

Shili LIU, Zezhong WANG, Jing SUN

Simplified parasitic capacitance extraction of shield in HVDC converter system with boundary element method

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Abstract It is critical to build a wide-band circuit model to conduct research on the characteristics of the electromagnetic disturbance source during the localization of high voltage direct current (HVDC) technology. Parasitic capacitance is most essential for modeling the equivalent circuit, so a fast and accurate computation of capacitance parameters plays a vital role. Because of the large size and complex structure of the converter equipment, it is impossible to obtain capacitance parameters by means of measurement or simulating calculation with finite element software. In this paper, a simplified method of capacitance extraction based on boundary element method is proposed, which can provide an efficient means of establishing simulation models. In the method presented, simulation model of the shield may not be chamfered. Consequently, the edge and corner of the shield do not need to be handled with a sphere, cylinder and other curved surface model. The availability of this method is demonstrated by comparing the capacitance parameters of chamfered shield with that of non-chamfered shield.

Keywords parasitic capacitance, shield, chamfer, boundary element method (BEM), simplified model, extraction

1 Introduction

With the development of the national economy, there is a growing demand for electricity in China. Long-distance and large-capacity power transmission has become inevitable due to the distribution characteristics of energy and load center. As a result, the government is devoting major efforts to develop high voltage direct current (HVDC) transmission systems. The thyristor valve is the

core component of the HVDC converter system and its normal work is the critical condition to ensure the reliable operation of the HVDC system. It is necessary to establish a wide-band circuit model to predict the characteristics of the electromagnetic disturbance source [1]. During the modeling process, the parasitic capacitance is the most essential for the equivalent circuit, so a fast and accurate extraction of capacitance parameters plays an important role. The accuracy of capacitance parameters has a decisive impact on the correctness of the circuit model.

Many numerical methods have been used for the parasitic capacitance extraction, such as finite element method (FEM) [2,3], boundary element method (BEM) [4–6], finite difference method (FDM) [7], and semi-analytical approaches [8]. BEM is an efficient method for capacitance extraction, due to the reduced size of the problem, the ability to handle complicated three-dimensional structures, and the higher accuracy because it directly solves electrical potential and its normal derivative.

Owing to the large size and complex structure of the shield in HVDC converter system, it is rather difficult to calculate the capacitance parameters with FEM or FDM. This paper presents a simplified method of capacitance extraction based on boundary element method.

From the perspective of surface electric field, chamfering state of the shield will have significant effect on electric field distribution. To avoid the emergence of electric field singularity, the simulation model must be chamfered in field intensity analysis. The edge and corner should be handled with sphere, cylinder and other curved surface model, and the calculation involves curve surface integral and coordinate conversion [9–13]. Consequently, the simulation model is very difficult to establish and it also appeals for a higher computational cost including time and memory. However, from the perspective of capacitance extraction, more attention should be paid to total surface charge than to partial charge distribution on the conductor. That means, to a certain extent, we can neglect the effect of local charge on capacitance parameters. In other words, we

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Shili LIU (✉), Zezhong WANG, Jing SUN
Beijing Key Laboratory of High Voltage & EMC, North China Electric Power University, Beijing 102206, China
E-mail: liushili994102@yahoo.com.cn

cannot take chamfer into account during modeling the shield in capacitance extraction. By comparing the computational results of chamfered shield with that of non-chamfered shield, the simplified modeling method proposed in this paper proved simple, accurate and highly efficient and can be widely used in capacitance extraction of metal frameworks with large size and complex structure.

2 Principles of capacitance extraction

A shield generally consists of metal conductors and they have equipotential surfaces. For an electrostatic isolated system with $n + 1$ metal conductors, the total amount of positive and negative charges equals to zero. Letting conductors' numbers be $1, 2, \dots, n$ and No. 0 conductor be reference conductor, the self and mutual capacitances of metal conductors constitutes a capacitance matrix C_{ij} . Consequently, the relationship between charges and potential can be expressed as

$$Q_i = C_{i0}U_{i0} + \sum_{j=1}^n C_{ij}U_{ij}, \quad i, j = 1, 2, \dots, n, \quad j \neq i, \quad (1)$$

where Q_i is the charges on the i th conductor, C_{i0} is the self capacitance of the i th conductor, C_{ij} is the mutual capacitance between the i th and j th conductor ($i \neq j$), U_{i0} is the potential difference between the i th and the reference conductor, U_{ij} is the potential difference between the i th and j th conductor. Capacitance between conductors i and j is the free charge on the j th conductor when the potential of the i th conductor is 1 V and the other conductors are 0 V. This procedure can be repeated n times to get the capacitance matrix C_{ij} .

To compute the capacitances parameters, we need to compute the conductor surface charges, given certain conductor electrostatic potentials. BEM is a numerical technique for solving boundary integral equations. Unlike the finite element method [14], which must use an extended solution space, BEM uses only elements on the surfaces which are the material interfaces of assigned boundary conditions. This technique allows us to describe mathematically the electromagnetic phenomena by appropriate equation systems in integral form

$$\phi(\mathbf{r}) = \iint_S \frac{\sigma(\mathbf{r}')}{4\pi\epsilon_0 R} dS, \quad (2)$$

where \mathbf{r} is the field point, \mathbf{r}' is the source point, $\phi(\mathbf{r})$ is the known conductor surface potential, S is the conductor-air interfaces, ϵ_0 is the vacuum dielectric constant, σ is the charge density on S , dS is the incremental conductor surface area. Equation (2) can be numerically solved. Then we can get the free charge on each metal conductor.

Using the principles described above, mutual capacitance of the following metal structure is calculated. As

shown in the meshing model (Fig. 1), the box is located above the plate and the center distance is 0.36 m. Table 1 shows the computational and measured results. We can conclude that BEM is practicable to calculate capacitance parameters of metal conductors with large size.

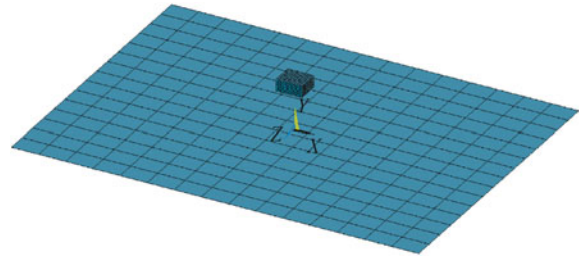


Fig. 1 Meshing model for box-plate structure

3 Study on simplified model

3.1 Model description

The shield used for modeling is a thyristor valve shield (Fig. 2) employed on an HVDC converter station in China. Limited by commercial technological security, this paper provides only a shielding structure diagram without specific parameters. Research on the effect of chamfering situation on capacitance extraction is carried out with BEM. Figure 3 shows the symmetric structure of shielding sheets and numbered map, where A and B, E and F, G and H, K and L are electrically connected.

To prevent local electric field from being too strong, which results in breakdown accident, shielding sheets must be chamfered and kept smooth in practical engineering. Figure 4 shows the actual shape of chamfered sheets.

To determine the effect of chamfer on parasitic capacitance, sheets in three typical positions are dealt separately with chamfered model and non-chamfered model.

3.2 Analysis of capacitance extraction

3.2.1 Capacitance calculation between A and L sheets

1) The self capacitance of A sheet and the mutual capacitance between A and L sheets with neither of them chamfered

The effect of valve hall on capacitance has been taken into account during calculation, but it is not shown in following figures for viewing convenience. Figure 5 shows the meshing model which is partitioned into 1600 elements. The results are as follows:

$$C_{AL} = 7.13 \text{ pF},$$

$$C_{A0} = 2.35 \text{ pF}.$$

Table 1 capacitance and parameters for box-plate structure

structure	length × width × height	simulated result	measured result
box	0.205 m × 0.165 m × 0.085 m	11.1 pF	11.2 pF
plate	3.2 m × 2.3 m × 0.005 m		

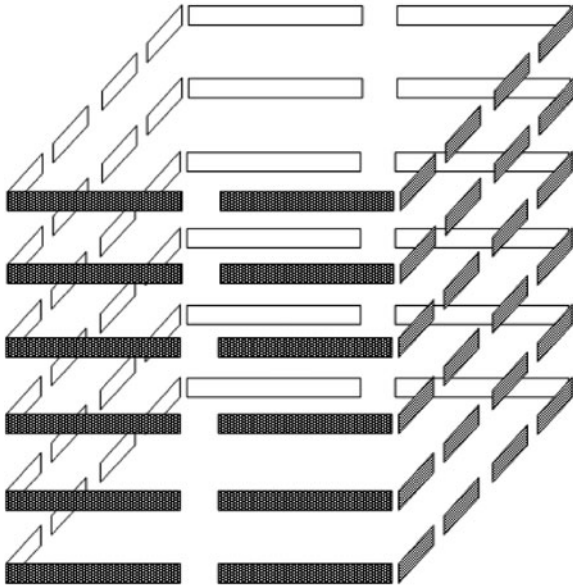


Fig. 2 Shield of converter system tower

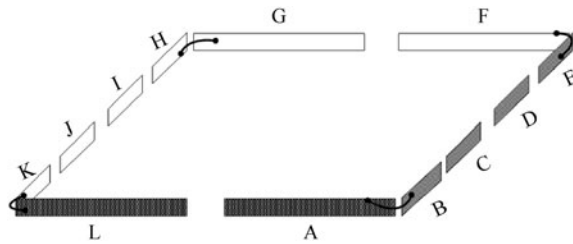


Fig. 3 Schematic diagram of numbering for shielding sheets

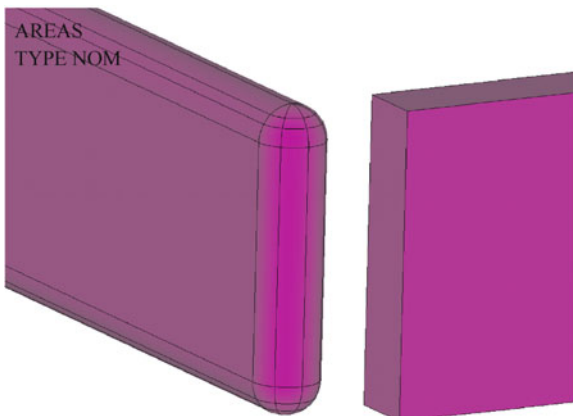


Fig. 4 Schematic diagram of fillet for shielding sheet

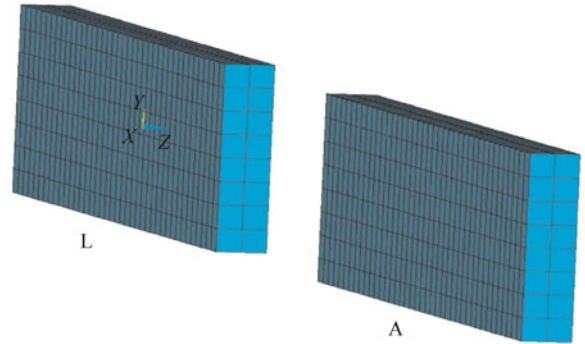


Fig. 5 Meshing model for A and L sheets with neither of them chamfered

2) The self capacitance of A sheet and the mutual capacitance between A and L sheets with only A sheet chamfered

Figure 6 shows the meshing model which is partitioned into 2000 elements. The results are as follows:

$$C_{AL} = 6.88 \text{ pF},$$

$$C_{A0} = 2.24 \text{ pF}.$$

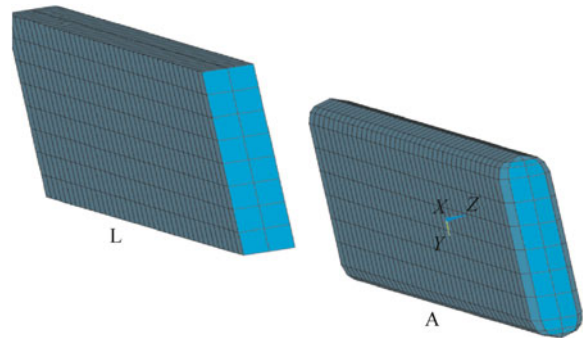


Fig. 6 Meshing model for A and L sheets with only A sheet chamfered

3) The self capacitance of A sheet and the mutual capacitance between A and L sheets with both of them chamfered

Figure 7 shows the meshing model which is partitioned into 2400 elements. The results are as follows:

$$C_{AL} = 6.66 \text{ pF},$$

$$C_{A0} = 2.22 \text{ pF}.$$

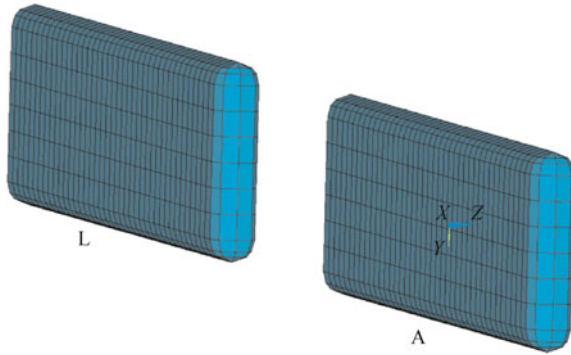


Fig. 7 Meshing model for A and L sheets with both of them chamfered

In Table 2, we compare capacitance parameters of A sheet obtained in three kinds of chamfered situation.

3.2.2 Capacitance calculation between A and C sheets

The self capacitance of A sheet and the mutual capacitance between A and C sheets like Sect. 3.2.1 1)–3).

Table 3 shows the computational results obtained in three different kinds of chamfered situations.

3.2.3 Capacitance calculation between A and F sheets

The self capacitance of A sheet and the mutual capacitance between A and F sheets like Sect. 3.2.1 1)–3).

Table 4 shows the computational results obtained in three different kinds of chamfered situations.

3.2.4 Capacitance parameters error analysis

With capacitances of chamfered sheets as a standard, we compare the mutual capacitances of different couples of sheets in Table 5. The maximum error of capacitance with neither sheets chamfered is about 7.7%. In addition, the effect of chamfer on self capacitance is about 6%, which can be derived from Table 2.

4 Conclusion

In this paper, the effect of shield chamfer on parasitic capacitance has been studied based on BEM. By comparing the computational results of chamfered shield with that of non-chamfered shield, we can find that the maximum relative error of capacitance parameters is no more than 7.7% and draw a conclusion that the influence is so little that the chamfer cannot be taken into account during modeling the shield in capacitance extraction. The simplified modeling method which provides a better trade-off between accuracy and efficiency, proved simple and satisfactory. It can be widely used in capacitance extraction of metal frameworks with large size and complex structure in the electrical engineering field.

Table 2 Parasitic capacitance of A and L sheets

A and L sheets	neither of them chamfered	only A sheet chamfered	both of them chamfered
C_{AL}/pF	7.13	6.88	6.66
C_{A0}/pF	2.35	2.24	2.22

Table 3 Parasitic capacitance of A and C metal sheets

A and C sheets	neither of them chamfered	only A sheet chamfered	both of them chamfered
C_{AC}/pF	6.15	5.92	5.71
C_{A0}/pF	2.34	2.24	2.22

Table 4 Parasitic capacitance of A and F metal sheets

A and F sheets	neither of them chamfered	only A sheet chamfered	both of them chamfered
C_{AF}/pF	5.06	4.87	4.72
C_{A0}/pF	2.35	2.23	2.23

Table 5 Capacitance parameters error

chamfered state	capacitance parameters error/%		
	C_{AL}	C_{AC}	C_{AF}
only A sheet chamfered	3.3	3.7	3.2
neither of them chamfered	7.1	7.7	7.2

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