Research on multifunctional automatic transmission line automatic robot system

Jiajing Li¹, Yaodong Zhang²-⁵, Chao Ma³ and Cheng Cheng⁴

¹ School of Mechanical and Electronic Engineering (Wuhan University of Technology), Wuhan, Hubei, 430070, China
² State Grid Hubei Electric Power Co., Ltd. Electric Power Research Institute, Wuhan, Hubei, 430077, China
³ State Grid Xi'an Electric Power Supply Company, Xi'an Shaanxi, 710032, China
⁴ China State Grid Shanxi Electric Power Company, Xi'an Shaanxi, 710048, China
⁵ E-mail: 31345220@qq.com

Abstract. In this paper, a special power industry robot suitable for live maintenance and repair of overhead transmission lines is studied. The robot meets the requirements of live working on transmission lines, which can autonomously climb up and down the transmission line and crawl along the lines. The robot has a variety of work function heads, which achieves fastening strain clamp drainage plate, replacing shock hammer, repairing wire, cleaning up and many other live working projects. The robot has advantages of overall flexibility, reasonable structural design, reliable shielding and protective performance, and convenient operation. Instead of manual work, it can be used to accomplish various live operation tasks for overhead transmission lines, which effectively avoiding potential safety hazards of high voltage, strong electric fields and high-altitude operations. The robot also greatly improves operating efficiency and reduces the labour intensity of humans. This paper describes a number of systems, such as the manipulator, the autonomous up and down system, the function control system, the wireless video transmission system, the remote control system and so on.

1. Introduction

Live working is a special engineering technology for inspection, maintenance and replacement of power transmission line components under the condition of charged line. For a long time, live working has generally adopted the manual operation method. The operators need to be in the environment of high altitude, high pressure, and strong electromagnetic fields for a long time, and there is a large potential safety hazard [1]. In order to improve the automation level of live working and the safety of operation, and reduce the labor intensity and the personal hazards of operators under strong electromagnetic environment, according to the current technical requirements of live working process of the line and the characteristics of the working environment, the use of robots to carry live work is imminent.

The research of inspection robots for high-voltage transmission lines began in the late 1980s, and developed countries such as Japan, Canada, and the United States successively carried out research on inspection robots. In 1988, Sawada et al. of Tokyo Electric Power Co., Ltd. developed an optical fiber composite overhead ground wire (OPGW) mobile inspection robot [1]. In 1989, a prototype of a cantilevered autonomous patrol robot was developed by the United States TRC Corporation [2]. In 1998, Professor Wu Gongping of Wuhan University of Water Conservancy and Electric Power
developed an inspection trolley for overhead high voltage lines [3]. The trolley adopts a single three-wheel drive structure with stable walking and crossing obstacle functions, and can smoothly pass over insulators, hammers, and suspension clamps. The trolley equips a near-infrared fault diagnostic instrument to complete the diagnosis of the line. The walking and obstacle crossing of the trolley is achieved by artificial remote and mechanical control.

This article discusses a transmission line maintenance robot, its functional characteristics is that it can carry a variety of equipment and end tools, instead of artificial on-line repair of charged lines, it saves manpower with high efficiency and low security risk. It mainly solves the technical problems of lightweight, portable, versatile, and quick installation of maintenance robots for transmission lines. The uses of robots reduce the work intensity of repair workers, improve operating efficiency, and shorten the repair time of transmission lines.

2. Multifunctional power robot system composition
The split-type combined self-winding multi-function electric robot adopts modular design and can replace working tools. The main machine is the working platform of the overall equipment. It can take the different machine heads to go online and offline, and can also bring different machine heads [4]. Walk on the wire and transport the head to the work site. It is also responsible for supplying power and control signals to different functional heads. The overall design is integrated and multifunctional, to facilitate on-site installation and use. The sockets of the power supply system; host body and remote control controller adopt waterproof sockets and prevent electric shocks, equipped with protection against electric shock design. With a standardized interface, the tool can be replaced quickly and easily. The entire robot system is divided into five modules by function:
① Online and offline system
Complete the task and isolate the high voltage electric field from the operator. The master-slave control has high precision, good real-time performance, great weight, small weight, and stable and reliable performance.
② Robot walking system
The robot host includes an automatic running guide wheel that rolls and walks through the clamped wire and transports the robot arm to the line working position.
③ Head and tool system
Including strain-resistant clamp drainage head, shock hammer replacement head, wire repair head, plug pin head, electric wrench, nut break tool, foreign body cleaning tools.
④ Wireless video system
Wireless data and image transmission and robot control technology under strong electromagnetic environment. Under strong electromagnetic environment, 2.4G communication technology is adopted to achieve image transmission and robot remote control distance of more than 200 meters. The system has the characteristics of simple operation, flexible buttons, clear and clear functions, etc. It can be easily adjusted in real-time through convenient man-machine interface, such as wireless connection app.
⑤ Wireless remote control system
Ensure that the operator is completely isolated from the high-voltage electric field, and at the same time, the robot has good insulation between the earth and the phases, and it can accurately control the robot remotely. Implement the corresponding maintenance operations after the mobile robot has crossed the obstacles, such as the replacement of shock hammers, strain-resistant clamps and bolts fastening of the drainage boards, pin insertion and removal of gold fittings, wire repair, and removal of foreign objects.

3. Multifunctional power robot host structure
The mainframe structure is mainly divided into two parts: the main body and the flip cover. The main body contains the battery, control system, wireless remote control system, wireless video system, independent online and offline system, and head mounting base. The flip covers the wire holding and
walking system, before the equipment goes online. The flip cover is in the open state, and the flip cover closes after going on the wire. The travel wheel clamps the wire above the wire and takes the weight wire of the device to walk. In order to improve the reliability of the robot operation, a three-dimensional visual-aided robotic arm is used to carry out autonomous operations locally. The front end of the main unit is a head-mounted seat on which a working robotic arm can be mounted, and the carrying-operation robotic arm can be moved intelligently and operated as shown in figure 1.

![Figure 1. Multi-function power robot host.](image)

Before the start of live work, the equipment is placed on the ground, the lifting mechanism is activated so that the two strands of insulating rope wound in the on-line wheel are continuously released, and the end of the rope is thrown by the drone or the thrower to throw the rope around the overhead line and fall to the ground. And it is fixed on the ground. Invert the reel by activating the lifting mechanism, so that the discharged insulation rope is continuously retracted. Since the insulation rope at the discharge end is fixed, the insulation rope is continuously retracted inside the equipment, and the equipment is continuously raised and approached to the grounding conductor. When the equipment contacts the grounding conductor, it is stopped. Continuously apply force to the rope to keep the equipment from sliding down. The cover of the remote control device is rotated to above the overhead line until the device cover covers the grounding cable, the ground fixed end is loosened, and the remote control device circuit is rotated to wind and retract the insulating rope. At this time, the entire device is completely independent above the overhead line and the ground. No connection. When the remote control device goes offline, the sheave rotates. The lower rope of the lower sheave will fall due to the gravity of the small lead ball at the end until it hangs down to the ground. The ground staff will fix the rope to maintain the traction. Stop the work, close the robotic arm, and extend the cutting cutter disc to retract to the starting position; keep the traction force of the device's lower wire and rotate the remote control device cover open until the device is disconnected from the wire, at this time, the wire rope wheel of the remote control device continues Turning, equipment continues to decline. The offline action is completed until the device landing. The top cover of the remote control device is turned to close, and the remote cable reels of the remote control device are reversed.

In the process of split-type combined autonomous online multi-function power robots, the robots and power equipment may be damaged due to the operator's misoperation. For this reason, the robot has designed perfect protection and exception handling functions, including the robot arm joints mechanical limit, the robot lifting system limit, the main hand activity space limit, and the robot arm overload protection, lifting system interlock protection. If the circuit is abnormal, the alarm light is on. When the fault is removed, the power supply can be reset.

4. Multifunctional power robot applications

Due to the overhaul of overhead transmission lines, the types of operations, such as replacement of insulators, replacement of shockproof hammers, bolt fastening of strain relief clamps, pin removal and insertion of plugs, wire repair, and removal of foreign materials, are extremely varied. Complex, so the development of different end-of-end execution tools, the ability to quickly and easily assemble the robotic platform with an overhaul is the best choice, and the corresponding inspections are performed.
4.1. Shock hammer replacement head
The function is to remove the shockproof bolts for replacement, cut the old shockproof hammers, replace the new shockproof hammers, and reset the shockproof hammers. Electric wrenches and electric nut breaking tools are important special tools for the replacement of shock hammers. Their main function is to install and disassemble shockproof hammers that need to be repaired. For the replacement of the shockproof hammer, firstly carry the cutting head with the cutting function, then carry the head with the clamping and fastening function and carry the new shockproof hammer to the set position for fastening installation, so as to realize the replacement of the shockproof hammer. As shown in figure 2.

![Figure 2. Shock hammer replacement diagram.](image)

Dismantle the shock-proof hammer: remove the anti-vibration hammer and connect it with a milling cutter to realize the removal of the anti-vibration hammer and not damage the ground wire. Install the anti-vibration hammer: install the anti-vibration hammer independently to the original position of the ground wire. The installation torque of the shock hammer meets the design requirements.

4.2. Wire repair head
To achieve the emergency repair of overhead transmission line damage line breakage stocks, including a set of two heads and a variety of specifications with the overhead transmission line specifications of the split pressure pipe. The split pressure tube is mounted on the front of the mainframe and is controlled by the mechanical jaws of the main machine. When the host walks with the crimping tube to the damage location of the overhead power transmission line, the position is adjusted to the best through video observation, and the jumper or loose strand conductor is reset by a special resetter, and then a special split type crimping and fixing is adopted. And through the bolt connection, the clamping clamp is installed in the damaged part of the overhead transmission line, and plays the role of wire repair. The unit carries a specific repair part to reach the broken strand of the wire, and the main unit fixes the U-shaped buckle on the broken part of the wire; the other auxiliary machine is a winding part and drives the spiral clamp to screw in the wire to wind the wire. In this way, the entire device can replace the artificial walking and operation on the wire in the case of semi-remote and semi-automatic, and achieve the purpose of repairing the local damage of the overhead transmission line by means of remote control and automatic fastening and automatic disengagement of the device, as shown in figure 3.

![Figure 3. Wire repair schematic.](image)
4.3. Foreign body cleaning head
For the removal of foreign matter on the line suspension, a cutting head with a cutting head and cutting function is used for cutting. The cutter coil is mounted on the front of the mainframe and is controlled by the mainframe extension frame. When the host takes the crimping tube to the position of the foreign object on the overhead power transmission line, the position is adjusted to the best through video observation, and then the claws are clamped by the remote control and the foreign material is clamped. Then the cutter head is rotated to extend and gradually cut, as shown in figure 4.

![Figure 4. Cleaning of foreign objects.](image)

The foreign body removal head is installed at the front end of the main body and mainly includes two parts, one part is a clamping jaw part. After the foreign matter is in the range of the fingers of the clamping claws, the clamping claws clamp the foreign materials to complete the fixation of the foreign materials; the second part is the cutting of the foreign materials. The blade is mounted on the telescopic arm, and the double blade rotates and moves back and forth through the telescopic arm to achieve the purpose of cutting and removing foreign objects.

4.4. Strain clamp bolt head
For the fastening of strain-resistant clamps, the robot can independently tighten the bolts on the strain-resistant clamps. The tightening torque meets the design requirements. The solution is to design a vibratory wrench fastening machine. The vibratory wrench is installed on the front end of the host and is equipped with hardware. The nut sleeve adapted to the nut can be remotely moved in both horizontal and vertical directions. The mainframe and vibrating wrench are detachable rigid connections. The vibratory wrench is installed at different positions and angles of the mainframe in different situations to align the direction of bolts and nuts on the hardware that needs to be operated. The vibratory wrench can be installed and various Fittings Nuts Wrenches of various sizes that are compatible with the specifications of the fastening nut can be tightened tightly on the side of impact vibration and can be tightened much faster than a uniform speed rotation. The required tightening torque of the locking nut is achieved. The output torque of the vibrating wrench can be adjusted, and it can be slipped while rotating and tightening to reach the set locking torque value, and the protection device itself will not be damaged, as shown in figure 5.
5. Summary
Because the traditional manual inspection and live work cannot meet the actual demand, this paper
studies the automatic multi-role transmission line robot system, combined with the actual needs of the
site, designed a variety of types of heads, can be used to clamp the tension of the overhead
transmission line clamp, Replace shock hammers, repair wires, and cleanup of foreign materials.

① For shock hammer replacement, firstly carry a head with cut-out function to cut, and then carry
a head with clamping and fastening function which transports the new shock-absorbing hammer to a
set position for installation and fastening, so as to achieve the replacement.

② For wire repairing head, specific repair parts are brought to the place where wire breaks, and the
host will fix the U-shaped buckle on the broken part of the wire; the other auxiliary machine is the
winding part, which drives the spiral clip into the conductor and wind the wire.

③ The foreign object cutting blade is mounted on the telescopic arm, the double blade rotates and
moves back and forth through the telescopic arm to achieve the purpose of cutting and removing
foreign objects.

④ Vibrating wrench can be installed with a variety of hardware fittings to meet the specifications
of the fastening nut size specifications of the nut socket wrench, can be tightened at the side of the
impact shock fastening, and can obtain a much larger rotation of the lock force to achieve the required
tightening torque of the locking nut.

The technology is highly practical and can replace manual operations through on-site testing. It is
safe, reliable, and easy to carry and operate, has good applicability, and saves time and effort.

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

References
[1] Sawada J, Kusumoto K and Munakata T 1991 IEEE Transactions on Power Delivery 6(1) 309 -
315
[2] Kobayashi H, Nakamura H and Shimada T 1989 Electrical World 5 71-72
[3] Ghamisi P, Couceiro M S and Benediktsson J A 2015 IEEE Transactions on Geoscience &
Remote Sensing 53(5) 2935-2947
[4] Montambault S and Poulion N. 2012 Proceedings of IEEE 11th International Conference on
Transmission & Distribution Construction, Operation and Live-Line Maintenance 1-9