Converter Transformer Valve Winding DC Field Analysis of Nonlinear Anisotropic

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Abstract—Due to the resistivity of insulating materials with nonlinear and anisotropic, in the computation of converter transformer value side winding DC field need to take into account the insulation material nonlinear and orthogonal anisotropy. The author uses the ANSYS secondary development technique, calculated by considering insulation resistivity with the field strength and temperature change of the nonlinear DC field and nonlinear anisotropic dc field. Calculation results show that considering the insulation resistivity under the condition of nonlinear and anisotropic, the distribution of electric field and not to consider that conditions are quite different. Therefore, the converter transformer valve side winding DC field should be according to the nonlinear anisotropic field calculation.

Keywords- Converter transformer; the anisotropic; nonlinear; valve side winding; the electric field

I. INTRODUCTION

As the Chinese people's living standard greatly increased and the rapid economic growth, people increasingly high dependence on energy. Among them, all of the energy consumption in the secondary energy consumption proportion is increasing. So, how high-quality, reliable power to the user has become an important issue to be considered by the national electricity sector. Power for China, there has been a problem rational allocation of long-distance transport is essential. Converter transformer is one of the key equipment of the transmission system, as well as the weak link in the insulation system. Therefore, it is necessary to conduct in-depth research. Author of converter transformer value side winding DC field has carried on the detailed and thorough research.

II. THE BASIC PRINCIPLE OF THE CONVERTER TRANSFORMER

A. Introduction of converter transformer

In long distance transmission line converter transformer is considered to be one of the most critical components, often used as the main transformer [1]. The main role of the converter transformer is in operation with the converter valve with each other to complete the conversion of AC power transmission and DC.

There are many types of the connection mode of high voltage DC, one of the current common mode as shown in Fig .1.

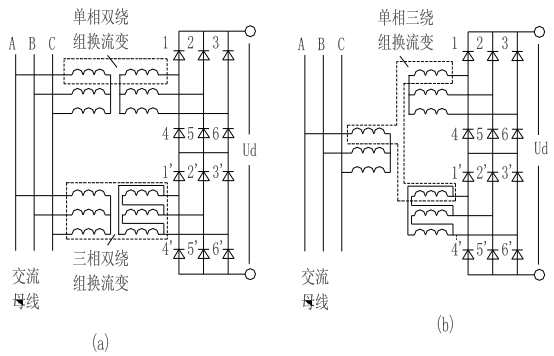

Figure 1. Common connection mode of Dc transmission system

Two single composite form a bipolar, the construction scale and the size of the dc voltage grade of general type of converter transformer can be determined. [2]For the choice of its model in addition to the voltage level, capacity and other professional data, should also pay special attention to the transport of size, when the dc transmission capacity is bigger per two groups of the basic level in the connection mode of flow unit [2-4].

B. The characteristics of the converter transformer

The same as the common power transformer, converter transformer insulation system includes transformer oil and insulation board. But under the effect of high voltage dc voltage, the electric field distribution of converter transformer insulation system depends on the electrical conductivity of insulation materials, instead of dielectric constant. The transformer oil and the electric field intensity of insulating board is related to the resistivity, humidity and temperature, the performance is nonlinear.

The influence of the laminated technology of converter transformer insulation board of resistivity, exists in the laminated and vertical direction the anisotropy. Therefore, in the solution of converter transformer value side winding dc field should be according to the nonlinear anisotropic field calculation [5].]

III. *NONLINEAR DIRECT CURRENT FIELD CALCULATION METHOD*

A. *Considering the influence of electric field intensity on the resistivity*

In actual for rheological run, the resistivity of insulating medium change with insulating medium temperature, humidity, especially the electric field. In operation, the converter transformer space of the electric field intensity affects the resistivity of insulating medium, the resistivity of insulating medium has changed, the electric field intensity changes of the space, so the iterative procedure can be used to simulate the interaction of the process. [43]When calculating the nonlinear dc field, adopts the secondary development of ANSYS software technique, the ANSYS parametric design language. The basic idea is through iterative method, using * VGET command will be the first to solve the field intensity of saved as an array, the array is used to calculate the resistivity of each finite element unit. Then using EMODIF command to change of each finite element unit resistivity[6]. In circulation, until meet or iteration precision reaches the maximum number of iterations. Fig.2. Program block diagram are presented.

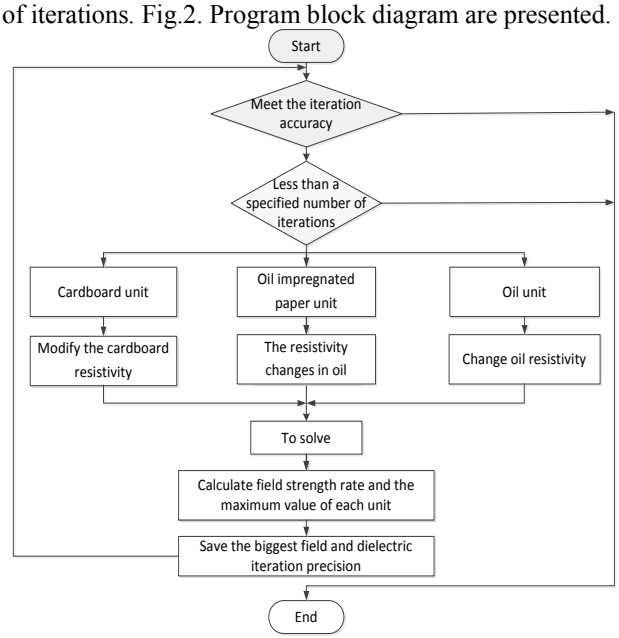

Figure 2. The flow chart considering the effect of electric field intensity on the resistivity

In the iterative calculation, the convergence criterion is reasonable or not directly related to the calculation accuracy and the number of iterations. A good convergence criterion should not only satisfy the requirement of accuracy and minimize the number of iterations, should also be independent of the field of subdivision. There are so many choices insulated electric field calculation in the paper: from field measured criterion (object), preferable potential, field intensity, regional electric conductivity rate; from the algorithm has a variety of ways. Here, as the field strength E is the focus of the concern, therefore, E as criterion of object, considering the independence of the criterion, the algorithm on the unit field strength E on the basis of the maximum rate of change. $\max\left[\frac{E'_{k+1}-E_k}{E_k}\Big|_{k=1\to N}\right]\% \le E_{\max}$, K as the number of iterations, $E_{\max}$ as the maximum field strength of the rate of change. Among them, $E'_{k+1}=E_k+\omega(E_{k+1}-E_k)$, E_{k+1}, E_k respectively the k + 1, the first k iteration of the field intensity value, ω as owe relaxation convergence factor[7].

B. *Introduction of Simulation Model*

This paper uses the calculation model for $\pm$500 kV winding end model of converter transformer, model structure as shown in Fig .3

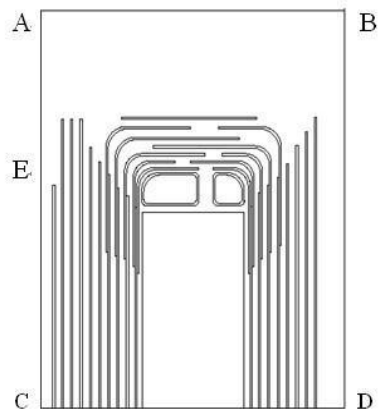

Figure 3. The computational model for converter transformer through simplified

C. *Determination of Boundary Conditons*

Based on the converter transformer actual assessment standards, AB section of calculation model for iron yoke part, calculation boundary value is zero potential, under the tank wall and web winding is equivalent to CE, when calculate the exchange converter transformer, the valve side winding and high voltage electrostatic ring, so the CE period should be set to zero potential. Electrostatic ring part of the valve side is set to high potential, for a class of boundary. Upper left for web section, on the right side of the part of electrostatic, Ring above AE BD and underside CD as the second class boundary[8].

D. *Determination of Test Voltage*

According to GB/T18494.2-2007, for the applied dc voltage tolerance test, and add the test voltage at the end of converter transformer value side winding:

$$U_{\mathrm{dc}}=1.5[(N-0.5)U_{\mathrm{dm}}+0.7U_{\mathrm{vm}}]\ . \tag{1}$$

Among them, U_{dc} as Converter transformer valve side winding dc test voltage applied, N as the amount of six

bridges, U_{dm} is the highest dc voltage of each valve bridge, U_{vm} as Valve side winding and the maximum working voltage, according to the test standard to determine the value of 643 kv[9].

E. Results Analysis

Analysis of electric field intensity impact on resistivity.When computing the relative dielectric constant of transformer oil is 2.2, the relative dielectric constant of oil impregnated paper and board of 3.3 and 4.4, resistivity of transformer oil is $\sigma_1 = 1.0 \times 10e^{12} S/m$, the resistivity of oil impregnated paper for $\sigma_2 = 5 \times 10^{13} S/m$, resistivity of insulating board is $\sigma_3 = 1 \times 10^{14} S/m$, the assignment of each medium resistivity, the nonlinear state, all as initial value of resistivity, the electric field intensity of nonlinear using formula $\sigma_1 = \sigma_{10} e^{0.011E}$, $\sigma_2 = \sigma_3 = \sigma_{20} e^{0.05E}$ the influence of the type of E as the field strength, the unit is kV/mm,25°C,E=0kV/mm insulation board and transformer oil resistivity estimates[45]. Fig. 4 and Fig. 5 respectively insulation resistivity at constant nonlinearity and resistivity distribution of equipotential line that converter transformer value side.

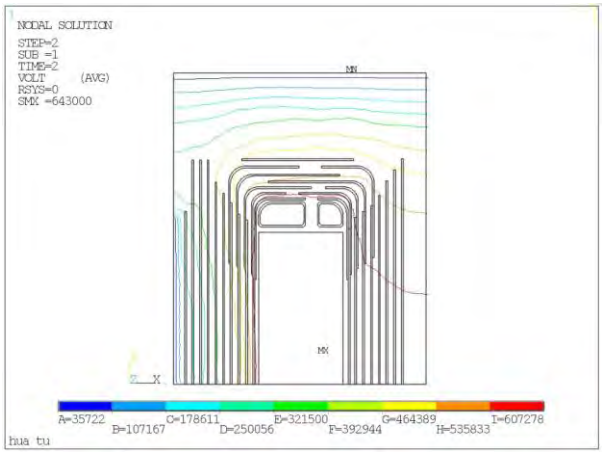

Figure 4. Potential profile of the insulation medium resistivity in nonlinear

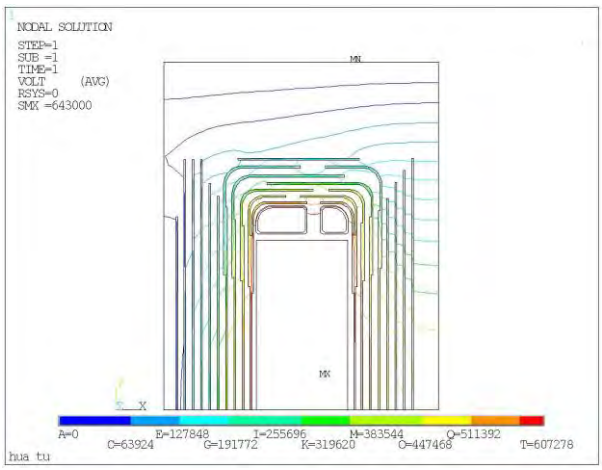

Figure 5. Potential profile of the insulation resistivity in linear

Comparing Fig. 4 and Fig. 5 you can see, considering the resistivity of nonlinear, equipotential line of oil increased significantly, due to the direct current field, the field strength is determined by the medium resistivity, indicated that the nonlinear medium resistivity changes, the electric field produced very big change, because the resistivity of oil impregnated paper and cardboard than oil resistivity of 50 times and 100 times greater, respectively, so the maximum field strength still appeared in the board, but oil of distortion is more serious, caused field intensity increases[10-12].

Considering dielectric nonlinearity, The location of the maximum field strength appeared with same linear, but in the oil field intensity is 5.73 kV/mm than that without considering nonlinear resistivity of 4.86 kV/mm, oil impregnated paper insulating board and the electric field intensity is 25.89 kV/mm, 36.43 kV/mm than that without considering nonlinear resistivity of 26.56 kV/mm, 38.77 kV/mm to small, show that in considering the nonlinear medium resistivity of field intensity change, oil field strength of the increase, it's also a place where attention should be paid to the insulation. Given in table I considering the resistivity nonlinear dielectric field strength results.

TABLE I. FIELD STRENGTH RESULTS OF THE INSULATION MEDIUM CONSIDERING RESISTIVITY NONLINEAR

Insulating medium	Transformer oil	Oil impregnated paper	Insulation board
Linear dc electric field	4.85	26.54	38.76
Nonlinear dc electric field	5.72	25.87	36.42

Analysis the influence of temperature on the resistivity .In practical problems, in addition to the field intensity, the change of temperature and humidity can also affect the resistivity, make its produce nonlinear[46].However, the effects of temperature on material resistivity is not certain, different materials, the influence of temperature on the resistivity is different, for the metal conductor, with the increase of temperature of material resistivity can present downward trend, in a word, when the temperature within a certain range, the temperature and resistivity are related [47].

Ac voltage in the state of the resistivity of insulating medium can be regarded as constant, but in the dc function, the resistivity of insulating medium is often due to electric field intensity, the change of factors such as temperature and humidity changes, generally uses the iterative algorithm for solving this problem[48049]. Set $\sigma_1 = \sigma_{10} e^{0.0571T}$, $\sigma_2 = \sigma_{20} e^{0.016E+0.0978T}$, E as the field strength, the unit is kV/mm, σ_{10}, σ_{20} is 25°C, respectively, E =0kV/mm insulation board and transformer oil resistivity estimates [50]. Figure 7 shows the considering linear temperature converter transformer isotherm distribution [13].

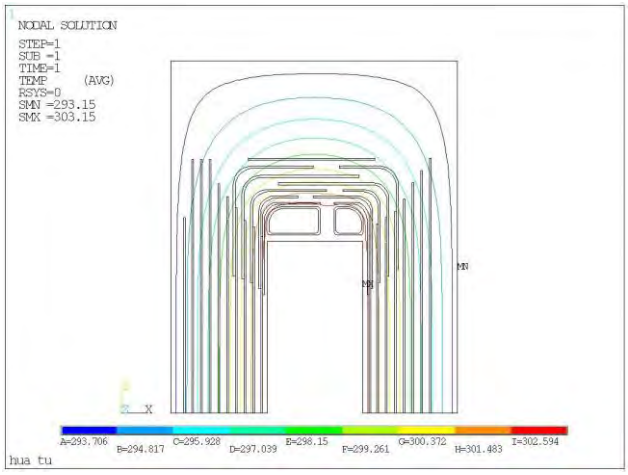

Figure 6. Isotherm distribution of converter transformer considering the linear temperature

Comparing consider the effect of temperature and field nonlinear on the resistivity, and only considering the influence of the nonlinear electric field strength on the resistivity, for the former, the maximum electric field strength kV/mm increased from 4.86 to 5.32 kV/mm, maximum field strength in the oil impregnated paper kV/mm drop from 26.56 to 24.25 kV/mm, maximum field strength of insulating board by 38.77 kV/mm down to 35.25 kV/mm.

Due to the nonlinear influence of temperature, the maximum field strength increases, in transformer oil on insulation strength itself has a high burden of transformer oil, the oil impregnated paper and cardboard, however the maximum field strength is decrease, the temperature is relatively high, the field strength decrease.

TABLE II. FIELD STRENGTH RESULTS OF THE INSULATION MEDIUM CONSIDERING RESISTIVITY AND TEMPERATURE NONLINEAR

Insulating medium	Transformer oil	Oil impregnated paper	Insulation board
Linear DC electric field	4.85	26.53	38.76
Nonlinear DC electric field	5.31	24.23	35.23

Analysis of anisotropic DC field.This article adopts the resistivity of insulating board level on paper, and set σ_h as $0.8\times10^{14}\Omega\cdot\mathrm{m}$, σ_t is $0.5\times10^{14}\Omega\cdot\mathrm{m}$,as the vertical resistivity of paper. Figure 8 and figure 9 shows the dc voltage insulation medium under the action of various members of the opposite sex equipotential line distribution and electric field intensity distribution of cloud.

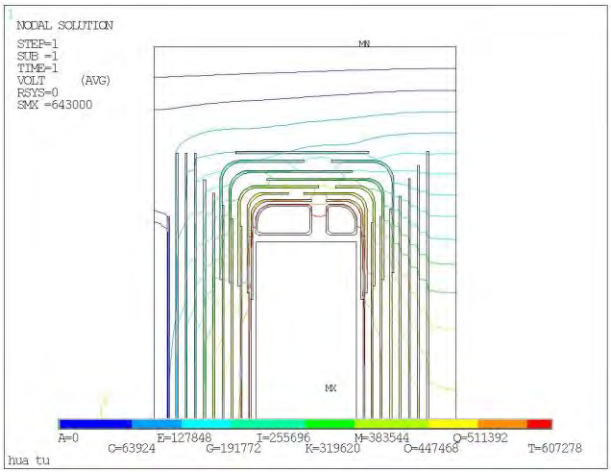

Figure 7. Potential line of insulation medium in anisotropic DC voltage

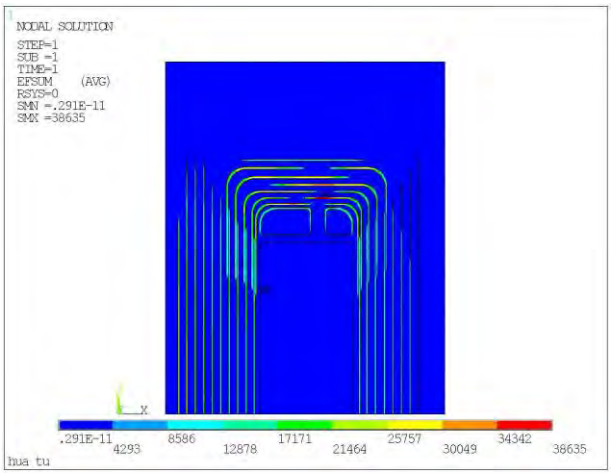

Figure 8. Electric field intensity nephogram of insulation medium in anisotropic under DC voltage

The Fig. 8 shows that under the effect of DC field, compared with isotropic dielectric anisotropy, they almost unanimously of the distribution of potential line account isotropic dielectric heterosexual little impact on the distribution of equipotential line;

The Fig. 5, it can be seen that consider dielectric anisotropy, the maximum field strength of converter transformer from 38.77 kV/mm down to 38.64 kV/mm, change is very small, the location of the maximum field strength appeared also did not change, so the dielectric anisotropy, the converter transformer little influence upon the electric field strength and potential distribution [14-15]. Table III shows the different medium isotropic anisotropic field maximum field strength.

TABLE III. FIELD INTENSITY VALUE CONSIDERING INSULATION MEDIUM ANISOTROPIC

Insulating medium	Transformer oil	Oil impregnated paper	Insulation board
Isotropic electric field	4.85	26.54	38.75
Anisotropic electric field	4.82	26.41	38.63

IV. CONCLUSION

Through the analysis and calculation, we can get the following conclusion:

1) Considering nonlinear dielectric properties, first consider the effects of electric field intensity on the resistivity, considering nonlinear dielectric resistivity, the location of the maximum electric field strength in the same as the resistivity at constant, but in the oil field intensity is 5.73 kV/mm bigger than that without considering nonlinear resistivity of 4.86 kV/mm, cardboard and oil-immersed paper in the electric field intensity is 36.43 kV/mm, 25.89 kV/mm smaller than that without considering nonlinear resistivity of 38.77 kV/mm, 26.56 kV/mm.

2) Considering the influence of temperature on the insulating medium resistivity, due to the effect of temperature, maximum field strength of transformer oil was increased, which demand high levels of insulation oil to produce for itself the burden, and in the oil impregnated paper and cardboard, maximum field strength is reduced, where the temperature is relatively higher, medium field intensity are common less.

3) Only consider dielectric anisotropy, the maximum field strength of converter transformer from 38.77 kV/mm down to 38.64 kV/mm, change is very small, the location of the maximum field strength appeared also did not change, so the dielectric anisotropy, the converter transformer little influence upon the electric field strength and potential distribution.

4) Dielectric anisotropy, keep the resistivity in horizontal and vertical direction of paper on the same ratio, but with the direction of the initial value increases gradually, less and less oil medium bit line distribution, and the distribution of equipotential line in the board is more and more intensive, field strength is also trend to gradually rising.

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