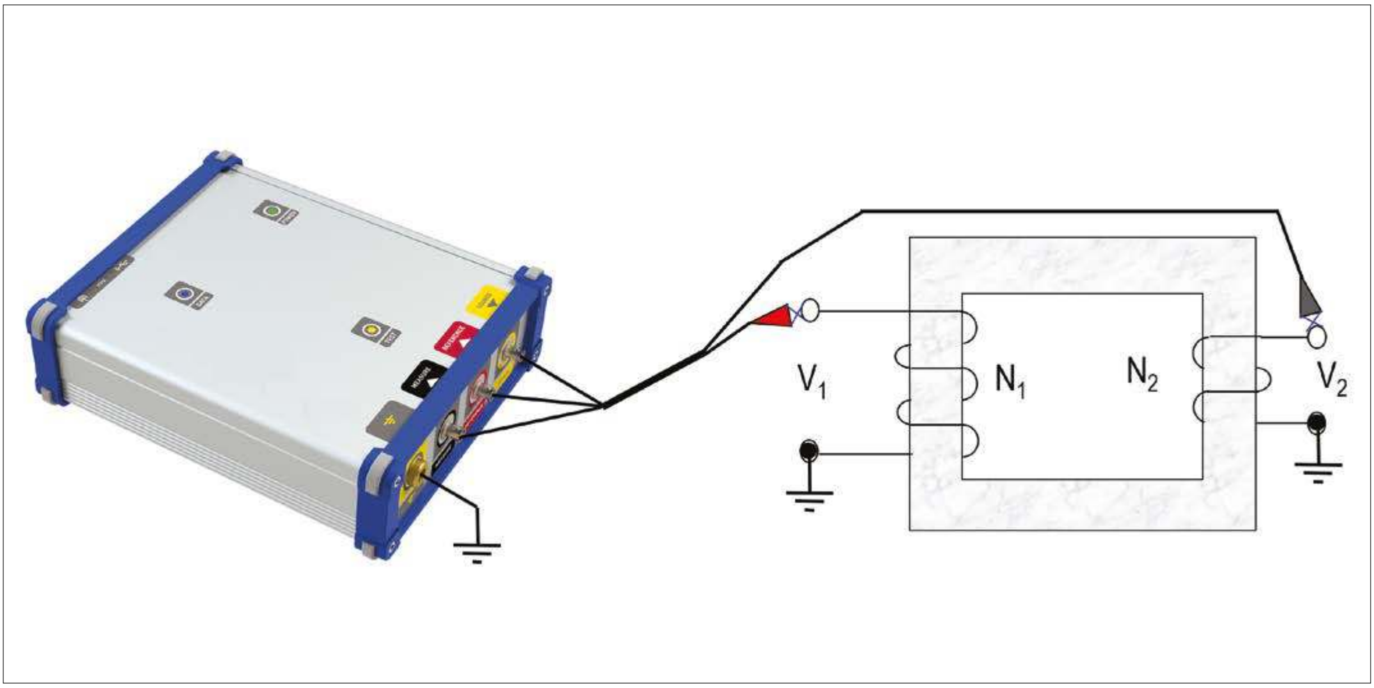
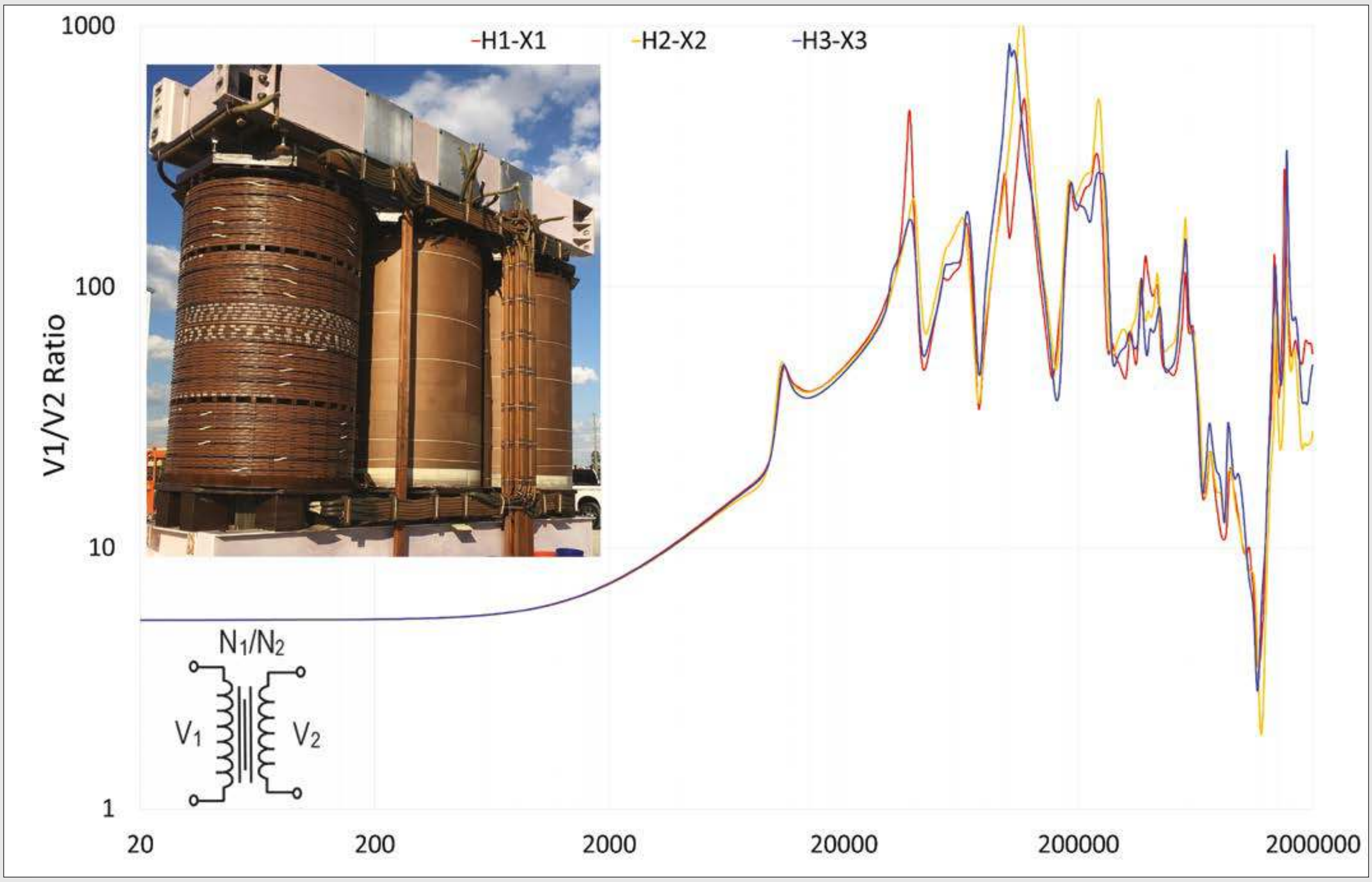


Figure 1. Basic setup for SFRA ratio test



An interesting observation is that with a higher frequency range the SFRA ratio seems to behave in a way similar to the traditional open circuit and short circuit tests

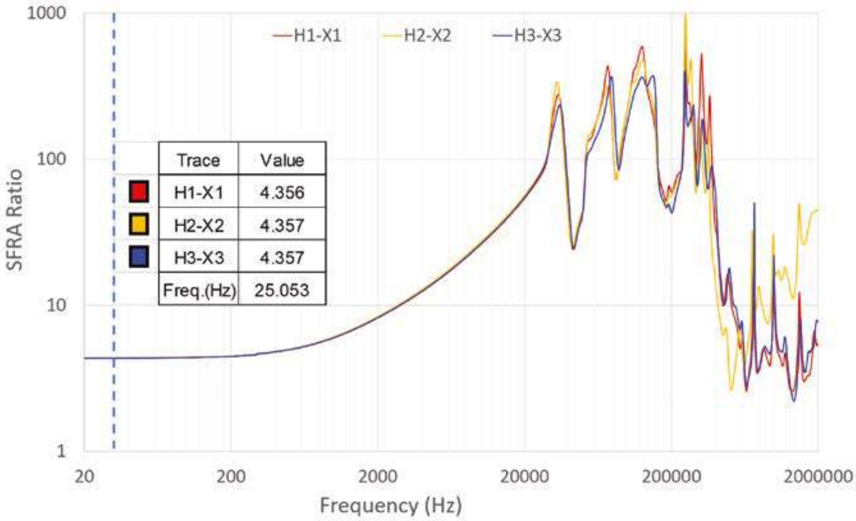
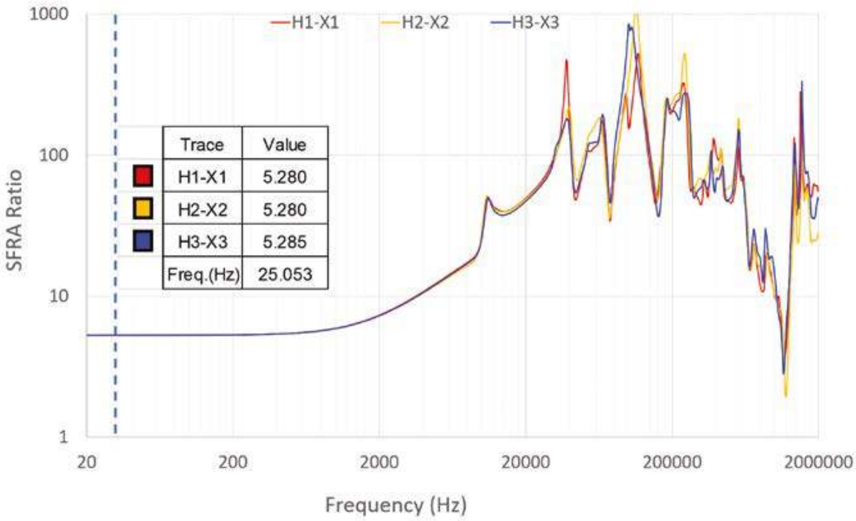
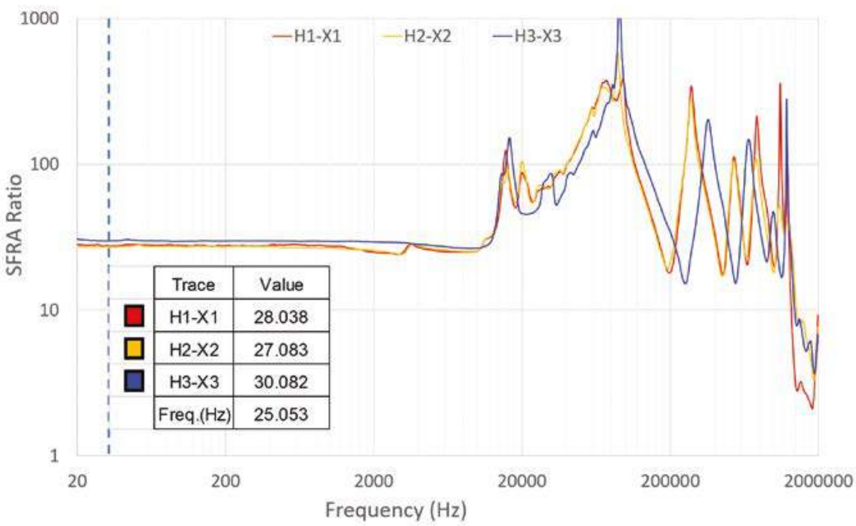
3. Experience

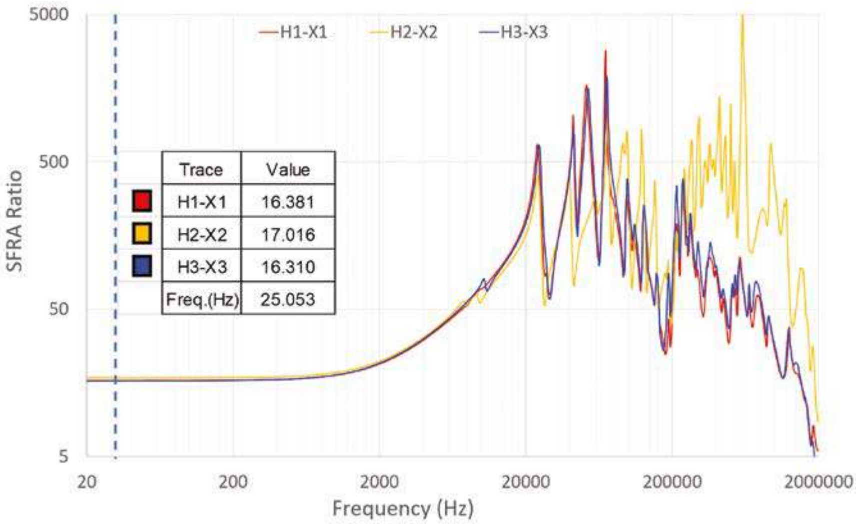
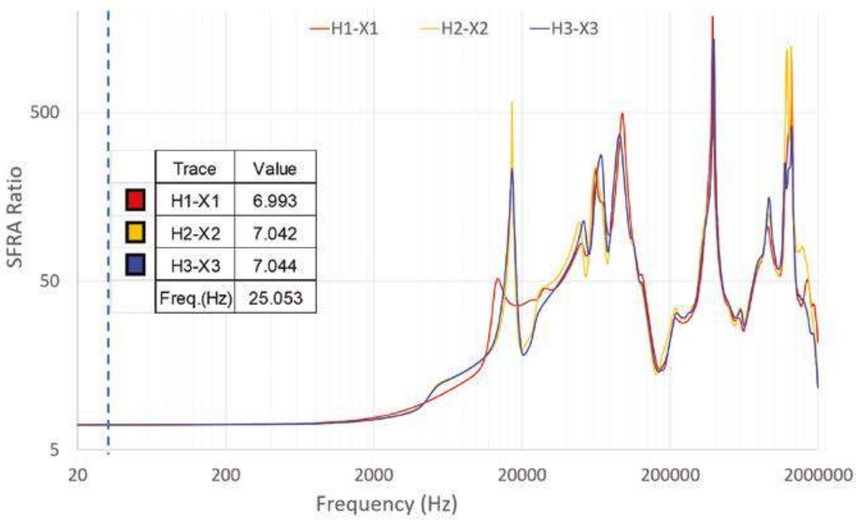
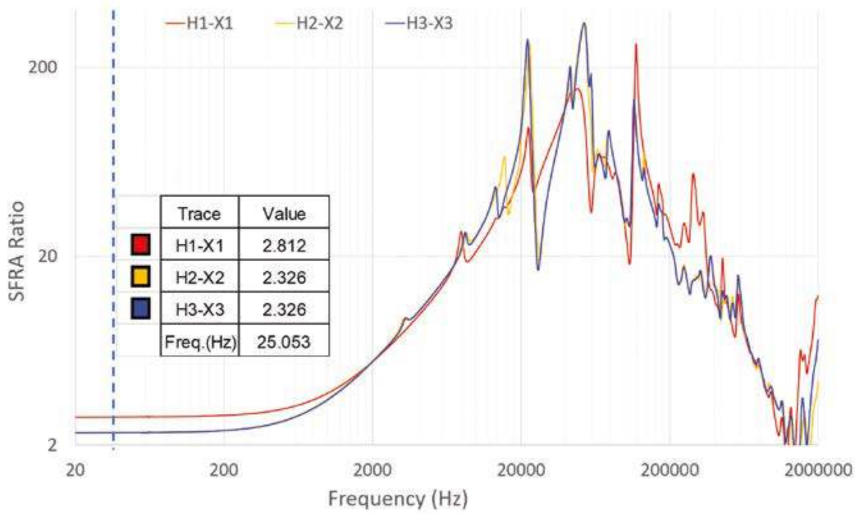
Six transformers in different conditions were used to demonstrate the SFRA ratio application. These units have different winding configurations with conditions varying between good and with a fault such as shorted turns in either the primary or secondary winding, as summarized in Table 1. The analyses of the test results are summarized in Table 2.

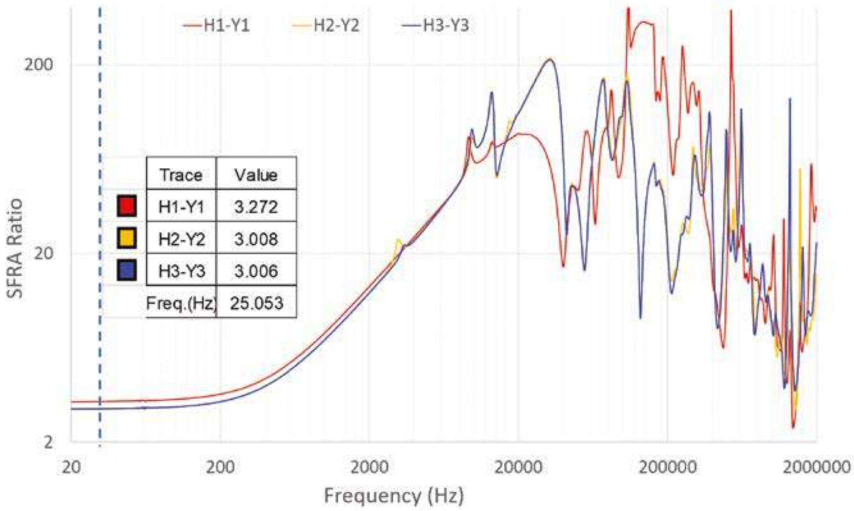
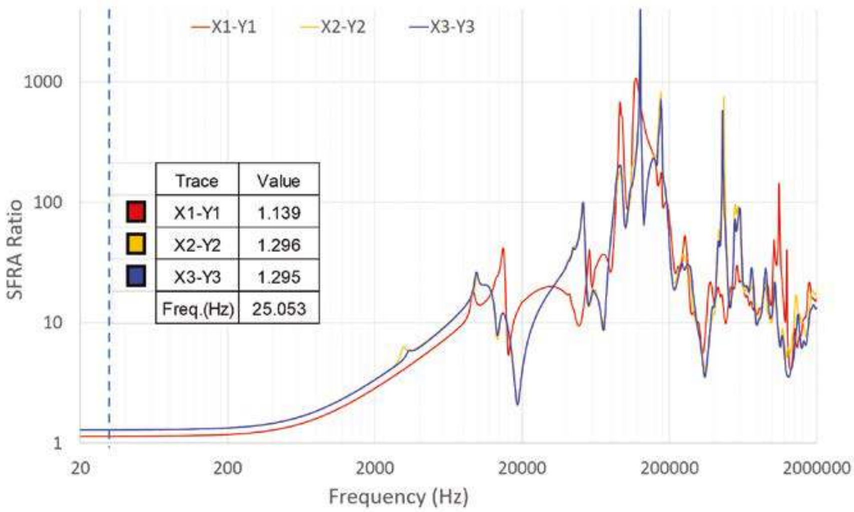
Table 1. Transformers tested

Unit #	Condition	Winding	Manufacturer	MVA and voltage at tested tap position
1	Good	Dyn1 -2012	Electric Power Service	12.5 MVA, 34.5 / 13.8 kV
2	Good	YNd1 -1962	General Electric	40 MVA, 120.75 / 13.2 kV
3	Fault on LV	YNd1-1989	Westinghouse	41.6 MVA, 120.75 / 13.2 kV
4	Fault on LV	Dyn1-1970	Moloney Electric	18 MVA, 115.5 / 13.2 kV
5	Fault on HV	YNd1-1998	Ferranti Packard	300 MVA, 241.5 / 20 kV
6	Fault on LV	YNa0d1-1971 H-X	McGraw-Edison	33 MVA, 230 / 99.4 kV
	Fault on TV	H-Y		230 / 44 kV
	Fault on LV, TV	X-Y		99 / 44 kV

Table 2. Data review

<table>
<tr><th>SFRA ratio data</th><th>Observations</th></tr>
<tr><td>
</td><td>1) Δ25Hz = 0.023 %
2) SFRA ratio is reasonably close to NP ratio. The expected Δ25Hz is within ± 0.5 %.
3) No fault detected</td></tr>
<tr><td>
</td><td>1) Δ25 Hz = 0.095 %
2) SFRA ratio is reasonably close to NP ratio.
3) No fault detected</td></tr>
<tr><td>
</td><td>1) Δ25 Hz = 10.56 %
2) SFRA ratio values on each phase drastically deviate from the NP ratio.
3) H3-X3 trace is higher than traces of the other two phases, indicating that fault is present in phase 3 of X winding.</td></tr>
</table>

<table>
<tr><th>SFRA ratio data</th><th>Observations</th></tr>
<tr><td>
</td><td>1) ∆25 Hz = 4.26 %
2) SFRA ratio values deviate from the NP ratio.
3) H2-X2 trace is higher than traces for the other two phases, indicating that fault is present in the phase 2 of X winding.</td></tr>
<tr><td>
</td><td>1) ∆25 Hz = 0.72 %
2) SFRA ratio is reasonably close to NP ratio.
3) H1-X1 trace is lower than traces of the other two phases, indicating that fault is present in the phase 1 of H winding.</td></tr>
<tr><td>
</td><td>1) ∆25 Hz = 19.52 %
2) SFRA ratio in phase 1 significantly deviates from both the NP and SFRA ratio values in other phases.
3) H1-X1 trace is higher than the traces of the other two phases, indicating that fault is present in the phase 1 of X winding.</td></tr>
</table>

SFRA ratio data	Observations
	1) Δ25 Hz = 8.61 % 2) SFRA ratio in phase 1 significantly deviates from both the NP and SFRA ratio values in other phases. 3) H1-Y1 trace is higher than traces of the other two phases, indicating that fault is present in the phase 1 of Y winding.
	1) Δ25 Hz = 12.62 % 2) SFRA ratio in phase 1 deviates from both the NP and SFRA ratio values in other phases. 3) X1-Y1 trace is lower than traces of the other two phases, indicating that fault is present in the phase 1 of X winding. This suggests that X winding has a higher percentage of shorted turns than Y winding.

Conclusion

In summary, the reported experience shows that in tested transformers, the SFRA ratio test was successful in both, detecting the presence of the shorted turns as well as identifying the winding that has the fault. As the analysis guideline, the maximum deviation among phases near 25 Hz (Δ25Hz) should be within ± 0.5 %, Another interesting observation has to do with a higher frequency range where the SFRA ratio seems to behave in a way similar to the traditional open circuit and short circuit tests, i.e., dominated by the interactions within/between the windings as well as with surrounding components. More studies are required to validate this observation and to establish a practical diagnostic.

The experience shows that the SFRA ratio test was successful in both, detecting the presence of the shorted turns as well as identifying the winding that has the fault

Author

Long Pong works as a Senior Principal Engineer in the Client Service Department at Doble Engineering Company. He has amassed over 30 years of experience in the power utility industry and has published numerous technical papers pertaining to condition assessment, troubleshooting and new test techniques of electrical power apparatus. Before joining Doble in 2000, he was employed at Alcan-Énergie Électrique and Hydro-Quebec. He is an IEEE member, a registered professional engineer in North Carolina and obtained a Bachelor of Electrical Engineering from École Polytechnique de Montreal, Quebec, Canada, in 1988.