Calculation of Power Transformer Short-current Force

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Abstract. This research studies the magnetic field and forces on the windings of transformer due to short-circuit. Three dimensional finite element computation of three-phase power transformer is carried out. The model developed have been applied to power transformer and the results are verified experimentally. To verify the computation results, they are compared with those obtained using ANSYS software simulation.

Introduction

In this paper a new optimal design of soccer robot control system which is based on mechanical analyses and calculations on the pressure and transmutation states of chip kick mechanics, this new control system with high precision for speed control and high dynamic quality.

One of major reason for fault in power transformers is deterioration of winding and insulation of conductors due to the oscillations resulted from the electrodynamics forces. The over-current and rated current result in the above-mentioned forces. Therefore, the transformers coils must be protected mechanically and connected to each other by ribbon and wedges. The structural criterion for this support is generally those forces that are generated by the maximum possible current [1]. A large transient current during a short-circuit apply abnormal electromechanical forces upon the windings of transformer that may damage the whole windings. Short-circuit forces and resultant stresses must be predicted in the design stage. These forces must be in the range that is specified by manufacturer.

The accurate evaluation of the magnetic field and the resulting forces on power transformer windings under short-circuit is very important for the design of the device. It enables, in particular, to avoid mechanical damages and failures during short circuit tests and the power system faults. As the forces grow rapidly with the transformer rating their prediction is of crucial importance for the design of very large apparatus. In such cases short-circuit magnetic field and force tests under normal voltage are very laborious and expensive. The computation results are compared with those obtained by application of finite element method.

Cause of Short-Circuit Magnetic Field and its Currents

After a transformer is connected to current pass a transient mode and then reaches the steady-state mode .

windings magnetic field of power transformer is a typical 3D nonlinear eddy current problem with a multiply connected region. In the region of windings, the field equations and boundary conditions is reflected the intensity of magnetic induction B .In the case of frequency，Ignore the impact of displacement current .

Maxwell’s equations as in

$$\nabla \times \mathbf{H} = \mathbf{J} \tag{1}$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial \mathbf{t}} \tag{2}$$

$$\nabla \cdot \mathbf{B}=0 \qquad (3)$$

$$\nabla \cdot \mathbf{J}=0 \qquad (4)$$

Magnetization of ferromagnetic materials is quite complicated. If we still write

$$\boldsymbol{B}=\mu \boldsymbol{H} \qquad (5)$$

The permeability μ is function of magnetic field $\boldsymbol{H}$ and depends on the history of magnetization **.**

The electric current density is

$$\boldsymbol{J}=\sigma E \qquad (6)$$

Where σ is called conductivity.

Junction conditions as in

$$\mathbf{H}_1 \times \boldsymbol{n}= \mathbf{H}_2 \times \boldsymbol{n} \qquad (7)$$

$$\mathbf{B}_1 \bullet \mathbf{n} = \mathbf{B}_2 \bullet \mathbf{n} \qquad (8)$$

$$\mathbf{J}_1 \bullet \mathbf{n} = \mathbf{J}_2 \bullet \mathbf{n} \qquad (9)$$

$$\mathbf{E}_1 \bullet \mathbf{n} = \mathbf{E}_2 \bullet \mathbf{n} \qquad (10)$$

In the eddy area, **H**(t) can directly from the source current and the external applied magnetic field to calculate the current density. That is calculated by the following relationship

$$\nabla \times \mathrm{H}=\mathrm{J} \qquad (11)$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \qquad (12)$$

We consider a part inside the surface of a magnetized body as shown in Figure 1. For calculating the magnetic force acting on this part, the magnetic material inside is separated from the rest of the magnetic material by means of an imaginary gap of infinitesimal width. The magnetic force is the rate of change in magnetic energy when the magnetic medium is undergoing an incremental displacement with the magnetic excitation held fixed. The magnetic and elastic properties of ferromagnetic and other materials depend on each other. The different couplings between these properties are called magnetoelastic effects. These effects can be separated into two main categories, namely direct effects and inverse effects

According to the principle of virtual work , the magnetic energy is given as

$$\partial w = -\int_v \frac{\partial f_v}{\partial t}\delta v_i dv - \int_s \frac{\partial f_s}{\partial t}\delta v_i ds \qquad (13)$$

Where ∂w is virtual work, δv_i is virtual speed of transfomer iron The total magnetic force $\boldsymbol{F}$ acting on any part of the transfomer is calculated from the magnetic energy $\boldsymbol{W}$ as

$$F = -\frac{\partial W}{\partial u} = \int_{\mathrm{v}} f_{\mathrm{v}} dv + \oint_{\mathrm{s}} f_{\mathrm{s}} ds \qquad (14)$$

Where $\boldsymbol{u}$ is the vector of virtual displacements in the considered coordinate system

$$f_v = J \times B - \frac{1}{2}H^2\nabla\mu + \frac{1}{2}\nabla\left[H^2\tau\frac{\partial\mu}{\partial\tau}\right] \qquad (15)$$

Prepare Finite Element Method for Force Computation

Maxwell stress tensor is used for force computation by finite element method , in this paper, ANSYS finite element analysis method of three-dimensional on SZ9-40000-110 parameter of power transformer is shown as table I.

Table I. Parameters of Power transformer Windings

	inner diameter (mm)	external diameter (mm)	turns	windows High (mm)	Phase current (A)
HV	818	988	671	1115	210
LV	612	754	111	1115	1269.8

Based on the above parameters, Meshing of three-phase power transformer with specifications are given in Figure 1.

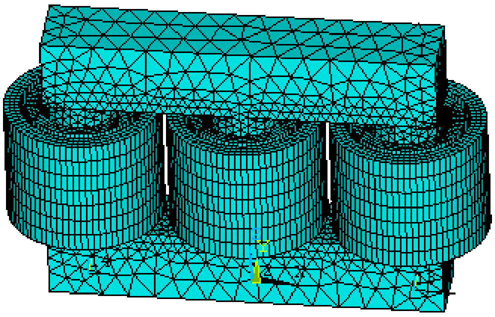

Fig.1. one-half meshing model of finite element

A. *Inrush Current Force*

To verify the validity and reliability of abovealgorithm, some experiments on SZ11-31500/66, such as switching unloadtransformer, switching unload transformer with a smallturn-to-turn fault as well as turn-to-turn fault duringnormal running, are completed on an Yn/Δ-11 transformerbank. The other experiments, such as the saturation ofcurrent transformer when switching unload transformer,are carried on another Yn/Δ-11 transformer bank. Theparameters of the former are given as follows, ratedcapacity 40000kVA, rated voltage in primary winding66kV, rated voltage in secondary winding 10.5V,rated current in primary winding 275.6A, steady magnetizing inductance 5.37H. Figure2 show the Inrush current in different case. Switching angle is zero(t=0.058s), remanent magnetism of three-phase are (A-phase=0.8Wb/m2，B-phase=-0.4 Wb/m2，C-phase=0.4 Wb/m2)

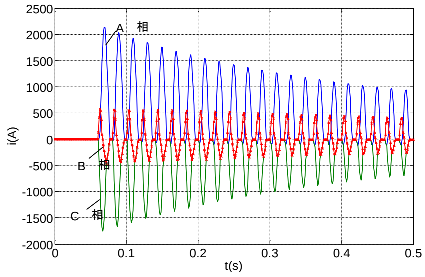

Fig.2. α=0rad Br is[0.8，-0.4，0.4]pu

Changes of force on bilateral windings during dynamic state is shown in Figure 3 and Figure 4.

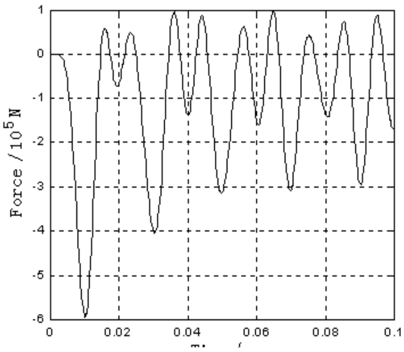

Fig.3. Upper end of winding

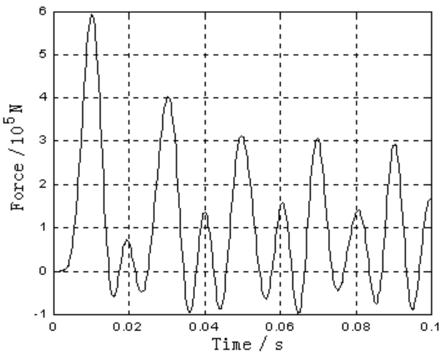

Fig.4. Lower end of winding

B. *Short-circuit Force*

There is little electrodynamic force in axis direction of both inner and outer windings.Moreover , there exists pushing force between adjacent pies or turn ofwindings. Especially , the enormous short-circuit electrodynamic force will make the windings distorted , the HV voltage winding phase currents during two-phase short-circuit is shown in Figure5.Axial short-circuit forces sign on the HV winding of the three-phase transformer with specifications is given in Figure6.

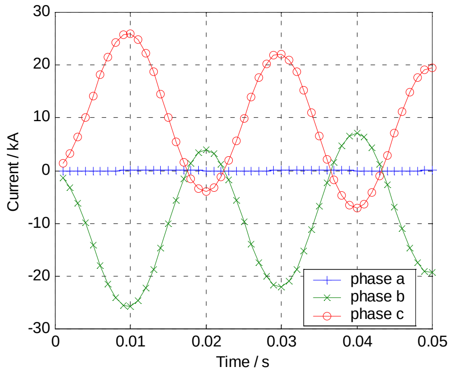

Fig.5. HV voltage winding phase currents

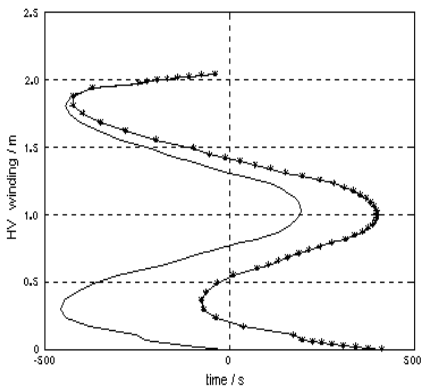

Fig.6. Distribution of radial magnetic force

Since the transformer's core normally enters a state of saturation, the magnitude of inductance is reduced, the current increases quickly due to the decrease in inductance. This phenomenon has the some dangerous effects. Instant in time when voltage is zero during continuous operation. Since the core non-linear does not take into account and Sinusoidal input voltage therefore the use of transient analysis. Three-phase current include primary A-phase current is currA, B-phase current is currB and C-phase current is currC.

Conclusion

In this paper, The establishment of a iron description of sinusoidal electromagnetic field in the mechanical properties of the mathematical model are built .According to electromagnetic field theory and elasticity theory . Formulas for the calculation ofmagnetic and magnetostrictive forces are also derived. The implemented method is used to computethe vibrations of the iron of transformer under the effect of magnetic and magnetostrictive forces. The effect of coupling between the magnetic and elastic fields is alsocomputed for power transformer. The magnetic forces means here the interaction between the magnetic and elastic fields in the iron parts of a transformer. magnetostriction is the phenomenon by which an iron part changes its dimensions under the effect of a magnetic field. The results show that the Electromagnetic force and the magnetostrictive effect is the phenomenon of different，it is important to establish mathematics model. We can research vibration and noise characteristics of the power transformer.

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