Research on robot for repairing broken strands in 500kV High Voltage Live Operation

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Abstract: The 500kV transmission line is an important part of the power transmission network. Due to the complex climate internal stress corrosion, lightning, external damage and other factors, transmission line is prone to crack in the wire, aluminum wire broken and spread phenomenon. It result in the current carrying capacity of transmission wire reduced. The local heating of the broken section is serious and the safety distance between the lines becomes short which affects the safe operation of the line and even causes serious accidents such as interphase short circuit and flash over of the transmission line. Therefore, repair must be carried out and the traditional manual repair method requires climbing the pole and tower and high in the air to eliminate the potential safety risks in time. Working in the strong electromagnetic field environment and most are in the state of power failure, even if the electrical maintenance must wear insulation clothing. There is a large labor intensity, high risk and low efficiency. Use of robots to replace manual operation can effectively reduce labor intensity and risk improve operation efficiency.

1. Introduction
High voltage overhead transmission line is the main way of long distance transmission and distribution. Ensuring the safe and stable operation of transmission line is the primary task of long distance transmission. However, transmission lines are basically set up in the field. After being exposed to wind and sun and being corroded by water vapor with high salt concentration in coastal areas. The dangerous phenomena such as line damage and broken strand are easy to occur [1] which will reduce current carrying capacity of transmission lines, local heating of lines and reduced insulation distance of multi-split wires. If it is not handled in time, the stable operation of long-distance transmission will be seriously threatened [2].

At present, The measures taken by the high-voltage operation team of the power system are manual repair when inspection personnel find damaged lines, broken strands and scattered aluminum wires in the transmission lines[3]. Operators reach the broken strands with the help of special auxiliary operation tools and carry out the repair task of broken wires. The broken wire is usually located in the center of the line where the maximum force is exerted. It need specially trained operators to climb a series of dangerous areas such as poles and towers, insulator strings and vibration hammers to reach the broken wire and begin repair. However, operators in high altitude and under the environment of strong electromagnetic field which are time consuming, high risk and serious shortage of labor intensity. The repair process[4-5] must also be wearing shielding clothing so that the whole repair process efficiency is lower and the intensity of labor and the risk increased significantly. Therefore, it
is necessary to develop a live work robot that can quickly complete the repair work of broken wires to replace manual online work, improve work efficiency, reduce labor intensity and risk. It ensure the safety of engineers and technicians, reliable and stable operation of transmission lines.

2. Development
The use of electric special operation robot to carry out routine line maintenance work can not only reduce the working intensity and danger of operators and reduce the personal injury caused by strong electromagnetic field, but also improve the efficiency of line maintenance work, improve the automation level of power grid, and meet the needs of intelligent development of social economy. Therefore, There are many countries such as Canada, Japan, the United States and France on the transmission line power special operations robot research since the 1980 s. In the early, line inspection robot as the main research object, under the artificial remote remote control walking along the tower overhead ground wire. Subsequently, a variety of operating robots [6] were developed for line hardware failures such as vibration-proof hammer, drainage plate bolt and conductor damage, but most of them were operated by ground technicians remotely, which was highly dependent on technicians' experience and environmental factors.

In 2015, The Hydropower Research Institute of Quebec in Canada developed. LineScout[7] multi-functional inspection and maintenance robot, as shown in Figure 1. The LineScout robot consists of a walking wheel arm, a barrier crossing claw arm and a driving body. It is also equipped with a working arm that can repair wires and bolts. The LineScout electric robot runs on a single transmission wire using a peristaltic approach to avoid obstacles and keeps two or three driving wheels at all times to grab the wire.

In 2008, Debenest et al. in Kansai Electric Power And Hibot designed and developed the Expliner prototype of the long-distance high-voltage transmission inspection robot. The robot has a two-line driving structure with two groups of front and rear walking wheels, and a two-degree-of-freedom manipulator with adjustable center of gravity is installed at the bottom. The system power supply, communication control circuit, servo driver and other electrical equipment are placed in the control box at the end of the manipulator. Similarly, the back end is made to cross the domain obstacle in a similar way. In the same way, the vertical line clamp of straight pole tower, anti-vibration hammer and interphase spacer rod.

![Figure 1. LineScout robot from the Hydro-Power Institute of Quebec, Canada](image)

Some universities, research institutes and power grid companies in China have also successively started the research work of PMU for high-voltage transmission network, distribution network and substation power special robot, and developed a variety of power special operation robot experimental prototype since the end of the 1990s. The robot control system adopts man-machine interactive control technology to realize the instruction interaction between the robot body and the control end and use the walking and lifting function of the bucket arm car to reach the work area of the fault point. The operator can remotely control the robot arm through the ground end to complete the tasks such as breaking the wire, wiring, replacing the insulator and repairing the wire, as shown in Figure 2.
Figure 2. Test prototype of distribution network live work robot

The Shenyang Institute of Automation Chinese Academy of Sciences has also carried out research on aerial ground and transmission line inspection robots and wire repair robots [9], as shown in Figure 3. The robot consists of a moving platform and a crimping mechanism. The vision method of transmission line breakage detection based on support vector machine is adopted. On this basis, the behavior plan of the robot repair operation is formulated by combining the internal and external sensor information of the robot and the wire repair process. The cable pulling tool is installed beside the driving wheel of the support arm to reset the bifurcated aluminum wire to the original route slot and increase the insulation distance. The crimping mechanism has two degrees of freedom. After the broken aluminum wire is reset, the crimping clip is installed at the broken aluminum wire to reinforce the damaged and broken wire, and prevent the broken wire from deteriorating or the aluminum wire from dispersing again.

Figure 3. Broken strand repair robot

To sum up, domestic and foreign research institutions mainly focus on distribution network and transmission network transmission lines and line fittings, and have developed a number of line inspection robots and maintenance robot experimental prototypes. The double live working robot in the bucket arm platform car insulation installed. The mechanical arm is only plain area distribution network. The robot working location and operating range is restricted and adopts double 6 redundant degree of freedom mechanical arm system high, large volume, high cost and complicated operation, maintenance cost and the difficulty is relatively high. The line inspection robot is equipped with a specific manipulator or end-effector to form a transmission line inspection robot which can complete the operation tasks such as bolt fastening of line fittings and wire repair. However, aluminium bag tight type of repair method, the final effect is difficult to meet the specification requirements and are mostly ground operators than computer video remote control robot ontology completing the mission and the traditional wire broken stocks based on HOG+SVM method[10].
3. Robot operating environment and tasks

High-voltage transmission line routing poles and towers, overhead ground wires, transmission wires, insulator strings, anti-vibration hammer and other accessories. The overhead ground wire is generally located at the top of the tower and plays the lightning protection role of the whole transmission line. The way of the line across the tower, in addition to the hanging line clip, and laying drainage plate, drainage line and long string insulators and other forms.

Due to the continuous operation of open power lines for a long time, fatigue damage will occur under the erosion of extreme weather. And the line is installed on the anti-vibration hammer to restrain the line swing with the wind when the wire swing anti-vibration hammer and wire friction each other is easy to appear wire damage, broken strands and other phenomena. After the line is struck by lightning, the lightning is quickly diverted to the ground through the overhead ground wire. At this time, the local temperature of the line will rise and the outer aluminum wire strand of the steel core aluminum strand will be fused.

When a robot is used to repair broken wires, the body mechanism of the robot should have the following functions as follow: driving along the wire and having certain climbing ability to adapt to the situation of large span and steep inclination in mountainous areas in southwest China; In the process of walking, crossing the anti-vibration hammer and repairing work to prevent the robot body from leaving the wire and moving its position; Finally, it can carry out straightening, resetting, reinforcing and repairing tasks for the broken wires such as line damage, aluminum wire split bifurcation and multi-strand spread. To sum up, the task listed in Table 1 must be taken into account for the robot body mechanical structure design.

| Task                  | Specific content                                      | Requirement                                      |
|-----------------------|------------------------------------------------------|--------------------------------------------------|
| Run                   | Drive smoothly along the line and reach the designated operation point | Capable of climbing and emergency braking         |
| Obstacle cross        | Cross the shock hammer barrier to the fault location to perform the task | To the shock hammer and wire connected to the broken position |
| Protection mechanism  | Protect the robot from falling to the ground when the line swings and jumps over obstacles | Lock the robot body and wires                     |
| Repair and Strengthen | Reinforce the damaged wire, straighten the bifurcated aluminum wire, and repair the broken strand | The reinforcement and repair measures are safe and feasible without causing secondary damage to the line |

4. Problems

Using robots to repair broken wires instead of humans can effectively avoid a series of dangerous actions such as climbing poles and towers, climbing over insulator strings and anti-vibration hammers by electric workers wearing insulation shielding suits. However, if you want to use robots to repair wire broken strands, the following problems need to be analyzed and solved.

(1) Climbing and obstacle climbing problems: considering the line particularity of wire maintenance robot operation task only between two adjacent poles and towers. There is no need to span multiple poles and towers, overhanging wire clips and anti-vibration hammer and other line obstacles. It is rare for multiple wire breakage faults to occur on the two pole and tower lines so the wire repair task is a single fixed point maintenance and the robot carries multiple terminal repair devices at high altitude. It is also a complex problem for the overall mechanical structure design, volume and weight control of the robot. Therefore, the overall mechanical structure design of the wire repair robot does not adopt the design idea of complex and heavy walking mechanism such as "peristalsis" and "somersaulting".
(2) Anti-fall safety protection issues: the robot should be equipped with a sensor to detect its own balance and swing amplitude, there is to prevent the walking wheel off the line of the insurance mechanism design. It will affect the robot walking and operation when high voltage overhead line gear distance is large and the cable will swing in the wind.

(3) Wire stripping and reinforcement: the robot can complete wire stripping and reinforcement tasks for different wire breaking situations. Therefore, the mechanical structure design of wire breaking maintenance terminal device is proposed to realize the reset and reinforcement of broken wire.

5. Conclusion
Based on the traditional steps of repairing wires by manually climbing the tower, this paper puts forward the method of repairing broken wires by robots instead of workers. It also points out the key technical problems to be solved when robots repair broken wires. Wire breakage repair robot instead of manual online work to improve work efficiency, reduce labor intensity and risk. It can ensure the safety of engineers and technicians. And make operation of transmission lines reliable and stable.

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