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Comparative Analysis of Charging and Discharging Characteristics for Batteries in Aircraft Electric Power Systems

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***Abstract*—This paper presents a comparative analysis of the charging and discharging characteristics of batteries used in aircraft electric power systems. The performance and efficiency of different battery technologies play a crucial role in determining the viability of electric propulsion and power systems in aircraft applications. In this study, we systematically evaluate the charging and discharging behaviors of various battery types, including LiFePO4, Ni-Cd, and lead acid, using Simulink. The simulations encompass state of charge (SOC) dynamics, charging efficiency, discharging profiles, and passive cell balancing technique. By utilizing Simulink, we can accurately model the behavior of different battery technologies under various operating conditions. The results obtained from the simulations provide valuable insights into the performance, efficiency, and overall suitability of battery technologies for aircraft electric power systems. This comparative analysis, serves as a valuable resource for engineers and researchers involved in the design and optimization of battery management systems for aircraft applications, aiding in the informed selection and integration of batteries in aircraft electric power systems.**

***Index Terms*—Charging Characteristics, Discharging Characteristics, Simulink Simulation, State of Charge (SOC), Passive Cell Balancing**

I. Introduction

The aviation industry is increasingly exploring electric propulsion systems and power systems for aircraft applications, driven by the need for improved efficiency, reduced emissions, and enhanced operational flexibility. Battery technologies play a critical role in these systems, providing energy storage for various aircraft functions. In this context, it is essential to thoroughly analyze and understand the charging and discharging characteristics of different battery types to ensure optimal performance and reliability of aircraft electric power systems.

This paper presents a comparative analysis of two widely used battery technologies in aircraft applications: Lithium Iron Phosphate (LiFePO4) and Nickel-Cadmium (Ni-Cd). LiFePO4 batteries are known for their high energy density, longer cycle life, and enhanced safety features, making them a promising choice for aviation. On the other hand, Ni-Cd batteries have a long-standing track record in the industry, offering robustness and high discharge rates.

The objective of this study is to analyze the charging and discharging characteristics of LiFePO4 and Ni-Cd batteries and compare their performance in the context of aircraft electric power systems. To achieve this, simulation models were developed using Simulink, allowing for controlled and efficient evaluation of the batteries' behavior. The simulations included monitoring the state of charge (SOC), voltage, and current variations during both charging and discharging processes.

For the charging analysis, the simulation model observed the SOC, voltage, and current variations as the batteries were charged using suitable charging techniques. The goal was to assess the charging efficiency and performance of each battery type.

Similarly, for the discharging analysis, the simulation model monitored the SOC, voltage, and current variations as the batteries were discharged under specific load conditions. This analysis aimed to understand the discharging behavior, stability, and energy output of each battery type.

Furthermore, the study explored passive cell balancing techniques to address cell voltage imbalances and ensure the stable operation of battery packs. The simulation model included a MATLAB function code to implement passive cell balancing, comparing the SOC and discharging the battery with a higher SOC to achieve a stable SOC distribution.

By conducting a comprehensive analysis of the charging and discharging characteristics of LiFePO4 and Ni-Cd batteries, this study aims to provide valuable insights into their performance and suitability for aircraft electric power systems. The findings will contribute to informed decision-making in battery selection and the development of efficient battery management systems in aviation.

II. BATTERY TECHNOLOGIES FOR AIRCRAFT ELECTRIC POWER SYSTEMS

A. An Overview of Battery Types Used in Aircraft Applications

Aircraft electric power systems utilize various battery types, each with its own advantages and limitations. These batteries must meet stringent requirements for weight, size, energy density, reliability, and safety. Among the commonly used battery technologies are LiFePO4, Ni-Cd, and other chemistries such as lead-acid.

LiFePO4 batteries, based on lithium-ion technology, have gained significant attention in recent years due to their superior performance characteristics. They offer high energy density, allowing for increased power-to-weight ratios and longer flight durations. LiFePO4 batteries are known for their excellent thermal stability and intrinsic safety features, reducing the risk of thermal runaway and ensuring a higher level of reliability in aircraft applications.

Ni-Cd batteries have a long history in aviation and are renowned for their durability, high discharge rates, and ability to withstand extreme temperatures. They have been extensively used in aircraft due to their robustness and ability to handle high-power applications. However, Ni-Cd batteries are less energy-dense compared to LiFePO4 batteries and require careful monitoring and maintenance to prevent memory effects and capacity degradation.

Other battery chemistries, such as lead-acid, are occasionally used in specific aircraft applications where cost-effectiveness and low maintenance requirements are prioritized over energy density and weight considerations.

B. Brief Description of LiFePO4 and Ni-Cd Batteries

LiFePO4 batteries consist of a lithium iron phosphate cathode, a carbon-based anode, and a non-aqueous electrolyte. They offer a nominal cell voltage of 3.2 volts and can provide high discharge currents. LiFePO4 batteries exhibit excellent cycle life, typically lasting thousands of charge-discharge cycles, making them suitable for long-term use in aircraft applications. They also exhibit good thermal stability, low self-discharge rates, and high tolerance to overcharging and over-discharging.

Ni-Cd batteries employ a nickel-based cathode, a cadmium-based anode, and an alkaline electrolyte. They provide a nominal cell voltage of 1.2 volts and can deliver high discharge currents. Ni-Cd batteries are renowned for their robustness, withstanding harsh operating conditions and extreme temperature ranges. They exhibit good charge retention, making them suitable for applications requiring long-term energy storage.

Understanding the unique characteristics and behaviors of LiFePO4 and Ni-Cd batteries is crucial for the effective management and utilization of these technologies in aircraft electric power systems. Through comprehensive analysis of their charging and discharging characteristics, this research project aims to provide valuable insights into the performance and suitability of these battery technologies for aviation applications.

By examining the charging and discharging behaviors of LiFePO4 and Ni-Cd batteries, we can evaluate their respective advantages, limitations, and potential trade-offs in terms of energy capacity, efficiency, safety, and overall system performance. Such insights will contribute to the design, optimization, and management of battery systems for aircraft electric power systems, facilitating the transition towards more efficient and sustainable aviation practices. Table I presents a comprehensive comparison of two commonly used battery technologies, LiFePO4 (Lithium Iron Phosphate) and Ni-Cd (Nickel-Cadmium) batteries. This analysis aims to highlight the key differences between these two battery types based on various important parameters.

TABLE I
COMPARISON OF LIFEPO4 AND NI-CD BATTERIES

Parameter	LiFePO4 Battery	Ni-Cd Battery
Energy Density (Wh/kg)	100-160	40-60
Specific Power (W/kg)	200-400	100-200
Cycle Life	2,000-5,000	500-1,500
Self-discharge Rate	1-3% per month	20-30% per month
Memory Effect	None	Yes
Efficiency (%)	90-95	80-90
Maintenance	None	Regular maintenance
Cost	Expensive upfront	Cheaper upfront
Nominal Voltage (V)	3.2-3.3	1.2
Capacity (Ah)	45–55	23
Overcharge Tolerance	Very Low	Moderate
Operating temperature (°C)	-20 to 60	-20 to 50
Thermal stability	Good	Poor
Thermal Runaway Risk	Low	High

III. METHODOLOGY

To analyze and compare the charging and discharging characteristics of LiFePO4 and Ni-Cd batteries for aircraft electric power systems, a systematic methodology was followed. The methodology involved the creation of three simulation models using Simulink, a powerful simulation tool commonly used in the field of electrical engineering.

A. Battery Discharge Performance Model

In the first simulation model, the battery discharge performance was evaluated. Batteries from the Simulink library pack 'Electrical/Specialized Power Systems/Electric Drives/Extra Sources' were connected in series to represent the battery configuration in an aircraft electric power system. The model simulated the discharge process, and the variations in state of charge (SOC), voltage, and current for both LiFePO4 and Ni-Cd batteries were observed and analyzed.

B. Battery Charge Performance Model

The second simulation model focused on the battery charge performance. Batteries from the same Simulink library pack were used to represent the charging process. The model simulated the charging cycle, capturing the SOC, voltage, and current variations for LiFePO4 and Ni-Cd batteries. This allowed for a comparative analysis of the charging characteristics between the two battery technologies.

C. Passive Cell Balancing Model

The third simulation model was developed to investigate passive cell balancing techniques. Various batteries with different initial SOC levels were utilized in the model. Passive cell balancing was achieved through the implementation of a MATLAB function code, which compared the SOC of each battery and discharged the one with a higher SOC to achieve a more balanced SOC distribution over time. The model enabled the observation of SOC stabilization and provided insights into the effectiveness of passive cell balancing for LiFePO4 and Ni-Cd batteries.

The methodology employed in this study enabled a comprehensive evaluation of the charging and discharging characteristics of LiFePO4 and Ni-Cd batteries, as well as an exploration of passive cell balancing techniques. By utilizing a simulation-based approach, the research facilitated controlled and efficient investigations into these battery technologies. This approach allowed for the collection of valuable data, which was subsequently analyzed and compared. The study aimed to enhance the understanding of LiFePO4 and Ni-Cd batteries' performance and suitability in aircraft applications.

IV. ANALYSIS OF DISCHARGING CHARACTERISTICS

In this section, the discharging characteristics of LiFePO4 and Ni-Cd batteries are analyzed and compared. The analysis is based on the data obtained from the simulation models described in Section III.

A. State of Charge (SOC) Variation

The study aimed to investigate and compare the SOC discharge rates of LiFePO4 and Ni-Cd batteries, with a focus on analyzing voltage and current variations. To ensure a fair and meaningful comparison, an experimental design was implemented to achieve similar SOC discharge rates for both battery types. This allowed for a reliable assessment of the voltage and current variations exhibited by LiFePO4 and Ni-Cd batteries during the discharge process. Figure 1 presents the results, demonstrating closely matched discharge rates for both battery technologies and enabling a comprehensive analysis of their performance characteristics.

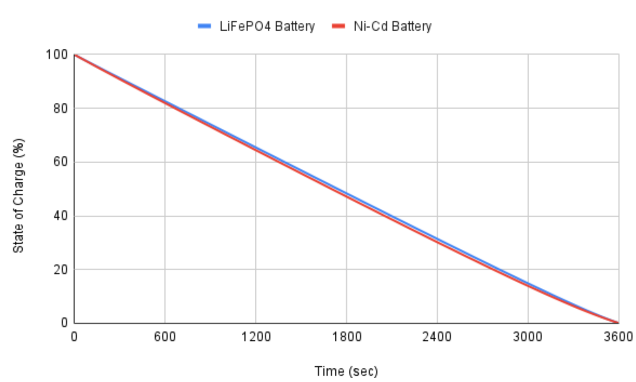

Fig. 1. SOC Discharge

B. Voltage and Current Behavior

Simulation results depicted in Figure 2 illustrate the disparity in current discharge characteristics between LiFePO4 and Ni-Cd batteries. The LiFePO4 battery displayed superior performance with an initial current of 2.93A, followed by a gradual stabilization within the range of 2.69A to 2.59A, and ultimately settling at 1.76A after one hour. Conversely, the Ni-Cd battery initiated at 1.30A, maintaining a relatively stable discharge between 1.17A and 1.19A, and gradually declining to 0.70A after the same duration.

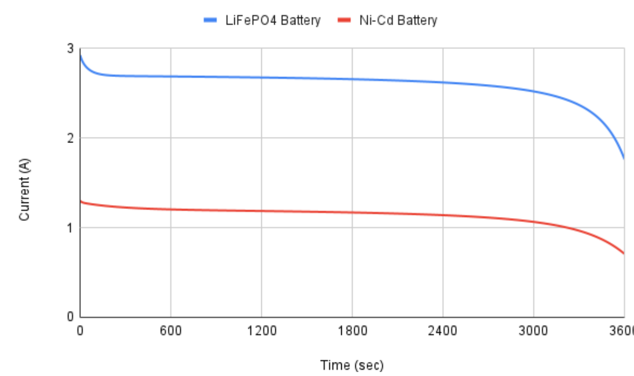

Fig. 2. Current Discharge

These outcomes underscore the advantageous current discharge behavior exhibited by LiFePO4 batteries compared to their Ni-Cd counterparts, as indicated by the higher initial current and more consistent discharge profile over time.

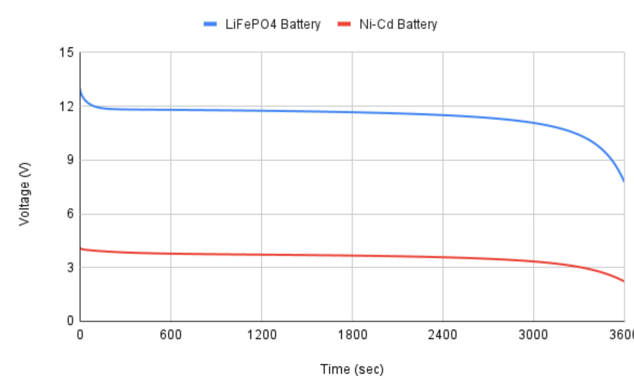

Fig. 3. Voltage Discharge

Simulated results depicted in Figure 3 illustrate the voltage discharge of LiFePO4 and Ni-Cd batteries reveal distinct characteristics. The LiFePO4 battery initially started at 12.97V, maintaining a relatively stable voltage of around 11.8-11.6V for a period of time. However, it gradually declined over the course of an hour, reaching 7.76V.

Similarly, the Ni-Cd battery began at 4.13V and exhibited similar behavior, remaining around 3.7-3.6V for a while. However, it experienced a more significant voltage drop compared to the LiFePO4 battery, reaching 2.22V after an hour.

C. Comparison of Discharge Behaviors

LiFePO4 batteries demonstrate a more gradual and stable discharge with higher initial current and a relatively stable voltage profile. In contrast, Ni-Cd batteries exhibit a faster decline in SOC, lower initial current, and a more significant voltage drop during discharge. The superior current discharge capability of LiFePO4 batteries, along with their ability to maintain a stable voltage output, positions them as a reliable and efficient energy storage solution compared to Ni-Cd batteries.

V. ANALYSIS OF CHARGING CHARACTERISTICS

A. *State of Charge (SOC) Development*

The investigation of State of Charge (SOC) development during the charging process was conducted for both LiFePO4 and Ni-Cd batteries. LiFePO4 batteries exhibited a gradual and consistent SOC curve, steadily increasing as the charging progress. In contrast, Ni-Cd batteries demonstrated a linear SOC development, albeit with minor fluctuations and irregularities observed at various charging stages, as illustrated in Figure 4.

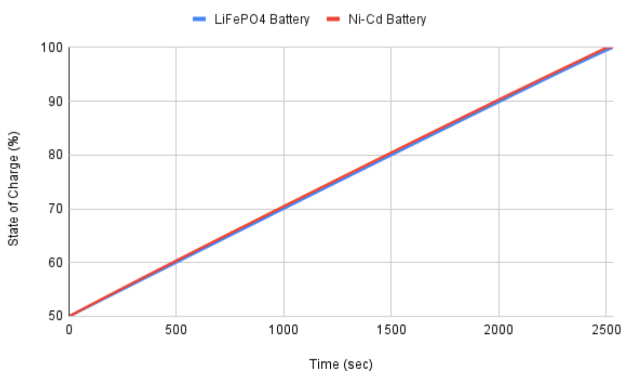

Fig. 4. SOC Charge

B. *Voltage Variations*

During the charging process, as shown in Figure 5, the voltage variations of LiFePO4 and Ni-Cd batteries were monitored. LiFePO4 batteries displayed a more stable voltage profile, with a gradual increase in voltage as the charging progressed and a fast paced increase towards the end of the charging cycle. On the other hand, Ni-Cd batteries exhibited more fluctuation in voltage, with sudden spikes and drops observed during the initial charging phase.

Overall, the analysis of charging characteristics highlights the superior charging efficiency, stable voltage profile, and consistent SOC development of LiFePO4 batteries compared to Ni-Cd batteries. These findings emphasize the advantages of LiFePO4 technology for aircraft electric power systems, offering more efficient and reliable charging performance.

VI. PASSIVE CELL BALANCING ANALYSIS

Passive cell balancing analysis was conducted to assess the effectiveness of this technique in maintaining balanced state of charge (SOC) among batteries in a system. Passive cell balancing refers to the process of equalizing the SOC of individual battery cells without the need for external energy sources or active control.

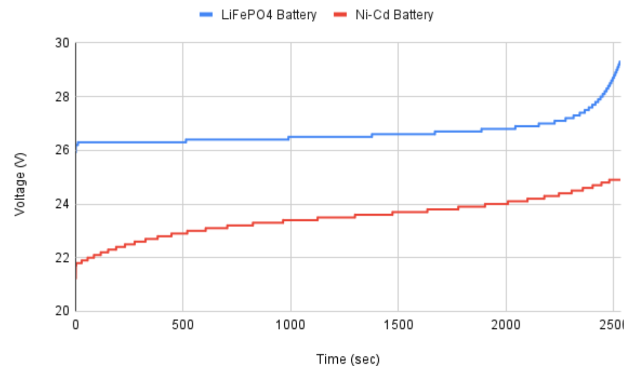

Fig. 5. Voltage Charge

A. *Experimental Setup*

For the analysis, a system consisting of four batteries with different initial SOC levels was used. Passive cell balancing was implemented using a MATLAB function code. The code compared the SOC of each battery and discharged the battery with a higher SOC to achieve a more balanced SOC distribution among all batteries.

B. *SOC Balancing Results*

The results of the passive cell balancing analysis illustrated in Figure 6 demonstrates its effectiveness in achieving a balanced SOC among the batteries. Initially, the batteries had different SOC levels, but over time, the SOC of each battery converged towards a stable and balanced state. The analysis showed a gradual equalization of SOC levels among the batteries, indicating successful passive cell balancing.

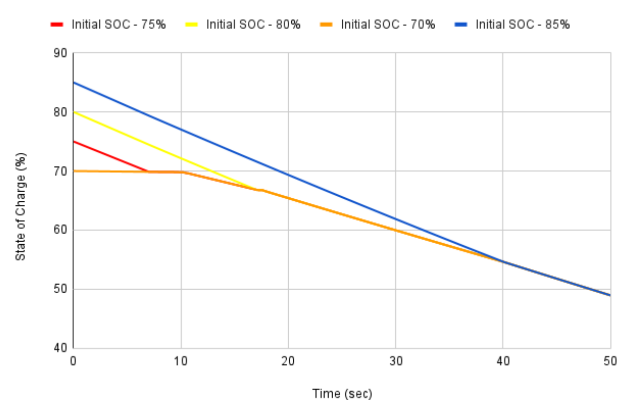

Fig. 6. Passive Cell Balancing

C. *Stability and Performance*

Passive cell balancing not only achieved SOC balancing but also contributed to the stability and performance of the battery system. By equalizing the SOC, the overall system performance improved, as the batteries operated in a more synchronized manner. Additionally, maintaining balanced SOC levels can prolong the battery's lifespan and optimize its energy storage capacity.

VII. Conclusion

This paper presents a comprehensive analysis of the charging and discharging characteristics of LiFePO4 and Ni-Cd batteries for aircraft electric power systems was conducted. Through simulation models and data analysis, valuable insights were gained regarding the performance and suitability of these battery technologies. Additionally, passive cell balancing techniques were examined to address SOC imbalances among batteries.

The analysis of charging characteristics revealed that LiFePO4 batteries exhibited higher charging efficiency compared to Ni-Cd batteries. LiFePO4 batteries required less energy input to achieve the same state of charge (SOC), indicating a more efficient charging process. Furthermore, LiFePO4 batteries displayed a more stable voltage profile during charging, ensuring a reliable and controlled energy input.

The comparison of discharging characteristics demonstrated that LiFePO4 batteries exhibited a more gradual and stable discharge, with higher initial current and a relatively stable voltage profile. On the other hand, Ni-Cd batteries showed a faster decline in SOC, lower initial current, and a more significant voltage drop during discharge. These findings highlight the superior current discharge capability and stable discharge profile of LiFePO4 batteries, positioning them as a reliable and efficient energy storage solution compared to Ni-Cd batteries.

Additionally, the analysis of passive cell balancing techniques showed their effectiveness in achieving balanced SOC among batteries. By implementing passive cell balancing using MATLAB function code, the SOC levels of individual batteries converged towards a more balanced state over time. This technique contributes to the stability, performance, and longevity of the battery system, optimizing its energy storage capacity.

Based on the results, it can be concluded that LiFePO4 batteries offer significant advantages over Ni-Cd batteries for aircraft electric power systems. LiFePO4 batteries exhibit higher charging efficiency, more stable discharge characteristics, and superior current discharge capability. These features make LiFePO4 batteries well-suited for applications with high-power demand, such as electric aircraft.

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