Corrosion Analysis of Connecting Bolt Used for Terminal Block of Isolation Switch in 220kV Substation

Hao Chen*, Weiwei Gong, Xin Qiao and Yunfei Sun

Inner Mongolia Electric Power Science & Research Institute Hohhot, Inner Mongolia, China

*chenhao3@impc.com.cn

*chenhao1984223@163.com

Abstract—Isolation switch is mainly composed of insulation part, conductive part, supporting frame, transmission mechanism and operating mechanism, which is of great importance for the safety and stability of power grids. In this paper, the seriously corroded connecting bolts used for terminal block of isolation switch in 220kV substation was investigated by means of macro-morphology inspection, hardness testing, zinc coating thickness measurement, scanning electron microscope, microstructure analysis and energy spectrum analysis. The result showed that the poor quality of the zinc coating was the main cause of the corrosion failure of the bolting and the gap between the bolt and the aluminium terminal block provided electrolyte environment for galvanic corrosion. In addition, targeted suggestions were put forward in order to improve the corrosion resistance of the connecting bolts and avoid the similar corrosion failure.

1. INTRODUCTION

Isolation switch is a switch apparatus with simple structure, which plays a key role in isolating power supply, switching operation, connecting and cutting off small current circuits. Meanwhile, isolation switch is usually installed outdoors and operates under the complex weather such as strong wind and rainstorm, which makes the corrosion failure of metal parts such as connecting bolts and supporting frame inevitable. With rapid development of power system, more and more accidents caused by corrosion of connecting bolt used in isolation switch occurred, thus the safety and stability of power grids would be severely affected.

In recent years, a number of research efforts have been made on corrosion mechanism and behaviour of the connecting bolt, and great progresses have been made in this field. Zhu [1] investigated the corrosion damage mechanisms of the free lengths of prestressed rock bolts subjected to an aggressive environment and found that the prestress had a great influence on the corrosion of the rock bolts. Elshawesh [2] analysed the reason for corrosion and cracking of internal bolts used for assembly of multistage water pump in a severe working environment and concluded that the galvanic coupling between bolts and nuts in addition to the severe working environment played major role in the premature failure of bolts. Wu [3] compared the fractographic features of both serviced-failed and laboratory-failed cable bolts and thought that hydrogen-assisted SCC was the dominant fracture mechanism in cable bolt failures. Wei [4] adopted a low-coherent fiber-optic sensing technique to monitor the corrosion of rock bolt and found that uniform interface between cement and rock bolt determined the progress of corrosion development.
During the patrol inspection of a 220kV substation, it was found that the connecting bolts of several electrical equipment were rusted, especially for the connecting bolts used in the terminal board of the isolation switch. In this paper, different physical and chemical test methods were adopted to analyse the corrosion reason of the seriously corroded connecting bolts. Meanwhile, the corrosion mechanism and corrosion behaviour of the connecting bolts were systematically investigated and protective measures were put forward, which could provide the technical support for the operation and maintenance of the isolation switch.

2. EXPERIMENTAL RESULTS AND ANALYSIS

2.1 Macroscopic observation
Figure 1 shows the macro-morphology of the corroded connecting bolts and it is clearly observed that most bolts have seriously rusted and the galvanized layer has completely fallen off. Meanwhile, most of the corroded bolt surface is covered by brown corrosion products, while there is a small amount of white powder corrosion products at the thread of the bolts, which should be aluminium oxide. Additionally, the surface of the corroded bolt is rough with a lot of corrosion pits and the cross section has been significantly reduced. Through observing the residual zinc coating of the unrusty bolts, it could be found that its coating is silver-white and smooth with metallic luster, which is consistent with the coating characteristics of electro galvanizing process.

(a) Entirety

(b) Serious corrosion region

Figure 1. The macro morphology of the corroded connecting bolts.

2.2 Zinc coating thickness measurement and Hardness testing
Using coating thickness gauge, the thickness of the residual zinc coating for unrusty bolts is tested. It is found that the galvanized layer of the connecting bolt is uneven and its thickness is in the range of 3.6～12.9μm, which is much lower than the minimum thickness of 45μm required in the standard. In
addition, the Vickers hardness of the bolt is determined in the range of 203~215HV by fully automatic Vickers hardness tester, which meets the requirements of DL/T 284-2012 standard.

2.3. Microstructure and energy spectrum analysis of corrosion products

The micro morphology of the corrosion products sampled from the corroded connecting bolt is investigated by means of scanning electron microscope (SEM) and the result is shown in Figure 2. It is clearly seen that there are a large number of cluster particles and irregular blocks with different sizes on the surface of the corrosion products.

The chemical compositions of the brown and white powder corrosion products (as shown in figure 3) on the surface of the corroded connecting bolt are analysed by energy spectrum analyser, and the testing results is shown in Figure 4 and table I. The result shows that the white powder corrosion products mainly contain aluminium and oxygen without other elements, which should be aluminium oxide. While the brown corrosion products are composed of iron oxide, calcium oxide and aluminium oxide, and the calcium oxide should be the sand adsorbed on the surface of the bolt.

Figure 2. The SEM morphology of corrosion products

Figure 3. The region for energy spectrum analysis
TABLE 1. ENERGY SPECTRUM ANALYSIS RESULT OF CORROSION PRODUCTS (WT%)

| Chemical element          | Fe   | Al  | O   | Ca  |
|---------------------------|------|-----|-----|-----|
| White powder corrosion products | —    | 61.17 | 38.83 | —  |
| Brown corrosion products   | 34.50 | 26.63 | 38.13 | 0.74 |

Figure 4. Energy spectrum analysis chart for corrosion product.

2.4. Metallographic structure analysis

Figure 5 shows the metallographic microstructures of the corroded connecting bolt. In the whole cross section, the metallographic structure of the bolt is mainly polygonal ferrite and equiaxed pearlite, without obvious deformation. Additionally, there are many corrosion pits in different sizes and depths on the surface of the corroded bolt.
3. ANALYSIS AND DISCUSSION

During the operation of the isolation switch, rainwater and snowmelt could infiltrate into the gap between the connecting bolt and aluminium terminal block to form the electrolyte environment. Usually, the corrosion potential of Zn, Al and Fe increases in turn in salt water, thus aluminium terminal block and galvanized layer of the bolt could form a corrosion couple due to the contact of different metals [5, 6]. In the initial stage of galvanic corrosion, the zinc coating of the bolt is intact, thus the galvanized layer could be used as a sacrificial anode to protect the aluminium terminal block and the exposed steel substrate from corrosion [7, 8]. Meanwhile the depolarization reaction of oxygen occurs at the cathode and the reaction equation is described as follows:

Anodic reaction: \( \text{Zn} - 2e \rightarrow \text{Zn}^{2+} \)

Cathodic reaction: \( \text{O}_2 + 2\text{H}_2\text{O} + 4e \rightarrow 4\text{OH}^- \)

The overall reaction:

\( \text{Zn}^{2+} + \text{OH}^- \rightarrow \text{Zn(OH)}_2 \rightarrow \text{ZnO} \cdot \text{H}_2\text{O} \)

However, according to the test results of zinc coating thickness and its macro-morphology, the anti-corrosion process for the bolts of the disconnector should be electro galvanizing process. Compared with the hot-dip galvanizing process, the coating has poor adhesion and thin thickness, which is easy to cause premature failure of the zinc coating. Without the protection of zinc coating, the exposed steel substrate is in direct contact with the aluminium terminal block, so that the aluminium terminal block is used as the anode to provide protection for the bolt. Therefore, it accelerates the corrosion rate of the aluminium terminal block due to the effect of primary battery and produces a large number of silver white aluminium oxide powder on the bolt surface [9, 10].

4. CONCLUSIONS

In this paper, the reason of corrosion for the connecting bolts used in isolation switch was systematically investigated and analysed. Through comparing and analysing the experimental results, the following conclusions are drawn.

1) The thickness of the galvanizing layer on the connecting bolts of the disconnector is in the range of 3.6～12.9μm, which is much lower than the standard requirements, resulting in insufficient corrosion resistance. With the continuous infiltration of rainwater and snowmelt into the gap between the terminal block and the bolt, the galvanizing layer would suffer galvanic corrosion due to high electrode potential. Therefore, the zinc coating fails prematurely due to insufficient corrosion resistance, which causes serious corrosion of steel substrate and aluminium terminal block.

2) In view of the large number of bolts with corrosion failure, more and more attention should be paid to the inspection of the connecting bolts used for terminal block of isolation switch in 220kV substation, and the seriously corroded bolts and electro galvanized bolts should be replaced in time.
3) The application of anti-corrosion grease could effectively prevent the infiltration of rainwater and snowmelt, which plays an important role in prolonging the service life of connecting bolts and terminal blocks.

4) Generally, hot dip galvanizing process is adopted for the metal components in the power grid equipment as anticorrosive coating. Compared with the electro galvanizing process, the hot-dip galvanized layer is a thicker one with strong adhesion, which could play an anti-corrosion role for the metal components in a longer period of time. Therefore, before the connecting bolt of isolation switch is put into use, the quality of galvanized layer should be comprehensively tested, and the thickness of zinc coating should meet the standard requirements.

ACKNOWLEDGMENT
The authors would like to acknowledge the financial support from the Science and Technology Project of Inner Mongolia Power Company (Grant No. 2019-102).

REFERENCES
[1] J. B. Zhu, X. W. Wang, C. Li and B. Lu, “Corrosion damage behavior of prestressed rock bolts under aggressive environment,” KSCE Journal of Civil Engineering, vol. 23, pp. 3135–3145, 2019.
[2] F. Elshawesh, K. Abusowa, H. Mahfud and H. Ezuber, “Stress-corrosion cracking and galvanic corrosion of internal bolts from a multistage water injection pump,” Journal of Failure Analysis and Prevention, vol. 8, pp. 48–53, 2008.
[3] S. S. Wu, J. P. Li, J. P. Guo, G. B. Shi, Q. H. Gu and C. W. Lu, “Stress corrosion cracking fracture mechanism of cold-drawn high-carbon cable bolts,” Materials Science & Engineering A, vol. 769, pp. 1-10, 2020.
[4] H. M. Wei, X. F. Zhao, D. S. Li, P. L. Zhang and C. S. Sun, “Corrosion monitoring of rock bolt by using a low coherent fibre-optic interferometry,” Optics and Laser Technology, vol. 67, pp. 137–142, 2015.
[5] Z. Q. Wu, L. Chen, X. Zhang, Q. Feng and C. Wu, “Analysis on large area corrosion of high strength bolts in wind power tower tube,” Hot Working Technology, vol. 48, pp. 253–259, 2019.
[6] J. K. Zhang, G. H. Chen, J. Q. Wang, T. Zhang, X. Wang and W. M. Tang, “Microstructures of corrosion layer of ACSR conductor in atmospheric corrosion and corrosion mechanism,” The Chinese Journal of Nonferrous Metals, vol. 21, pp. 411–417, 2011.
[7] C. Pan, M. X. Guo and Z. Y. Wang, “Effect of MgCl₂ on the corrosion behavior of copper under periodic wet/dry cycle condition,” Journal of Materials Engineering and Performance, vol. 28, pp. 2562–2572, 2019.
[8] A. K. Bhattamishra, K. La, G. G. Nair and R. Kumar, “Corrosion behavior of overhead aluminum/alloy conductors in industrial and coastal environments,” NML Technical Journal, vol. 29, pp. 20–24, 2002.
[9] S. B. Lyon, G. E. Thompson and J. B. Johnson, “Accelerated atmospheric corrosion testing using a cyclic wet/dry exposure test: aluminum, galvanized steel and steel,” Corrosion, vol. 43, pp. 719–726, 1987.
[10] A. Pandya, D. Saha, J. K. Singh, S. Paswan and D. D. K. Singh, “Effect of environmental pollution on corrosion characteristics of 3003 Aluminium alloy exposed in different parts of India,” Transactions of the Indian Institute of Metals, vol. 70, pp. 1607–1620, 2017.