Research and design of live maintenance robot for substation equipment

Jinbin Li, Yaodong Zhang, Tao Wang and Jun Chen
State Grid Hubei Electric Power Co., Ltd. Electric Power Research Institute, Wuhan, Hubei, 430077, China

E-mail: 369178871@qq.com

Abstract. This paper focuses on the reform of the live working mode in substation and the urgent need for the development of safe live working equipments. A multi-agent live maintenance automatic robot has been designed. On the basis of satisfying insulation safety protection requirements, it has flexible operation characteristics, and can independently implement typical live maintenance and detection projects for substation equipments. The robot is appropriate for narrow space and complex working conditions with high precision. Through design, manufacturing, simulation test, field application and other methods, the research and prototype development of this live maintenance robot for substation are carried out from the aspects of operational requirements, structural design and key component design.

1. Introduction
Live maintenance of substation equipment is very strict for safety protection and shielding. With the development of substation equipment towards integration and miniaturization, it further restricts the implementation of traditional live maintenance projects in substation. In the operation and maintenance work, some routine maintenance items of substation equipment, such as defects elimination of overheating joints or loosening bolts, need be carried out by power cut. The maintenance of busbar side equipments, such as busbar disconnecting switch and insulator, even need to shut down the busbar. Traditional manual live maintenance mode is now quite difficult to meet the high reliability requirements of power grid.
2. Requirement analysis of live maintenance in substation

This paper is oriented to meet the needs of live maintenance requirements in substation. The research and design of the live maintenance robot is applicable to 220kV and below voltage level. It can solve the problem of live maintenance in harsh environment, improving the working efficiency, reducing the safety risk to the minimum extent of both the equipments and workers. The live maintenance diagram of the robot is shown in Figure 1.

2.1. Live line connecting and disconnecting

This function can implement automatic live line connecting and disconnecting working task on the substation busbar. The robot can fulfill the task without need to stop the busbar. Thus, the busbar disconnecting switch and other kinds of equipments can then be safely inspected by workers under visible fracture. At the same time, it can also be used for the defect treatment of the joint overheating, bolt loosening or other defects [1-3].

When conducting the live line connecting and disconnecting task, the live maintenance robot drives into the working area near the equipment. After elevating the upper equipotential work platform to the designed working position, the site will be reconstructed in three dimensions by the 3D scanner carried by the platform. After judging the safe working space, the main and auxiliary manipulators are used in combination with the stereo vision subsystem to live connect or disconnect the line [4-6]. The robot’s operating attitude during live line connecting and disconnecting is shown in Figure 2.

![Figure 2. The robot’s operating attitude during live line connecting and disconnecting.](image)

![Figure 3. The robot’s operating attitude during insulator air blow cleaning.](image)
2.2. Air blow cleaning of insulator

The robot can also carry the insulator air blow cleaning tool. The main manipulator is used for 3D scene reconstruction, and the insulator axis is thus calculated. The air blow cleaning tool will be sent to the target through the auxiliary manipulator. The auxiliary manipulator is programming controlled to move up and down, and the target insulator will be non-contact cleaned. In order to make the air blow cleaning device has enough air source and ensure its cleaning effect, the air pump is placed on the ground, and the dry compressed gas is conveyed to the upper equipotential work platform through the tube.

When detecting hydrophobicity, the robot can also carry the spray gun, and then the stereo visual subsystem extracts the edge of the water drop on the insulator to judge its surface condition.

The robot’s operating attitude during insulator air blow cleaning is shown in Figure 3.

3. Overall system design

The whole system consists of the upper equipotential work platform and the insulating mobile carrier. The upper platform includes the main control system, the manipulator subsystem, the stereo vision subsystem, the battery subsystem and the monitoring subsystem. The insulating mobile carrier consists of the insulating aerial device and the mobile carrier.

![Diagram of Insulating Mobile Carrier](image)

**Figure 4.** The overall system architecture design.

On the upper equipotential work platform, the important hardware equipments of the main control system are the system control cabinet and the motion controller, they communicate with each other through industrial Ethernet. The main hardware equipments of the manipulator subsystem are the main manipulator, the auxiliary manipulator and the working tools. The manipulators are connected to the motion controller. The working tools communicate with the CAN communication module in the
system control cabinet through the CAN bus. The main hardware equipments of the sensor subsystem are a 3D scanner and a binocular camera [7-10], and they communicate with the IPC (Industrial Personal Computer) in the system control cabinet through USB and wired network respectively. The main hardware equipment of the battery subsystem is the lithium battery, and rs-485 serial communication is adopted between the subsystem and the IPC. The main hardware equipments of the monitoring subsystem are the monitoring cameras and the wireless router. The monitoring cameras utilize network camera and communicate with the ground console through the wireless network. The overall system design is shown in Figure 4.

The system hardware functional requirements are shown in Table 1.

| Major hardware/software modules | Number | Function                          |
|--------------------------------|--------|-----------------------------------|
| Manipulator                    | 2      | Operation performing              |
| Motion controller              | 2      | Manipulators control              |
| IPC                            | 1      | Data Analysis                     |
| 3D Scanner                     | 1      | Coarse positioning                |
| Binocular camera               | 2      | Fine positioning                  |
| Monitoring camera              | 2      | Auxiliary monitoring              |
| Mainframe                      | 1      | Remote control                    |
| Displayer                      | 1      | Monitor screen display            |
| Wireless router                | 2      | Signals sending and receiving     |
| Battery                        | 1      | Normal power supply               |
| Backup battery                 | 1      | Emergency backup power            |
| Tools                          |        | Automatic working                 |

4. Key component design

4.1. Upper equipotential work platform

According to the optimal motion path of the manipulators and the stability of each joint transition of the manipulators during the task, the upper equipotential work platform is designed in detail. The location of the hardware on the platform is reasonable layout, avoiding the space occupied by other equipments constraining the manipulator movement. At the same time, considering the limitation of load bearing of the insulating mobile carrier, the upper equipotential work platform needs to be as compact as possible. Therefore, the design of the upper equipotential work platform needs to ensure both the abundance of space and the compactness of the structure. Its design structure diagram is shown in Figure 5.

The total quality of the upper equipotential work platform is about 300kgs. The manipulators have six degrees of freedom, and their average kinematic error is within 1mm in the direction of X, Y and Z.

4.2. Insulating mobile carrier

In order to meet the live maintenance robot’s autonomous movement function, lifting function, and adequate insulation function, an insulating mobile carrier which is suitable for small space operation in substation is designed and developed. Its external dimension in walking attitude is 6.02m·1.63m·2.29m, and the outer edge of the track can be shrunk to 863.6mm. The insulation lifting device adopts the mixed structure of a folding arm and a telescopic arm, which is convenient to use in
narrow spaces. The folding angle of the folding arm and the telescopic arm is -5° to 79° and -25° to 75°. The maximum working height is 13.3m, and the maximum side reach is 9.1m. The insulating aerial device and mobile carrier of the insulating mobile carrier are shown in Figure 6 and Figure 7, respectively.

Figure 5. Design structure diagram of the upper equipotential work platform.

Figure 6. Insulating aerial device design structure diagram.
Figure 7. Mobile carrier design structure diagram.

(a) Unsupported leveling condition.  (b) Support leveling condition.

The walking attitude and working attitude of the live maintenance robot are shown in the Figure 8 and Figure 9. The robot can be a sustainable automatic tool which can be used in substations, and can finish live line connecting or disconnecting working task within 25mins.

Figure 8. Walking attitude of the live maintenance robot.

Figure 9. Working attitude of the live maintenance robot.
5. Conclusions
In this thesis, the key technologies of automatic robot in the field of substation live maintenance are developed and deeply studied. A special robot for live maintenance of substation equipment is developed. On the basis of flexible live maintenance features, the robot meets the insulation safety protection requirements, and can conduct typical live maintenance projects instead of manual work. The scheme can further enrich the means of live maintenance in substation, and improve the level of mechanization, automation and intelligence of live maintenance work.

Acknowledgments
This work is supported by State Grid Corporation of China (SGCC) Science and Technology Project (52153216000R).

References
[1] Liang D, Su Y, Liu Z and Liu S 2017 An integrated power grid equipment operation and maintenance solution based on big data, cloud computing, the internet of things and mobile internet Automation, Control and Intelligent Systems vol.5 no.5 pp 67-72
[2] Jain R K and Majumder S 2013 SCARA based peg-in-hole assembly using compliant IPMC micro gripper Robotics and Autonomous Systems 61(3) 297-311
[3] Hammer B, Koterba S and Shi J 2010 An autonomous mobile manipulator for assembly tasks Autonomous Robots 28(1) 131-149
[4] Chen S Y and Li Y F 2011 Active vision in robotic systems: a survey of recent development The International Journal of Robotics Research 30(11) 1343-1377
[5] Wang P, Xu X and Zhang Z M 2010 Study on the position and orientation measurement method with monocular vision system Chinese Optics Letters 8(1) 55-58
[6] M R Pedersen, L Nalpantidis, R S Andersen, et al. 2016 Robot skills for manufacturing: From concept to industrial deployment Robotics and Computer-Integrated Manufacturing vol.37 pp 282-291
[7] Wang H, Wang J, Chen W and Xu L 2017 Automatic illumination planning for robot vision inspection system Neurocomputing vol.275 pp 19-28
[8] Zhou K, et al. 2014 Mobile manipulator is coming to aerospace manufacturing industry 2014 IEEE International Symposium on Robotic and Sensors Environments pp 94-99
[9] S Bhat and M Meenakshi 2016 Vision and embedded system based military robot path planning International Journal of Computer Applications vol.148 no.5
[10] Han Y, Mu S, Lu S, Wang Z, Li J, Li J and Zhao J 2016 The remote control terminal for electric maintenance robot in substation Applied Robotics for the Power Industry (CARPI) 4th International Conference on Applied Robotics for the Power Industry pp 1-4