Practice on Typical Quality Issue Analysis of Main Equipment and Construction of Quality Issue Database System

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Abstract: Equipment quality issue cases are a direct reflection of the quality of main equipment. To enhance equipment reliability, this research focuses on the characteristics of typical quality issues of main equipment in previous projects, including IGBT breakdown, power supply board failure, and central control board malfunction. It conducts an in-depth analysis of the causes and mechanisms of these quality issues. It designs and implements a typical equipment quality issues database, which realizes functions such as rapid information storage, multi-dimensional query, and statistical analysis of typical quality issues data. Furthermore, it summarizes and extracts quality control risk points in the design, production, and installation processes of converter valves, providing guidance for subsequent converter valve design, production, and installation work.

Keywords: Equipment Typical Quality Issues; Quality Issue Database System; Information Management; Equipment Supervision

1. Introduction

VSC-HVDC technology (Voltage Source Converter-Based High-Voltage Direct Current Technology) has significant technical advantages in fields such as large-scale renewable energy grid connection, large city power supply, and coastal island interconnection [1,2]. With the rapid growth of power grid demand, VSC-HVDC technology is evolving toward higher voltage and larger capacity [3]. As the core primary equipment of VSC-HVDC transmission systems, malfunctions of VSC-HVDC converter valves are likely to trigger severe consequences such as system outages and equipment damage. Consequently, the establishment of a quality issues database has emerged as a critical initiative to enhance operation and maintenance (O&M) efficiency and ensure power grid stability [4,5]. Currently, the development of this Quality Issue Database is in the phase of technological integration and practical advancement, with significant progress achieved in core architecture, technical application, and industrial practice. Sun Hongzhi et al. proposed a remote monitoring method and system for transformer materials based on an Enterprise Information Portal (EIP) platform [6], enabling the management of transformer production schedules and processes as well as the administration of remote supervision data. In the field of oilfield equipment supervision, Chen Tie et al. constructed a supervision management platform that implements functions including workflow management during on-site equipment supervision and the control and traceability of typical issues [7]. Guo Depeng et al. suggested realizing functions such as the circulation of supervision tasks through informatization, noting that the establishment of an information-based work platform for equipment supervision will facilitate equipment supervision management [8]. Zhang Peng et al. put forward methods and measures to avoid or mitigate problems in the hydrostatic testing of nuclear-grade pumps [9]. Nevertheless, the construction of Quality Issue Database still encounters challenges such as standardization and collaborative sharing. This study collects and investigates the characteristics of typical issues in previous projects, analyzes their causes and mechanisms, and leverages database management technology, data visualization analysis and presentation technology, etc., to construct a typical quality issues database system for VSC-HVDC converter valves. The collected and analyzed issue information is integrated into this database, enabling functions such as information entry, query and retrieval, statistical analysis, and data sharing of typical quality issues data. This system promotes the rapid extraction of risk points and the efficient development of reliability test schemes for converter valves and valve cooling systems, providing data references and experience support for issue analysis of converter valve equipment in subsequent Flexible HVDC projects.

2. The Key Functions of the Quality Issue Database

2.1 Research Ideas

This study was conducted following the research framework illustrated in Figure 1. First, typical quality issues of converters in previous Flexible HVDC projects were collected and systematically analyzed. Subsequently, database management technology and big data analytics were employed to establish a typical quality issue case database system for flexible HVDC converter Valves, where the collected and processed quality issue information was integrated. On this basis, the causes and mechanisms of these quality issues were explored, and key points for enhancing the reliability and quality control of converter equipment were proposed. These efforts facilitate the rapid identification of risk points and the development of reliability test schemes for converters and valve cooling systems. Ultimately, this study provides guidance for the design, production, and installation of converters in subsequent Flexible HVDC projects, as well as data references and empirical support for the analysis of converter equipment quality issues in such projects.

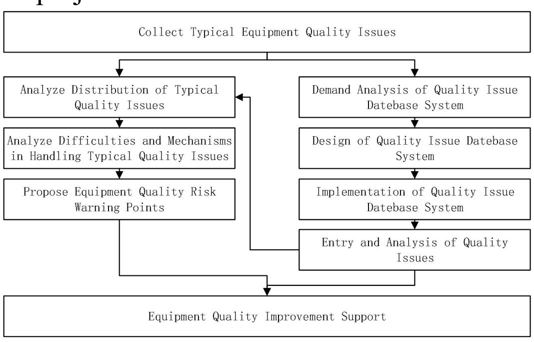

Figure 1. Research Framework

2.2 Analysis of Common Quality Issue Types for Key Equipment

Quality issues of flexible HVDC converter Valves can be classified into five categories based on their causes: raw materials, manufacturing processes, testing, design, and packaging. Their specific manifestations and impacts are detailed as follows:

(1) Raw Material Issues

The core lies in inherent quality defects of components or materials, such as uneven material composition of IGBT chips, excessive aging rate of insulating materials in energy storage capacitors, and substandard purity of insulating parts. These issues directly lead to early component failure, triggering faults like IGBT breakdown, capacitor bulging, and insulation breakdown, which in turn result in sub-module outage or even overall equipment malfunction.

(2) Process Issues

Mostly occurring during manufacturing and assembly, such as substandard welding processes causing cold solder joints, insufficient tightening torque of busbars, misalignment in fiber optic connector installation, and lack of sharp edge protection for wire processing. These problems give rise to hidden hazards including increased contact resistance, distorted signal transmission, and wire wear-induced short circuits, which may lead to sudden equipment failures during operation or shortened service life.

(3) Test Issues

Caused by non-standard factory tests, type tests, or on-site acceptance tests—for example, failure to complete voltage withstand tests, partial discharge measurements, and other items in accordance with standards, unreasonable setting of test parameters, or incomplete data recording. This results in undetected potential defects, making the equipment prone to insulation failure, control abnormalities, and other problems after commissioning, with difficulties in rapid traceability.

(4) Design Issues

These are inherent defects, such as the lack of electromagnetic shielding design for the layout of primary and secondary systems, excessively long water paths or excessive joints, inadequate heat dissipation due to unreasonable radiator layout, and missing explosion-proof structure design for sub-modules. Such issues trigger faults like electromagnetic interference, water leakage, component overheating, and sub-module explosion [10], and may also increase maintenance difficulty and safety risks.

(5) Packaging Issues

Mainly affecting the transportation and storage of equipment, such as packaging failing vibration tests, lack of impact protection structures, and insufficient sealing measures. This causes displacement of internal components, loose boards, and seal failure during transportation. After installation and commissioning, the equipment is prone to mechanical structure failures, poor contact of control boards, and other problems, or even direct damage to core components.

2.3 Core Functions and Characteristics of the Quality Issue Database System

The core role of the flexible HVDC converter valves quality issue base system lies in quality issue handling support and knowledge accumulation, with its core characteristics focusing on practicality, reliability, and scalability. Its key research points and functions are mainly reflected in the following aspects:

(1) quality issue Rapid Diagnosis and Handling

It integrates various quality issue cases (raw materials, processes, design, etc.), providing complete references for quality issue phenomena, causes, and solutions. This helps operation and maintenance personnel quickly match similar cases, shorten troubleshooting and repair time, and reduce equipment outage losses. It fully records the entire quality issue process information (causes, handling procedures, liability identification), providing a basis for quality issue traceability and liability division while meeting industry norms and audit compliance requirements.

(2) Through the data integration of systems at various stages, quality issue handling experience is shared across manufacturing plants and projects. This addresses technical experience gaps, enables remote quality issue diagnosis, improves the accuracy of quality issue diagnosis, and enhances the efficiency of converter valve quality issue handling.

(3) Optimization of Equipment Quality Control

Through case data analysis, it explores the laws of quality issue occurrence, providing data support for equipment design improvement, factory test optimization, and operation and maintenance strategy adjustment, thereby reducing the probability of quality issue recurrence.

3. System Design and Implementation

The overall architecture of the Quality Issue Database System is shown in Figure 2. It is divided into a 5-layer structure: the Frontend Presentation Layer, Service Interaction Layer, Business Application Layer, Data Layer, and Infrastructure Support Layer.

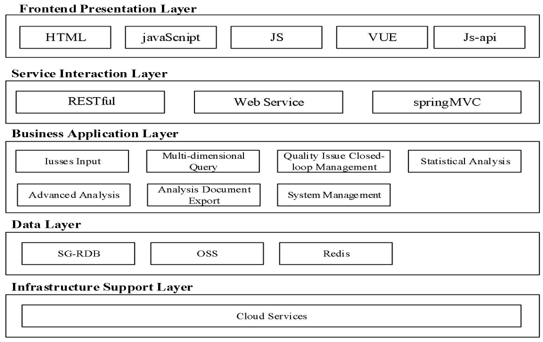

Figure 2. System Architecture Design

(1) Frontend Presentation Layer: As the direct interface for system-user interaction, the frontend presentation layer undertakes core responsibilities including function visualization, operation response, and experience optimization, serving as a key support for personnel involved in equipment supervision to carry out work efficiently. The system adopts a Browser/Server architecture, accessible via web browsers and supporting cross-terminal adaptation to meet the multi-scenario usage needs of supervision personnel in offices, manufacturing plants, and other locations. Core page construction relies on HTML5, with native components such as Canvas and SVG enabling the rendering of supervision data visualization charts (e.g., quality issue distribution maps, supervision progress Gantt charts). Interaction logic is implemented through JavaScript and mainstream frameworks, ultimately providing intuitive and smooth system usage experiences for supervision management units, supervision agencies, and supervision teams.

(2) Service Interaction Layer: Acting as the core hub connecting the frontend presentation layer and backend data layer, the service interaction layer is responsible for parsing frontend user requests, scheduling backend business logic, and returning processing results. It supports data interaction requirements throughout the entire equipment supervision process (e.g., entry and query of quality issues, real-time synchronization of supervision progress data, permission verification). Technologies such as RESTful, Web Service, and SpringMVC are adopted for service interaction.

(3) Business Application Layer: The Business Application Layer serves as the core function output layer of the system facing users, focusing on the full-process business scenarios of equipment supervision and converting backend data capabilities and frontend interaction requirements into directly operable functional

applications. It includes functions such as quality issue import, quality issue closed-loop management, multi-dimensional query, statistical analysis, advanced analysis, analysis document export, and system management.

(4) Data Layer: It is the data support of the system, and system data can be divided into structured data and unstructured data. Structured data such as Quality Issue descriptions, discovery time, Quality Issue types, root cause analysis, and handling measures are stored in databases. Unstructured data such as Quality Issue record photos, test screenshots, and handling result photos are stored using object-oriented storage. Specifically, structured data is stored in the SG-RDB (State Grid - Relational Database), unstructured data adopts object-oriented storage, and Redis caching technology is additionally utilized.

(5) Infrastructure Support Layer: It is the software and hardware environment support for the platform, mainly operating based on a private cloud environment.

3.2 System Functions

The database system is mainly developed for equipment supervision and management applications, with primary users including equipment supervision management units, equipment supervision entities, and equipment supervision teams. Its core functions cover quality issue import, quality issue closed-loop management, multi-dimensional quality issue query, quality issue statistical analysis, advanced analysis of quality issue cases, analytical document generation, and system management.

(1) Quality Issue Import: The primary users are the supervision teams. Quality issues originate from two aspects. On one hand, quality issue information is obtained by interfacing with the original business system; on the other hand, it is obtained through manual collation and import. The quality issue information includes details such as the description of the quality issue, discovery time, quality issue type, root cause analysis, and handling measures. Attachments include types such as images, videos, and PDFs. For typical quality issues, one-click collection is supported to form a typical quality issue case library, as shown in Figure 3.

(2) Quality Issue Closed-Loop Management: The primary users are the supervision teams. Handlers at each stage update the progress of quality issue disposal in real time, including key nodes such as on-site investigation, implementation of handling plans, and verification. Core data during the disposal process (such as investigation results, adopted measures, and spare parts used) is recorded. Managers can real-time monitor the status of quality issue handling through the system, send reminders and follow-ups for overdue tasks, ensuring the disposal process is controllable.

(3) Multi-Dimensional Query: The primary users including equipment supervision management units, equipment supervision entities, and equipment supervision teams. Supports multi-dimensional query of cases. As shown in Figure 4, precise retrieval can be performed based on conditions such as equipment manufacturer, equipment type, affiliated project, quality issue type, occurrence link, closed-loop status, and time period, meeting diverse query needs.

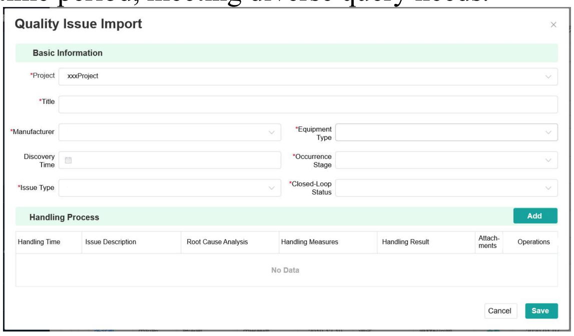

Figure 3. Quality Issue Import

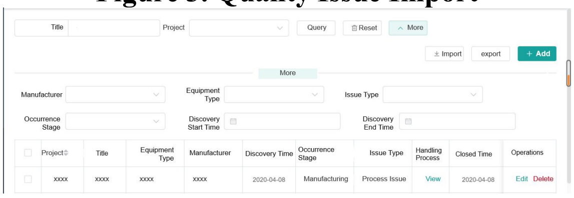

Figure 4. Multi-Dimensional Query of Quality Issues

(4) Quality Issue Statistical Analysis: The primary users including equipment supervision management units, equipment supervision entities. The statistical function supports statistics by quality issue type, by project (Figure 5), by manufacturer, and by closed-loop status. Through statistical analysis across multiple dimensions, we can identify the projects, processes, and manufacturer equipment where key quality issues are concentrated. This supports targeted problem localization and analysis, enabling focused tracking, prevention, and control.

(5) Advanced Analysis of Quality Issue Cases: The primary users including equipment

supervision management units, equipment supervision entities. It can conduct multi-dimensional statistics on quality issue data and generate core indicator reports, intuitively presenting distribution patterns and disposal efficiency. Through algorithm models, it predicts quality issue trends, identifies high-risk points, and assists in formulating preventive measures in advance.

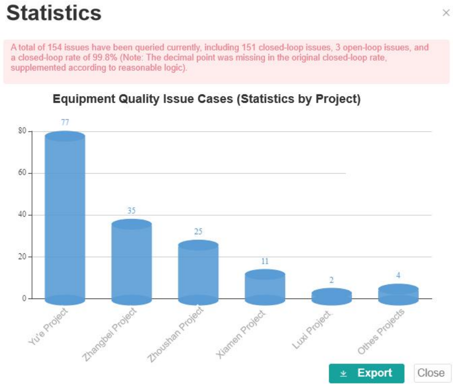

Figure 5. Statistical Analysis of Quality Issues

(6) Analysis Document Export: The primary users including equipment supervision management units, equipment supervision entities. It summarizes case statistical analysis according to standardized templates to generate analysis reports (Figure 6), with support for report export. Through the reports, supervision management units and supervision entities can intuitively view supervision progress, quality issue analysis information, quality issue distribution, and quality issue closed-loop status. They can also grasp key problem risk points and convene coordination meetings to implement focused risk prevention and control.

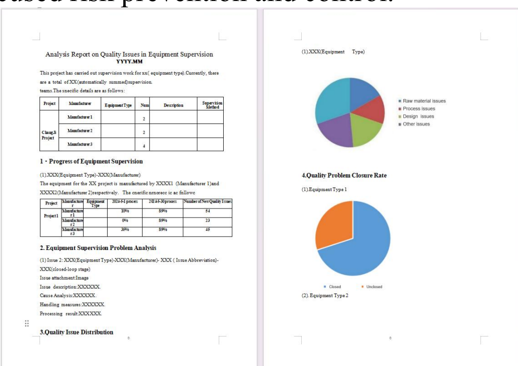

Figure 6. Analysis Report Sample

(7) System Management: System management serves as the foundation of system construction. This module enables the management of system users, organizations, role permissions, connected data, and security auditing. System users include those from supervision management units, supervision entities, and supervision teams. The system classifies and controls functional permissions and data permissions based on supervision work responsibilities. During data integration, it monitors the stability and integrity of data interfaces. The security auditing module implements system security protection through system access permission control and system logs.

4. Key Points for Engineering Application and Equipment Quality Improvement

By utilizing the typical quality issue database, 164 typical quality issue cases of converter valve equipment from 6 Flexible HVDC projects were collected, including 161 closed-loop cases and 3 unclosed-loop cases, with a closed-loop rate of 98.2%.

Relying on the quality issue case library, the distribution and causes of various problems in previous projects were analyzed, and key points for quality improvement and control of converter valve equipment were proposed. These mainly include: improving the structure and process of equipment sub-modules; the design of sub-modules and components should follow the principles of primary and secondary system partition isolation, explosion-proof and flame-retardant, water circuit optimization, etc., while balancing layout compactness and maintenance convenience, and doing a good job in the protective design of wires and optical fiber openings. During installation, specifications such as joint fastening, identification filing and optical fiber alignment must be strictly implemented, and contact resistance should be sampled and tested in proportion during annual maintenance. In addition, it also includes improving the reliability of monitoring functions and interface design, and perfecting the relevant test system. In the optimization of the test system, aging screening tests are conducted for IGBT devices of converter valves, and random inspection tests for the reliability of device packaging processes are strengthened. Voltage withstand tests are carried out for sub-module central control boards under the open-circuit condition of low-voltage arm voltage-divider resistors, among other tests.

5. Conclusion

By collecting and researching the typical fault characteristics of converter valves in previous Flexible HVDC projects, this study has established and implemented a typical fault case library. Through analyzing the causes and mechanisms of faults, key points for improving the reliability and quality control of converter valve equipment are proposed. The construction and practice of the equipment fault case library provide a solid foundation for the standardized management and scientific analysis of equipment fault data, and offer key support for identifying weak points in all links and solving similar problems in subsequent projects. The collection, analysis, and in-depth utilization of fault information in the case library cannot be achieved overnight. It needs to be integrated into the equipment quality management work of all project links to fully release its data and experience value, and continuously contribute to the improvement of equipment quality.

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