Design and implementation of a new energy storage information universal management platform

Shulei Pan[*a], Qiangsheng Dai[b], Xuesong Huo[b], Yunlong Du[b], Guobing Guan[a], Yang Zhang[a], Hui Wang[a]
[a]Yancheng Power Supply Branch, State Grid Jiangsu Electric Power Co., Ltd., Yancheng, Jiangsu, China; [b]State Grid Jiangsu Electric Power Co., Ltd., Nanjing, Jiangsu, China

ABSTRACT

Battery energy storage technology is crucial for advancing new energy solutions, achieving carbon neutrality, and promoting sustainable development. Effective monitoring and management systems are essential components of this technology. This paper presents the design and implementation of a new energy storage information universal management system. The proposed system offers real-time monitoring of battery voltage and temperature via an intuitive visual human-machine interface, while also enabling authority management. It further supports remote protection and control operations, including battery access and connection management. Moreover, the system is capable of systematically collecting and analyzing battery performance data on a regular basis.support IEC 61850/IEC 104 background monitoring, and enable power conversion with PCS. Experiments on multiple energy storage power stations have shown that the system significantly improves the management efficiency and safety of battery energy storage, improves user interaction, and reduces maintenance costs.

Keywords: Battery energy storage technology, real-time monitoring system, remote protection and control, data analysis and management

1. INTRODUCTION

Battery energy storage technology is pivotal in the integration and utilization of renewable energy sources, including solar and wind power. An effective monitoring system for battery energy storage is fundamental to ensuring the efficient operation and management of these technologies. Currently, battery energy storage systems mainly involve large warehouses filled with lead-acid and NiMH batteries, categorized and densely packed[1]. However, these storage environments are characterized by limited space, strong chemical odors, poor temperature regulation, high humidity, and low light levels, making them unsuitable for manual operations. The efficient management and monitoring of these systems are vital to ensure safety, performance, and longevity[2].

Xue et al. (2018) discussed the resource allocation technology of relay protection device research, which is crucial for optimizing energy storage systems[3]. They highlighted the significance of component type and logic diagram-based design (Xue et al., 2017) in enhancing efficiency[4]. Similarly, Ahmad et al. (2022) explored data-driven probabilistic machine learning in sustainable smart energy systems, emphasizing the role of machine learning algorithms in predicting and managing energy storage data[5]. This integration of advanced technologies facilitates the creation of more resilient and adaptable energy storage solutions, capable of meeting the dynamic demands of modern power grids.

Gu and Li (2018) proposed an automatic identification method for substation main wiring modes using fuzzy K-nearest neighbor algorithms[6]. This methodology underscores the importance of accurate data collection and real-time processing in energy storage systems. Implementing such methodologies ensures that energy storage systems can efficiently gather and process vast amounts of data, leading to more informed decision-making and improved system reliability.

Yang (2017) introduced a data consensus framework for the energy internet, which is instrumental in facilitating the integration of diverse energy sources into a unified system[7]. This framework can be adapted to the universal management system for energy storage information, ensuring seamless communication and data sharing among different components of the smart grid. Moreover, Zhou et al. (2015) discussed the practical applications of distributed bus protection in ring networks, highlighting the benefits of decentralized data management in enhancing system robustness and fault tolerance[8]. These applications demonstrate the potential of a universal management system in optimizing the

[*]1748425192@qq.com

International Conference on Optics, Electronics, and Communication Engineering (OECE 2024), edited by Yang Yue, Proc. of SPIE Vol. 13395, 133953L · © 2024 SPIE · 0277-786X · Published
under a Creative Commons Attribution CC-BY 3.0 License · doi: 10.1117/12.3048851

performance and reliability of smart grid infrastructures.

The availability of digital data and robust data connectivity underpin the development and deployment of various software utilities. Among these are intelligent energy applications that bolster the security of energy supply, enhance the efficiency of electrical systems, and optimize the use of infrastructure across electricity generation, distribution, and consumption. These applications utilize real-time measurements within smart grids and buildings to provide deeper insights into energy system states, particularly in the context of distributed energy resources (DERs) such as distributed generation, electric vehicles, and battery storage[9]. Furthermore, these tools empower consumers to manage their electricity consumption proactively and engage in electricity markets. The platform discussed in this paper is designed to demonstrate these capabilities.

2. BATTERY MANAGEMENT SYSTEM

2.1 Battery box management unit (BMU)

The Battery Box Management Unit (BMU) is the smallest management unit within the energy storage information universal management system, typically overseeing 12 energy storage batteries within an independent battery box. The primary functions of the BMU are to monitor critical parameters such as voltage, temperature, and alarm statuses of these batteries, ensuring they operate within safe and optimal conditions[10]. By managing these parameters, the BMU helps to maintain the overall health and performance of the batteries, providing real-time responses to any issues that may arise.

The battery box managed by the BMU can be configured and adjusted according to specific needs and situations, though it typically contains 12 batteries by default. The BMU's capability to collect and relay vital information about these batteries is fundamental to the system's real-time monitoring and long-term reliability. This granular level of management allows for detailed oversight and immediate action when necessary, highlighting the BMU's integral role in the system architecture and ensuring the batteries' optimal performance and safety[11].

2.2 Battery cluster management unit (BCMU)

The Battery Cluster Management Unit (BCMU) serves as the management unit for battery clusters, each of which typically includes 20 BMUs. This configuration allows the BCMU to monitor, control, and transmit information from up to 240 batteries within a single cluster. The BCMU is responsible for collecting data from the BMUs, summarizing this information, and communicating it to the higher-level Battery Bin Information Management Unit (BIMU). This hierarchical structure ensures smooth data flow from individual batteries to higher-level management units for analysis and action.

The BCMU's ability to efficiently handle a large volume of data is critical for maintaining the overall health and performance of the battery storage system. By summarizing and analyzing the information collected from the BMUs, the BCMU ensures comprehensive data availability for system-wide management and decision-making. This structure not only facilitates effective monitoring and control of the battery clusters but also enhances the efficiency and reliability of the entire energy storage system[12].

2.3 Battery bin information management unit (BIMU) and external communication unit

The Battery Bin Information Management Unit (BIMU) is designed to manage and analyze the information collected by both BMUs and BCMUs. It provides a visual human-computer interaction interface that allows field personnel to monitor the entire system in real-time. This interface is crucial for facilitating immediate responses to any issues detected within the battery clusters or individual battery boxes. Additionally, the BIMU supports authority management, distinguishing between different user roles to enhance security and reliability. It integrates various communication interfaces, including RS-485 and Ethernet, to ensure seamless data transmission across the system.

One of the key functionalities of the BIMU is its ability to store data persistently using an SQLite database. This allows for long-term analysis of battery performance and consumption trends, providing valuable insights into the system's operation. By maintaining a comprehensive historical record of battery data, the BIMU enables operators to identify patterns and predict potential issues before they become critical, thereby optimizing the performance and lifespan of the battery storage system.

The external communication unit, while not a submodule of the system itself, plays a vital role in the overall architecture. It facilitates the integration of the battery energy storage system with other systems and networks, enhancing its functionality and interoperability. The external communication unit ensures seamless communication with various external devices and platforms, supporting the exchange of information crucial for large-scale implementations where the battery storage system interacts with other components of the smart grid.

3. PLATFORM DESIGN

3.1 Requirements and design method

The diverse design requirements for the data platform stemmed from the interdisciplinary nature of the research project, which concentrated on a range of energy-related datasets and applications. The platform was required to integrate multiple data sources within the building, a feature that is atypical in the building sector. The application demands encompassed straightforward real-time visualizations, quick control responses, and the capability to manage large volumes of data. However, many of these requirements lacked clear definition during the design phase, resulting in design decisions that emphasized comprehensive data management—an approach generally not viable in standard commercial solutions.

The platform was designed to adapt to the existing environment without requiring specific standards from data sources or significant changes at the site. This adaptability facilitates future implementation at other sites. Consequently, the platform needed to be flexible and scalable to accommodate various data sources, data transfer methods, and data flows. While most communication protocols and data formats conformed to common standards, some manufacturer-specific solutions were encountered. Data sources were added incrementally as they became available, agreements for data collection were made, and technical specifications were received from different energy storage equipment suppliers.

To achieve a flexible and scalable design, a bespoke data collection system, independent of specific manufacturers and technologies, was deemed most effective. The data acquisition module, known as the Data Collector, was decoupled from the backend infrastructure to facilitate real-time data access and support rapid control responses. The energy storage management platform, supplied by a project partner, was employed to create visualizations and conduct analyses within the backend, complemented by data analysis using external tools. The primary objective was not to innovate a new architecture but to provide a practical solution for aggregating diverse data sources, enabling their integration and application in smart energy research and applications.

3.2 Data acquisition module

The initial design of this system was intended for bidirectional communication, enabling both the acquisition of data from IoT devices and the transmission of control commands to them. Although its current functionality is primarily focused on data collection, relying solely on backend storage and analysis would introduce issues such as network latency and the inefficiencies of centralized computation, particularly in control loop scenarios. Consequently, the platform's architecture adopts an edge computing paradigm, which not only facilitates the preliminary filtering and pre-processing of data prior to backend transmission but also integrates data from diverse sources into a cohesive data model, thereby enhancing its semantic richness..

The edge computing unit, referred to as the Data Collector, is designed to interface with local devices, ensuring minimal latency. It processes, adapts, and filters the data as required before transmitting it to the backend, which consists of an energy storage management platform and a network drive. To protect user privacy and minimize data transfer, only a subset of the filtered data is forwarded to the energy storage management platform, while the unfiltered data is securely stored on a university network drive for research or decision-making purposes. Access to this network drive is strictly controlled due to the sensitive nature of the raw data. The system employs network backups to manage limited disk space, allowing the Data Collector to retain unfiltered data for up to seven days. The stored data includes identifiers, timestamps, and corresponding values, organized chronologically within a single file based on the order in which the Data Collector receives the data. Additionally, the Data Collector is capable of buffering data for delayed transmission to the backend if necessary and can integrate external data sources, such as weather forecasts, to support decision-making processes.To enhance flexibility and accommodate diverse data sources, the Data Collector is designed with a modular architecture comprising two primary components: adapters and a multiplexer. Adapters are lightweight programs that interface with local devices and other data sources, retrieve data using the source's specific protocol, convert the data into a standardized internal model (including ID, value, and timestamp), and transmit it to the multiplexer. The multiplexer aggregates data from multiple adapters, stores the complete dataset locally, packages the filtered data into larger blocks, and transfers these to the backend energy storage management platform via its REST API. Data required for decision-making and control processes is directly forwarded from the multiplexer to the decision-making system. The separation of adapters from the multiplexer allows for dynamic selection and reconfiguration during runtime. This architecture also supports platform scalability, enabling adapters to operate across multiple hosts. If a single multiplexer instance is unable to manage the entire data load, additional instances can be deployed, and certain adapters can be reconfigured to direct data to the new multiplexer instances.

Adapters are designed to isolate generic functionalities from those specific to the data source whenever feasible. For instance, when data from two source devices was provided via Modbus, a versatile and configurable BMS/PCS adapter was employed for both, as illustrated in Figure 1. The data source adapter, driven by metadata, consists of both general-purpose and source-specific components. This modular approach, which separates all components of the Data Collector, facilitates the flexible integration or removal of adapters. However, ensuring swift and reliable communication between the various components of the Data Collector is crucial to avoid data loss during transmission. UDP is used for communication between components, with acknowledgment logic to ensure data receipt. This logic is configurable to balance between high throughput (where some data loss is acceptable) and ensuring all data is received.

Beyond the communication protocol and data model, data sources exhibit diverse temporal behaviors. Certain sources provide updates upon any change in values, whereas others require periodic polling. The frequency of these updates is determined by the nature of the data source; for instance, weather forecasts are refreshed every six hours, while electrical measurements from eQL Quality Meters are updated every second. Each recorded measurement is accompanied by a timestamp, which is standardized to UTC time by the adapter components. At present, the Data Collector components, including the multiplexer and adapters, are entirely developed in Python. However, this does not preclude the possibility of future adapters being created using alternative technologies, provided they are compatible with UDP communication. The platform is versatile and can be deployed in any environment that supports Python; in our specific implementation, this flexibility is leveraged., we use a Rocky-6.0.80 Linux environment.

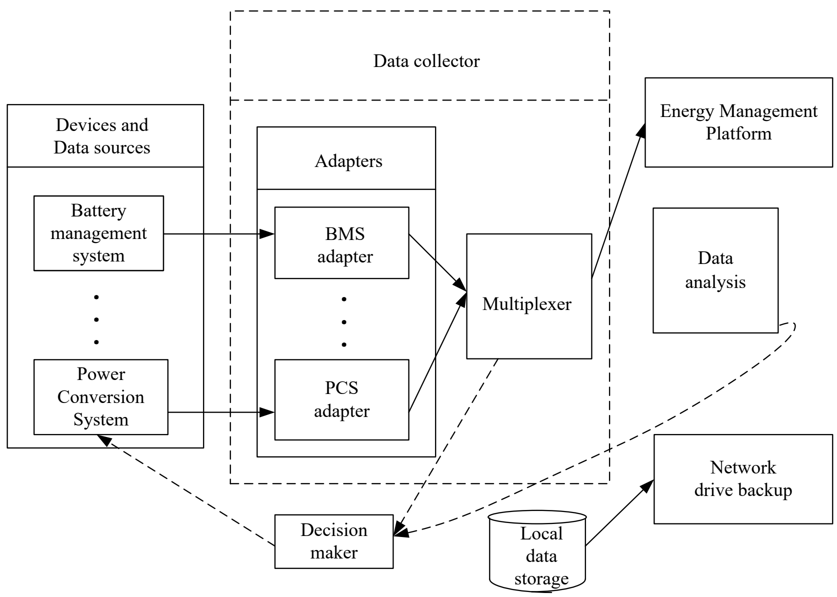

Figure 1. Diagram of the data collection and management platform architecture.

3.3 Data handling platform

The IoT-Ticket platform, serving as the back-end energy storage management system, was utilized for the storage and visualization of the collected data. It was deployed within the same virtualized environment as the building's Data Collector. The data acquired from the Data Collector needed to be formatted to conform to IoT-Ticket's tree-structured hierarchical data model. In this structure, specific measurements, such as phase voltage or external temperature, are organized under device components within data nodes, represented as lists of value-timestamp pairs. The entire building was represented as a singular device, with all associated measurements cataloged accordingly.

In IoT-Ticket, each data node is assigned a unique name and path that uniquely identifies it. This led to the creation of a naming hierarchy analogous to those used in many file systems, employing a four-part path:

/system/subsystem/location/type. The "system" component categorizes the primary nature of the measurement, the "subsystem" offers additional specifics about the target, such as ventilation, the "location" indicates the physical site, like the battery compartment number, and the "type" defines the nature of the measurement, such as temperature or voltage. Each data node received a distinct name to facilitate easy identification, while the path provided contextual information that aids in the seamless navigation of the data through the IoT-Ticket web browser interface.

IoT-Ticket supplies web-based tools for the visualization and analysis of collected data through dashboards, which can be constructed via a graphical user interface, eliminating the need for programming expertise. These dashboards are capable of monitoring real-time measurements or delving into historical data. External applications can access the data through IoT-Ticket's integrated REST API, or data can be exported directly from the browser interface. Figure 2 illustrates the internal workings of the adapter and multiplexer components within the Data Collector, using the battery management system as an example to depict data processing. Despite the diversity of data sources, each adapter follows the general workflow depicted in Figure 2.

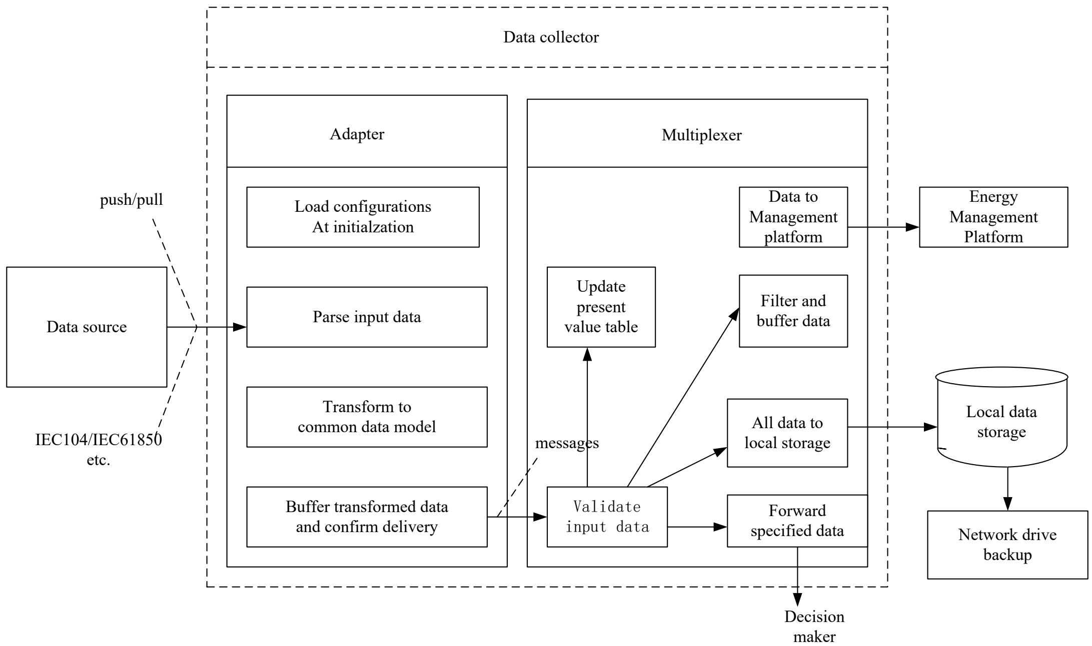

Figure 2. Diagram of data collection architecture detailing adapter and multiplexer logic: simplified with one data source and adapter.

3.4 Charging and discharging forecasting for energy storage power stations

The dataset employed for model training comprised time series of one-minute averages of total active power. The primary aim was to evaluate the data's accessibility and investigate how electrical measurements from the energy storage power station could be leveraged for forecasting purposes. This capability could be integrated into the back-end energy storage management platform, enabling it to deliver forecasts to decision-makers. The model generated a two-week charging and discharging forecast, as depicted in Figure 3. The blue forecast line demonstrates a closer alignment with the measurement points during weekdays compared to weekends, suggesting that the forecast accuracy could be enhanced through improved model tuning and the incorporation of additional data.

In future research, these forecasts could be applied to evaluate the effects of energy efficiency measures on charging and discharging cycles or to estimate the demand response potential of an energy resource or a cluster of electrical appliances. The platform offered high time-resolution data, and the historical data was readily utilized in the model training process.

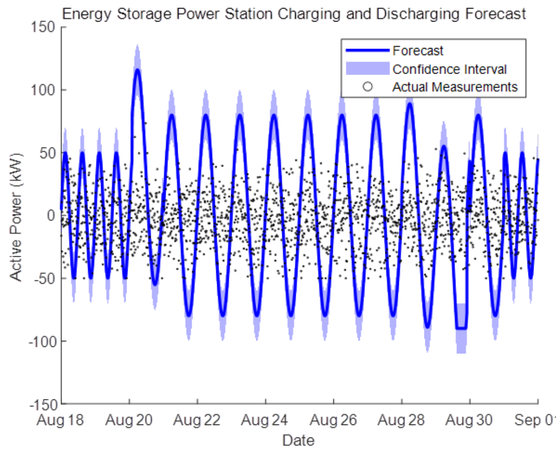

Figure 3. Two-week charging and discharging forecast (blue line), uncertainty (blue area), and measurements (black dots) for energy storage power station.

4. CONCLUSIONS

This paper details the design and implementation of a new energy storage information universal management system, focusing on its critical role in advancing battery energy storage technology. The system is designed to address the growing need for effective monitoring and management of energy storage solutions, which are essential for achieving carbon neutrality and promoting sustainable development. By incorporating a visual man-machine interface, the system allows for real-time monitoring of battery voltage and temperature, ensuring that operators have immediate access to crucial data for maintaining optimal battery performance. The system also supports authority management, enhancing security by distinguishing between different user roles and ensuring that only authorized personnel can perform specific operations. Furthermore, it facilitates remote protection and control actions, such as battery access and connection, thus reducing the need for manual intervention and minimizing the risk of human error.

In addition to real-time monitoring, the system is equipped with features that enable long-term data collection and analysis, providing valuable insights into battery performance. The system supports multiple databases, ensuring persistent data storage and easy access for analysis. The system's capability to support IEC61850 background monitoring allows for seamless integration with other components of the smart grid, enhancing interoperability and ensuring efficient data exchange between different systems. Moreover, the system enables power conversion with PCs, further broadening its applicability in various energy storage scenarios. Network connection experiments conducted in multiple substations have validated the system's effectiveness. These experiments have demonstrated that the system significantly enhances the management efficiency and safety of battery energy storage, improves user interaction, and reduces maintenance costs, thereby proving its feasibility and ease of use.

Overall, the new energy storage information universal management system represents a significant advancement in battery energy storage technology. Its comprehensive design, which includes real-time monitoring, remote control capabilities, and long-term data analysis, addresses the critical needs of modern energy storage solutions. By improving management efficiency, enhancing safety, and reducing maintenance costs, the system not only supports sustainable development goals but also offers a robust solution for the challenges faced in energy storage management. The successful implementation and testing of the system in various energy storage power stations underscore its practicality and effectiveness, making it a valuable tool for advancing the future of energy storage technology.

ACKNOWLEDGMENT

Thanks to the State Grid Jiangsu Electric Power Co., Ltd. for funding the science and technology project "Research on New Energy Storage Comprehensive Data Management Technology and Device Development" (Project No. JF2023019).

REFERENCES

[1] Ahmad, T., Madonski, R., Zhang, D., Huang, C. and Mujeeb, A., "Data-driven probabilistic machine learning in sustainable smart energy/smart energy systems: Key developments, challenges, and future research opportunities in the context of smart grid paradigm," Renewable and Sustainable Energy Reviews, 160, 112128 (2022).

[2] Balsalobre-Lorente, D., Sinha, A. and Murshed, M., "Russia-Ukraine conflict sentiments and energy market returns in G7 countries: Discovering the unexplored dynamics," Energy Economics, 125, 106847 (2023).

[3] Cui, L., Yue, S., Nghiem, X. H. and Duan, M., "Exploring the risk and economic vulnerability of global energy supply chain interruption in the context of Russo-Ukrainian war," Resources Policy, 81, 103373 (2023).

[4] Gu, L. and Li, Y., "Automatic identification method for substation main wiring modes based on fuzzy K-nearest neighbor algorithm," Guangdong Electric Power, 31(2), 130-135 (2018).

[5] Suo, J., Liu, K. and Yuan, L., "Construction of parallel test system for relay protection static simulation," Guangdong Electric Power, 33(10), 46-55 (2019).

[6] Xue, Z., Dong, B., Zhang, Y. and Yang, B., "Research on resource allocation technology of relay protection device research and development," Protection and Control of Power System, 46(4), 144-149 (2018).

[7] Xue, Z., Dong, B., Zhang, Y. and Yang, B., "Design and implementation of relay protection device selection function," Electrical Appliances and Energy Efficiency Management Technology, 2017(20), 28-32 (2017).

[8] Yang, Y., "A data consensus framework for energy internet," Guangdong Electric Power, 30(12), 22-28(2017).

[9] Zhou, X., Wang, S. and Wu, Z., "Discussion on local distributed bus protection based on MapReduce architecture," Protection and Control of Power System, 46(6), 128-135 (2015).

[10] Xue, Z., Dong, B., Zhang, Y., et al., "Relay protection platform based on component type and logic diagram," Electrical Appliances and Energy Efficiency Management Technology, (20), 28-32 (2017).

[11] Wu, L., "Discussion on main electrical connection modes of municipal solid waste incineration power plant," Guangdong Electric Power, 30(11), 79-84 (2017).

[12] Lummi, K., et al., "Analysis of transition steps towards power-based distribution tariff of small customers," CIRED-Open Access Proc. J. 1: 2611-2614 (2017).