The Detection Efficiency Improvement of the Distribution Equipment Based on the Intelligent Industrial Technology

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***Abstract*—With the rapid development of distribution network automation, the efficiency of the production, operation and management of equipment in distribution network need to be improved. The intelligent distribution network equipment includes the distribution terminal and the distribution overhead line malfunction indicator, which are important to the reliability of the power system. It is necessary to ensure the superior performance and reliability of the distribution terminal and malfunction indicator products. So, batch inspection need to be carried out. In this paper, the intelligent industrial automatic technology is used to detect the malfunction indicators and distribution terminals to improve detection efficiency. An intelligent industrial detection system is proposed for the batch inspection of distribution network equipment. The system is mainly composed of the automatic detection assembly line, the integrated management system and the control system. The appearance structure inspection, function performance test, data statistics, multi-dimensional analysis and the multiplex display can be performed by the assembly line. Based on the artificial intelligence vision recognition technology, the industrial robot technology and the big data analysis technology, the proposed system realizes the multi-level interaction of the detection procedure, improve the detection speed, and secures the accuracy of the equipment detection. The intelligent detection system is a pilot project for the large-scale and high-precision inspection of the distribution network equipment.**

***Index Terms*—process control, intelligent detection, distribution terminal, malfunction indicator, integrated control system**

I. Introduction

In recent years, the rapid development of China's economy has led to the rapid development of smart grid construction, and the backbone grid is becoming more and more mature. As an important part of smart grid, the efficiency of management for the distribution system should to be improved [1]-[4], especially for the distribution automation system. The reliable operation of equipment in distribution network relates to the safety and stability of distribution network automation system. At present, the product quality of automation equipment in distribution network in China is not guaranteed [5], with the continuous expansion of distribution automation construction, some equipment in distribution network are exposed to maloperation, miss trip, low accuracy, abnormal communication and other functional performance defects. In order to ensure the quality of products and the reliability after installation, the appearance structure, function, performance and communication protocol of the equipment should be comprehensively tested before being installed in the distribution network [6].

In the face of a large number of detection work for equipment in distribution network, it is urgent to design and build a batch detection system for the distribution network equipment. The system has high automation, strong adaptability, detection ability and expansibility. It can not only standardize the detection process to ensure the quality level of the detection equipment, but also shorten the detection time greatly. Hence the work efficiency can be improved, the labor input reduced, and the overall quality of the distribution network equipment effectively controlled [7]. This paper uses the intelligent industrial technology for the inspection of equipment in distribution network, bring forward a design of system management platform according to artificial intelligence, hereinafter referred to as detection system. Based on the vision recognition technology, the technology of industrial robot and the application technology of big data analysis, the automatic detection assembly line of distribution terminal and malfunction indicator is designed. The intelligent control method of loading, inserting, detecting, disconnecting, storing is developed to test full type of distribution terminal and malfunction indicator. At the same time, in order to control the quality of equipment in the distribution network panoramically, the integrated management and control system of the equipment detection information is developed by using the basic information of distribution terminal and malfunction indicator, inspection information and operation information.

II. Construction Scheme of Detection Syestem

A. System Function

The functions of intelligent industrial detection system for equipment in distribution network include the following two parts:

Manuscript received July 13, 2019; revised November 5, 2019.

doi: 10.18178/jiii.7.2.42-47

1) The system checks up the full type of distribution terminal and malfunction indicator automatically and in batches.

2) The system realizes the process control, data management and test results analysis of each detection object. The detection system consists of assembly line, detection platform, integrated management and control system. The system architecture diagram is shown in Fig. 1.

In addition to the manual participation in loading and unloading, the automation of the overall process can be realized.

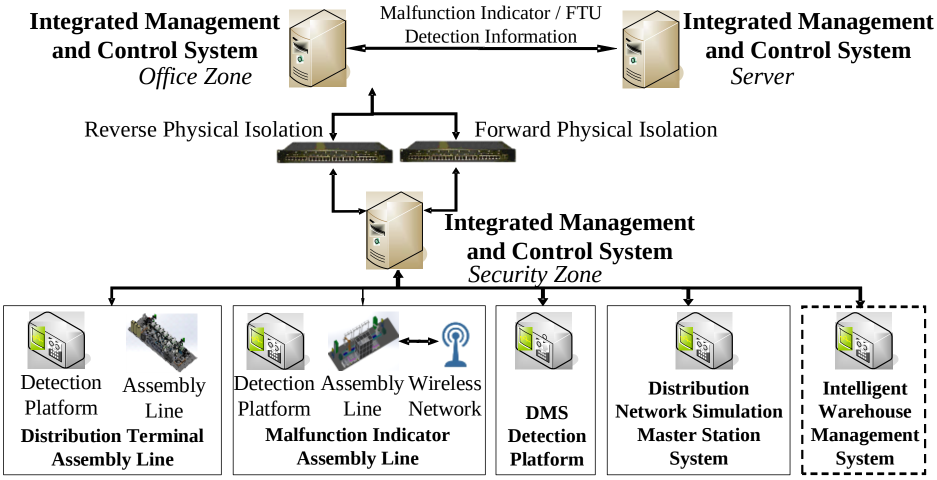

Figure 1. Intelligent industrial detection system architecture diagram

B. Design Concept of the Detection System

According to the function orientation of the detection system, combined with intelligent industrial technology, the design concept of the system is put forward as the following 3 steps:

1) Preparation

The detection assembly line obtains basic device information by scanning the QR (Quick Response) code on the equipment, and matches the pre-set detection scheme in the database from the integrated management and control system.

2) Detection

In each process of the assembly line, the control system realizes the interaction between the transmission mechanism and the robots. The assembly line completes the action of accurately placing the detected device at the specified position in each step, the detection platform sends out the test signal and receives the test process data, then comparing and analyzing the data to generate the test results. The inspection is completed item by item with this method. Detection includes distinguishing the appearance structure features of the equipment, checking if remote communication, remote sensing, remote control and telemetry meets the standard. The control system also interactively transfers the test information between platforms.

3) Data collection and analysis

The integrated control system bases on the test information and uses data mining technology to manage and control the quality of distribution network equipment panoramically. On this basis, a multi-dimensional evaluation index system is established to improve the management and control capability of equipment in distribution network in the province.

III. FACILITIES PART OF DETECTION SYESTEM

The facilities of automatic detection system for distribution network equipment is composed of assembly line and detection platform. This system is used to detect the appearance structure and function performance of the equipment. The assembly line sets up the flow channel and the inspection station. The detection platform is mainly composed of the control cabinet and the interface adapter. The detection system combines intelligent robot with automatic assembly line by interactive control. It completes the steps of equipment loading, wiring, testing, report formation and automatic sorting. While meeting the requirement of 24 hours automatic batch detection, a practical solution is given to solve the past problems to ensure the quality and efficiency of the inspection.

A. Automatic Detection of Distribution Terminal

The structure of the automatic detection assembly line of the distribution terminal is shown in Fig. 2. The main detection object is feeder terminal unit (FTU). Hereinafter referred to as FTU assembly line. The assembly line includes the following equipment: 1 loading platform and 1 unloading platform, each has an area of 1100mm×1300mm. 1 loading robot arm and 1 unloading robot arm, each has 6-axis action degree of freedom, its maximum load capacity is 100kg, maximum coverage area is 259m^2, and the repeat positioning accuracy is ±0.2mm. 1 plugging robot arm which has 6 axis of motion degree of freedom, its maximum load capacity is 20kg, the coverage is 1725m^2, the repeat positioning accuracy is ±0.05m^2. 1 double speed chain conveyor, including the lifting and moving mechanism and the backboard lifting mechanism, its length is about 12m. 6 trays that can be flexibly adapted to different types of FTU. The design of FTU assembly line structure supports the parallel testing of up to 6 devices.

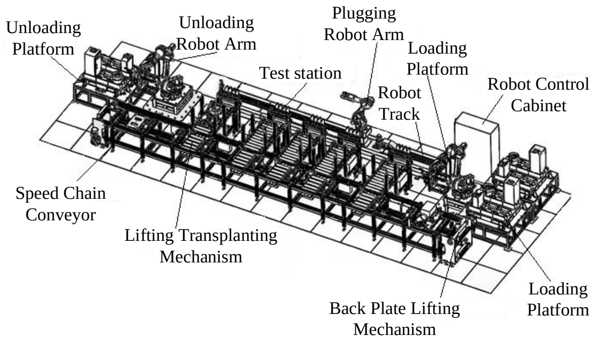

Figure 2. Distribution terminal detection assembly line diagram

According to the characteristics of FTU structure, the process of FTU assembly line detection is designed as follows:

1) The loading robot grabs the device, reading the equipment basic information to retrieve the corresponding detection scheme from the database.

2) Using visual recognition technology to identify whether the appearance of FTU equipment meets the standard, the qualified product will be sent to the inspection station. Besides the unqualified product will be picked up and removed from the assembly line.

3) When all the 6 inspection stations reach the specified detection position, the plugging robot arm automatically plug aviation connector at corresponding socket. After confirming that the plugging action is completed, the detection platform starts to output the detection signal through data wire to simulate the actual scene.

4) After the inspection, the unloading robot arm sorts the qualified products, and the unqualified products are picked to different trays.

B. Automatic Detection of Malfunction Indicator

The design of automatic detection assembly line structure of malfunction indicator is similar to that of FTU assembly line, which supports parallel testing 4 devices. In the test method, there is a difference between the two of them.

A complete malfunction indicator consists of 3 acquisition units and 1 convergent unit. In engineering applications, 3 acquisition units are installed on three-phase power lines to detect voltage and current, the corresponding convergent unit receives the data from the acquisition units via wireless communication, then processes and sends it back to detection platform. Because of the different application scenarios, a set of malfunction indicator devices are not all placed on the tray for testing like FTU. In order to fully simulate the equipment operation site, this paper pioneered the hanging measurement method of the acquisition units. The specific form expressed as the acquisition units hung on the distribution line simulator through a fixed structure.

In order to set up the acquisition unit correctly, the automatic buckle-opening robot and the platform are designed on the malfunction indicator line. With high adaptability, the wire spring of various types of acquisition unit can be turned over. It effectively solves the problem of opening buckle for non-standard appearance malfunction indicators uniformity.

C. Application of Visual Recognition Technology

In the detection process of FTU, visual recognition technology is used to complete the appearance detection and plugging action.

1) Appearance detection

Firstly, the robot arm fixes the FTU at the specified position, and the camera captures the original data image. Then the original image is simply filtered, the filtering algorithm selects median filtering. The algorithm can obtain good image edge features and can filter out some noise. The quality of the original image is relatively high, so the median filter should select the two-dimensional template as small as possible to avoid the problem that small defects cannot be identified. Since the original image features are obvious and the edge discrimination is large, after the above processing, the edge of the FTU device can be directly extracted after binarization, and the region to be identified can be obtained. Finally, the standard defect-free FTU appearance image in the database is retrieved, compared with the identified identification area, and the defect threshold is set to determine whether the FTU is defective. If the FTU has a defective appearance, the assembly line will alarm, the device will be removed from the assembly line and placed in a centralized position.

The industrial camera cannot automatically zoom during use. To obtain a clear FTU surface image, it is necessary to place the recognition object at the focus every time after determining the focal length of the camera. Therefore, it is chosen to use a high-precision robotic arm to move the FTU to a specified position to ensure image quality. In order to ensure the consistency of imaging, reduce the noise of the original image, and improve the accuracy of identifying defects, the FTU surface should be as bright as possible, the reflected light should be uniform, and local over-brightness or too darkness should not occur before capturing the original data image. Therefore, in the design of the assembly line structure, a light-filling system is installed on both sides of the camera. The physical view of the appearance detection facility is shown in Fig. 3.

Figure 3. The Physical View of the Appearance Detection Facility

2) Plugging action

The application of visual recognition in the plugging is done by the plugging robot arm and image processing. During the detection process, the plugging robot arm needs to insert the data wire into the FTU socket, connecting the FTU with the detection platform. The FTU receives the test signal from the detection platform and feeds back the test result to simulate the field operation status. Generally, the FTU has 5-6 data ports. When the aviation connector of the data wire is inserted into the socket, the socket should be in one-to-one correspondence with the pins in the slot to prevent the FTU from being damaged during the plugging process, to ensure the normal operation of the running detection program. However, during the production process of FTU, the internal rotation angle of each socket is not fixed. Therefore, after the data wire is grabbed, the plugging robot needs to rotate the aviation connector according to the pin angle of the socket. Meanwhile, due to the control deviation, there will be a slight positional deviation between the aviation connector and the socket. So, it is necessary to adjust the aviation connector to the appropriate position and angle. This operation uses image recognition to calculate the socket angle, then feeds back to the plugging robot to make corresponding adjustment actions. Plugging actions process chart is shown in Fig. 4.

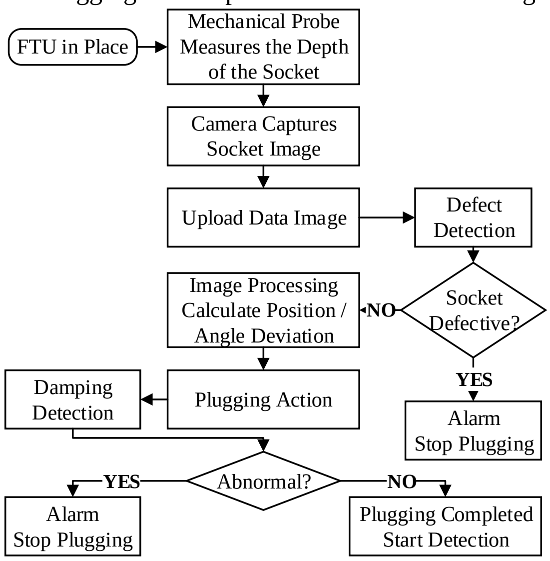

Figure 4. Plugging actions process chart

The process for running plugging is described as follows:

In the beginning, the plugging robot arm grabs the aviation connector of the data wire and moves it to the specified detection position, which is the focus position of the debugged industrial camera. The angle of the end effector is then adjusted to ensure that the axis of the socket coincides with the center axis of the camera. The camera captures the original data image of the end face of the socket, and upload it to workstations to process the acquired image. The processing method is basically the same as the above-mentioned appearance defect detection. After the grayscale and error point processing, if the captured image cannot identify the socket, command the camera to shoot again. If the captured image meets the recognition criteria, proceed to the next image processing. Because the image captured by the lens is distorted and cannot reflect the actual shape of the socket end face, the camera needs to be calibrated in advance to correct the distortion of the image to obtain the actual image. The image obtained after processing does not need to be image-matched, but needs to find the marker point. In order to ensure the accuracy of the identification, a red marker point is placed at the corresponding position of the socket buckle as the positive direction of the x-axis in the socket coordinate system, so that the angle θ between the positive direction and the positive direction of the predetermined socket can be obtained. Finally, the calculated rotation matrix is assigned to the plugging robot arm, and the robot arm makes corresponding adjustments to accurately insert the aviation connector into the socket. In the process of operation, supplemented by damping detection, when there is an error in visual recognition, or the robot arm misunderstands, the connector and the pins cannot fully correspond, and the damping between them will be very large. When the detected damping is greater than the set threshold, the robot arm stops the plugging action and sends an alarm message to prevent loss of personnel and property, and achieve sufficient robustness.

The above is introduction of the application of visual recognition technology in the plugging actions.

IV. Integrated Management and Control System

For the FTU and malfunction indicator assembly line above-mentioned, each station adopts a separate information module to detect, the large information and various quantities makes it difficult to rely on manual maintenance and management. For this reason, the system has established a comprehensive control system of distribution detection information, centralized control of the detection process, and unified management of each test data. The scope of control covers all aspects of the detection, and realizes the omni-directional control of the distribution network equipment detection center. The results of multi-dimensional analysis of detection information can support for quality control of distribution network equipment.

A. System Architecture and Function

The integrated management and control system realize the interaction of many systems, unifies management of the integrated information and the test result of each detecting device. The functions include account management, business process control, analysis of test results, data mining and display, etc. The business data interaction structure of the control system is shown in Fig. 5.

The system is based on application database, network management, security management and system automatic configuration management. It integrates multi-level information and maintains information manually to form basic data. Combined with big data, business process management, oriented data mining and other technologies, the omnidirectional management and efficient utilization of detection information can be realized, and the comprehensive business level can be improved.

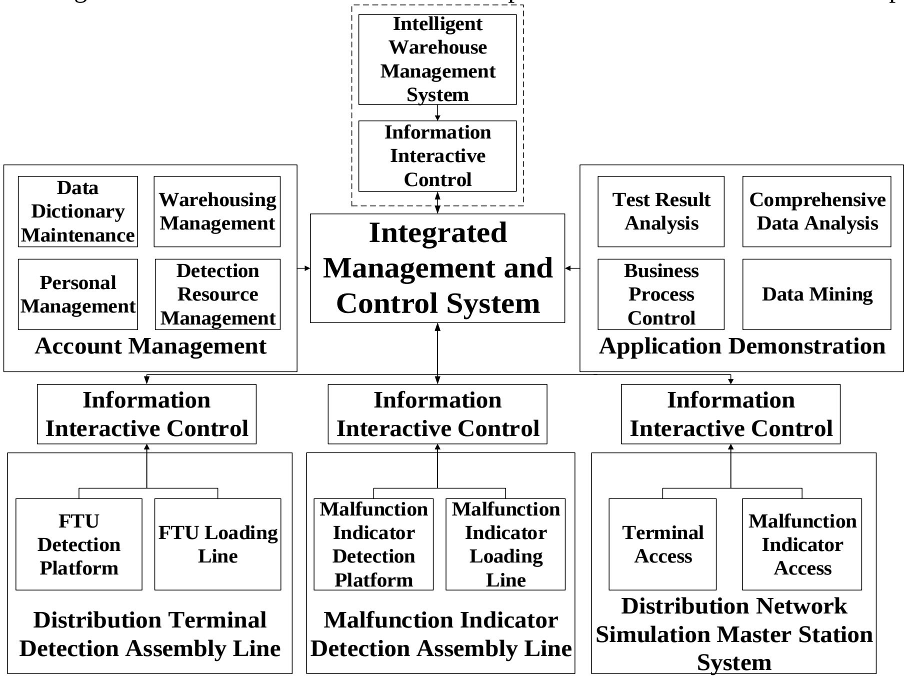

Figure 5. Business data interaction structure diagram

B. Account Management

1) Database management

The method of combining relational database with real-time database is used to meet the requirements of high-speed real-time data access and high reliability data storage. Relational database realizes the storage and access of basic data and historical data, such as static model and related equipment parameters, system configuration, etc. Real-time database provides high-speed data access to realize data interaction between systems, meeting the requirements of data analysis such as integrated control and control of inspection process, data mining and so on. Real-time database structure is shown in Fig. 6.

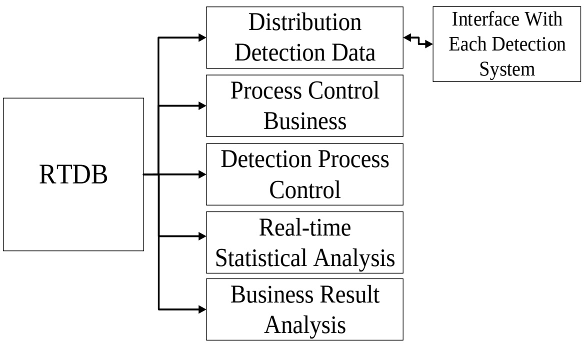

Figure 6. Real-time database overall structure

2) Detection resource management

Resource management establishes the dynamic management of the equipment static model. The system models the related equipment to provide the basic data for the integrated management and control of the detection process. The modeling content includes the detection equipment of the distribution network master station, the management of terminal unit detection resources and assembly line detection resources. The modeling process of the indicator is shown in Fig. 7.

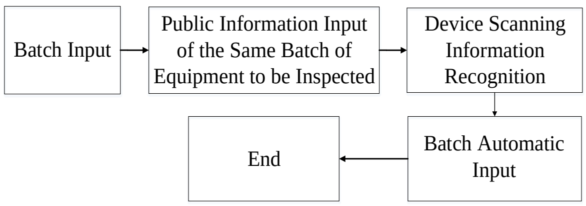

Figure 7. Diagram of the Distribution Terminal Modeling Process

3) Maintenance for detection information and data dictionary

According to all kinds outline of equipment inspection, the system maintains from the test items, test sample name, test program and supplier details of 4 aspects. Data dictionary maintenance mainly provide basic data for the detection system. It can also add, modify, delete basic data and provide other maintenance functions.

C. Warehousing Management

Warehousing management is managed by the warehousing administrator, including winning lot registration, sample collection management, sample management and other functions.

D. Business Process Management and Result Analysis

Business process management includes integrated control of inspection process and integrated control of information interaction. This work is the basis of the automatic detection of the system.

1) Test result analysis

Test result analyzing summarize data and check the results of the finished samples, including the essential of the test information and the detailed query of the test results.

2) Detection resource management

Comprehensive data analyzing combine the present data with the historical data of the system operation, providing targeted business data mining analysis. Through the detection data summary and analysis, different dimensions of indicators are shown, the overall control of equipment quality is achieved, to provide distribution inspection managers with equipment testing program optimization advice and data support, further improve detection efficiency. In addition, the test results for non-qualified equipment would be all-round analyzed, in order to guide manufacturers to find out the reasons.

3) Maintenance for detection information and data dictionary

Interactive control of detection assembly line: The system provides assembly line control and information interaction, with online device selection, startup and pause function. It also has the interactive function of assembly line current process state information.

Interactive control of detection platform: The system provides information and control interaction with detection platform. It has functions including equipment information transmission, detection case selection, detection status, results and process controlled real-time interactive function.

Interactive control of superior equipment quality control system: The system interacts by reporting the detection information of distribution network equipment to the superior equipment quality analysis system, and adjusts the testing scheme according to the testing requirements of the superior equipment quality analysis system to realize the dynamic negative feedback correction.

V. Conclusion

In this paper, the detection efficiency improvement of FTU and malfunction indicator based on the intelligent industrial technology, the construction scheme, facility and software facilities design of the detection system is studied. Adopting the design method based on time series control, the high compatibility detection assembly line is designed combining AI and industrial robot arm. The application of visual recognition technology ensures the accuracy of assembly line operation, and different detection scenarios for device design for different application scenarios is simulated to the large part of extent. At the same time, based on data mining technology and big data analysis technology, integrated management and control system of detection information is constructed, which creates an effective platform for comprehensive management and meta-analysis of detection information. The system has guiding significance for the practical work of equipment selection, operation and maintenance, scrapping and other distribution network construction management. It also lays a solid foundation for the management of the whole life cycle of equipment.

To sum up, using the intelligent industrial technology to detect equipment in distribution network realizes the batch and automatic detection of the whole process. At the same time, it creates a new way to solve the batch detection of non-standard power equipment. Since then, the completion of intelligent industrial detection system for distribution network equipment marks the transition of distribution network equipment detection from "traditional manual mode" to "intelligent industrial mode".

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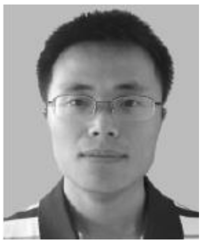

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