Demagnetization of Power Transformers Following a DC Resistance Testing

Dr.ing. Raka Levi
DV Power, Sweden

Abstract
This paper discusses several methods for removal of remanent magnetism from power transformers. Causes of this phenomena, such as winding dc resistance testing, and consequence of the remanent flux are described. The IEEE Standard 62-1995 (section 6.1.3.5) approach and its deficiency is shown. Experience with a simple but secure method automated by powerful instrumentation system shows successful demagnetization on transformers up to 1100MVA. Detection and verification of demagnetization process using FRA and other techniques is explained.

Introduction
Remanence or remanent magnetization is the magnetic flux left behind in a ferromagnetic material (such as iron) after an external magnetic field is removed. In a power transformer, windings are wound on the iron core, or magnetic core, to provide flux path for the process of voltage induction. In a demagnetized state of the core all atomic magnetic moments or dipoles are randomly oriented to cancel each other. Once they are forced to take one direction by the current in the winding, or to get the magnetic core magnetized, another force would be needed to return them into the original demagnetized state. However, it is not that easy to accomplish.

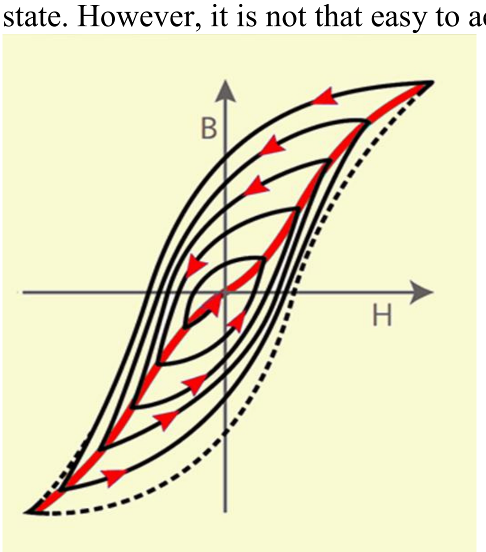

Figure 1. Hysteresis

CAUSES
The remanent magnetism is caused several different ways:
a. DC testing – a winding resistance measurement on a power transformer is performed using dc current in the order of 10% rated current of the winding under test. This test is normally performed as the very last due to effects of remanence to other ac test results.

Proper winding resistance technique, to speed up the process of result stabilization, requires that the magnetic core is brought into saturation. Having dc current at that level makes the transformer core magnetized. Once the test is done, switching the current off, the winding is discharged, but is not demagnetized.

b. Taking the transformer out of service – as in the most cases the voltage and current are not in phase, interrupting current makes the flux remain in the non-zero state at the point where the alternating current is interrupted by a circuit breaker in the moment it passes through the zero value.

c. Clearing high fault currents – this is the subset of the case (b) where the relays open the circuit carrying very high short circuit currents.

Thus, the magnetic core of a transformer out of service is almost always magnetized to a certain degree. The dc winding resistance test is the worst culprit in this process.

EFFECTS

Several problems are caused by the remanent magnetism in the energy sector. The most problems caused by remanence is to system protective relays, power transformers, and the power system itself.

a. Incorrect operation of relays

The protective devices for overloads and internal faults may falsely operate and disconnect the transformer from the electrical system. The figure 2 shows a situation where the inrush current was switched off after 5 cycles of transformer energization. The A phase current exceeded 400A in the first half cycle, while the other two phases show great asymmetry, presence of higher harmonics in the current waveform.

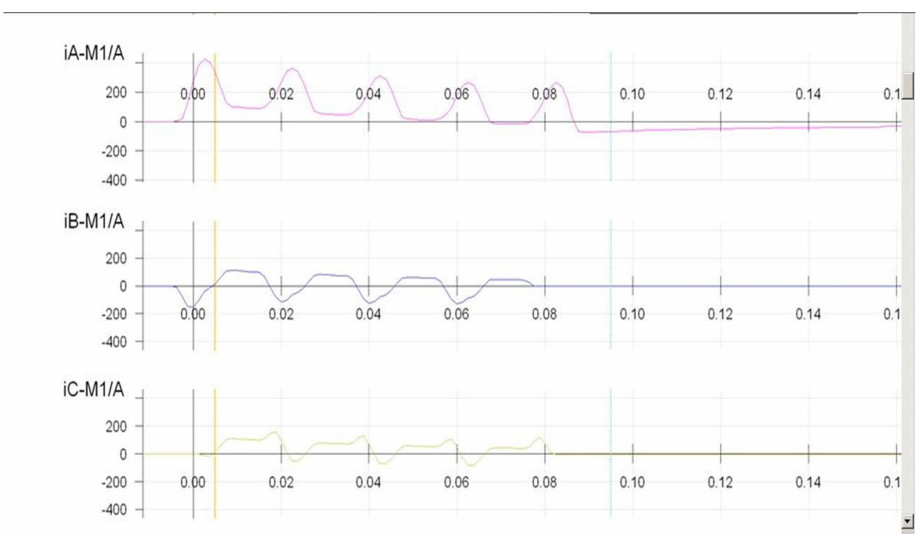

Figure 2. Relay operating after 5 cycles on Inrush current of phase A

The consequence of this unnecessary relay operation is the need for another subsequent powering of a transformer, introducing another mechanical shock to the unit.

b. Mechanical damage to transformer active parts
The windings are exposed to mechanical stress proportional to the square of the current. Over-current caused mechanical shocks may damage the coils and release the clamping pressure, that would eventually lead to loose windings and a transformer failure.

It was shown that inrush currents calculated at the head of the feeder were reduced by about 60% when a power transformer was previously demagnetized [1].

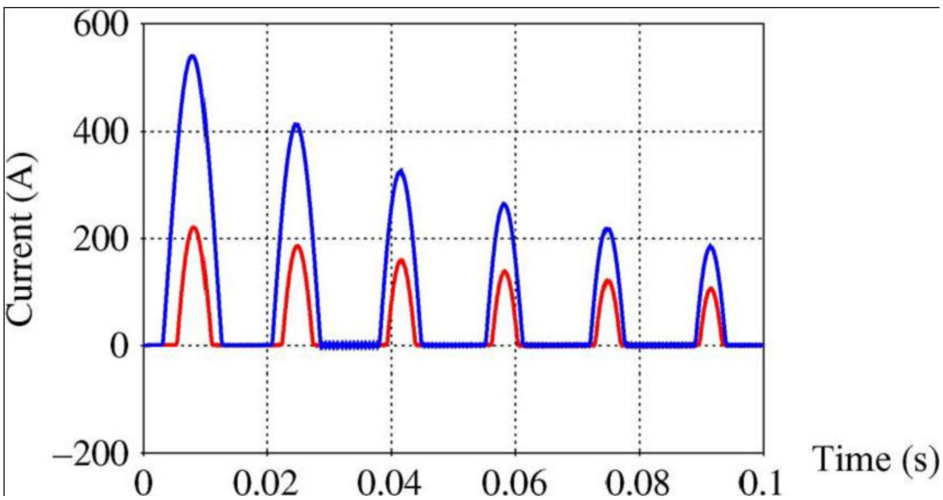

Figure 3. Comparison of maximum inrush current with and without residual flux

c. Disturbance and power quality problems, high resonant harmonic overvoltages, and voltage sags are all present when the transformer operates in the first few cycles after the energization if remanence was present.

d. Incorrect diagnostic test results
The Frequency Response Analysis (FRA) test is influenced to a significant degree around 1kHz region by remanent flux [4]. This may lead to incorrect conclusion that the active part of a transformer is damaged when comparing with the factory tests.

The magnetizing or excitation current used for transformer diagnostics may provide incorrect analysis based on results obtained with core being magnetized [2]. Internal transformer defect may be falsely indicated, as test results are not in line with the benchmark or previous tests.

As shown in the table 1, magnetized transformers had lower excitation current than the same units after demagnetization, due to the high capacitance of the windings, as explained by Polin in [3].

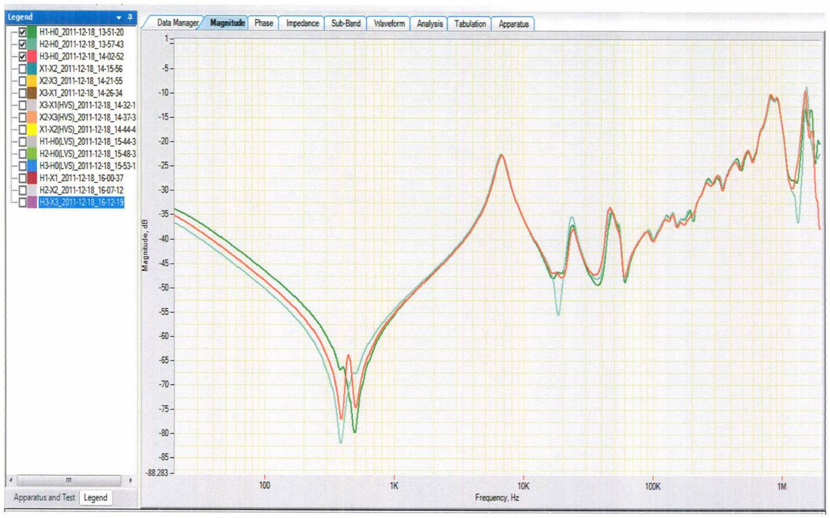

Figure 4. FRA graph of a 90MVA magnetized transformer

These two ac-type tests are always performed before the dc winding resistance testing for that particular purpose – not to get influenced or results skewed by remanence.

Table 1. Results of excitation/magnetization current of 3 single phase units

	10 kV Magnetization/Excitation Currents (mA)					
	S/N GBM31062		S/N GBM31063		S/N GBM31064	
	H1-H2	H2-H1	H1-H2	H2-H1	H1-H2	H2-H1
mag	14.9	14.9	28.3	28.3	15.4	15.4
mag	14.9	14.9	28.6	28.6	15.5	15.5
demag	33.8	33.8	34	34	33.8	33.8

DEMAGNETIZATION

Methods of remanence removal - demagnetization

Remanent magnetism in magnetic materials is dissipated naturally through the thermal demagnetization process over a very long period of time or at very high temperatures (order of 550 degrees C for magnetite or hematite) [5]. This is not practical for electrical systems, thus an artificial demagnetization is performed for power transformers.

We will discuss several methods for removal of remanent magnetism from power transformers: Variable Voltage Constant Frequency Source (VVCFS), Constant Voltage Variable Frequency Source (CVVFS), Decreasing Amplitude of an Alternating Polarity *dc* Current (DAAPC), and Constant Alternating Voltage with Decreasing Time (CAVDT).

The VVCFS - Variable Voltage Constant Frequency Source – is the best method, performed in the factory, and requires very large energy source. Impractical for field operation it provides industrial frequency (50 or 60Hz) source powerful enough to magnetize the magnetic core. Another requirement is the possibility to control and slowly reduce this voltage. By reducing the voltage and current from nominal to zero, the core is demagnetized; however, this is impossible to do in the field on even a medium size power transformer.

The paper published by Deleon et al. [7] explains simple and quick method to demagnetize the iron core of a power transformer measuring and calculating coercive force to be applied in a single application. This is a variation of the CVVFS (Constant Voltage Variable Frequency Source) The experiment in that publication shows results for single phase and three phase units. The method has been verified on Y-Y connections for three-and five-limb transformers as well.

The IEEE Standard 62-1995 (section 6.1.3.5) directs one to alternate the polarity of a fixed voltage with decreasing application time per alternation of polarity. This is the CAVDT method. With each alternation, the voltage is applied until the current flow has reversed and is "slightly lower" in absolute magnitude than the current in the previous application.
The explanation is clear: with decreasing time you should obtain slightly lower magnitude of the current. However, this is easier said than done. Once the current reaches the knee-point of the saturation curve, with applied fixed voltage it changes too fast to manually control with precision. Experience has shown that improper procedure very often caused other core legs to get magnetized while one was being demagnetized. Thus, no successful demagnetization could be reported in most cases.

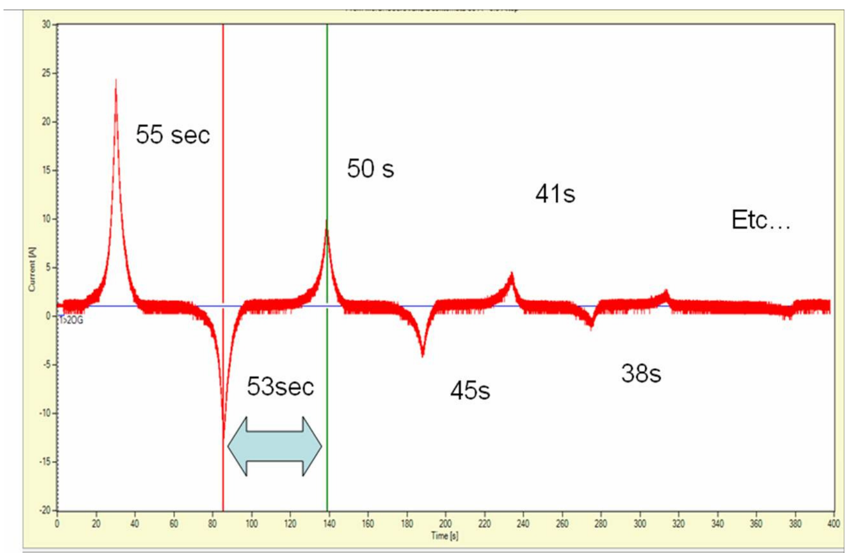

Figure 5. A 780MVA transformer demagnetization example

As shown in the figure 5, proper time sequence for diminishing current magnitude should be after the first sequence reaching the amplitude of 25A at: 55, 53, 50,45,41,38… seconds. Not to mention that at lower current levels we may be talking fractions of a second.

Modern electronically controlled high-power dc-test instruments can control the amplitude of the applied current with high precision (the DAAPC method) and they can be programmed to perform polarity reversal and automatic demagnetization of the power transformer magnetic core [6]. As shown in the figure 5, current is interrupted at preselected value and following a discharge process, the opposing polarity current is applied. In this subsequent step the amplitude at which the supply is interrupted is lower by 40% of the previous cycle. The process is repeated down to the lowest practically controllable current amplitude. A successful demagnetization was obtained on various sizes of power transformers up to 1100MVA, in both configurations: star or delta.

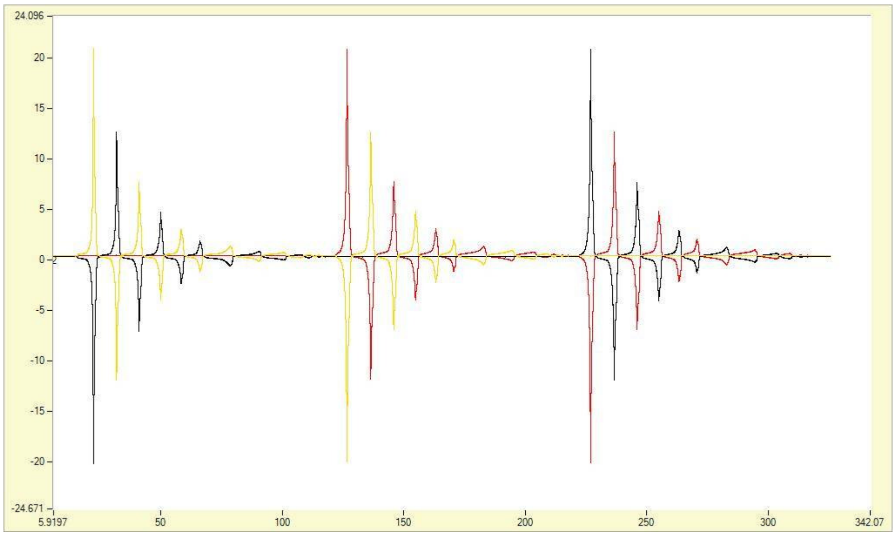

Figure 6. Delta winding demagnetization

A large generator step up transformer rated 1100MVA and 400/13kV was demagnetized as shown in the figure 6 from the secondary – the LV side connected in triangle (Delta), with all three phase currents recorded and shown in three appropriate colors.

A variation of DAAPC method, applying current to all three phases from AC to B was also tested. This applies for a Y connected three phase winding, where a special procedure was attempted to run current through the middle core-leg winding and return to the source by splitting through the other two phases. Theoretically all three phases, all three legs of the iron core are demagnetized this way. However, it has shown to be too long a duration for establishing current at large power transformers, and proved to be impractical.

VERIFICATION

Verification of the demagnetization process
There are three ways of confirming remanent flux is eliminated:
a. measuring volt seconds
b. comparing magnetization currents of each phase
c. checking the FRA graphs for distortion around 1kHz

Direct measurement of volt-seconds is applied in measurement of magnetization state of current transformers. It may be applied to the power transformers as well. As each measurement would modify the state of the magnetized core, the complete integration of all half cycles has to be performed during one demagnetization process.

The magnetization current comparison is a good tool to establish the success of the demagnetization process. On a normal three phase transformer the single phase excitation current results should follow a pattern of two similar and one lower value.[8] These values are very voltage dependent and for comparison, tests should be performed always at the same voltage. Remanent magnetism will show as a discrepancy in the pattern expected for the three current values.

The FRA graphs should also follow a pattern of two identical traces for the outer phases and a different one (with one peak at 1kHz region) for the phase located on the middle transformer leg [4]. Any additional peaks or movement of peaks towards higher or lower frequencies will indicate magnetization of the core, while comparing with the benchmark obtained where the transformer was demagnetized in the factory following a high voltage ac tests.

Conclusion

Following a DC winding resistance test power transformer core is always magnetized. Several methods for demagnetization of power transformers exist. Modifications of these processes were evaluated and the most practical one was selected for a commercially available demagnetizer with 50V dc source and currents of up to 60A. Alternating polarity of this source can successfully demagnetize the largest of transformers. Putting demagnetized transformer into operation saves mechanical damage to the unit and eliminates system disturbances.

REFERENCES

[1] B. Kovan, F. de Leon, D. Czarkowski, Z. Zabar, L. Birnebaum, 2011: "Mitigation of Inrush Currents in Network Transformers by Reducing the Residual Flux With an Ultra-Low-Frequency Power Source", IEEE Transactions on Power Delivery, vol. 26 issue 3, 1563-1570.

[2] Ronald A. Proffitt , “Glaring Example of the Effects of Residual Magnetism on Large Single-phase Transformers as Determined by Routine Excitation-current Tests”, Minutes of the 1997 Doble Client Conference

[3] Bertrand Poulin, “EXCITING CURRENT OF POWER TRANSFORMERS”, Proceedings of the 1996 International Conference of Doble Clients - Sec 8-9

[4] CIGRE Brochure 342, “Mechanical-condition assessment of transformer windings using FRA”, Cigre WG A2.26, April 2008

[5] Conall Mac Niocaill, Magnetic Domains & Remanence Acquisition, Oxford University presentation

[6] DV Power, Instruction manual: DEM 60C three-phase Demagnetizer

[7] F.de Leon et al., Elimination of Residual Flux in Transformers by the Application of a Slowly Alternating dc Voltage Source

[8] A. Rickley et al., Field Measurements of Transformer Excitation Current as a Diagnostic Tool, Power Apparatus and Systems, IEEE Transactions on (Volume:PAS-100 , Issue: 4) Page(s):1985 - 1988 , 1981