Numerical Analysis of Transient Electromagnetic Radiation Field in GIS Electronic Instrument Transformer Under VFTO Excitation

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For revealing the electromagnetic radiation coupling interference mechanism and its influence factors of gas insulated switchgear (GIS) electronic instrument transformer under very fast transient overvoltage (VFTO) excitation during the operation of disconnector, the transient electromagnetic radiation field in a 220 kV GIS electronic instrument transformer is modeled and calculated by implicit finite element time domain (FETD) method. The primary sensor and metal acquisition box of electronic instrument transformer is separated by the epoxy resin terminal board disc, and the waveform of VFTO is obtained from physical tests. The results show that when VFTO excitation source is 1.25p.u., the transient electric field intensity and magnetic field intensity both far exceed the existing electromagnetic compatibility test standards, inducing a strong radiation coupling interference on electronic instrument transformers. Transient electromagnetic field distribution under different diameters of the terminal board disc and connecting lengths is analyzed. The results show that electric shielding effectiveness is 27.16 dB and magnetic shielding effectiveness is 26.07 dB when the diameter of the terminal board disc is reduced from 80 mm to 40 mm. When the connection length is increased from 30 mm to 90 mm, the electric shielding effectiveness is up to 23.04 dB, and the magnetic shielding effectiveness is 14.13 dB.

***Index Terms*—instrument transformers, electromagnetic radiative interference, electromagnetic transients, time-domain analysis**

I. Introduction

With the advantages of small size, simple insulation, and high anti-saturation performance, electronic instrument transformer has been applied to the intelligent substations. However, since GIS electronic instrument transformer is close to conductor pole, it's extremely vulnerable to electromagnetic interference caused by VFTO during disconnector operation, eventually leading to acquisition circuit breakdown, signal distortion, and other failures.

Electromagnetic interference induced by VFTO is mainly divided into conduction coupling interference and radiation coupling interference. Most of former research on interference of VFTO to electronic instrument transformer is focused on conduction coupling interference [1], and the mechanism and suppressing measures of VFTO [2]-[4]. There is little research on radiative interference of electronic instrument transformer. Therefore, this paper establishes the numerical calculation model of GIS electronic combined instrument transformer based on the implicit FETD method, and calculates the VFTO transient electromagnetic field distribution inside the metal acquisition box. In order to propose the suppression measures of electromagnetic radiative interference, we analyze the factors that affect the distribution of transient electromagnetic fields in the electronic instrument transformer, including the diameter of the terminal board disk and the connecting length between the metal acquisition box and GIS enclosure.

II. Modeling of Electronic Instrument transformer

A. GIS electronic combined instrument transformer model

The simplified model of a 220 kV GIS electronic combined instrument transformer is shown in Fig. 1(a). The primary sensor element and metal acquisition box of GIS electronic combined instrument transformer is separated by the terminal board disc, as shown in Fig. 1(c), which is made of epoxy resin without electromagnetic shielding effect, so the transient electromagnetic field induced by VFTO will radiate to the metal acquisition box, generating electromagnetic radiative interference to secondary equipment. The connecting part between metal acquisition box and GIS enclosure is shown in Fig. 1(b), and its length is 30 mm, and diameter of terminal board disc is 80 mm.

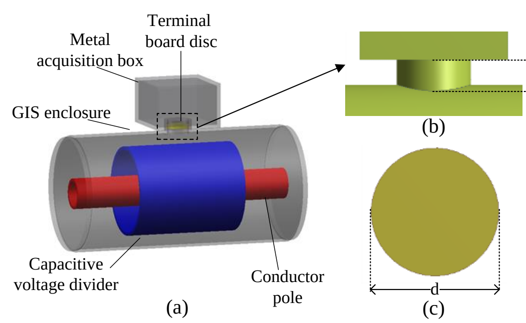


Fig. 1. GIS electronic combined instrument transformer. (a) Simplified model; (b) Connecting part; (c) Terminal board disc.

B. The calculation method

As the dominant frequency of VFTO is tens of MHz, we use implicit FETD method to calculate the transient electromagnetic field. The vector wave equation of electric field is

$$\nabla\times\frac{1}{\mu_r}\nabla\times\boldsymbol{E}+\mu_0\sigma\frac{\partial\boldsymbol{E}}{\partial t}+\frac{\varepsilon_r}{c_0^{\,2}}\frac{\partial^2\boldsymbol{E}}{\partial t^2}=-\mu_0\frac{\partial\boldsymbol{J}}{\partial t}. \tag{1}$$

where c_0 is speed of light in free space, σ is the conductivity, and ε_r and μ_r are the relative permittivity and permeability. Performing the inner product of (1) with a testing function, and applying Green's first vector identity to get weak solution, and then calculating the weak form's second-order ordinary differential equation, we get its approximate equation

$$[\mathrm{T}_\varepsilon]\frac{1}{(\mathrm{c}_0\,\Delta\mathrm{t})^2}(\mathrm{e}^{n+1}-2\,\mathrm{e}^{n}+\mathrm{e}^{n-1})+[\mathrm{T}_\sigma]\frac{\eta_0}{\mathrm{c}_0\,2\Delta\mathrm{t}}(\mathrm{e}^{n+1}-\mathrm{e}^{n-1}) \\ +[\mathrm{S}][\beta\,\mathrm{e}^{n+1}+(1-2\beta)\,\mathrm{e}^{n}+\beta\,\mathrm{e}^{n-1}]=0. \tag{2}$$

which leads to the implicit update equation [5]

$$\begin{aligned} e^{n+1} = & [[T_\varepsilon] + \frac{1}{2}\eta_0\, c_0\, \Delta t [T_\sigma] + \beta(c_0\, \Delta t)^2 [S]]^{-1} \\ & \cdot \{[2[T_\varepsilon] - (1-2\beta)(c_0\, \Delta t)^2 [S]] e^n \\ & - [[T_\varepsilon] - \frac{1}{2}\eta_0\, c_0\, \Delta t [T_\sigma] + \beta(c_0\, \Delta t)^2 [S]] e^{n-1} \\ & - (c_0\, \Delta t)^2 [\beta f^{n+1} + (1-2\beta) f^{n+1} + \beta f^{n-1}]\}. \end{aligned} \tag{3}$$

where e^n is the discrete-time representation of e, and β is a constant, and the boundary condition is simplified to be an radiation boundary.

The shielding effectiveness is defined as the ratio of the electronic field intensity (or magnetic field intensity) before shielding to the electronic field intensity (or magnetic field intensity) after shielding at the same position, which can be expressed as

$$SE(\text{dB}) = 20\lg\frac{E_0}{E_1} \tag{4}$$

$$SE(\text{dB}) = 20\lg\frac{H_0}{H_1} \tag{5}$$

III. Simulation Results of Transient Electromagnetic Field in Electronic Instrument transformer

With the help of the VFTO test platform of UHV GIS in the China Electric Power Research Institute, we get the measured VFTO waveform as shown in Fig. 2, whose amplitude is 224 kV, or 1.25p.u. By applying the measured VFTO waveform to GIS conductor pole, we calculate the transient electric field distribution and transient magnetic field distribution in GIS.

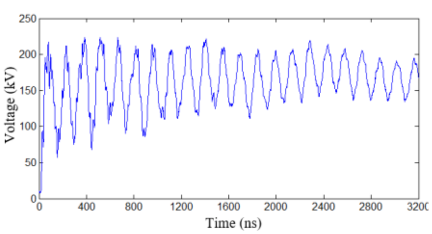
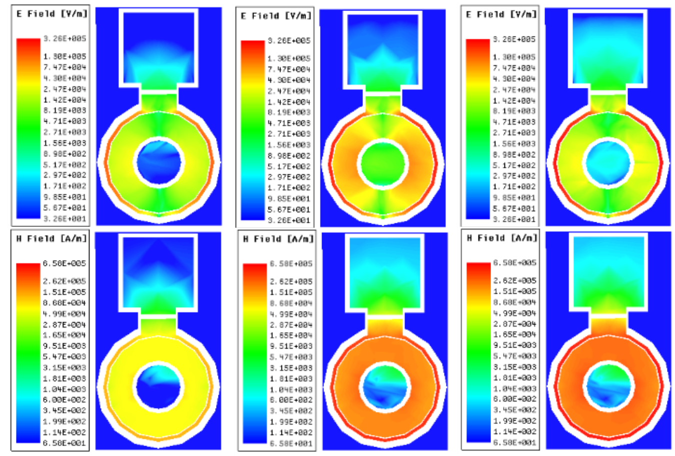


Fig. 2. The measured VFTO waveform.

The transient electric field distribution and the transient magnetic field distribution of a certain transverse cross section of GIS electronic instrument transformer at three time points is shown in Fig. 3. The results show the transient electric field intensity and the transient magnetic field intensity generated by VFTO both far exceed the existing electromagnetic compatibility test standards, which is the maximum electric field intensity being less than 10 V/m, and the maximum magnetic field intensity being less than 1000 A/m.

IV. The Influence Factors of Transient Electromagnetic Fields in Electronic Instrument transformer

Based on the simulation results above, we change the diameter of the terminal board disc, and the connecting length between the metal acquisition box and GIS enclosure. The comparison results are shown in Table I and Table II, and we find that reducing the diameter of the terminal board disc and lengthening the connecting length between the metal acquisition box and GIS enclosure could suppress the electromagnetic radiative interference effectively.



(a) 382.4ns (b) 1208.0ns (c) 1443.2ns

Fig. 3. The transient electric field and magnetic field distribution of VFTO at different time points.

TABLE I
VFTO Radiated Electromagnetic Field With Different Diameters of Terminal Board Disc

Terminal board disc's diameter /(mm)	Maximum electric field intensity /(V/m)	Magnetic field intensity /(kA/m)	Electric shielding effectiveness /(dB)	Magnetic shielding effectiveness /(dB)
40	128.4	1.2802	27.16	26.07
60	1075.5	6.2321	8.70	12.32
80	2928.9	25.7420	-	-
100	7495.9	43.7479	-	-

TABLE II
VFTO Radiated Electromagnetic Field With Different Connecting Lengths

Connecting length /(mm)	Maximum electric field intensity /(V/m)	Magnetic field intensity /(kA/m)	Electric shielding effectiveness /(dB)	Magnetic shielding effectiveness /(dB)
20	3837.1	32.0700	-	-
30	2928.9	25.7420	-	-
60	747.6	4.4547	11.86	15.24
90	206.5	0.8752	23.04	14.13

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