Research on Overvoltage Distribution of HVDC Converter Valve in Special Environment

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Abstract. HVDC transmission technology has great advantages in long-distance, large-capacity cross-region power transmission. Thyristor converter valve is the core equipment of HVDC transmission technology, and its reliability directly affects the reliability of the whole system. During the operation of HVDC transmission system, it will face the special operating environment, including high altitude nuclear electromagnetic pulse(HEMP), operating overvoltage, lightning, and steep wave overvoltage. In order to study the reliability of the converter valve under special circumstances, the wideband equivalent circuit model of the key components were built in this paper. On this basis, the overvoltage distribution inside the converter valve under special environments is simulated and analyzed. The results show that the overvoltage distribution inside the converter valve under special environments is simulated and analyzed. The results show that the overvoltage distribution inside the converter valve system is related to the characteristic parameters of the special environment, and the distribution trend of the overvoltage of the saturated reactor and the thyristors is also different, so the weak components of the converter valve system under special circumstances can be obtained. It has certain reference value for studying the reliability of the converter valve system under special circumstances.

1. INTRODUCTION

As the core equipment of HVDC transmission system, the converter valve has qualified reliability in
normal operating conditions. However, in actual engineering, the converter valve will face various abnormal conditions. For example, the converter valve may be subjected to AC and DC systems and overvoltage surges during thunderstorms, and will also experience the HEMP environment. These special operation conditions puts higher demands on the reliability of the converter valve. Therefore, based on the broadband circuit model of each key device and considering some parasitic parameters existing in the valve tower, the Gao-Zhao HVDC transmission project is taken as an example to build a broadband circuit model of HVDC converter valve. The overvoltages of the saturated reactor and the thyristors under special environment were simulated and compared. The purpose of this paper is to study the vulnerable parts in the converter valve under special circumstances through overvoltage simulation analysis, and provide reference for improving the life and the reliability of the converter valve.

2. Structure of the Converter Valve
There are two valve halls in the ±500kV GaoZhao HVDC converter station, with 3 valve towers in each valve hall. And the valve tower is using the hanging layout in the valve hall, as shown in Fig.1. In this project, the single valve tower consists of two left and right sides, six layers above and below and a total of 12 valve modules. Each valve module contains two valve sections, and one single valve contains three valve modules, so one valve tower consists of four single valves in series. In addition, each valve section of the GaoZhao project consists of 13 thyristor levels connected in series with two saturable reactors, and then in parallel with a DC grading capacitor.

3. Wideband Model of Converter Valve

3.1 Wideband model of thyristor level
For a single thyristor device, a capacitor is usually used as the thyristor wideband model. However, EMP is a wide frequency range excitation source, and therefore a more accurate model which could simulate high frequency characteristics is required[1], as shown in Fig.2.

![Wideband model of thyristor](image)

Accordingly, the wideband model of thyristor level is shown in Fig.3, in which RSC and CSC form the snubber circuit, RG is the grading resistor.
3.2 Wideband model of saturable reactor

The saturable reactor is a non-linear device and its characteristics is related to its current. The wideband model of saturable reactor is shown in Fig.4[5]. As the structure can be seen in the figure apparently, the parameters considered are as follows, where \( L \) is the main inductance, \( R_{Cu} \) is the ohmic losses, \( R_D \) is the damping resistance, \( L_{Leak} \) is the leakage inductance, \( R_{Ed} \) is the eddy current losses, and \( CSR \) is the stray capacitance inside the reactor.

\[
\begin{align*}
& C_{Sc} & R_{Sc} \\
& C_T & R_T & L_T \\
& R_D & L_{Leak} & C_{SR} \\
& R_{Cu} \\
\end{align*}
\]

Figure 4. Wideband model of saturable reactor

3.3 Wideband model of Valve section

The structure of the valve section is shown in Figure 5. It is generally composed of dozens of thyristor levels connected in series, and in the same time in series with one or two saturable reactors, and then connected in parallel with a DC grading capacitor. According to the topology of Fig.5, the wideband circuit model of the converter valve component is combined according to the actual electrical connection mode, and the wideband equivalent circuit model of the single converter valve section is obtained as shown in Fig.6.

\[
\begin{align*}
& C_{k} \\
& \text{Saturable reactor} \\
& 1 & 2 & n \\
\end{align*}
\]

Figure 5. structure of the valve section

\[
\begin{align*}
& C_{k} \\
& R_D & C_1 & C_2 \\
& R_{Ed} \\
\end{align*}
\]

Figure 6. Wideband Equivalent circuit model of valve section

3.4 Wideband Equivalent circuit model of valve tower

There are many stray capacitances in the valve tower of the converter valve. It must be considered when constructing the model of the valve tower. This paper takes the converter valve of the ±500kV GaoZhao HVDC transmission project as an example to carry out the wideband model of the valve tower. The wideband model of the valve section of Fig.6 is connected in electrical order. The wideband model of the converter valve tower with the valve section as the basic unit and including the
stray capacitance parameters is shown in Fig.7. The parameters considered are as follows: CMM represents the capacitance between two valve modules on the same layer; CLL represents the capacitance between the upper and lower valve modules; CLG represents the capacitance between each valve module and the ground.

![Figure 7. Wideband Equivalent circuit model of valve tower](image)

4. Overvoltage Distribution

According to the basic theory of electromagnetic pulse, the common electromagnetic pulse waveform can be expressed in the form of double exponential function, as shown in equation (1).

\[
v(t) = V_0 k (e^{-\alpha t} - e^{-\beta t})
\]  

A relatively reasonable electric field can be given in this function when we calculate. The function also has good application value. The parameters considered are as follows, where \(V_0\) represents the peak voltage of the pulse, \(k\) is the correction factor, \(\alpha\) and \(\beta\) are the time constants. The following calculations involve HEMP, lightning overvoltage, operating overvoltage and steep wave. The peak voltage of the electromagnetic pulse in this paper is 150kV. The characteristic parameters are shown in Table 1.

| Type         | Pulse rise time | Half pulse width | \(k\)     | \(\alpha\) | \(\beta\)    |
|--------------|-----------------|------------------|-----------|-----------|--------------|
| HEMP         | 10ns            | 184ns            | 1.0502    | 4\times10^6 | 4.76\times10^4 |
| Lightning wave | 1.2\mu s        | 50\mu s          | 1.0372    | 0.0147\times10^6 | 2.4689\times10^6 |
| Operation wave | 0.25ms         | 2.5ms            | 1.1434    | 0.033\times10^8 | 0.0115\times10^6 |
| Steep wave   | 0.4\mu s        | 1.2\mu s         | 85.470    | 2.1459\times10^6 | 2.2173\times10^6 |
According to the converter valve connection mode of the ±500kV GaoZhao HVDC converter station and the wideband equivalent circuit model of the converter valve tower, the electric stress distribution of the converter valve under special circumstances is simulated. The simulation results as shown in fig.8 (a)- (d).

![Graphs showing the overvoltage distribution of the converter valve in different special environments](image)

Figure 8. overvoltage distribution of the converter valve in different special environment

It is noted that in the HEMP environment, the saturable reactor is subjected to most of the overvoltage, and the thyristor is subjected to a little overvoltage. In the case of lightning overvoltage, the thyristor is subjected to most of the overvoltage, and the saturable reactor is subjected to a little overvoltage, but the wave front is steep; when the overvoltage is operation wave, the thyristor is almost full of the surge voltage, and the saturated reactor is subjected to a very little voltage. Under the action of steep wave, in the initial stage, the saturable reactor is subjected to most of the overvoltage, and the wave front is steep. However, in the later period, the thyristor is subjected to more overvoltage.

The results show that the HEMP environment has almost no effect on the saturable reactor, the thyristor is the weak component in the converter valve under the HEMP environment, when encountering this environment in the actual project, it is necessary to pay more attention to the reliability of the thyristor.

The influence of the thyristors is extremely small in operation wave, and the excessive overvoltage is endured by the saturable reactor. Therefore, when encountering this environment in actual engineering, it is necessary to pay more attention to the life of the saturated reactor; In the lightning environment, although the saturated reactor is subjected to excessive overvoltage, however, when the electromagnetic pulse acts, the thyristor has a large voltage overshoot. Therefore, this environment requires the thyristor have the ability to absorb the overvoltage, to prevent the pulse from breaking through the thyristor.

5. CONCLUSION

In this paper, based on the wideband circuit model of the key components in the existing converter valve system, the broadband equivalent circuit model of the thyristor converter valve of sorghum DC transmission engineering is built. The model is the research object, and the converter valve in special
environment. The overvoltage under the system was simulated and analyzed. The overvoltages of thyristors and saturable reactors under HEMP, lightning wave, operating overvoltage and steep wave electromagnetic pulse were analyzed in detail.

The simulation results show that the weak link inside the converter valve is different under different electromagnetic pulse environment, but the saturated reactor and thyristor are the main equipments to withstand the overvoltage. In order to improve the reliability of the converter valve system under special circumstances, it is necessary to improve the thyristor. And the life of the saturable reactor and the ability to withstand overvoltage surges. The results of this paper have certain guiding significance for analyzing the reliability of actual engineering.

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References
[1] Liu C L, Shuai Q, Qi L, et al. Quantitative analysis of voltage distribution within ±1100kv HVDC converter valve tower under various transient over-voltage conditions[C]// Lightning Protection. IEEE, 2014:1558-1564.
[2] Wik M W. International standardization of immunity to high altitude nuclear electromagnetic pulse (HEMP)[C]// International Symposium on Electromagnetic Compatibility. IEEE, 1992:1-2-4/1-2.
[3] Xie Y Z, Wang Z J, Wang Q S, et al. High altitude nuclear electromagnetic pulse waveform standards: a review[J]. High Power Laser And Particle Beams, 2003, 15(8):781-787.
[4] Yang J, Tang G, Cao J, et al. Study on Equivalent Circuit Model for HVDC Valve Thyristor Junction Temperature Calculation[J]. Proceedings of the Csee, 2013, 33(15):156-163.
[5] Sun H, Cui X, Qi L, et al. Calculation of overvoltage distribution in HVDC thyristor valves[C]// Electromagnetic Compatibility. IEEE, 2010:540-543.
[6] Qi L, Shuai Q, Cui X, et al. Parameters Extraction and Wideband Modeling of ±1100kV Converter Valve[J]. IEEE Transactions on Power Delivery, 2016, PP(99):1-1.