Executive Summary

A load bank is a specialized testing device that converts electrical energy into heat (or other forms of energy) for dissipation. It is widely used in testing and validation scenarios for generator sets, uninterruptible power supplies (UPS), energy storage systems, frequency converters, and data center infrastructure.

With the acceleration of global digitalization and the continuous expansion of data center scale, the strategic value of load banks in ensuring the reliability of critical power supply systems is becoming increasingly prominent.

This white paper systematically introduces the working principles, technical classifications, core performance indicators, typical application scenarios, and selection methods of load banks. It aims to help technical engineers, procurement decision-makers, and relevant practitioners fully understand the value and selection logic of load banks.

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1. Background and Market Drivers

1.1 Extreme Dependence of Critical Infrastructure on Power Supply Reliability

In the digital economy era, the requirements for power supply continuity in critical infrastructure such as data centers, communication rooms, medical facilities, and rail transit have reached an almost demanding level.

An unexpected power outage or performance degradation of power supply equipment can cause data loss, business interruption, equipment damage, and even safety accidents, with economic losses easily reaching several million yuan.

Key Industry Data:

- Average loss per unplanned data center outage: **over $1 million USD** (Uptime Institute, 2024)
- Global data center market forecast: **over $600 billion USD** by 2028, annual growth rate ~12%
- Over **70%** of data center operators report regular load testing as a core requirement for operational compliance

Against this background, load banks have evolved from "optional accessories" to "essential equipment" as the core tool for verifying the actual performance of power supply equipment.

1.2 Compliance and Standards Drivers

Multiple domestic and international industry standards and regulations explicitly require periodic full-load or near-full-load testing for critical power equipment such as UPS and generators:

Standard	Description
GB/T 7260 Series	UPS Testing Standard (China)
IEC 62040 Series	International UPS Standard
NFPA 110	US Emergency Power Supply System Standard
ISO/IEC 27001	Information Security (indirectly requires availability verification testing)
Uptime Institute Tier	Certification requires periodic full-load performance verification

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2. Basic Working Principles of Load Banks

2.1 Working Principle

The core function of a load bank is to **convert electrical energy into heat and safely dissipate it**, thereby providing a simulated real-load environment for power supply equipment.

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Power Flow:

Power Supply Equipment (UPS / Generator / Battery) ↓ Output Power

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Load Bank (Resistive/Inductive/Capacitive Load Elements) ↓ Converts electrical energy into heat

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Cooling System (Air Cooling / Water Cooling) → Heat dissipation to environment
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Through precise regulation of load power via the control system, testers can simulate various operating conditions from no-load to full-load, observe key parameters such as voltage, frequency, waveform, and temperature rise of the power supply equipment under different load conditions, thereby verifying whether their actual performance meets standards.

2.2 Key Electrical Concepts

Concept	Description
Active Power (P, Unit: kW)	Actual power consumed, corresponding to the power generated as heat by the load bank
Reactive Power (Q, Unit: kvar)	Generated by inductive or capacitive loads, does no work but affects system power factor
Apparent Power (S, Unit: kVA)	Vector sum of active and reactive power, determines capacity configuration of power supply equipment
Power Factor (PF)	P/S, reflects load efficiency of power supply equipment; pure resistive load PF=1
Harmonic Distortion (THD)	Harmonic content introduced by non-linear loads, affects power quality

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3. Technical Classification of Load Banks

3.1 Classification by Load Type

3.1.1 Resistive Load Bank

Working Principle: Uses resistance wire, resistance grids, or stainless steel resistance elements as loads, power factor close to 1.0, outputs pure active power.

Features:

- Simple structure, relatively low cost
- Low waveform distortion, intuitive test results
- Suitable for basic full-load verification of power supply equipment

Typical Applications: Generator factory testing, basic UPS performance verification, regular maintenance testing in data centers

3.1.2 Inductive Load Bank

Working Principle: Uses inductive coils as load elements, generates lagging current, outputs inductive reactive power, power factor typically 0.8 (lagging).

Features:

- Simulates real load characteristics of inductive equipment such as motors and transformers
- Often used in combination with resistive load banks to achieve comprehensive power factor testing

3.1.3 Capacitive Load Bank

Working Principle: Uses capacitor banks as loads, generates leading current, outputs capacitive reactive power, power factor typically 0.8 (leading).

Features:

- Simulates loads from large LED lighting systems, frequency converters, and other capacitive equipment
- Can be combined with resistive and inductive load banks to achieve arbitrary power factor testing

3.1.4 Electronic Load Bank

Working Principle: Uses power semiconductor devices such as IGBT and MOSFET to precisely regulate load current waveform and amplitude through program control, simulating arbitrary load characteristics.

Features:

- High precision, fast response speed (μs level)
- Can simulate complex dynamic loads, such as server step loads, charging pile pulse loads

- Compact size, suitable for laboratory and precision testing scenarios
- Higher cost

Typical Applications: Precision testing of battery packs, testing of new energy vehicle charging systems, energy storage system performance evaluation

3.2 Classification by Cooling Method

Cooling Method	Principle	Advantages	Application Scenario
Air-Cooled	Forced convection cooling by fans	Simple structure, flexible installation	Small-medium power, indoor/outdoor
Water-Cooled	Circulating cooling water carries away heat	High cooling efficiency, low noise	High power, noise-sensitive indoor scenarios
Liquid-Cooled	Immersion or cold plate heat dissipation	Extremely high cooling density, ultra-quiet	Ultra-high power density scenarios

4. Application Scenarios in Data Centers (Focus)

Data centers are the most important and highest-value application field for load banks. The following introduces the key nodes in the data center lifecycle.

4.1 New Data Center Acceptance Testing (Commissioning Test)

Background: Before a newly built data center is put into operation, complete acceptance tests must be conducted on the power supply and distribution systems to ensure that each system operates stably under design capacity.

Test Content:

- **UPS Full-Load Test:** Load the UPS to rated power (100% load), run for at least 4 hours continuously, verify temperature rise, efficiency, output waveform stability
- **Generator Set Startup and Load Test:** Simulate power failure scenario, verify the time from generator cold start to full load (typically required ≤ 10 seconds) and load stability
- **Battery Discharge Test:** Simulate IT equipment load through load bank, verify the actual discharge capacity of the battery pack within the designed backup time (e.g., 15 minutes, 30 minutes)

- **Transfer Test:** Verify the transfer time of ATS (Automatic Transfer Switch) during power failure and load continuity during the transfer process

4.2 Regular Preventive Maintenance Testing

Importance: Research shows that the failure rate of UPS and generator systems without regular load testing during real emergency events is **3 to 5 times** that of regularly tested systems. Most standards require full-load testing quarterly or semi-annually.

⏰ **Typical Test Plan:**

Monthly Inspection:

- UPS battery float charge voltage check
- Generator no-load start test (15 minutes)

Quarterly Test:

- UPS 50% load operation test (1 hour)
- Battery discharge capacity quick verification

Annual Comprehensive Test:

- UPS 100% full-load test (4 hours)
- Generator full-load continuous operation test (2 hours)
- Complete battery discharge to design termination voltage
- Simulated power failure full-process transfer drill

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5. Liquid-Cooled Load Banks: Technical Advantages and Market Prospects

5.1 Definition and Classification of Liquid-Cooled Load Banks

Liquid-cooled load banks refer to load bank products that use liquid (water, ethylene glycol aqueous solution, or dielectric liquid) as the main cooling medium, differing from traditional air-cooled load banks that rely on air convection cooling. Based on the liquid cooling method, they can be divided into three categories:

① Indirect Liquid Cooling (Plate Heat Exchanger Type)

- Resistance heating elements are tightly coupled with liquid cooling flow channels through heat conduction plates, heat is transferred to circulating cooling water
- External connection to cooling towers or water chillers, cooling liquid circulates in a closed loop
- Mature structure, simple maintenance, currently the mainstream liquid cooling solution in the market

② Direct Liquid Cooling (Immersion Type)

- Resistance elements or power semiconductor devices are directly immersed in dielectric cooling liquid
- Highest cooling efficiency, can support extremely high power density (>100 kW/m^3)
- Higher cost, suitable for ultra-high power density scenarios

③ Spray Liquid Cooling

- Cooling liquid is directly sprayed onto the surface of heating elements through nozzles
- Extremely high phase-change cooling efficiency, but high system complexity, currently mostly in research stage

5.2 Core Technical Advantages of Liquid-Cooled Load Banks

Advantage	Description	Impact
Cooling Power Density	Liquid has ~3500x specific heat capacity of air	Can support: Air cooling 20-50 kW/m^3, Liquid cooling 100-300 kW/m^3, Immersion 300-800 kW/m^3
Noise Reduction	Eliminates large cooling fans, operating noise can be reduced to 45-55 dB(A)	Suitable for noise-sensitive indoor testing scenarios

Advantage	Description	Impact
Test Continuity	Large thermal inertia of liquid system, small impact from ambient temperature fluctuations	Ensures consistency of test conditions over hours of full-load testing
Synergy with DC Infrastructure	Can be directly connected to data center chilled water loop	Significantly reduces deployment costs and on-site construction complexity

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6. Market Trends and Technical Evolution

6.1 Intelligence and Digitalization

Modern load banks are rapidly evolving towards intelligence:

- **IoT Access:** Supports cloud remote monitoring, test data uploaded to operation management platform in real-time
- **AI-Assisted Analysis:** Establishes power equipment health models through historical test data, predicts potential failures
- **Automated Test Process:** Preset test scripts, complete entire test process without manual intervention and generate compliance reports

6.2 Green and Energy-Efficient

- **Energy Regenerative Load Bank:** Feeds back electrical energy consumed during testing to the grid, can recover over 90% of test power, significantly reduces test costs and carbon emissions
- **Low GWP Refrigerant:** Uses new refrigerants to replace high GWP substances, meets environmental protection regulations such as F-Gas

6.3 Ultra-High Power Density

With the increase of single rack power in data centers from 5kW to 30kW and higher, load banks are also evolving towards higher power density to meet testing requirements for new infrastructure such as liquid-cooled data centers and AI computing clusters.

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7. Conclusions and Recommendations

7.1 Core Conclusions

1. **Load banks are the last line of defense** for the reliability of critical infrastructure power supply, having irreplaceable value in high-availability scenarios such as data centers, communications, medical, and industrial.
2. **Data centers are currently the largest application market for load banks,** with three types of demand: acceptance testing, preventive maintenance, and expansion verification, forming a continuous and stable market space.
3. **Technical selection should start from the characteristics of the equipment under test,** comprehensively considering power scale, power factor requirements, cooling method, automation level, and compliance certification, to avoid over-configuration or under-configuration.
4. **Energy regenerative load banks already have significant economic advantages** in high-power scenarios, and are important tools for data center operators to achieve green operations.

7.2 Action Recommendations

For Data Center Operators:

- Establish standardized load testing procedures, integrate load testing into annual compliance audits
- For medium to large-scale data centers, prioritize evaluating the purchase of mobile modular load banks to achieve cross-campus asset reuse
- Pay attention to energy regenerative equipment to reduce test costs and carbon emissions in long-term operations

For Procurement Decision Makers:

- Focus on TCO (Total Cost of Ownership) over the entire life cycle, not just comparing procurement prices
- Require suppliers to provide complete certification qualifications (CE/CCC/UL/CB, etc.) and commitments for localized service support
- Clearly define technical parameter thresholds in tender documents (load regulation accuracy, THD, communication protocol, etc.)

Appendix

Appendix A: List of Common Technical Terms and Abbreviations

Abbreviation	Full Name	Chinese Description
UPS	Uninterruptible Power Supply	Uninterruptible Power Supply
PF	Power Factor	Power Factor
THD	Total Harmonic Distortion	Total Harmonic Distortion
ATS	Automatic Transfer Switch	Automatic Transfer Switch
PUE	Power Usage Effectiveness	Power Usage Effectiveness
DCIM	Data Center Infrastructure Management	Data Center Infrastructure Management

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For more information, please feel free to contact our team.

This white paper is for technical reference only. For specific product selection and engineering solutions, please combine with the actual application environment and professional engineer recommendations.

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