Strengthening technique on firestop system of valve hall for existing UHVDC converter stations

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Abstract. The ultra-high voltage direct current (UHVDC) converter station is the core of the UHVDC project to realize the mutual conversion of alternating current (AC) and direct current (DC). Its operational reliability directly affects the safety of personnel and equipment and the stable operation of the grid. The firestop system is key part of the protective system in converter station, and it faces the threat of fire and explosion of converter transformer. In this paper, in order to improve the safety performance of the firestop system of the valve hall of the existing converter station, the blast resistant design target of the firestop structure and a fireproof and blast resistant strengthening scheme are proposed; For a typical UHV converter station, the dynamic response process under different explosion conditions is further analyzed by numerical model. The results show that the strengthening scheme proposed in this paper can effectively meet the requirements of blast resistant design targets, and greatly improve the safety performance of the firestop system of the valve hall of the converter station under fire and explosion.

1. Introduction

The UHVDC converter station is the core to realize mutual AC/DC conversion in UHVDC projects. Its operational reliability is directly related to the safety of personnel and equipment and the grid stability. There is more than 100 tons of insulating oil in the tank of a converter transformer. Once the fault arc causes fire or explosion, the firestop system of the valve hall would be destroyed, and the fire would spread to the inside, leading to immeasurable economic loss and serious social impact. In recent years, fire accidents caused by explosion of converter transformer occur from time to time. For example, on April 7, 2018, an explosion occurred at the ±800kV Tianshan Converter Station in Hami, Xinjiang, resulting in the destruction of a high-end valve hall and six converter transformers, which is a heavy economic loss.

In order to ensure that the converter transformer can be moved conveniently, it is arranged adjacent to the valve hall, as shown in Figure 1. They are separated by a firestop system made of PAROC plates (a lightweight rock wool sandwich panel: 0.5mm degaussing stainless steel plate + 150mm rock wool + 0.6mm degaussing stainless steel plate). This structure does not take into account the effect of explosion. Once the converter transformer explodes and catches fire, the firestop system may be directly damaged, losing its fire proofing function completely, leaving the fire spread to the valve hall.
This will cause incalculable economic losses and affect the operation of the national economy. Therefore, it is necessary to conduct in-depth research on the protection performance of the firestop system of the valve hall of the converter station so as to improve the system design, deliver better fire control performance, and avoid the damage to the internal facilities of the valve hall caused by fire or explosion after the failure of the converter transformer. It is of great significance not only to the safe and stable operation of the national power system, but also to the sound development of the national economy and the national defense security.

![Scheme of the firestop system in a typical valve hall](image1.jpg)

**Figure 1. Scheme of the firestop system in a typical valve hall**

2. Blast resistant design target

2.1 Reference specification

Article 5.3.1 of GB50779-2012 "Code for design of blast resistant control building in petrochemical industry" [1] stipulates that, the peak incident overpressure and corresponding positive pressure action time used in the blast resistant design of the control room should be determined and evaluated by comprehensive safety analysis based on the characteristics of petrochemical unit and plane layout; if there isn't an evaluation, it can also be determined according to the following provisions and should be stated in the design files:

(1) The maximum value of the shock wave peak incident overpressure can be reached to 21 kPa, the positive pressure action time can be 100 ms, which is recorded as “BLAST_A”; the shock wave peak incident overpressure maximum value can be taken as 69 kPa, and the positive pressure action time is taken as 20 ms, which is recorded as “BLAST_B”.

(2) The time of explosion impact waveform is from zero to positive pressure action time, and the peak incident overpressure is triangular distribution from maximum to zero, as shown in Figure 2.

![Incident overpressure of blast loads in “Code for design of blast resistant control building in petrochemical industry”](image2.jpg)

**Figure 2. Incident overpressure of blast loads in “Code for design of blast resistant control building in petrochemical industry”**
2.2 **Test Data**

On May 6th, 2019, the project team of China Electric Power Research Institute Co., Ltd. conducted a simulated discharge test on the network side ascending flanged base of the converter transformer at the Suzhou Electric Power Research Institute in Jiangsu Province. A total of three operating conditions were tested. In case 1, the fixing bolt of the ascending flanged base cover was only 1/8 of the designed number. In case 2, all the fixing bolts on the top of the ascending flanged base were tightened. In case 3, pressure release valve was not set, so the fault arc caused the internal pressure of the ascending flanged base to rise and burst, and caused a fire in the oil and gas mixture. The comparison diagrams and the plane layouts of the equipment before and after the test are shown in Figure 3. The center of the ascending flanged base on the network side was 2.85m away from the pressure sensor on the side wall of the valve hall.

During the test of case 1 and case 2, the pressure relief valves had changed, and the explosion pressures generated in the side wall of the valve hall were relatively close. The time history curve of the middle part pressure at the valve hall side wall measured in case 2 is shown in Figure 4, and the simplified blast load is obtained based on the characteristics of the curve, which is recorded as “BLAST_C”; The time history curve of the pressure at the valve hall side wall measured in case 3 is shown in Figure 5, which is simplified as a trapezoidal load, and recorded as "BLAST_D".

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**Figure 3. Test layout**

**Figure 4. Simplified blast load of test case 2**
To sum up, for the goal of the converter station valve hall firestop system structure resistance to blast fortification, and based on the converter transformer arc fault location, and the size of the arc energy, and such factors as the position of the initiation and firestop structure from security analysis, we should propose a comprehensive evaluation and determination to guarantee fire prevention performance of firestop system is not affected after the design of explosion shock loading; when the conditions are limited and cannot be reliably evaluated, it can also be determined according to the following regulations and should be stated in the design documents.

(1) Refer to the provisions of Article 5.3.1 of GB50779-2012 "Code for design of blast resistant control building in petrochemical industry" to determine:
(a) The shock wave peak incident overpressure maximum value can be reached to 21 kPa, the positive pressure action time can be 100 ms; the shock wave peak incident overpressure maximum value can be taken as 69 kPa, and the positive pressure action time is taken as 20 ms.
(b) The explosion shock waveform takes a time from zero to positive pressure and the peak incident overpressure shows a triangular distribution from maximum to zero.

(2) According to the simulated discharge test of the ascending flanged base at the converter transformer network side, it is determined that:
In actual engineering, the distance between the center of the ascending flanged base of the converter transformer network side and the valve hall firewall is usually larger than 5m, and the distance in the simulated discharge test is only 2.85m. Therefore, the simplified "BLAST_C" and "BLAST_D" obtained in the test were taken as the design blast loads, and the results obtained by the calculation were partial to safety.

The resulting blast resistant design target for the valve hall firestop system of the converter station can be defined as: the firestop system has four explosions of "BLAST_A", "BLAST_B", "BLAST_C" and "BLAST_D" as shown in Figure 6. After these blast loads impact, the fire performance of the system can still satisfy the requirements.
3. Introduction to the strengthening scheme

As shown in Figure 7, in order to minimize the construction period, the strengthening scheme considers not to remove the original firestop system, and arranges the blast resistant structure system like steel keel or blast resistant fiber plate outside the valve hall firewall hole, and at the same time, to enhance the fire performance of the firestop system, a layer of high-performance fireproof plate can be affixed to the outside or inside of the original single-layer PAROC plate firestop system based on the actual situation on site. The basic idea of the strengthening scheme is the blast resistant and fire separation of the firestop system. The blast resistant and fire protection are respectively undertaken by the independent blast resistant structure system and the fire-blocking system, and only the maximum blast resistant structure system under the design of the explosion load is controlled. The deformation does not exceed the distance from the outside of the firewall to the outer surface of the original single-layer PAROC plate firestop system, that is, the firestop system under blast loading is basically unaffected, so that the explosion-burning condition caused by the fault arc of the converter transformer can be ensured. The fire performance still maintains design values to prevent fires from spreading to the interior of the valve hall.

For the steel keel-steel plate or steel keel-blast resistant fiber plate system, the steel keel structure shown in Figure 8 can be considered. Among them, the steel keel form A only arranges the horizontal or vertical keel, which is the most convenient for construction; the steel keel form B adds an appropriate amount of orthogonal keel on the basis of the form A. This method is also relatively simple and blast resistant performance is also improved; the steel keel form C has the best blast resistant performance, but the construction is relatively time consuming. The final choice of steel keel structure needs to be determined by calculation based on the blast resistant design target.

Figure 7. The strengthening scheme for the typical firestop system

Figure 8. The steel keel form for the strengthening scheme
4. Numerical examples
Taking Shuanglong Station as an example, the size of the hole is 5030mm×4350mm. Considering the three steel keel structures in Figure 8, in this study, the steel keel section size is 150mm×80mm×6mm, and the outer surface steel plate thickness is 5mm. The distance between the outside of the hall firewall and the PAROC board is 90mm. In the general finite element software LS-DYNA, three numerical models of steel keel structure are established respectively [2, 3]. Firstly, the blast load “BLAST_D” with higher peak value is considered. The calculated time history curve of the blast resistant structure is shown in Figure 9. It can be seen from the figure that the maximum deformation of the steel keel structure form B is slightly larger than 90 mm, and the maximum deformation of the steel keel form A is about 165 mm, which is much larger than 90 mm.

![Figure 9. Dynamic response of the steel keels under “BLAST_D”](image)

In order to deeply analyze the dynamic response process of the three steel keel structures under the target load, the four blast loads “BLAST_A”, “BLAST_B”, “BLAST_C” and “BLAST_D” are applied to the steel keel blast resistant structure A, B, C, and calculated time-history curves of the middle deformation of the structure are shown in Figure 10, Figure 11 and Figure 12, respectively. It can be seen from Figure 10 that the maximum deformation of the steel keel structure A under the blast load "BLAST_A" is about 60 mm, which is smaller than the distance between the outer side of the firewall and the PAROC plate surface layer of 90 mm, indicating that the steel keel structure A behaves well under this blast load condition, and the forging requirements are satisfied; the maximum deformation of the steel keel structure A under the blast loads "BLAST_C" and "BLAST_D" is close to 90 mm; the maximum deformation of the steel keel structure A under the blast load "BLAST_B" is about 165 mm, which is far more than 90 mm. It indicates that the steel keel structure A cannot guarantee the fireproof performance of the firestop system under the action of the blast load "BLAST_B". According to the definition of the blast resistant design target of the firestop system of the valve hall of the converter station, the steel keel structure form A cannot meet the conditions, and it is necessary to further enhance the blast resistant capability of the structure.

The steel keel structure form B adds a small amount of steel keels in the orthogonal direction on the basis of A. It can be seen from Figure 11 that the blast resistant ability of the structure basically meets the requirements, and the maximum deformation in the middle of the structure under the action of the blast load "BLAST_B" is slightly larger than 90mm. On the basis of the steel keel structure B, part of the transverse steel keel is continuously added to obtain the steel keel structure form C. It can be seen from Figure 12 that the maximum deformation of the central part of the steel keel structure C under the four blast loads impact are less than 90 mm, indicating that the structure form has the best blast resistant ability. Based on the above calculation results, for the firestop system of the valve hall of Shuanglong Station, if the steel pipe with the cross-section size of 150mm×80mm×6mm is selected, the steel plate with 5mm thickness is strengthened, and the steel keel structure form B is most suitable, which can satisfy the firestop system blast resistant requirements and simplify the construction process as much as possible.
5. Conclusions

In this paper, the blast resistant design target of the firestop system of the valve hall of the converter station is proposed. The blast resistant performance analysis method of the firestop structure is established, and the strengthening scheme of the firestop system of the valve hall of the converter station is proposed. The main conclusions are as follows:

(1) Separate blast resistant structure system on the outside of the firewall is the best way to strengthen the performance of the firestop system in the valve hall of the converter station. The fire protection and blast resistant functions are separated, and the blast load is completely sustained by the blast resistant structure system. The firestop system is not affected by the blast load;
(2) The established blast resistant performance analysis method of the firestop structure can be used to optimize the design of the blast resistant structure of the strengthening scheme, and obtain reasonable steel keel section size, steel keel layout and surface blast resistant steel plate thickness.

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