

Research on Stray Parameters Accurate Calculation Methods of MMC Valves under Complex Environments

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In this paper, 3-Dimensional electric field calculation method is used to accurately compute the stray parameters of the converter valve in a complex environment. Initially, the electric field distribution of modular multilevel converter (MMC) valve and frequency domain characteristics of excitation in MMC system were analysed. Geometric equivalent calculations were performed on the key metallic components and insulating components that may cause electric field concentration in the MMC valve. Subsequently, the layout of the MMC valve in the valve hall was analysed, and the valve stray parameters calculations were performed based on the different positions of the valve towers in hall. Finally, the impact of mesh density on the calculated values of electric field strength was investigated. An optimization algorithm was used to determine the optimal grid size, which was then used to accurately compute the stray parameters of the MMC valve. The detailed calculation process and parameter calculations under different voltage excitations will be presented throughout the paper.

Index Terms—Modular multilevel converter (MMC), tray capacitance, electric field calculation, mesh optimization.

I. INTRODUCTION

Because of the different positions and geometric dimensions of the metal components, the distributed capacitance of each valve layer in the valve varies. Under transient operating conditions, this can cause damage to the valve. Moreover, the presence of stray parameters in the valve may lead to damage to other equipment. Therefore, accurate calculation of the stray parameters of the valve is crucial for the safe operation of the MMC system. However, due to the complex structure of the MMC valve and the complex electromagnetic environment in which it operates, accurate calculation of the stray parameters becomes quite challenging. Tao Sun analyzed a calculation method of IGBT insulation voltages based on sub-module stray capacitors in MMC in 2024^[1]. Ruimin Zhu described a novel snubber circuit for MMC submodule using gap-RC to suppress fast transient overvoltage in 2021^[2]. Parameter extraction and wideband modeling of ± 1100 kV converter valve was analysis by Lei Qi in 2017^[3].

In this paper, a 3-Dimensional electric field calculation method was used to perform detailed calculations of the MMC valve stray parameters. Initially, detailed equivalent calculations and modeling were performed on the metal and insulating components in the MMC valve. Subsequently, local electric field equivalent calculations were performed based on the different positions of the valves in the hall. Finally, an optimization algorithm was used to determine the optimal grid size, which was then used to accurately compute the stray parameters of the MMC valve. Through the calculation principles and methods described in this paper, the stray parameter values of the valve in a complex environment can be accurately obtained. Detailed theoretical derivations and calculations will be provided in the full paper.

II. MODELING FOR VALVE STRAY PARAMETERS CALCULATION

The MMC system schematic diagram and MMC valve in hall are illustrated in Fig. 1.

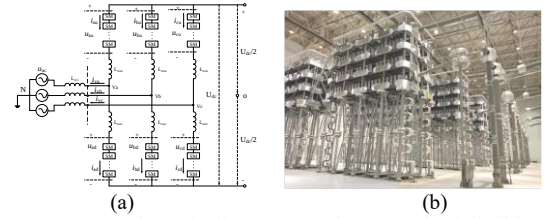


Fig. 1 MMC system schematic diagram(a) and MMC valve in hall(b)

The structure of the MMC valve is relatively complex, with a large number of conductors of various shapes, and the internal insulation structure is also quite complex.

According to the physical definition, capacitance is a measure that describes the ability to store electric field energy. The accurate calculation method of stray capacitance based on electric field energy calculation is defined as:

$$\begin{cases} E_{ij} = -\nabla \varphi_{ij} \\ W_{Cij} = \frac{\epsilon_{ij}}{2} \int E_{ij}^2 dv \\ C_{ij} = \frac{2W_{Cij}}{u_{ij}^2} \end{cases} \quad (1)$$

In the (1), E_{ij} is the electric field between conductors. φ_{ij} are the potential distribution of conductors. ϵ_{ij} is the dielectric constant of the insulating structure between conductors. W_{Cij} is the electric field energy stored between conductors. C_{ij} is the capacitance between conductors. u_{ij} is the voltage between conductors.

According to Gauss's Law, the shape of the outer surface of a conductor has a significant impact on the electric field distribution, while the internal structure does not affect the

electric field distribution. The modeling process for the accurate calculation of MMC valve based on electric field analysis is shown in Fig. 2.

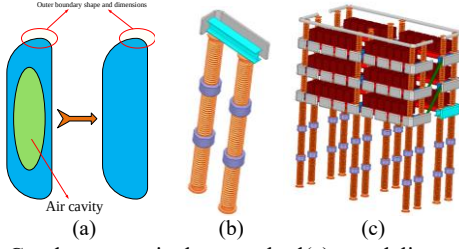


Fig. 2 Conductor equivalent method(a), modeling of insulation structure(b) and modeling for valve capacitance accurate calculation

III. EQUIVALENT PROCESSING OF COMPLEX ENVIRONMENT

The MMC valve is composed of multiple conductors, and all conductors need to be processed in the capacitance calculation. The capacitances of the valve shields is shown in Fig. 3.

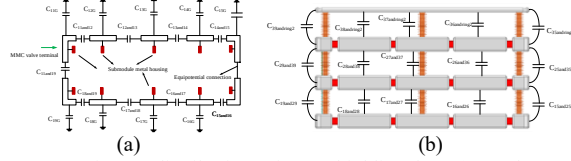


Fig.3 Capacitance distribution of one shielding layer(a) and capacitance distribution between layers shield(b)

Fig.3 illustrates the capacitance distribution of one shielding layer and capacitance distribution between layers. C_{1iG} is the ground capacitance of conductor i in the layer 1. C_{1ij} is the capacitance between conductor i and conductor j in layer 1. The $C_{1iand2i}$ is the capacitance between conductor i in layer 1 and conductor i in layer 2.

The MMC valve operates in a complex electromagnetic environment. The modeling process of the MMC valves in the hall is shown in Fig. 4.

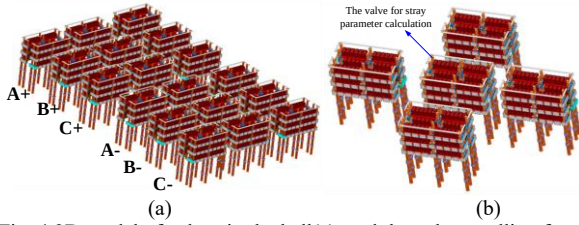


Fig. 4 3D model of valves in the hall(a) and the valve modeling for capacitance calculation

IV. ELECTRIC FIELD CALCULATION FOR CAPACITANCE

The accuracy of electric field calculations is crucial for the determination of capacitance. The maximum electric field strength is used as a reference value. The relationship between the calculation error rate, mesh density, and calculation time is shown in Fig. 4.

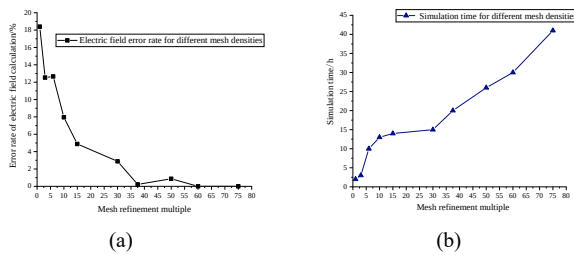


Fig.4 Relation between mesh (a) and error rate, and calculation time (b)

The electric field distribution obtained using the intelligent modeling method presented in this paper is shown in Fig. 5.

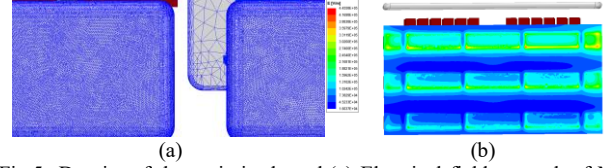


Fig.5 Density of the optimized mesh(a) Electrical field strength of MMC valve(b)

The stray capacitances of MMC valve using the accurate calculation method presented in this paper is shown in Table I.

Capacitor type	Capacitor number	Capacitance value
Ground stray capacitance of the first layer of the MMC valve	C_{11G}	37.21pF
	C_{12G}	14.23pF
	C_{13G}	21.42pF
	C_{14G}	14.27pF
	C_{15G}	48.26pF
	C_{16G}	14.31pF
	C_{17G}	21.36pF
	C_{18G}	14.31pF
	C_{18G}	27.36pF
	C_{18G}	27.36pF

V. CONCLUSION

A 3-Dimensional electric field calculation method was used to accurately compute the stray parameters of the MMC valve. Based on the characteristics of the electric field distribution and the excitation features of the MMC system, geometric equivalent calculations were performed on the key components of the MMC valve. Then, local complex electric field equivalent calculations were carried out according to the different positions of the valve towers. Finally, through optimization calculations, a reasonable mesh size was determined, and the stray parameters of the MMC valve were computed. That will provide an important basis for the design of MMC-HVDC system and the valve.

REFERENCES

- [1] T. Sun, X. Lu, and J. Cai, "A calculation method of IGBT insulation voltages based on submodule stray capacitors in MMC," *IEEE Trans. Power Electron.*, vol. 39, no. 12, pp. 16187–16200, Dec. 2024.
- [2] R. Zhu, N. Lin, and V. Dinavahi, "An accurate and fast method for conducted EMI modeling and simulation of MMC-based HVDC converter station," *IEEE Trans. Power Electron.*, vol. 35, no. 5, pp. 9876–9887, May. 2020.
- [3] L. Qi, Q. Shuai, and X. Cui, "Parameter extraction and wideband modeling of ± 1100 kV converter valve," *IEEE Trans. Power Electron.*, vol. 32, no. 3, pp. 1823–1832, Jun. 2017.
- [4] R. Zhu, N. Lin, and V. Dinavahi, "An accurate and fast method for conducted EMI modeling and simulation of MMC-based HVDC converter station," *IEEE Trans. Power Electron.*, vol. 35, no. 5, pp. 9876–9887, May. 2020.
- [5] W. Zhou, B. Zhao, and Y. Lou, "Current oscillation phenomenon of mmc based on IGBT and fast recovery diode with high surge current capability for HVDC application," *IEEE Trans. Power Electron.*, vol. 36, no. 6, pp. 4689–4702, Jun. 2021.
- [6] H. Shen, X. Zhang, and L. Qi, "A novel snubber circuit for mmc submodule using gap-rc to suppress fast transient overvoltage," *IEEE Trans. Power Electron.*, vol. 38, no. 10, pp. 12406–12410, Oct. 2023.
- [7] Y. Shao, B. Zhang, and Y. Xie, "A voltage full-waveform reconstruction method based on radiative near-field of electric field for the hybrid dc breaker of MMC-HVDC," *IEEE Trans Power Dle.*, vol. 38, no. 5, pp. 3496–3509, Oct. 2023.