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Modelling and Analysis of Electromechanical Stress in Transformers Caused by Short-Circuits

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Abstract. A common reason for internal faults in transformers windings is the weakness insulation caused by vibration / deformation related to electromechanical forces produced by high short circuit currents. This phenomenon significantly reduces the transformer life expectancy and may even lead to its instantaneous or timing destruction. Focusing this subject this paper is aimed at presenting the performance of a time domain model inserted in a finite element program i.e. the 3D software package and the investigation of the relationship between high current levels occurring at transformer windings and the internal mechanical stresses. To highlight the overall model and the software performance, a laboratory 15 kVA transformer is utilized to show the programme facilities and potentially. The transformer has been built with concentric double-layer windings and ferromagnetic core with three columns and this equipment has been submitted to a balanced three-phase short- circuit. In addition, the computational simulations were carried out using distinct geometries to the windings i.e. with and without deformation.

Key words

Mechanical transformer stresses, radial forces, axial forces, windings deformations, finite element simulation.

1. Introduction

Power transformers are essential devices and represent a significant part of the overall electrical system cost. When these devices are damaged or fail their repair or even the replacement demand very high financial costs. The reason for that is the high commercial cost of this equipment as well as the energy loss transference during a period of time [1]. The failures of these devices are mainly due to the weakness insulation caused by the electrochemical process involving the cooling liquid (oil), the vibrations produced by the electromechanical forces during normal operation, i.e. in steady state, and also by windings deformations caused by high short circuit currents. An analytical methodology which includes studies related to electromechanical transformer stress caused by short-circuit is presented in references [2] and [3].

Focusing the above subject this paper aims to present the results of an investigation in the field of electromechanical stresses. The idea consists in using a finite element model for the transformer so as to calculate the corresponding radial and axial forces. The software selected is the flux 3D software package which is a very well known product offered by CEDRAT – France. Throughout the insertion of the transformer equations in the mentioned program it becomes possible to perform investigation studies in relation to the effect of short-circuit conditions on the transformer internal mechanical forces. To illustrate the computational facilities, investigations about the relationship between three-phase short circuits and their effects on a given transformer are then carried out using a laboratory 15 kVA transformer data. This device is made of traditional ferromagnetic core with three columns and two concentric windings double layer. Two different situations concerning the winding conditions, with and without internal deformation have been taken into account. The computational results are, at the end, compared to expected values derived from analytical expressions traditionally used for such calculations, as well as from experimental tests.

2. Electromechanical Failures In Transformers

Under normal operation, the electromechanical forces and the leakage flux in the transformer are relatively small. Therefore, the mechanical structures support the efforts with no difficulty. However, under short-circuit condition, if the coils are not adequately built with appropriate mechanical structures, the leakage flux associated with high currents reach relatively high values. It could cause a partial or even a complete mechanical destruction of the transformer built in structure [2].

A. Radial forces

The radial forces are produced by the axial component of leakage flux and it results in different effects in the outer