Available Online: 4 December 2025 DOI: 10.54254/2977-3903/2025.30286

Design and application of electromechanical and automation systems for the Xuliujing Riverside Hub Project

Weimin Wu[1*], Bihan Tao[2], Qingsong Wang[3]

[1]Changshu Municipal Government Service Center, Suzhou, China
[2]Changshu Water Conservancy Project Construction Management Center, Suzhou, China
[3]Changshu Water Services Center, Suzhou, China

*Corresponding Author. Email: 12363499@qq.com

Abstract. The operational safety and scheduling flexibility of water conservancy projects are now subject to increasingly stringent requirements. As the core support of modern hydraulic hubs, electromechanical and automation systems directly influence the reliability, cost-effectiveness, and intelligence level of such projects. Taking the Xuliujing Riverside Hub Project as a case study, this paper systematically presents how electromechanical and automation design can address complex hydraulic demands while integrating advanced technologies to enhance project performance. The insights provided can serve as a reference for similar low-head, bidirectional pumping stations and contribute to the advancement of water conservancy projects toward intelligent and sustainable development.

Keywords: water conservancy projects, electromechanical systems, automation

1. Introduction

1.1. Research background

The Xuliujing Riverside Hub Project is located at the Tongjiang estuary of the Xuliujing River and serves as a flood control and drainage gate structure along the Changshu section of the river. The project comprises a 10 m-wide sluice gate, as well as a bidirectional pumping station for both water intake and drainage, with a designed discharge capacity of 30 m^3/s. The performance of the water pump units is determined based on the required water intake capacity. The primary objectives of the project are flood control and drainage, while additional benefits include water supply and navigation facilitation.

With the intensification of global climate change and the increasing frequency of extreme weather events, water conservancy projects face heightened demands for operational safety and scheduling flexibility. As the core support of modern hydraulic hubs, electromechanical and automation systems directly influence the reliability, economic efficiency, and intelligence of such projects. Electromechanical equipment is key for converting hydraulic energy and controlling flow in water conservancy projects. Its performance directly affects project efficiency: pump selection determines the head–flow characteristics for drainage and water supply, while the stability of the electrical system is crucial for power supply security and energy consumption management. Traditional water conservancy projects rely heavily on manual operation, which is slow in response and costly to manage. The introduction of automation technologies enables real-time monitoring, intelligent control (such as unit coordination and automatic gate adjustment), and remote management, thereby reducing on-site staffing requirements and enhancing emergency response capabilities. Conventional systems, however, have technical limitations. Early control modes depended on manual scheduling and single-machine Supervisory Control and Data Acquisition (SCADA) systems, presenting three major drawbacks: Data silos—hydraulic, mechanical, and electrical parameters were collected independently, preventing holistic optimization of decision-making [1]; Passive maintenance—periodic inspections led to unplanned downtime exceeding 120 hours per year [2]; Rigid energy consumption—standard frequency motors wasted more than 25% of electrical energy under off-design operating conditions [3].

As a bidirectional pump sluice with both drainage and water supply functions, the Xuliujing Riverside Hub Project requires its electromechanical and automation systems to accommodate diverse operating conditions and ensure stable performance under complex scenarios, including Yangtze River tide fluctuations and inland water level variations.

In recent years, domestic and international research on water conservancy electromechanical and automation systems has focused on several key areas: High-efficiency hydraulic machinery, to improve overall efficiency and reduce hydraulic losses; Intelligent control systems, for real-time monitoring of equipment status; Artificial intelligence-based predictive maintenance; Green and energy-saving technologies, integrating renewable energy to reduce carbon emissions; Digital twin and remote operation, constructing digital twin models of hydraulic projects to optimize operational strategies through virtual simulation; 5G communication technologies, supporting remote monitoring and enabling "unmanned" operation modes. Despite significant technological advancements, challenges remain in adapting electromechanical and automation systems to complex operating conditions, ensuring equipment reliability, achieving system integration, and addressing data security and network risks.

This paper takes the Xuliujing Riverside Hub Project as a case study to systematically illustrate how electromechanical and automation design can meet complex hydraulic requirements while integrating cutting-edge technologies to enhance project performance. The experiences shared here can serve as a reference for similar low-head bidirectional pumping stations and promote the intelligent and sustainable development of water conservancy projects.

1.2. Project overview

1.2.1. Regional overview

Changshu City is located in the northern part of Suzhou, bordering Taicang to the east, Kunshan and Xiangcheng to the south, Wuxi and Jiangyin to the west, Zhangjiagang to the northwest, and facing Nantong across the Yangtze River to the north. The Xuliujing Riverside Hub is situated at the Tongjiang estuary of the Xuliujing River in northern Changshu.

The territory of Changshu lies within the alluvial plain of the Yangtze River Delta, with the topography sloping from northwest to southeast. The city features a dense water network, with the Wangyu River serving as a boundary: the area west of Yu belongs to the Chengxi-Yu water system, while the area east of the Wangyu River belongs to the Yangcheng water system. The water network mainly consists of three ring rivers and thirteen radial trunk channels extending outward from the city, forming a "three rings, thirteen radials, and seventeen cross channels" structure. This network supports water intake, drainage, regulation, storage, and navigation. Xuliujing is one of the thirteen main trunk rivers in the Yangcheng area, running south from Sujiajian to the Yangtze estuary, with a total length of 6.6 km. It functions as a regulating channel for both drainage and water intake, located approximately 800 m from the estuary. A control sluice, the Xuliujing Tongjiang Gate, was previously built here, serving multiple functions including tidal blocking, water diversion, drainage, and navigation, with a net gate width of 8 m.

Changshu belongs to the alluvial plain of the lower Yangtze River, with relatively uniform topography. The city lies in a subtropical monsoon climate zone, with an average annual temperature of 16.1 °C, an average wind speed of 3.4 m/s, and an average annual precipitation of 1,056.55 mm. Precipitation is highest in summer (June–August), accounting for approximately 35–40% of annual rainfall. Early summer is dominated by plum rain, while late summer and early autumn experience tropical cyclone storms. Regional flooding is primarily caused by plum rain and typhoon-induced heavy rainfall. During non-flood seasons, prolonged droughts are common, often resulting in drought disasters.

Over the years, the Changshu municipal government has persistently implemented water management measures, gradually establishing a relatively complete system for flood and tide control, drainage, irrigation, and water supply. These achievements have provided a solid foundation for the city's rapid socio-economic development. However, with continued economic growth, Changshu still faces dual pressures from water environment management and flood/drainage control. In recent years, during periods when the Wangyu River discharges Taihu Lake floodwaters or when the eastern diversion gates of the "Yangtze-to-Taihu Water Transfer" project are closed, rivers along the bank often become stagnation zones. Additionally, due to the influence of tidal drainage and uneven rainfall distribution, most rivers in the city have no fixed flow direction, meandering with complex movement patterns. After implementation, the project significantly enhances regional floodwater discharge capacity. During peak discharge periods, the northern Yangcheng area's outflow to the Yangtze River increases, while water levels at various control sections are reduced to varying degrees. As a key gate project in the Yangcheng area, the Xuliujing Riverside Hub can effectively alleviate drainage pressure on the Baimaotang and Changhu Rivers within the Taihu Lake basin's Yangcheng area, support emergency drainage operations, and improve regional emergency response capabilities.

1.2.2. Project components

This project involves the demolition and reconstruction of the original Xuliujing Sluice. The sluice station consists of a pumping station and a control gate. The pumping station operates bidirectionally, primarily for drainage and secondarily for water intake. Based on the water levels in the internal and external rivers, either the control gate or the pumps are activated according to drainage or water intake requirements. When floodwaters cannot be discharged naturally due to high Yangtze River levels, the riverside pumping station can be used to draw off water, reducing regional water levels, ensuring flood and drainage safety, and enhancing emergency response capability.

The pumping station is designed for a discharge flow of 30 m³/s and is equipped with three vertical axial-flow pump units, each with a power of 560 kW, giving a total installed capacity of 3 × 560 = 1,680 kW. The station is classified as medium-sized. The control gate consists of one sluice opening, operated using a winch-type hoist. As a county-level medium-sized pump station, the pumping station's electricity load class is Level 3. According to design standards, when technical and economic conditions are similar, the rated voltage of motors should preferentially be 10 kV. Since each motor in this project has a rated power of 560 kW, 10 kV motors are selected.

The pump units use vertical axial-flow pumps directly coupled to motors, with a rotation speed of 187.5 r/min. Due to the low speed and high power, selecting asynchronous motors would require large-capacity reactive power compensation devices, result in inefficient motor structures, increase rated currents, lower efficiency, and reduce economic performance. Therefore, vertical synchronous motors are chosen to match the pumps.

In addition, to achieve the operational goal of "unmanned or minimally manned" operation, a computer-based monitoring system has been installed. The pumping station's monitoring data is also uploaded to the higher-level dispatch center for centralized control.

2. Electromechanical system design

2.1. Hydraulic machinery system

2.1.1. Pump type selection and performance analysis

The Xuliujing Pumping Station operates under a low head and functions as a bidirectional pump station. It accommodates two main operating conditions: drainage and water intake, with differing design heads for each condition. Pump selection must therefore consider the overall performance under both operating modes. Due to the head difference, the design flow rates for drainage and water intake vary; the pumps must safely and stably operate across the full range of design heads while meeting the required design flows under both conditions.

Advanced design experiences from existing bidirectional pump stations were adopted as references for this project. The pump type selection considered technological maturity, installation convenience, structural simplicity and reliability, minimal maintenance workload, and overall economic efficiency. Additionally, pumps must exhibit strong anti-cavitation performance, and both cavitation and energy efficiency were comprehensively evaluated during selection. The installation elevation of the pumps was reasonably determined, and the pump room layout was designed to be simple, with straightforward flow passage construction, ensuring economical project investment [4].

Currently, low-head bidirectional pump stations typically employ either X-type double-channel vertical axial-flow pumps or S-shaped blade bidirectional horizontal pumps. In existing operational pump stations, the maximum single-pump flow for vertical axial-flow pumps reaches 40 m³/s, while bidirectional vertical-shaft mixed-flow pumps achieve 20 m³/s per unit. For this project, the drainage design flow is 30 m³/s, and the water intake capacity is determined according to pump unit selection parameters, with a net operating head of 0–3.58 m. Both X-type double-channel vertical axial-flow pumps and vertical-shaft mixed-flow pumps are suitable. At this stage, a comparative selection between vertical axial-flow pump units and vertical-shaft mixed-flow pump units was conducted.

(1) Hydraulic Performance: The vertical axial-flow pump with X-channel configuration paired with a unidirectional impeller achieves higher efficiency, whereas the bidirectional vertical-shaft mixed-flow pump with a bidirectional impeller exhibits relatively lower reverse-flow efficiency. Both pump types achieve similar design-point efficiency under drainage conditions. Under water intake conditions, the vertical axial-flow pump shows significantly higher efficiency than the vertical-shaft mixed-flow pump. Overall, across the operating range, the energy performance of the vertical axial-flow pump is superior. Regarding cavitation performance, the axial-flow pump impeller outperforms the vertical-shaft mixed-flow pump.

Given the low net operating head of the Xuliujing Pumping Station, the hydraulic model was selected based on the station's water level combinations, head, and flow requirements, referencing models tested for the South-to-North Water Diversion Project in Tianjin. After comparison, the TJ04-ZL-07 hydraulic model was determined suitable for this project. The Xingou River Riverside Hub Pumping Station employs X-type double-channel vertical axial-flow pumps with the TJ04-ZL-07 hydraulic model for unit model tests. For this station, selection calculations are based on the model test results of the Xingou River unit, and the combined characteristic curve of the pump type is shown in Figure 1. For a configuration with three pumps, calculations indicate an impeller diameter of 1,910 mm, pump speed of 187.5 r/min, and blade angle of –2°. The design points for drainage and water intake are indicated on the scaled prototype characteristic curve in Figure 2. The maximum head does not enter the unstable "saddle-shaped" region.

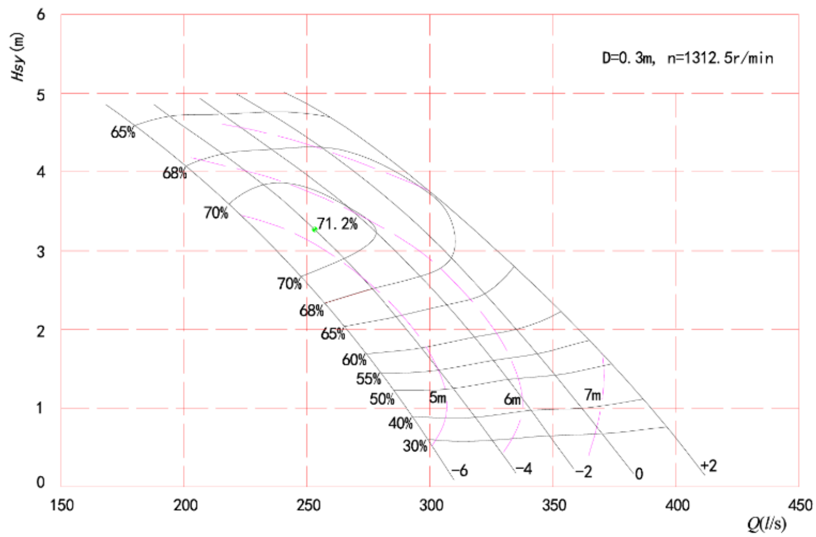

Figure 1. TJ04-ZL-07 model pump combined characteristic curve for Xingou River Riverside Hub

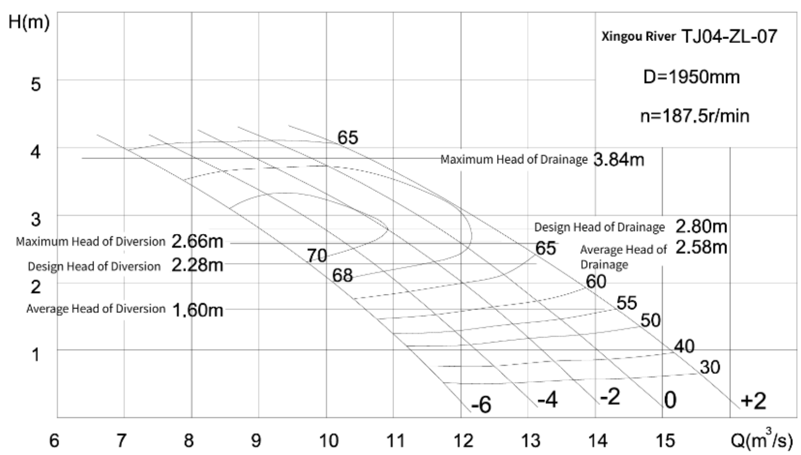

Figure 2. Characteristic operating points of 3 vertical axial-flow pumps

(2) Economic Considerations: The vertical-shaft mixed-flow pump requires a gear reducer and a more complex blade adjustment mechanism compared to the vertical axial-flow pump. Its accompanying motor has slightly higher power, resulting in a higher cost. The pump shaft power is also larger, leading to higher electricity consumption during operation. Regarding civil works, the axial-flow pump requires a wider and deeper flow channel but a shorter base slab, whereas the vertical-shaft mixed-flow pump has a narrower, shallower channel with a longer base slab, resulting in slightly higher construction costs for the latter.

(3) Operation and Maintenance: In the vertical-shaft mixed-flow pump scheme, the flow differences between drainage and water intake conditions under the same blade angle are relatively large. The vertical-shaft space is limited, and installing the blade adjustment mechanism is complex, making operation and maintenance inconvenient.

(4) Additional Functions: The vertical axial-flow pump can utilize the lower channel of the X-type configuration to enhance self-intake and self-discharge capabilities of the hub.

X-type double-channel vertical axial-flow pumps have been successfully applied in Jiangsu Province at the Taizhou Diversion River Hub Pumping Station, Changshu Wangyu River Hub Pumping Station, Zhangjiagang Chaodongwei Port Hub Pumping Station, and Changshu Haiyangjing Hub Pumping Station, demonstrating good performance and extensive construction experience. Although these stations are located in different urban areas, the outer Yangtze River water levels are similar, and inner river water levels are only slightly different, providing a reliable reference for pump selection in this project. The Xuliujing Pumping Station is a medium-sized station. Considering location, function, type, and operational management, it is advisable to unify the pump types across these riverside stations as much as possible. Based on the above analysis, the X-type double-channel vertical axial-flow pump scheme was selected.

2.1.2. Unit configuration

Generally, a higher number of main pumps provides greater operational flexibility but requires higher investment, while fewer pumps reduce flexibility but lower costs. Considering the operational characteristics and layout feasibility of the pumping station, and constrained by the river channel width, two schemes were considered: a two-pump scheme and a three-pump scheme. The comprehensive performance curve of the two-pump scheme is shown in the figure below. A comprehensive comparison shows that both schemes are technically feasible, with only minor differences in total cost. In terms of operation and maintenance, individual pump maintenance is similar for both schemes. The three-pump scheme achieves a more rational overall coordination with the gate chamber, while the two-pump scheme, due to larger unit size and deeper excavation, is prone to sediment accumulation. With more units, operational scheduling is more flexible; in the two-pump scheme, a failure of one pump or unit inspection has a significant impact on scheduling and operation. Therefore, the three-pump scheme was selected, with a single-pump flow of 10 m^3/s. In drainage operation, there is no standby; in water diversion operation, a 2-in-use-1-standby arrangement is adopted.

2.1.3. Blade adjustment method

The pumping station experiences significant variation in head, with large differences between forward and reverse design heads, but with similar flow requirements. Fixed-blade pumps cannot meet this requirement, so a fully adjustable blade method is proposed. By adjusting the blade angles, pump operating conditions can be optimized, improving device efficiency. Combined with the online vibration and water pressure pulsation monitoring systems, blade angles can be adjusted according to unit stability data to regulate flow under low-head conditions, enhancing operational stability.

Currently, full-adjustment methods include mechanical full-adjustment, hydraulic full-adjustment, and built-in synchronous hydraulic adjustment, all of which have been successfully applied. The hydraulic full-adjustment system provides high regulating force, minimal mechanical wear, high reliability, convenient operation, and precise dynamic control; however, it has a complex structure, requires high technical and machining precision, and needs an external pressure oil system. Mechanical full-adjustment systems are simple, easy to operate, and convenient for installation and maintenance, with minimal auxiliary equipment, but they offer a limited adjustment range and may experience shaft-lifting issues at large negative angles under low-head conditions. The built-in synchronous hydraulic adjustment system integrates the hydraulic system internally, eliminating the need for external oil supply, resembles a mechanical regulator in appearance, but has a much lower height, simpler structure, and lighter weight. Therefore, the pumping station adopts a built-in synchronous hydraulic adjustment system for full blade regulation.

2.1.4. Online unit condition monitoring system

The Xu Liu Jing riverside pumping station is equipped with an online unit vibration monitoring system. Similar systems have been installed in the Qingduntang, Changhu River, and Baimaotang pumping stations in Changshu. The online unit vibration monitoring system applies electronic and computer technology to equipment management, enabling stability assessment and fault analysis. This monitoring system uses mechanical fault diagnosis technology as its core, supported by IoT technology. It continuously records equipment operation data over long periods, which is processed by the host computer into relevant data, graphs, and curves. This allows operators to fully understand, monitor, and control unit operation, identify faults, and take appropriate measures, thereby improving overall operational management.

2.2. Pump unit starting method

According to GB 50265-2010 "Design Code for Pumping Stations," the starting of electric motors should be calculated based on the minimum power supply configuration and the most adverse combination of units. When all synchronous motors are connected to the same bus, the starting calculation is performed assuming the largest unit starts first. The results indicate that full-voltage starting requirements are satisfied. Since the main motors are directly connected to a 10 kV bus, the starting current imposes a significant impact on the power grid. Referring to assessment requirements for bus voltage drops during motor starting in similar pumping stations, a high-voltage soft starter is adopted. This allows the motor to accelerate smoothly and continuously, controlling the current ramp during startup. The starting current is limited to within 3.5 times the rated current, reducing the impact on the power grid and extending the motor's operational lifespan.

2.3. Metal structural equipment

2.3.1. Lift-roll steel gate design for control sluice

The control sluice is an open-type structure with a single opening, having a net width of 10 m and a sill elevation of –1.0 m. Its main functions are flood prevention and drainage. This project uses a lift-roll (rising-lying) steel gate supported by cantilever wheels, capable of bi-directional water blocking and dynamic water operation. The gate structure is simple and lightweight. During opening, the cantilever wheels travel along an arc-shaped track, and when fully opened, the gate rests horizontally above the opening. This design effectively lowers the hoist platform elevation, reduces civil works volume, and minimizes impact on the surrounding landscape. Lift-roll gates are widely applied on sluices in China's plains regions and are considered a mature gate type.

2.3.2. Anti-Corrosion design

Underwater metal structures, such as gates and trash racks, are prone to corrosion, resulting in high maintenance costs. For this project, corrosion protection measures are implemented as follows: Embedded parts and exposed surfaces: Stainless steel is used for exposed embedded components. Exposed gate surfaces are protected by hot-dip galvanized zinc spraying followed by a sealing coating. Surface preparation: Steel surfaces are cleaned by sand or shot blasting to a cleanliness level of Sa2½, with surface roughness Rz of 60–100 μm. Coating system: Hot-dip zinc layer thickness is 140 μm. The sealing coating comprises an 80 μm epoxy zinc-rich primer, an 80 μm epoxy micaceous iron intermediate coat, and an 80 μm epoxy topcoat, with a total dry film thickness of 240 μm. Rotating components: Shafts of rollers and hoists are protected by electroplated hard chromium, first with 0.05 mm of nickel-chrome, followed by 0.05 mm hard chromium, then ground to design dimensions. Sealing installation: Stainless steel bolts and nuts are used. Hoist wire ropes: Galvanized steel wire ropes are employed. Hoists are coated with protective paint for corrosion prevention.

3. Automation system design

3.1. Computer monitoring system architecture

3.1.1. Network communication system

Based on the actual conditions of the pumping station and in accordance with the principle of fully utilizing public networks, the station's computer network connects to the higher-level dispatch center via leased public ADSL lines. Communication between the monitoring layer at the station and the local on-site monitoring layer is implemented through a fiber-optic ring network, with a transmission rate of 1,000 Mbps. The medium used is multimode fiber, and the network protocol follows the international industrial standard TCP/IP. The on-site monitoring layer communicates with microcomputer-based protection and control devices, intelligent instruments, and auxiliary system PLCs via fieldbus.

3.1.2. Hierarchical control of the monitoring system

The computer monitoring system adopts a distributed architecture. According to operational authority, three hierarchical levels are established: remote monitoring, station-level control, and on-site control. The control priority follows the order: on-site → station-level → remote. The station-level control layer, located in the central control room, centrally monitors and controls the station's main operating equipment, including pumping units and their auxiliary devices, gates, auxiliary machinery, and power distribution equipment. On-site monitoring and control are achieved through local control cabinets (or boxes) and protection and control units installed at each piece of equipment. When authorized, the remote control layer can receive dispatch instructions from higher-level management authorities, enabling remote monitoring.

The main monitoring targets include main pumps, main motors, transformers, high- and low-voltage incoming lines and distribution devices, DC systems, UPS units, reactive power compensation devices, technical water supply systems, seepage drainage systems, and gates. Key monitored parameters include electrical parameters, water levels, pressure, temperature, gate opening, and operational status. At the on-site control level, seven PLC-based Local Control Units (LCUs) are installed on-site, each equipped with a 10.4-inch color touchscreen serving as the human-machine interface.

The monitoring host system periodically collects and verifies operational data, recording and saving inspection results. Operators in the central control room use the human-machine interface to monitor the station's production processes and operational status, including equipment parameters, conditions, and trends. Changes in parameters or equipment status can be analyzed and addressed promptly. Pumping station operators can control monitored targets in real time via the operator workstation. The system records all operations, alarm times, and real-time parameter reports for every monitored device, automatically generating daily and monthly reports. In the event of fault indications or accidents, the monitoring system provides guidance for incident handling and recovery operations. Self-diagnosis and self-recovery functions are crucial for achieving "unmanned" or minimally manned operations. The system comprises multiple interconnected devices, each performing internal self-checks and mutual inspections, generating diagnostic reports. Abnormal conditions trigger timely alarms to notify operational or on-duty personnel for prompt action. Certain anomalies can be automatically isolated or resolved by the system to ensure continuous operation [5].

The on-site units include unit monitoring screens, common monitoring screens, auxiliary equipment monitoring screens, and gate monitoring screens. Each LCU, when connected to the system, functions as an integrated component executing system-designated operations. When operating independently, the LCU can continue on-site monitoring autonomously.

3.2. Data management and analysis

To improve the operational efficiency and management level of the pumping station and fully realize its integrated benefits, a Pumping Station Control Center has been established as part of the water resources informatization initiative. The control center network provides fundamental data communication and information-sharing functions and is capable of distributed processing of comprehensive tasks.

The on-site monitoring layer uploads collected field data to the pumping station's monitoring network database server. Through leased public ADSL lines, the computer network transmits monitoring data and video information to the higher-level pumping station management platform in real time, enabling dispatchers to quickly and intuitively understand the station's operational status. The monitoring system uploads collected data to the control center server, where it is classified and stored according to the water resources information database schema to provide data services for application systems. Simultaneously, the monitoring data is transmitted to the higher-level dispatch platform to achieve data sharing. Large-scale comprehensive tasks can also be submitted to multiple computers for parallel processing. Users can allocate network resources efficiently and conduct local, rapid data processing as needed. Additionally, the system incorporates network security measures.

3.3. Monitoring and control system

The monitoring design primarily focuses on the pump house, sluice chamber, inlet and outlet pools, stilling basin, and wing walls, with appropriate instrument placement. To meet modern management requirements, an automated monitoring system has been established, enabling fully automated network management and remote control of the entire project. This allows timely safety assessment, real-time online monitoring of structures, and substantial reduction of manual observation, resulting in significant labor cost savings [6].

Monitoring items are selected based on current codes and standards, combined with the project's specific requirements. The main monitoring items include: (1) Deformation Monitoring: Horizontal and vertical displacements of the pump house, sluice chamber, inlet/outlet pools, and wing walls. (2) Seepage Monitoring: Uplift pressure and seepage pressure at the base of the pump house and sluice chamber. (3) Stress-Strain Monitoring: Stress and strain monitoring of the pump house and sluice chamber base slabs.

The project mainly implements automated monitoring for the pump chamber, inlet/outlet sluices, and associated connecting sections, with the control center located within the management station. The automated monitoring system consists of two components: hardware and software for data analysis and management. The system can perform patrol inspections, selective measurements, and continuous measurement of critical points for connected automation devices; calculate the required physical quantities from collected data; store essential data and establish a database; and output necessary charts and reports (display, print, or plot). Additionally, the system can perform real-time analysis and evaluation of measured results using monitoring indicators, quickly assess dam operation status, provide forecasts for each measurement, and issue alerts when values exceed allowable thresholds.

3.4. Video surveillance and security system

3.4.1. High-definition video and centralized display control

To improve monitoring conditions and ensure normal operation, the station is equipped with an industrial video surveillance system, divided into on-site imaging and centralized display/control.

The system comprises four components: front-end devices, transmission devices, control devices, and display/recording devices. The front-end devices consist of high-resolution integrated color cameras installed in and around the pumping station, responsible for image and data acquisition and signal processing. Transmission devices are selected based on distance and image quality requirements, delivering video and data signals to the central control room. Centralized control devices, including reliable Digital Video Recorders (DVRs), manage front-end device operations, image switching, pan-tilt-zoom control, zoned and grouped control, image retrieval and processing, and compress and transmit video and data signals via IP to required locations. Display and recording devices can be selected according to different image presentation needs.

Within the central control room, a video workstation and large-screen display system provide clear images of pumps, gates, and inner/outer river channels. To enable recording and playback of critical events and images, video network switches and disk recorders are installed, with a video security cabinet set up in the secondary equipment room.

3.4.2. Fire alarm system

This pumping station is of medium scale. According to GB 50987-2014 "Fire Protection Code for Water Conservancy Projects," an automatic fire alarm system is installed, configured as a centralized alarm system. A fire alarm control panel is located in the central control room, with smoke detectors, temperature detectors, and manual alarm buttons arranged for different areas. The control panel receives alarms from each detector, triggers audible and visual alarms, and notifies on-duty personnel to respond promptly.

4. Conclusion

The design and innovations implemented in the electromechanical system of this project have significantly enhanced system performance, and its experience can serve as a reference for other designs. For example, traditional blade-adjusting mechanisms often suffer from structural complexity and difficult maintenance. By integrating a built-in synchronous hydraulic regulator with an intelligent control module, this project enables fully automated blade angle adjustment, reducing mechanical wear, decreasing maintenance frequency, and extending equipment lifespan. In terms of water supply, open systems are prone to blockage from debris in river channels, while fully closed systems face challenges with replenishment and air entrapment. This pumping station adopts a non-closed circulating water supply system, combined with chillers and variable-frequency supply pumps, to achieve circulating cooling water reuse, saving 30% of water, reducing operational energy consumption by 15%, and lowering maintenance costs by 20%. Regarding the high starting current of synchronous motors (up to 5–7 times the rated current), a thyristor-based high-voltage soft starter is employed to achieve current ramp control, limiting the starting current to within 3.5 times the rated current, thereby reducing impacts on the power grid. In combination with variable-frequency technology, the pump speed can be adjusted under low-head conditions to reduce ineffective energy consumption. Furthermore, the online vibration monitoring system for the units achieves a fault diagnosis accuracy of 90% and reduces unplanned equipment downtime by 40%.

The pumping station's bidirectional operation also achieves notable efficiency improvements. For the drainage condition, at the design head of 2.40 m, the flow per pump reaches 10.06 m^3/s with a 70% device efficiency, and it remains stable at the maximum head of 3.58 m. For the water diversion condition, at the design head of 1.88 m, the single-pump flow is 10.82 m^3/s, with a device efficiency of 68.2%, representing a 15% improvement over traditional pumping stations. In addition, the design provides energy-saving and cost-optimization benefits. The 30 m^3/s design drainage flow can withstand a 10-year return period flood, protecting downstream farmland and residents. The annual water diversion of 120 million m^3 effectively improves the water quality of inland rivers, promotes regional ecological balance, and significantly enhances both social and ecological benefits.

References

[1] deWardener, Z. A. (2023). *Defining the digital twin for Industry 4.0* [Master's thesis, University of Rhode Island]. URI DigitalCommons. https://digitalcommons.uri.edu/theses/2438

[2] Toirov, O., & Khalikov, S. (2023). Analysis of the Safety of Pumping Units of Pumping Stations of Machine Water Lifting in the Function of Reliability Indicators. *E3S Web of Conferences, 365*, 04010. https: //doi.org/10.1051/e3sconf/202336504010.

[3] Iacob, M., Bejan, C., & Andreescu, G. (2009). Supervisory Control and Data Acquisition Laboratory. *Telfor Journal, 2*(1), 49–54.

[4] Yang, J. (2025). Discussion on Methods to Improve the Operation and Maintenance Management Level of Electromechanical Equipment in Hydraulic Engineering. *Engineering Construction and Design*, (4), 251–253. https: //doi.org/10.13616/j.cnki.gcjsysj.2025.02.283.

[5] Zhao, W. (2020). Installation Problems and Maintenance Measures of Electromechanical Equipment in Hydraulic Engineering. *Equipment Management and Maintenance*, (20), 56–58. https: //doi.org/10.16621/j.cnki.issn1001-0599.2020.10D.32.

[6] Liu, P., & Wang, L. (2024). Application and Development of Energy-saving Technologies in Hydraulic Electromechanical Equipment. In *Proceedings of the 2024 Forum on Smart Building and Economic Development from the Perspective of New Quality Productivity* (Vol. 4, pp. 181–182). Jiangsu Water Conservancy Construction Engineering Co., Ltd.