

# Elimination of Residual Flux in Transformers by the Application of an Alternating Polarity DC Voltage Source

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**Abstract**— The paper presents the experimental verification of a power electronics device for demagnetizing transformers. Laboratory and field tests on single- and three-phase transformers demonstrate that the residual flux is eliminated. The purpose of demagnetizing is twofold: (1) to reduce the inrush currents when transformers are energized; and (2) to make sure that the FRA (Frequency Response Analysis) tests are consistent to avoid false diagnoses of damage during transportation. A nearly complete demagnetization was observed in the laboratory for a small single-phase isolation transformer. The results of demagnetizing an 80 MVA transformer in the field are also presented. The method proposed in this paper is applied to three-phase transformers with different core configurations and connections. Topologically correct modeling and numerical simulations confirm the full demagnetization of all the branches of three-phase (three- and five-limb) transformer cores. Inrush current measurements and FRA plots before and after demagnetization confirm the effectiveness of the process.

**Index Terms**—Demagnetization, FRA, inrush currents, residual flux, transformers.

## I. INTRODUCTION

**I**NRUSH currents often emerge when a transformer is energized. Depending on the transformer parameters, this transient phenomenon may last for a few cycles or seconds [1]-[4]. The magnitude of the inrush currents depends on the phase angle of the applied voltage, winding resistance, the air-core inductance of the energized winding, and the residual flux in the core. The worst scenario for inrush currents happens when the core has residual flux and the switching occurs at voltage zero-crossing in the direction that builds flux in the core. Under this condition the transformer core goes into super saturation [5]-[9]. Hence, to avoid large inrush currents transformers can be demagnetized before energization.

As a diagnostic tool, FRA (Frequency Response Analysis) tests are performed on large power transformers in order to detect early defects such as core movement or deformation. Different ranges of the frequency spectrum correspond to de-

fects associated with the core, windings, bushings, or connections [10]. The low frequency region of the FRA is very much affected by the magnetizing status of the core [11]. The last test in factory, performed after FRA, is the *dc* winding resistance test, which may leave the transformer core magnetized [12]. If the core is not properly demagnetized, the footprint of the FRA performed at the installation site is different than the one performed in the factory. This could be mistaken as a possible winding movement during transportation. Examples can be found in the CIGRE working group report [10]. Therefore, demagnetization of large power transformers in the field has become routine after performing the *dc* resistance tests on the windings.

A method to reduce residual flux in the core was presented in [13] using an ultra low frequency power source. In [13] the effectiveness of the method was illustrated with numerical simulations using the EMTP. Following a short-circuit, a set of transformers in a feeder were demagnetized before re-energization. Substantial reduction in the magnitude of the inrush currents was obtained.

This paper presents the demagnetization results obtained experimentally with a laboratory prototype of the power source proposed in [13]. Laboratory tests are conducted on an isolation transformer of 1 kVA, 120 V. It is demonstrated that one can successfully monitor the demagnetization process of the transformer by plotting the  $\lambda$ -*I* curve. Results are verified by measuring the inrush currents drawn when the transformer is energized at voltage zero-crossing through a controlled switch. In addition, it is shown by topological modeling in the EMTP that the technique works well for three-phase transformers with various core constructions and winding connections.

The paper also presents experiences accumulated with commercially available demagnetizers tested and used on transformers of up to 1100 MVA rated power and 1000 kV nominal voltage [14].

## II. AVAILABLE DEMAGNETIZING TECHNIQUES AND THEIR PERFORMANCE ON LARGE TRANSFORMERS IN THE FIELD

The demagnetization of transformer cores can be performed in several ways as discussed in [13]: (1) Variable Voltage Constant Frequency (VVCF) source; (2) Constant Voltage Variable Frequency (CVVF) source; (3) Decreasing the amplitude of an alternating *dc* current, which is a variation

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