Changes to the Vibration Response of a Model Power Transformer with Faults

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Current vibration-based techniques for transformer condition monitoring mostly rely on the vibration response caused by operating excitations, which consist of electrical excitations from the core and winding. Therefore, it is worthwhile to study the electrically-excited frequency response function (FRF), as it carries information of transformer mechanical and electromagnetic properties. This paper includes a sensitivity analysis of the mechanically and electrically excited FRFs of a model transformer to the reasons behind its failures. A model power transformer is used as an example to demonstrate the variation of its vibration response to a couple of causes of transformer faults, such as looseness of clamping forces in winding and core. Experimental evidence is presented to show the quantitative description of the causes of artificial faults and to extract features of variations of FRFs that might be useful to the vibration-based detection of the causes of transformer faults in general.

1. INTRODUCTION

In the power industry, monitoring health conditions and detecting the causes of power transformer failures are often done using one of three methods: dissolved gas analysis (DGA), frequency response analysis (FRA), and vibration-based methods.[1–5] These methods focus on measuring the indicators of transformer faults and correlating the trends of changes in these said indicators with respect to the causes of transformer failures.

As an online and nonintrusive method, the vibration-based condition monitoring method has attracted considerable attention for transformer health monitoring in the past few decades. Previous work has demonstrated that this method provides an option for assessing the mechanical integrity of a transformer.[6–12] Unlike the DGA and FRA methods, it relies on changes in the vibration response of the transformer under both steady-state and transient processes. For an example, Berler found that looseness in the winding clamping force might cause variations at twice the operating frequency and its harmonics.[6] The transient vibration evoked by transformer energize/de-energize operations was also employed to detect abnormalities in transformer winding.[7] To further develop the vibration-based condition monitoring method, efforts were also made in the area of signal processing to extract the vibration features of a damaged transformer by advanced signal processing methods, including the wavelet transform, the Hilbert Huang transform, and their combinations.[10]

Although the feasibility of using the vibration method for transformer condition monitoring was verified in these case studies, there is still a gap in understanding the physical correlation between the changes in the vibration response and changes in the transformer's mechanical properties associated with the causes of failures. A better understanding of vibration changes caused by transformer mechanical faults is beneficial to fault allocation, even to the development of novel monitoring strategies, which is the research motivation of this work.

The vibration response of a power transformer is a measure of the transformer vibration (as outputs) with respect to the transformer's electrical inputs. Since the transformer online monitoring techniques mostly rely on the vibration response caused by operating excitations that consist of electrical excitations from core and winding, it is more straightforward to study the electrically excited FRF and its variations as opposed to the mechanical excitation. The previous work by Wang and Pan examined the vibration FRFs of a model power transformer to the electrical excitation.[13] However, their changes to different failure causes and corresponding change sensitivities have not been inferred.

Because the vibration of the winding and core are nonlinear functions of the electrical inputs, the traditional concept of the frequency response function (FRF) for linear systems does not apply. In a previous work, it was found that the steady-state response was characterized by the frequency components at twice the excitation frequency and its harmonics.[5] Therefore, the nonlinear vibration response of the transformer with respect to a sinusoidal input can still be specifically defined in the frequency domain. For example, if the secondary winding is in an open circuit condition, then the vibration response function is defined as:

$$H(x_i|\omega) = \sum_{k=1}^{\infty} H_{2k}(x_i|2k\omega_o); \quad (1)$$

where x_i was the measurement location of the vibration re-