Design and Application of Intelligent Live Cleaning Device for Substation Pillar Insulator

Qiang Chen, Jian Li, Jianxiang Li, Zhenli Wang, Xu Dong, Jizhi Liu, Tao Li
State Grid Intelligence Technology Co., Ltd, Jinan, Shandong, China
e-mail: chq0531@126.com

Abstract. As the core and key hub of a strong smart grid, substation plays an important role in the stable operation of power system. According to the technical specifications of live operation in substation, an intelligent live cleaning device for substation pillar insulators is designed and applied in substation field.

1. Introduction
Substation pillar insulators have been placed outdoors for a long time. Industrial pollution and natural pollution in the air deposit on the surface of insulators to form a pollution layer. Pollution flashover accidents are easily caused by the pollution layer under humid conditions, which seriously affects the safe operation of the power system.

Therefore, in order to prevent insulator pollution flashover caused blackouts and other accidents, it is necessary to use external forces to clean up the polluted layer accumulated on the insulator surface. It is necessary to carry out power outage cleaning work regularly every year in areas with serious contamination. With the continuous development of society, the development of power grid is facing the demand of high power supply reliability, high load density and high power quality. Users are more and more strict about outage time. It is difficult to arrange outage for important key lines, and the opportunity of outage maintenance is becoming less and less.

At present, there are the following shortcomings in the live cleaning device of substation pillar insulators: The existing live cleaning device for insulators is mainly used to lift two brushes to the contact position of insulators manually through the insulating rod, and the motor installed at the bottom of the insulating rod drives the brush to rotate through the insulating transmission rod. This kind of structure and operation mode causes great physical and psychological burden to the operator, and the cleaning effect is only observed manually from the ground, so the evaluation error is large.

Substation pillar insulator live intelligent cleaning device can use mobile operating platform (insulated bucket arm truck) to enter the equipment area of substation to complete live cleaning of pillar insulator, which improves the efficiency and automation level of substation pillar insulator cleaning.

2. Mechanical structure
The live intelligent cleaning device for substation support insulators is mainly composed of vertical lifting mechanism, encircling rotating mechanism, cleaning actuator and intelligent control system. The encircling rotating mechanism is installed in the vertical lifting mechanism and can move up and down along the lifting mechanism. The left and right ends of the encircling rotating mechanism are equipped with a cleaning actuator, which can drive the cleaning actuator to rotate horizontally around
the axis of the substation pillar insulator. The cleaning mechanism sweeps the substation pillar insulator. Intelligent control system can control the cleaning device to clean the target insulator independently and intelligently.

![Figure 1. Structural schematic diagram of live intelligent cleaning device for pillar insulators.](image)

1. Brush; 2. Cleaning motor bracket; 3. Sweeping motor; 4. Embracing device; 5. Embracing motor; 6. Enclosure drive gear; 7. Lift drive motor; 8. Lift drive gear; 9. Lifting rack

The vertical lifting mechanism includes lifting rack, connecting bracket, lifting hydraulic motor and lifting gear. The connecting bracket is placed on the lifting rack. The lifting hydraulic motor is connected with the lifting gear through the worm gear reducer. The lifting gear and the lifting rack constitute the transmission pair. The lifting hydraulic motor is used to drive the lifting gear along the lifting gear. The rack moves up and down, thus driving the connecting bracket to move up and down.

The embracing rotating mechanism is composed of embracing bracket, gear ring, gear ring bracket and guide groove, etc. The embracing bracket is welded by engineering plastic sheet, and a guide groove is arranged on the bottom of the inner cavity of the bracket. The ring and gear ring bracket are confined in the guide groove and moved along the guide groove.

The hydraulic motor of the embracing mechanism is directly connected with the gear and exposed through an opening on one side of the embracing support to match the gear ring. The hydraulic motor of the embracing mechanism is used to drive the gear ring to rotate horizontally around the axis of the embracing support in the inner cavity of the embracing support.

The circumferential rotating mechanism also includes a rotating control device, which includes two circumferential limit position proximity switches and a retaining iron, the retaining iron is set on the cleaning mechanism respectively, and the circumferential limit position proximity switch is set on the embracing bracket respectively, so as to send the electric signal to the ratio of the circumferential hydraulic motor when the position of the retaining iron is sensed. The directional valve reverses the proportional directional valve to drive the rotary gear to turn.

The cleaning actuator includes a brush, a rotary motor and a cleaning motor bracket. The cleaning motor bracket is fixed on the encircling rotating mechanism. The rotary motor is installed on the cleaning motor bracket. The brush is connected to the output shaft of the rotary motor and driven by the rotating motor.

3. Hydraulic system
Considering the special working conditions of live work, the device uses hydraulic transmission as the main power source, and its hydraulic schematic diagram is shown in the following figure. The hydraulic system mainly includes quick change joint, high precision filter, electro-hydraulic proportional directional valve and hydraulic motor.
Figure 2. Hydraulic Principle Diagram of Intelligent Live Cleaning Device for Pillar Insulator
1. Quick Change Connector; 2. Filter; 3. Electromagnetic directional valve;

According to the speed regulation requirements of intelligent cleaning device, the hydraulic system adopts electro-hydraulic proportional directional valve, which is a hydraulic load-sensitive multi-way valve, mainly composed of pump side module, basic module and end cover. Load sensing system is a closed-loop system with differential pressure feedback, which can realize the following control of the load pressure of the pump. That is to say, the load pressure is fed back to the load sensing pump, so that the load sensing pump can output a slightly larger pressure than the load, and the difference is set by the spring of the load sensing valve.

Table 1. Main Technical Parameters of Electro-hydraulic Proportional Directional Valve.

| Type               | Parameter          |
|--------------------|--------------------|
| Pressure(MPa)      | 37.5               |
| flow rate(L/min)   | 10                 |
| voltage (V)        | 0~12               |
| response time(S)   | 0.45               |
| power (W)          | 8                  |
| temperature (℃)    | -30~60             |

When the load decreases, the output pressure of the load sensitive pump decreases, which reduces the energy consumption. The system can not only ensure the automatic matching of the pressure and load of the hydraulic pump, but also control the load speed accurately. Because the pressure compensation valve can ensure that the pressure difference between the front and back of the reversing valve (i.e. the difference between the pump outlet pressure and the load pressure) is constant, the flow rate of the pump is only determined by the opening size of the reversing valve, and has nothing to do with the load pressure.

The reliability of the hydraulic system of the live intelligent sweeping device for substation pillar insulators has an extremely important influence on the overall reliability of the whole device in the operation process. It is required that the hydraulic system should be in normal operation state and be able to realize its pre-operation without failures or fewer failures during long-term storage and repeated use under specific conditions. Periodic effectiveness. Therefore, it is necessary to analyze the reliability of hydraulic system.

Table 2. Basic Failure Probability Table for Hydraulic Components

| Components                | failure probability |
|---------------------------|---------------------|
| tank                      | 1.3                 |
| Oil filter                | 0.4                 |
| Hydraulic pump            | 12.5                |
| Unidirectional hydraulic valve | 4.5               |
Hydraulic relief valve 6.7
Hydraulic motor 6.7
Proportional reversing valve 4.6

Hydraulic system is composed of several hydraulic components in series or in parallel. According to the principle of reliability, the reliability of n components in series is as follows:

\[ R_s(t) = R_1(t) \times R_2(t) \times \cdots \times R_n(t) = \prod_{i=1}^{n} R_i(t) = e^{-\sum_{i=1}^{n} \lambda_i t} \]  

(1)

\( \lambda \) – Real failure probability of components; \( \lambda = k \times \lambda_0 \)

\( k \) – Environmental coefficient, Usually take 10

\( R_i(t) \) – Reliability of \( i \) components, \( R_i(t) = e^{-\lambda_i t} \), \( i = 1, 2, \ldots, n \)

The reliability of components in parallel is as follows:

\[ R_p(t) = 1 - \left[ 1 - R_1(t) \right] \times \left[ 1 - R_2(t) \right] \times \cdots \times \left[ 1 - R_n(t) \right] = 1 - \prod_{i=1}^{n} [1 - R_i(t)] \]  

(2)

During its operation, the walking motor is shut down, four leg cylinders are in parallel, and the rest hydraulic components are in series. So its reliability is:

\[ R(t) = \left[ 1 - \left( 1 - e^{-3.5 \times 10^4 t} \right) \right]^7 \times \left[ 1 - \left( 1 - e^{-4.6 \times 10^4 t} \right) \right]^7 \times e^{-1.3 \times 10^4 t} \times e^{-6.7 \times 10^6 t} \]  

(3)

The trouble-free running time of the hydraulic system during operation is as follows:

\[ MTVF = \int_0^\infty R(t) dt = 2387 h \]  

(4)

4. Test and Application

According to the "Basic Technical Requirements and Design Guidelines for Live Work Tools", live work tools need to be tested before acceptance. Under the test voltage, the electrical insulation performance experiments of 110-220 kV open substation live overhaul operation and robot-mounted post insulator operation are carried out. The experimental pictures are shown in the following figure. The experimental verification shows that the robot platform is equipped with insulator cleaning tool. Under the test voltage of 220 kV, the test current is 329.7 \( \mu A \), which is small. 500 \( \mu A \) stipulated in "Basic Technical Requirements and Design Guidelines for Live Working Tools".

Table 3. Test data of live operation of robot with insulating cleaning tool

| Voltage /kV | leakage current/ \( \mu A \) |
|------------|--------------------------|
| 50         | 64.94                    |
| 110        | 173.4                    |
| 160        | 262.2                    |
| 220        | 329.7                    |
The live cleaning device of substation pillar insulator has been tested in a 220 kV substation of Southern Power Grid Company. The test results show that the live cleaning device of substation pillar insulator can meet the live operation demand of substation under 220 kV voltage level. Compared with manual live cleaning, it can reduce labor intensity and enhance work. Industry efficiency, reduce blackout time.

5. Conclusion and Prospect
Successful development of live cleaning device for substation pillar insulators has opened up a new era of live operation in substations, and achieved breakthroughs in insulation protection, mobile platform and self-positioning of operation targets. Next, on the basis of successful research and development of the live cleaning device for the pillar insulators, dry ice cleaning, wire repair and foreign body removal of the pillar insulators in substations will be carried out.

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