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Current state of transformer FRA interpretation

Patrick Picher[a]*, Stefan Tenbohlen[b], Mark Lachman[c], Alaor Scardazzi[d], Poorvi Patel[e]

On behalf of CIGRE WG A2.53

[a]*Hydro-Québec Research Institute,180, boulevard Lionel-Boulet, Varennes, Québec, Canada, J3X 1S1*
[b]*Universityof Stuttgart, Pfaffenwaldring 47, 70569 Stuttgart, Germany*
[c]*Doble Engineering Company, 85 Walnut Street, Watertown, MA 02472, United States*
[d]*Siemens, AV. Eng. Joao F.G. Molina, 1745 13213-080 – Jundiai – SP, Brazil*
[e]*ABB Inc., 4350 Semple Avenue, St.Louis, MO 63120-2241, United States*

Abstract

Measurement of the frequency response, from a few Hz to a few MHz, is now commonly used in the transformer industry for the condition assessment of transformer windings and has demonstrated its sensitivity for detecting various mechanical and electrical failure modes. The present generally applied practice for interpretation is visual comparison of frequency responses, either with a previous measurement on the same or an identical unit, or between the phases of a three-phase transformer. Examples of curve comparison for typical mechanical and electrical failure modes have previously been published in CIGRE and IEEE guides. Over the last 15 years, numerous technical papers have been published regarding the interpretation of the results in an aim to make it more objective and quantitative. In 2016, CIGRE initiated a new working group titled "Objective interpretation methodology for the condition assessment of transformer windings using Frequency Response Analysis (FRA)". This paper, written on behalf of the new working group, reviews the basics of FRA interpretation and summarizes the state-of-the-art regarding the potential methods that can be applied to achieve a more objective and quantitative interpretation of the results.

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Keywords: Transformer; Frequency Response Analysis; FRA, diagnostics.

* Corresponding author. Tel.: +1-450-652-8256.
E-mail address: picher.patrick@ireq.ca

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1. Introduction

The Frequency Response Analysis (FRA) method, initially introduced by Dick and Erven [1], is used to assess the mechanical and electrical condition of transformer windings. The measurement can be applied to assess the condition after a through fault, damage following a component failure (bushing or tap changer) or damage during transportation. The method has recently been studied at the international level in various IEEE, CIGRE and IEC working bodies. The generally accepted methodology for analyzing the data is to visually compare the measurement of the frequency response on a transformer with a previous measurement on the same unit, a measurement on an identical unit or comparison between the phases (or limbs) of the same unit.

Even if the frequency-response measurement technique is now mature, there is still a need in the transformer community to obtain more guidance on the interpretation of the results. To that end, CIGRE initiated in 2016 a new working group (A2.53) with the objective to study the feasibility of developing an objective interpretation methodology for FRA that can be generally accepted and be used, for instance, as a pass-fail criterion for short-circuit testing.

This paper, prepared on behalf of CIGRE WG A2.53, summarizes the current state of frequency response measurement and interpretation and reviews some quantitative approaches that can be applied to achieve a more objective interpretation methodology.

2. Basics of the measurement of frequency response and the sensitivity to winding damage

The frequency response is measured using a low-voltage signal supplied to a terminal with respect to the tank. Even if the frequency response measurement can be obtained via an impulse and then transformed from the time domain to the frequency domain, the more commonly used approach is to use a variable frequency sinusoidal source, i.e. the so-called swept frequency response. As illustrated in Fig. 1, a voltage is measured at the input terminal (V_{in}) and a second voltage signal (the response signal) is measured at a second terminal (V_{out}). Both V_{in} and V_{out} are measured across an impedance of 50 Ω to match the characteristic impedance of the coaxial cables and avoid reflections. The amplitude of the frequency response is the scalar ratio between V_{out} and V_{in} (given in dB). The phase of the frequency response is the phase difference between V_{in} and V_{out} (given in degrees). Although both the amplitude and phase of the voltage ratio are recorded during frequency response measurements, generally only the amplitude information is reviewed and used for visual interpretation of the result. The logarithmic frequency scale is often used to show the complete frequency range or specific frequency bands.

The sensitivity of the measurement for detecting winding damage relies on the fact that the geometry is closely related to the distributed self- and mutual inductances and capacitances between conductors, disks and layers of the windings, which characterize the many series and parallel resonances in the frequency response. If there is a mechanical displacement, e.g., axial or radial displacement of conductors, the resonance frequencies will be shifted and the damage can be detected by a comparison between the measurement on the damaged winding with a reference measurement on a winding (same or identical) in good condition. The reference measurement could be from the factory baseline or a previous measurement performed in the field before failure.

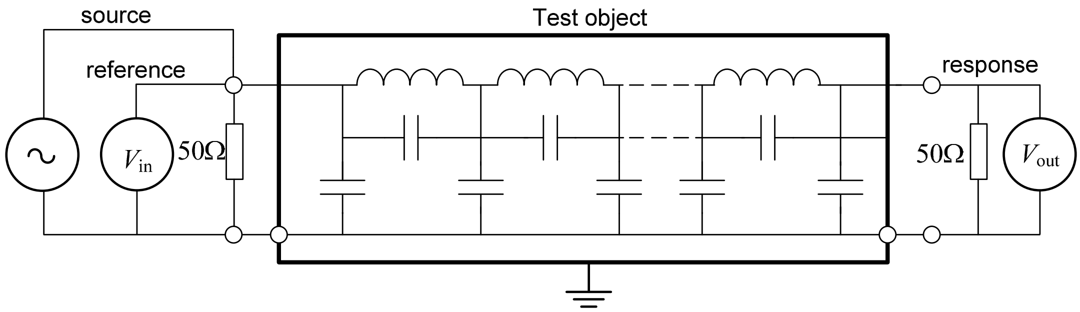

Fig. 1. Basic frequency measurement circuit.