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THE IMPACT OF INTELLIGENT CONTROL CHARGERS ON THE DURABILITY AND PERFORMANCE OF INDUSTRIAL BATTERIES

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Abstract
The introduction of intelligent chargers into the industry is aimed at improving the durability and performance of batteries. The purpose of the study is to evaluate the impact of adaptive and intelligent charging technologies on the performance of industrial batteries. The study used simulation models and field test analysis. The results showed that intelligent memory devices that regulate charging depending on the condition and temperature of the batteries reduce the risk of overheating and extend battery life by 25-40%. Optimizing the charging process improves the efficiency of the equipment, reducing operating costs. The findings of the study confirm that the use of intelligent charging systems contributes to the sustainable and cost-effective operation of batteries, ensuring the fulfillment of set goals and objectives.

Keywords Intelligent chargers, durability, performance, industrial batteries, adaptive charging control.

INTRODUCTION

The development of the industrial sector and technological processes in recent decades has been accompanied by an increased reliance on battery systems, which are essential for ensuring uninterrupted power supply and maintaining equipment operations across various industries. Industrial batteries play a critical role in transportation, energy, logistics, and manufacturing. This creates a demand for improving their efficiency and durability, necessitating new approaches to managing charging and discharging processes.

Traditional battery charging methods do not always support optimal operational performance, especially under high loads and extended usage. In such conditions, the risk of overheating, wear, and premature failure of batteries increases. Intelligent chargers represent modern solutions capable of adapting to the state and parameters of batteries, ensuring precise control of the charging process and preventing adverse effects on battery components.

The relevance of this topic is driven by the growing industrial need for reliable and durable battery systems, as well as the necessity to reduce operational costs and enhance environmental sustainability. The implementation of intelligent chargers optimizes charging processes, minimizes the risk of damage, and ensures stable equipment operation. This study aimss to analyze the impact of intelligent charging systems on the longevity and performance of industrial batteries and to assess their potential for enhancing efficiency.

METHODS

Industrial batteries hold a significant position in modern technologies, providing a stable and efficient energy supply for various production processes. Several main types of batteries exist, each with unique characteristics suitable for specific applications [1]. In the energy sector, industrial batteries are used for storing surplus energy generated by renewable sources. In transportation, they power electric vehicles. In telecommunications, these batteries serve as backup power sources, while in manufacturing, they ensure uninterrupted operations [2].

Industrial batteries are classified by the type of active materials and electrolytes used. A representation of the variety of industrial batteries is shown in Figure 1.

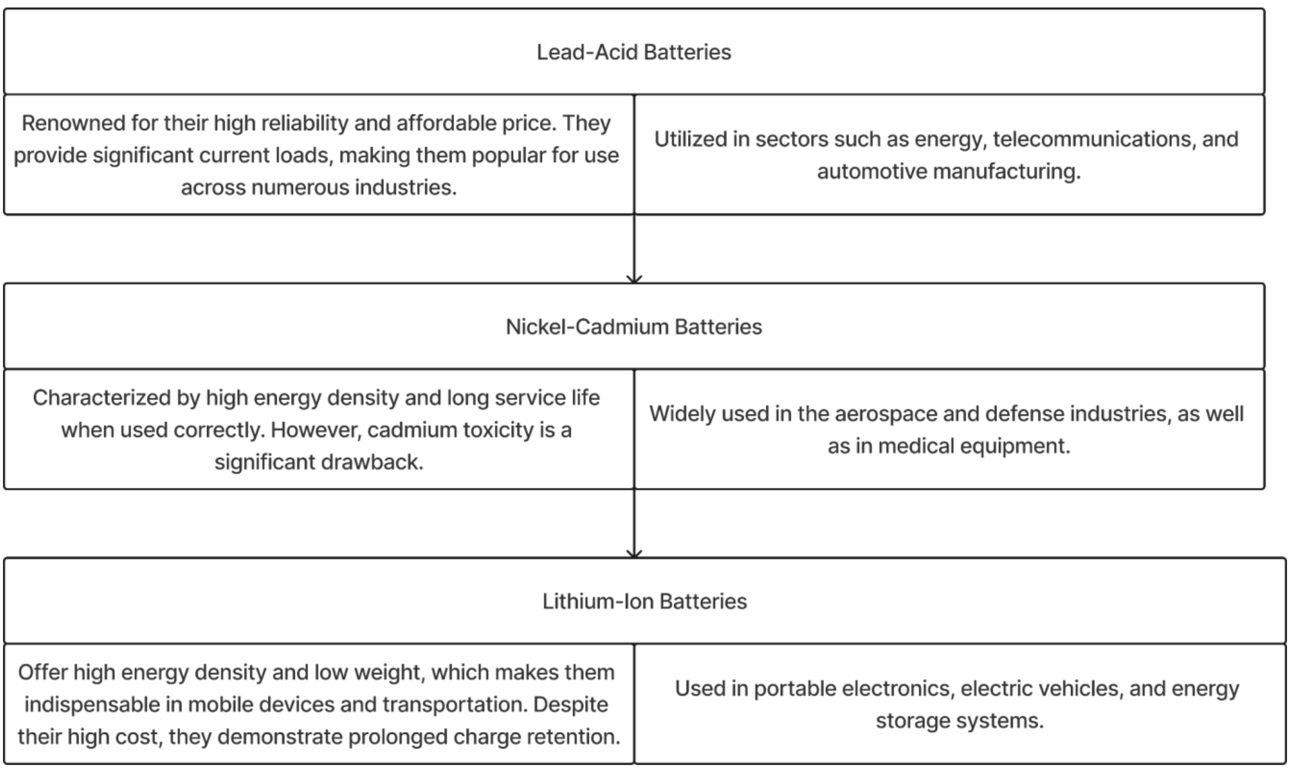

Fig.1. A variety of industrial batteries [3].

Modern battery charging methods rely on microprocessor-based technologies that implement two-, three-, or four-stage charging modes. Devices known as "intelligent charging stations" manage the process based on battery parameters, allowing precise monitoring of the battery's condition. The three-stage process for lead-acid batteries includes bulk, absorption, and float stages, with an optional equalization phase. A two-stage scheme typically involves only the bulk and float stages [4]. Selecting the appropriate voltage, adhering to battery manufacturers' recommendations, and using high-quality charging stations with microprocessor control contribute to extending battery lifespan and maintaining capacity [5].

Intelligent battery management systems (BMS) are gaining popularity as batteries become widely used across various industries. Regular monitoring and maintenance are required for stable operation and extended service life. Previously, engineers conducted manual testing, which was time-consuming and often failed to provide comprehensive data.

Modern BMS technologies offer optimized maintenance solutions, significantly enhancing the accuracy and efficiency of battery condition monitoring. This, in turn, improves performance and safety. The primary function of a BMS is to monitor battery parameters, such as voltage and temperature, and adapt settings according to system requirements [6].

Intelligent battery management systems (BMS) prevent overloading and excessive discharge of batteries, minimizing potential issues. BMS provides data on the state of charge (SoC) and state of health (SoH) of batteries, enhancing their operational performance.

BMS includes various components: cutoff field-effect transistors (FETs), charge level sensors, cell voltage monitors, and temperature sensors. FETs manage the connection of battery cells, reducing the need for high-voltage devices. Charge level sensors evaluate voltage changes in conjunction with load and time, determining the remaining driving range of a vehicle. Cell voltage monitors track battery conditions, recording data on charging and discharging rates. Temperature sensors adjust the charging and discharging processes based on thermal conditions.

BMS operates as an integrated computer system, linking various sensors to monitor the temperature, voltage, and current of each battery cell. The system ensures accurate data acquisition and anomaly detection, enabling prompt actions to maintain battery safety and efficiency.

If the temperature exceeds permissible levels, the management system activates cooling methods to lower the battery temperature. Modern BMS supports cell voltage equalization, eliminating variations. With advanced technologies, BMS enhances battery protection and capacity management, providing electrical and thermal safeguards while optimizing battery performance.

The operation of battery management systems involves technical complexity due to the intricacy of their components. A well-designed BMS monitors and protects battery modules, preventing deviations from the parameters set by the manufacturer. Lithium-ion batteries require a specialized approach, as their allowable currents and voltages depend on operating conditions. BMS monitors and regulates these parameters, ensuring stable battery performance [7].

The battery management system (BMS) performs several key functions to ensure optimal operation and safety, as detailed in Table 1.

Table 1. Functions of the Battery Management System (BMS) [8]

Function	Description
Monitoring Status	BMS tracks battery parameters and records the number of charge/discharge cycles, voltage, and current thresholds to maintain battery functionality.
Analytical Function	Based on data, BMS calculates permissible charge/discharge current levels, energy-charged and discharged, internal cell resistance, and the overall battery lifespan.
Communication	The data collected by the system can be transmitted to external devices via wired

	or wireless connections.
Protection	BMS ensures safety by monitoring parameters and preventing critical situations such as overcurrent, overvoltage during charging, Undervoltage during discharge, overheating/cooling, and current leakage. BMS can disconnect the battery from the load or charger when parameters exceed allowable limits.
Balancing	BMS equalizes cell charge levels to extend battery lifespan: redistributes energy from more charged cells to less charged ones (active balancing), reduces current for fully charged cells (shunting), and adjusts the output current through modular charging.

The intelligent battery management system (Smart BMS) for lithium-ion batteries offers several advantages, enhancing performance and safety. Key benefits of using Smart BMS include:

- Extended Battery Lifespan: Modern battery management systems extend the lifespan of lithium-ion batteries by continuously monitoring and precisely adjusting operational parameters, ensuring stability over extended periods.

- Enhanced Safety Measures: Equipped with advanced protection mechanisms, Smart BMS prevents overcurrent, overcharging, and deep discharge, and monitors temperature to minimize risks of overheating and other potential hazards, ensuring safe operation.

- Optimized Energy Management: Smart BMS employs intelligent algorithms to manage charging and discharging processes efficiently, maximizing resource utilization and enhancing overall system productivity.

- Remote Monitoring and Control: Advanced Smart BMS solutions enable remote access to battery data and operational control, allowing real-time parameter monitoring and management regardless of location.

- Data Logging and Analysis: BMS provides detailed data collection and analysis on battery performance, facilitating the development of preventive measures and optimization strategies, thus improving operational efficiency and reliability.

- Integration with Smart Grids: Modern battery management systems are designed for seamless integration with smart grids and IoT, automating energy management processes and enhancing efficiency for residential and commercial applications [9].

However, the capabilities of BMS in obtaining detailed information about battery conditions remain limited, hindering accurate assessments of wear levels and safety evaluations. This highlights the necessity of comprehensive battery management throughout their entire lifecycle. Under operational conditions, particularly in transportation, BMS faces challenges in handling large volumes of data due to low processing performance and limited speed.

Optimizing battery management requires in-depth research into aging processes and thermal phenomena in batteries. The integration of big data technologies and artificial intelligence (AI) into BMS offers opportunities for effective lifecycle monitoring of batteries. With the advancement of big data, AI, blockchain, and IoT technologies, the concept of the digital twin (DT) gains new prospects. A digital twin enables the creation of a synchronized model of the physical object, allowing real-time condition monitoring and performance forecasting.

Initially, DT was applied in the aerospace industry to predict remaining resource life and manage the condition of equipment. For example, the study by Ezhilarasu and colleagues discusses the use of DT for assessing the operational readiness of complex systems, such as aircraft. Li and co-authors developed a digital model for analyzing system states and monitoring the formation of cracks in aircraft wings. Although still in development, this methodology shows significant potential for optimizing and forecasting complex systems.

Lithium-ion batteries are complex systems with nonlinear, interdependent internal parameters. Their lifespan is influenced by numerous factors, requiring advanced research for accurate state assessment, rapid charging, thermal regulation, and lifespan extension. Utilizing DT for battery systems enables the creation of a virtual structure synchronized with the physical battery. This model incorporates sensors for collecting data on voltage, current, and temperature, as well as various models, such as geometric and thermal, housed in a virtual environment. AI and big data technologies provide capabilities for monitoring, predicting, and managing batteries across all lifecycle stages.

Figure 2 illustrates the possibilities of employing modern technologies for monitoring battery conditions.

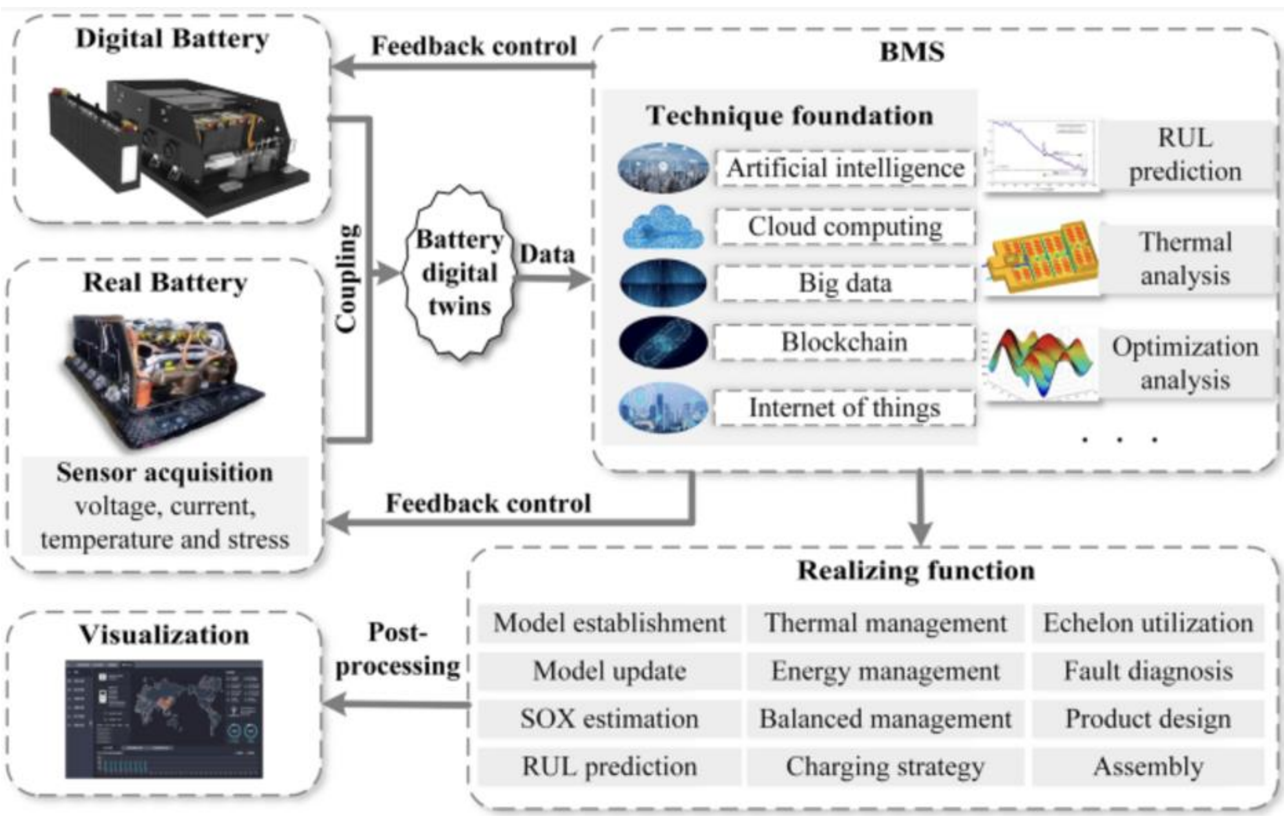

Fig.2. The use of modern technologies in monitoring the state of the battery [10].

Based on the above, it is evident that battery management, including BMS (Battery Management Systems), contributes to extending battery lifespan, enhancing safety, and optimizing energy consumption. The introduction of intelligent monitoring systems and emerging technologies, such as big data and AI, opens up new possibilities for improving battery management at every stage of their lifecycle. Nonetheless, challenges related to condition monitoring persist, underscoring the need for further research to enhance the accuracy of performance evaluations and wear predictions for batteries.

RESULTS AND DISCUSSION

Smart charging devices influence the durability and performance of industrial batteries by optimizing charging and discharging processes. Equipped with algorithms and sensors, these devices monitor parameters such as charge level, temperature, battery condition, and equipment usage intensity. These capabilities minimize the risk of battery damage, extend battery lifespan, and improve overall efficiency.

Toyota Material Handling, one of the world's largest manufacturers of warehouse equipment, employs smart chargers for electric forklifts and stackers. Toyota's charging systems automatically adjust voltage and current based on battery conditions, preventing overheating and overcharging, which can damage batteries and shorten their lifespan. Customers using this equipment have reported a 30% increase in battery life compared to traditional chargers. Maintenance costs have also decreased, as batteries require less frequent replacement, as confirmed by company reports [11].

Enersys, a major supplier of industrial and energy system batteries, develops and implements smart charging systems, such as the IMPAQ series. These chargers integrate with battery management systems, allowing users to remotely monitor equipment status in real-time. This is particularly relevant for companies relying on batteries in backup power networks, such as data centers and manufacturing facilities. In one case within the energy sector, Enersys demonstrated that smart chargers increased battery capacity by 20%, reduced recovery time, and enhanced the reliability of critical systems [12].

Caterpillar, a global leader in mining equipment production, deploys smart charging systems to manage the batteries of its electric and hybrid underground vehicles. Accurate battery charging control is essential in mining environments to maintain durability and reliability. Caterpillar's systems monitor battery temperature and charge levels in real-time, adjusting charging processes based on environmental conditions. This prevents overheating and potential damage caused by the high temperatures often encountered in mines.

A notable example of successful implementation was recorded in Canadian mines, where the use of smart chargers extended battery life by 35%. Consequently, companies utilizing these solutions reduced battery replacement frequency and maintenance costs—critical advantages in the highly competitive and cost-intensive mining industry [13].

The Swedish company Sandvik, specializing in equipment for the mining industry, develops and utilizes smart charging systems for electric drilling rigs used in underground operations, where both equipment performance and reliability in conditions of limited access and high humidity are critical. Sandvik has implemented intelligent charging devices that automatically adjust the charging current based on environmental conditions and battery usage intensity. In a project in Australia, the company demonstrated that the use of such technologies increased the operating time of drilling rigs by 15% without requiring battery replacement. This reduces equipment downtime and enhances mining efficiency [14].

Smart chargers are utilized across various industries, including mining, ensuring the longevity and high performance of batteries under challenging operational conditions. Company examples illustrate that employing such technologies extends equipment lifespan, reduces operational costs, and enhances overall efficiency and environmental sustainability in mines and underground facilities.

CONCLUSION

The study revealed that smart charging systems positively influence the durability and performance of industrial batteries. The analysis demonstrated that these systems optimize charging and discharging processes, preventing overheating and wear of battery components. By adapting charging parameters to the current battery condition, smart devices provide precise control over battery health, extending their lifespan and improving overall efficiency.

The results of trials and simulation models showed that implementing smart charging technologies can increase battery lifespan by 25–40% and reduce operational costs associated with maintenance and replacement. Additionally, the use of intelligent chargers minimizes equipment downtime and enhances reliability, which is particularly important for critical industrial applications.

In conclusion, the study confirms the prospects of using smart charging systems for industrial applications, enabling not only improved battery system longevity but also enhanced operational performance of enterprises. The adoption of such technologies contributes to sustainable development and increased economic efficiency across various industrial sectors.

REFERENCES

1. Olabi A. G. et al. Rechargeable batteries: technical progress, problems, current and future applications //Energy. – 2023. – vol. 266. – p. 126408.
2. Krekov V. O., Mizina Yu. V. Innovations in the industry of production of carbon material for batteries //The creativity of the young belongs to their native region. - 2023. – pp. 418-422.
3. Ivanov A. S., Klenova T. V., Koneva D. A. Development of domestic industrial policy: new conditions and factors //Bulletin of the Volgograd State University. Episode 3: Economics. Ecology. – 2023. – vol. 25. – No. 2. – pp. 19-32.
4. Mokryak A. V. Factors influencing the aging of a lithium-ion battery // Modern Science. - 2021. - No. 4-1. - P. 468-471.
5. Chernov M. B., Golubkov A.V. Computer simulation of charge state dynamics (SOC) of electric batteries //Scientific notes of UlSU. The series "Mathematics and Information Technology". – 2023. – No. 1. – pp. 171-179.
6. Gabber H. A., Ataman A.M., Abdus Sami M. R. Review of Battery Management Systems (BMS) and industrial standards developments //Technologies. – 2021. – Volume 9. – No. 2. – p. 28.
7. Habib A. K. M. A. et al. Lithium-ion battery management system for electric vehicles: constraints, challenges, and recommendations //Batteries. – 2023. – T. 9. – №. 3. – C. 152.
8. Battery Management System (BMS). [Electronic resource] Access mode: https://e-solarpower.ru/faq/vse-ob-akkumulyatorah/sistema-upravleniya-batarei-bms / (accessed 07.09.2024).
9. Wang W. et al. Application of digital twin in smart battery management systems //Chinese Journal of Mechanical Engineering. – 2021. – Vol. 34. – No. 1. – p. 57.
10. Ratnikov S. A., Simonov B. M. Application of the mathematical model of batteries //Intelligent systems and microsystem technology. - 2022. – pp. 99-104.
11. Find the light energy solutions for your

operation. [Electronic resource] Access mode: https://toyota-forklifts.eu/solutions/energy-solutions /(accessed 07.09.2024).

12. Powering the Future - Everywhere for Everyone. [Electronic resource] Access mode: https://www.enersys.com/en-gb /(accessed 07.09.2024).

13. Caterpillar presents a revolutionary dynamic energy transfer solution for battery and diesel-electric mining equipment. [Electronic resource] Access mode: https://klimov.com/news/article/caterpillar-predstavlyaet-revolyucionnoe-reshenie-po-dinamicheskoi-peredache-energii-dlya-akkumulyatornogo-i-dizel-elektricheskogo-gornogo-oborudovaniya/(accessed 07.09.2024).

14. Electrification. [Electronic resource] Access mode: https://www.rocktechnology.sandvik/ru/products/%D1%82%D0%B5%D1%85%D0%BD%D0%BE%D0%BB%D0%BE%D0%B3%D0%B8%D1%8F/electrification/(accessed 07.09.2024).