Optimization of energy storage material properties in renewable energy systems based on big data analysis

Lei Wang[1], Cheng Zhang[1, *], Xuanren Yao[1], Yuanjian Wu[2], Jinlong Gong[3], Qijun Zhou[2]

[1] College of Ocean Engineering and Energy, Guangdong Ocean University, Zhanjiang, 524008, China

[2] College of Mathematics and Computer Science, Guangdong Ocean University, Zhanjiang, 524088, China

[3] College of Shipping and Maritime Transport, Guangdong Ocean University, Zhanjiang, 524002, China

Abstract. In recent years, the overall scale of distributed renewable energy projects has been rising, which makes the distributed energy development symbiosis system even larger. The number of sectors involved in the system has gradually increased, while the connection between the subsystems has become increasingly close. At the same time, the optimization of energy storage materials in the symbiotic system of distributed renewable energy projects under the integration of resources and demand has broadened the scope of traditional energy market technologies. Therefore, this paper takes the distributed renewable energy symbiosis system as the research object, and analyzes in depth the research of optimizing the performance of energy storage materials in the distributed renewable energy system to provide decision support for the regional distributed renewable energy industry planning.

Keywords: Big data; renewable energy; energy storage; performance optimisation.

1. Background and significance of the study

1.1 Background of the study

Energy is the basis of human production and life. As human civilization gradually enters the information age, the form of production manifests itself in features such as decentralization, resulting in a centralized energy system that is difficult to fully meet the needs of today's energy system [1]. The large-scale development of distributed renewable energy further improves the reliability of power supply on the user side and reduces the risk of power outages in traditional energy systems [2]. Distributed energy is a new type of energy system with the construction and operation goal of maximizing the benefits of resources and users, which is able to integrate and optimize the state of energy demand and resource allocation for various users, and is a decentralized method of energy supply rather than centralized energy supply [3]. According to the criteria of whether the distributed energy system is grid-connected or not, distributed energy can be divided into independent distributed energy system and grid-connected distributed energy system. From the perspective of the source of energy use, distributed energy can be divided into distributed natural gas systems and distributed renewable energy systems. From the point of view of energy system, it can be divided into independent energy, wind-solar storage complementary and combined cooling, heating and power supply to meet the multiple energy needs of users and owners [4].

As distributed energy pursues the maximization of end-use energy efficiency, it is significant to optimize the integration of supply and demand for distributed energy resource allocation [5]. The performance of energy storage materials in renewable energy systems is a key factor in determining the improvement of energy allocation efficiency. Therefore, based on the basic characteristics of demand differentiation over spatial regions, regional interaction mechanisms and constraints are analyzed. Evaluating the performance of energy storage materials using big data network systems can provide theoretical and empirical references for the formulation of strategic policies for the development and utilization of distributed energy resources [6]. It provides a basis for the study of the spatial distribution and coupling relationship between distributed energy resources and demand, and ultimately maximizes the symbiotic value of regional renewable resources, distributed energy projects and user energy demand [7].

1.2 Significance of the study

The construction and development management of distributed energy resources in China has shifted from the government-guided scale construction stage to the integrated management stage of coordinated development of multiple types [8]. In this context, creating a green regional distributed renewable energy system is crucial to guaranteeing energy security, saving energy and reducing emissions, as well as building a green and low-carbon clean energy power system. The spatial characteristics of distributed energy projects and energy demand are analyzed through the entry of big data network[9]. Through exploratory spatial data analysis, the potential of matching the resource side and demand side of regional distributed renewable energy can be explored, which can open up a new important reference system and analysis paradigm for the evaluation and optimization research of regional distributed energy development [10]. The optimization of energy storage material performance can be analyzed through the energy demand situation to further enhance the distributed energy consumption rate, making the distributed energy resources dynamically optimized, and ultimately realizing the symbiotic value of regional renewable resources, distributed energy projects and energy demand.

1.3 Current status of domestic and international research

By sorting out the existing research on regional distributed energy under the guidance of big data, the deficiencies in the research in the field of distributed energy projects and optimization of storage material performance are discussed. It can provide the research basis and rationale for the subsequent related research [11]. At this stage, scholars at home and abroad mainly focus on the index research of distributed energy projects in distributed energy evaluation. In distributed energy evaluation research, hierarchical analysis is a more common analysis method used by domestic scholars in recent years. Some scholars combine principal component analysis and hierarchical analysis to obtain a comprehensive evaluation model of distributed power system and optimization allocation method[12]. On the basis of comprehensively analyzing the characteristics of distributed power system, the three-dimensional index system of distributed energy is constructed, and the multi-indicator comprehensive evaluation model of empowered distributed energy project is proposed. Foreign scholars established a comprehensive evaluation system by integrating the three types of indicators of safety, reliability and economy. The hierarchical analysis method is used to evaluate distributed energy access programs under different scenarios, and the rationality of the constructed method system is verified [13]. Some domestic scholars constructed a multidimensional evaluation index system for decentralized wind power projects by broadening the index system to the flexibility dimension and taking into account the simulation of system projects of decentralized energy. Other scholars have constructed a post-evaluation model for distributed energy generation projects based on hierarchical analysis [14]. A comprehensive evaluation model for the whole life cycle of distributed energy projects was constructed based on value engineering theory, hierarchical analysis and fuzzy comprehensive evaluation [15]. In summary, at this stage, the research on distributed energy evaluation mostly involves hierarchical analysis method, in which the optimization of the performance of energy storage materials will provide research insights for carrying out the relevant analysis of distributed renewable energy projects in this paper.

2. Experimental materials and methods

2.1 Experimental materials

The electric blast drying oven (101A-1ET) was from Shanghai Experimental Instrument Factory Co. The electronic balance (BSA224S-CW) was obtained from Sartorius Scientific Instruments Co. Vacuum drying oven (DZF-6020) from Shanghai Boxun Industrial Co. Electrochemical workstation (CHI760E) from Shanghai Chenhua Instrument Co. The battery test system (LAND CT 21001A) was obtained from Wuhan Land Electronics Co. The physical model sketch is shown in Fig. 1. The energy storage cell is a circle with an internal radius R_1 of 20 mm and an external radius R_2 of 40 mm, where the internal structure is a ribless design, and Model 2 is equitably divided into upper and lower parts by adding vertical separating ribs for the lower chamber, and horizontal steel at 1 mm. The divided chambers will be filled with the same different materials [16].

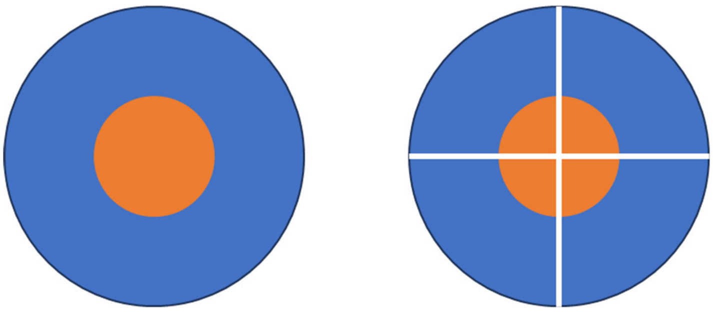

Figure 1. Sketch of the model

2.2 Experimental Methods

Considering the effect produced by the energy change in the region of the phase transition material, two-dimensional continuity, momentum and energy equations are established in the cross-section, and the phase transition of the material is modeled by the braising method, in which braising and temperature are used as the parameters to be solved.

Continuity equation.

$$\nabla \cdot \vec{v} = 0$$

Momentum equation:

$$\frac{\partial \vec{v}}{\partial t} + \vec{v} \cdot \nabla \vec{v} = \frac{1}{\rho}[-\nabla p + \mu \nabla^2 \vec{v} + \rho \beta \vec{g}(T - T_{\mathrm{ref}})] + \vec{S}_{\mathrm{g}}$$

Energy Equation:

$$\frac{\partial H}{\partial t} + \nabla(\vec{v}H) = \nabla\left(\frac{\lambda}{\rho c_p}\nabla H\right)$$

β is defined as.

$$\beta = \begin{cases} 0, T < T_{\mathrm{s}} \\ 1, T > T_1 \\ \dfrac{T - T_{\mathrm{s}}}{T_1 - T_{\mathrm{s}}}, T_{\mathrm{s}} < T < T_1 \end{cases}$$

whereT_{s} -solid state critical temperature K ;-solid state critical temperature K T_1 -liquid critical temperature K, the same value for some phase change materials.

2.3 Calculation conditions and methods

In this paper, ANSYS Fluent software is used for numerical simulation[17]. For the mesh division of the physical model, the Solidification & Melting model based on the braising method is introduced to deal with the material phase transition process, the velocity and pressure solution method is the unsteady implicit SIMPLEC algorithm, the pressure term is discretized by the PRESTO method, and the convection term is discretized by the QUICK format[18].

3. Results and discussion

3.1 Energy storage calculation based on incremental capacity analysis

Incremental capacity analysis (ICA) is a classical analytical method to study the behavior of energy storage. The advantage of ICA is that the plateaus involving first-order phase transitions on the voltage curve are transformed into those that can be clearly identified on the IC curve, and the change in the peak value in the IC curve can be used to reflect the increasing or decreasing behavior of energy storage.

The IC curve varies in the number of peaks exhibited due to the multiplicity as well as the electrochemical reaction rate, usually 3-5 peaks. The degree of reaction of energy storage is mainly related to the material capacity decline and internal resistance increase. The loss of active materials and ions occurs due to irreversible side reactions that occur during energy charging and discharging. The capacity of the energy storage material also declines gradually. The peak variation reflects the degree of performance, and the highest peak corresponds to the highest electrochemical reaction rate, so the regional capacity analysis method extracts the health factor from the highest peak to evaluate the energy storage material. Its calculation formula is as follows:

$$Q = I \cdot t$$

$$V = f(Q), Q = f^{-1}(V)$$

$$(f^{-1}) = \frac{dQ}{dV} = \frac{I \cdot dt}{dV} = I \cdot \frac{dt}{dV}$$

$\frac{dQ}{dV}$ Evolution with energy decay, the peak value can reflect the rechargeable capacity capability of the energetic material at different electrode potentials, reflecting the internal electrochemical properties of the material, and the peak value of the IC curve can be used as a health factor to evaluate the electrical properties. The results are shown in Fig. 2, and it can be seen that as the input value increases, the energy storage of the material also increases, showing a positive correlation trend, in which the energy storage reaches the highest 116.52 Ah at an input value of 3720 cm^{-1}.

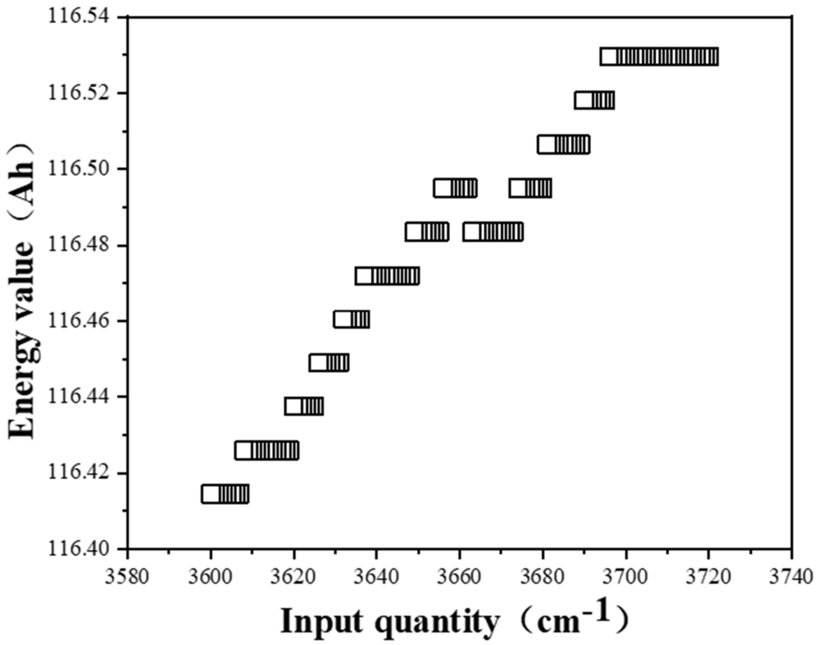

Figure 2. Incremental Capacity Analysis

3.2 Simulation analysis based on big data

Based on the LAN uncertain scenario construction method, the initial net load scenario set and real-time energy scenario set are established, and the improved scenario reduction method based on two-stage reduction is applied to reduce the scenarios and select the final set of scenarios to be retained. The simulation results show that when the final number of retained scenes varies within a certain range, the evaluated results do not differ much, so the simulation modeling concept based on big data has practical significance. The set of net load and real-time tariff scenarios retained for energy material storage is shown in Fig. 3. In this, it can be seen that the first set has poor simulation and analysis results, which indicates that the cyclicity of its power is low within the net load field, and therefore it is not used. Whereas, the second group has a stable power output and the power has been reaching its maximum value with the increase in the number of days. The third and fourth groups have the same trend as the second group. In general, the simulation analysis based on big data can provide a reference for optimizing the performance of energy storage materials in renewable energy systems.

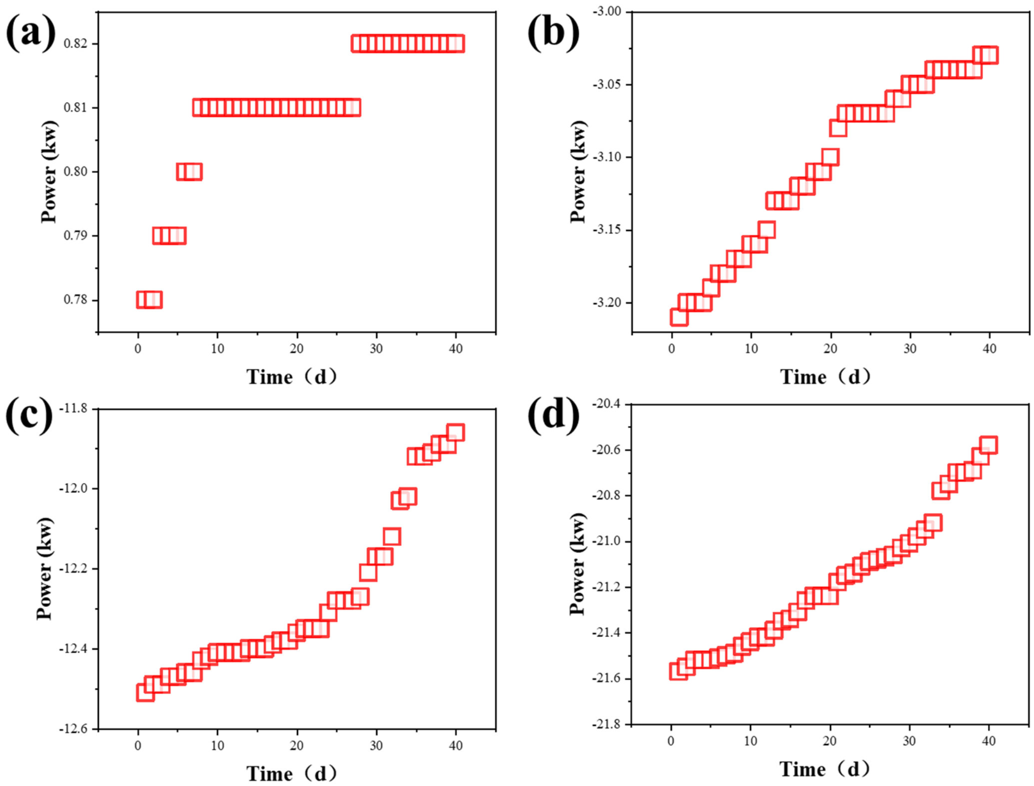

Figure 3. Energy analysis based on big data (a) Group I (b) Group II (c) Group III (d) Group IV

4. Conclusion

Renewable energy system is a complex system with the participation of many subjects, especially for the evaluation of the performance of energy storage materials there are bottlenecks. In this paper, we use complex system modeling theory to construct a network integration model and conduct in-depth research. This paper proposes the energy storage analysis based on incremental capacity analysis, which solves the problem of prediction error in practical energy management, optimizes the scheduling method of renewable energy system, the control method based on the processing of big data, and further research on the performance improvement of energy storage materials, which makes it have a wider scope of use in renewable energy system.

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