Application of X-ray Detection Technology in Routine Tests of High Voltage Bushings and Arresters

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Abstract. The improper control of the production process can easily cause defects in the power equipment that cannot be found by routine tests. In this paper, X-ray detection technology was used to test high voltage porcelain bushings, high voltage composite bushings and metal oxide surge arresters polymeric with series gaps, which are prior to working. It is found that there are air gaps between the waterproof glue on the flange and the body of bushings, which will increase the vibration frequency of the porcelain bushings and will cause the bushings to be abnormally stressed. There is a misalignment or poor contact between the contact surface of internal valve pieces of the MOA, which will reduce the flow capacity of the series valve pieces. The above phenomena will reduce the reliability of the power grid operation. This paper believe that the current routine tests should be improved, X-ray detection technology should be used as a new routine test for high-voltage bushings and arresters to improve the reliability of equipment operation.

1. Introduction
The results, tracing the cause of the failure of the power equipment, show that the main fault reason is usually caused by the production process. The internal defects, caused by the production process, were not effectively detected during the routine test and the well-directed running test was not taken during the operation, so the fault occurred [1-2]. At present, the X-ray industrial CT testing has been used as a new effective method to detect the internal defects in the production of the basin-type insulator of GIS, and the test results would show what is feasible and effective to internal detection of the basin-type insulator [3].

Facing the good results of X-ray detection technology in non-destructive testing of power systems [4-7], the authors decided to verify the possibility of applying the X-ray technology to the routine test in other equipment like high voltage porcelain bushings, high voltage composite bushings and metal oxide surge arresters polymeric with series gaps. Through previous tests, some internal structural phenomena, which had not been found by existing testing methods, were discovered. These structural phenomena can adversely affect the operation of the equipment and reduce the life of the equipment.

Using the X-ray detection technology can image the power equipment without disassembly and stripping. Combined with other existing routine tests, it can contribute to the improvement on product quality. It is considered that X-ray testing technology should be used as one of the routine tests of the
high voltage bushings and the metal oxide arresters.

2. Technology and method

2.1. X-Ray detection technology

X-ray has attributes of penetrability, when it penetrates an object, it will be weakened by absorption and scattering effects, and different materials have different X-ray absorption and scattering capabilities [8]. If there are some defects inside the object, the attenuation coefficient of the defect part will be different from the body of the object, and the intensity of the ray passing through the defect area will be different from the surrounding area. The imaging plate is light sensitized by the X-ray transmitted through the object. The fluorescent emitting material on the imaging plate has the ability for retaining potential image information and form a latent image. After the laser scanner converts the signal, the X-ray image stored on the imaging plate can be converted into a digital image and stored in the computer. The detection system consists of X-ray machine, imaging plate, Laster Scanner, control box and computer. The detection process is shown in Figure 1.

The X-ray machine model is ERESCO MF4X, which is portable and produced by GE. Its highest output tube voltage is 300kV, the maximum tube current is 6mA, the penetration capability is >65mm (iron). The output parameters are remotely controlled by the control box.

![Detection process of X-ray](image)

2.2. X-ray detection method

In the production workshop, the high voltage porcelain bushings, high voltage composite bushings and metal oxide surge arresters polymeric were selected for testing, and they had all passed the existing standard routine tests. In total sample, two bushings of each voltage level, including 110kV, 220kV, 330kV and 400kV, were randomly selected in sequence. Five arresters of each voltage, including 35kV and 220kV, were randomly selected in sequence.

Appropriate parameters must be chosen to achieve high quality imaging of different types of samples. The parameters include the tube voltage (U) of the X-ray machine as well as the tube current (I), the focal length (F) and the exposure time (T). The test parameters determined by the combination of different parameters are shown in Table 1.

| Object          | Tube voltage (kV) | Tube current (mA) | Exposure time (s) | Focal length (mm) |
|-----------------|-------------------|-------------------|-------------------|-------------------|
| porcelain bushings | 200～280          | 3                 | 10                | 1000              |
| composite bushings | 100～150          | 3                 | 10                | 1000              |
| MOA polymeric | 80～100            | 3                 | 10                | 1000              |

Figure 1. Detection process of X-ray
3. Detection results

3.1. Porcelain bushings
The porcelain bushings of 110kV, 220kV, 330kV and 400kV voltage levels were tested. The test results showed that no abnormal phenomenon was found in the X-ray images of the porcelain bushings of various voltage levels. However, the interface of the assembly at the two ends of the porcelain bushings could be easily distinguished. Figure 2 is a typical X-ray image of the head-end of an 110kV voltage-level porcelain bushing.

![Figure 2. X-ray image of porcelain bushing](image)

3.2. Composite bushings
The composite bushings of 110kV, 220kV, 330kV, 440kV voltage grade were tested separately. Figure 3(a) is a typical X-ray image of the flange position on the head of the composite bushing. The imaging gray level difference between the bushing core and the shed can be visually observed, and the abnormal air gap was found at the contact surface of them. Figure 3(b) is an enlarge view of the air gap at this position. Figure 4(a) is a typical X-ray image of the flange position on the end of the position bushing. It is found from the image that the waterproof glue on the flange position and the surface of the bushing was not tightly bonded, and there are some air gaps. Figure 4(b) is an enlarge view of the air gap at this position. The X-ray images shown above are only 110kV voltage grade composite bushings, but the problems they display are common to the various voltage grade. Of all the test samples, only one composite bushing did not find abnormal air gap.

![Figure 3. X-ray image of composite bushings](image)

![Figure 4. X-ray image of composite bushings](image)
3.3. MOA polymeric with series gaps
The metal oxide surge arresters polymeric of 35kV and 220kV voltage grade were tested separately. Figure 5 is the X-ray image diagram. It indicates that the contact surface of the internal series valve piece of the arresters is placed off-center (Figure 6), and the most serious is that there is an air gap at the contact surface (Figure 7). For the five tested metal oxide surge arresters polymeric, 220kV voltage grade level, they all have different degrees of placed off-center, and three of them have air gaps. All five tested metal oxide surge arresters polymeric, 35kV voltage grade level, they also have different degrees of placed off-center, and two of them have air gaps. The X-ray images shown above are just some typical examples of all.

![Figure 5. X-ray image diagram](image)

(a) Typical image one  (b) Typical image two
Figure 6. X-ray image of the placed off-center

(a) Typical air gap one  (b) Typical air gap two
Figure 7. X-ray images of the air gaps

4. Discussion
The porcelain bushings have a high density, and the transmission capacity of the selected X-ray machine is limited, so the porcelain bushings have not been detected to be abnormal, and it is necessary to select a higher tube voltage level X-ray machine for further testing.

For the test of the composite bushings, the abnormal air gaps were found at the contact surface of the bushing core and the shed, and the abnormal air gaps at the waterproof glue on the flange position and the surface of the bushings. The composite bushings and the porcelain bushings adopt the same waterproof technology, it can be inferred that the same problem exists on the porcelain bushings. Air gaps present can affect the waterproofness of the bushings.

For the porcelain bushings, the strength of the cement, between the flange and the hollow porcelain bushing, will be reduced after water absorption. This will affect the reliability of the connection between the hollow porcelain bushing and the flange, resulting in looseness. The vibration frequency of the porcelain bushings will increase during operation and the flange section will amplify the dynamic response of the porcelain bushings. In addition, the volume and hardness of the cement will
increase after water absorption, so that the porcelain bushings are slowly subjected to stress. Cracks will appear after the cement setting. In cold areas, the water in the voids and cracks immersed in the cement will repeatedly freeze and dissolve due to changes. As a result, the cement freezes and expands, causing the porcelain to be subjected to abnormal stress. Abnormal vibrations and stresses can increase the probability of failure of the porcelain bushings during operation.

The metal oxide arrester should have sufficient flow capacity to bleed lightning current and absorb lightning impulse energy. Ideally, the current distribution of each part of the valve with good internal contact of the arrester should be the same. Due to the unevenness of the valve plate, it is actually difficult to achieve, so the reduction in the uniformity factor results in a decrease in the flow capacity of the arresters. The detection results of the arresters indicate that the placed off-center phenomenon between the internal series valve pieces are common, and some of the arresters may have poor contact between the internal valve pieces and have air gaps. These can affect the reliable contact of the valve piece, reduce the actual flow area of the valve piece, and ultimately reduce the flow capacity of the arresters. The inrush current density easily exceeds the allowable limit value, causing the valve plate to be damaged, and the multiple valve pieces are gradually cracked, eventually causing the valve piece to be destroyed under the power frequency voltage. Due to the high power of the power frequency power supply, the valve piece will be broken or explosion.

5. Conclusion
The high-voltage bushings and arresters tested have undergone rigorous type test verification. The performance must meet the requirements and there is no design problems. However, the existing routine test standards cannot find the air gaps in the high-voltage bushings, the off-center and the air gaps phenomena in the metal oxide surge arresters, which will reduce the reliability of the grid operation. It is believed that the routine test standard should be improved, and the X-ray test technology is used as a new test item for the high-voltage bushings and the metal oxide surge arresters, to eliminate potential danger equipment and improve the reliability of the power grid operation.

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