Calculation of Electrical Stress Distribution and Influencing Factors Analysis of HVDC Converter Valve in Special EMP Environment

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Abstract. The thyristor converter valve is the core equipment in HVDC (high voltage direct current) transmission system, and to evaluate its reliability in special electromagnetic environment is quite important. In this paper, based on the existing wideband model of the key components of the converter valve, the modified wideband model of the converter valve system is built to study the electrical stress of the converter valve under the special electromagnetic environment, and the weak parts of the valve are further studied. The influence of stray parameters in the valve tower on the electrical stress of thyristors is mainly studied. The results show that it is practical and feasible to provide basic conditions and numerical parameters for the reliability evaluation of thyristor components.

1. Introduction
From the 1970s, the research on HVDC converter valve in EMP (electromagnetic pulse) environment mainly focuses on voltage characteristics in foreign countries, including the calculation of overvoltage distribution, analysis of influencing factors, and mathematical approximation of model parameters, etc. [1-2]. A number of domestic universities and research institutes have carried out a series of studies on the electrical stress distribution of the converter valve, especially the voltage stress characteristics, including wideband measurement and modeling of the converter valve components, overvoltage distribution calculation and electromagnetic disturbance characteristics analysis, etc. [3].

The aforementioned studies is mainly on the wideband modeling and voltage stress calculation of the converter valve. The influence of the EMP environment on the reliability of the converter valve can be qualitatively determined, but there is no systematic and quantitative analysis. When the converter valve is in abnormal operating conditions, especially in special environment such as HEMP (high electromagnetic pulse), the stress intensity and environment of the converter valve components are completely different from the normal conditions, and the electrical stress of valves is affected by various stray parameters existing in the valve tower.

Therefore, considering the special working conditions and stray parameters, the electrical stress of each thyristor in the valve is analyzed in detail, which paves the way for the study of the lifetime of thyristor in the special EMP environment, and provides the basic conditions and numerical parameters for the reliability evaluation of converter valve components.
2. Modified wideband model of converter valve

To calculate the electrical stress distribution of converter valve, a wide-band circuit model is established necessarily which accords with the spectrum width of the electromagnetic pulse. However, the applicable frequency band of the traditional wideband models can only reach 500kHz-1MHz, which cannot meet the energy band [10kHz, 30MHz] of the HEMP under the Bell laboratory standard[4]. Therefore, the traditional wideband needs to be revised to build a wider modified wideband model.

The model established in this paper is mainly based on the engineering test data of the research group, and is obtained with reference to relevant researches of universities such as North China Electric Power University and Tsinghua University[5].

![Fig. 1. High-frequency modified wideband model of thyristor](image1)

![Fig. 2. High-frequency modified wideband model of resistor](image2)

![Fig. 3. High-frequency modified wideband model of capacitor](image3)

![Fig. 4. High-frequency modified wideband model of saturable reactor](image4)

2.1. Modified wideband model of thyristor

Thyristor can be approximately equivalent to a junction capacitance in the low frequency band. The wideband model of thyristor studied in this paper is shown in Fig.1. Where $C_T$ is the parasitic capacitance, $R_T$ is the ohmic losses, and $L_T$ is the distributed inductance between thyristor bipolar[6]. The model parameters are obtained based on data provided by the manufacturer[7]. The comparison of impedance frequency characteristics between thyristor measurement and simulation is shown in reference[8]. It is highly coincident below 30MHz, which can meet the spectral requirements of electromagnetic and the special properties at high frequencies.

2.2. Modified wideband model of resistance

The resistor of the converter valve includes the damping resistance of the RC circuit and the grading resistor. The wideband model after high-frequency correction based on the impedance frequency characteristics of the measured resistance is shown in Fig.2, and the comparison curve with the measured characteristics is shown in the reference [9].

2.3. Modified wideband model of capacitor

The capacitor in the converter valve includes the damper capacitor of RC circuit and grading capacitor of valve section. The modified wideband model of capacitor is shown in Fig.3. The comparison between the model and measured impedance frequency characteristic curve is shown in reference [7].
2.4. Modified wideband model of saturable reactor
The saturable reactor is a non-linear device composed of a coil and iron core. It can be approximated as a linear component at high frequency[10]. The wideband model of saturable reactor is shown in Fig.4, where $L$ is the iron core inductance, $L_{\text{leak}}$ is the coil hollow inductance, $R_{\text{Cu}}$ is the copper loss, $R_{\text{ed}}$ is the eddy current loss, $R_D$ is the damping resistance and $C_{\text{SR}}$ is equivalent to the parasitic capacitance across the reactor.

2.5. Stray capacitances of valve tower
As a multiple-layer structure, the stray capacitance distribution in the valve tower is shown in Fig.5.

The parasitic capacitances considered are as follows: $C_{G1} - C_{G4}$ represent the capacitances between valve module and the ground; $C_{G0}$ and $C_{G5}$ represent the capacitances between the shielding plates and the ground; $C_{L2} - C_{L4}$ represent the capacitances between one valve section and the section above or below; $C_{L1}$ and $C_{L5}$ are the shielding plates capacitance to ground; $C_{WB}$ is the capacitance of the wall bushing which connected the converter transformer.

![Fig. 5. Stray capacitances of valve tower](image)

![Fig. 6. Simulation diagram of the converter valve system](image)

3. Calculation of electrical stress distribution of converter valve
To accurately obtain the electrical stress of the whole converter valve system in HEMP environment, four single phase valve towers in the bipolar - dual 12 pulsating converter system are taken into account in this paper.

3.1. HEMP waveform and the equation
The functional process of HEMP could be divided into three sections[11], in which the early stage contains broad frequency signals and could perform destructive effects to converter valve. The waveform of HEMP could be simplified and simulated by the following equation[12]:

$$v(t) = V_0 A (e^{-\alpha t} - e^{-\beta t})$$  \hspace{1cm} (1)

where $V_0$ represents the peak value of pulse, $A$ is the correction factor, $\alpha$ and $\beta$ are the time constants. The standard of Bell Laboratory is widely used and therefore the following analysis is based on this standard, whose parameters is: $\alpha = 4.0 \times 10^6 \text{ s}^{-1}$, $\beta = 4.76 \times 10^8 \text{ s}^{-1}$, $A = 1.052$, $V_0 = 50 kV/m$.

3.2. Electrical stress calculation of converter valves
The simulation diagram of the converter valve system wideband model is shown in Fig. 6. Each valve tower contains two single valves, two valve modules form a single valve, and a valve module contains...
two valve sections. The structure of the valve tower 1 is shown in detail. Simplified diagrams of the 
valve towers 2, 3 and 4 are given. In the simulation model, the impulse source is applied at the port 
where the valve section 1 of the valve 1 is located.

The voltage distribution of valves is shown in Fig. 7. The result indicates that the voltage 
distribution is extremely non-uniform, while most of the voltage is assumed by the first valve. Valve 2 
withstand nearly 10% HEMP, while the rest could be neglected.

The voltage distribution of different valve sections in a valve is shown in Fig. 8. It can be seen that 
the voltage distribution of valve sections in the same valve is not uniform, and the valve section 
closest to the impulse source bear greatest voltage stress. The voltage stress of valve section 2 and 3 
coincides highly because it has no stray parameters between the two sections in the established 
wideband model, therefore, stray parameter is the key factor which cause the uneven voltage stress 
distribution in converter valves could be proved.

4. Analysis of influencing factors of electrical stress distribution of converter valve

The electrical stress distribution is not identical of different valve sections is caused by the stray 
capacitances in the valve tower. The stray capacitances are set respectively to 20%, 100%, 500% of 
the original value, and the three cases are compared as follows.

4.1. Stray parameters of the ground

Stray parameters $C_{00} - C_{05}$ are the capacitances to the ground, which affect the voltage distribution of 
valve sections in valve 1 is shown in Fig. 9. It can be seen that the larger the stray parameters to the 
ground, the greater the voltage of the thyristor in valve section 1 which closest to the electromagnetic 
pulse source, and the smaller the thyristor voltage in other valve sections.

The result indicates that, with the increase of stray parameters to the ground, the non-uniform 
degree of electrical stress distribution increases. The electrical stress environment of the thyristor 
closest to the impulse source of valve 1 becomes the severest, and the electrical stress intensity of the 
thyristor in other valve sections decreases.

4.2. Stray parameters between valve sections

The influence of stray parameters between valve sections on the thyristor voltage distribution of each 
valve section is shown in Fig. 10.

Based on the analysis results of voltage stress, it can be concluded that, with the increase of stray 
parameters between sections, the non-uniform distribution of electrical stress of the converter valve 
decreases, the electrical stress of the thyristor which far away from the impulse source increases, and 
the electrical stress of other thyristors is more gentle.
4.3. Stray parameters of wall bushing

In addition to the stray parameters of valve tower itself, the wall-bushing capacitance of the connecting cable to the converter transformer to the ground should also be considered. The effect of wall bushing capacitance on the thyristor voltage distribution of each valve section in valve 1 is shown in Fig. 11. Compared with the stray parameters to ground and the stray parameters between valve sections, the influence of wall-bushing capacitance is relatively small. When the capacitance increases, the voltage stress of each valve section thyristor slightly increases.

5. Conclusion

Based on the established wideband model of converter valve, the electric stress distribution of valve sections and thyristors in each converter valve is studied with the electromagnetic pulse of special environment as the excitation source. The results show that the stray parameter of valve tower is the main reason for the uneven distribution of electrical stress in converter valve under special
environment. The influence of different stray parameters on the voltage stress distribution is analyzed in detail, and the conclusion is drawn that the closer to the impulse source, the greater the electrical stress of the thyristor is. All thyristors of the same valve section are subject to the same electrical stress, and the analysis of the electrical stress of thyristors should be based on the valve section.

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