Chapter 12
Detection of Transformer Faults Using Frequency Response Analysis with Case Studies

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ABSTRACT

Power transformers encounter mechanical deformations and displacements that can originate from mechanical forces generated by electrical short-circuit faults, lapse during transportation or installation and material aging accompanied by weakened clamping force. These types of mechanical faults are usually hard to detect by other diagnostic methods. Frequency response analysis, better known as FRA, came about in 1960s (Lech & Tyminski 1966) as a byproduct of low voltage (LV) impulse test, and since then has thrived as an advanced non-destructive test for detecting mechanical faults of transformer windings by comparing two frequency responses one of which serves as the reference from the same transformer or a similar design. This chapter provides a background to the FRA, a brief description about frequency response measuring methods, the art of diagnosing mechanical faults by FRA, and some case studies showing typical faults that can be detected.

INTRODUCTION

Background

Power transformers are so designed that they can withstand mechanical stresses in the course of their lifetime. Enormous mechanical force generated by short-circuit faults is by far the main cause of mechanical deformations or displacements of the core and the windings structure of power transformers. A comprehensive mechanical force/stress analysis of transformer windings and how each stress component causes different mechanical failure modes can be found in Vecchio, Poulin, Feghali, Shah and Ahuja (2002) and Kulkarni and Khaparde, (2004). The main causes for transformers being mechanically stressed out of service are lapse in transportation and mishandling in the course of an installation.

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Over the past few decades, a number of diagnostic tools have been developed for monitoring the health of transformers in order to take remedial actions in time before a catastrophic failure occurs. Among others, off-line leakage or short-circuit impedance measurement, which is a single value measurement at the network frequency, had been the recognized tool for tracking down mechanical deformations and displacements of transformer windings. This method has its own standard measurement procedure and an interpretation method stipulated by both IEC and IEEE standards (International Electrotechnical Commission [IEC], 2004; The Institute of Electrical and Electronics Engineers [IEEE], 1995). It is customary to perform a short-circuit impedance measurement during the factory acceptance test in order to ascertain the value that the transformer is designed for, which is later available on the nameplate as a percentage value. In the field when performing diagnostic testing or routine maintenance testing of power transformers, the short-circuit impedance measurement is often in the list of the measurements to be performed as it is either requested by the customer or suggested by the measurement and diagnostic provider. Despite its widespread usage, it is a well-known fact that the leakage impedance is primarily sensitive to significant deformations or displacements of the main duct or the channel in between the primary and the secondary windings where most of the leakage magnetic flux flows. Over the last two decades, the frequency response analysis has gradually gained a reputation for being able to detect wide varieties of mechanical and some of the electrical faults; for example, an axial deformation of a winding is hard to distinguish in the 50/60 Hz leakage reactance measurement, while FRA has a successful history of detecting such faults.

FRA emerged in the 1960s as a byproduct of LV impulse test performed in factories (Lech & Tyminski, 1966). Since then, frequency response analysis of transformers has been developed substantially, today being considered a mature test technique performed by dedicated FRA instruments. FRA is a comparison based test technique, where a frequency response measurement of a transformer is compared with a reference measurement, which could be from the same unit measured at an early stage, twin/sister unit or an another phase of the same transformer. In case of no reference measurement from the same transformer or twin/sister unit is available; the phase comparison is the only option which is often the case for old transformers. Today, FRA measurements are predominantly carried out by dedicated instruments most of which employ the swept frequency method and only a few follow the impulse response method. Despite the FRA being an off-line test technique as yet, performing the FRA on-line, (i.e., recording transfer function while a transformer is in operation) has been under investigation and growing number of attempts have been reported (Leibfried & Faser, 1994, 1999; Coffeen, McBride, Cantrelle, Mango & Benach, 2006; Wimmer, Tenbohlen, & Faser, 2007).

Scope of this Chapter

First, this chapter presents a background of the FRA measuring techniques and then the central discussion of this chapter; detection of faults by FRA followed by the challenges experienced at present. Towards the end of the chapter is a short section about the future trend in the FRA research field, especially on-line FRA. The chapter ends with a section on conclusive remarks.

FREQUENCY RESPONSE MEASUREMENT OF TRANSFORMERS

Transfer Function

A transfer function is generally defined as the input-output relationship of a linear time-invariant system with zero initial conditions. For a linear

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