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Resonant behavior of EHV transformer windings under system originated oscillatory transient over voltages

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ABSTRACT

Grid connected EHV transformers experience various terminal disturbances when in service. The present work attempts to investigate the voltage stresses that may develop on the transformer insulations under a variety of terminal disturbances. A number of standard and non-standard wave shapes like lightning impulse, chopped lightning impulse, steep-front long tail switching surge and oscillatory transient over voltages have been simulated and impressed on the terminals of a 400 kV EHV power transformer operating in the Indian power grid to ascertain how the winding insulations are stressed under these disturbances. Relevant section of the Indian power grid and the transformer has been modeled using Alternative Transient Program (ATP). It has been established that oscillatory system transients can trigger natural resonate frequencies of the transformers causing high voltage stresses on the insulations. Short Time Fourier Transform (STFT) analysis of the oscillatory voltage response of the windings confirmed the presence of resonant frequencies indicating forced resonance. Some remedial measures involving winding design modifications have been suggested in the paper to overcome the problem.

1. Introduction

Transformers operating in EHV power networks often encounter terminal disturbances of complex and varying wave shapes which can produce voltage stresses well above normal operating values inside the transformer. This phenomenon was reported in [1,2] and evoked fresh attention to the transient voltage response of power transformer windings following a series of reports of dielectric failure in several large EHV transformers in the American Electric Power (AEP) system between 1968 and 1971 [3,4]. Power system voltage transients are often of unknown shapes and are mostly oscillatory in nature. Dielectric test standards [5–7] stipulated for transformers are traditionally based on pulse type voltage wave shapes which are considered to be adequate in simulating stress conditions in transformer windings that are likely to be experienced in real life service. Consequently, the transformer designers have been mostly concerned with the response of windings to these standard pulse type voltage wave shapes. This paper however focuses on the response of transformer windings to a variety of standard as well as non standard terminal excitation voltages like lightning impulse voltage, chopped lightning impulse, steep front – long tail switching surge and system originated oscillatory transient over voltages and reveals a comparative assessment of the voltage stresses likely to develop on the transformer windings under these excitation voltages by experimental studies on a developed high frequency EMTP (ATP) model of 400/200/132 kV EHV power transformer operating in the power grid of an Indian power utility. Studies aimed to analyze the nature of internal voltage amplification and voltage stresses on major and minor winding insulations under these wide variety of terminal excitations, and to assess, whether the standard surge type test waves [8] can adequately represent the worst possible voltage stresses conditions experienced by transformers in field, or whether other non-standard voltage wave shapes including oscillatory transient over voltages can produce even more severe stress conditions for winding insulations.

2. Development of high frequency EMTP model of the 400 kV transformer

For investigation of the transient phenomena inside a transformer, a lumped parameter high frequency circuit model of the concerned 400/220/132 kV transformer has been developed by the authors based on transformer geometry and configuration [9,10]. Coil by coil lumped parameter representation of the windings have been considered to be sufficient for the present purpose. A schematic diagram of the developed high frequency model has been shown in Fig. 1.

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