Research on Power Transformer Winding Deformation Under Multiple Short-Circuit Conditions Through Magnetic–Structural Coupling analysis

Shuang Wang, Shuhong Wang, *Senior member, IEEE*, Youpeng Huangfu, Hailin Li, Dongsheng Yuan, Song Wang

State Key Laboratory of Electrical Insulation and Power Equipment, Faculty of Electrical Engineering,
Xi’an Jiaotong University, Xi’an, 710049, China,
shwang@mail.xjtu.edu.cn

A computation of windings deformation for a 110 kV transformer under multiple short-circuit conditions is performed based on the finite element method. The computation is conducted by considering the influence of plastic winding deformation on the distribution of magnetic leakage field inside the transformer, through magnetic–structural coupling analysis. The “birth and death” element method is applied to update the winding model and simulate crack growth, as well as failure path of windings material under multiple short-circuit conditions. The deformation characteristics and cumulative deformation after several short-circuit faults is obtained, using the plastic mechanic theory. The results can provide reference for the design and maintenance of transformers.

***Index Terms*—Power transformer, winding, deformation, multiple short-circuit, magnetic–structural coupling analysis.**

I. INTRODUCTION

POWER transformer is one of the most important equipment in power systems. It is known that the transformer may suffer from all kinds of short circuit faults inevitably in service time. The huge and dynamical electromagnetic forces under short circuit fault may cause winding deformation, and even lead to winding conductor rupture, which results in serious accidents.

Recently, many publications have studied the winding deformation and its calculation method. Short-circuit performance of split-winding transformer was investigated using coupled field-circuit approach in reference [1]. H. Zhang et al analyzed dynamic deformation of power transformer windings in short-circuit fault by finite element method [2]. Hyun-Mo Ahn et al dealt with experimental verification and finite element analysis (FEA) for short-circuit force prediction of a 50 kVA dry-type transformer [3]. The radial stability of large transformers windings under multiple short-circuit conditions is researched in reference [4]. Most of these researchers are related to elastic deformation of the transformer windings.

In this paper, an improved method is applied to the calculation of deformation for a 110 kV transformer windings under multiple short-circuit conditions, considering the influence of plastic winding deformation on the distribution of magnetic leakage field inside the transformer, through magnetic–structural coupling analysis. The plastic mechanic theory is used to obtain the deformation characteristics and total plastic deformations after several short-circuit faults. The results could provide reference for the design and maintenance of transformers.

II. TRANSFORMER MODEL AND PARAMETERS

The three-dimensional simplified model of a two winding, 110 kV power transformer (including high-voltage and low-voltage windings, simplified with HV and LV) is established, presented in Fig. 1. The specification of it is shown in Table I.

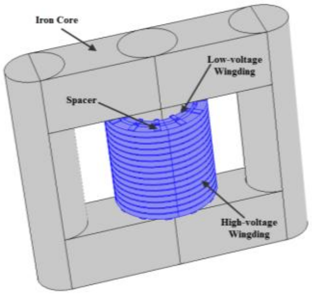

Fig.1 The 3-D simplified model of transformer.

TABLE I
SPECIFICATION OF OIL-IMMERSED-TYPE 110KV POWER TRANSFORMER

Quantity	Value	Unit
Rated Power	25000	kVA
Rated voltage	110	kV
Impedance	10.74	%
No. winding turns of HV/LV winding	938/141	-
Inner diameter of HV/LV copper disk	371.5/276	mm
Outer diameter of HV/LV copper disk	457/334.5	mm
Elasticity modulus of copper/spacer	115/8	GPa
Poisson ratio of copper/spacer	0.33/0.25	-

III. METHOD AND PRINCIPLE OF COMPUTATION

A. *Calculation of electromagnetic field*

According to Maxwell equations, the control equation of electromagnetic field with magnetic vector potential A is described as follows:

$$\nabla \times \left(\frac{1}{\mu} \nabla \times A\right) = J \tag{1}$$

Where μ denotes the permeability, A denotes the magnetic vector potential, J is the current density.

B. *Electromagnetic force*

The electromagnetic volume force is deduced by the magnetic flux densities B and the current densities J as follows:

$$F(\Delta u, t) = J \times B \tag{2}$$

the winding deformation or displacement expressed by Δu

may also influence the spatial distributions of current density J and magnetic flux density B.

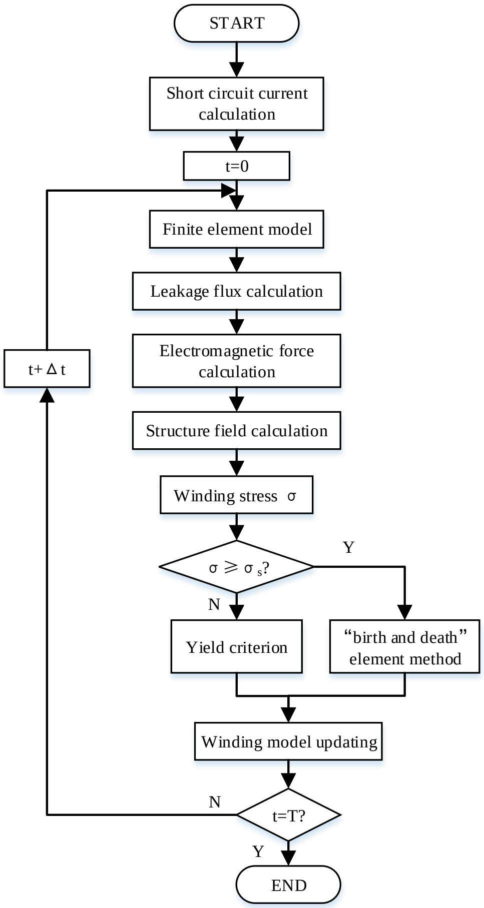

Fig. 2 Flow chart of computation of winding deformation.

C. Flow chart of computation of winding deformation

Yield criterion is applied to the calculation. And thus once the maximum stress value exceeds the yield stress level of winding material, the plastic deformation occur initially. But if the maximum stress value exceeds ultimate tensile strength σ_s of winding material, the material may fracture directly. In this case, the "birth and death" element method is used to update the winding model and simulate crack growth, as well as failure path of windings material under multiple short-circuit conditions. The flow chart of computation of winding deformation is shown in Fig. 2.

IV. RESULT AND DISCUSSION

A part of the work, related to distribution of Von Mises stress and cumulative deformation, is shown in the followings.

Fig. 3 shows the distribution of Von Mises stress with elastic deformation at 0.01s. Fig. 4 illustrates the plastic deformation of the top disk of LV winding. Cumulative deformation of windings resulting from short circuit faults is shown in Fig. 5.

The different extents of deformations distributed in windings due to different numbers of short circuit fault, the failure path and characteristics of windings are also obtained, and will be presented in full paper.

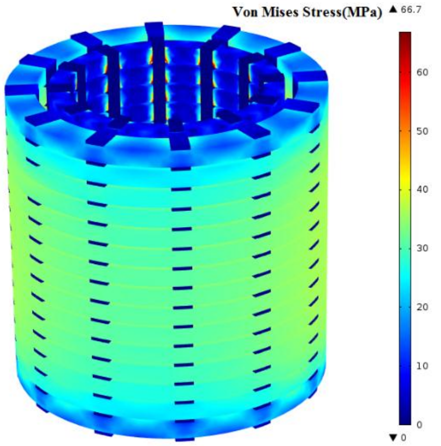

Fig. 3 Distribution of Von Mises stress.

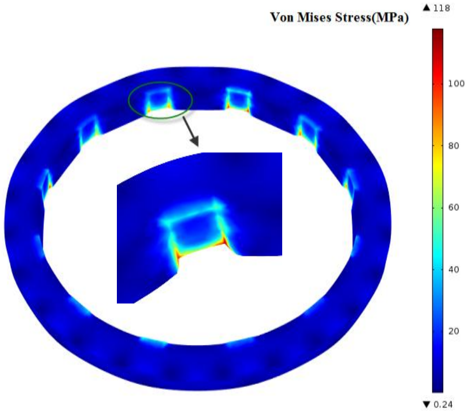

Fig. 4 Plastic deformation of the top disk of LV winding.

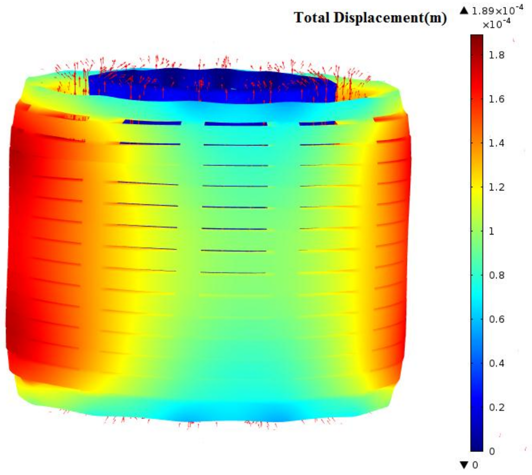

Fig. 5 Cumulative deformation of windings.

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