Research on Full Link Intelligent Control Platform for Substation Maintenance through Edge-Aware

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Abstract. In view of the imperfect process control, safety control and data control in substation maintenance operation, this paper proposes a full link intelligent control platform for substation maintenance operation based on edge-aware. The platform is composed of on-site edge-aware system and big data decision service system. The on-site edge-aware system uses various intelligent tools to collect data, carries out real-time safety behavior early warning, maintenance quality control and maintenance process supervision through edge computing technology, and uploads the analyzed and processed information to the big data decision service system. The big data decision service system provides support for online decision-making of substation equipment maintenance according to the panoramic multi-source information of the maintenance site provided by the site edge perception system. The full link intelligent control platform for substation maintenance operation has built a control system for real-time control of on-site maintenance operation process, on-site maintenance information and on-site maintenance safety information, which improves the management efficiency of substation maintenance on-site operation and enhances the safety guarantee of maintenance operation.

Keywords: full link intelligent control platform; edge-aware; data control; process control; safety control.

1. Introduction

China's industrial modernization has an increasing demand for energy such as electricity. The safe and stable supply of electricity is related to the national economy and the people's livelihood. Power transformation enterprises are the main body of power generation and supply, and bear vital responsibility for the rationality of power market price and the stability of power supply. Substation equipment maintenance is an important means to ensure the smooth operation of substation enterprises, which has been paid attention by the management of substation enterprises. The research on power equipment maintenance and operation related technologies has important basic theoretical significance and practical application value [1-4].

According to the field work experience, there are the following problems in the daily business of substation maintenance:
(1) At present, there is a lack of digital and information management and control means for substation maintenance, the maintenance management data is not perfect, and the whole link process data of maintenance business and on-site safety management and control data are not included in the system. In the face of several existing management systems operating in isolation, the maintenance data cannot be interactive, shared and integrated, and cannot be analyzed and evaluated uniformly [5].

(2) The instruments and tools involved in substation maintenance are relatively conventional, and all test data and conclusions also depend on the manual records of the staff. Due to different personal habits and inconsistent data models, the test data cannot be standardized and unified, and the real-time performance is poor. In some cases, fake data will appear. This situation has seriously affected the accuracy and timeliness of maintenance work, leaving hidden dangers for subsequent operation and maintenance management [6].

(3) Safety production has always been the core of substation maintenance. In terms of on-site operation safety control, the substation maintenance work area has invested a lot of human resources and public resources. Safety control still depends on human supervision and paper records. There is a lack of effective comprehensive control and more scientific trace management. How to supervise the safety of personnel and work area in real time, Early warning of possible risks of personnel is an urgent problem to be solved.

To solve the above problems, many researches are committed to enabling maintenance business with new technologies. Literature [7] uses ASR technology to solve the error prone problem of manual management of a large amount of information data in substation; Literature [8] uses VR panoramic technology to make three-dimensional real scene account for each equipment of substation; Literature [9] provides a new technical means and research idea for the operation and maintenance of power equipment by using artificial intelligence technology; Literature [10] and literature [11] applied the edge cloud collaborative service architecture to substation equipment condition monitoring, and developed edge computing equipment to provide condition evaluation and edge application services; Literature [12] uses edge computing and cloud collaboration technology to solve the problems faced by power system, and designs power system service architecture based on edge computing to provide technical support for the development of smart grid; Literature [13] discusses the importance of 5G technology for the establishment of power Internet of things. Overall, the improvement methods proposed in various studies are relatively general, and the research on the process, information and security control of maintenance business is not systematic.

2. Full link intelligent control platform for substation maintenance based on edge perception
The full link intelligent control platform of maintenance operation based on edge perception proposed in this paper is composed of on-site edge perception system and maintenance big data decision support system. It constructs a control system of real-time control of on-site maintenance operation process, real-time control of on-site maintenance information and real-time control of on-site maintenance safety information.

The full link intelligent control platform for on-site maintenance operation presents a hierarchical structure of data acquisition layer, service component layer, data storage layer and interactive application layer. The overall hierarchical design is shown in Figure 1.
Fig 1. The hierarchical structure of system

1) The data acquisition layer is mainly related to the on-site edge perception system, including intelligent tools, concentrators and on-site intelligent brain robots.

2) Platform service layer, data storage layer and data application layer are mainly related to big data decision service system.

With the help of abundant computing resources and panoramic multi-source information of substation maintenance provided by the field terminal processing system, the platform service layer constructs the on-line decision support capability of substation equipment condition based maintenance and provides application functions.

The data storage layer is used to store all data information of the full link intelligent control platform for on-site maintenance operations.

The data application layer calculates the key indicators according to the data stored in the data storage layer, and shows them to decision makers and users in the form of data reports.

3. Field edge sensing system

3.1. System composition
The on-site edge sensing system is composed of intelligent brain robots responsible for edge computing and a series of intelligent devices to automatically complete the real-time control of on-site maintenance business, on-site maintenance safety and on-site maintenance information in the whole maintenance operation. The functions and corresponding intelligent devices of the field edge sensing system are shown in Table 1.
### Table 1. System functions and corresponding intelligent devices

| System function                                      | Corresponding intelligent device                        |
|-------------------------------------------------------|---------------------------------------------------------|
| real time management and control of maintenance business | handheld terminal                                       |
| real time management and control of maintenance information | intelligent loop resistance tester                    |
|                                                      | intelligent torque wrench                               |
|                                                      | intelligent multimeter and tester                       |
|                                                      | intelligent dielectric loss tester                      |
|                                                      | identification of tools and instruments                 |
| maintenance safety real-time control                 | smart helmet                                            |
|                                                      | intelligent electronic fence                            |
|                                                      | smart seat belt                                         |
|                                                      | intelligent early warning ladder                        |
|                                                      | intelligent safety grounding wire                       |
|                                                      | lift truck bucket and boom                              |
| data collection, edge calculation                    | intelligent brain robot                                  |

Various intelligent devices send the collected data to the intelligent brain robot, which performs edge calculation, analyzes the data through each control module, and sends the corresponding feedback back to the staff and big data decision service system. The work flow of the field edge sensing system is shown in Figure 2.

![Fig 2. The workflow of system](image)

#### 3.2. Intelligent maintenance tools and instruments

Intelligent maintenance tools and instruments include intelligent switch contact resistance test equipment, intelligent torque wrench, intelligent multimeter and tester, intelligent dielectric loss tester, identification of tools and instruments, etc.

1. **Intelligent switch contact resistance test equipment**
   The output data of the intelligent switch contact resistance test equipment is directly transmitted to the on-site intelligent brain robot to automatically generate the test report, analyze whether the value meets the requirements and guide the on-site inspection.

2. **Intelligent torque wrench**
According to the selected sleeve size, the intelligent torque wrench identifies the inserted sleeve size (ID) and automatically adjusts it to the set torque value, so as to reduce the hidden danger of unqualified torque caused by personnel's wrong data or setting error.

(3) Intelligent multimeter and tester
The intelligent relay protection tester and multimeter have data output interfaces, and the output data is directly transmitted to the intelligent robot.

(4) Intelligent dielectric loss tester
The intelligent dielectric loss tester has a data output interface, and the output data is directly transmitted to the intelligent brain robot.

(5) Smart helmet
Bind personnel identity, locate personnel position, interconnect with on-site operation robot, and monitor and warn the distance between personnel and electrified body in real time.

(6) Identification of tools and instruments
All kinds of intelligent tools and instruments have the positioning function ID code. When entering and leaving the warehouse and substation, they can timely read the ID code information, record the location, and submit it to the database in real time.

3.3. Intelligent maintenance safety tools and instruments
Intelligent maintenance safety tools and instruments include intelligent electronic fence, intelligent safety belt, intelligent early warning ladder, intelligent safety grounding wire, lifting truck bucket and boom.

(1) Intelligent electronic fence
Distinguish between maintenance and operation areas, identify whether personnel cross the fence for violation or other interference that does not need alarm, and interact with the data of the robot.

(2) Smart safety belt
The intelligent safety belt is used to detect whether the hook is firm, whether the safety belt is worn correctly, and interact with the data of the robot.

(3) Intelligent early warning ladder
Realize the functions of exceeding the limit height reminder, angle alarm device, unattended alarm, scanning personnel identity, data interaction with the robot and so on.

(4) Intelligent safety grounding wire
Correctly record the status of the operation site, locate the position status of the grounding wire and upload it to the database in real time, realize the unbuckled reminder through the electric quantity sensor and interact with the robot data.

(5) Lift truck bucket and boom
Carry out real-time monitoring and early warning function for the safe distance between the lifting truck bucket, boom and electrified body.

3.4. Intelligent brain robot
(1) The on-site intelligent brain robot is composed of ontology, communication fusion system, maintenance information edge computing system and multi-level human-computer interaction system. The core system directly related to the business is the maintenance information edge computing system. The maintenance information edge computing system consists of safety behavior early warning module, maintenance quality control module and maintenance process supervision module.

The safety behavior early warning model is an "air ground human" three-dimensional safety behavior early warning expert model of digital safety control tool.

The maintenance quality control module is a fidelity traceability maintenance quality control expert model of digital quality control tools.

The maintenance process supervision module is a digital supervision process involving the whole link process of power maintenance.
3.5. Field edge sensing system example

The example of field edge sensing system takes the typical scene of c-check between two 220kV lines in 220kV substation as an example. The field application steps of field edge sensing system are shown in Figure 3:

![Field edge sensing system example diagram](image)

**Fig 3.** The process of maintenance

1. **Site survey and preliminary preparation**
   During the preparation, the paper materials are input into the management and control platform composed of server, app and web management page in advance by means of web management page to prepare the file package, select spare parts for preparation, or app side photography and QR code scanning. The tools, instruments and preparation are sent to the big data decision-making service platform in real time in combination with the readers of on-site warehouse and substation.

2. **Build digital maintenance site**
   Install electronic fence and positioning device; For the access and use of operation grounding wires and working grounding wires: all kinds of grounding wires are taken out from the storage place, and the reader at the storage place will timely record the access of grounding wires and submit them to the system. The personnel only need to check whether there are outbound records on the system. After using the grounding wire, put it back to the storage place, and the system will display that it has been put into storage. Personnel only need to check whether there is any grounding wire not stored in the system to determine whether there is any grounding wire on the site.

3. **Work ticket permit and confirm the status of safety measures**
   Check the equipment status when approving the work ticket, confirm and record the equipment status once by taking photos. When checking the safety measures, the completed safety measure shall be reserved by using the handheld terminal realized by industrial tablet combined with app software.

4. **Standing meeting**
   Read the work content of this line interval C inspection, pay attention to the electrification of adjacent intervals, confirm the scope of the intelligent fence, confirm that the working surface and identity information of the staff pass through the intelligent helmet, ensure a safe distance during the operation and work in the fence. The staff shall confirm and sign the face recognition on the handheld terminal device of the person in charge of the work. For helmets with different labels on different working
surfaces, the maintenance personnel follow the sub principals to enter the corresponding maintenance site. The site safety and technical measures can be realized by means of proximity sensing and pressure sensing. At the same time, the helmets with different labels can be used to confirm whether the special vehicles are within the limited range, whether the air switch and signboard safety measures are in place, etc.

(5) Maintenance data control during operation
During the working process, all test data are automatically uploaded through intelligent tools and instruments.

When the primary maintenance personnel maintain each contact surface, the measured loop resistance data is synchronously uploaded to the background for verification and storage through the intelligent equipment.

Relay protection professionals shall fill in and confirm the secondary safety measures card on the handheld terminal step by step, take photos and upload. Connect the relay protection tester to the network, tighten the screw, automatically upload the measured voltage, current, action time and input data of the protection measurement and control device to the standard process, and automatically review and confirm the data to form a calibration report. After passing the acceptance, restore the safety measures and confirm that the safety measures are restored in place. Confirm the equipment status, take photos and upload them to the terminal for comparison with the pre work status.

High voltage test professionals use intelligent tools and instruments to test during the test. The measured equipment withstand voltage, partial discharge, insulation characteristics and DC resistance data automatically generate the test report, and automatically upload it to the system for verification and storage.

(6) Safety control during operation
Ensure the safety in construction through UWB technical positioning personnel, bucket boom crane and ladder of special vehicles;

For violations, some on-site violations are identified through image and video soft processing, fed back to the intelligent helmet through the intelligent robot terminal, and a warning prompt is sent to the violators.

For safety measures, confirm whether there is any change in safety measures in real time to ensure that personnel, maintenance equipment and vehicles always operate under correct and unchanged safety measures.

For the personnel of foreign manufacturers, they shall be within a set safe distance from any supervisor through helmet identification, so as to ensure that the foreign personnel are working under the supervision all the time.

(7) Job termination
After the operation is completed, the staff shall confirm that all personnel, tools and instruments have left and there are no left items on the site through image, video and equipment positioning. After the work of each discipline is completed, the person in charge of the work shall confirm the equipment status with a handheld intelligent device, and handle the work ticket termination procedures on the terminal after there is no error.

4. Big data decision service system
Big data decision service system is a system based on substation maintenance data integration system, substation maintenance data model as the core and decision support system as the main body.

4.1. Substation maintenance data integration system
The substation maintenance data integration system is used to integrate various data of substation maintenance business. The technical architecture is shown in Figure 5. The system is divided into five layers, from bottom to top, followed by data source, ETL subsystem, data warehouse, pre-aggregation subsystem and visual Bi components.
In practical application, the data sources of the system are operational system databases such as maintenance quality control system and maintenance safety control system. After ETL subsystem imports the data source data into hive data warehouse, hive data warehouse stores the imported data according to the designed data model. After building the data cube, the pre aggregation subsystem provides the function of analysis and query, and displays the visual results through the open source Bi tool. In addition, the pre aggregation subsystem also extends the function points of job failure alarm, metadata backup, cluster garbage cleaning and so on. The big data component of the cluster ensures the smooth operation of the cluster.

![Image](image.png)

**Fig 4.** The architecture of data integration system

4.2. **Substation maintenance data model**

The construction of substation maintenance data model includes two levels. The first part is based on knowledge base and data warehouse. The second part is based on data mining, using data mining methods to analyze the data in the database to form a data analysis model more in line with the business needs.

The data model based on substation maintenance business requirements includes:

1. Equipment health status and failure probability calculation model: used to evaluate the current health status of equipment, calculate and determine the equipment failure probability, and provide basis for risk cost analysis.

2. Power grid topology identification model: according to the real-time state information of power grid, analyze and determine the power grid topology to form the grid structure model required for power grid calculation.

3. Maintenance decision model: including short-term maintenance decision and medium and long-term maintenance decision.

4.3. **Substation maintenance decision support system**
From the perspective of decision-making process, the on-line decision-making system for substation equipment maintenance mainly includes multi-source input data fusion processing, maintenance decision evaluation and analysis, and output display of decision results. See Figure 6 for details.

![Diagram of substation maintenance decision service system]

**Fig 5.** Composition of substation maintenance decision service system

Multi source input data fusion processing: the adaptive data interface can analyze the complex information accessed by various business systems and form a standardized data storage format.

Evaluation and analysis of maintenance decision: during maintenance, the operation status and potential loss of substation equipment shall be comprehensively evaluated, and the maintenance strategy shall be customized and optimized according to this evaluation.

Output display of decision results: the operation and maintenance personnel need to refer to the system output results when formulating the maintenance plan.

5. Epilogue

This paper presents a full link intelligent control platform for maintenance operation based on edge perception. The full link intelligent control platform for on-site maintenance operation is composed of on-site edge sensing system and maintenance big data decision support system, which realizes the three control objectives of real-time control of on-site maintenance operation process, real-time control of on-site maintenance information and real-time control of on-site maintenance safety information, improves the management efficiency of on-site operation of Substation maintenance and enhances the safety guarantee of maintenance operation.

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Reference

[1] Chinese Society for Electrical Engineering Information Committee. Chinese electric power big data development white paper[M]. Beijing, China: China Electric Power Press, 2013.
[2] LI Gang, YU Changhui, LIU Yunpeng, et al. Challenges and prospects of fault prognostic and health management for power transformer[J]. Automation of Electric Power Systems, 2017, 41(23): 156-167.
[3] XUE Yusheng, LAI Yening. Integration of macro energy thinking and big data think: part one big data and power big data[J]. Automation of Electric Power Systems, 2016, 40(1): 1-8.
[7] CHENG Xuan. Research on common safety problems and Countermeasures in substation maintenance[J]. Cleaning World, 2019, 35(12): 42-43.

[8] YANG Wangxia, SHENG Xue, WANG Dongmei, ZHANG Cheng, CHEN Jianping. Research on intelligent management platform of power grid maintenance application business[J]. Wireless Internet Technology, 2020, 17(02): 43-44.

[9] LI Xu. The Internet plus the big data solution strategy for substation maintenance[J]. Telecom World, 2019, 26(12): 243-244.

[10] LIU Yitong, LI Yulei, Lixu. Intelligent operation inspection management system of substation based on ASR Technology[J]. New Technology & New Products of China, 2019(21): 19-20.

[11] XIE Zhengwei, LIU Chunping, YANG Wei, LI Shanshan. Application of VR panoramic technology in substation maintenance[J]. Electric Technology & Software Engineering, 2019(23): 59-60.

[12] PU Tianjiao, QIAO Ji, HAN Xiao, ZHANG Guobin, WANG Xining. Research and Application of Artificial Intelligence in Operation and Maintenance for Power Equipment[J]. High Voltage Engineering, 2020, 46(02): 369-383.

[13] SI Yufei, TAN Yanghong, WANG Feng, et al. Cloud-Edge Collaborative Structure Model for Power Internet of Things[J]. Proceedings of the CSEE, 2020, 40(24): 7973-7979+8234.

[14] JIANG Yi, LIU Zhengyang, WANG Wenrui, et al. Research on multi-state monitoring system of substation equipment based on edge-cloud collaboration[J]. Power System Protection and Control, 2021, 49(06): 138-144.

[15] BAI Yuyang, HUANG Yanhao, CHEN Siyuan, et al. Cloud-edge Intelligence: Status Quo and Future Prospective of Edge Computing Approaches and Applications in Power System Operation and Control[J]. ActaAutomatica Sinica, 2020, 46(03): 397-410.

[16] XIONG Ke, ZHANG Ruichen, WANG Rui, et al. 5G-Enabled Electricity Internet of Things: the Network Architecture and Key Technologies[J]. Electric Power, 2021, 54(03): 99-108.