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Development and Research of Substation Pillar Insulator Decontamination Robot System

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Abstract. In order to realize the automatic cleaning operation of UHV vertical insulators and reduce manual labor to the maximum extent, so as to improve operation efficiency and reliability, this paper proposes a cleaning operation system which is equipped with mechanical arm, double manipulator and its end tools on the vehicle-mounted platform, in which the end is equipped with cleaning brush and reaches the operation point by moving on the ground of the vehicle-mounted platform. Then the robot arm sends the end tool to the cleaning position through multi-joint motion, and the nozzle on the brush sprays water mist on the insulator disk surface, then the brush realizes the no-blind cleaning of the insulator disk surface. Based on the above analysis of the cleaning task, the basic structure and virtual prototype model of the robot are designed, and the corresponding physical prototype system is developed. The field operation experiment was carried out in the substation under the jurisdiction of Hunan Electric Power Company. The experimental results show that the robot can realize the no-blind cleaning operation of pillar insulators and the cleaning effect is sound, which verifies the feasibility and effectiveness of the robot structure. The research of this paper has important theoretical significance and practical application value for improving the automation level of operation and maintenance management for substation system.

Keywords. Pillar insulator, decontamination robot, mechanical system, structural design, cleaning experiment

1. Introduction

With the rapid development of power grid construction in our country, the electric power energy interconnection between different parts is becoming more and more close.

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Substation [1-2] is an important part of the power system. Due to its special electromagnetic field environment, the surface area pollution of the equipment in the station, especially the insulator is serious, which significantly reduces the hydrophobic performance of the insulator, and bringing great security risks to the safe operation of the equipment in the converter station [3-5]. At present, insulator cleaning is mainly done by manual cleaning. Personnel carrying clean water are cleaned from top to bottom with the assistance of high-altitude working vehicles. In the cleaning and maintenance process of a ±800kV substation power outage, 400 operators and 10 high-altitude working vehicles are needed for continuous cleaning for 20 days, with low cleaning efficiency and unquantifiable cleaning effect. It is urgent to develop new automated robots to replace manual work. The pollution flashover caused by the pollution of insulator plate area has great harm to the power system. Therefore, the pollution cleaning of insulator surface has been carried out at home and abroad for a long time. Insulator cleaning mainly including power outage cleaning and live cleaning [6-8]. Power outage cleaning requires professionals to carry wiping tools to the equipment to clean the insulators in the event of power outage in the working area, resulting in heavy labor intensity and poor cleaning effect. However, live water cleaning is to use high-speed water column to wash the contaminated layer on the insulator surface without equipment power failure. However, this method will cause great waste of water resources and has little effect on the oil pollution on the insulator surface. Based on this, a modular pillar insulator cleaning robot is proposed in this paper and its physical prototype system is developed. The feasibility and effectiveness of the robot mechanical system design is verified by field operation experiments.

2. Cleaning Object Analysis and Robot Structure Design

2.1. Cleaning Object Analysis

Figure 1 shows the schematic diagram of the pillar insulator string, which is composed of multiple single-piece insulators. Pillar insulators are mainly divided into top, middle and bottom parts. When cleaning the pillar insulator string, the robot takes turns to wash the three parts. The robot system needs to move the platform to carry the cleaning system to the operation point. In addition, the pillar insulators have a certain height, so it is necessary to adapt to the cleaning requirements of different pieces of insulator string. The robot has a mechanical arm system that can be lifted up and down. On the basis of satisfying the above motion rules, the virtual prototype model of the robot can be obtained through the integrated design.

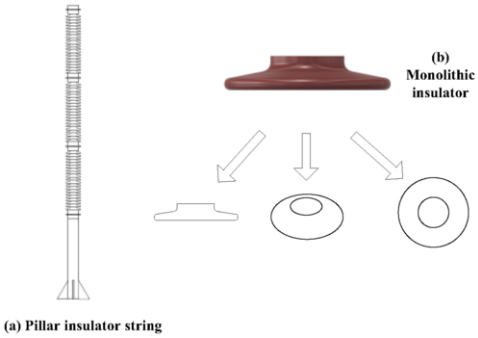


Figure 1. Structural diagram of pillar insulator strings.

2.2. Robot Structure Design

Based on the analysis of insulator cleaning requirements, the insulator cleaning robot mechanism as shown in figure 2 is designed. The whole robot system consists of the following parts which are a robot vehicle-mounted mobile platform and a manipulator system with multiple degrees of freedom, which is installed above the robot moving platform body and has telescopic, rotation and pitching joint movements to send the decontamination end-effector to the cleaning position. The electrical control system of the robot comprises a control system control box and a coupling, which is located between the cleaning end effector and the end of the manipulator; Cleaning end effector includes the up and down motion mechanism of the actuator, the forward and backward motion mechanism, the opening and closing motion mechanism, the brush motion mechanism and the group of brush on the cleaning actuator. Before cleaning and field transportation, each module of the end-effector, electrical control system, manipulator system and mobile robot platform can be separated separately and assembled quickly in field application, which can effectively reduce the unit weight of the robot and facilitate field transportation. After arriving at the operation point, each part can be assembled quickly and conveniently to form a complete operation system, so as to complete substation pillar insulator decontamination live work task.

Figure 2. Virtual prototype model of pillar insulator string cleaning robot.

3. Robot Cleaning Mechanism Design and Cleaning Motion Planning

3.1. Cleaning Mechanism Design

The end-execution system of the insulator cleaning robot is shown in figure 3, which is mainly composed of the robot cleaning component and the robot mobile platform. The robot mobile platform can be connected and installed with the high-altitude working vehicle and sent to the vicinity of the insulator by the high-altitude working vehicle to realize the mechanized cleaning of the high-altitude insulator. The robot cleaning component consists of a scissor-type opening mechanism, a rotary mechanism, a cleaning mechanism, a spraying system, et al. The scissor-type opening mechanism includes a left and right support frame and a scissor-type opening power part, which can open the cleaning mechanism to enter the insulator; Rotary mechanism includes gear group, arc guide rail, driving part, et al. Cleaning mechanism includes driving part and cleaning brush. The two kinds of mechanisms realize the revolution and rotation of the cleaning mechanism to realize the insulators cleaning.

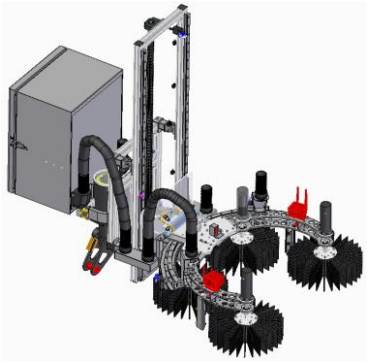
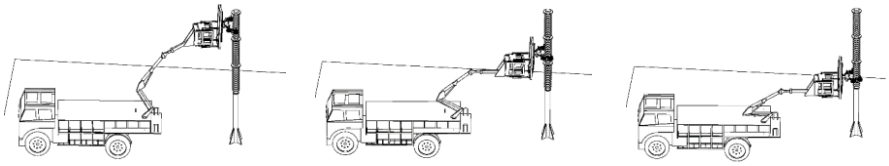


Figure 3. Insulator string cleaning mechanism.

3.2. Analysis of Stability for Navigation Motion Controller System

The decontamination process of insulators is shown in figure 4, including the following steps. First, in the initial operation state, the robot support device is put away, the end cleaning device is placed on the support device connected with the robot carrier, and the robot arm is in the shrinking state. Second, the robot starts the vehicle-mounted walking device after receiving the instruction, and drives the robot to reach the predetermined decontamination site by walking on the ground. After reaching the predetermined working site, the robot puts down its support device, the suction cup contacts the ground, and starts the next step after stabilizing the robot. Third, the robot arm delivers the end cleaning device to the predetermined insulator cleaning position through the coordinated movement of all joints. The end moving mechanism moves forward to cover the open scissor-type opening mechanism on the insulator plate surface, and then closes it to start the cleaning brush motor and its moving mechanism motor, which can realize the back and forth cleaning operation of the brush on the insulator plate surface. Fourth, after the robot finishes cleaning the top of the insulator, the cleaning mechanism stops running, the scissor opening mechanism opens, and the cleaning brush exits the insulator. Finally, after the robot arm begins to shrink to the

middle of the insulator, the robot arm begins to extend to send the cleaning mechanism to the designated place, the scissor opening mechanism opens, the brush enters the plate surface of the insulator, the opening mechanism closes, the brush enters the skirt of the insulator, the motor starts to clean, and the above process is repeated to realize the cleaning of the middle insulator. In the same process, the robot can realize the cleaning operation of the bottom insulator string, so as to realize the decontamination operation of the whole pillar insulator.



(a) Top cleaning (b) Middle cleaning (c) Bottom cleaning

Figure 4. Robot cleaning operation motion planning.

4. Robot Prototype Development and Test Experiment

Through the integrated design of mechanical system, measurement and control system and software system, a complete physical prototype system for pillar insulator cleaning robot of substation is developed. The actual pillar insulator cleaning operation experiment is carried out in the substation under the jurisdiction of State Grid Hunan Electric Power Company, as shown in figure 5. The field operation experiment shows that the whole robot system moves flexibly. In particular, the professional cleaning end can realize the cleaning of the top, middle and bottom of pillar insulators without blind spots, greatly improving the automation level of pillar insulator cleaning in substation, additionally, after the cleaning of insulators, the performance of insulators is shown in table 1. As can be seen from table 1, the performance of cleaned insulators has been significantly improved. Therefore, the cleaning method proposed in this paper is effective.

(a) Top cleaning (b) Middle cleaning (c) Local cleaning

Figure 5. Physical prototype model and cleaning experiment.

Table 1. Insulation cleaning performance comparison.

Insulation cleaning performance	Conductivity /μS·cm^{-1}	Salt density /mg·cm^{-2}	Grey dense /mg·cm^{-2}
Before cleaning	815	0.218	1.129
After cleaning	22.9	0.009	0.007

5. Conclusion

(1) Based on the analysis of the pillar insulator decontamination task, the basic configuration of the insulator decontamination robot is proposed and the corresponding robot virtual prototype model is developed.

(2) Based on the developed robot virtual prototype model, the motion planning and motion control method for cleaning the insulators of the robot prop is proposed.

(3) The corresponding physical prototype system is developed, and the field cleaning operation experiment is carried out on the substation pillar insulators, which verifies the rationality of the structure designed in this paper.

Acknowledgement

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