DC bias Elimination and Magnetic-integration Technique in Single-phase Transformer

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This paper studies the DC bias phenomenon and magnetic-integrated technique in a single-phase transformer. A new transformer with function of DC bias elimination based on nano-composite magnetic material is designed and filter reactors are integrated into the transformer via magnetic-integrated technique. Mathematical model of hysteresis of the magnetic material is established and a kind of magnetic circuit of DC bias elimination is designed to insure the flow direction of DC magnetic potential and elimination magnetic potential; DC bias in transformer core can be eliminated directionally using the conversion of coercivity and remanence. And the filter reactors have notable characteristics of decoupling with other windings, high linearity, less extra covering area, and energy saving. It can be used as 5, 7 and 11 single tuned filters on the filtering side which verifies the correctness of decoupling theory.

***Index Terms*—Transformer, magnetic-integrated, magnetic material, hysteresis and decoupling**

I. Introduction

The flow of DC in the power transformer winding can cause half-cycle saturation of transformer, this saturation can cause leakage flux increase, transformer overheat, and some additional power system problems like unbalanced reactive power in power system, and reactive power also affects the power network stability and power quality seriously. Some papers or studies have been made some contribution to eliminate the effect of DC bias in transformer. But there are a few methods to eliminate DC bias from structure design of transformer, and these traditional methods have drawbacks which poses a great threat to security of neutral grounding in power transformer [1].

It is shown that reactive power compensation and harmonic suppression device mainly concentrate on the controllable reactor, capacitor, active filter and the combination of them. But reactor has disadvantages of slow response speed and poor reliability which cannot meet the requirement of reactive power compensation. In power systems, passive filter plays an important role in harmonic control and reactor power compensation. A simple structure, low-cost, high reliability and low operating costs are the design objective of passive filter.

This paper presents a new method to eliminate DC bias and integrates three filter reactors in a transformer, structural and electromagnetic design of the transformer is completed. And a decoupling scheme is implemented by a reasonable windings arrangement of the transformer and reactor [2]-[3].

II. Nano-Composite Magnetic Material

The molecular formula of nano-composite magnetic material is: Fe3B/Nd2Fe14B, containing a little of Co and Cr, a kind of multifunctional material with magnetic conductive, non-conductive, excitation and other magnetic characteristic. Its magnetic characteristic can be converted under certain condition of external magnetic field and the magnetic potential direction can be controlled.

Because nano-composite magnetic material has two working points, the magnetization characteristic is very complex. This paper establishes mathematical model of hysteresis and gets the hysteresis loop of magnetic material based on Preisach [4]-[5].

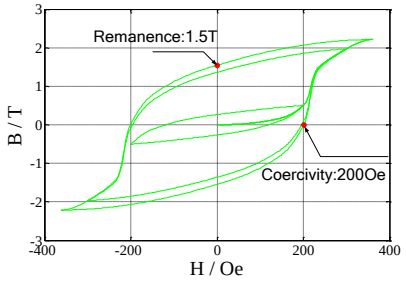


Fig. 1. Hysteresis loop of nano-composite magnetic material

III. Magnetic Circuit of DC Bias Elimination Design

A reasonable magnetic circuit design is important to insure the elimination magnetic potential flows in transformer main core as required which the purpose of DC bias elimination could be achieved. Transformer works in a normal environment.

According to recent research of nano-composite magnetic material, the most reasonable plan is that makes material work on both sides of transformer side-yoke. Fig. 2 is the structure of new transformer.

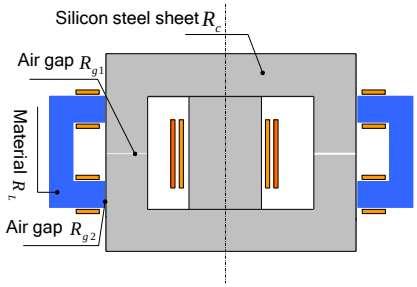


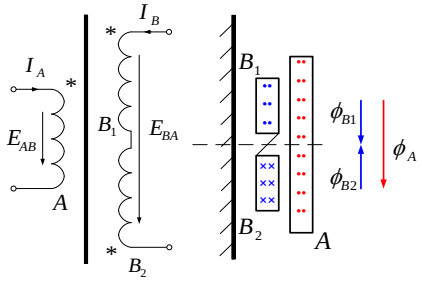
Fig. 2 Structure of new transformer

The direction of elimination magnetic potential produced by nano-composite magnetic material is opposite to the direction

of DC bias magnetic potential by controlling the relationship between reluctance R_{g1} and R_{g2}. Because transformer has a bilaterally symmetric structure, we analyze its 1/2 model.

IV. Decoupling Theory

In complicated electromagnetic field, coupling of different windings is inevitable. A reasonable windings arrangement of transformer and reactor could realize a complete decoupling. Fig. 3 is arrangement of the windings A and B.



(a) (b)

Fig. 3 Arrangement of the windings A and B. (a) Circuit model (b) Winding arrangement

Which, I_A and I_B are currents in windings A and B. Winding B is consisted of two windings B_1 and B_2 which have the same turn numbers in series opposing. In space domain, winding B_1, B_2 and A are parallel. It can be got that the mutual inductance of windings B_1, B_2 and A:

$$M_{AB2} = -M_{AB2} \ , \ M_{B1A} = -M_{B2A} \tag{1}$$

ψ_{B1A}、ψ_{B2A} is the magnetic chain of B_1 and B_2 under the magnetic field of winding A, induction electromotive forces produced by winding A:

$$E_{B1} = -\frac{d\psi_{B1A}}{dt} \ , \ E_{B2} = -\frac{d\psi_{B2A}}{dt} \tag{2}$$

From (1) and (2), we can get the mutual induced voltage in winding B produced by I_A:

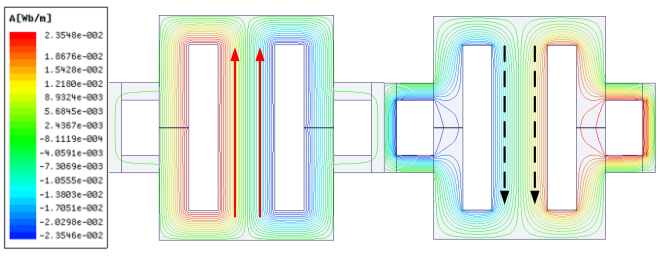
$$E_{BA} = E_{B1A} + E_{B2A} = -(M_{B1A} + M_{B2A})dI_A / dt = 0 \tag{3}$$

Similarly, the mutual induced voltage in winding A produced by I_B:

$$E_{AB} = E_{AB1} + E_{AB2} = -(M_{AB1} + M_{AB2})dI_B / dt = 0 \tag{4}$$

We know that there is electromagnetic coupling existing in windings A and B, but because of a reasonable windings arrangement, the complete decoupling is implemented.

V. Results and Discussion



(a) (b)

Fig.4. Distribution of magnetic line. (a) Under DC bias (b) Material working

In this paper, DC bias elimination is studied based on a 2D finite-element transformer model [6]. Nano-composite magnetic material is magnetized to counteract the DC bias magnetic potential in transformer core when DC bias occurs; the material is demagnetized when DC bias disappears, and transformer returns to normal work. Fig. 4 shows distribution of magnetic line of the transformer. Solid line is the direction of DC bias magnetic potential and dotted line is the direction of elimination magnetic potential. It can be seen that elimination effect is good; the direction of elimination and DC bias magnetic potential is opposite.

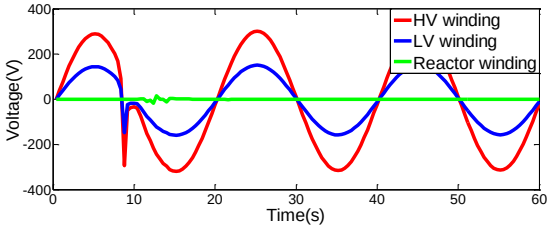


Fig.5. Induced voltage in reactor winding when transformer is working

In this paper, decoupling effect in windings is our concern. The induced voltage in transformer and reactor windings is discussed respectively. When transformer is working, we detect the voltage in the reactor windings; and when reactor is working, we detect the voltage in transformer windings, including HV, LV windings. In fig.5, the induced voltage in reactor winding is 0V when transformer is working [7].

VI. Conclusion

In this paper, a new transformer with function of DC bias elimination based on nano-composite magnetic material is designed. The mathematical model of hysteresis of material is deducted and the hysteresis loop is built; a magnetic circuit of DC bias elimination is designed. The DC bias elimination has a good effect. A decoupling theory based on magnetic-integrated technique is presented, decoupling effect with other windings is good from simulation, the integrated reactor and transformer could work normally.

References

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