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Analysis of short circuit and inrush transients in a current transformer using a field-circuit coupled FE formulation

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ABSTRACT

The existing models based on the lumped-circuit approach consider the constant leakage inductance during transient simulations. However, leakage inductance of the current transformer (CT) may not remain constant. In fact, it may vary with the degree of saturation of the core. During severe saturation conditions, leakage inductance variation in fact may result in significant difference between the calculated and the measured secondary currents. In this work, a nonlinear, field-circuit coupled finite element model of a current transformer (CT) is presented. The model considers the variation in leakage inductance during the simulation of transient conditions. Moreover, since geometry of the transformer was taken into account, it was possible to estimate forces associated with the short-circuit current. Hysteresis characteristic of the core was taken into account by using Jiles–Atherton model in conjunction with fixed-point iteration method. The formulation was realized using a code developed in MATLAB and implemented for a 69 kV, 200/5 A current transformer. The normal operation and other cases such as short-circuit, and transformer sympathetic inrush current through the primary of the CT are presented. These cases demonstrate modeling flexibility of the field-circuit coupled formulation.

1. Introduction

A current transformer is one of the important and critical components in an electric power system. Saturation of a CT can cause malfunction of protective relays. Since it is a series connected device, breakdown or fault may lead to an unplanned outage. Hence, it is desirable to minimize the frequency and duration of these unwanted outages. The performance and reliability of a CT can be improved by accurate evaluation and analysis under steady state as well as transient conditions. Magnetization characteristics and time constants of primary and secondary side networks can influence the transient performance of a CT.

Several models of CTs have been proposed in the literature [1–4]. Some of these models are based on equivalent or lumped electric and magnetic circuits. However, during the transient conditions, the leakage flux pattern in the intercoil space is particularly complex and the flux tends to leave part of the core in which density is highest. During the transient conditions there can be a significant difference between the calculated and measured values of the secondary currents of a CT [5]. This complex leakage field pattern may not be well captured by using lumped parameter models and needs to be studied further using distributed or numerical models based on Finite Element Method (FEM) or Finite Difference Method (FDM). These numerical modeling techniques are well established to enable representation of all the important phenomena occurring inside a typical power apparatus [6–8]. The field-circuit coupled formulation is commonly used in conjunction with nonlinear transient electromagnetic field model of devices [7–9]. Earlier, these kinds of formulations were successfully applied to analyze many intricate problems related to the design and operational aspects of power and distribution transformers [9–12]. Present work relates to the application of the field-circuit coupled formulation to a current transformer. A transient model that includes dynamic change in leakage inductances during saturation has been developed. Since geometry of the transformer was taken into account, it was possible to estimate forces associated with the short-circuit current.

2. Field-circuit coupled formulation

For finite element analysis of behavior of a CT under transient conditions such as short-circuit, inrush, and high burden, the current densities in winding domains must be known. A CT is fed by primary currents while secondary current is not known during transient conditions. A field-circuit coupled model can be developed for transient conditions even without the knowledge of secondary current. Fig. 1 shows a typical field-circuit coupled model

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