Electrical Power and Energy Systems 76 (2016) 147–155

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Electromagnetic force investigation on distribution transformer under unbalanced faults based on time stepping finite element methods

Atabak Najafi [a,*], Ires Iskender [b]

[a] Department of Electrical Engineering, Germi Branch, Islamic Azad University, Germi, Iran
[b] Department of Electrical and Electronics Engineering, Engineering Faculty, Gazi University, Ankara, Turkey

ARTICLE INFO

Article history:
Received 2 November 2014
Received in revised form 11 August 2015
Accepted 18 September 2015
Available online 21 November 2015

Keywords:
Electromagnetic force
Single phase to ground short circuit
Leakage flux
Inrush current
TSFEM

ABSTRACT

The occurrence of short circuit faults is a major cause behind the windings deformation in the transformers. Mechanical force is proportional to the square of the current. Hence under short circuit condition, it will be very high. These stresses radially or axially affect the transformer windings. Therefore, in the transformer designing, evaluating the effects of short-circuit current and inrush current is very important. In this paper, 2-D and 3-D time stepping finite element methods (TSFEM) that improved in Ansoft-Maxwell, are utilized as Instruments to investigate the leakage flux and electromagnetic forces due to short circuit and inrush current on the windings of 1000 kV A, 10/0.4 kV three-phase, three leg, distribution transformer. Electromagnetic forces in the transformer windings are produced as a result of combination between the current density and the leakage flux density in the winding regions. The study demonstrates that, especially, under single phase-to-ground short circuit fault, leakage flux density on the windings of transformer remarkably increase. The interaction between this high leakage flux with current density, causes the significant increase in the electromagnetic forces in transformer windings.

Introduction

Transformers as static electric machines, play an important role in the energy system. When short circuit occurs in the winding of transformer, this winding subjected under the electromagnetic force that is proportional to the square of the current. These forces with the radially or axially stress cause the high pressure and eventual deformation of windings. The resistance and inductance ratio of the short circuit is low. For this reason the duration of inrush current is longer than that of short circuit current. Nevertheless, under this condition the temperature of windings increases to a hazardous case. In order to calculate the electromagnetic force in the short circuit condition, different methods have been presented in the literature. The most popular method which is used in the literature, is Rogowski's method [1]. This method creates an approximate leakage field analysis, by considering only the interwinding gap reluctance. Another method in order to compute the electromagnetic force under short circuit in the large transformer that proposed by Renyuan is called improved T–Ω method [7]. In the literature different analytical methods [9] and numerical methods [5], have been used to compute the leakage reactance and leakage flux in the transformer windings. But these methods when the axial length of HV and LV windings are not equal, are not valid.

In this paper, 2-D and 3-D time stepping finite element methods based on vector potential formulation have been used in order to modeling and investigation of leakage flux and electromagnetic forces due to short circuit and inrush current in a three-phase, 1000 kV A distribution transformer. The simulation results show that, there is a difference between the calculated electromagnetic stress and leakage flux in 2-D and 3-D TSFEM methods.

Distribution transformer analysis using time stepping finite element method

FEM is a numerical technique to solve the differential and integral equations such as electromagnetic, magneto static, thermal conductivity, solid and structural mechanics and fluid dynamics. The basic idea of FEM is subdividing physical problems with complicated differential equations into a number of sub-problems and dissolving these equations in the linear systems. A 3-phase, Dyn11, 1000 kV A, 10/0.400 kV distribution transformer is studied in this paper. The mesh operation has been done in 10 passes in which the increasing rate of meshing has been considered as 5% per pass. Based on this procedure, the number of meshes in magnetic core, windings, and core clamp is respectively 65,350, 22,430, and

* Corresponding author.
E-mail addresses: najafi_atabak@yahoo.com (A. Najafi), iresis@gazi.edu.tr (I. Iskender).

http://dx.doi.org/10.1016/j.ijepes.2015.09.020
0142-0615/

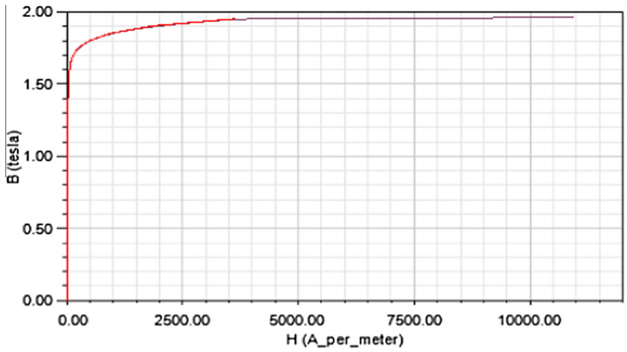

Fig. 1. *B–H* curve of laminating type of M5 material.

40,000. The total number of meshes in elements is 127,780. In the three-dimensional modeling, all the shapes of meshes are tetrahedral.

Eq. (1) displays the variations of magnetic vector potential *A* [2,3].

$$\nabla^2 A - \mu\sigma \frac{\partial A}{\partial t} + \mu J_0 = 0 \quad (1)$$

In this equation, μ is the magnetic permeability, σ is the electrical conductivity, and J_0 is the applied current density.

$$\frac{\partial A}{\partial t} = jwA \quad (2)$$

Eq. (3) displays, three dimensional model of magnetic field in the cartesian coordinate (x, y, z), hence:

$$\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial A}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{1}{\mu}\frac{\partial A}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{1}{\mu}\frac{\partial A}{\partial z}\right) - jw\sigma A + J_0 = 0 \quad (3)$$

curl of the B, used to calculate the magnetic vector potential A:

$$B = \nabla \times A \quad (4)$$

laminations of the transformer core, M5 type silicon alloy steel plates with 0.30 mm thick are used. Fig. 1 shows the *B–H* curve of the magnetic material. It can be seen in this fig that saturation flux density is approximately 1.92 T and the distribution of leakage flux

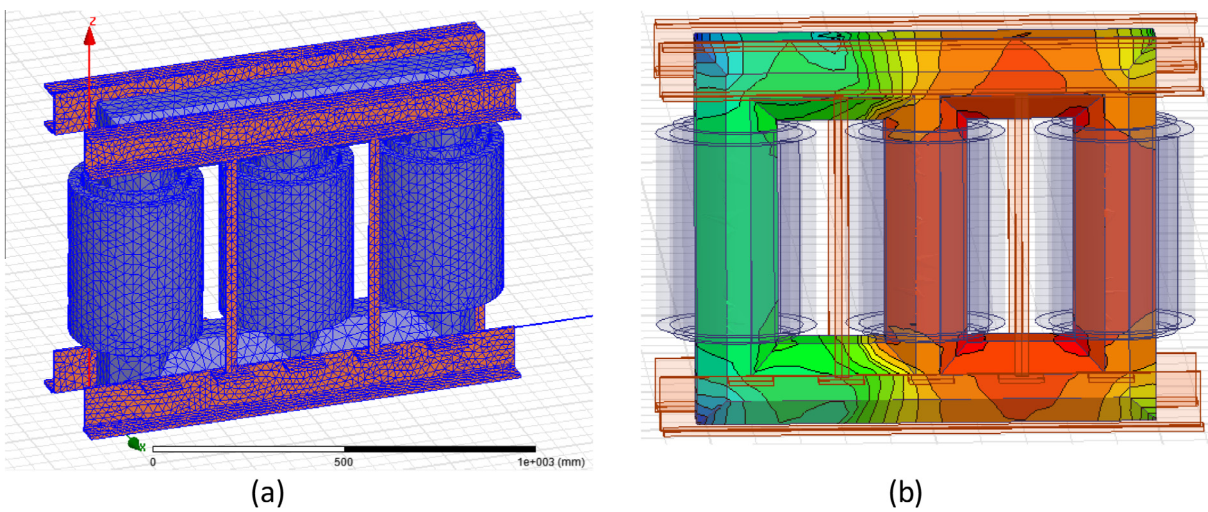

Fig. 2. (a) 3-D mesh operation of studied transformer and (b) flux density distributions in a transformer core.

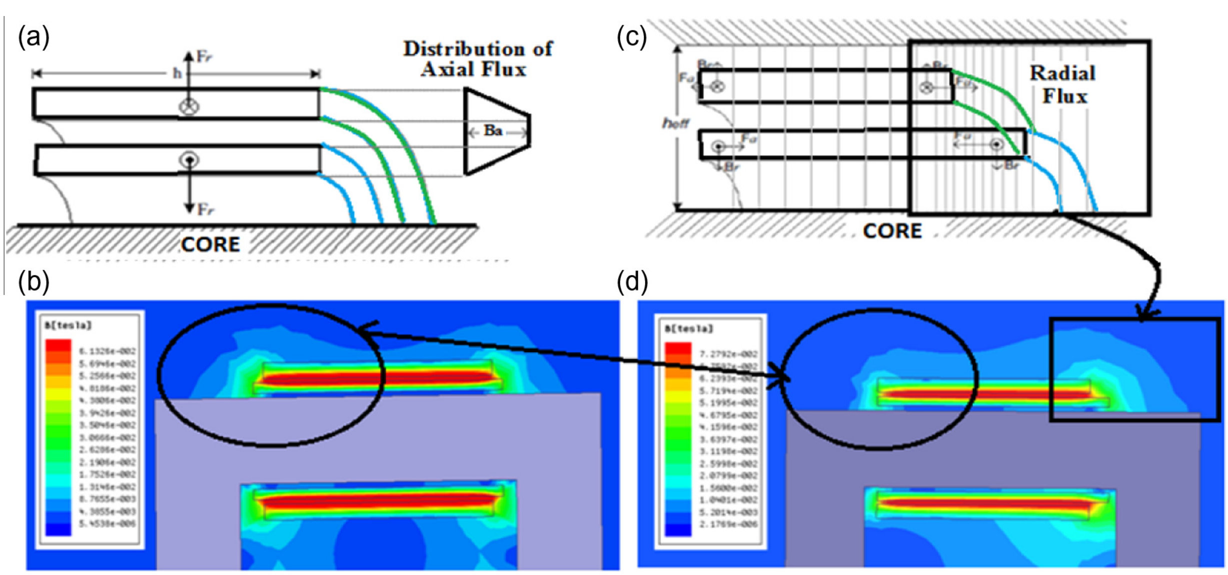

Fig. 3. Concentric windings with (a) and (b) are the axial leakage flux and radial force, (c) and (d) are the radial leakage flux and axial force.