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Test instrument for the automatic compliance check of cast resin insulated windings for power transformers

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ABSTRACT

In this paper a new instrument specifically designed for the compliance check of windings for Medium Voltage/Low Voltage (MV/LV) cast resin insulated power transformers is presented. The proposed instrument, based on the SFRA (Sweep Frequency Response Analysis) measuring technique, has been designed to carry out automatic measurements during the industrial production of the windings. In this paper the main hardware and software instrument features are presented, with particular consideration of the algorithm adopted for the compliance check. Finally, results obtained during both the lab instrument characterization and the on-field validation at the BTicino winding production factory is also presented.

1. Introduction

Dry type cast resin transformers are used in a vast range of medium voltage power systems. For confirming the specifications and performances of an electrical power transformer it has to go through some testing procedures, as type tests (done in a prototype unit of a lot to verify the specifications), routine tests (for confirming operational performance of every manufactured unit) and special tests (done as per customer requirements). At the manufacturer site the resin transformer is generally tested when entirely assembled. It the test fails, up to ten hours are needed for disassembling the machine and repair the fault. Since frequent causes of non-compliance are caused by flaws in the windings, the on line winding quality control during the industrial production process makes possible to intercept any winding non-compliance before mounting it, lowering production time and cost.

There are so many reasons that suggest for early testing of transformer components during the production cycle. In addition to standard diagnostic techniques [1,2] (analysis of partial discharges, monitoring of over temperature, analysis of vibration and acoustic noise, measurement of insulation resistance), the diagnostic techniques based on the injection of a low-voltage test signal into the machine terminals and on the acquisition and processing of output signals have emerged as promising approaches to providing enhanced test performances. These very reliable and sensitive techniques mainly evaluate the inductive and capacitive reactances at different frequencies, whose changes are mainly produced by mechanical deformation of core or windings or resin defects. They can detect transformer core displacements, winding deformations and displacements, faulty core grounds, collapse of partial winding, broken or loosen clamp connections, short circuited turns, open winding conditions and other defects.

In this paper, a low-cost compact instrument for the on line quality control of cast resin transformer windings is presented. The instrument analyses the winding response to a variable frequency sinusoidal input, applying the SFRA (Sweep Frequency Response Analysis) technique [3–7]. SFRA is a special test generally carried out at the end of the transformer assembly process by acquiring the frequency response of each winding that is compared with that of a new and healthy machine. Any deviation between the two responses reveals damages or incoming faults. It is also possible to evaluate the deterioration of a winding by repeating the SFRA over time. The IEC 60076-18 standard [8] imposes manufacturers to add SFRA test results to the transformer test report,

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starting from June 2012. Our proposal in this paper is to apply this technique to test a single winding before the final assembly of the transformer.

On the market is it possible to find a number of SFRA measurement instruments, even if they are generally oriented to the noncompliance analysis of the overall assembled transformer. On the contrary, the on-line test of a single winding in an industrial environment requires: a special measurement setup, a customized measurement algorithm, higher measurement speed, compactness and versatility, a particular noise immunity, as well as ability of managing measurements for different typology of windings.

Before starting this research activity, we investigated the application of a SFRA based technique to unmounted transformer windings. The first measurements have been performed with a test system based on general purpose instruments, with the aim to investigate its applicability to this particular application, obtaining promising results [6,9].

After this positive step, a special instrument has been developed within cooperation between the Department of Industrial and Information Engineering and Economics of the University of L'Aquila and the BTicino Legrand group, a leader manufacturer of cast resin transformers operating in the plant of Castellalto, Italy. The instrument allows quality assessment of each winding to be carried out by means of an automatic procedure [10].

This paper is focused on the description of instrument hardware and software architecture and of the specific measurement algorithms. The first experimental results obtained testing a wide range of medium voltage and high voltage windings in the BTicino factory are also shown.

2. The proposed instrument

2.1. Windings measurement setup and requirements

SFRA measurements on a winding are performed by applying (and measuring) an input sinusoidal signal between one winding terminal and ground, and measuring the output signal between the other winding terminal and ground, as shown in Fig. 1. The measurement setup requires three coaxial cables for connecting: (i) the signal generator output to the input terminal of winding under test; (ii), the winding input terminal to the first data acquisition channel (V_{in} in Fig. 1); (iii) the winding output terminal to the second data acquisition channel (V_{out}). A 50 Ω resistance is inserted to adapt the input channel impedance with the output generator impedance. Normally the SFRA tests were conducted by considering the transformer core as equipotential reference surface. In our case, in the absence of the core, we referred the signals to an external ground plate which special geometry ensured the required measurement repeatability.

According to [11] the required specifications of measuring system are: (i) accuracy of V_{out}/V_{in} ratio better than ±0.3 dB, in the interval from +10 dB to −40 dB; (ii) accuracy of V_{out}/V_{in} ratio better than ±1 dB, in the range from +10 dB to −80 dB; (iii) accuracy of V_{out}/V_{in} ratio better than ±0.3 dB, in the range from +10 dB to −40 dB; (iv) maximum signal bandwidth of 10 Hz for frequencies below 100 Hz and less than 10% of the measured frequency above 100 Hz; (v) phase measurement accuracy better than ±1° in the range from +10 dB to −40 dB; (vi) input voltage up to 50 V_{pp}; (vii) characteristic impedance of 50 Ω and less than 0.3 dB attenuation at 2 MHz for input and output coaxial cables; (viii) 50 Ω ± 2% for the generator internal impedance, data acquisition input impedance and cable characteristic impedance, for the entire measuring range.

The required signal frequency range was experimentally set from 20 Hz to 2 MHz, to be able to reveal most common winding production defects. Test duration must not exceed 90 s, in order to be suitable with the industrial process needs. Tables 1 and 2 and synthetize the main specifications for signal generation and acquisition sections.

2.2. Instrument hardware architecture

To reduce the cost, the proposed instrument has been implemented adopting a COTS-based (commercial off-the-shelf) approach. A Picoscope 5442B (a 4-channel oscilloscope including an arbitrary waveform generator) has been used for both signal generation and acquisition. It has been connected via USB to a PCLOG 8SC fanless PC, rugged for the use in industrial applications and equipped with the Microsoft Windows embedded operative system. The measurement program, developed in the NI LabVIEW environment [12,13], manages the Picoscope and executes all the signal processing routines. Fig. 2 shows the proposed instrument architecture.

The PCLOG sets the generator to apply a 4 V peak-to-peak sinusoidal voltage to the DUT. Signal frequency gradually increases through discrete values, which are pre-loaded into an array stored in the test configuration file. The PCLOG also sets the Picoscope channels A and B to acquire input V_{in} and output V_{out} voltages, with a 15-bit ADC resolution.

Signals, sampled at 60 MSample/s, are initially stored in the 16 MS internal buffer and successively transferred to the PC at 10 MS/s.

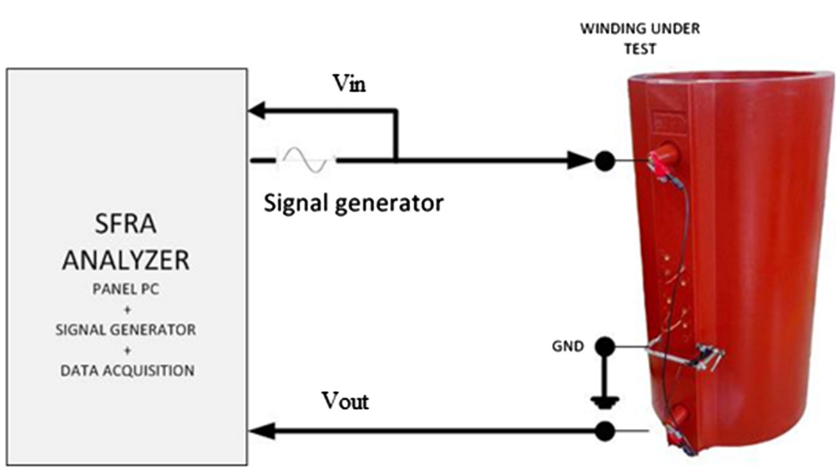

Fig. 1. Block diagram of connection setup.