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Current Status Analysis and Improvement Suggestions on Power Supply Reliability Technologies for Airport Microgrids

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ABSTRACT
The reliability of airport power supply systems is crucial for flight scheduling, air traffic control operations, and passenger safety. In recent years, microgrid technology has become a key solution for enhancing airport power supply reliability due to its flexibility, renewable energy integration capability, and emergency power supply advantages. However, challenges remain in areas such as extreme environment adaptability, redundancy design, energy storage technology, and intelligent management. Through literature analysis and case studies, this paper explores the core requirements and current status of airport microgrid power supply reliability, summarizes key technological trends in redundancy design, energy storage optimization, and intelligent scheduling, and proposes optimization strategies to provide references for improving airport power supply systems.

KEYWORDS
Airport microgrid; Power supply reliability; Redundancy design; Energy storage optimization; Intelligent scheduling

1 Introduction

1.1 Research Background and Significance

Airports, as critical hubs of modern transportation, require power supply systems with exceptionally high reliability to ensure flight operations, air traffic control, and passenger safety. For instance, in 2017, a power outage at Hartsfield-Jackson Atlanta International Airport led to the cancellation of over 1, 200 flights, causing direct economic losses exceeding $150 million. Any power interruption can result in flight delays, communication failures, or even safety incidents, leading to significant financial losses and social repercussions. Microgrid technology, with its flexibility, renewable energy integration capabilities, and emergency power supply advantages, has emerged as a vital solution for enhancing airport power supply reliability. As the aviation industry accelerates its transition to net-zero emissions, the rapid adoption of electric aircraft (EA) and electric vehicles (EVs) in airport parking lots imposes higher demands on ground power systems [1]. Microgrids must not only withstand extreme environments (e.g., low temperatures, salt mist), manage dynamic loads (e.g., instantaneous power demands up to 3 MW during aircraft takeoff/landing), and achieve ultra-high reliability (⩾99.999%), but also support the integration of electric aircraft charging facilities and vehicle-to-grid (V2G) technologies. These requirements present dual challenges for infrastructure planning and energy dispatch strategies.

1.2 Literature Review

Globally, airports in Europe and the U.S. lead in microgrid applications. For example, Singapore's Changi Airport has deployed photovoltaic systems (2.85 MW capacity) and energy storage technologies to explore synergies between renewable energy and emergency power supply [2]. Frankfurt Airport in Germany employs digital twin technology to optimize terminal energy management, though its application in microgrid fault prediction requires further refinement. Domestically, Beijing Daxing International Airport integrates photovoltaics, energy storage, and diesel generators in its microgrid system. However, challenges such as lithium battery capacity degradation in low-temperature environments remain industry-wide issues [3]. Existing research focuses on redundancy design, energy storage optimization, and intelligent control algorithms, but systematic studies on multi-energy coordination and extreme environment adaptability are lacking. For instance, NSGA-II algorithms have been used to optimize microgrid scheduling, demonstrating that V2G strategies improve economic efficiency [4]. Fault tree and Monte Carlo simulations quantify microgrid reliability in islanded modes, providing theoretical foundations for extreme event responses [5]. Distributed energy management strategies for AC/DC microgrids balance critical load supply and multi-agent privacy protection [6]. Nevertheless, gaps persist in environmental adaptability, multi-energy coordination, and management mechanisms, particularly in scenarios integrating electric aviation and microgrids.

1.3 Methodology

This study aims to systematically analyze the current status and common challenges of airport microgrid power supply reliability through literature reviews and case studies, while proposing targeted improvement strategies. The methodologies include:

Literature analysis: Summarizing domestic and international technological approaches and engineering practices.

Case comparison: Selecting representative cases (e.g., Beijing Daxing Airport, Singapore Changi Airport) to evaluate technological applications, including the impact of electric aircraft charging on microgrid loads.

Inductive synthesis: Identifying technical bottlenecks and management deficiencies, and proposing optimization strategies aligned with multi-energy coordination and privacy protection requirements.

2 Core Requirements and Current Status of Airport Microgrid Power Supply Reliability

2.1 Special Requirements of Airport Power Supply Systems

As critical infrastructure, airport power systems must meet stringent requirements. The International Civil Aviation Organization (ICAO) recommends a "five-nines" availability standard (⩾99.999%), with annual downtime not exceeding 5 minutes. Core loads (e.g., air traffic control radars, runway lighting, terminal emergency systems) require zero-interruption switching. High-latitude airports must withstand extreme cold (e.g., -40°C at Beijing Daxing Airport), while coastal airports require resistance to salt mist corrosion (e.g., Hong Kong International Airport). Additionally, microgrids must dynamically match fluctuating loads: aircraft charging power can reach 3 MW, requiring microgrids to respond within 50 ms. Furthermore, microgrids must balance constant loads (e.g., terminal lighting) and pulse loads (e.g., baggage conveyor startups).

2.2 Classification and Comparative Analysis of Existing Reliability Technologies

Existing technologies fall into three categories, with their applications and limitations summarized in Table 1:

Table 1 Classification and comparison of existing power supply technologies

Technology Type	Typical Solution	Advantages	Limitations
Redundancy Design	Dual-circuit supply, diesel backup	High fault tolerance, continuous core load supply	High switching delay (>200 ms), diesel startup issues in cold conditions
Energy Storage	Lithium batteries,super-capacitors,flywheels	Fast response (<20 ms), instantaneous power compensation	Lithium battery capacity decay in cold (-20°C: 30% loss), short cycle life
Intelligent Control	AI fault prediction, digital twin monitoring	Real-time energy optimization, reduced human intervention	High data dependency, initial investment costs

The integration and coordination of multi-energy systems (solar, wind, fuel cells) remain technical challenges [7].

3 Case Studies on Power Supply Reliability Challenges in Airport Microgrids

Airports, as critical infrastructure, face unique challenges in ensuring power supply reliability under environmental and load fluctuations. Three case studies illustrate current challenges and improvement directions.

3.1 Case Selection Criteria

Cases were selected based on:

Extreme climate impacts: Testing energy storage performance under low temperatures or salt mist.

Redundancy and fault response: Backup system switching speed and critical load protection during failures.

Digital monitoring and dispatch: Enhancing stability via digital twins and real-time monitoring.

3.2 Case Analysis

Case 1：Munich Airport, Multi-energy Complementarity and Redundancy Design

Munich Airport employs a self-built central thermal power station connected to the regional grid. Redundant systems (diesel generators) ensure continuous power supply under extreme weather, enabling rapid switching during failures to maintain reliability.

Case 2：Singapore Changi Airport , Green and Low-carbon Microgrid Construction

Changi Airport integrates solar PV, energy storage, and gas turbines. Large-scale rooftop PV arrays and smart grid switching ensure high reliability and energy efficiency, serving as a model for digital and intelligent energy management.

Case 3：Frankfurt Airport, Digital Twin and Intelligent Control Applications

Frankfurt Airport uses digital twins for real-time energy monitoring, enabling dynamic load management and fault prediction. During a localized fault, the system achieved seamless backup switching via predictive scheduling, ensuring uninterrupted critical load supply.

3.3 Case Summary

These cases highlight trends in multi-energy complementarity, green energy integration, and digitalization. Future improvements should focus on enhancing energy storage adaptability, refining intelligent dispatch systems, and optimizing redundancy designs.

4 Key Issues in Airport Microgrid Power Supply Reliability

4.1 Technical Challenges

Existing technical challenges primarily include short lifespan and poor low-temperature performance of energy storage systems. Due to the extreme environments where airports are often located (e. g., low temperatures in high-latitude regions, salt mist in coastal areas, and high humidity), current energy storage devices such as lithium batteries exhibit significant capacity degradation and reduced charge/discharge efficiency under low temperatures. These issues weaken the microgrid's ability to support instantaneous high-power demands during load peaks and emergencies. Another problem is the insufficient speed of redundancy switching. Some airports rely on backup systems (e.g., diesel generators) with slow startup delays, resulting in temporary power interruptions for critical loads during primary system failures. Existing redundancy designs fail to achieve millisecond-level fast switching, thereby affecting overall power supply continuity and system stability.

4.2 Management Challenges

Current management challenges include a lack of cross-domain expertise among maintenance personnel. Airport microgrids involve multiple fields such as power systems, aviation equipment, and information technology. Maintenance teams often lack professionals with interdisciplinary skills in electrical engineering and aviation systems, leading to blind spots in fault handling and routine maintenance. Additionally, insufficient cross-departmental collaboration impacts overall operational efficiency and fault response speed.

4.3 Environmental Adaptability Challenges

In coastal airports, salt mist corrosion poses a significant challenge. Over time, salt mist corrodes metal components of electrical equipment (e. g., transformers, switchgear), accelerating aging and reducing reliability. Inadequate anti-corrosion measures and improper material selection are primary causes of this issue. In high-latitude airports, low temperatures degrade the performance of energy storage systems, control units, and other critical components, reducing overall system efficiency. While low-temperature environments demand higher battery charge/discharge performance and energy conversion efficiency, existing equipment and temperature control measures require further improvement.

5 Strategies to Enhance Airport Microgrid Power Supply Reliability

5.1 Technical Improvement Recommendations

To address performance degradation of energy storage systems in extreme environments and slow response of backup systems, hybrid energy storage systems combining lithium batteries and supercapacitors should be promoted to leverage their respective advantages. Furthermore, constructing digital twin platforms and improving data acquisition systems will enable coordinated dispatch of multiple energy sources (solar, wind, diesel generators), thereby enhancing overall system efficiency and stability [8-9].

5.2 Management Optimization Recommendations

At the management level, interdisciplinary maintenance teams integrating experts from power engineering, aviation systems, and information technology should be established. Regular training and cross-departmental collaboration will improve fault response and routine maintenance capabilities. Concurrently, standardized emergency plans should be formulated, and regular full-system or localized fault simulation drills should be conducted to verify backup power switching and system recovery capabilities, ensuring rapid response during emergencies.

5.3 Environmental Adaptability Recommendations

For airports in regions with harsh climates, anti-salt mist and low-temperature heating technologies should be adopted. Examples include using corrosion-resistant materials and low-temperature-protected energy storage cabinets to mitigate equipment aging and enhance operational efficiency in cold environments. Environmental monitoring systems should also be strengthened to track parameters such as temperature, humidity, and salt mist concentration in real time. Preventive maintenance measures should be implemented, and renewable energy sources (solar, wind, biomass) should be further integrated to reduce reliance on traditional fuel-based power generation, achieving green, low-carbon, and sustainable power supply solutions.

6 Conclusions and Future Prospects

6.1 Conclusions

This study systematically analyzed the main challenges faced by airport microgrid power supply reliability through literature review, comparative analysis of typical cases, and problem induction. The research shows that airport power supply systems in extreme environments (such as low temperatures, salt mist, and high humidity) are prone to performance degradation of energy storage equipment. The insufficient redundancy design and fast-switching capability of backup power sources may lead to power interruptions of critical loads due to single-point failures. Meanwhile, the coordinated dispatch between multi-energy systems and data monitoring platforms are still underdeveloped.

6.2 Future Prospects

Future advancements in digital twins, artificial intelligence, IoT, and next-generation energy storage technologies will drive smarter and greener airport microgrids. Technologically, hybrid energy storage systems, rapid redundancy switching devices, and multi-energy coordination platforms will enhance system stability. Managerially, interdisciplinary teams and refined emergency drills will improve fault response capabilities. Environmentally, specialized equipment (e. g., anti-corrosion materials, low-temperature heating systems) will ensure long-term operational efficiency. Additionally, policy support, industry standards, and innovative business models will provide a robust foundation for sustainable improvements, enabling airports to meet future demands for low-carbon, intelligent, and highly reliable power supply systems.

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