



SPower 240o

Installation & Commissioning Manual

Rongke Power Vanadium Flow Battery System

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1. Safety Precautions

1.1 Statement

Before transporting, storing, installing, operating, using, or maintaining the equipment, please read this manual thoroughly, follow the instructions strictly, and adhere to all safety precautions indicated on the equipment and within this manual. In this manual, "equipment" refers to the products, software, components, spare parts, or services related to this manual; "our company" refers to the manufacturer (producer), seller, or service provider of the equipment; "you" refers to the entity responsible for transporting, storing, installing, operating, using, or maintaining the equipment.

The "Danger", "Warning", "Caution", and "Note" items in the manual do not encompass all safety measures that should be followed. You must also comply with relevant international, national, or regional standards, as well as industry practices. Our company is not responsible for any liabilities arising from the violation of safety operation requirements or the breach of safety standards in the design, production, and use of the equipment.

This equipment should be used in environments that meet the design specifications. Otherwise, equipment malfunctions, abnormal functions, or component damage caused by non-compliance are not covered under the equipment quality guarantee; and our company is not liable for any personal injuries, property losses, etc., that may result.

All operations including transportation, storage, installation, operation, use, and maintenance should comply with applicable laws, regulations, standards, and normative requirements.

It is prohibited to perform reverse engineering, decompilation, disassembly, adaptation, implantation, or other derivative operations on the equipment software. You may not study the internal logic of the equipment, obtain the source code of the equipment software, infringe on intellectual property rights in any way, nor disclose any performance test results of the equipment software.

Our company is not responsible for the following situations or the results they cause:

- Damage to the equipment caused by force majeure such as earthquakes, floods, volcanic eruptions, mudslides, lightning strikes, fires, wars, armed conflicts, typhoons, hurricanes, tornadoes, extreme weather, etc.;
- Operation outside the usage conditions specified in this manual;
- Installation and use environments that do not comply with relevant international, national, or regional standards;
- Installation and use by unqualified personnel;
- Failure to follow the operation instructions and safety warnings in the product and documentation;
- Unauthorized disassembly, alteration of the product, or modification of the software code;
- Damage caused by you or a third party you commissioned for transportation;
- Damage caused by storage conditions that do not meet the product documentation requirements;

Materials and tools you provide that do not meet local laws, regulations, and relevant standards;

Damage caused by your or a third party's negligence, intentional misconduct, gross negligence, improper operation, or reasons not attributable to our company.

1.2 Personal Safety

- **Danger**
 - During installation, it is strictly prohibited to perform operations with live electricity. Do not install or remove cables while they are energized. When cable cores come into contact with conductors, arcs or sparks may occur, which can lead to fires or personal injury.
 - When equipment is energized, improper or incorrect operations may cause fires or electric shocks, resulting in personal injury, death, or property damage.
 - During operations, it is strictly prohibited to wear conductive objects such as watches, bracelets, bangles, rings, or necklaces to avoid electric shock or burns.

➤ During operations, specialized insulated tools must be used to prevent electric shock or short-circuit faults. The insulation voltage rating must comply with local laws, regulations, standards, and requirements.

- **Warning**

➤ During operations, specialized protective equipment must be used, such as protective clothing, insulated shoes, safety goggles, helmets, etc.

1.3 Conventional Requirements

- Do not deactivate the equipment's protective devices or disregard the warnings, cautions, and preventive measures outlined in the manual and on the equipment.
- If a malfunction that could potentially cause personal injury or equipment damage is detected during the operation of the equipment, immediately cease operation, report to the personnel responsible, and implement effective protective measures.
- Do not power the equipment if it has not been fully installed or confirmed by a professional.
- Avoid direct contact, using other conductors to touch, or indirectly contacting powered equipment through damp objects. Measure the voltage at the contact point before touching any conductor surface or terminal to ensure there is no risk of electric shock.
- Strictly prohibit fingers, components, screws, tools, or boards coming into contact with operating fans to prevent injury or equipment damage.

1.4 Personnel Requirements

Personnel authorized to operate the equipment include professionals and trained personnel.

- **Professionals:** Individuals who are familiar with the principles and structure of the equipment, have experience in training or operating the equipment, and can clearly understand the various potential sources and magnitudes of hazards during the installation, operation, and maintenance of the equipment.
- **Trained personnel:** Individuals who have undergone appropriate technical and safety training and possess the necessary experience are aware of the potential dangers that may arise when performing a certain operation, and can take measures to minimize the risk to themselves or others.
 - Personnel responsible for the installation and maintenance of the equipment must first undergo rigorous training, master the correct operating methods, understand various safety precautions, and be familiar with the relevant standards of the country/region.
 - Only qualified professionals or trained personnel are permitted to install, operate, and maintain the equipment.
 - Only qualified professionals are permitted to remove safety facilities and service the equipment.
 - Personnel involved in special scenarios such as electrical operations, working at heights, and operating special equipment must possess the special operation qualifications required by the local country/region.
 - Replacement of equipment or components (including software) must be performed by authorized professionals.
- Except for personnel authorized to operate the equipment, other individuals should not approach the equipment



Personal Protective Equipment (PPE)

1.5 Electrical Safety

- **Danger**
 - Before proceeding with electrical connections, ensure that the equipment is free from damage, as failure to do so may result in electric shock or fire.
 - Irregular or incorrect operations may lead to accidental incidents such as fires or electric shocks.
 - During operation, it is imperative to prevent foreign objects from entering the equipment, as this could cause short circuits, equipment damage, reduction or loss of load power supply, and personal injury.
- **Warning**
 - For equipment that requires grounding, the protective ground wire must be installed first during installation, when removing The equipment, the protective ground wire must be removed last.
- **Caution**
 - Cables are not permitted to pass through the air intake and exhaust vents of the equipment.
 - Due to the electrochemical corrosion effects between copper and aluminum, it is strictly prohibited to use aluminum wires for direct connection.

1.6 General Requirements

- Installation, operation, and maintenance must be carried out in accordance with the step-by-step procedures outlined in the manual. Unauthorized modification, addition, alteration of the equipment, or changes to the installation sequence are strictly prohibited.
- Erect temporary barriers or warning ropes around the work area and display "No Entry" signs. Entry is strictly forbidden for non-authorized personnel.
- Before installing or removing power cables, ensure that the equipment itself and its upstream and downstream switches are turned off.
- If any liquid is found to have entered the equipment, immediately shut off the power and discontinue use.
- Prior to operating the equipment, carefully inspect all tools to ensure they meet the required standards and log them in the register; after operation, account for all tools to prevent them from being left inside the equipment.
- Before installing power cables, confirm that the cable labels are correct and that the cable terminals are properly insulated.
- When installing the equipment, use a torque tool with an appropriate range to tighten the screws.

1.7 Grounding Requirements

- The grounding impedance of the equipment must comply with the local electrical standards.
- The equipment should be permanently connected to protective earth. Before operating the equipment, inspect the electrical connections to ensure that the equipment is reliably grounded.
- The protective earth connection of the equipment and the grounding screw of the metal casing should have a reliable electrical connection.
- It is prohibited to operate the equipment without installing the grounding conductor.
- It is forbidden to damage the grounding conductor.

1.8 Mechanical Safety

- **Danger**

When working at heights, it is mandatory to wear a safety helmet, safety belt, or waist rope, which must be secured to a sturdy structural component. It is strictly prohibited to attach to moving, unstable objects or metal with sharp edges to prevent the hook from slipping and causing a fall accident.
- **Warning**

Ensure that all tools are fully prepared and have passed inspection by a professional organization. The use of tools with defects, those that have failed inspection, or those beyond their inspection validity period is strictly forbidden. Guarantee that all tools are secure and not subjected to overload.

1.9 General Requirements

- Any paint scratches that occur during the transportation or installation of the equipment must be promptly repaired; prolonged exposure of scratched areas is strictly prohibited.
- Arc welding, cutting, or similar operations on the equipment are forbidden without prior evaluation by our company.
- Installation of additional equipment on top of the existing equipment is prohibited without prior evaluation by our company.
- When performing work in the space above the equipment, protective measures should be added on top of the equipment to prevent damage.
- Please use the correct tools and ensure that you are familiar with their proper usage methods.

1.10 Safety at Heights

- Any work conducted at a height of more than 2 meters above the ground is considered **high-altitude work** and must be supervised by a designated safety overseer.
- Personnel must undergo relevant training and obtain the necessary certifications before they are permitted to perform **high-altitude work**.
- **High-altitude work** should be ceased if the steel pipes are wet from rain or if there are other hazardous conditions. Once these conditions have passed, a safety officer and relevant technical personnel must inspect all work equipment to confirm safety before work can resume.
- The high-altitude work site should be demarcated as a danger zone with clear signage, and entry by unauthorized personnel is strictly prohibited.
- Guardrails and signs should be installed at the edges and openings of high-altitude work areas to prevent accidental falls.
- The ground area beneath high-altitude work zones must not have scaffolding, planks, or other debris piled up. Ground personnel are strictly forbidden from staying or passing directly below high-altitude work areas.

1.11 Lifting Safety

- Personnel involved in lifting operations must undergo relevant training and be qualified before they are allowed to work.
- The lifting area must be cordoned off with temporary warning signs or barriers.
- The foundation for lifting operations must meet the load-bearing requirements for crane operations.
- Before lifting, ensure that lifting tools are securely fastened to fixed objects or walls that meet load-bearing standards.
- During lifting, walking under the boom or the lifted load is strictly prohibited.
- During lifting, dragging wire ropes or lifting gear is forbidden, and striking with hard objects is not allowed.

2. Production Introduction

2.1 Introduction

The SPower 240o is an advanced, industrial-scale energy storage solution engineered for:

- Long operational life with minimal degradation.
- High efficiency in energy conversion and storage.
- Modular scalability to meet diverse power demands.

Intended Audience

This manual is designed for qualified engineers with expertise in energy storage systems. It provides critical guidance for:

- ✓ Safe Installation – Proper setup of SPower 240o systems.
- ✓ System Integration – Compatibility with third-party equipment (e.g., inverters, PV panels).
- ✓ Commissioning – Procedures to ensure peak performance



2.2 User Feedback and Revisions

- Users can report issues or suggest improvements through the official website. Each new revision of this manual will integrate feedback to improve clarity and usability.

3. Tools and Materials Required

This section outlines the tools and materials necessary for the proper installation and commissioning of the Rongke Power Vanadium Flow Battery System. This list includes both general tools and specialized equipment needed for electrical and mechanical assembly, as well as Aqueous Vanadium Electrolyte handling.

3.1 General Tools

These tools are required for basic assembly and electrical connections:

- Multimeter: For voltage, current, and resistance measurement.
- Insulation resistance tester: For checking insulation integrity.
- Torque wrench: For applying precise torque to bolts and fittings.
- For securing electrical connectors.
- Screwdrivers (insulated): For connecting and securing electrical components.
- Wrenches and spanners: For tightening bolts and nuts in various sizes.
- Wire stripper: For cable preparation.
- PVC pipe cutter: For cutting conduit pipes for cabling.
- Cable ties: For cable management.



3.2 Specialized Equipment

Specialized tools ensure proper installation and system setup:

- Personal Protective Equipment (PPE): Safety helmet, safety glasses, protective gloves (acid-resistant), overalls, insulated footwear, and ear protection.
- Aqueous Vanadium Aqueous Vanadium Electrolyte handling tools: non-reactive containers, pumps, and acid-resistant materials.
- Aqueous Vanadium Aqueous Vanadium Electrolyte transfer pump: For filling Aqueous Vanadium Electrolyte into storage tanks.
- Battery management system (BMS) communication interface tools: MODBUS and CANBUS interface equipment for system integration and testing.
- Power analyzer: For monitoring system performance during commissioning.

3.3 Materials

Critical materials required for installation:

- Electrical Cables: Properly rated cables for connecting the system to external power components.
- Sealants and Gaskets: Prevent leaks in pipelines and joints.
- Aqueous Vanadium Aqueous Vanadium Electrolyte: Delivered in specialized containers to prevent contamination.
- Grounding Materials: Includes copper rods and connectors compliant with IEC60364-5 standards.

3.4 Site-Specific Tools and Materials

- Site-specific fasteners: Depending on the location, certain fasteners and anchors may be required to secure the battery containers to the mounting surface.
- Sun protection equipment: For installations in outdoor environments, shading structures or protective covers may be needed protection from the elements, and space for future maintenance.

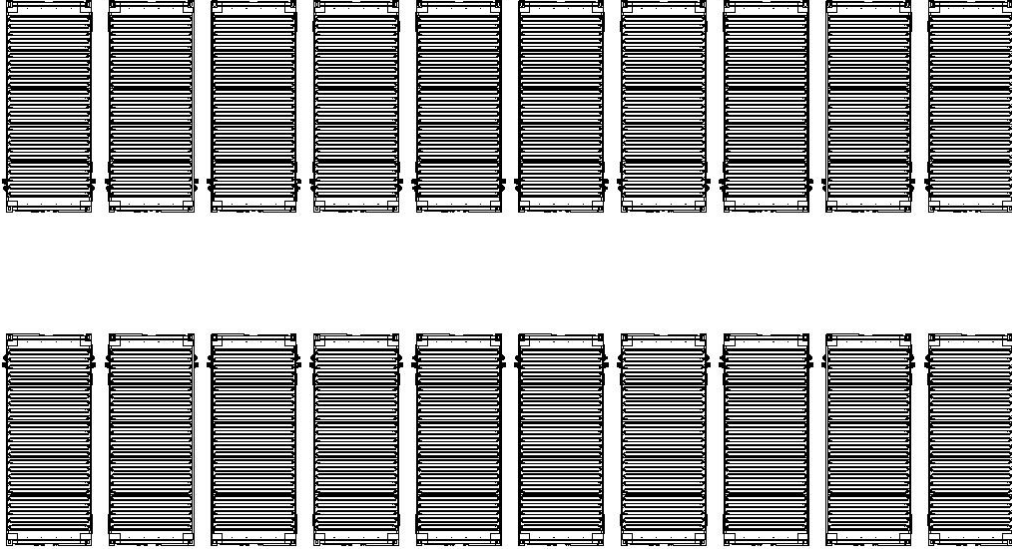


Fig.3.4.1 Layout Diagram

4. Site Requirements

Proper site preparation is critical to ensure the safety, performance, and longevity of the Vanadium Flow Battery system. This section outlines the environmental and physical requirements for the installation site, including load-bearing capacity.

4.1 Environmental Conditions

The SPower 240o system operates within the following environmental conditions:

- Temperature Range: -20°C to 50°C (additional heating/cooling may be required in extreme climates).
- Humidity: Max. 95% (non-condensing) – adequate ventilation is essential to prevent moisture buildup.
- IP Rating: IP54 (standard), with an optional IP65 upgrade for dust- or water-prone environments.

4.2 Site Layout and Space Requirements

- Minimum Clearance: A minimum maintenance distance of 5 meters must be maintained at the front of the BMS.
- Access Points: Plan access to critical components like BMS cabinets, Aqueous Vanadium Electrolyte tanks, and pumps for regular inspections.

4.3 Load-Bearing Capacity

The foundation must support a load of 4 metric tons per square meter. Consult a structural engineer to verify compliance.

4.4 Grounding and Electrical Infrastructure

- Grounding: A dedicated grounding system is required to protect the battery and personnel. Grounding must meet local electrical codes and standards.
 - Connection Points: Each battery container should have dedicated grounding points, clearly marked, and connected to the main grounding grid.
 - Materials: Use copper grounding cables of at least 10mm² in diameter to ensure proper conductivity.
 - Standards: Grounding must achieve a resistance level of less than 5 Ω, as per IEC60364-5 standards.
- Power Supply: Ensure the site is equipped with the appropriate AC and DC power infrastructure, including wiring and circuit breakers, rated to handle the system's power demands.
 - Interfaces for Third-Party Systems: Plan for the connection to third-party inverters or PCS (Power Conversion Systems). The interface points for
 - MODBUS and CANBUS communication should be easily accessible.

5. System Overview and Components

The Rongke Power Vanadium Flow Battery (VFB) system is a modular, scalable energy storage solution designed for both small-scale and large-scale applications. This section provides an overview of the core components of the system, their functions, and interconnections.

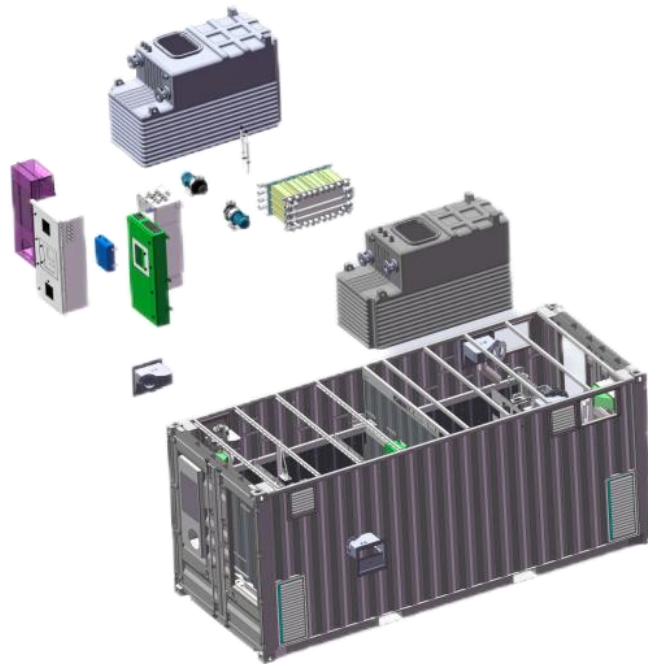


Fig.5.1.1 Explosion Diagram

5.1 Battery Containers

Each battery container consists of:

- Stack: The electrochemical unit where the energy conversion process (charging and discharging) occurs.
- Integrated Aqueous Vanadium Electrolyte Storage Tanks: The Aqueous Vanadium Electrolyte storage tanks and battery stacks are housed within the same 20-foot container for easy access and maintenance.
- Aqueous Vanadium Electrolyte Circulating Pumps: These pumps drive the Aqueous Vanadium Electrolyte solution between the storage tanks and the stack during operation.

5.2 Battery Management System (BMS)

- BMS system is the center of the whole battery system, which closely connects the large and scattered battery systems.
- BMS system is responsible for all information collection, information analysis and instruction distribution of battery system, so as to achieve the purpose of precise control of equipment.

5.3 U-pipe

- A U-Pipe with a neutralization agent ensures that any byproducts are safely treated before being released.
- To ensure the long-term effectiveness of the U-pipe, it is recommended to apply the additional oil on top of the neutralization agent, in accordance with the manufacturer's specifications, during installation and commissioning.

6. Installation Setup

The installation of the VFB system must follow a step-by-step process to ensure safety, reliability, and proper system functionality. This section outlines the installation procedures for each major component.

6.1 Layout & Foundation Inspection and Acceptance

- Document Review:
 - Check whether design drawings, construction records, material inspection reports, and other documents are complete and comply with specifications.
 - Confirm whether the foundation design meets local building codes and safety standards.
- Visual Inspection:
 - Inspect whether the foundation surface is level, free of cracks, settlement, or deformation.
 - Verify whether the foundation dimensions, elevation, and levelness meet the design requirements.
- Strength Testing:
 - Use tools such as rebound hammers or ultrasonic testers to check whether the concrete strength meets the design requirements.
 - Conduct core sampling if necessary to verify the actual strength of the concrete.
- Bearing Capacity Test:
 - Perform static load tests or dynamic penetration tests to verify whether the foundation's bearing capacity meets the weight requirements of the energy storage container.
- Drainage System Inspection:
 - Inspect whether the drainage system around the foundation is complete, ensuring no water accumulation or leakage.
 - Confirm whether the drainage slope meets the design requirements.
- Anchor Point Inspection:
 - Check whether the position, dimensions, and strength of anchor points (e.g., embedded bolts) on the foundation comply with the design requirements.
 - Confirm whether the anchor points match the installation interface of the energy storage container.
- Environmental Adaptability Check:
 - Confirm whether the foundation design considers local climate conditions (e.g., wind speed, rainfall, temperature changes).
 - Inspect whether frost-proofing, corrosion protection, and seismic measures have been implemented for the foundation.
- Safety Assessment:
 - Evaluate the foundation's resistance to earthquakes, wind, and flooding to ensure it can withstand natural disasters.

Hoisting Objects

- Step 1: Select the position of the crane station and the parking position of the container carrier according to the crane model, container weight, platform position, etc.
- Step 2: Determine the side of the container that is heavy (the side where the stack is installed is heavy), close and lock the container door.
- Step 3: If the crane station is more than 5 meters away from the container's position, use two 80-ton cranes to stand at both ends of the lifting container, each lifting end, and coordinate with each other. (Choose the suitable crane model according to the crane's actual lifting performance curve.)
- Step 4: Do a good job of container protection to prevent the sling from wearing the container and causing the container to drop paint.
- Step 5: Tie a rope on each side of the container to control the direction of the container.
- Step 6: Lift slowly, observe the deformation of the container and other safety matters.

- Step 7: After the container is in place, hit two laser levels and measure the distance from the bottom of the four legs of the container to the laser horizontal line. If the distance is the same,
- Step 8: the container is level. If the distance is different, use gaskets to pad under the legs to the same distance.

Note:

- Before hoisting, ensure that hoisting personnel, hoisting company and hoisting equipment are qualified, and ensure that hoist personnel are equipped with labor protection supplies.
- Do not stand under objects or in dangerous areas during hoisting.
- Crane operators must follow the instructions of the commander, and illegal operations are strictly prohibited.
- In case of wind, rain, snow and other bad weather, should immediately stop lifting operations.
- After hoisting, check the equipment to ensure that there is no damage.



Fig.6.1.1 Hoisting Tools

6.2 Integrated Aqueous Vanadium Electrolyte and Stack System

The Aqueous Vanadium Electrolyte storage tanks, and battery stacks are housed within the same container. This integrated design simplifies installation and maintenance. Ensure the container is placed with adequate clearance for easy access to maintenance areas and connections within the container.

- Ensure personnel involved in handling the containers are equipped with proper PPE, including helmets, gloves, and safety boots.
- Verify stability of the container before releasing the lifting equipment.

6.3 Unpacking and Inspection

- Inspect the Packaging: Before unpacking, visually inspect all packaging for signs of damage during transport.
- Check Components: After unpacking, verify all components against the shipping list. Ensure that no parts are missing or damaged.

6.4 Cable Connection

- **DC bus connection**
 - Confirm that the DC output ports (positive and negative terminals) of the energy storage battery match the DC input ports of the PCS.
 - Use appropriately sized DC cables to connect the positive terminal (+) of the battery to the positive terminal (+) of the PCS, and the negative terminal (-) to the negative terminal (-) of the PCS.
 - Ensure the cable connections are secure, using insulated terminals or junction boxes to prevent loosening.
 - Use a multimeter to measure the continuity and polarity of the cables to ensure accuracy.

- **Power cable connection:**

When connecting the power cable, make sure that:

- Connect the positive and negative terminals of the power cable according to the wiring diagram to avoid reverse connection.
- Ensure that the power cables are separated from other cables (such as communication cables) to avoid interference.
- After the connection is complete, use a multimeter to check whether the voltage is normal.

- **Communication cable connection:**

When connecting communication cables, make sure that:

- Use shielded twisted pair or dedicated communication cable to ensure the stability of signal transmission.
- Connect the pins of the communication cable correctly according to the device interface definition
- Avoid laying communication cables parallel to high-voltage power cables to reduce electromagnetic interference.
- After the connection is complete, check whether the communication is normal and ensure that the data transmission is correct.
- Communication Protocol Confirmation: Confirm the communication protocols supported by the energy storage battery and PCS (e.g., CAN, RS485, Modbus).
- Set the same communication parameters (e.g., baud rate, address) in the configuration interfaces of the PCS and energy storage battery.
- Test the communication to ensure data can be transmitted correctly.

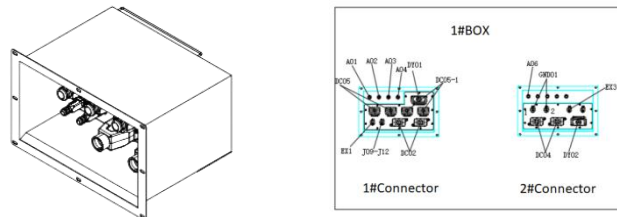


Fig.6.4.1 Cable Connector 1

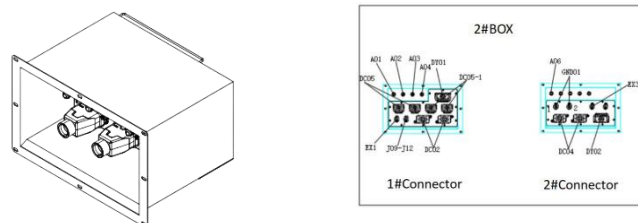


Fig.6.4.2 Cable Connector 2

6.5 Ground connection

- **Laying the Grounding Wire:**
 - Route the grounding wire from the grounding electrode to the grounding busbar of the energy storage system.
 - Ensure the grounding wire follows the shortest path, avoiding bends or detours.
 - Connect the grounding terminals of the energy storage battery and PCS to a unified grounding system, ensuring the grounding resistance meets requirements (typically less than 4Ω).
- **Securing the Grounding Wire:**
 - Use cable clamps or fixing brackets to secure the grounding wire, preventing loosening or wear.
 - Connect the grounding wire to the grounding busbar of the energy storage system, ensuring the connection point is secure and has good conductivity.

- Testing Ground Resistance:
 - Use a ground resistance tester to measure the resistance value of the grounding system.
 - Ensure that the ground resistance value meets the design requirements.

7. Initial Safety Check

- Danger
 - Use only approved protective gear and insulated tools to prevent electric shock or short-circuit hazards.

Important Notes

- The following procedures may trigger power interruptions or alarms. Notify the alarm monitoring center before and after performing these tasks.
- Equipment testing involves complex technical operations. Only trained personnel should perform these tasks, strictly following the testing guidelines.
- Unless specified otherwise in this manual, retain default parameter settings. Consult technical support before making any changes.
- Live electrical work is required during testing. Stand on dry insulating material and remove all metallic objects (e.g., watches, jewelry). Use properly insulated tools.
- Never simultaneously touch two conductors at different voltage potentials.
Before energizing any circuit, verify that all relevant components meet operational requirements.
- If unauthorized operation must be prevented during work, post clear warning signs such as "DO NOT ENERGIZE - PERSONNEL AT WORK" on distribution equipment.
- Monitor system behavior continuously during testing. Immediately power down if abnormalities occur, and resume only after identifying and resolving the issue.

7.1 Preparation

- Confirm Equipment Specifications: Ensure that the voltage, current, power, and other parameters of the energy storage battery and PCS are compatible.
- Check Equipment Status: Verify that the energy storage battery and PCS are powered off to ensure safe operation.
- Tool Preparation: Prepare necessary tools such as a multimeter, insulation tester, cables, and terminal blocks.
- Document Review: Review the technical manuals of the energy storage battery and PCS to understand interface definitions and connection requirements.

7.2 Safety Check

- Ensure there are no flammable or explosive materials around the system, and the working environment is well-ventilated.
- Check that all pipelines, valves, pumps, storage tanks, and other components are securely installed and leak-free.
- Confirm that the Aqueous Vanadium Electrolyte level is normal, and the Aqueous Vanadium Electrolyte ratio meets requirements.

7.3 Equipment Status Check:

- Ensure that the battery stack, PCS (Power Conversion System), BMS (Battery Management System), and other equipment are powered off.
- Verify that all electrical connections are correct, and cables are undamaged.

8. Power on the battery

8.1 Personnel Safety Preparations

1. Qualifications and Personal Protective Equipment (PPE)

- Operators must be professionally trained and familiar with the operational procedures of the VRFB system, Power Conversion System (PCS), transformers, and Battery Management System (BMS).
- Required PPE:
Corrosion-resistant gear: Acid-resistant gloves, goggles, and protective clothing (Aqueous Vanadium Electrolyte is acidic; avoid skin contact).
- Electrical safety gear: Insulated gloves and shoes (for high-voltage operations).
- Emergency equipment: Eyewash stations and emergency showers (in case of Aqueous Vanadium Electrolyte leakage).

2. Work Permits and Supervision

- High-risk operations (e.g., high-voltage energization, Aqueous Vanadium Electrolyte filling) require a work permit and must be supervised.
- Safety warnings: Post warning signs in critical areas (e.g., stack, PCS, transformer) to restrict unauthorized access.

8.2 System Safety Checks

1. Aqueous Vanadium Electrolyte System Inspection

- Aqueous Vanadium Electrolyte condition:
 - Check the level, concentration (typically 1.6-2.0M vanadium ions), and temperature (recommended: 15-40°C) of both positive and negative Aqueous Vanadium Electrolytes.
 - Ensure no precipitation, impurities, or abnormal discoloration (e.g., turbidity may indicate vanadium ion imbalance).
- Piping and valves:
 - Inspect all pipes, fittings, and valves for leaks and ensure proper sealing.
 - Verify that pump inlet/outlet valves are correctly positioned (to prevent dry running or pressure buildup).
- Storage tanks and ventilation:
 - Check Aqueous Vanadium Electrolyte tanks for damage and proper fluid levels; ensure ventilation is unobstructed (to prevent hydrogen accumulation).

2. Stack Inspection

- Mechanical checks:
Confirm the stack has no physical damage, bolts are tightened, and seals are intact.
- Electrical checks:
 - Measure insulation resistance (typically $\geq 1 \text{ M}\Omega$ to prevent short circuits).
 - Inspect electrodes and bipolar plates for corrosion or contamination.

3. PCS and Electrical System Inspection

- PCS status:
 - Ensure DC-side (stack connection) and AC-side (transformer connection) circuit breakers are open.
 - Check for no fault alarms and confirm cooling fans are operational.
- Transformer inspection:
 - Perform insulation tests (megger test on windings).
 - Check oil levels (for oil-immersed types) and cooling systems (e.g., fans, oil pumps).
 - Verify high-voltage and low-voltage circuit breakers and grounding switches are open.
- Protection systems:
 - Test overvoltage, overcurrent, short-circuit, and temperature protection (via simulation if necessary).

4. BMS and Control System Inspection

- Battery Management System (BMS):
 - Confirm State of Charge (SOC) and State of Health (SOH) readings are normal.
 - Ensure voltage, temperature, and flow sensors transmit data correctly.
- SCADA/Monitoring system:
 - Verify remote monitoring, alarm functions, and historical data logging are operational.

8.3 Environmental and Emergency Preparedness

1. Environmental Conditions

- Temperature: Maintain ambient temperature between 5-40°C (extreme temperatures may affect Aqueous Vanadium Electrolyte and stack performance).
- Ventilation: Ensure the storage container or cabin is well-ventilated (to prevent hydrogen buildup).
- Fire safety: Provide acid-resistant fire extinguishers (e.g., CO₂ or dry powder); avoid water-based extinguishers (Aqueous Vanadium Electrolyte may react exothermically with water).

2. Emergency Response Plan

- Aqueous Vanadium Electrolyte leakage:
 - Keep neutralizing agents (e.g., sodium carbonate solution) and absorbent materials (e.g., sand) on hand.
 - Immediately stop pumps and wear PPE in case of a spill.
- Electrical faults:
 - Trip circuit breakers if PCS or transformer malfunctions; troubleshoot before re-energizing.
- First aid:
 - Provide emergency eyewash stations (flush eyes with water for 15 minutes if exposed to Aqueous Vanadium Electrolyte and seek medical help).

8.4 Final Pre-Startup Checklist

Before energization, verify the following:

Check Item	Acceptance Criteria	Verified (✓/X)
Aqueous Vanadium Electrolyte level & concentration	≥80% fill, 1.6-2.0M vanadium ions	
No leaks, valves positioned correctly	Pump valves open, no leaks	
Stack insulation resistance ≥1 MΩ	Passes megger test	
PCS DC/AC breakers open	Confirmed de-energized	
Transformer insulation & cooling OK	Oil level normal, fans operational	
BMS communication stable	SOC, temperature, voltage readings OK	
Fire & emergency equipment ready	Extinguishers, eyewash functional	

8.5 Power-On and Shutdown Procedures

1. Pre-Startup Checks

- Transformer Inspection:
 - Verify insulation resistance, oil level (for oil-immersed transformers), and cooling systems (fans/oil pumps).
 - Ensure all circuit breakers (HV/LV sides) and grounding switches are in the **OFF** position.
- PCS (Power Conversion System) Inspection:
 - Confirm DC and AC circuit breakers are **disconnected**.
 - Check for active alarms and ensure cooling systems (fans) are functional.
 - Inspect Aqueous Vanadium Electrolyte levels, piping, and BMS status (if applicable).

2. Startup Sequence

- Auxiliary Systems Activation
 - Control Power: Apply low-voltage power (AC 220V / DC 48V) to BMS, SCADA, and PCS controls.
 - Cooling Systems: Start Aqueous Vanadium Electrolyte pumps, transformer cooling, and PCS thermal management.
- Transformer Energization
 - Grid-Side Preparation (if applicable):
 - Ensure the HV-side breaker is open and grounding switches are disengaged.
 - Close the HV-side disconnect (if present).
 - No-Load Startup:
 - Close the LV-side breaker (AC side).
 - Close the HV-side breaker to energize the transformer.
 - Monitor inrush current, temperature, and noise for abnormalities.
- PCS Activation
 - DC-Side Power-Up:
 - Close the DC breaker (connected to the battery stack).
 - Allow BMS to stabilize the stack voltage before proceeding.
 - AC-Side Power-Up:
 - Confirm transformer output voltage is stable.
 - Close the AC breaker (connected to the transformer LV side).
 - PCS performs self-checks and synchronizes with grid parameters (voltage, frequency, phase).
 - Grid Connection: Gradually ramp up power output in the desired mode (charge/discharge).
- **System Operation**
 - Adjust Aqueous Vanadium Electrolyte flow (if applicable) and optimize power flow via BMS/PCS coordination.
 - Continuously monitor transformer temperature, PCS efficiency, and stack voltage balance.

3. Critical Safety Notes

- **Transformer Sequence:**
 - Step-down transformers: Always energize the LV side first, then the HV side.
 - Step-up transformers: Follow manufacturer guidelines (may require HV-side first).
- **PCS & Transformer Matching:**
 - Ensure PCS AC voltage matches the transformer LV rating.
 - Complete grid synchronization before full operation (unless in island mode).
- **Protection Systems:**
 - Validate differential/overcurrent protection before full load operation.

4. Shutdown Procedure

- Reduce Power: Gradually decrease PCS output to zero and desynchronize from the grid.
- Disconnect AC Side: Open the PCS AC breaker, then the transformer LV breaker.



- Disconnect DC Side: Open the PCS DC breaker to deactivate the battery stack.
- Auxiliary Shutdown: Turn off cooling pumps and fans, then cut control power.

5. Special Operating Modes

- Black Start: In grid-off scenarios, use PCS island mode to establish local voltage before connecting loads.
- Multi-PCS Systems: Activate units sequentially to prevent grid disturbances.

Note: Always follow manufacturer guidelines and safety standards (IEC 62477-1). For initial commissioning, consult a qualified electrical engineer.

9. Battery Management System (BMS)

The BMS is crucial for ensuring safe operation and optimal performance of the VFB system. This section outlines the specific steps for setting up the BMS.

9.1 Initial Setup

- **Power Up the BMS:** Once all physical connections are made, power up the BMS using the provided control panel.
- **Configure Communication Interfaces:** Set up the MODBUS and CANBUS communication protocols. Ensure that all external systems, such as the PCS, are correctly interfacing with the BMS.

9.2 Register Overview

The BMS uses various registers to monitor and control battery operation:

- **Preparation**
 - Tool Preparation: Install MODBUS debugging tools (e.g., ModScan, Modbus Poll).
 - Document Review: Obtain the MODBUS register mapping table for the energy storage device to understand the addresses and functions of each register.
 - Hardware Connection: Ensure the energy storage device is properly connected to the debugging computer via RS485 or TCP/IP.
- **Configure MODBUS Parameters**
 - Communication Parameter Settings: Configure baud rate, data bits, stop bits, parity, etc., to ensure they match the device settings.
 - Device Address Settings: Confirm the MODBUS address of the device and configure it correctly in the debugging tool.
- **Connection Testing**
 - Establish Connection: Use the debugging tool to connect to the device and confirm normal communication.
 - Read Registers: Attempt to read holding registers or input registers to verify the device's response.
- **Register Mapping Verification**
 - Data Verification: Read register data and compare it with the mapping table to confirm accuracy.
 - Function Verification: Test write functions to ensure proper control of the device.
- **Troubleshooting**
 - Communication Failure: Check wiring, parameter settings, and device address.
 - Data Anomalies: Verify register addresses and data types.
 - Device No Response: Check the device's power supply and communication status.
- **Debugging and Optimization**
 - Data Monitoring: Continuously monitor key registers to ensure data stability.
 - Performance Optimization: Adjust communication parameters, optimize read frequency, and improve system performance.

9.3 System Initialization

- **Aqueous Vanadium Electrolyte Circulation:**
 - Start the Aqueous Vanadium Electrolyte circulation pump to ensure the positive and negative Aqueous Vanadium Electrolytes circulate normally between the battery stack and storage tanks.
 - Check for air bubbles in the pipelines and perform venting if necessary.
- **System Pressure Check:**
 - Check that the pressure in the Aqueous Vanadium Electrolyte circulation system is within the normal range, ensuring no leaks or blockages.

9.4 System Debugging

- **Protection Function Test:**
 - Simulate abnormal conditions such as overvoltage, undervoltage, and overcurrent to test the protection functions of the BMS and PCS.
 - Confirm that the system can safely shut down and trigger alarm signals.

9.5 Normal Operation

- **Parameter Monitoring:**
 - Monitor real-time parameters such as SOC (State of Charge), voltage, current, and temperature of the battery stack in the monitoring system.
 - Ensure the Aqueous Vanadium Electrolyte circulation system operates normally, with no leaks or abnormal noises.
- **Data Recording:**
 - Record key parameters during the power-on and debugging processes for future operation and maintenance reference

9.6 Hybrid Thermal Management (Passive + AC Cooling)

- External circulation mode: When the outdoor temperature is low, the system is cooled by the electric shutter + the main body fan.
- External circulation mode: When the outdoor temperature is slightly higher, the system is cooled by the cabinet air conditioner + the electric shutter + the main body fan.
- Internal circulation mode: When the outdoor temperature is high, the container is a closed space. The system is cooled by the internal circulation of the cabinet air conditioner + the main body fan

9.7 Precautions

- Always wear protective equipment during operation to avoid contact with the Aqueous Vanadium Electrolyte.
- Ensure all equipment is in normal condition before powering on to avoid operating with faults.
- If any abnormal conditions are detected (e.g. leaks, voltage anomalies), immediately stop and inspect the system.

10. Verification Tests and Final Checklist

Before declaring the system ready for operation, perform the following tests and complete the final checklist.

10.1 Preparation

- **Confirm Equipment Specifications:** Ensure that the voltage, current, power, and other parameters of the energy storage battery and PCS are compatible.
- **Check Equipment Status:** Verify that the energy storage battery and PCS are powered off to ensure safe operation.
- **Tool Preparation:** Prepare necessary tools such as a multimeter, insulation tester, cables, and terminal blocks.
- **Document Review:** Review the technical manuals of the energy storage battery and PCS to understand interface definitions and connection requirements.

10.2 System Preparation Phase

1. Equipment Status Verification

- Check Aqueous Vanadium Electrolyte storage tank levels
- Verify Aqueous Vanadium Electrolyte temperature

- Inspect initial valve states in the piping system (main circulation pump inlet/outlet valves open, bypass valves closed)

2. Electrical System Inspection

- Confirm PCS DC-side and AC-side circuit breakers are in the open position
- Check transformer HV/LV-side switch status (HV-side grounding switch open, LV-side circuit breaker open)
- Verify Battery Management System (BMS) + EMS + SCADA integration communication is normal (all sensor data readable)

10.3 Auxiliary System Startup

1. Thermal Management System

- Start cooling water circulation pump (if equipped)
- Enable cooling fans (if required)

2. Aqueous Vanadium Electrolyte Circulation System

- First, start the negative Aqueous Vanadium Electrolyte circulation pump (low-speed operation)
- After a 30-second interval, start the positive Aqueous Vanadium Electrolyte circulation pump (low-speed operation)
- Gradually increase to rated flow rate after confirming stable system pressure

10.4 Main System Power-On Sequence

1. Low-Voltage Control System Power-On

- Close control power switch (AC220V/DC48V)
- BMS self-test (confirm no fault alarms)
- EMS system startup (complete data communication test)

2. High-Voltage System Power-On

- Step 1: Close the transformer LV-side circuit breaker
- Step 2: Close the transformer HV-side circuit breaker (observe no-load excitation current)
- Step 3: Close the PCS AC-side circuit breaker (complete grid synchronization check)
- Step 4: Close the PCS DC-side circuit breaker (soft-start mode)

10.5 System Operation Monitoring

1. Initial Operating Parameters

- Stack voltage (single-cell voltage control range)
- Aqueous Vanadium Electrolyte flow rate (maintain within design deviation)
- System temperature (stack temperature differential)

2. Power Adjustment

- Increase power in 10% rated power steps
- Stabilize for 5 minutes after each adjustment
- Switch to automatic control mode upon reaching target power

10.6 Electrical Performance Testing

1. No-Load Test

- Verify system self-check is normal (no alarms or fault signals)
- Measure open-circuit voltage (theoretical range: 1.2–1.6V per cell)

2. Charge/Discharge Test

- **Capacity test:** Charge/discharge at rated current, confirm actual capacity \geq rated capacity (e.g., 4-hour discharge capacity)
- **Efficiency test:** Validate per relevant test documentation

- **Cycle test:** Perform multiple charge/discharge cycles, check performance degradation within allowable limits (if required)
3. Dynamic Response Test
 - Simulate power fluctuations to test system response time and stability

10.7 Safety & Functional Verification

1. Protection Function Test
 - Simulate overcharge, over-discharge, overtemperature, and short-circuit conditions to verify protection system (e.g., BMS) response
2. Insulation & Withstand Voltage Test
 - Measure system-to-ground insulation resistance ($\geq 1 \text{ M}\Omega$)
 - Perform withstand voltage test (e.g., DC 1500V for 1min, no breakdown)
3. Leakage & Emergency Handling
 - Test Aqueous Vanadium Electrolyte leakage alarm system
 - Verify emergency shutdown and drainage procedures

10.8 Precautions

1. Safety Regulations
 - Operators must wear full protective gear
 - At least two personnel must be present during power-on
 - Emergency equipment (neutralizing agents, fire extinguishers, etc.) must be available
2. Abnormal Handling
 - Immediately shut down in case of Aqueous Vanadium Electrolyte leakage
 - Reduce power if abnormal single-cell voltage is detected
 - Investigate PCS alarms before resuming operation

Note: This procedure should be adjusted according to specific power station design parameters. Initial power-on should be performed under manufacturer guidance. All operations must comply with electrical safety regulations, and complete records must be maintained.

11. VRFB Energy Station Exit Inspection Items

1. System Status Inspection

- **State of Charge (SOC) Adjustment**
 - Reduce SOC to 20%~30% to avoid storage at high voltage or high energy state.
- **Aqueous Vanadium Electrolyte Management**
 - Check whether storage tanks, pipelines, and valves are properly sealed to prevent leakage.
 - If long-term storage is required, consider draining the Aqueous Vanadium Electrolyte and storing it properly.
- **Electrical Isolation**
 - Disconnect all external electrical connections (e.g., PCS, BMS).
 - Shut down the Battery Management System (BMS) and record critical operational data.

2. Mechanical & Structural Inspection

- **Storage Tanks & Pipelines**
 - Check for corrosion, cracks, or potential leakage risks.
- **Stack Inspection**
 - Ensure electrodes and membranes are intact, and fasteners are properly tightened.
- **Auxiliary Equipment**
 - Inspect pumps, sensors, and other components to ensure normal operation and prevent damage during prolonged shutdown.

3. Safety Protection Measures

- **Leak Prevention**
 - Ensure storage tanks and valves are tightly closed to prevent Aqueous Vanadium Electrolyte evaporation or leakage.
 - Equip the storage area with anti-corrosion leak emergency kits (e.g., neutralizers, absorbent materials).
- **Fire & Electrical Safety**
 - Verify no short-circuit risks; ensure the storage environment is dry and well-ventilated.
 - Keep away from high temperatures and flammable materials, and provide acid-resistant fire extinguishers (e.g., dry powder type).

4. Documentation & Records

- **Operation Log**
 - Record key parameters before shutdown (e.g., SOC, temperature, voltage).
- **Maintenance Records**
 - Update battery status and note any pending repair issues (e.g., pipeline aging, stack efficiency decline).

5. Storage Environment Requirements

- **Temperature Control**
 - Recommended range: 0~30°C to avoid adverse effects on Aqueous Vanadium Electrolyte stability due to extreme temperatures.
- **Moisture & Dust Prevention**
 - Maintain a dry environment to prevent electrical components from moisture damage or corrosion.

12. Glossary of Terms

- **BMS** (Battery Management System): The system responsible for monitoring and controlling battery performance, safety, and communication.
- **SOC** (State of Charge): A measurement of the battery's current charge level.
- **MODBUS**: A communication protocol used for connecting industrial electronic devices.
- **CANBUS**: A robust vehicle bus standard designed to allow microcontrollers and devices to communicate with each other without a host computer.
- **PCS** (Power Conversion System): A device that manages the charging and discharging process, performs AC/DC conversion, and supplies AC power to loads.
- **IP Rating** (Ingress Protection): A standard that defines the level of protection against dust and water ingress.
- **IEC Standards**: International standards for electrical systems, including safety and performance specifications.
- **Aqueous Vanadium Electrolyte**: A liquid medium in vanadium flow batteries that facilitates energy storage and transfer.
- **Grounding Resistance**: The measure of a grounding system's ability to safely conduct electrical current to the earth.



Contact us

HEADQUARTERS

RKP International Limited
HONGKONG
SAR
<https://rkpstorage.com>

BANCHOFFICES-UNITED ARAB EMIRATES

RKP ENERGY STORAGE MIDDLE EAST-FZCO
DUBAI
UNITED ARAB EMIRATES
<https://rkpstorage.com>

BANCHOFFICES

AUSFLOW ENERGY PTY LTD
BRISBANE
AUSTRALIA
<https://ausflowenergy.com>

BANCHOFFICES-GERMANY

RKP GERMANY UG
BERLIN
GERMANY
<https://rkpstorage.com/de>

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