Development of Simulation Modeling Software for Transformer Winding Leakage Magnetic Field Based on C#

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Abstract. The simulated calculation model of transformer winding leakage magnetic field is developed based on the development of C# language, and combined with electromagnetic field and transformer theory of this paper. Taking a transformer winding data as an example, the axisymmetric two-dimensional model is established to verify the engineering application effectiveness of the software.

Introduction

As the continuous expand of the scale of the power grid, the stability requirements for transformer performance are much higher. At the same time, as the capacity of the transformer continues to increase, the loss and thermal and dynamic stability of the transformer are attracted increasingly attention from manufacturers and power grid [1, 2]. The premise that the above problems can be analyzed accurately is to accurately analyze the leakage magnetic field of the transformer winding. With the development of numerical calculation, finite element software has sufficient engineering precision to meet the requirements of electromagnetic field calculation [3], but in the general numerical calculation, the calculating model established can only be used to analyze specific physical problems, and its calculating model cannot be applied to analyze other issues [4]. Therefore, in-depth study of the types of transformer windings, how to automatically establish a method to accurately describe various winding models through simple input has become an urgent research topic.

Mao Fengchun et al. recommended the model modeled by pie (line) by comparing the geometric models of windings with different fineness levels [5]. However, for large-scale power transformer, the windings contain various structural forms and structures is complex, which require high technical capabilities and experience of analysts. And the manual modeling method is much time consuming. Therefore, the large-scale power transformer winding modeling software which could apply to design, analyze and verify actual transformers is necessary to be developed.

The winding is the core component of the transformer, and its variety is various. It is a top priority to construct the model to reasonably establish the winding conductor model to realize the analysis of the distribution of the winding leakage magnetic field. Based on the theory of transformer leakage magnetic field analysis, the calculation and modeling methods of magnetic flux leakage in transformer windings is discussed in this paper. The object-oriented analysis and design software is adopted, the class required for winding modeling is reasonably abstracted. According to various windings, the winding model in which the conductor ring is as the base and the layer unit is as the core are proposed. The C# language is used as a tool to develop simulation modeling software for transformer winding leakage magnetic field. The coil model for different structural forms of the transformer is established quickly and easily via the analysis software, and the output of the software can be easily identified by the finite element software for the simulation of the leakage magnetic field.
Model Construction Principles

Leakage Magnetic Field Criterion

When the transformer winding is connected to the power supply, the magnetic flux is induced in the core of winding. The magnetic flux induced in the core is the main magnetic flux, and the main magnetic flux is mainly closed in the ferromagnetic material such as the stem and the iron yoke. When the load current flows into the transformer winding, the leakage flux is induced at the periphery of the winding, and its magnitude is proportional to the load current. The leakage flux passes through the air passage between the high and low voltage windings and then returns to the space occupied by the winding.

When the transformer is working under load state, the high and low voltage windings satisfy the principle of magnetic potential balance. Since the excitation current is small in value (which can be ignored), the principle of the magnetic potential balance is as follows:

\[ I_1W_1+I_2W_2=0 \]  

(1)

where: \( I_1, I_2 \)—high and low voltage windings current;
\( W_1, W_2 \)—the number of turns of the high and low voltage windings;

The high voltage windings magnetic potential and the low voltage windings magnetic potential are numerically equal and differ in phase by 180°. The excitation applied to the calculation model of the leakage magnetic field should be applied to the high and low voltage windings respectively to apply the ampere balance surface current density to get the correct solution.

Model Simplification Principle

The center line of the three-phase winding meets the requirements of axis symmetry and can be simplified into a two-dimensional model. It can be seen from the boundary conditions of the field quantity on the interface of different media that the magnetic flux leakage line is perpendicular to the core. In order to reduce the number of finite element units, the core column and the yoke are not used as the solution field.

Software Design

Introduction to WPF

WPF is a form graphic display system in C#, and the hit testing for point or 2D graphics data is supported of its visual layer, this feature can be used to determine whether geometry or point coordinates are within the rendering content of a given object, enabling to graphical interaction.

The basis for quickly creating input images are provided by the rich data binding. A method based on XML input and output serialization is provided by .NET language, which can conveniently save and recover complex data objects.

Winding Model Species

An entity class transformer winding obtained via object-oriented analysis and design methods is shown in figure 1. Describes the discrete connections of objects in the software is described and the planning of the different windings for the entire winding is demonstrated in the winding model class association figure. In the physical positioning of the winding conductor ring model, according to the modeling principle, the member variables and attributes in different levels of the transformer winding are planned, and the winding information can be accurately expressed, thus realizing the establishment of the model. The hierarchical structure of the windings is: winding class, layer class, segment class and wire class. The inheritance and polymorphic characteristics are used to realize the establishment of various complex winding conductor ring models.
The physical class of the transformer winding includes a winding class, a layer class, a segment class, a wire class, a transformer class and a winding conductor ring class as an abstract class, and a winding conductor ring is derived as a winding class and a layer class, wherein the layer class is derived as a layer winding, spiral windings, cake-type windings, and wire-like enamels are derived to from flat copper wire class, combined wire class, transposition wire class.

In the figure, the number * indicates a plurality, and 1..* indicates an object corresponding to one or more classes. A transformer winding model contained multiple winding classes. The logic layer of the winding is described by the layer class. For the winding of the middle incoming line, it can be divided into upper logic layers and lower logic layers. For the end incoming winding, it is a logical layer object. The segment class is an imaginary cake of a cake or a cylindrical winding in a pie-shaped winding. Each layer of windings has a plurality of segments, each of which has a one-to-one correspondence, and one of the wire-like objects contains one or more conductor ring objects. The conductor loops are studied with a single wire, while the wire loops are studied with a single wire.

**Interface Class**

The interface class has a main interface class, an input parameter interface class, a display result interface class, and a data storage class shown in figure 2.

![Interface Class Association Diagram](image-url)

Figure 1. Winding model class association figure.

Figure 2. Interface Class Association Diagram.
The software toolbar design is seen as the main interface class, the required parameter data input interface for the winding model is established by the input parameter interface class; the display result interface class is the WPF display object, which is the description of the physical space of the wire cross-sectional shape on the WPF, when the graphic amplified to a certain extent, the winding insulation can be well presented; the data storage class uses the storage of the mathematical model data of the winding, in which the MSNL data storage is used.

**Software Interface and Function**

The design idea of the leakage magnetic field calculation software for the power transformer winding described in this paper is: C# language and WPF is applied to design and develop the software interface. When user inputs the necessary design parameters, the structure and material parameters in the engineering design are processed through the pre-processing program to convert to the parameters required for finite element electromagnetic field calculation firstly; then the transformer winding model according to line is established, and the electromagnetic field of transformer is analyzed by finite element software. According to the analysis of transformer windings, C# programming language is used to develop transformer winding model software, the developed software has unique advantages:

1. Data port development, with good openness.
2. For calculation of ampoule balance problem, different forms of the winding combination can be analyzed.
3. Model has strong applicability and can be used for calculation of different problems to improve calculation accuracy.

The software works on the Windows operating system platform and is suitable for the establishment and drawing of single-phase and three-phase power transformer winding models of various voltage levels. By calling the finite element software, the magnetic field diagram of the electromagnetic field distribution of the transformer can also be drawn.

1. Technical parameter input module: According to the menu requirements, input the transformer related design parameters, such as winding inner diameter, outer diameter, height, wire size, line data, current, etc., which are used for software pre-processing.
2. Preprocessing module: The design data input through the menu is converted into parameters used in the finite element program, such as finite element mesh data calculated by magnetic field, winding ampere distribution, and the like.
3. Result output and display module: The module can complete the reading of finite element calculation result data, winding model and magnetic line diagram display.

**Example Demonstration**

A three-phase dual-winding load-regulating power transformer of the model SFPZ10-180000/220 transformer is taken as an example to maximize the tapping of the transformer.

Table 1. Example Product Winding Parameters.

|                  | Regulated | Low-voltage | High-voltage | Regulating |
|------------------|-----------|-------------|--------------|------------|
| Inner diameter   | 954       | 1030        | 1333         | 1651       |
| Outer diameter   | 990       | 1212        | 1551         | 1695       |
| high/mm          | 1450      | 1520        | 1520         | 1420       |
| Winding turns    | 45        | 95          | 543          | 54         |

Enter the parameters of the above table into the software, and the transformer winding model is established as shown in Figure 3:
The mathematical model is generated by the model built in the example, and the finite element software is called in the background to simulate the leakage magnetic field in the winding region. The magnetic field diagram of the leakage magnetic field can be obtained as shown in Figure 4:

Conclusion
The main implementation method principle and function characteristics of the research is introduced of this paper and the development results of the transformer winding magnetic field simulation modeling software. The hierarchical structure of the winding conductor ring model is
summarized. The engineering practicality and accuracy of the software is verified by the data input software of a power transformer.

(1) The established technical measures are correct and effective, and the functions of convenient use and result display are realized, the data input and modeling are completed quickly, and the image display and interactive code are simplified.

(2) The combination of theory, versatility and engineering usability are embodied in this software, and an interface is provided with other programs, which effectively improves the ability of transformer automatic analysis.

(3) The development of this software provides a model basis for the calculation of related problems such as transformer winding loss and short circuit.

References

[1] Cheng Zhiguang, "Electromagnetic Field Analysis and Verification of Power Transformers", Ph.D. Thesis, Tsinghua University, 1994

[2] Zhou Jianming, finite element integrated simulation method of electromagnetic field and research on leakage magnetic field of large transformer, PhD thesis of Huazhong University of Science and Technology, 1990

[3] Er and Mubayar, Li Yan, Sun Wei, et al. Three-dimensional eddy current field calculation and shielding problem analysis of power transformer. High-voltage electrical appliances, 47 (2011) 69-74.

[4] Wei Ping, Yang Erlong, Liu Renbiao, et al. Research and development of transformer winding model based on WPF[J].Transformer, 53 (2016) 17-21.

[5] Mao Fengchun, Peng Qingjun, Zou Dexu, et al. Study on the Influence of Transformer Geometric Model Fineness on Short Circuit Impact Calculation Based on Finite Element Method. Transformer, 55 (2018) 11-16.

[6] Wang Zezhong. Concise electromagnetic field numerical calculation Beijing: Mechanical Industry Press, 2011. Reference to a chapter in an edited book:

[7] Vasicinsky C B. Theory and calculation of transformers. Cui Lijun, Du Entian, et al. Translation. Beijing: Mechanical Industry Press, 1983. Reference to a chapter in an edited book:

[8] Baoding Tianwei Baobian Electric Co., Ltd., Xie Yucheng. Power Transformer Manual. Mechanical Industry Press, 2014. Reference to a chapter in an edited book: