Research on new blast and fire stopping system of valve hall for UHVDC converter stations

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Abstract. In this paper, a new blast and fire stopping system of valve hall for UHVDC converter station is proposed. With the hydrocarbon temperature rise curve, the fire resistance test of a 1.4m×1.8m sample was carried out, a numerical model for blast resistant analysis of the firestop structure was established, and the blast resistant performances of the original firestop structure and the new structure were calculated. The results show that the new fire and blast stopping system proposed in this paper has a fire endurance time limit of more than 4 hours with the hydrocarbon heating curve. At the same time, compared with the original system, the blast resistant capability of the new firestop structure is greatly improved.

1. Introduction

As the demand for electric power continues to increase, China's ultra-high voltage (UHV) project is under rapid construction. As of November 2017, the UHV project “Eight alternating current (AC) lines and Eight direct current (DC) lines” has been completed and put into operation, the “Two AC lines and Three DC lines” projects are still under construction, and the project “One AC lines” was approved, which have a total of more than 32,000 kilometers of UHV lines, 330 million kilovolt-amperes (kW) of power transformation (current conversion) capability, and more than 30 converter stations with voltage levels of 500kV and above.

The converter station is the core of the UHVDC project to realize the mutual conversion of AC and DC, which operational reliability directly affects the safety of personnel and equipment and the stable operation of the power grid. The insulating oil in the converter transformer tank is more than 100 tons. Once the fault arc causes fire or even explosion, the firestop system of the valve hall will be destroyed, and the fire will spread to the inside of the valve hall, which will cause immeasurable economic loss and social impact. In recent years, fire accidents caused by explosion rupture of converter casings have occurred. For example, on April 7, 2018, an explosion occurred at the ±800kV Tianshan converter station in Hami, Xinjiang, resulting in one high-end valve hall and 6 converter transformers burned down and the economic losses were heavy.

In order to ensure the convenient movement of the converter transformer, the converter transformer is arranged adjacent to the valve hall, as shown in Figure 1, which is separated from the valve hall by a firestop system composed of PAROC plates (a lightweight rock wool sandwich board, 0.5mm degaussing stainless steel board +150mm rock wool +0.6mm degaussing stainless steel board), and the
size can reach 7m×7m. Although the fire resistance limit of PAROC plates is more than 3 hours (ISO834 standard heating curve), the firestop system consisting of PAROC boards has not been tested by qualified testing institutions, and there is still a large uncertainty in the true fireproof capacity of the system. On the one hand, a large amount of insulating oil is stored inside the converter transformer, and its ignition is closer to a hydrocarbon fire. Compared with cellulose combustion (ISO834, standard heating curve), hydrocarbon fire combustion has a high heating rate and can be extremely short. In the time of reaching 1100 °C, it is easy to cause rapid degradation of the performance of fireproof blocked materials; On the other hand, the structure of such firestop system does not consider the explosion effect. Once the converter transformer has an explosion combustion accident, the structure of the firestop system may be directly exploded and destroyed, and the fire-proof ability will be completely lost, causing the fire to spread to the valve hall, causing incalculable economic losses and even affecting the normal operation of the national economy.

Therefore, this paper proposes a new type of blast and fire stopping system by introducing blast resistant structure system and improving fire-proof performance. The fire resistance test of a scale model and the numerical calculation method are used to verify the fire and blast performance of the system, thus guiding the improved design of the original firestop system, improving the fire prevention of the system, and avoiding the converter transformer fire or explosion caused the destruction of the internal facilities of the valve hall, which has great significance for the safe and stable operation of the national power system, the sound development of the national economy, and even the national defense security.

![Figure 1. Scheme of the firestop system in a typical valve hall](image)

2. Introduction of the new firestop system

If the distance between the converter transformer and the firewall is small or the distance between the PAROC plates surface of the original valve hall firestop system and the outer edge of the firewall is small, it is difficult to set up a separate blast resistant structure on the outside of the firewall. Therefore, the firestop system can be properly removed, and the new firestop system is considered from the integration of fire prevention and blast resistance.

Due to the lack of fire and blast resistant capability of the original PAROC plates firestop system, based on the full consideration of the fire prevention and explosion protection objectives of the firestop system, this paper proposes a new composite firestop structure, as shown in Figure 2. From outside layer to inside layer, the structure is constructed by 100mm thick structural rock wool board, 9.5mm thick fiber reinforced blast resistant panel, 80mm×80mm×6mm steel keel structure, 9.5mm thick fiber reinforced blast resistant panel and 100mm thick structure rock wool board.

The fiber reinforced blast resistant panel is composed of a sandwich structure, the surface structure is 0.5mm thick galvanized steel plate, the interlayer is 8.5mm thick reinforced fiber cement board. The surface steel plate is fully struck with 5mm round holes with an interval of 20mm, and the steel plate shape inside the hole is jagged. The cement layer is finally tightly combined with high pressure, as shown in Figure 3.
3. Fire resistance test

In order to study the fire resistance performance of the new firestop system proposed in this paper, a reduced scale test sample was prepared as shown in Figure 4. The sample size was 1.4m×1.8m, and the temperature measuring points of 1 to 11 were arranged on the back surface of the sample. Temperature measuring points 12 and 13 are placed on the inner steel keel. The sample was installed on the test furnace and tested by the hydrocarbon heating curve. The measured furnace temperature is shown in Figure 5. The furnace temperature agrees well with the theoretical hydrocarbon heating curve, indicating the temperature and design of the sample are consistent. The temperature curve of the sample on the unexposed surface of the sample is shown in Figure 6. After 4h of heating by the hydrocarbon curve, the maximum temperature of the 1 to 11 measuring points was only about 60 °C, which is much smaller than the fire resistance limit temperature of 180 °C. At the same time, the temperature of the steel keel of the sample was also lower than 180 °C. The new scheme of the firestop system has been tested to show that the fire resistance limit was more than 4h under hydrocarbon fire.

At the same time, after the fiber reinforced blast resistant panel was removed, the fire resistance test was carried out on the sample of the same size. The measured internal steel keel heating curve is shown in Figure 7. The steel keel temperature in the middle layer of the sample reached nearly 500 °C. Therefore, in the real application conditions, the firestop structure with a size of 5m×5m or more is necessary to increase the fiber reinforced blast resistant panel to prevent the steel keel structure temperature from exceeding 500 °C, thereby improving the strength of the firestop structure.
Figure 4. Test specimen and layout of measuring points

Figure 5. Furnace temperature curves

Figure 6. Temperature curves of measuring points
4. Blast resistance analysis

Taking Shuanglong Station as an example, the firestop system consists of a single layer of 150mm thick PAROC plate without steel keel system. Therefore, the numerical model of the blocked system is established according to the actual situation in LS-DYNA [1]. Among them, the surface layer stainless steel and the rock wool core material of the PAROC sheets adopt shell and solid elements, respectively, and the bond failure of the surface layer and the rock wool core material is not considered. For the convenience of modelling and analysis, the height of the hole is adjusted from 4.35m to 4m in the numerical calculation. It is assembled by four 1m wide PAROC sheets, the outer frame is simulated by rigid material, and the joint is defined by the contact failure algorithm. The numerical model is shown in Figure 8.

For the new blast and fire stopping system proposed in this paper, the steel keel section size is 150mm×75mm×8mm, the plane layout is shown in Figure 9, and the structural plane size is 5030mm×4350mm. Through the previous research results, the design blast loads of the blocked system is shown in Figure 10. In this paper, the explosion condition “BLAST_B” is considered. The blast load is from GB50779-2012 “Code for design of blast resistant control building in petrochemical industry” [2].

Figure 11 shows the displacement time history curve of the firestop system. Under the action of “BLAST_B”, the maximum displacement of the original PAROC plate blocking system reaches about 550mm, which has far exceeded the deformation limit. It shows that the original blocked system fails under the action of this explosion condition, and the system loses the fireproof function; while the new blast and fire stopping system proposed in this paper has a maximum deformation of only 10mm in the middle, the firestop structure basically is still in an elastic state, and its fire performance is not affected by the explosion.
5. Conclusions
In this paper, a blast and fire stopping structure system with steel keel is introduced, and the fire and blast resistance performance of the system is verified by the scaled test and the finite element numerical calculation. The main conclusions are as follows:

(1) The fiber reinforced blast resistant panel can effectively improve the fire-proof and blast resistance performance of the firestop system;

(2) The proposed blast and fire stopping system has a fire endurance of more than 4h, and the blast resistance performance can satisfy the requirements of the fortification target.

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