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Research on the Method of Calculating Short-circuit Voltage for High-voltage Rectifier Transformer for Electrostatic Precipitation by Using the ANSYS Maxwell

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Abstract

The high-voltage rectifier transformer for electrostatic precipitation is a transformer operated under constantly varying load conditions, i.e., no-load, rated, and short-circuit conditions, and it is important to set properly and to calculate the short-circuit voltage in its design to ensure the manufacturing cost of the transformer and safe operation of the transformer. In this paper, we analyzed and compared the calculation methods of leakage reactance traditionally used in transformer design and propose an approach using ANSYS Maxwell to calculate the leakage reactance more accurately. It can investigate an electromagnetic phenomenon happening in the transformer intuitively and can perform the simulation for the practice operating process and the short-circuit test process directly using the ANSYS Maxwell program. In the post-processing, when ANSYS Maxwell has completed a solution because it can apply the various mathematical functions and some of these functions can operate along an entire curve, for example, dev, min, max, integ, avg, rms, and so on, it is afforded every facility for the analysis of the engineering calculations. The accuracy of the proposed method is verified by comparing the proposed method with conventional leakage reactance calculation methods and analyzing the error of the experimental results.

Keywords

High voltage rectifier transformer, Short circuit voltage, Finite element method, Electrostatic precipitation

1. Introduction

The electrostatic precipitator is an essential equipment for thermal power plants, cement plants, chemical plants, and mines.

Its function is to clean the smoke and particulate dust contained in the gas that is discharged from the process, thus improving the environmental pollution caused by the smoke and particulate dust in the gas and improving the quality of air.

The fundamental principle of operation of an electrostatic precipitator is that the particulates are passed through an electric field where they initially receive an electric charge and then, as a charged particle, are deflected across the field to be collected on an earthed plate. A high-voltage rectifier transformer is one of the most important parts of the electrostatic precipitation equipment and is a kind of special transformer [1-6].

Since the high-voltage rectifier transformer for electrostatic precipitation operates in an unsteady state where frequent flashover and harmonic components are relatively high, the structure is specific compared to the conventional transformer, and the requirements for its design, inspection, and protection are all specific.

And when designing this transformer, a structure with a large short-circuit voltage is chosen.

The effect of the magnitude of the short-circuit voltage is the leakage inductance, and research to calculate the leakage inductance in a transformer has been carried out for many years [7-10].

Since the electromagnetic force on the winding during short-circuit and the short-circuit current are very large if the leakage reactance is too small, it is proposed to choose the lower current density in the design, whereas if this value is too large, the winding eddy loss and the stray loss in the structure are increased, so that the temperature rises and, in this case, it is proposed to make the current density lower and improve the cooling system.

Therefore, depending on the magnitude of the leakage reactance, the cost of the transformer will vary and the technical characteristics will change.

In general, the short-circuit voltage for small distribution transformers is more than 2.5% and it for large transformers is more than 20% [11]. Except for the cost of the transformer, the short-circuit voltage should meet the international standards AMSI/IEEEC57.12.00 and IEC60076-1.

For two-winding transformers with short-circuit voltage greater than 2.5%, the value should be±7.5% tolerance and it should be±10% tolerance for transformers with relatively short-circuit voltage less than 2.5% [2].

[1] introduced the traditional methods for the calculation of leakage inductance in power transformers and proposed a new analytical calculation method of leakage inductance combining the results obtained by 2D FEM with a simple analytical method.

In order to calculate the leakage reactance, a simple analytical method was assumed [3, 5]:

(1) The leakage field is dominated by the axial component.

(2) The magnetization along the winding is uniformly distributed.

(3) The permeability of the core is infinitely large.

The method of applying this assumption has been widely used for the calculation of leakage inductance because of its simplicity.

Actually, the leakage field is dominated by the axial component in the winding, while the leakage flux at the end of the winding is represented by the edge flux with the shortest path [11].

When designing this transformer, a structure with a large short-circuit voltage is chosen [12]

Therefore, both axial and radial magnetic field components should be considered in the leakage reactance calculations [4].

Among the methods proposed to include edge flux effects in leakage-induced resistance calculations are the Rogowski method [13] and the Roth method [14].

These methods describe the magnetic vector potential over the entire space as a single Fourier series (Rogowski method) and a double Fourier series (Roth method) [3].

The disadvantage of these methods is that the calculation becomes very complicated when the winding height is different.

A simple method for the Rogowski method is to apply a simple analytical method, called the Rogowski coefficient, to account for the edge flux effect in the leakage reactance calculation [11].

However, this method can achieve good results in the leakage reactance calculation only if the winding heights are the same.

To overcome this limitation, the Steppon method and the imaging method were proposed.

This method is based on an analytical formula for the magnetic vector potential as it assumes that an image of the conductors is placed in the boundary conditions of the problem, and an energy formula is also applied to calculate the leakage reactance for different winding heights [16].

In this case, to reduce the calculation error, the number of layers of the image must be increased, and the computation time is much reduced compared to 2D FEM [13].

However, when the winding geometry is complicated, the number of layers of the image must be increased in order to obtain an accurate solution, so although this method is applied, the computational time is not greatly reduced.

The finite element method is the most widely used numerical solution method for the accurate calculation of leakage inductance for nonstandard winding configurations, and asymmetrical and irregular magnetizing force distributions [17-20].

Since this method directly solves Maxwell's equations, it provides an accurate solution to the problem even when the geometric model is complex [21].

Using ANSYS software, it is possible to analyze a wide variety of problems in the electromagnetic field domain, e.g. inductance, capacitance, flux density, eddy current, electric field distribution, magnetic lines of flux, force, motion effects, electrical circuits, and energy losses, and to efficiently analyze the sightseeing problems of the various equipment including generators, transformers and motors [22-25].

The program provides enough linear and non-linear material substitution, including all directions of isotropic and anisotropic permeability, dielectric constant, B-H characteristic curve of the material, and demagnetization curves of the permanent magnet material.

In addition, due to its post-processing function, the user can display the flux lines and flux density, and calculate the force, torque, terminal voltage, and other parameters [26].

The high-voltage rectifier transformer for electrostatic precipitation is designed and manufactured with the structure in which the rectifier transformer and rectifier circuits are assembled together in one transformer housing, and the high-voltage winding is designed with several stages depending on the withstand voltage condition of the rectifier [27].

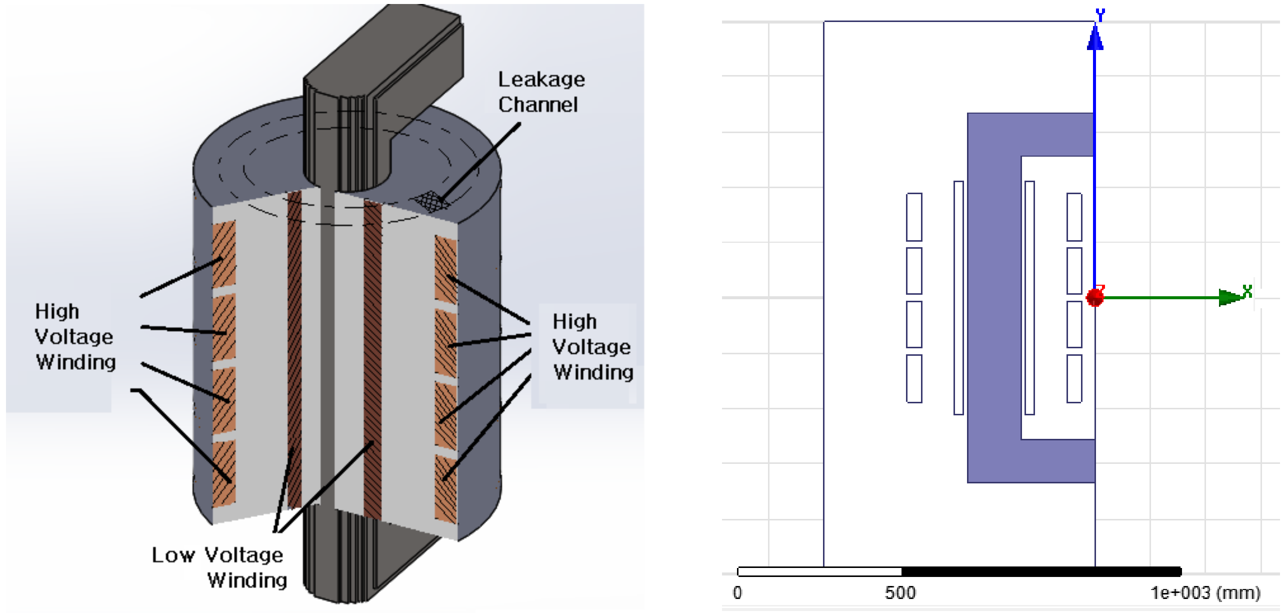
Therefore, it is difficult to calculate the leakage inductance of a high-voltage rectifier transformer consisting of windings with a large number of windings and different winding heights by the conventional calculation method.

In this paper, a method for calculating leakage inductance using ANSYS Maxwell for two-winding transformers with different winding heights and a large number of windings is proposed and compared with the results calculated by applying conventional analytical methods, and the accuracy of the proposed calculation is verified by error analysis with test results.

2. Traditional methods for leakage reactance calculation

In this section, the conventional methods for calculating the leakage inductance of the high-voltage rectifier transformer for electrostatic precipitation are introduced and the error of each calculation method is compared.

For this purpose, the winding dimensions and arrangement relationships of the high-voltage rectifier transformer are fixed as shown in Fig. 1 and Table 1.



a) One-half of 3D model

b) One-half of 2D model

Figure 1. One-half model of high voltage rectifier transformer.

Table 1. Structural dimensions of transformer and winding arrangement

Parameter	Sign	Unit	Value
Core diameter	D	m	0.1
First winding height/width	h_1/w_1	m	0.420/0.176
Second winding height/width	h_2/w_2	m	0.085/0.027
First and second winding turns	N_1/N_2		176/30848
First and second winding gap width	w_g	m	0.058
Second and second winding gap width	w_{22}	m	0.048
Yoke width	w_y	m	0.080
Window height	h_w	m	0.54
Core and first winding gap width	δ	m	0.008
frequency	f	Hz	50

2.1 Calculation method by a simple analytical expression

A simple analytical calculation assumes that the leakage magnetic field is entirely axial between the two windings, and its calculation is carried out only in the region between the two windings [1-5].

In this method, the magnetization is uniformly distributed along the windings, and the windings are treated in the form of an infinitely long solenoid with a concentrated magnetic field [4].

Therefore, the leakage inductance is

$$X_{l12} = 2\pi f \frac{\mu_0 N^2}{h}\left(\frac{l_{m1}w_1}{3} + \frac{l_{m2}w_2}{3} + l_{mg}w_g\right) \tag{1}$$

where f is the frequency, μ_0 is the permeability of free space, and N is the number of turns of the winding relative to the induced resistance and h is the height of the winding.

The winding height is calculated by approximating the average value $h=(h_1+h_2)/2$ for different arrangements.

The average lengths of the two windings are denoted by l_{m1}, l_{m2}, respectively, and w_1, w_2 are the widths of the primary and secondary windings.

And w_g is the gap width between primary and secondary windings.

The average length is denoted by $l_{mi}=2\pi R_{mi}$, where i means 1, 2, and g.

The total leakage inductance calculated for the transformer shown in Fig. 1 and Table 1 is 0.756Ω.

2.2 Method to calculate the simplified Rogowski model

The simplified Rogowski model is applied to take into account the edge flux effect at the end winding by introducing the Rogowski coefficient $K_r(<0)$ [12].

The Rogowski coefficient is calculated as

$$K_r = 1 - \frac{c}{\pi h}\left(1 - e^{\frac{-\pi h}{c}}\right) \tag{2}$$

where c is calculated as follows:

$$c = w_1 + w_g + w_2 \tag{3}$$

In the calculation method by simple analytical expression, h is substituted by calculating the average height of the winding in Eq. (2) when the height of the primary and secondary windings is different, whereas, in the simple Rogowski model, the height h_r corrected by the Rogowski coefficient is calculated and substituted.

$$h_r = h/K_r \tag{4}$$

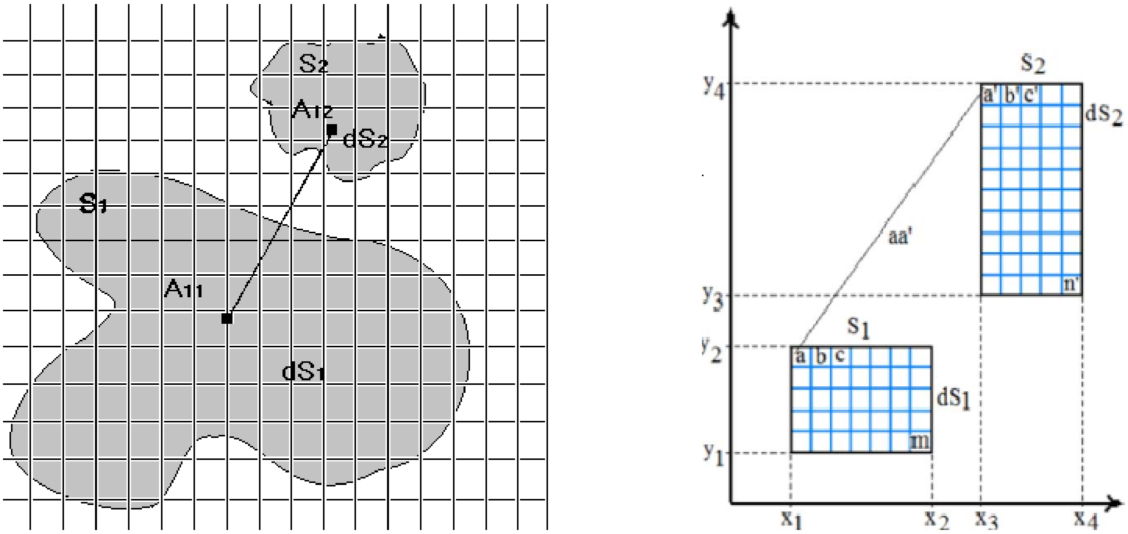
Finally, substituting h instead of h in Eq. (1), we can calculate the magnitude of the reactance considering both the axial and radial components of the leakage flux.

Hence, the total leakage inductance calculated by the simple Rogowski model is 0.78Ω.

2.3 Computational methods using magnetic vector potentials

This method employs the concept of geometric mean distance to determine the flux linkage and represents and computes the magnetic vector potential obtained in the conductors of two windings by an analytical expression.

We consider together the imaging method to take into account the core effect of the transformer.



(a) Given an arbitrary cross section of the conducting element. (b) The cross section of the conductive element is rectangular.

Figure 2. Computational model of geometric mean distance.

Considering any conductor cross-section S_0, the inductance L depends on all flux linkages with the conductor, and the magnetic vector potential A=A_0 bounded by the flux lines is defined as

$$\mathrm{L} = \frac{1}{IS_0}\int (A_0 - A)ds \tag{4}$$

Hence, the flux linkage to any conductive section S_1 shown in Fig. 2 can be calculated as follows if the thickness or depth is bounded by section S_2.

$$\lambda = \frac{D}{S_1}\int (A_{12} - A_{11})\, dS_1 \tag{5}$$

where A_{12} is the magnetic vector potential at any point inside the section S_2 by conductor S_1 and A_{11} is the magnetic vector potential generated by the conductor S_1 at one point in section S_1 by itself.

The magnetic vector potential generated in a conductor with a very small cross-section is [7].

$$\mathrm{A} = \frac{\mu \cdot I}{2\pi}\ln(r) \tag{6}$$

Therefore, for a conductor with a rectangular cross-section, the magnetic vector potential is:

$$\mathrm{A} = \frac{\mu \cdot I}{2\pi S}\int_0^p \int_0^q \frac{1}{2} ln[(x' - x)^2 + (y' - y)^2]dx'dy' \tag{7}$$

where r is the radial distance from the point (x', y') of the conductor to the point of interest (x, y) in the Cartesian coordinate system.

P and q are the width and height of the rectangular conductor so$S = p \cdot q$.

Substituting Eq. (7) into Eq. (5), the flux linkage to the conductor S_1can be expressed as

$$\lambda = \frac{\mu \cdot IDN_1^2}{2\pi S_1 S_2}\iint \frac{1}{2} ln\left[(x'_2 - x)^2 + \left(y'_2 - y\right)^2\right] dS_1 dS_2 - \frac{\mu \cdot IDN_1^2}{2\pi S_1 S_1}\iint \frac{1}{2} ln\left[(x'_1 - x)^2 + \left(y'_1 - y\right)^2\right] dS_1 dS_1 \tag{8}$$

In order to solve the quadruple integral such as Eq. (8), it is necessary to simplify the expression by introducing the concept of geometric mean distance.

$$ln(\mathrm{dmg}) = \frac{1}{S_1 S_2}\iint ln(r) S_1 dS_2 \tag{9}$$

The geometric mean distance shown in Eq. (9) can be expressed analytically in the form of a continuous model and a discrete model, from which the flux linkage of conductor S_1 can be expressed as

$$\lambda = \frac{\mu\cdot \mathrm{D} N_1^2 I}{2\pi}[\ln(dmg_{12}) - \ln(dmg_{11})] \tag{10}$$

Therefore, the inductance and leakage inductance of the high-voltage and low-voltage windings in the two-winding transformer are as follows:

$$\mathrm{X}_{d1} = \omega L_{d1} = \frac{\omega\cdot\mu\cdot \mathrm{D}_e N_1^2}{2}[\ln(dmg_{12}) - \ln(dmg_{11})] \tag{11}$$

$$\mathrm{X}_{d2} = \omega L_{d1} = \frac{\omega\cdot\mu\cdot \mathrm{D}_e N_2^2}{2}[\ln(dmg_{21}) - \ln(dmg_{22})] \tag{12}$$

In general, short-circuit tests are carried out at the high-voltage side, so it is advantageous to calculate the leakage inductance at the high-voltage side as well.

Assuming thatdmg12=dmg21, the following result is obtained by substituting Eq. (11) and (12) into Eq. (13):

$$\mathrm{X} = \frac{\omega\cdot\mu\cdot \mathrm{D}_e N_{HV}^2}{2}\ln\left(\frac{{dmg_{12}}^2}{dmg_{11}dmg_{22}}\right) \tag{14}$$

Hence, the total leakage inductance calculated using the simple magnetic vector potential is 0.842Ω.

2.4 Calculation of leakage inductance by FEM

There are numerous examples of using Finite Element Method (Finite Element Method) to calculate the leakage inductance of a transformer.

In this paper, the methods are introduced and compared, but some specific methods of calculation are applied to calculate and compare the leakage inductance of a high-voltage rectifier transformer with the parameters listed in Table 1.

In [1], by combining the results obtained by 2D FEM and the calculation method by means of a simple analytical expression, a method is proposed to calculate the exact leakage inductance values for different heights and configurations of the two windings.

We use the conversion factor *c* to the leakage inductance calculated by the simple analytical expression used in the case of equal winding height, where the conversion factor *c* is expressed as

$$\left.\begin{aligned} X'_{l12} &= X_{l12}(1+\mathrm{c}) \\ c &= \frac{u^2}{a^2} + \frac{v^2}{b^2} \\ \mu &= \frac{\sqrt{2}}{2}\left(\frac{h_1}{h_w} - 1\right) + \frac{\sqrt{2}}{2}\left(\frac{h_2}{h_w} - 1\right) \\ \nu &= \frac{\sqrt{2}}{2}\left(\frac{h_1}{h_w} - 1\right) - \frac{\sqrt{2}}{2}\left(\frac{h_2}{h_w} - 1\right) \end{aligned}\right\} \tag{15}$$

Where variables μ and ν are determined using a parabolic curve and variables *a2 and* b^2 indicate the radius of parabolic function and are determined through a multiple linear regression model.

The determination of variables a^2 and b^2 is carried out through the performance of the two-dimensional FEM simulation with winding widths w_1, w_2, and gap widths w_g between windings and window widths w_w, from which a multiple linear regression model is constructed.

$$\left.\begin{aligned} a^2 &= \alpha_1\frac{w_1}{w_w} + \alpha_2\frac{w_2}{w_w} + \alpha_3\frac{w_g}{w_w} \\ b^2 &= \beta_1\frac{w_1}{w_w} + \beta_2\frac{w_2}{w_w} + \beta_3\frac{w_g}{w_w} \end{aligned}\right\} \tag{16}$$

where the coefficients α_1, α_2, α_3, β_1, β_2, β_3 are determined using the numerical values obtained from the Eq. (1), (15), (16) and the result from 2D FEM.

The leakage inductance of the high voltage rectifier transformer calculated by this method is 0.847Ω.

In [5], a method for calculating leakage inductance is proposed by applying hybrid FEM and 3D FEM, respectively.

The total energy stored in the magnetic field of the model is calculated as

$$\mathrm{W} = \int_V \frac{B\cdot H}{2}dV = \int_V \frac{|B|^2}{2\mu}dV \tag{17}$$

Using this energy, the leakage inductance from the secondary side is calculated as follows:

$$L_l = \left(\frac{n_2}{n_1}\right)^2 L_{l1} + L_{l2} = \frac{2W}{i_2^2} \tag{18}$$

where L_{l1}, L_{l2} are the leakage inductances of primary and secondary windings, and the leakage inductance is $X_l=2\pi f L_l$.

Hybrid FEM is an analytical method that combines two-dimensional analysis and axisymmetric two-dimensional analysis, combining two-dimensional Cartesian coordinates (x, y) and axisymmetric coordinates (r, ζ) to reduce the computational cost, taking into account both the end-winding and core effects.

The leakage inductance calculated with the hybrid FEM is 0.846Ω, and the leakage inductance calculated with the 3D FEM is 0.842Ω.

Table 2 summarizes the leakage reactance values calculated by the above methods.

Table 2. Leakage inductance of high voltage rectifier transformer

Method / Parameter	Simple analytical method	Rogowski model	Magnetic vector potential method	Analytical equation+ FEM	Hybrid FEM	3D FEM
Leakage inductance, Ω	0.756	0.78	0.842	0.847	0.846	0.842
Short-circuit voltage, %	19.377	19.993	21.58	21.71	21.68	21.58

As shown in Table 2, the maximum error of leakage reactance calculated by the six methods is 13.5% and the minimum error is 3.1%.

3. Calculation of leakage inductance and short-circuit voltage using ANSYS maxwell

A high-voltage rectifier transformer is designed with the structure of a single-phase transformer, with two legs of the core.

The primary winding is placed close to the core leg as a low-voltage winding, and the secondary winding is placed outside the primary winding as a high-voltage winding.

Considering the withstand voltage condition of the rectifier used in the configuration of the rectifier circuit, four secondary windings are placed at each end of the core.

The ANSYS Maxwell program is a finite element analysis program of the electromagnetic field, which is widely applied in the world, and is a powerful electromagnetic field analysis tool that allows accurate calculation of the electromagnetic parameters of complex structures.

In this section, ANSYS Maxwell is used to calculate the leakage inductance of a high-voltage rectifier transformer and to estimate the percentage of short-circuit voltage.

3.1 Construction and meshing of the ANSYS Maxwell analytical model

The 3D FEM reflects the actual model, so the accuracy of the calculation results increases, but there is a disadvantage that the computation is done halfway and the results are not displayed if the computation time is long and the computer performance is low.

Therefore, it is very important to simplify the analytical model and perform the mesh efficiently.

In the ANSYS Maxwell program, the Set Symmetry Multiplier command is used to automatically apply the number of symmetries to all inputs and outputs, and the computational time can be reduced by simplifying the model to an electromagnetically symmetric structure and setting the symmetrical boundary conditions.

In this paper, the real model is simplified to a 1/2 model as shown in Fig. 3 and the electromagnetic field analysis is carried out.

The mesh is manually meshed using the Maxwell3D/Mesh/Operations/Assign/Inside Selection/Length Based command, the valve corresponding to the height of the low-voltage winding is selected and the maximum length of the element is chosen to be 0.5 mm to improve the calculation accuracy in the leakage channel. Figure 4 shows the results of manual meshing.

As shown in Fig. 4, the meshes of the primary and secondary windings are 1/5 times denser than those of the core, and the total meshes are around 4.5 million.

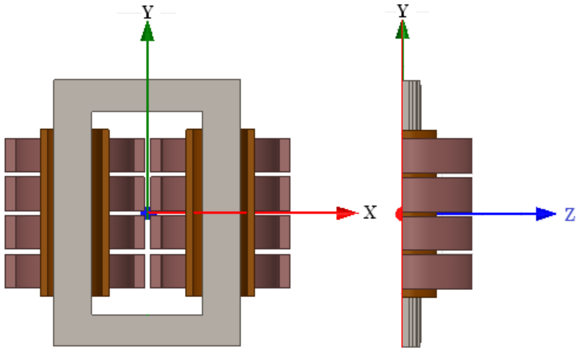


Figure 3. 3D FEM analysis model of high voltage rectifier transformer

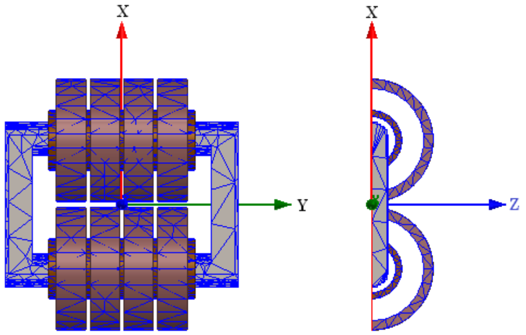


Figure 4. Segmentation for 3D FEM analysis.

3.2 Calculation of leakage inductance by two-dimensional magnetostatic field analysis

In general, if the magnetization of the primary and secondary windings in a transformer is equal in magnitude and opposite in direction, all the magnetic flux present in the transformer becomes the leakage flux.

Therefore, the leakage inductance is calculated by calculating the leakage inductance in terms of the current flowing through the winding after a three-dimensional magnetostatic field analysis under the same magnetic field of the primary and secondary windings [6].

When the primary winding current of the high voltage rectifier is 97.4A, the results of analyzing the leakage magnetic field are shown in Figs. 5-6.

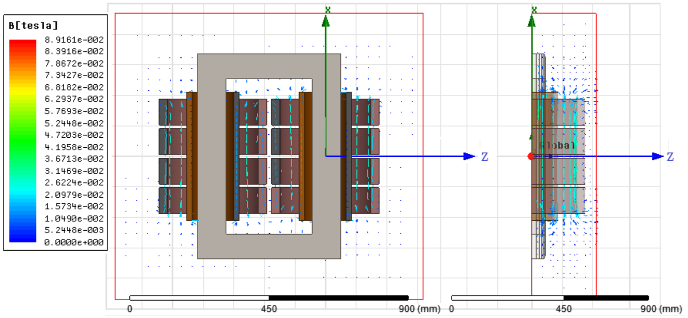


Figure 5. Leakage magnetic field vector diagram of high voltage rectifier transformer.

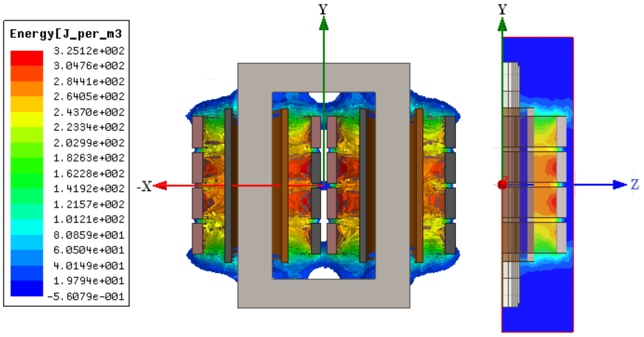


Figure 6. Concentration of leakage magnetic energy in a high voltage rectifier transformer.

As shown in Fig. 6, the maximum magnetic field energy is found in the leakage space between the secondary winding and the primary winding in the middle position in one leg of the core, which is 325 J/m3.

Fig. 7 shows the flux density distribution in the leakage space.

As shown in Fig. 7, winding 1 and winding 4 near the yoke has an edge effect of flux at the end, so that the inner diameter of the primary winding and the secondary winding has a constant magnitude of magnetic field at the outer end.

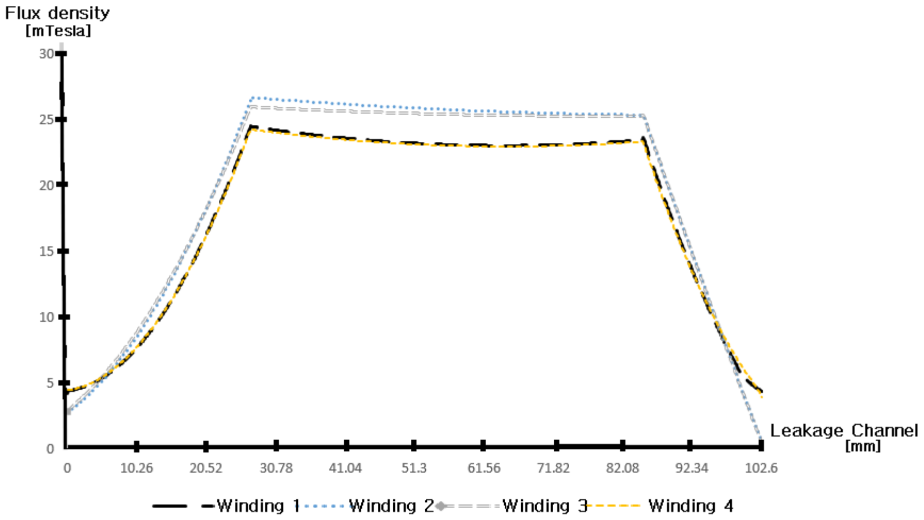


Figure 7. Magnetic field distribution in the leakage channel.

In addition, the flux density in the leakage space of winding 2 and winding 3 in the middle position of the iron-core bridge is maximized and its value is around 25mT.

Since the total volume of the leakage channel in the high-voltage rectifier transformer simulated by ANSYS Maxwell software is 0.04 m^3, using Eq. (18), the leakage inductance is 2.74mH and the leakage inductance is 0.861 Ω.

The second order is 413.28Ω.

Calculating the short-circuit voltage from the magnetic field energy is

$$U_k = \frac{4 * \pi * f * W}{S} = \frac{4 * 3.141592 * 50 * 325 * 0.04}{37020} = 0.2206$$

Using the ANSYS Maxwell program, the three-dimensional magnetostatic field analysis is carried out, the leakage reactance is obtained, and the short-circuit voltage of the high-voltage rectifier transformer considering the effective resistance reflecting the short-circuit loss is 22.06%.

3.3 Review calculation of short-circuit voltage by transient electromagnetic field analysis

The ANSYS Maxwell program has a field-circuit coupled analysis function, so the transient electromagnetic field analysis in electrical machines can be carried out in a simple way.

Using this analytical function, the electromagnetic parameters of the transformer, including no-load current, no-load loss, short-circuit voltage, etc., of the high-voltage rectifier transformer can be calculated accurately.

If the leakage inductance of a high-voltage rectifier transformer is calculated based on the above method, the short-circuit voltage can be approximately calculated, but it has a certain error due to not considering the effective component of the short-circuit impedance.

In this section, we describe how to obtain an accurate calculation of the short-circuit voltage considering the effective component of the short-circuit impedance based on transient electromagnetic field analysis.

The transient electromagnetic field analysis model and mesh are used as shown in Figs. 3 and 4.

In the period of load condition, the primary and secondary windings are selected to excite in the external circuit coupling mode.

The external circuit and its parameters applied to the primary and secondary windings are shown in Fig. 8.

In Fig. 8, the equivalent resistance of the primary circuit is 1.58mΩ, and the equivalent resistance of the secondary circuit with “winding 3” is chosen to be 100μΩ, since the transient electromagnetic field analysis is carried out with one circuit in the secondary circuit.

If the current of the short-circuited secondary circuit is rated as a stable short-circuit current, the voltage applied to the primary circuit is determined by the short-circuit voltage, and the percentage of the rated voltage is calculated.

Using the ANSYS Maxwell program, the time to reach the stable short-circuit current is about 4s, with the maximum value of the primary winding voltage applied being 130.3V, and the percentage of rated voltage is 22.4%.

Finally, the error of the short-circuit voltage obtained by transient electromagnetic field analysis and the short-circuit voltage obtained by 3D magnetostatic field analysis is 0.2%.

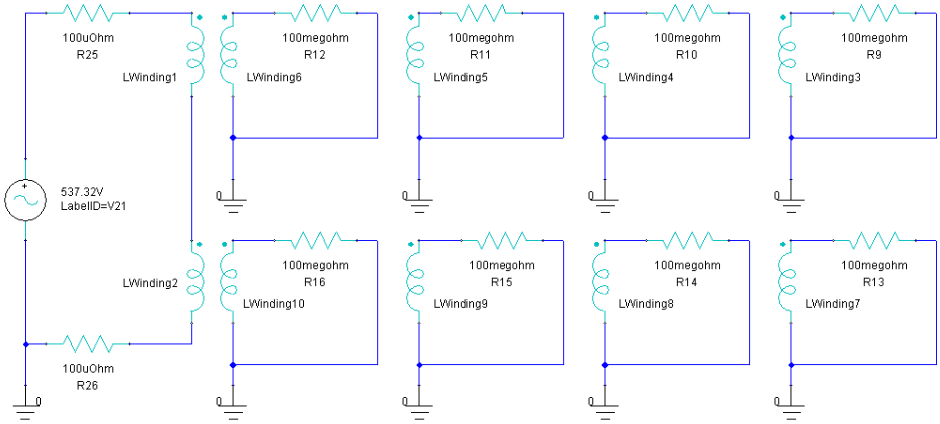


Figure 8. External circuit and parameters.

According to the method proposed in [23], a short-circuit experiment with a large number of secondary windings is carried out and compared with the experimental and calculated values.

Since the short-circuit voltage ratio obtained through the short-circuit experiment is 22.2%, the error with the calculated value is 0.89% and is satisfied with the International Standard Regulation IEC 60076-1, the proposed method can be applied to calculate the leakage inductance and short-circuit voltage of the transformer.

4. Conclusions

This paper, it is described the calculating method of the leakage inductance and short-circuit voltage for the HV rectifier transformer.

As above mentioned, the values of leakage inductance and short-circuit voltage of transformers are very important parameters of the characteristic and the manufacturing cost, there are many methods to calculate them, and working on them calculated quickly and accurately for years.

It compared the result based on the usual method with one based on the proposed method, also with the one based on short-circuit test. The result of the analysis shows that the ANSYS Maxwell program is a more precise and easy method for calculating the leakage inductance and short-circuit voltage of the transformers.

Using the ANSYS Maxwell program, it can be investigate an electromagnetic phenomenon happening in transformer intuitionally and can perform the simulation for the practice operating process and the short-circuit test process directly. In the post-processing, when ANSYS Maxwell has completed a solution, because it can apply the various mathematical functions and some of these functions can operate along an entire curve, for example, deriv, min, max, integ, avg, rms and so on, it is afforded every facility for analysis of the engineering calculations.

In the future, when the performance of computers is improved and the technique that the transformer actual model is replaced into a simple simulation model is introduced, it is expected that the proposed method will be more effective in accurately calculating the leakage inductance and short-circuit voltage in transformers with more complex winding arrangements in a faster time.

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