

Dynamic Response Characteristics Analysis of Energy Storage System Based on Multimodal Data Fusion and Methods for Improving Power Supply Stability in Data Centers

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ABSTRACT With the rapid development of the digital economy, the scale of data center computing power continues to expand, and the high-density, high load, and uninterrupted power supply demand puts forward extreme requirements for the dynamic response capability and power supply guarantee accuracy of the supporting energy storage system. The traditional data center energy storage power supply control mode relies on a single electrical monitoring data, which has defects such as one-sided state perception, delayed dynamic response, weak disturbance suppression ability, and poor adaptability to multiple working conditions. It is difficult to cope with power supply instability caused by complex working conditions such as grid voltage fluctuations, instantaneous load changes, aging of energy storage modules, and environmental parameter drift. In response to the above pain points, this article proposes a dynamic response characteristic analysis method for energy storage systems based on multimodal data fusion and an optimization system for data center power supply stability.

INDEX TERMS Multi modal data fusion; Energy storage system; Dynamic response characteristics; data center

I. INTRODUCTION

A. RESEARCH SIGNIFICANCE

Against the backdrop of the comprehensive implementation of digital infrastructure and the large-scale development of the artificial intelligence computing power industry, data centers, as the core infrastructure of the digital economy, exhibit development characteristics of high-density deployment, high-power operation, and all-weather uninterrupted work. According to the latest statistics from the Ministry of Industry and Information Technology, the number of large and ultra large data centers in China has been increasing year by year. The power density of single cabinet has increased from traditional 3-5 kW to 15-30 kW, and some intelligent computing center cabinets have exceeded 50 kW. The high load and strong fluctuation operation characteristics have put forward strict requirements for the reliability, stability, and fast response capability of the power supply system. Data centers carry core key businesses such as cloud computing, big data computing, artificial intelligence inference, and government data storage. Transient power outages, voltage fluctuations, frequency offsets, and other power supply disturbances can all lead to data loss, equip-

ment downtime, and business interruptions, causing huge economic losses and social impacts. Therefore, ensuring absolute stability of the power supply system is the core prerequisite for the safe operation of data centers.

B. CURRENT RESEARCH STATUS AT HOME AND ABROAD

The dynamic response characteristics of energy storage systems refer to the dynamic changes in output power, voltage, current, and other parameters of energy storage devices under the effects of charge discharge switching, power command adjustment, and external disturbances. They are the core indicators for measuring energy storage regulation capabilities and power supply adaptability. At present, scholars at home and abroad have conducted extensive research on the dynamic response characteristics of energy storage systems, covering lithium battery energy storage, flywheel energy storage, supercapacitor energy storage, and hybrid energy storage systems.

Multimodal data fusion technology is an information technology that registers, fuses, and mines features of heterogeneous data from different sources, dimensions, and

types. It can effectively compensate for the information deficiencies of single data, improve state perception and analysis accuracy, and has been widely used in fields such as power equipment state monitoring, fault diagnosis, and system optimization and control.

In the field of energy storage, the application of multi-modal data fusion mainly focuses on battery state assessment and fault diagnosis. Some scholars have integrated battery voltage, current, and temperature data to construct a multimodal fusion model, achieving accurate estimation of battery SOC and SOH; Another study combines infrared image thermal modal data with electrical timing data to achieve thermal runaway fault warning for energy storage batteries. Existing applications mostly focus on monitoring the status of individual energy storage devices, and there is relatively little research on multimodal fusion for analyzing the dynamic response characteristics of energy storage systems. Most fusion algorithms are shallow feature fusion, which cannot explore the implicit coupling relationships between multimodal data, resulting in low fusion accuracy and poor real-time performance, making it difficult to meet the needs of dynamic real-time control of energy storage in data centers. Meanwhile, existing research has not established a quantitative correlation model between multimodal data and dynamic response characteristics of energy storage, as well as power supply stability, making it impossible to achieve active optimization of power supply stability based on multimodal perception.

II. MECHANISM OF ENERGY STORAGE AND POWER SUPPLY SYSTEM IN DATA CENTERS AND CONSTRUCTION OF MULTIMODAL DATA SYSTEM

A. ARCHITECTURE AND OPERATING MECHANISM OF DATA CENTER ENERGY STORAGE AND POWER SUPPLY SYSTEM

Under normal operating conditions of the system, the municipal power grid provides normal power supply to the data center load, while the energy storage system is in a floating charge standby state to maintain the rated power reserve and ensure instantaneous power switching in case of grid failure; When there are disturbances such as voltage fluctuations and frequency offsets in the power grid, the energy storage system responds quickly by adjusting the bus voltage and frequency through charging and discharging, suppressing power supply fluctuations; When the mains power is interrupted or the power grid fails, the energy storage system instantly switches to an independent power supply mode, providing uninterrupted power supply for key computing power loads and ensuring continuous business operation; When the load of the data center suddenly increases and the peak valley difference is too large, the energy storage system smooths the load power fluctuation, reduces the power supply pressure of the power grid, and avoids power supply instability caused by sudden load changes by peak shaving and valley filling, as shown in Table 1 below.

TABLE 1. Multi-modal data acquisition parameters of energy storage system

Data Modal	Core Collection Indicators	Sampling Frequency	Data Method	Preprocessing	Monitoring Function
Electrical Modal	Bus voltage, charge/discharge current, output power, SOC	100 Hz	Wavelet denoising, alignment	threshold time stamp	Reflect power output dynamic characteristics
Thermal Modal	Cell temperature, module temperature difference, temperature rise	50 Hz	Median filtering, spatial registration	spatial registration	Analyze thermal interference on response speed
Working Condition Modal	Load power, grid voltage fluctuation, switching state	20 Hz	Linear interpolation for missing data		Characterize load and grid disturbance intensity
Environmental Modal	Room temperature, humidity, air flow velocity	10 Hz	Sliding average filtering		Quantify external environmental interference

B. COLLECTION INDICATOR SYSTEM

Based on the operating mechanism of the energy storage power supply system in the data center and the factors affecting power supply stability, this paper constructs a multi-modal data system consisting of four categories: electrical mode, thermal mode, working mode, and environmental mode, covering the full dimensional state information of the energy storage system operation. The collection indicators, collection frequency, and data types of each modal data are as follows.

Thermal modal data is a key non electrical data that affects the response speed and operational stability of energy storage charging and discharging. The response characteristics, aging rate, and fault risk of lithium battery energy storage are closely related to the temperature state. The core collection indicators include: energy storage unit temperature, module maximum temperature, minimum temperature, module temperature difference, temperature rise rate, cooling fan operating status, and infrared thermal imaging temperature distribution matrix. The frequency of thermal data collection is 50Hz, which takes into account the hysteresis of temperature changes and real-time dynamic monitoring. It can accurately characterize the uniformity of energy storage thermal distribution and analyze the inhibitory effect of temperature factors on energy storage dynamic response, as shown in Table 2.

TABLE 2. Performance comparison of multi-modal fusion algorithms

Fusion Algorithm	Fusion Accuracy /%	Convergence Time /s	Operation Delay /ms	Feature Fitting Degree
Improved DBN (Proposed)	96.7	12.4	8.6	0.952
Traditional DBN	83.2	27.9	21.3	0.816
BP Neural Network	79.5	31.6	26.7	0.773
Weighted Average Fusion	72.1	4.2	3.5	0.685

Environmental modal data is an external environmental parameter that indirectly affects the operational status and response characteristics of energy storage. By affecting battery heat dissipation efficiency and internal resistance changes, it alters the dynamic response performance of energy storage. The core collection indicators include: am-

bient temperature, ambient humidity, air flow rate, and dust concentration in the energy storage room. The frequency of environmental data collection is 10Hz, and environmental parameters change slowly. Low frequency collection can reduce data redundancy while ensuring the integrity of environmental status monitoring.

C. MULTIMODAL DATA PREPROCESSING METHODS

The multimodal data collected in this article is a typical multi-source heterogeneous data, which has problems such as different data dimensions, large dimensional differences, inconsistent sampling frequencies, noise interference, data loss, spatiotemporal misalignment, etc. Directly using the original data will result in low fusion accuracy and large deviation in characteristic analysis. Therefore, it is necessary to standardize the original multimodal data, which mainly includes four steps: data denoising, missing completion, spatiotemporal registration, and normalization processing.

On site data collection for energy storage is susceptible to electromagnetic interference, equipment shaking, and signal transmission errors, resulting in high-frequency noise and random pulse noise. For high-frequency noise, the wavelet threshold denoising algorithm is adopted, and the db4 wavelet basis is selected for 5-layer wavelet decomposition. The high-frequency components are filtered through adaptive thresholding to reconstruct pure data, preserving the effective dynamic features of the data while filtering out high-frequency interference; To address pulse noise, the median filtering algorithm is used to replace abnormal pulse points in the data sequence, avoiding interference from noisy data in the analysis of characteristics.

Due to sensor failures, signal interruptions, and other factors, there is a problem of local missing data in multimodal data. Linear interpolation is used to complete the missing data for a short period of time; For long-term continuous missing data, based on temporal correlation features, tensor completion algorithm is adopted to combine historical data patterns under the same working conditions and states to accurately complete missing data, ensuring the integrity and continuity of the data sequence, as shown in Table 3 below.

TABLE 3. Grey correlation degree between energy storage response indicators and power supply stability

Energy Storage Dynamic Re- sponse Index	Grey Correlation Degree	Influence Level
Power Tracking Error	0.942	Primary core factor
Fluctuation Suppression Rate	0.915	Primary core factor
Response Delay	0.887	Secondary key factor
Steady-State Stability	0.853	Secondary key factor
Response Overshoot	0.812	General influence factor
Working Condition Adaptability	0.768	Weak influence factor

There are differences in the sampling frequency and collection time of various modal data, resulting in spatiotemporal misalignment of data and inability to directly couple and fuse. This article uses electrical high-frequency time-series data as a benchmark and adopts timestamp alignment

method to interpolate and match low-frequency data of thermal state, working condition, and environment in a time-series manner, unifying the time resolution of all modal data to 100Hz. At the same time, based on the spatial distribution position of energy storage modules, spatial registration of temperature and electrical data is completed, achieving accurate correspondence of multimodal data at the same spatiotemporal node.

III. RESEARCH ON HIERARCHICAL MULTIMODAL DATA FUSION ALGORITHM BASED ON IMPROVED DBN

A. LIMITATIONS ANALYSIS OF TRADITIONAL MULTIMODAL FUSION ALGORITHMS

Deep Belief Network (DBN), as a typical deep learning fusion model, has strong nonlinear feature mining and deep coupling capabilities, which can achieve autonomous feature learning of multi-source data without human intervention and adapt to multimodal heterogeneous data fusion scenarios. However, traditional DBN models suffer from problems such as vanishing activation function gradients, slow convergence speed of weight updates, and low accuracy of small sample feature fitting. When directly applied to energy storage multimodal data fusion, problems such as insufficient feature extraction, lagging fusion results, and large steady-state errors may arise, which cannot meet the needs of real-time analysis and precise control of energy storage dynamic response in data centers. Based on this, this article improves the traditional DBN model and constructs a layered multimodal deep fusion algorithm.

B. IMPROVE THE DBN MULTIMODAL FUSION ALGORITHM PROCESS

The specific execution process of the improved DBN hierarchical multimodal fusion algorithm proposed in this article is divided into five steps, achieving end-to-end autonomous fusion without the need for manual feature intervention. The specific process is as follows:

Step 1: Data input and preprocessing. Read the raw data of electrical, thermal, working conditions, and environmental modes, complete noise reduction, completion, spatiotemporal registration, normalization preprocessing, and construct a standardized multimodal dataset, as shown in Table 4 below.

TABLE 4. Quantitative index comparison of power supply stability under different control strategies

Working Condition	Index	Traditional Fixed PID	Proposed Adaptive Collaborative Control
Steady State	Bus Voltage Volatility /%	4.7	1.02
Load Fluctuation	Response Delay /ms	42.7	25.1
Grid Disturbance	Frequency Offset /Hz	0.48	0.18
High Temperature	Continuous Stability	68.2	90.0
Aging	/h		
Disturbance Working Condition	Power Tracking Error /kW	11.3	5.1

Step 2: Model initialization. Set hyperparameters such as the number of layers, nodes, iterations, learning rate, and initial momentum factor to improve the DBN model network and complete the initialization of model parameters.

Step 3: Pre train layer by layer. Adopting an unsupervised layer by layer pre training method, each layer of the RBM network is trained sequentially. By improving the weight update strategy, the parameters of each layer of the network are iteratively optimized, and the hierarchical features of multimodal data are autonomously learned.

Step 4: Reverse fine-tuning optimization. Based on annotated samples, the entire network model is globally fine tuned using error backpropagation algorithm to correct parameter deviations during pre training and improve model fusion accuracy.

Step 5: Fusion feature output. After iterative convergence of the model, output multimodal deep fusion feature vectors to complete multimodal data deep fusion and achieve accurate representation of the comprehensive operation status of the energy storage system.

C. PERFORMANCE VERIFICATION AND COMPARATIVE ANALYSIS OF FUSION ALGORITHMS

To verify the superiority of the improved DBN fusion algorithm in this article, traditional DBN algorithm, BP neural network fusion algorithm, and weighted average fusion algorithm were selected as comparison models, and performance comparison tests were conducted using four indicators: fusion accuracy, convergence speed, computation time, and feature fitting degree. The test dataset uses multimodal data from the actual operation of the energy storage system in the data center, including five typical operating conditions: steady-state, load fluctuation, power grid disturbance, low-temperature operation, and high-temperature aging.

IV. ANALYSIS OF THE CORRELATION MECHANISM AND INSTABILITY FACTORS BETWEEN ENERGY STORAGE RESPONSE CHARACTERISTICS AND DATA CENTER POWER SUPPLY STABILITY

A. QUANTITATIVE INDICATOR SYSTEM FOR POWER SUPPLY STABILITY IN DATA CENTERS

To accurately establish the correlation between energy storage dynamic response characteristics and power supply stability, this article combines the data center power supply industry standards to construct a quantitative index system for power supply stability. Four core indicators, namely bus voltage fluctuation rate, power supply frequency offset, instantaneous power supply deviation rate, and power supply continuous stability, are selected to comprehensively quantify the quality and stability level of power supply.

The fluctuation rate of bus voltage characterizes the degree of fluctuation of the power supply voltage. The smaller the value, the better the voltage stability, and it is the core indicator for the safe operation of data center equipment; The deviation amplitude of the power supply frequency is

characterized by the offset of the power supply frequency. If the offset is too large, it will cause abnormal operation of the computing equipment; The instantaneous power supply deviation rate characterizes the matching deviation between power supply and load demand under dynamic operating conditions, which directly affects the continuity of business operation; The continuous stability of power supply characterizes the ability of uninterrupted power supply during long-term operation, reflecting the reliability of the system's steady-state operation, as shown in Table 5.

TABLE 5. Three-mode collaborative control strategy of grid-energy storage-load

Operation Mode	Trigger Condition	Core Control Logic	Energy Storage Regulation Target
Steady State Cooperative Control	Normal grid, stable load	Optimize floating charge voltage, balance module temperature	Maintain standby state, eliminate hidden thermal risks
Disturbance Cooperative Control	Load sudden change, grid voltage fluctuation	Pre-adjust power, grid auxiliary compensation	Rapidly suppress voltage & frequency fluctuation
Fault Emergency Control	Mains power failure, grid outage	Seamless switching to off-grid power supply	Prioritize power supply for core computing loads

B. CONSTRUCTION OF COUPLED CORRELATION MODEL BASED ON GREY RELATIONAL ANALYSIS

There is a nonlinear and multivariate coupling relationship between the dynamic response characteristics of energy storage and power supply stability, and traditional linear analysis methods cannot accurately quantify the degree of correlation between the two. This article uses the grey relational analysis method to construct a multidimensional coupled correlation model, quantifying the correlation between various energy storage response characteristic indicators and power supply stability indicators, and accurately locating the core factors that affect power supply stability.

The model construction process is as follows: Firstly, select energy storage response delay, power tracking error, response overshoot, fluctuation suppression rate, steady-state stability, and working condition adaptability as comparison sequences, and select four power supply stability indicators as reference sequences; Secondly, dimensionless processing is applied to the sequence data to eliminate the influence of dimensionality; Then, calculate the grey correlation coefficient between each sequence and solve for the average correlation degree; Finally, based on the degree of correlation, the core influencing factors are identified. The higher the degree of correlation, the more significant the impact of energy storage response characteristics on power supply stability.

C. CORRELATION CALCULATION RESULTS AND COUPLING MECHANISM ANALYSIS

The ranking results of the correlation degree of each indicator were obtained through multi condition data calculation: power tracking error (0.942)>fluctuation suppression rate (0.915)>response delay (0.887)>steady-state stability (0.853)>response overshoot (0.812)>condition adaptability (0.768).

Based on the correlation results, the core coupling mechanism is revealed: firstly, the accuracy of energy storage power tracking is the most critical factor affecting the stability of data center power supply. An increase in power tracking error will directly lead to a mismatch between power supply and load demand, causing bus voltage fluctuations and instantaneous power supply deviations, which are the primary causes of power supply instability; Secondly, the ability to suppress fluctuations determines the system's ability to respond to external disturbances. Insufficient suppression rate can lead to direct transmission of power grid and load disturbances to the data center power supply bus, causing power supply oscillations; Thirdly, response delay directly affects the real-time response of disturbance. If the delay is too long, the disturbance cannot be suppressed in a timely manner, and the instantaneous power supply fluctuation will intensify; Fourthly, steady-state stability, overshoot, and adaptability to operating conditions mainly affect the stability of power supply under long-term and multi operating conditions, indirectly reducing the quality of power supply.

From the perspective of multimodal coupling, uneven thermal parameters and aging energy storage can increase power tracking errors, while load and grid disturbances can exacerbate response delays and fluctuations. The degradation of multimodal parameters affects the dynamic response characteristics of energy storage, ultimately leading to power supply instability in data centers, forming a complete instability transmission chain of "multimodal parameter anomalies - degradation of energy storage dynamic response - decrease in power supply stability".

D. SUMMARY OF CORE CAUSES OF POWER SUPPLY INSTABILITY IN DATA CENTERS

Based on the correlation mechanism and multi condition test results, summarize the three core causes of unstable energy storage power supply in data centers:

- (1) The lag in regulation caused by incomplete state perception. The traditional single electrical data perception mode cannot capture implicit anomalies in thermal state, environment, and working conditions, resulting in the inability of energy storage regulation strategies to adapt to real-time state changes, insufficient power tracking accuracy, and power supply fluctuations.
- (2) Insufficient adaptability of dynamic response. The fixed parameter control strategy cannot adaptively adjust according to multi-modal state changes. In complex working conditions such as load mutations, power grid disturbances, and

high temperature aging, the response speed and adjustment accuracy of energy storage significantly decrease, and the disturbance suppression ability is insufficient.

- (3) Multi factor coupled disturbances cannot be effectively suppressed. Under complex working conditions, multimodal parameter cross coupling leads to multidimensional degradation of energy storage dynamic response, and a single control method cannot solve the problem of power supply instability caused by the superposition of multiple factors.

V. ADAPTIVE IMPROVEMENT METHOD FOR POWER SUPPLY STABILITY IN DATA CENTERS DRIVEN BY MULTIMODAL PERCEPTION

A. OVERALL DESIGN CONCEPT FOR IMPROVING POWER SUPPLY STABILITY

In response to the causes of power supply instability in data centers, this paper proposes a multimodal perception driven adaptive improvement method for power supply stability. The core idea is to build a "perception evaluation regulation optimization" closed-loop control system based on multimodal deep fusion real-time state perception, quantified results of energy storage dynamic response characteristics, and optimized power supply stability indicators. By using multimodal real-time perception of energy storage operation status and working condition changes, dynamically evaluating the dynamic response performance of energy storage, adaptively adjusting energy storage charging and discharging control parameters and power regulation strategies, coordinating the operation status of the power grid, energy storage, and load, achieving active prevention and rapid suppression of power supply disturbances, and comprehensively improving the stability of data center power supply.

B. IMPROVED ADAPTIVE PID ENERGY STORAGE CONTROL ALGORITHM DESIGN

Traditional PID control parameters are fixed and cannot adapt to dynamic changes in multiple operating conditions, resulting in low control accuracy and weak disturbance resistance. This article is based on multimodal fusion features and dynamic response characteristics of energy storage, and designs a parameter adaptive PID control algorithm to achieve dynamic real-time adjustment of proportional, integral, and derivative parameters.

C. GRID ENERGY STORAGE LOAD COORDINATED POWER SUPPLY STABILITY CONTROL STRATEGY

To achieve stable power supply under all operating conditions, this paper constructs a multi-modal perception driven "grid energy storage load" tripartite collaborative control strategy, which is divided into three modes: steady-state collaborative control, disturbance collaborative control, and fault emergency control.

Under rated steady-state conditions, real-time monitoring of the power grid, energy storage, and load operation status is achieved through multimodal data to optimize the energy

storage float charging voltage and standby power, maintain the optimal standby state of energy storage, balance the operation status of various energy storage modules, and proactively avoid potential power supply risks caused by uneven thermal states and poor module consistency, ensuring zero fluctuations in steady-state power supply.

When load fluctuations and power grid disturbances are detected, the intensity and duration of the disturbances are predicted based on multimodal fusion features. Priority is given to quickly and dynamically adjusting energy storage to suppress power supply fluctuations, and adaptively adjusting charging and discharging power and response speed; Simultaneously linking with the power grid to complete power coordination compensation, predicting power demand in advance based on load fluctuation patterns, achieving active pre regulation of energy storage, suppressing power supply disturbances from the source, and significantly reducing voltage and frequency fluctuation amplitudes.

When extreme working conditions such as power grid faults and instantaneous power outages occur, the multimodal system instantly identifies the fault state, triggers the seamless switching of energy storage power supply mechanism, optimizes the emergency discharge strategy of energy storage, and ensures zero interruption of power supply switching; At the same time, based on the remaining energy storage capacity and thermal state, the emergency power supply power is dynamically adjusted to prioritize uninterrupted power supply to the core computing load, maximizing the reliability of power supply under fault conditions.

D. SIMULATION COMPARISON VERIFICATION AND RESULT ANALYSIS

To verify the effectiveness of the stability improvement method proposed in this article, a traditional fixed PID control method was set as the control group, and simulation comparative tests were conducted under five typical operating conditions to compare the power supply stability indicators and energy storage response performance indicators of the two methods.

The simulation results show that compared with traditional methods, the adaptive collaborative control method proposed in this paper achieves significant improvement in power supply stability under all operating conditions. Under steady-state conditions, the fluctuation rate of bus voltage is reduced by 78.3%, and the power supply frequency is basically unchanged; Under load fluctuation conditions, the energy storage response delay is reduced by 41.2%, the power tracking error is reduced by 54.7%, and the voltage fluctuation suppression rate is increased to 95.6%; Under the condition of power grid disturbance, the deviation of power supply frequency is reduced by 62.5%, and the instantaneous power supply deviation rate is significantly reduced; Under high temperature and harsh aging conditions, it can effectively compensate for the power supply fluctuations caused by the deterioration of energy storage performance,

and improve the continuous stability of power supply by 32.7%.

The overall test results fully demonstrate that the multimodal perception driven adaptive control strategy can accurately adapt to the complex operating conditions of data centers, effectively solving the problems of response lag, insufficient accuracy, and poor adaptability of traditional control methods, and comprehensively improving the dynamic response performance of energy storage and the stability of data center power supply.

VI. CONCLUSION

In response to the industry pain points of traditional data center energy storage power supply control mode, such as single perception dimension, lagging dynamic response, and insufficient power supply stability, this paper systematically conducts research on the dynamic response characteristics analysis and power supply stability improvement of energy storage systems through multimodal data fusion. A complete multimodal perception, characteristic analysis, mechanism modeling, and strategy optimization system is constructed. Through theoretical analysis, simulation verification, and engineering measurement, the core conclusions are as follows: (1) We have constructed a multimodal data acquisition and preprocessing system for energy storage systems that covers electrical, thermal, working conditions, and environmental aspects. This system solves the problems of traditional single data perception being one-sided, multi-source data being spatially and temporally misaligned, and noise interference. It can comprehensively and finely characterize the complex operating states of energy storage systems, providing high-quality data support for precise analysis of dynamic response characteristics.

(2) We have established a quantitative evaluation system for the dynamic response characteristics of energy storage systems under multiple operating conditions, completed characteristic analysis under five typical operating conditions, clarified the differential effects of external operating condition disturbances and internal state degradation on the speed, accuracy, and stability of energy storage response, and summarized the evolution law of energy storage dynamic response characteristics under multimodal coupling. (3) Propose a multimodal perception driven adaptive PID control algorithm and a grid energy storage load collaborative power supply stability control strategy to achieve dynamic adaptive optimization of energy storage control parameters and effectively adapt to complex and changing operating conditions. The test results show that the proposed method can shorten the energy storage response delay by 41.2%, improve the power supply stability index of data centers by 32.7%, significantly enhance the anti-interference ability and operational reliability of the power supply system, and fully adapt to the power supply needs of high-power density data centers.

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