Research on UHV Isolating Switch Technology with Multi-source Action Signal

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Abstract. With the improvement of the voltage level of power transmission and transformation lines, the development of smart grids has highlighted a major demand, and relevant enterprises and scientific researchers in the UHV field at home and abroad have explored the research of water intelligent isolation switch equipment. This article explains the current problems of traditional substation isolation switches, and analyzes the advantages and disadvantages of UHV isolation switch technology and its application status through three aspects: isolation switch, isolation switch contact and isolation switch sensor. Studies have shown that the development and application of isolating switches with multi-source action signals, and further improving the proportion and accuracy of smart devices to replace manual labor are the development trends of UHV isolating switches.

1. Introduction

Power grid security is an important prerequisite for ensuring the comprehensive, coordinated and sustainable development of the social economy. Power grid dispatching is a key link for the safe and stable operation of the power grid. At present, the risk of large-scale power grid accidents always exists. From the perspective of the actual operation of the power grid, safety work faces many pressures. The construction of smart grid is an important way to realize the controllable, controllable and in-control of grid security risks. It is an important means to enhance grid disaster prevention and mitigation and risk emergency resilience, and to ensure the sustainable and healthy development of the national smart grid [1-4].

China State Grid has gone global and has become a leader in the global energy revolution. The voltage levels of transmission and transformation lines have developed from high voltage (AC110kV, AC220kV), super-high voltage (AC330kV, AC500kV, AC750kV; DC±500 kV) to ultra-high voltage (AC1000kV, DC±800kV and above). In 2018, the State Grid Corporation of China formally proposed advanced technology requirements such as "one-key sequence control" operation in substations, and issued the "Technical Specification for One-key Sequence Control Transformation in Substations (Trial)"), which will study the application of "one-key sequence control" in substations operation and other advanced technologies are listed as key tasks; it is required to speed up the research and application of advanced technology of "one-key sequence control" to solve the problems of complex switching links, low efficiency, high risk of misoperation and high personal safety risks; requirements for R&D with dual sources key equipment such as action signal HV/SHV/UHV isolation switches meets the technical
requirements of the third-generation smart substation and "strong smart grid, ubiquitous power internet of things", and promotes the pace of upgrading and upgrading the national smart grid.

The development of HV/SHV/UHV isolation switch technology with dual-source/multi-source action signals not only involves theoretical research, but also needs to consider engineering implementation issues in the face of complex operating conditions under strong electric fields, strong magnetic fields, and extreme ambient temperatures. Among them, the UHV isolating switch has the most technical difficulty[5]. This article focuses on the major needs of the development of smart grids, and conducts certain investigations and studies on the technology of UHV isolation switches with multi-source action signals.

2. Research and Application in the Field of UHV Isolating Switches

Traditional substation isolation switches have the following problems[6~9]: ①Traditional switching links are complicated and low in efficiency. Before operation, orders, ticket writing, auditing, simulation and other links are required, and there are many repetitive tasks. ②Traditional switching operations are risky, costly, and difficult. Traditional switching operations rely on manual completion. The quality of personnel is uneven, and they are susceptible to various factors, which can easily lead to misoperations and missed operations. ③Traditional switching has a high personal safety risk. ④Traditional switching is difficult to meet the needs of the growth of the power grid.

At present, in order to solve the problems of traditional switching links, such as complexity, low efficiency, high risk of misoperation, high cost, high difficulty, and high risk of personal safety, it adapts to the current development trend of smart grid dispatching construction. The research in the field of UHV isolating switches around the world mainly focuses on three aspects: isolating switches, isolating switch contacts and isolating switch sensors.

2.1 Research and Application of Isolating Switch Structure

Peng et al.[10] of Tongji University analyzed the influence of the type of support and its connecting beam and disconnector switch mechanism on the seismic response of the isolating switch (Figures 1 and 2), and found that the connecting beam of the support can improve the in-plane rigidity of the isolating switch. The stress at the root of the pillar insulator was small, but the bending moment was large. The safety of the flange under this earthquake should be further studied.

Li[11] used an object recognition algorithm based on local features to realize the matching and recognition of the state of the high-voltage isolating switch during the switching operation. The target partial image template map was selected, and the recognition accuracy rate was 99.75%, and the recognition efficiency was high; Wang et al.[12] of Shanxi Electric Power Research Institute, China studied the VFTO characteristics of isolation switches under the connection of transformers with different structures and fully enclosed combined electrical appliances (GIS), as well as the field measurement of VFTO of GIS equipment, and proposed the optimization of test equipment. The combined scheme improved the capabilities and utility of all aspects of the measurement equipment, and provided a reliable foundation for equipment maintenance and life cycle management.
Guo et al.\cite{13} researched a single-arm foldable plug-in ±1000kV UHV DC isolating switch. The contact adopted an internal hollow tail open structure, which had good convection and heat dissipation effect, which could effectively reduce the contact temperature rise of the contact finger and had strong flow capacity; Li et al.\cite{14} researched an intelligent outdoor high-voltage AC isolating switch, which was equipped with a static contact clamping force detection unit, a main knife temperature detection unit, a moving contact displacement detection unit, and an AC current leakage sensing module to realize the measurement of the high-voltage isolating switch digitization, control networking, function integration, information interaction and status visualization.

2.2 Research and Application of Isolating Switch Contact

Qin et al.\cite{15} of China Henan Pinggao Electric Co., Ltd. increased the flow capacity of the contacts by 25% through the plating process. The addition of new conductive elements to the original contact matrix elements proved that the contacts with silver paint on the surface had higher conductivity than the untreated contacts; Wang et al.\cite{16} of Xi’an Jiaotong University used a composite plating method to electrodeposit a silver-rare earth (Ag-RE) composite coating, which was harder and more wear-resistant than a pure silver coating. The contact resistance was relatively low. The comparison of the SEM photos of the arc erosion of AgNi traditional contacts and nanocomposite contacts was shown in Figure 3 below. The erosion area of nanomaterials was about twice that of traditional materials, and there was obvious scattered arc phenomenon.

Figure 3. SEM micrographs of tradition and nanocomposite AgNi contact materials eroded by arc: (a) tradition AgNi (×45), (b) tradition AgNi(×1000), (c) nanocomposite AgNi (×50), and (d) nanocomposite AgNi (×800).

Wang et al.\cite{17} of the China Academy of Engineering Physics used ion implantation surface optimization technology to inject carbon ions into the surface of pure iron using a multi-energy superposition method at different temperatures. The contact materials prepared by this nanotechnology not only had significantly improved physical properties, but also the electrochemical corrosion ability had also been significantly improved by 10%–15%. Table 1 showed the fitting results of the anodic polarization curve test of the pure iron sample (No. 0) and the superimposed energy ion implanted carbon sample (No. 1, No. 2, and No. 3).

| Sample serial number | $E_{corr}$/mV | $J_{corr}/(\mu A \cdot cm^{-2})$ |
|----------------------|--------------|-------------------------------|
| 0                    | -533         | 11.72                         |
| 1                    | -454         | 9.06                          |
| 2                    | -479         | 5.49                          |
| 3                    | -405         | 3.42                          |

Li et al.\cite{18} produced a force measuring contact used to measure the clamping force of the contact finger of a double-post horizontal opening and closing switch. The force sensor was integrated into the contact to replace the original conductive contact, used to sense the change of contact clamping force during opening and closing process. Jensen et al.\cite{19} checked the contact heating by measuring the V-I curve of the contacts in the switch, and found that a larger contact force resulted in a decrease in contact resistance during the softening process, suppressing contact heating, and thus providing higher power.
handling capabilities for the switch design. Brown et al.\cite{20} conducted a series of experiments to characterize the switching performance of RF MEMS under variable environmental conditions and low temperatures. Experiments had found that the contact voltage could selectively separate the adsorbed membrane from the contact surface without softening the switch contacts, ensuring the service life of the switch.

2.3 Research and Application of Isolating Switch Sensor Device
Lin et al.\cite{21,22} of Beijing Information Science and Technology University adopted the micro-mechanical process to make the regular octagonal sensor sensitive omni-directional horizontal attitude. The sensor was not only small in size, but also compact in structure, simple in process, and good in output consistency of the sensitive components; Gebre-Egziabher et al.\cite{23,24} developed a sensor fusion algorithm based on euler angles and quaternions, and proposed methods for gain scheduling and estimation of pole placement. They used simulation and flight test results to show the algorithm based on quaternions which simplified the gain scheduling and improved the transient response and the sensitivity of the attitude sensor. Figure 4 showed the gain history for the quaternion mechanization associated with the attitude history. San et al.\cite{25} of Xiamen University proposed a new structure of piezoresistive pressure sensor (as shown in Figure 5) in order to eliminate the influence of humidity, acid and alkali, electrostatic particles and other harsh environments on the pressure sensor varistor. The results showed that at 25℃~125℃, its linearity was less than 2.73%, and the sensitivity was about 20mV/V-MPa, which met the requirements of modern industrial use.

Liu et al.\cite{26} studied an intelligent device and method for sensing the opening and closing positions of high-voltage switchgear. The absolute photoelectric encoder was installed on the shaft of the isolating switch operating mechanism, and the absolute photoelectric encoder output at different angle positions. Different codes realized the real-time perception of the absolute position of the rotating shaft and the moving contact of the operating mechanism; Xie et al.\cite{27} of Henan Pinggao Electric Co., Ltd. improved the base mechanism of the double-column horizontally retractable high-voltage AC isolating switch. The mechanical transmission system composed of a group of spatial four-bar linkage and a group of planar four-bar linkage mechanism was improved into a mechanical transmission of a group of spatial four-bar linkage, which improved the transmission efficiency and reliability; Wang et al.\cite{28} studied an isolation switch operating torque real-time monitoring device. The torque sensor was coaxially connected to the torque output structure of the drive mechanism, which could monitor the change of the operating torque during the operation of the isolating switch in real time; Liu et al.\cite{29} studied a device for measuring the contact pressure of the isolating switch. A pressure sensor was installed on the analog static contact to detect the pressure when the analog static contact and the moving contact were closed and plugged.
At present, China’s intellectual property rights in the field of "UHV isolating switches with multi-source action signals" are close to blank. It has not been found that the company can realize the large-scale production of UHV isolating switches with multi-source action signals. The vast majority of enterprises still stay in the research and development and production of HV/SHV/UHV isolating switches with single-source action signals, such as Henan Pinggao, Shandong Taikai and other high-voltage isolating switch manufacturers. See Table 2 for specific research. In terms of the high-voltage switch industry "UHV isolating switch with multi-source action signal" technology industry, the fastest growing is in France\cite{30}. After the electromagnetic sensor technology debuted in France at the end of 2016, up to now, the French SENSEOR company has researched and designed high-voltage switchgear temperature and pressure sensor monitoring technology\cite{31}, and is accelerating the development and transformation progress. The French company ALSTOM applies this technology to the production of AC110kV-220kV high-voltage isolation switch products\cite{32}. The specific research situation is shown in Table 3. However, there are certain hidden dangers for complex operating conditions such as strong electromagnetic fields and extreme temperature environments for super-high voltage and ultra-high voltage isolation switches.

Table 2. Chinese development profile

| Number | Company          | Type      | Territory | Research situation                                                                 |
|--------|------------------|-----------|-----------|------------------------------------------------------------------------------------|
| 1      | Henan Pinggao    | Manufacturer | Henan    | Henan Pinggao is developing intelligent high-voltage switchgear that can monitor the position and state of the transmission chain. |
| 2      | Shandong Taikai  | Manufacturer | Shandong | Shandong Taikai is pre-researching intelligent high-voltage switchgear that can monitor the pressure information of the contact fingers. |
Table 3. French development profile

| Number | Company | Type      | Territory | Research situation |
|--------|---------|-----------|-----------|--------------------|
| 1      | SENSeOR | Manufacturer | France    | SENSeOR has developed intelligent electromagnetic sensor equipment suitable for high-voltage switches. |
| 2      | ALSTOM  | Manufacturer | France    | ALSTOM has developed 110kV-220kV high-voltage switchgear that can monitor the temperature of the contact. |

3. Conclusion

Through the analysis of the three-angle analysis of the disconnector structure, disconnector contacts and disconnector sensors in the UHV field, this paper finds that the current technical focus is mainly on controlling the disconnector through a single detection device, and is concentrated on controlling the general high voltage disconnector and theory. Research is the main focus, such as installing a clamping force detection device on the static contact of the isolating switch, installing a temperature detection unit of the main knife on the isolating switch, etc. However, in the face of the severe operating conditions of UHV isolating switches, there is a lack of multiple sources in the world in-depth research on motion signal fusion sensing technology lacks mature solutions.

With the improvement of the voltage level of transmission and transformation lines, the integrated dispatch operation of China's State Grid needs to continuously improve and improve technical support to ensure the flexibility and reliability of smart grid operation. Therefore, this article believes that focusing on major technical requirements such as "one-key sequence control" of smart grids, the multi-source action of the isolation switch opening and closing positions is studied for complex operating conditions such as strong electric field, strong magnetic field, extreme high and low temperature, and harsh outdoor protection. Signal sensing technology\[^{[33]}\], the development and application of isolating switches with multi-source action signals, and further improving the proportion and accuracy of smart devices to replace manual labor\[^{[34,35]}\] are the development trends of UHV isolating switches.

Acknowledgments

This work was financially supported by a project funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD), Key Research and Development Program of Jiangsu (BE2019060).

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