Demagnetization of power transformers

1. Introduction

In the marketplace for electrical transformer test equipment, there is a lot of talk about demagnetization of transformers. It is a recommended practice that probably will make it into the international guidelines and standards for transformer testing in the future.

The importance of demagnetization is generally understood, but the underlying reasons and mechanisms are often unknown. This application note strives to explain the magnetic properties of the transformer, how standard measurements can affect these properties and how the transformer can be brought back to an un-magnetized state. The application note also describes when demagnetization is important and when it can be left out with little risk to the integrity of the electrical network.

2. Magnetic properties of the transformer core

In its simplest form, an electrical transformer is a ferro-magnetic core around which two coils, or windings, are wrapped. The AC voltage in the primary coil induces an alternating magnetic flux in the core which, after having been carried by the core, in turn induces a voltage of different magnitude in the secondary coil. The voltage transformation ratio is directly proportional to the ratio between the number of turns in each winding.

Current flowing through turns of wire (i.e. a coil) creates a magnetic field strength, generally denoted **H**. **H** is in relation to the number of turns as well as the current (the line integral over any closed loop of the H-field is equal to the current times the number of turns). In the transformer, this magnetic field strength generates magnetic flux, generally denoted **B**, which is essentially confined to the core as the reluctance the magnetic flux experiences is significantly smaller in the core than in the surrounding materials.

The on-load tap changer is the only moving part connected to the transformer windings and, as such, is the most susceptible to failure. The importance of its reliability cannot be over emphasized. Taking a transformer off the system to investigate an internal problem with a tap changer is an expensive exercise; therefore, it is in every utility’s interest to carry out condition

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assessments of their tap changers to help detect developing faults at an early stage. According to a CIGRE survey, about 27 % of failures in large transformers over 100 kV are due to the tap changer failures, see Figure 1 below.

Had the coil core been vacuum, air or any other non-magnetic material, the magnetic flux would had been proportional to the magnetic field strength **H**, the purely electrical component of magnetism, by a factor μ_0, the permeability in vacuum. But as the core has magnetic properties, **B** and **H** have a more complex relationship. If plotted against each other, the factors **B** and **H** form a magnetization curve

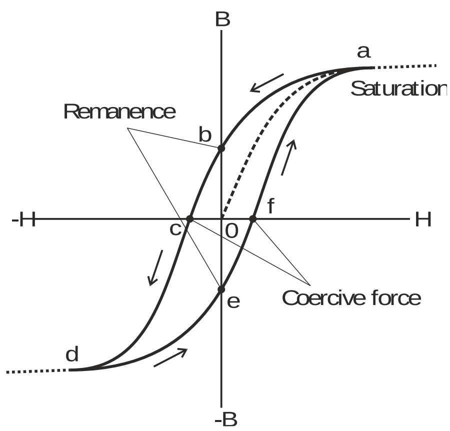

Figure 1: Magnetization curve for ferro-magnetic material

In the region close to zero (0), **B** increases with **H,** but as the magnetic field strength increases (higher current), the magnetic flux flattens out and eventually reaches saturation (a); an increase in the magnetic field strength by an increase in the current flowing in the winding will have little or no effect on the magnetic flux. This means that there is a limit to the amount of flux density that can be generated in the core. When being subjected to a magnetic field, tiny magnetic domains in the core material align with the magnetic field and when the field strength is high enough, all these domains will be aligned and the flux density cannot increase more. Beyond the saturation point, the transformer acts as if it had had an air core.

Another effect that occurs in in ferro-magnetic cores is retentivity; that is that the magnetic flux does not completely disappear when the current stops flowing in the coil in either direction and the magnetic field strength is returned to zero (b and e). The reason for this is that the tiny magnetic domains of the core material do not return to a random pattern, but rather retain some orientation of the magnetic field previously applied. This residual magnetism is also called remanence. To remove the remanence, a negative field strength (i.e. current) must be applied down to a level called the coercive force (c or f).

If the current flows in the negative direction, the same phenomena occur, but in the opposite direction. The resulting total B-H curve thus forms a loop with double crossings of each axis for remanence and coercive force, as well as saturation events in each end. This looped curve is called the magnetic hysteresis curve.

If an electrical transformer was operated from saturation point to saturation point, it would move along the magnetization loop with one turn for each power cycle (a-b-c-d-e-f-a-b-c…). A transformer is however, under normal circumstances, never magnetically saturated as saturation means total loss of transformation ability; beyond saturation it does not function as a transformer and all extra power input is lost. Normally, the maximum magnetization of the core stays within 90 % of saturation. The magnetic status of the core thereby moves along a smaller hysteresis loop of similar shape and components inscribed in the larger saturation-to-saturation loop. The work done to overcome the coercive force for each AC cycle is one of the components of core losses in transformers. Modern core materials are therefore designed to have very low hysteresis: the loop is very thin. The core materials are also designed to be able to conduct high magnetic flux: the loop is very steep.

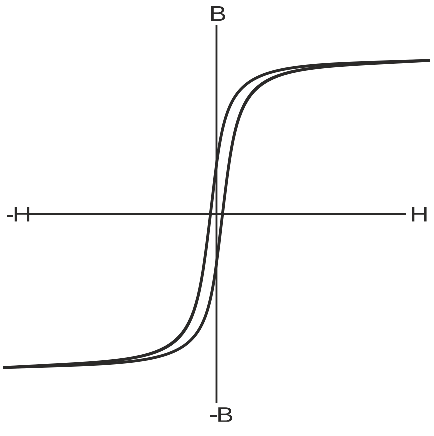

Figure 2: Typical magnetization curve for transformer core

Remanence due to switching operations

If the transformer is taken out of service, the magnetization status of the core is determined by the momentary position of the AC cycle; a positive last voltage half-cycle will yield a positive remanence and a negative last half-cycle a negative remanence. The exact status can be seen

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as more or less random as the disconnection event rarely is synchronized with the AC cycle.

Remanence and DC winding resistance measurement

During winding resistance measurement (WRM), a DC current of some 1-10 % of the nominal current is injected into the winding and a resistance reading is taken by means of measuring the voltage over the winding. The current shall be large enough to saturate the core, i.e. eliminate any inductive components of the impedance, but not so large that it heats up the winding through resistive losses and thereby affects the resistance value.

The DC current used during WRM thus pushes the magnetization status of the core to the right in the magnetization curve, past the point of saturation (or left, if the current is applied in reverse). After a winding resistance measurement when the current is turned off, the core of a transformer is, therefore, always left magnetized to the level of the core material retentivity.

Other sources of remanence

The transformer core may also be magnetized due to geomagnetic phenomena, much in the same way as certain minerals exhibit natural magnetization.

3. Effects of residual core magnetization

When a transformer is energized, the momentary position in the applied AC cycle is just as random as when the transformer was disconnected; If the polarity of the first voltage half-cycle has the same polarity as the remanence in the iron core (left from the preceding half cycle when the transformer was taken out of service or from WRM) a larger than normal current will flow into the transformer, possibly for several AC cycles, as no work is needed to overcome the remanence.

This phenomenon is called the in-rush current and could potentially be harmful to transformers as it increases both thermal and mechanical stresses. Most transformers are, however, designed to withstand even short circuiting, so the influence of an increased in-rush current itself can be seen as acceptable. Smaller transformers are generally more resilient to high in-rush currents, or even short circuiting, as their mechanical design is more compact and the forces at play are much smaller.

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The in-rush currents may, however, cause problems if the transformer is connected to a network where protective relays are used; the in-rush current could be interpreted as the start of an adverse event and the relay will trip to protect the transformer and possibly other energized parts of the grid, something that may result in costly power outages. Typically, only larger transformers are fitted with network protective measures as their proper function is essential for large portions of the network and that they represent high financial value. Inversely, smaller transmission and distribution transformers are less critical and also less valuable. It can, therefore, be argued that proper demagnetization is very important for larger transformers, but less so for smaller; for transformers under a certain size or far out in the electrical network, demagnetization is probably not needed at all.

Another effect of remanence is that consequent measurements could yield erroneous results; measurements such as SFRA (Sweep Frequency Response Analysis), magnetic balance and excitation current are all affected. Therefore, it is in international standards recommended to, in a series of different measurements, first do WRM, perform a proper demagnetization and only then continue with other measurements.

4. Demagnetization

The principle of demagnetization is simple; the residual magnetism of the transformer core should be brought to zero by overcoming the coercive force. This can be accomplished by a number of methods.

The first method is to ramp diminishing alternating current up and down to one of the windings. For most transformers, due to high voltage ratings involved, this method is impractical and involves safety hazards.

Another method is to use an alternating direct current. The principle of this method is to neutralize the magnetic alignment of the core iron by applying a direct voltage of alternate polarities to the transformer winding for decreasing intervals. The alternating DC injection is reduced for each cycle with typically 10 to 50 % and the process is continued until the current level is “zero”. On three-phase transformers, the usual practice is to perform the procedure on the HV phase with the highest exciting current reading [1]. In most cases, experience has demonstrated that this procedure is sufficient to demagnetize the whole core.

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This method is used in Megger MTO210 and 250 where the injected current automatically decreases according to the pattern: +100 %, -100 %, +20 %, -20 %, +4 %, -4 %, +1 %, -1 %. In MTO106, the process is similar, but the user has to manually select decreasing current settings (from the measurement current down to the lowest selectable) and swap the terminals between each current setting. The current in each step should reach at least 50 % of the set value. A typical current pattern could be: +6 A, -1 A, +100 mA, -10 mA, +1 mA. For all three instruments, the energy in the winding is automatically discharged between current cycles.

A variant of the above is to inject voltage and measure volt-seconds for each cycle and decrease the energy applied to the winding with typically 10 to 50 % for the next cycle. In practice, this becomes a Constant Voltage Variable Frequency method (CVVF).

A generic algorithm to demagnetize the core using CVVF is:

- Inject a start current that is high enough to saturate the core and then discharge the winding.
- Inject the current, but with negative polarity and at the same time, measure applied voltage and time needed (i.e. Vs) to reach the negative start current. Discharge.
- Inject current with positive polarity again until 80 % of the Vs in the previous cycle have been achieved. Discharge.
- Repeat until the Vs reach a reasonably low level.

With this method, which is automated in TRAX, it is also possible to calculate initial and resulting magnetization as % of saturation.

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5. Effectiveness of demagnetization

To test the effectiveness of the different demagnetization methods, WRM at 1 A is performed between phase A and C in a 500 kVA transformer in delta configuration (Primary: 10.9 kV / 26.5 A and secondary: 400 V / 721 A) with TRAX, MTO210 and MTO106. After the test, the core is demagnetized and the remanence is checked using the TRAX.

Instrument	Remanence after WRM @ 1 A	Remanence after demagnetization	Time needed for demagnetization
TRAX	52,9 %	< 1 %	15 s
MTO210	53,4 %	< 10 %	90 s
MTO106	52,86 %	< 10 %	120 s. 4 current levels at 15 s each plus time to swap the terminals between current levels.

The TRAX has by far the most efficient demagnetization process, but the MTO210 and MTO106 also perform well, the biggest difference being that the MTO106 requires swapping of the terminals between injection of the different current levels.

To further check the effectiveness of the demagnetization procedures, SFRA measurements using FRAX are done prior and after demagnetization for each instrument. Any residual magnetization can generally be seen as an elevation of the SFRA curve at lower frequencies.

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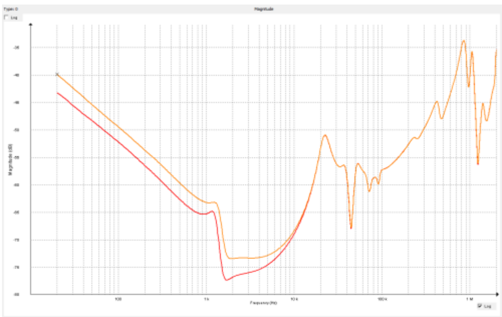

Figure 3: TRAX – before (top) and after (bottom) demagnetization

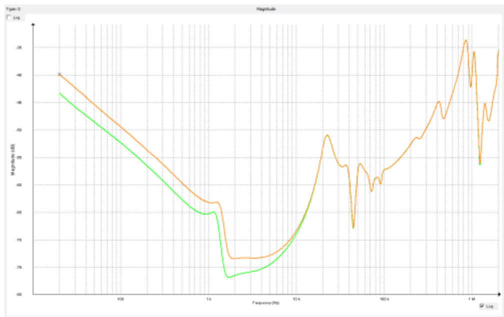

Figure 4: MTO210 - before (top) and after (below) demagnetization

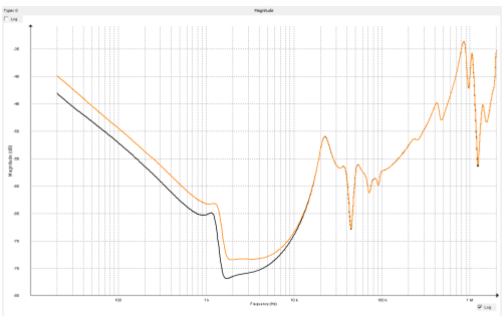

Figure 5: MTO106 - before (top) and after (below) demagnetization

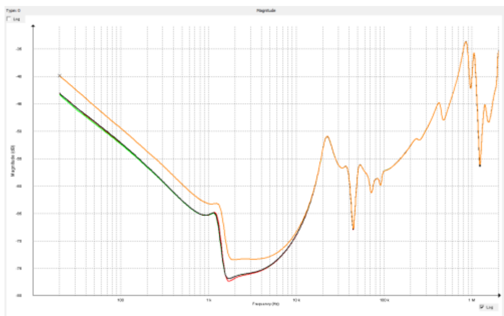

Figure 6: Composite view - before (top) and after (below) demagnetization

As can be seen in the composite view, the SFRA curves after demagnetization are virtually identical for all three instruments, meaning that all methods yield equally good results. There are tiny differences in the curves, but they can just as easily be attributed to the dis- and reconnection of FRAX terminals between the test runs.

6. Summary

- Residual magnetization in the transformer core can cause unwanted in-rush currents that could harm the transformer and trip protective relays in the network.
- For most smaller transformers, demagnetization can be left out as they generally are more robust and used in the distal regions of the electrical network where no protective components are used.
- The larger the transformer, the more important it is to perform a demagnetization after WRM. Assets critical to the larger network should always be demagnetized.

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- Megger instruments for DC WRM all provide effective methods for demagnetization.

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