Design of automatic robot with electrolytic wiring for isolating circuit breaker

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Abstract. Isolation circuit breakers are used in power stations to isolate voltages, and isolate the equipment to be repaired from live parts to form a safe operating space. In order to meet the needs of on-site maintenance and test of the new generation intelligent substation, avoid the need to stop other electrical equipment during the maintenance of the isolation circuit breaker, reduce the scope of equipment power failure and shorten the system debugging period, this paper proposes a design method of automatic live line disconnection robot for isolation circuit breaker, which can meet the requirements of bus clamp removal and installation, and improve the isolation of new generation intelligent substation Operation and inspection level of circuit breaker. The specific method is to design a mobile robot lifting platform, through the cooperation of manipulator, controller, arc strike rod, camera and other tools to realize the live line disconnection operation of three-phase bus. In this paper, 3D modeling and simulation show that the robot design scheme is feasible.

1. Introduction

Electricity is the main form of energy consumption in China, which has the largest power grid in the world, and the construction of smart grid and the enhancement of power supply reliability have become a national strategy. The new generation smart substation with "highly integrated system, reasonable structural layout, advanced and applicable equipment, economy, energy conservation and environmental protection" has become another milestone in the new way of power grid development and scientific and technological innovation [1].

In recent years, the isolation circuit breaker has been more and more widely used in the new generation of smart substations. Its main function is to isolate the voltage, so that the maintenance equipment and the live part form an obvious disconnect point, so as to ensure the safety of people and equipment [2]. After the failure of the isolation circuit breaker, the general operation is divided into two ways: power off operation and manual use of electrified insulation rod for operation. Large-scale power failure caused by power outage operation has a great impact on People's Daily production and life, so it is generally carried out live maintenance by manually using insulated operating lever [3]. This kind of traditional live operation is heavy workload, low efficiency and the technical level of the staff is uneven, which affects the quality of the operation. At the same time, live operation brings great threat to the life safety of the operator.
In order to meet the new generation of intelligent substation site inspection and test requirements, avoid isolation circuit breaker maintenance needs to stop with other electrical equipment, reduce equipment power range, reduce the cycle of the system debugging, it is necessary to study based on the isolation circuit breaker of robot line, connection between the technology and equipment technology, bus isolation circuit breaker and the connection between the robot hardware and isolation circuit breaker with electrolytic line, wiring, meet the requirement of bus bar clamp to dismantle, installation, and raise a new generation of intelligent substation isolation circuit breaker shipment inspection level.

2. Overall scheme design of robot

2.1. General structure and function description

The topological structure of the new-type three-phase DPMV motor is shown in Fig. 1. Two sets of permanent magnets are used in the motor, where one set is embedded into rotor and the other into stator. The motor stator is composed of iron core carrying convex tooth, three-phase armature winding and permanent magnet. Halbach flux gathering array is used for the permanent magnet embedded into stator to reduce magnetic flux leakage to improve the utilization efficiency of permanent magnet, and magnetic barrier is introduced at bottom of the array for magnetic shield. The permanent magnets are made of hybrid magnetic material, thus lowering the processing cost.

The overall structure scheme of the robot is shown in Figure 1.

![Figure 1 Schematic diagram of robot structure for live operation of isolating circuit breaker](image)

The overall structure of the robot can be divided into two parts: mobile lift car and live work platform. Live operation platform includes: two cooperative robot arm assembly, robot controller, battery, arc rod and binocular camera etc. Mobile lift car and live work platform are built in wireless WIFI module, through remote wireless control to achieve "dry and wet separation", to achieve the physical isolation of the operator and the whole robot, fundamentally to ensure personal safety. Considering the safe distance between the working robot and the isolated circuit breaker during operation, the equipment dimensions are shown in Table 1.

| Name                        | Value       |
|-----------------------------|-------------|
| Total size of equipment     | 1m×2.8m×3m  |
| (including lift car)        |             |
| Robot size                  | 0.7m×0.62m×3m |
| Robot Lifting height        | 2.2m        |
| Robot weight                | <180kg      |
2.2. Process and control of field operation

The field operation is divided into two parts: unwiring and wiring, as shown in Figure. 2. In the three-phase AC electrolytic line operation, take the first two sides of the phase lead, after the removal of the intermediate phase lead, in the wiring operation, take the first intermediate phase lead, after the two sides of the phase lead, through the step-by-step operation, to avoid the short circuit between leads, relative short circuit and other problems.

Figure. 2 Action diagram of robot for live operation of isolating circuit breaker

Isolation circuit breaker with electrolytic line, fire operation robot can be wireless remote control of the whole robot through the upper computer software. There are three interactive interfaces on the
software, which are: mobile elevator control interface, A manipulator operation control interface, B manipulator operation control interface. The upper computer communicates with the whole robot through the wireless WIFI module.

3. **Process design and simulation**

3.1. **Robot initial state setting**

The initial state is set for the live operation robot of isolating circuit breaker, and the state of each component is:

1. The working platform is lifted to a height of 3.4 meters above the ground, 2.1 meters from the busbar wiring position, and 1.2 meters from the busbar horizontally.
2. Fix the fittings on the fittings fixing seat.
3. The starting rod is located at the initial position (starting claw) 250mm away from the working platform plate, and the starting claw and the starting rod form a certain Angle (which is preset according to the height of the cable), and the starting claw is in the open state.
4. The arcing rod control device clamps the arcing rod so that the arcing rod is in a vertical state.

3.2. **Arc initiation process design**

Arcing process of live working robot with isolated circuit breaker I:

1. Arc rod control device: the device clamps the arc rod and drives the wheel to drive the arc rod upward to the position 0.4 meters away from the bus bar (not in contact with the wire).
2. Wiring receiver: in the process of moving arc rod, the wire receiver automatically releases the equipotential line under the action of traction force.
3. Arc pawl: the initial state of the arc pawl is open, and the front section of the arc pawl is provided with a guide grid, which is connected with the equipotential line.

Arc initiating process of live working robot with isolated circuit breaker II:

1. Arc rod control device: drive the arc rod to rotate counterclockwise to the preset Angle; Then the driving motor controls the arc rod to extend to the preset position.
2. Manipulator 1: Grasp the end of the arcing rod for fine tuning.
3. Arc pawl: after confirming the accurate position, the arc jaw grasps the position of the busbar end.

3.3. **Robot initial state setting**

Mobile process of robot platform for live operation of isolated circuit breaker I:

1. Arc rod control device: the clamping wheel of the device is relaxed, so that there is a large gap between the arc rod and the clamping wheel.
2. Lift car: lift car lift, so that the working platform distance from the bus 300mm.
3. Arc pawl: always in the state of grasping the bus bar.
4. The mechanical arm 1 drives the clamping claw to grasp the hardware.

Mobile process of robot platform for live operation of isolated circuit breaker II:

1. Arc rod control device: deflection mechanism with the horizontal movement of the elevator to a certain Angle of deflection (due to the clearance relationship, the accuracy is very low).
2. Lift car: move horizontally, so that the working platform is 500mm away from the horizontal position of the bus.
3. Arc pawl: always in the state of grasping the bus bar.

3.4. **Wiring process design**

Wiring process of robot platform for live operation with isolated circuit breaker:

1. The manipulator arm 1 drives the gripper to pull out the fittings from the fittings fixing seat, move the fittings to the front of the bus wiring row, and identify the fittings through the camera to ensure that the four holes of the fittings are aligned with the holes of the bus wiring board.
(2) The mechanical arm 2 drives the tightening gun to insert the screw into the hole, and the motor drives the tightening head to tighten.

(3) After the first bolt is screwed, manipulator arm 2 drives the tightening gun to the bolt storage position, drives the motor to rotate and sucks the bolt. Finally, repeat 3 and 4 to finish the screw tightening.

3.5. Detached process design
Process of robot platform detachment for live operation of isolated circuit breaker:
(1) The mechanical arm 1 and 2 are closed, and the working platform moves horizontally to 1.2 meters away from the bus by the drive of the lift car.
(2) the working platform in the lift car drive down to 2.1 meters away from the bus.
(3) The arcing rod is turned over to the vertical ground, and the arcing rod control device drives the arcing rod back to the initial position.
(4) The lift car moves back to continue the installation of the next phase conductor.

3.6. Job process simulation
Through the above modeling of the robot wiring operation process, the operating state of each component device in the operation process is clarified. On this basis, simulation can be carried out to verify the feasibility of the robot design scheme. The simulation process is shown in Figure. 3-7, which includes arc rod lifting, arc rod flipping, platform lifting, platform horizontal movement, and detachment process. The process of robot line unwinding is similar to this, which will not be described in detail in this paper.

Figure. 3 Simulation of arc rod lifting process
Figure. 4 Simulation of arcing rod turnover process
Figure. 5 Simulation of platform lifting process
Figure. 6 Simulation of horizontal movement of the platform
4. Conclusion
In view of integral windup and great current fluctuation problems of DPMV motor control system, a double-vector model predictive current control algorithm based on Anti-Windup controller was put forward in this study. The feedback compensation was realized in the integration element of this controller by using the variable structure with adaptive adjustment, and this can rapidly eliminate the integral windup. Following the analysis of insufficient traditional model predictive current control, the current control was predicted using a double-vector model in the inner current loop, and two voltage vectors were randomly selected within one control cycle and combined with duty ratio to further expand the range of choice of voltage vector and the adjustable range of amplitude. According to the simulation results, the proposed control algorithm can effectively repress the integral windup, reduce current fluctuation, and improve the system steady-state performance, what’s more, it is of preferable dynamic performance.

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