Analysis and Application of Modular UPS Power Supply Systems: Postprint

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Abstract

This article introduces the characteristics and applications of modular UPS. It analyzes the advantages of modular UPS from the perspectives of operating principle, power supply reliability, scalability, and maintainability, and elaborates on the solution for adopting modular UPS power supply systems in small and medium-sized data centers. Additionally, it presents the practical application of modular UPS power supply systems in the program-controlled computer room of Xinhua News Agency.

Full Text

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Abstract: This paper introduces the characteristics and applications of modular Uninterruptible Power Supply (UPS) systems. It analyzes the advantages of modular UPS from perspectives including operating principles, power supply reliability, scalability, and maintainability, and presents a solution for implementing modular UPS power supply systems in small and medium-sized data centers. The practical application of modular UPS power supply systems in the program-controlled computer room of Xinhua News Agency is also discussed.

Keywords: modular UPS; operating principle; hot-swappable; advantage analysis; application

1. Modular UPS System Overview

Modular UPS represents a new-generation infrastructure solution for computer rooms that simultaneously addresses requirements for green operation, high efficiency, easy scalability, and convenient maintenance through modular design principles. This approach enables rapid deployment and intelligent management of computer room infrastructure. In recent years, modular UPS technology has matured significantly, with increasing scale deployment in small and medium-sized data centers. Modular UPS systems consist of several low-power modules installed within a single cabinet, allowing configuration of different module quantities to meet load power requirements and achieve system redundancy. Compared with traditional tower UPS systems, modular UPS demonstrates clear advantages in availability, reliability, scalability, and maintainability. As critical equipment for ensuring power supply stability and continuity, modular UPS has been widely applied across various fields. The program-controlled computer room equipment at Xinhua News Agency was previously powered directly by utility supply without UPS protection. We have now completed the renovation of the power distribution system in Building 9' s program-controlled computer room, installing new distribution cabinets and configuring modular UPS power supplies to provide reliable power protection for the program-controlled switching equipment.

1.1 Composition of Modular UPS

Modular UPS primarily consists of a chassis frame, UPS power modules, control modules, static switch modules, display and communication modules, and battery banks. The system is built by stacking several independent high-frequency UPS power modules, with all modules connected in parallel at the output. The total capacity of the modular UPS equals the sum of individual power module capacities. Both the bypass switch section and overall control system are modularized, with control modules configurable in primary-backup redundancy. This stacking of individual modules within the chassis frame constitutes a complete modular UPS unit.

The power module serves as the main component of modular UPS, with each module comprising inversion, rectification, power factor correction, charging, and associated control circuits. All power modules support online hot-swappable installation and replacement. A key advantage of modular UPS is that control modules can also be configured with primary-backup redundancy, with system control management performed by two redundant hot-swappable control modules. A failure in one control module does not affect normal system operation, eliminating single-point-of-failure risks in the control section. The control module centrally manages parallel operation of power modules, ensuring uniform operation according to consistent parallel parameters. A faulty power module automatically exits the parallel system without jeopardizing the entire parallel connection.

The static bypass module comprises bidirectional thyristors and control circuits. When the UPS fails and cannot output power, the static bypass module automatically switches to utility power supply. The monitoring module provides real-time monitoring of UPS system operating status, acquisition and storage of operational parameters, fault recording and storage, fault analysis, and serves as a platform for human-machine dialogue and network-based monitoring.

1.2 Operating Principle of Modular UPS

The operating principle of modular UPS is illustrated in Figure 1 [Figure 1: see original paper]. UPS modules convert AC power to DC power through rectifier circuits. Under normal utility power conditions, the system continuously charges the battery bank while the inverter circuit within the UPS module converts DC power back to AC power with the same frequency and phase to supply the load. When utility power is interrupted, phase-deficient, or overloaded, the battery bank provides power to the load through the inverter. When the inverter fails or battery voltage drops below the threshold, the static switch instantaneously switches to bypass operation mode, with backup power directly supplying the load.

When the UPS operates in bypass mode, the maintenance bypass switch can be closed, allowing the load to be powered by backup power through the maintenance bypass. At this point, the UPS utility input switch and static bypass switch can be disconnected for maintenance of all UPS modules, charging modules, and battery banks. If the static switch is cut off due to overload or other reasons, operators can perform emergency manual switching to maintenance bypass to prevent extended load power outages.

Hot-swappable technology represents a key technology for modular UPS. Parallel control among UPS modules employs distributed logic control without master-slave distinction. Removal or insertion of any module does not affect normal operation of other modules. The system can be configured as N+1 or N+X redundant systems, allowing any single module to be inserted or removed from the parallel unit without power outage, thereby enabling online maintenance of the parallel system and significantly improving system reliability and comprehensive protection time for the load.

1.3 Advantages of Modular UPS

Compared with traditional UPS systems, modular UPS employs highly intelligent modular design and online hot-swappable technology to enable online replacement and maintenance, reducing maintenance difficulty. The specific advantages are analyzed as follows.

First, power modules easily achieve redundancy. Redundancy is realized by simply stacking power modules. For example, when the difference between total UPS power and load rate exceeds the power of a single module, redundancy of several power modules can be achieved. When this difference exceeds the power of X modules, "N+X" redundancy can be implemented, ensuring continued system operation during power module failures and guaranteeing stable, continuous power supply to equipment.

Second, control hosts feature redundancy. Modular UPS configures dual redundant control modules and redundant CAN control buses, completely eliminating single-point "bottlenecks" in the control section. This redundant design achieves true hot-swappable capability.

Third, maintainability. Traditional tower UPS systems typically connect each power module using cables or busbars with screw fastening, requiring substantial workload and time for replacement and maintenance. Maintenance must be performed in maintenance bypass mode, during which the load is powered by utility supply without UPS protection. Modular UPS employs hot-swappable technology, allowing individual modules to be inserted or removed from parallel units while UPS power supply remains continuous. This technology enables online maintenance of parallel systems, significantly reducing MTTR (Mean Time To Repair). Maintenance simply involves removing and replacing the faulty module, making the process extremely quick and convenient.

Fourth, scalability. Modular UPS system expansion is simpler. As long as expansion module installation positions are reserved during initial construction and input/output distribution switch and cable capacities are adequate, new modules can be directly inserted into the system and configured for immediate use, requiring less time than traditional tower UPS. Modular UPS enables a "pay-as-you-grow" investment model, allowing users to purchase fewer power modules initially and add modules as equipment increases. This simple, cost-effective expansion approach facilitates phased planning, design, and construction of UPS power systems, improving cost efficiency and UPS utilization.

2. Application of Modular UPS in Xinhua News Agency Building 9 Program-Controlled Computer Room

2.1 Power Distribution System of Building 9 Program-Controlled Computer Room

The Building 9 program-controlled computer room at Xinhua News Agency serves program-controlled switching and video teleconferencing system operations. We have completed renovation of the computer room' s power distribution system, configuring two modular UPS units with capacity no less than 100KVA to provide reliable UPS power to all cabinets in the program-controlled computer room. The power distribution system includes four new utility distribution cabinets: one utility input cabinet, one UPS input distribution cabinet, and two utility output distribution cabinets. The utility input cabinet includes two utility feeds and one diesel generator input, with three power sources configured for mutual backup. The power distribution solution is shown in Figure 2 [Figure 2: see original paper].

Distribution cabinet A1 contains two 630A circuit breakers and one PC-level 630A ATS (Automatic Transfer Switch) with dual bypass for automatic switching between the two utility feeds. Distribution cabinet A2 contains one 630A circuit breaker and one PC-level 630A ATS for switching between the output of cabinet A1 and the diesel generator.

Cabinet A3 serves as the UPS input distribution cabinet, equipped with four 250A input switches for main and bypass inputs of two UPS units, plus one spare 250A switch. Additionally, two 250A switches are installed as external maintenance bypasses for the two UPS units.

Cabinet A4 functions as the utility output distribution cabinet, containing two 160A switches for existing DC power supply inputs, two 100A and four 80A switches for computer room air conditioning and original first-floor distribution boxes, one 100A switch powering distribution box A5, and one spare 100A switch.

The computer room design employs the utility output cabinet as a power distribution cabinet, responsible for supplying power to UPS equipment, program-controlled computer room dedicated air conditioning, lighting, fresh air systems, and auxiliary outlets. Cabinet A4, as the utility output distribution cabinet, provides utility input for the program-controlled computer room' s DC power supply, first-floor and negative-first-floor air conditioning, two existing negative-first-floor lighting distribution boxes, first-floor lighting, fresh air, and computer room outlet distribution boxes.

The power distribution system adopts AC 50Hz, three-phase five-wire 380V/220V. The grounding system employs TN-S configuration with separate neutral and ground wires. The power distribution cabinet features overcurrent and short-circuit protection functions for switches, with current and voltage displays.

Cabinet A5 is the utility distribution cabinet responsible for lighting, fresh air, and auxiliary outlet power supply, with two ATS units for mutual backup output. The computer room power supply system distribution solution is illustrated in Figure 2 [Figure 2: see original paper].

2.2 Modular UPS Power Supply System

The current computer room AC equipment power is approximately 20KW, with DC power supply equipment at about 20KW (future loads will be transferred to UPS output). Upcoming projects will include storage, servers, and other equipment in four cabinets with power consumption of approximately 16KW, requiring a total UPS capacity of 56KW. The optimal UPS loading rate is 20%-70%, necessitating total capacity no less than 100KVA with redundant design. This system configures two modular UPS units for the computer room, providing dual power sources for the load. Each UPS frame supports up to 200KVA capacity and can accommodate four 50KVA power modules. Based on actual requirements, the initial configuration includes three 50KVA power modules per unit, providing 150KVA capacity per UPS with 2+1 redundancy for power modules and actual usable capacity of 100KVA. Future expansion to 200KVA per unit is possible by simply adding one power module, enabling online scalability.

Two UPS output distribution cabinets, A6 and A7, are configured, each containing one 225A switch and three 160A switches. Two of the 160A switches supply power to column head cabinets within the computer room, with other switches reserved as spares. One column head cabinet, A8, is configured in the program-controlled computer room, divided into A-side and B-side, each containing no fewer than 40 output switches supplying power to individual cabinets. The section from column head cabinets to equipment cabinet PDUs requires the use of industrial connectors with dual UPS power supply under the raised floor, with PDUs configured for each cabinet.

A monitoring system is established for the UPS units to continuously monitor operating status and parameters of the two UPS systems in operation, with alarm capabilities through the monitoring platform in case of faults. The monitoring system utilizes the SNMP communication interface and protocol built into the UPS equipment to transmit UPS data signals via local area network to monitoring servers, with monitoring platform software providing real-time monitoring of UPS output voltage, current, and other data. During UPS faults, the system indicates fault points through flashing corresponding sections in the simulation diagram, color changes, and voice alarms. The UPS also includes dry contact alarm connections for audible and visual alarms.

The two UPS units in this project employ redundant intelligent control modules—if one control module fails, a backup module activates without affecting overall system operation. Each module’ s control unit features redundancy, and inter-module communication lines are duplicated for dual communication paths.

Each UPS configured in this project includes components such as rectifiers, inverters, static bypass, manual maintenance bypass, and monitoring interfaces. The UPS inverter employs IGBT power modules with harmonic emission meeting international IEC standards. The UPS uses reliable static bypass switches to ensure uninterrupted switching to bypass power supply during internal UPS faults. Standard configuration includes main input, bypass input/output, and manual maintenance bypass switches, allowing uninterrupted load power during maintenance. The UPS features communication interfaces for remote monitoring of operating parameters and status, with fault diagnosis capabilities.

The UPS employs DSP digital control technology to ensure system safety and stability. It is equipped with LCD display screens showing equipment technical parameters and alarm information in menu format, with human-machine dialogue functionality allowing display and adjustment of important operating parameters via panel or remote controller. The system features soft-start capability, with parallel systems capable of sequential startup. Fans within each

UPS module employ redundant design—failure of any single fan at operating temperature does not affect normal UPS operation. Each UPS is configured with independent battery banks providing 30-minute backup time at full load, with current-limited charging capability, temperature compensation function for adjusting charging current based on UPS load and battery temperature, and over-discharge protection that automatically shuts down the UPS when battery banks reach their discharge voltage limit. Battery switches use pure DC circuit breakers as connections between UPS and battery banks. When the breaker is disconnected, batteries are completely isolated from rectifiers/chargers and inverters. The system includes release devices and auxiliary contacts to provide alarms in case of accidental breaker tripping. Electromagnetic compatibility standards: EMC meets EN50091-2 and IEC61000-4 series Class A standards.

Technical specifications for UPS input in this project include: voltage input range: 380V$±15±10±$0.1%; overload capacity: 150% for 1 minute, 125% for 10 minutes; voltage harmonic distortion for linear loads: <2%; voltage harmonic distortion for non-linear loads: <6%; crest factor: 3:1; output power factor: $ $0.9; voltage stability: transient variation <5%; transient response time <10ms; load capacity: operation for at least 2 hours at 100% load; operating environment: continuous high-temperature operation: $ $40℃ for 8 hours, maximum relative humidity: 95%; audible noise: <70dB (at 1 meter distance); other parameters: capability to handle 100% three-phase unbalanced loads; automatic switching to bypass when output overload exceeds 150%, with rapid return to normal UPS operation once input power is restored; overall efficiency: not less than 90% in double-conversion mode; inverter-to-bypass switching time <4ms; reliability: single-unit MTBF >100,000 hours; compatibility with generators requiring generator power no greater than 1.5 times UPS startup power.

Switching among the three power sources in distribution cabinets employs dual-power automatic transfer devices (ATS) with detection and automatic/delayed (continuously adjustable) switching functions for main and backup input power loss, phase loss, undervoltage, and overvoltage. Either source can be set as primary with selectable automatic/non-automatic recovery. All components should be made of non-hygroscopic and non-combustible materials. Distribution cabinet enclosures are fixed partition type. Cabinet wiring should be low-smoke, halogen-free, flame-retardant products, with busbars matched to switch capacity to handle required current while meeting dynamic and thermal stability requirements for low-voltage switchgear and connected components. Circuit breakers should have rated operational short-circuit breaking capacity and ultimate breaking capacity not less than 65kA/400-415V AC, with Ics=100%Icu. Circuit breakers feature open/closed operation status indicators showing breaker status. Utility input/output distribution cabinets and UPS input/output distribution cabinets include LCD displays for voltage, current, power, and other electrical parameters. Each switch of 80A and above is equipped with auxiliary contacts for connection to monitoring systems, supporting MODBUS or SNMP protocols for reporting and meeting requirements for unified management integration with the computer room’ s dynamic environmental management system.