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Design and Practice of Intelligent Safety Prevention and Control System for Overseas Power Plants

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Abstract: Against the backdrop of the Belt and Road Initiative, overseas thermal power enterprises face challenges such as complex geographical environments, difficult safety supervision, and prominent localized management issues. Huadian Xigang Power Generation Co., Ltd. (Cambodia) has constructed an intelligent safety prevention and control system with global perception as the core based on industrial Internet and artificial intelligence technologies. This paper elaborates on the architectural design, key technology applications, and practical effects of the system. Through innovative means such as 3D digital twin, AI intelligent patrol, and multi-system integration, it realizes the upgrade of safety management in overseas power plants from passive response to active prevention and control, providing a reproducible technical paradigm and management experience for safety governance of energy enterprises along the Belt and Road.

Keywords: Overseas power plant; Intelligent safety prevention and control; 3D digital twin; AI patrol; Global perception

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1. Introduction

With the in-depth advancement of the Belt and Road Initiative, the overseas investment scale of Chinese energy enterprises continues to expand. As an important carrier of energy infrastructure, the safe operation of overseas power plants is directly related to energy supply stability and sustainable enterprise development. However, overseas power plants generally face multiple safety challenges including firstly, complex geographical environments — countries in Southeast Asia such as Cambodia have high temperature and humidity, and frequent typhoons, which impose strict requirements on equipment reliability; secondly, significant differences in safety supervision systems — local safety standards differ from those in China, making compliance management difficult; thirdly, traditional safety prevention and control means rely on manual inspections, suffering from problems such as lagging response, high missed inspection rates, and data silos [1].

As a key thermal power project invested by China Huadian Corporation in Cambodia, Huadian Xigang Power Generation Co., Ltd. has an installed capacity of 2*350MW, undertaking the task of local industrial and domestic power supply. Aiming at the particularities of overseas operations, the company has innovatively constructed a safety management system of "global perception, intelligent linkage, and active prevention and control" relying on technologies such as industrial Internet, 3D digital twin, and AI visual analysis, realizing real-time monitoring of all elements of personnel, equipment, and environment and closed-loop risk management. Taking this project as the research object, this paper systematically analyzes the design logic, technical implementation, and application effects of its intelligent safety prevention and control system, providing a reference for similar overseas energy projects [2].

2. Architectural design of an intelligent safety prevention and control system

2.1. Overall framework: Global perception and hierarchical control

The intelligent safety prevention and control system of Huadian Xigang takes "data integration, business collaboration, and intelligent decision-making" as the core goal, constructing a technical system of "three-layer architecture plus five major modules" (**Figure 1**).

Perception layer: Deploy intelligent terminals such as unmanned aerial vehicles (UAVs), video surveillance, electronic fences, UWB personnel positioning, and environmental monitoring to achieve global data collection of the physical space of the power plant.

Platform layer: Build a 3D digital twin system based on the industrial Internet platform, integrate data from 12 subsystems such as video surveillance, access control management, and fire alarm, forming a unified safety management "One Map."

Application layer: Develop five core applications, including public safety prevention and control, operation process control, remote AI patrol, risk knowledge base, and mobile management terminal, realizing the full-process automation from risk early warning to emergency disposal [3].

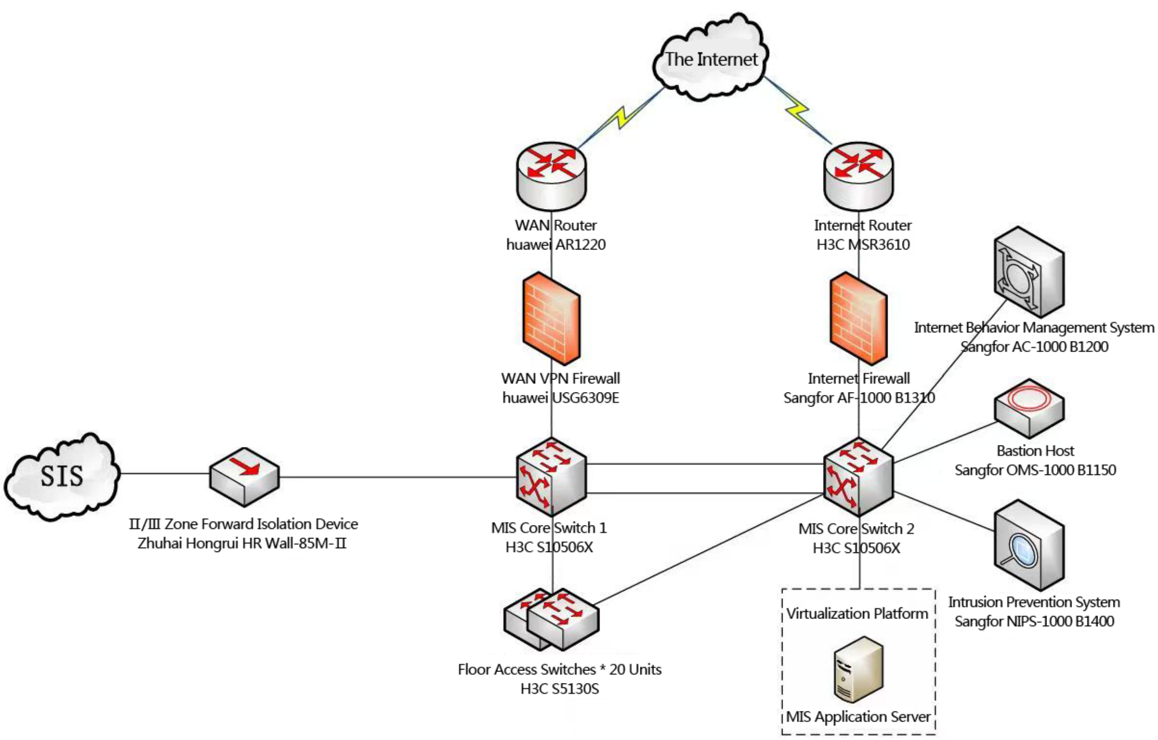

Figure 1. Topology map of the intelligent safety prevention and control system

2.2. Design of core functional modules

2.2.1. 3D digital twin global perception platform

Through 1:1 3D modeling technology, it completely restores physical entities such as power plant buildings, equipment, and pipe networks, realizing real-time mapping between the "virtual power plant" and the "physical power plant." Its core functions include the following.

Plant roaming and concealed facility management: Support gravity roaming and zero-gravity roaming modes. Operators can browse the plant through a first-person perspective or follow perspective, and view real-time data such as underground pipe network coordinates and equipment operation parameters; through three-dimensional and section analysis, it intuitively displays the structure of concealed projects, providing data support for maintenance.

Multi-system integration and linkage monitoring: Connect subsystems such as video surveillance, personnel positioning, and fire alarm. When personnel enter dangerous areas (such as hydrogen stations and oil tank areas), the system automatically triggers electronic fence alarms and simultaneously retrieves nearby camera images, realizing "positioning — monitoring — alarm" linkage.

2.2.2. Intelligent public safety prevention and control platform

Based on the concept of "intelligent security one map", it realizes rapid deployment of suspicious targets through data correlation analysis.

Personnel and vehicle management: Integrate data from access control, visitors, and vehicle gates, establish personnel/vehicle black and white lists, and automatically warn of unregistered personnel and overtime vehicles; use face recognition technology to real-time compare personnel identities and operation permissions to prevent illegal intrusion.

Low-altitude defense and perimeter protection: Deploy UAV countermeasure systems to real-time track the flight trajectories of unauthorized UAVs, link electronic fences to trigger sound and light alarms, and identify abnormal behaviors such as perimeter wall damage, and through intelligent video analysis, with an alarm response time of no more than 5 seconds.

2.2.3. Intelligent operation process supervision platform

Aiming at the complex operation environment of overseas power plants and the difficult management of outsourced projects, it constructs a full-process control system.

Personnel behavior and health monitoring: Use AI image recognition technology to real-time detect illegal behaviors such as personnel not wearing safety helmets, smoking, and playing with mobile phones, with an identification accuracy of 98%; collect physiological data such as blood oxygen and heart rate through intelligent bracelets to real-time warn of fatigue operation and poisoning risks.

Full-cycle management of high-risk operations: Combine the 3D scene with the "two-ticket management" process. Before operation, delimit electronic fences and mark risk points through the platform; during operation, real-time monitor personnel trajectories and environmental data, automatically suspend operations and notify supervisors in case of abnormalities; establish an outsourced project ledger to record contractor qualifications, operation quality, and safety performance, providing a basis for payment and assessment.

2.2.4. Automatic remote AI patrol platform

Adopt a collaborative patrol mode of "UAV plus Fixed Camera", replacing more than 60% of manual inspection work.

Multi-dimensional hidden danger identification: Identify hidden dangers such as equipment pipeline leakage (positioning accuracy no more than 5cm), abnormal instrument readings, and fire smoke through video analysis technology; realize early warning of equipment overheating and abnormal noise through infrared thermal imaging and acoustic monitoring.

Closed-loop management process: After discovering hidden dangers, the system automatically generates work orders and pushes them to the responsible persons. The processing results are fed back through mobile terminals, forming a closed loop of "Detection — Order Dispatch — Rectification — Acceptance", with an average processing time shortened by 40%.

2.2.5. Digital support system for safety management

Risk knowledge base system: Integrate data such as thermal power plant accident cases, safety standards, and operation specifications, establish a structured knowledge base, support intelligent Q&A and risk retrieval, and provide decision-making references for employee training and emergency disposal.

Mobile management terminal: Develop iOS/Android applications to realize functions such as task receipt, knowledge base query, operation approval, and real-time monitoring. Leaders can view the safety situation of the plant through mobile terminals at any time, with decision-making efficiency increased by more than 50%.

3. Key technical innovations and applications

3.1. Deep integration of 3d digital twin and physical systems

Traditional digital twins mostly stay at the visualization level. The Huadian Xigang project connects the underlying device data interface through industrial Internet protocols (such as OPC UA), realizing real-time linkage between the 3D model and PLC and DCS systems. For example, clicking on the steam turbine model in the 3D scene can directly view real-time operation parameters such as vibration and temperature. When abnormalities occur, the model automatically highlights and alarms, improving operation efficiency by 30% compared with the traditional SCADA system [3].

3.2. Localized optimization of AI visual analysis technology

Aiming at problems such as camera lens fogging and image blur caused by the high temperature and humidity environment in Cambodia, adopt an adaptive image enhancement algorithm combined with dynamic background modeling technology to improve the target recognition accuracy in complex scenes. The measured data shows that the recognition accuracy of personnel's illegal behaviors still remains above 95% under conditions such as light changes and dust interference [5].

3.3. Multi-system heterogeneous data integration technology

Overseas power plants often face the problem of incompatible protocols of equipment from different manufacturers. The project uses edge computing gateways to realize protocol conversion of Modbus, MQTT, ONVIF, etc., establishes a unified data middle platform, accesses 15 types of equipment and 876 data points in total, with a data delay of no more than 200ms, providing underlying support for global perception.

4. Practical effects and experience summary

4.1. Significantly improved safety management efficiency

Reduced labor costs: AI patrol replaces 60% of manual inspection, saving about 2 million RMB in labor costs annually; mobile approval reduces paper process circulation, and the operation permission processing time is shortened from 4 hours to 1 hour [2].

Enhanced risk prevention and control capability: After the electronic fence and intelligent alarm system are put into use, there are zero illegal intrusion incidents; the equipment's hidden danger discovery time is shortened from daily inspection to real-time monitoring, and the defect processing timeliness is increased to 99% [4].

Faster emergency response speed: The safety management command center integrates a large-screen visualization system, which can retrieve accident site videos, personnel distribution, and hazard source data within 30 seconds, shortening the emergency disposal process time by 50%.

4.2. Innovation of the localized management model

Compliance guarantee: Embed Cambodian labor safety regulations into the system process, such as mandating foreign employees to wear safety helmets and setting up Thai/English bilingual alarm interfaces to ensure compliance with local regulatory requirements.

Promotion of cultural integration: Through multi-language versions (Chinese/English/Cambodian) of the risk knowledge base and visual safety training modules, improve the safety awareness of local employees, and reduce the incidence of illegal behaviors by 65%.

4.3. Replicable technical paradigm

The core value of the Huadian Xigang model lies in the dual-drive of "technical integration plus management innovation."

Technical level: Form a standardized technical path of "3D modeling — Data Integration — AI Analysis — Closed-Loop Management", applicable to scenarios such as overseas power plants and chemical parks.

Management level: Construct an active prevention and control system of "Perception — Analysis — Decision-making — Execution", breaking through the traditional "post-event disposal" model and providing a methodological reference for safety management of overseas enterprises.

5. Conclusion

The practice of the intelligent safety prevention and control system for overseas power plants of Huadian Xigang Power Generation Co., Ltd. shows that through the deep integration of global perception technology and digital management means, the safety management problems of overseas energy projects can be effectively solved. The system not only improves the enterprise's own safety performance but also explores a path of "technical localization, management standardization, and intelligent response" for overseas safety governance, providing a reproducible Chinese solution for energy enterprises along the Belt and Road [1].

In the future, the following directions can be further explored: (1) Introduce 5G plus edge computing technology to improve real-time data processing capabilities; (2) Integrate blockchain technology to realize tamper-proof storage of safety data; (3) Develop VR emergency drill modules to enhance the collaborative disposal capabilities of Chinese and foreign employees. With the iteration of new technologies, the intelligent safety prevention and control system will upgrade towards "autonomy, self-adaptation, and self-optimization", providing a more solid guarantee for the long-term safety of overseas energy infrastructure [3–5].

Disclosure statement

The authors declare no conflict of interest.

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