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A Study on Improving the Rapid Assembly of Prefabricated Container-Type Substations in Cold, High-Altitude Regions

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Abstract: With the development of China's power industry, the government has been vigorously promoting the sector since the start of the 15th Five-Year Plan. There has been a significant increase in demand for prefabricated modular substations, which can shorten the construction and installation cycle of substation projects. The Nyingchi Construction Power Supply Package I project is located in Milin City at an altitude of 3,027 meters. Due to its high-altitude setting, the project faces harsh conditions such as extremely cold weather, underdeveloped infrastructure, and difficult transportation, which have posed numerous challenges to the construction of the substation. This paper primarily explores the rapid construction of prefabricated container-type substations in high-altitude areas of Tibet. Focusing on prefabricated container-type modular construction, the study analyzes the advantages of this approach in high-altitude regions, reduces on-site fabrication work, and facilitates modular manufacturing and installation. This method is environmentally friendly in the Tibetan region, minimizes the need for post-construction environmental and water restoration, and thus provides a reference for subsequent prefabricated container installation and application projects.

Keywords: High altitude; Cold climate; Prefabricated modules; Substation engineering; Substation.

1. Introduction

In line with the planning and development of China's energy strategy and the evolving needs of the power industry, coupled with the advancement of infrastructure construction in countries along the Belt and Road, the demand for building power grids in high-altitude regions continues to grow. Traditional substations are typically constructed on-site using brick-and-concrete masonry. In high-altitude and extremely cold regions, this method is generally associated with common challenges such as lengthy construction cycles, high labor intensity, low construction efficiency, difficulties in transporting materials and equipment, and difficulties in ensuring the quality of concrete curing. Prefabricated modular substations, with their advantages of factory prefabrication, modular installation, and rapid on-site assembly, have emerged as an effective solution to these challenges.

However, the adverse environmental conditions in high-altitude regions—including extreme temperature fluctuations, low atmospheric pressure, insufficient oxygen supply, and intense radiation—pose significant challenges to the installation of prefabricated modular substations. If installation quality is subpar, the unique conditions of high-altitude and extremely cold regions will directly shorten the service life of prefabricated container-type substations and pose a direct threat to the safety of the container's rigid connections. This can further lead to issues such as compromised container seals, equipment moisture ingress, and poor contact in primary and secondary circuits [1].

To address these issues, this paper systematically analyzes the mechanisms affecting the installation process of prefabricated container-type substations in high-altitude and extremely cold environments. It proposes a set of installation process improvement measures suitable for regions at altitudes of 3,000–5,000 meters, covering aspects such as deformation-resistant structural design of the container, weather-resistant reinforcement of the sealing system, precision control of on-site hoisting and positioning, anti-oxidation treatment for secondary wiring, and adaptive adjustments for foundation frost heave. Through high-altitude environmental testing and on-site engineering validation conducted during the Linzhi Construction Power Supply Project (Lot I) in Tibet, this study compared and evaluated the differences between the improved installation process and traditional methods in terms of installation efficiency, seal durability, and electrical insulation reliability. The aim is to provide a theoretical basis and technical support for the safe and rapid assembly and construction of prefabricated container-type substations in high-altitude and extremely cold regions.

2. Advantages of Prefabricated Modular Substations

2.1. Reduction in on-site workload

Because the substation employs a prefabricated, container-based modular installation approach, the use of factory prefabrication combined with parallel construction can significantly reduce construction time while simplifying the construction process. Factory prefabrication allows for optimized equipment interfaces, substantially reducing on-site work and shortening the construction schedule.

2.2. Modular Manufacturing

Prefabricated modular substations are manufactured using factory-based, modular production methods. This approach leverages the controlled environment of factory workshops to ensure the quality and reliable installation of electrical equipment, while also enhancing construction quality to meet design specifications.

2.3. Controllable Schedule and Quality

Prior to shipment, the primary and secondary compartments of prefabricated modular substations, along with the equipment inside them, can undergo trial assembly and commissioning both as individual units and as an integrated system. Additionally, they can be tested individually and as a whole based on actual site conditions and design requirements. Once it is confirmed that there are no issues, the units are packaged and loaded onto transport vehicles in accordance with large-item shipping requirements [2]. In accordance with the prefabricated modular substation assembly process, issues are identified and resolved during the factory production phase to ensure the quality of the substation upon delivery, guarantee the stability and reliability of the equipment, and enhance the overall quality of the prefabricated modular substation.

2.4. Environmentally Friendly

The environmental benefits of prefabricated container-type substations in high-altitude and frigid regions are primarily reflected in two aspects: first, the factory-prefabricated model reduces damage to the ecological environment of the Tibet region; second, the use of eco-friendly materials and energy-efficient designs lowers carbon emissions and energy consumption.

Specifically, this is manifested in reduced land use and vegetation damage. Because prefabricated container substations employ modular manufacturing and a fully enclosed container structure, This reduces the land footprint by approximately 34% compared to traditional substation construction. At the same time, they provide supporting infrastructure for future green energy projects, offering robust support for subsequent development in Tibet—such as new energy and power industry initiatives in Nagqu and Shigatse — and facilitating clean energy development in remote areas. By transmitting green electricity to replace traditional fossil fuels, they indirectly achieve economic and ecological benefits [3].

3. Specifications and Parameters of Prefabricated Modular Facilities

3.1. Dimensions of Prefabricated Modules

For the Power Supply Package I project in Nyingchi, Tibet, based on design specifications and on-site conditions, a double-deck container design is planned. To ensure compliance with transportation requirements and facilitate rapid on-site assembly, a comprehensive assessment has led to the decision to use prefabricated containers in the following dimensions: 10,200 × 3,050 × 3,950 mm, 7000 × 2700 × 3850 mm, and 7560 × 3700 × 3700 mm. The 10200 × 3050 × 3950 mm unit is shown in Figure 1 below.

Figure 1. Lifting diagram for a prefabricated module measuring 10,200×3,050×3,950 mm

3.2. Parameter Structure

The structure of prefabricated modules primarily consists of prefabricated floor panels, columns, wall panels, doors and windows, and a roof. Prefabricated modules designed for extremely cold, high-altitude regions must be capable of withstanding severe cold, intense ultraviolet radiation, and wind-blown sand. Therefore, the structural components must be corrosion- and rust-resistant, with a protection rating of IP55, and must remain rust-free for 30 years; The Construction Power Supply Package I project in Nyingchi, Tibet, utilizes weather-resistant metals such as aluminum-magnesium-manganese alloy panels, combined with weather-resistant sealing strips to provide UV protection. Additionally, the prefabricated modules must be insulated to prevent condensation. The wall panels employ a double-layer rock wool composite structure, with EPDM sealing strips and butyl tape used at the joints to create a layered thermal barrier, thereby preventing internal condensation and short circuits caused by temperature differentials. Finally, the prefabricated cabin must be load-bearing and fire-resistant, with a floor load-bearing capacity of approximately 800 kg/m^2; the structural fire resistance rating must be Class II or higher, and the materials must have a Class A fire rating. A site diagram of the prefabricated cabin is shown in Figure 2.

Figure 2. On-site view of the prefabricated modules

4. Analysis of Rapid Assembly Technology Applications

4.1. Key Technologies

The rapid assembly of prefabricated modules in Tibet's high-altitude, frigid regions hinges on a comprehensive systems engineering approach that integrates modular design with harsh environmental conditions. The core of this process lies in the seamless integration of on-site assembly with factory-manufactured modules throughout the entire workflow. The key points are as follows:

(1) Standardized Interfaces and Precise Assembly

Standardized interfaces for prefabricated modules are essential to ensure rapid assembly, thereby enabling construction within the brief construction window available in high-altitude, frigid regions and shortening the overall project timeline.

Transportation and Assembly Design of Prefabricated Modules: To comply with road transport size restrictions in Tibet, the prefabricated modules (dimensions: 10,200×3,050×3,950 mm) are disassembled at the factory and transported separately. Through standardized interfaces and waterproof joint designs between modules, the prefabricated modules can be rapidly assembled upon arrival at the site, reducing installation time by 35%–64% compared to traditional civil engineering construction.

Rapid Assembly Process: Prefabricated modules delivered to the construction site are assembled using a "segmental assembly+overall hoisting" process, which controls installation errors within±2mm. This ensures compliance with high-standard installation requirements. Simultaneously, waterproof sealing of the prefabricated modules is completed immediately after hoisting to prevent moisture intrusion in high-altitude and extremely cold regions.

(2) Factory Prefabrication Enables Detailed Design

The prefabricated modules for substations are manufactured in a factory setting, allowing the majority of work to be completed off-site. This is also key to reducing manual labor at high-altitude construction sites. All switchgear, circuit breakers, and measurement and control systems within the prefabricated modules can have their secondary wiring and installation completed prior to shipment. Over 92% of the assembly work is completed in the factory. Once transported to the site, the modules can be rapidly assembled using standardized interfaces, requiring only primary wiring to be completed on-site [4]. All equipment within the prefabricated modules undergoes functional testing and system integration at the factory, ensuring the quality of all electrical equipment from the source and significantly reducing the failure rate during on-site commissioning [5]. Based on actual field survey feedback, Table 1 below compares the construction schedules for traditional civil engineering methods and prefabricated substation construction.

Table 1. Comparison of Data in

Construction Methods	Civil engineering construction period (days)	Electrical installation duration (days)	Testing and commissioning period (days)
Traditional civil engineering construction	65	45	24
Prefabricated modular substation	65	15	11

A comparison of the data shows that prefabricated modular substations reduce construction time by 43 days compared to traditional civil engineering projects, resulting in a 32% increase in construction efficiency.

4.2. Project Examples

The key to the rapid installation of prefabricated modular substations in high-altitude, cold regions lies in replacing part of the "on-site construction" process with a "factory prefabrication + standard interfaces" approach. The feasibility and benefits of this approach have been validated by the Construction Project Department of the Nyingchi Power Supply Project (Lot I) in Tibet, which has confirmed that the prefabricated modular solution can significantly shorten construction schedules and enhance reliability.

(1) Shortened Construction Cycle: Prefabricated modules allow for 90% or more of the equipment installation and commissioning to be completed in the factory. Once delivered to the construction site, only on-site hoisting and connection work is required (civil engineering work can proceed in parallel with the factory production of the prefabricated modules). At the Nyingchi Power Supply Project I construction site in Tibet, the construction period was reduced by 57%, while equipment reliability increased by 79%. Compared to traditional civil engineering construction, the project duration was shortened by 43 days.

(2) Adaptability to Complex Terrain and Environments: Based on modular design, this approach reduces land disturbance and saves space in complex terrain environments such as forest areas and mountainous regions. Compared to traditional civil engineering construction, it reduces the land area required for material storage by 25%–70% and lowers construction-related expenses.

(3) Precision Assembly Process: The on-site "whole-unit hoisting + segmental assembly" process ensures assembly accuracy within 2 millimeters and guarantees waterproof sealing.

4.3. Application Promotion

Regarding rapid assembly technology for prefabricated substation modules in high-altitude and extremely cold regions, the adoption of these modules in such environments has reached a mature stage, and the technical solutions have been proven viable. However, the following points should be noted during subsequent practical implementation:

(1) Derating of equipment components within the prefabricated modules: In high-altitude areas with thin air, heat dissipation tends to be poor. Core components such as transformers and circuit breakers must be derated for use, and altitude factors must be taken into account during selection and verification.

(2) Improving sealing procedures: Significant fluctuations in temperature and humidity in high-altitude and extremely cold regions can easily lead to condensation. When assembling prefabricated modules on-site, sealing procedures must be strictly followed to prevent potential operational hazards.

(3) Overall Cost: Although the rapid assembly process of prefabricated substation modules significantly reduces construction time and costs, the expenses associated with high-grade thermal insulation, custom insulation, and long-distance transportation may result in a slightly higher cost for the prefabricated modules compared to conventional substations. A comprehensive cost analysis is required.

5. Summary

Based on the rapid assembly process of prefabricated modular substations, we can understand the characteristics and scope of application of prefabricated substation equipment, laying the groundwork and providing feasible solutions for the future prefabrication of entire substations. This has enhanced the practical application of prefabricated

modular substations in the power industry, further improved the construction efficiency of future substations, and shortened the construction cycle. At the same time, this addresses the issue of inconsistent construction quality in the electrical components of substations. The rapid assembly process for prefabricated modular substations enhances efficiency and the level of mechanized construction in subsequent substation projects. It also further improves construction quality, thereby indirectly meeting higher-quality power supply requirements [6].

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