On –site Power Transformer demagnetization

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Technique for on-site demagnetization of power transformers using a portable device, basics and validation by frequency response analysis

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Abstract:. After a power or distribution transformer is disconnected from the power grid or when a DC current is applied to it, for example during a routine winding resistance measurement, the transformer core is likely to have some remnant magnetism. This remnant magnetism will generate high over currents when the transformer is reconnected to the grid, and this is commonly known as transformer Inrush Current. This Inrush current, which runs for a few cycles, reaches a maximum when the polarity of the half cycle is the same as the polarity of the remnant magnetism, and could damage the transformer itself, or other components connected to it. To avoid this undesirable effect the transformer should be demagnetized before being reconnected to the grid by applying an AC voltage and reducing it slowly. The dimensions and price of the necessary high voltage three phases AC power supply to do so make this task on site almost impossible. The method presented in this paper shows the possibility of demagnetizing a transformer using a special iterative method and a small power supply.

Frequency response of a transformer will show a discernible displacement of the first minimum if the transformer is still magnetized. So frequency response can be considered a very sensitive and reliable method of validating proper demagnetization. Frequency response measurements using a three phase power supply and the new technique for demagnetizing a transformer are analysed to validate the new technique.

1   INTRODUCTION

An ideal transformer is based on two principles; a variable electric current produces a variable magnetic field; and this variable magnetic field produces a voltage across the ends of the coil. For better coupling of the two effects a ferromagnetic material is used for transferring the magnetic flux from one to the other (fig 1)
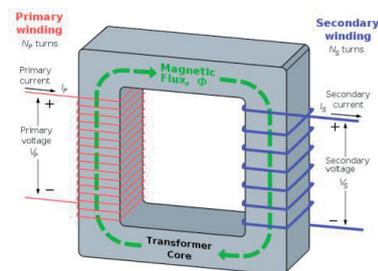
Fig 1. Transformer function sketch

Figure 2 shows this relation for a normal grain oriented magnetic steel used for the manufacturing of power transformers, it can be noticed that the flux density increases in proportion to the field strength until it reaches a certain value where it cannot be increased any more (saturation status).
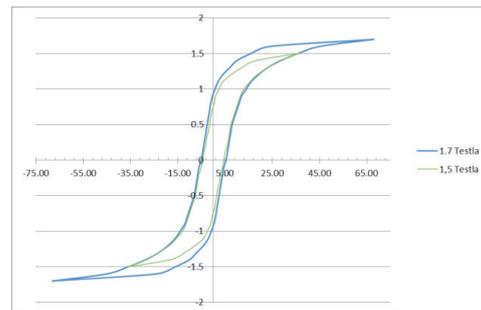
Figure 2: Hysteresis loop of grain oriented magnetic steel

The effect of magnetic hysteresis shows that the magnetisation process of a ferromagnetic core and therefore the flux density depends on which part of the curve the ferromagnetic core is magnetised in, as this depends upon the circuit's past history giving the core a form of "memory". However, soft ferromagnetic materials such as iron or silicon steel have very narrow magnetic hysteresis loops resulting in very small amounts of residual magnetism.

The hysteresis loop affects in two main ways; When the transformer is in service, it generates losses(That's why the area inside the hysteresis loop should be kept as small as possible). when transformer is disconnected from the grid, the real

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status of the magnetic core is unknown due to the remnant magnetism.

If a DC current is applied to the transformer, while measuring winding resistance for example or for any other reason, the transformer will be magnetized and therefore when the DC power supply is disconnected, the transformer will stay in an unknown state defined by the remnant magnetism of the transformer.

This unknown state can generate different problems, some of them are well known.

1. Inrush current while reconnecting the transformer
2. Wrong ratio measurement results
3. Wrong FRA (frequency response analysis) measurement results

Demagnetizing the transformer, (removing any remnant magnetism), thus would avoid the above undesirable effects.

The known technique to demagnetize the transformer is to apply an AC voltage to the LV or Tertiary winding of enough amplitude (110% of nominal) to saturate the transformer and then reducing the voltage slowly. This procedure is cumbersome and not feasible on-site because of size and weight considerations of the necessary 3 Phase power supply.

2 INRUSH CURRENTS

2.1 On a demagnetized transformer

The inrush current is described as the overcurrent that appears at the transformer input when the transformer is connected to the grid from steady state conditions. It can be easily described based on the basic transformer equations. For a sinusoidal voltage it would be.

$$e = E \sin \varpi t = \frac{d\Phi}{dt}$$

$$\Phi = \int e dt = E \int \sin \varpi t dt$$

$$\varphi' = \left(Vm / \varpi\right) \int_0^\Pi \varpi \sin \varpi t dt$$

$$\varphi' = \varphi_m \int_0^\Pi \varpi \sin \varpi t dt = 2\varphi_m$$

$\varphi_m = Maximum\ flux\ in\ normal\ operation$

From above equations, it can be deduced that the maximum flux after half a cycle when starting from steady state condition is 2 times the flux in normal operation.

As we already noticed, the flux density increases in proportion to the field strength in a non linear manner, reaching a maximum (saturation status) and becoming an almost horizontal line. Figure 3 shows the relation between voltages and currents in permanent cycle and during the transformer's first connection. The non-linear behaviour of the magnetization curve introduces an overcurrent while switching whose maximum will be defined by the slope of the magnetization curve.
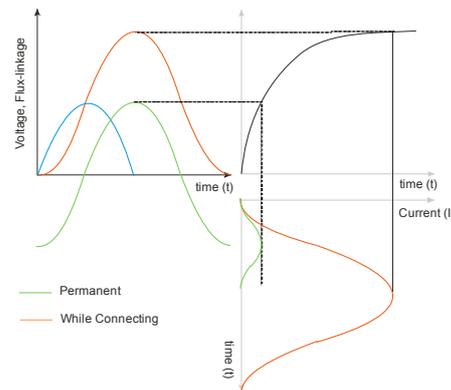
Figure 3: Voltage-currents while connecting and in permanent cycle

2.2 On a magnetized transformer

The magnetic material used for manufacturing the transformer's cores include this "memory" effect, which also influences the inrush current, increasing it drastically when remnant magnetism is opposite to the supposed value in normal operation. Fig 4 shows the particular condition.
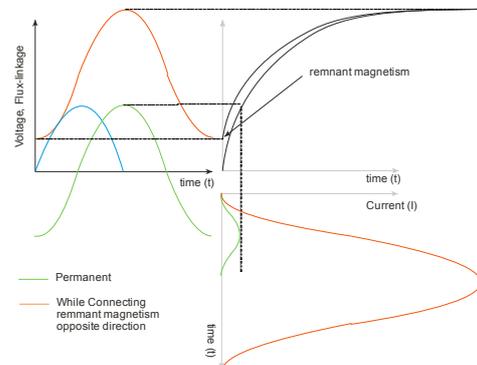
Figure 4: Voltage-currents while connecting and in permanent cycle, remnant magnetism opposite direction

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2.3 Starting complete transient

The inrush current transient occurring at the energization is damped as the transformer shifts to continuous operation phase.

Bertagnolli and Spetch developed mathematical formulae to calculate the envelope of this damped effect, while Holcomb proposed an improved analytical equation. These equations are commonly used by transformer manufacturers who normally adjust some experimental parameters, based on their experience, to calculate the inrush currents during connection.

Figure 5: Inrush current transient behaviour

3 EFFECTS ON OTHER PARAMETERS

3.1 Turns ratio

Turns ratio of power transformers is normally measured by applying some voltage to one or more phases, and measuring the voltage at the other winding. Voltages used for this measurement are normally in some tens of volts, and although it is an AC voltage, it is not enough to remove the remnant magnetism.

This remnant magnetism will affect the ratio measured as it moves the core to a less linear part of the magnetizing curve.

3.2 Frequency response analysis

Frequency response is the quantitative measure of the output spectrum of a system or device in response to a stimulus. It is a measure of magnitude and phase of the output as a function of frequency, in comparison to the input.

The normal implementation of this test is based on impressing a variable frequency sinusoidal signal and measuring the magnitude and phase at the other side of the element measured.

A transformer can be considered as a complex network of inductances and capacitances, and this network depends mostly on mechanical/electrical parameters, the frequency response of a particular

transformer acts as a fingerprint of this transformer and should remain the same during its life.

The interpretation of FRA results is based on the comparison of the fingerprint over time and therefore any parameter that could have an influence on the curve has to be avoided as this could inadvertently be understood as a transformer problem.

Remnant magnetism in the transformer core decreases its inductance values. The change is normally reflected in the position of the first minimum in the FRA results. Using PSPICE with a transformer equivalent circuit, 2%, 5% 10% and 20% inductance changes have been applied to the circuit, Figure 6 shows the results of these simulations.
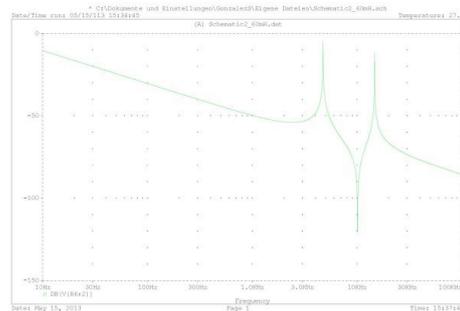
Inductance variation	f (min)
L	10'209 Hz
L (+ 2%)	10'116 Hz
L (+5%)	10'000 Hz
L (+10%)	9'770 Hz
L(+20%)	9'550 Hz

Figure 6: Variation on FRA first minimum by inductance changes

From the results of the above simulations, it is clear that FRA test is very sensitive to remnant magnetism.

It is also important to state that remnant magnetism will move the FRA first minimum to the right side (higher frequencies) as lower inductances are involved.

4 DEMAGNETIZATION

4.1 Background

As described before, demagnetizing a transformer is of major interest as it avoids several negative effects (some of them described above). Due to the power supply needed to perform the demagnetization by using the traditional method

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(applying an AC voltage and reducing the same slowly) the necessity of a portable device to allow the demagnetization on site increases. Several approaches were then taken into consideration to develop this function.

The method consists of two sub procedures, analysing the transformer by applying some power and an iterative reduction of the remaining magnetization by using a computerized algorithm. Since it is an iterative process multiple cycles are necessary.

5   METHOD VALIDATION USING FRA TEST

5.1 Demagnetization validation procedure description

A Three phase YYn 12,5MVA power transformer was used for the validation of the new demagnetization procedure. The FRA measurement has been selected as validation test because of its high sensitivity to remnant magnetism.

Procedure for the validation is described below.

1. No load losses test; applying voltage on the LV side, and slowly reducing to remove any remnant magnetism.
2. FRA test on the HV side of the transformer between Phase A and B.
3. High DC current applied to magnetize the core.
4. Repetition of the FRA test on same phase.
5. Demagnetization algorithms used on the transformer
6. Repetition of the FRA test on same phases.

5.2 Demagnetization algorithms validation

Figure 7 shows the results of the demagnetization algorithms.

	Demagne-tized	After resistance test	After demagnetiza-tion
U - V	Green trace	Red trace	Blue trace
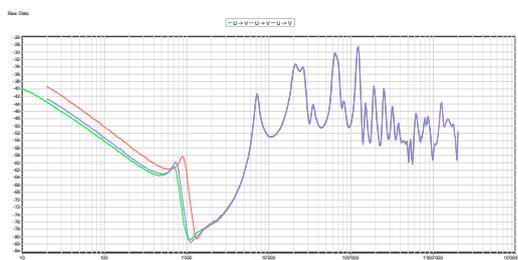
As expected FRA trace moves left, back to the original status after application of the demagnetization algorithm.

6   CONCLUSIONS

This paper shows the importance of a proper demagnetization of a power transformer before connecting to the power grid (due to inrush currents), and before conventional maintenance tests are done (especially frequency response analysis and turns ratio), as unreliable measurements could be collected as a result of remnant magnetism.

The FRA test has been described as the most sensitive test to detect this unwanted effect and it has been used to validate the new procedure.

From the results of the validation, it can be concluded that the new procedure, implemented in a small portable device (18 kg), allows a reliable demagnetization of the transformer.

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