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Mechanism Design of Electric Robot of Distribution Network for Cut Off or Connection of Leading Wire

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Abstract. As a typical distribution network live working project, the live disconnecting and connecting lead wires are frequently carried out in live working, and the working environment has the characteristics of unstructured and narrow working space. By comprehensively considering the working environment and work tasks of the live working robots in the distribution network, a distribution networked electric disconnecting and connecting streamline robot based on the adjustable crawler-type mobile platform is constructed. The adjustable crawler belt type mobile platform is designed to enhance the application range of the working robot. A six-degree-of-freedom multi-manipulator cooperative working mechanism system is proposed to design a high-performance live working end to realize the insulation wire stripping, clamping, nut tightening, loosen and other functions. The results show that the proposed power distribution disconnected and connected streamline robot can effectively replace the manual task and improve the intelligent level of the distribution network maintenance system.

1. Introduction

Electric power industry is the foundation of national economy. With the rapid development of social economy, the people's production and life depend more and more on power demand. Distribution network is at the end of power system, and a key link to ensure the continuous supply of power, the reliability of which plays a very important role in the whole power supply system. Because distribution network systems are mostly radiative topology, in case of sudden fault of the wire or equipment defect overhaul and transformation, continuous power supply will be unable to be guaranteed by switching operation mode. Live working refers to a method of maintenance and test without power outage on high voltage electrical equipment[1]. Distribution network live working is a kind of aloft, high-risk and high-intensity work, and has become the most direct and effective means to reduce power outage time, improve power supply reliability and service level. According to the full-coverage statistics of the State Grid Corporation of China (SGCC) in 2016, 801,000 live workings were carried out in the whole year, of which 88,698 were live disconnection or connection of leading
wires, accounting for 11% of the total number of working. Thus it can be seen that live disconnection or connection working plays a very important role in live working of distribution network.

Looking at the existing live working robots at home and abroad, most of them are wire inspection robots; in terms of overall structure, there are mainly two cases: one is a case that the operators represented by those from power companies of Japan and Shandong, etc. as shown in Figure 1. control the robot working via the control handle or the master manipulator in the aloft insulating hooper[2-5]; the other is a case that the operators represented by those from Canada carry out remote control of an aloft robot on the ground[6-7]. In the above cases, the operators may stand in the raised insulating hooper to operate the manipulator arm to complete the working, or observe or directly carry out visual inspection via the camera and partially use automatic positioning operation. The above methods have the following prominent problems: first, the operators need to stand in an aloft insulated hooper to operate the robot, while the personnel safety problem has not been fundamentally resolved; second, the robot adopts semi-autonomous remote control operation, featuring in low degree of intelligence and operation efficiency; third, the robot is too big and not suitable for narrow working spaces and complex working objects; fourth, the wheeled vehicle movement mode is not suitable for the complex terrain environment, which limits the popularization and application of live working robot. Traditional live disconnection and connection workings mainly rely on manual working. Since live working was carried out in China in the late 1980s, glove working method has been adopted, that is, the operators are insulated against the ground based on the aerial lift devices with insulating booms, wear insulating clothing and gloves and carry out insulation shielding of bare wire, hardware fitting, cross arm, pole and other equipment to carry out live working. After the 21st century, live disconnection and connection based on insulating rod has also been adopted. Because of the compact structure and the small safety distance margin of the distribution network equipment, live disconnection/connection of leading wire is easy to cause inter-phase and phase-ground short circuit. In recent years, personal casualty accidents caused by operators' negligence occurred occasionally, making it urgent to ensure the safety of operators. At the same time, due to the limitation of wire structure, terrain and traffic conditions, it is difficult for the aerial lift devices with insulating booms to reach the working position, making it impossible to carry out live working, and forced to carry out blackout overhaul and renovation and reducing the reliability of power supply, which seriously affects the national economic production. Therefore, it is of great significance to study the distribution network live working robot and promote the intelligent development of distribution network maintenance system. However, according to the existing literatures, there is no research on the robots for distribution network live disconnection or connection of leading wire.

In order to solve the above problems, this paper puts forward a kind of robot configuration for distribution network live working based on the adjustable crawler mobile platform, which can realize remote control, and does not need the aloft remote operation of the operator. Implement the research on the basic components of distribution network live working robot in view of the leading wire live disconnection/connection project to research crawler mobile insulation platform with adaptive attitude balance suitable for complex environment, and improve the adaptability of robot to complex terrain and geomorphology; research the main body of the distribution network live working robot with multiple manipulators based on insulation and isolation to complete the task of live disconnection/connection of lead wire, promote the safety and efficiency of live working, and widen the scope of operation.

2. Analysis on kinematics principle and working object of the electric robot

2.1. Kinematics principle of electric robot

The main body of robot can be regarded as a series of kinematic chains composed of rods connected by joints; a series of connecting rods on the joint chains are regarded as rigid bodies; and the adjacent connecting rods are connected by rotary or translational movement of joints. Establish corresponding coordinate system fixed with the rods at each rod of the robot, and use odd transformation to describe
the relative position and attitude between such coordinate systems, and deduce the relative position and attitude of rods required by D-H parameter method.

General matrix of D-H coordinate transformation:

\[
T_{i-1}^i = \begin{bmatrix}
  c\theta_i & -s\theta_i c\alpha_i & s\theta_i s\alpha_i & a_i c\theta_i \\
  s\theta_i & c\theta_i c\alpha_i & -c\theta_i s\alpha_i & a_i s\theta_i \\
  0 & s\alpha_i & c\alpha_i & d_i \\
  0 & 0 & 0 & 1
\end{bmatrix}
\] (1)

Where \( i \) is the serial number of the robot connecting rod; \( \theta \) denotes the rotating angle of the joint; \( \alpha \) denotes intersection angle; \( d \) denotes length of connecting rod.

2.2. Working tasks and objects

The main task of the robot is to carry out live disconnection and connection of leading wires on distribution network wire. The arrangement forms of the lead wire of the involved distribution wire are mainly triangular arrangement, vertical arrangement and horizontal arrangement; and the working space is relatively compact, as shown in Figure 2. The working objects of the robot mainly include: wire clamp, leading wire, conductive grease and insulating protective cover; the lead wire is coated with conductive grease; the leading wire is connected with the lead wire through the wire clamp; the connecting end between the wire clamp and the lead wire is provided with an insulating protective cover for insulation protection.

The distribution network disconnection and connection workings can be divided into four kinds of working: connecting lead wire, disconnecting lead wire, connecting lead wire with load and disconnecting lead wire with load, which is exactly the live working function to be realized by the developed live working robot.

3. Design of overall mechanism of the robot

The overall structure of the distribution network live working robot is as shown in Figure 3, which is mainly composed of mobile insulation platform, robot body, control base station, communication system and so on. The operating body of the robot is connected with the end of the telescopic arm of the mobile insulating platform, and adopts the motor drive mode to accomplish the working tasks through the cooperation of multiple working arms. The main body of the robot is designed with control system and power supply system to realize the operation control and continuous power supply of the robot, and adopts Wi-Fi communication mode to realize the information exchange with the ground operating system.
Figure 3. The overall configuration of the electric robot.

1. Self-leveling mobile insulation platform; 2. Working body of the robot; 3. Control base station; 4. Operation end ((1) Peeling end, (2) Clamping end, (3) Clamp mounting end).

3.1. Self-leveling mobile insulation platform

The simplified structure of the self-leveling crawler mobile insulation platform is shown in Figure 4, which is mainly composed of the lifting arm mechanism, the telescopic arm mechanism, the swing mechanism, the leveling mechanism, the walking device, the supporting leg, the hydraulic system, the electrical control system and the power device. The chassis of the mobile insulating platform adopts crawler type, with four self-leveling landing legs arranged symmetrically on both sides as the leveling mechanism of the insulation platform. The upper end is connected with the hydraulic lifting arm and the telescopic arm through the 360° rotating platform; the lifting arm and the telescopic arm can be folded in transportation to reduce the occupied space, and can be upward moved to lift the working body of the robot to the nearby of the working position.

The end of the folding arm is hinged with the head of the telescopic arm, which can rotate relative to the main arm in the vertical plane. The main arm, the turntable and the variable amplitude hydraulic cylinder are hinged in pairs separately. Under the action of the variable amplitude hydraulic cylinder, the main arm can continuously change the elevation angle from 0° to 86° in the vertical plane. The main arm is composed of three sections of arm which are set together. Under the action of a telescopic hydraulic cylinder, the turntable is connected with the frame through a rotary mechanism. The four landing legs can be independently adjusted according to the ground and space conditions; the power system is equipped with a low noise diesel engine and an AC motor. With the cooperation of the above devices, the spider-type aloft working platform can meet different operational requirements. The working envelope diagram is as shown in Figure 4.

3.2. Multi-manipulator working platform

The working body of the robot uses the mobile insulation platform as the carrier, as shown in Figure 5. It consists of a control box, an X-axis and Y-axis position and pose adjustment cross sliding table, an annular tool transfer device, a gripping manipulator, an insulated lead wire peeling manipulator and a device wire clamp mounting manipulator. The three manipulators are arranged in the center of the body in equilateral triangles, and are all six-degree-of-freedom mechanisms, as shown in Figure 6.
Figure 4. These two figures have been placed side-by-side to save space.

Figure 5. Multi-manipulator operation platform. 1. Robot control box; 2. Cross transverse sliding table; 3. Gripping manipulator; 4. Annular tool transfer device; 5. Cross longitudinal sliding table; 6. Device clamp mounting manipulator; 7. Insulated lead wire peeling manipulator; 8. Focusable visual sensor; 9. Wireless communication device.

The control box of the robot moves along the mobile insulation platform through the X and Y axes cross sliding table, which ensures the valid space for the multi-manipulator to work together; the manipulator of the insulated lead wire peeling device has 6 degrees of freedom, and can reach any position within the range of working point and can independently complete the task of peeling the insulation layer; the gripping manipulator mainly completes the working tasks of lead wire cleaning, coating conductive grease, and mounting of insulation protective cover, and can fix the device wire clamp to the terminal actuator of the device wire clamp mounting manipulator; the device clamp mounting manipulator is installed on the lead wire with the equipment clamp; the working function of each manipulator and its terminal tool is shown in Fig. 7. During the working, the gripping manipulator and the insulated lead wire peeling manipulator work together to neaten the leading wire; the insulated lead wire peeling manipulator controls the proper position of the lead wire to prevent the lead wire from touching the adjacent live phase; the gripping manipulator controls the leading wire connection end to insert the leading wire into the device wire clamp; the nut fastening mechanism motion at the working end on the device clamp mounting manipulator realizes the fastening of the bolt.

3.2.1. Peeling end. The peeling end, as shown in figure 8, consists of the upper end peeling device and the lower end drive device, both driven by the motor. The upper end peeling device can rotate around the central axis of the lead wire to cut the lead wire insulation layer, rely on the cutting force to realize the axis feed; the lower end transmission device is connected with the motor output shaft; the rotating motion of the output shaft is transformed into the rotary motion of the peeling device perpendicular to it to enhance the smooth operation of the peeling device.
The peeling device consists of a reverse lead screw nut mechanism, a clamping device, a sliding guide rail and a cutting blade. The clamping device can be replaced according to the diameter of the lead wire type to be peeled; the inner part of the device has a guide thread hole, one side of which has a cutting blade; a sliding table is arranged at the bottom of the device, which can be moved on the guide rail, and can drive the clamping device to separate or close by the forward or reverse rotation of the lead screw nut mechanism. Before the working, the lead screw nut mechanism moves to separate the clamping device and align the thread hole with the lead wire; then the lead screw nut mechanism moves in reverse to drive the clamping device to close, so as to clamp the lead wire in the threaded hole, and start the cutting operation of the insulation layer.

The lower end transmission device consists of a double worm wheel and worm mechanism and a semi-closed cylindrical gear transmission mechanism. The output shaft of the motor is connected to two worm wheels through the worm; the two worm wheels are symmetrically arranged on one side of the semi-closed cylindrical gear, which can drive the 360° rotation of the cylindrical gear; the inner side of the semi-closed cylindrical gear is connected with the lower end of the peeling device, and drives the peeling device to rotate around the center axis of the gear so as to complete the circumferential cutting motion.

3.2.2. Clamping end. The main function of the robot clamping end is to clamp various special tools for operations such as leading wire cleaning, conductive grease coating and mounting of insulation protection cover, and to clamp the leading wire connection end and insert it into the wire clamp while disconnecting/connecting the leading wire, as shown in Figure 9. The clamping end is mainly composed of insulated clamping finger, crank slider mechanism, screw nut mechanism and driving motor. The clamping finger is made of insulating material. In operation, the motor is used as the driving element to change the rotating motion into the linear motion of the nut through the screw nut
mechanism; the nut is connected with the symmetrically arranged insulating clamping finger through the double-crank slider mechanism, drives the clamping finger to separate or close, so as to realize the gripping function of the clamping end.

3.2.3. Clamp mounting end. When installing the leading wire, it is required to hang the device wire clamp on the leading wire and fasten the wire clamp bolt. In order to simplify the operation procedures and facilitate the device to find the correct bolt, the screw nut device and clamping device are simultaneously designed at the end of the on-line clamp mounting, as shown in figure 10; the screw nut fastening device is used to fasten or loosen bolts; and the clamping device is used to hold the device wire clamp. In order to make the hexagonal socket sleeve connect well with the rotation shaft and nut without external force, a cross hinge connection form is designed between the sleeve and the rotary shaft; and a rotary spring is arranged in the cross coupling to form a flexible connection. When the device is forced, the hexagonal socket sleeve can adjust a certain angle relative to the rotary axis to realize the docking with the nut.

The clamping device mainly includes the reverse lead screw nut mechanism, the mobile clamping plate and the sliding guide rail; the mobile clamping plate is fixed on the nut, with sliding block mounted at the bottom, which can be moved on the sliding guide rail; the whole device is driven by a motor. In operation, the motor drives the forward or reverse rotation of the screw nut mechanism to drive the two mobile clamping plates closer or farther, so as to realize the clamping of the device wire clamp.

4. Insulation protection

The researches on robot insulated isolation and shielding technologies mainly include those on multi-stage solid insulated isolation technology and those on control part shielding technology, the overall design frame diagram of which is shown in Figure 11.

The insulated isolation of mechanical system mainly considers the insulation of mobile platform against ground, the insulation between the robot body and the mobile platform, the entire insulation inside and outside the manipulator, the insulated isolation at the working end, and the solid insulated isolation of the robot against the ground, the phase and the adjacent wires, and mainly adopts physical insulated isolation method; the control system is designed in Faraday Cage principle to realize the anti-electromagnetic interference of electronic components.

The insulated isolation and shielding measures of the robot mainly include the following 6 aspects:

1. All the working ends are made of metal and insulating materials in a composite manner; the parts carrying high stress are made of metal materials; the parts in contact with charged body are made of insulating materials; this ensures the possession of insulation function, making the wire current not to flow through the inside of the robot;

2. The overall protection of the manipulator arm: the outer part is coated with insulating protective layer; the active part is sealed by the insulating cloth for external insulation; the fixed part is made of nylon material to protect the effective insulation between the robot and the conductive body, and to prevent the short circuit between the phases;

3. The rotating platform of the mobile insulation platform is effectively isolated from the robot body by using insulating materials;

4. The forearm of the mobile insulation platform adopts epoxy resin composite material and is mounted with leakage current detector for insulated isolation against the ground and insulation effect evaluation, so as to ensure the safety of operation.

5. The robot case is made of metal material, packaged and shielded in a complete manner.

6. The wire part adopts soft copper wire sheath for shielding.
5. Conclusions
This paper puts forward a kind of electric robot which can be used in distribution network to carry out live disconnection and connection of leading wire: a self-leveling crawler mobile insulation platform is designed, which can be applied in different complex working environments; the multi-manipulator working platform with six degrees of freedom and the high-performance live working end is developed to realize the functions of insulated wire peeling and clamping, nut tightening and loosening; the insulation protection of the working robot is reasonably designed; the multi-level insulated isolation and shielding protection measures are established for live working under the environment of strong electromagnetic field to ensure the safe working of the robot.

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