ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202501_8(1).0018

Application and Teaching Reform of Virtual Simulation Technology in Energy Storage Science and Engineering Education

Xuezhong Zhang, Dong Xiang, Yuanpeng Wu, Guilong Yan, Li Wang

School of New Energy and Materials, Southwest Petroleum University, Chengdu 610500, PR China

Abstract

As the global energy transition and "dual carbon" goals advance, the emerging discipline of Energy Storage Science and Engineering is evolving rapidly, presenting unprecedented opportunities and challenges. Traditional teaching methods often have limitations when demonstrating complex electrochemical processes and system dynamics, making it difficult for students to fully grasp related theories and applications. The introduction of virtual simulation technology offers a novel approach to this issue. Through virtual simulation, students can directly observe and analyze the dynamic characteristics of complex electrochemical reactions and energy storage systems, thereby deepening their understanding. This paper comprehensively analyzes the application status of virtual simulation technology in energy storage science and engineering education and focuses on a virtual simulation teaching design based on molecular dynamics for electrochemical interface storage. Integrating teaching practice, this paper proposes a reform plan for teaching with virtual simulation technology, aiming to improve educational quality, enhance students' practical skills, and foster innovative thinking, equipping them for future research and applications.

Keywords

Energy Transition, Dual Carbon Goals, Virtual Simulation, Electrochemical Processes, Educational Reform.

1. Introduction

With the promotion of "dual carbon" goals, energy storage technology has become a focal point worldwide as it plays a critical role in the efficient utilization of renewable energy and enhancing the flexibility of power systems. While Energy Storage Science and Engineering is garnering research interest and attention, its curriculum development and teaching resources remain in the early stages, especially concerning hands-on learning. Traditional laboratory teaching often falls short in addressing the complexity and diversity of energy storage systems, as these settings cannot fully illustrate the operating principles and processes of various storage technologies. Additionally, experiments involving high voltage or flammable substances pose safety hazards, limiting students' opportunities for hands-on experience [1-3]. In this context, exploring the application of virtual simulation technology in energy storage education becomes a key approach to improving teaching quality and enriching resources. Virtual simulation can model the complex dynamic processes in energy storage systems, allowing students to conduct experiments in a safe, virtual environment, thereby better understanding and mastering relevant knowledge. This not only complements traditional practical learning but also provides students with a broader learning experience, supporting the cultivation of future energy storage technology experts.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202501_8(1).0018

2. Current Applications of Virtual Simulation in Energy Storage Science and Engineering

Virtual simulation technology, as a modern teaching tool, builds 3D digital models to simulate physical and chemical processes, offering new possibilities in education. Its high fidelity, flexibility, and safety have led to widespread use across multiple disciplines, especially in energy storage science and engineering, where it plays an indispensable role. Traditional lab teaching in this field often faces limitations due to laboratory conditions. For instance, experiments involving extreme conditions like high voltage and high temperatures are both complex and carry certain safety risks. Moreover, due to the diversity and complexity of energy storage systems, traditional labs struggle to cover all storage devices and technologies comprehensively, restricting students' exposure to a broad range of experimental experiences and hindering their understanding and application of complex storage systems [4-6]. The introduction of virtual simulation has effectively overcome these barriers. Through simulating experiments in extreme conditions, virtual environments can reduce costs and increase efficiency. Students are no longer confined to physical lab conditions and can perform experiments anywhere and anytime in a virtual setting. This flexibility not only broadens learning opportunities but also provides instructors with more resources to design and structure the curriculum flexibly.

Another advantage of virtual simulation is its rich interactivity. In traditional lab settings, students are often passive recipients of knowledge, while virtual simulation provides an interactive learning environment where they can actively engage in experiments. In virtual labs, students can freely explore various parameters and observe how experimental phenomena change, enhancing the interactivity and enjoyment of learning. This interactive learning style boosts students' interest and promotes a deeper understanding and ability to apply knowledge [7].

Molecular dynamics simulation, as an essential component of virtual simulation, has found extensive application in energy storage science and engineering. In electrochemical interface energy storage, molecular dynamics simulation is widely used to reveal the complex interactions between electrode materials and electrolytes. By simulating ion migration, charge distribution, and electrode surface reactions during charge and discharge, students can directly observe microscopic changes, gaining a deeper understanding of the fundamental principles of electrochemical storage. Professor Kui Xu [8] has introduced a teaching design using LAMMPS and OVITO software for simulating electrode/electrolyte interface models, enabling in-situ charge-discharge simulations. Students can observe the evolution of atomic positions during charge-discharge processes, providing an accessible view of structural changes at the microscopic level.

Additionally, Professor Jichang Peng from Nanjing Institute of Technology [9] demonstrated how his institution uses virtual simulation to build a virtual energy storage plant and conduct grid-connected operation experiments for the Energy Storage Science and Engineering program. As shown in Figure 1, the virtual simulation platform constructs a full-scale digital energy storage plant, simulating key structures, operational features, and maintenance technologies. Through a 3D visual interface, students gain insights into the structure and functioning of energy storage plants, acquiring planning and design skills. This teaching model enhances students' practical skills and offers opportunities to interact with complex storage systems.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202501_8(1).0018

Figure 1. 3D Reconstructed Virtual Energy Storage Plant

The application of virtual simulation technology in energy storage science and engineering education not only enriches teaching resources but also effectively addresses the limitations of traditional practical instruction. By creating realistic virtual laboratory environments, virtual simulation provides students with a more flexible and safer platform, enabling them to gain in-depth insights into complex energy storage systems and technologies. This innovative teaching method enhances students' learning experiences while laying a solid foundation for cultivating skilled professionals with practical abilities and innovative thinking in energy storage technology. Looking ahead, as virtual simulation technology continues to develop and improve, its potential applications in the field of energy storage science and engineering will expand, offering new possibilities for both education and research [10].

3. Reform Plan for Virtual Simulation in Energy Storage Education

3.1. Curriculum Content and System Reform

In the curriculum system for Energy Storage Science and Engineering, the proportion of virtual simulation labs should be increased, integrating simulation technology into both theoretical and experimental teaching. In electrochemical interface storage, virtual labs can be combined with molecular dynamics simulations, using LAMMPS and OVITO software platforms [11]. Students can simulate electrode and electrolyte interactions during charge-discharge cycles in a virtual setting, observing dynamic microstructural changes. This platform not only helps students understand the fundamental principles of electrochemical storage but also visualizes ion migration, charge distribution, and surface reactions. In energy storage plant design, virtual simulation provides a platform where students can design and test different system configurations. They can choose and combine storage components to create varied system solutions, and through simulations, test each solution's feasibility and economic viability. For optimizing and dispatching storage systems, a virtual platform can simulate operating conditions under different scenarios, such as varying load demands, environmental factors, and energy supply conditions. Students can explore optimization and dispatch strategies in various scenarios.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202501_8(1).0018

3.2. Teaching Methods and Innovation

Integrating virtual simulation with traditional labs forms a blended learning model, retaining hands-on experience while overcoming physical lab limitations. For complex or high-risk experiments, virtual simulation offers a safe and efficient alternative. Additionally, virtual resources allow for personalized, self-paced learning; students can select experiments based on interests, adjusting parameters to deepen exploration and develop problem-solving skills. Instructors can track progress and provide targeted feedback, enhancing knowledge acquisition.

4. Conclusion and Outlook

The application of virtual simulation in Energy Storage Science and Engineering supports improved teaching quality and expanded resources. By developing virtual labs for molecular dynamics-based electrochemical interfaces and energy storage plant design, students gain a deeper understanding of storage principles and technical operations, fostering practical and innovative thinking. As virtual simulation technology continues to advance, its application in energy storage education will become broader and deeper, contributing to energy storage technology and talent cultivation.

References

[1] Wang Xiaomin, Deng Kunkun, Xu Meixian. Exploration of Teaching Reform for Energy Storage Devices Based on Virtual Simulation Experiments [J]. Digital World, 2021, (1): 199-200.

[2] Xin Jianying. Virtual Synchronous Power Generation Control Technology for Photovoltaic Energy Storage Micro Sources and Microgrid System Simulation [J]. Science and Technology Innovation and Application, 2022, 12(17): 68-71.

[3] Guan Biao, Feng Yongbao, Peng Qingsong, Wang Jie. Simulation Analysis of Heat Storage and Release Processes of Phase Change Energy Storage Materials Based on Fluent [J]. Energy Conservation, 2019, 38(10): 57-60.

[4] Dai Lanhua, Du Wenhan, Jiang Xiaoyan, Chen Lei, Zheng Min. Exploration of Curriculum Teaching Reform Based on Virtual Simulation Experiment Platform—A Case Study of "Wind Energy and Wind Power Generation Technology" Course [J]. Science Education and Culture, 2024, (2): 103-106.

[5] Li Dandan, Ju Zhiyu, Hou Xufeng, Niu Liangfeng, Huang Xiyao. Reform and Exploration of Organic Chemistry Experiment Teaching Based on Virtual Simulation Technology [J]. Guangzhou Chemical Industry, 2022, Vol. 50(12): 161-163.

[6] Lu Qing, Yang Yan, Ji Jie. Exploration of Basic Power Engineering Experiment Teaching Reform Based on Virtual Simulation Platform [J]. Science Education Guide (Electronic Edition), 2023, (30): 190-192.

[7] Wu Baohua. Exploration of "Electrical Experiment" Teaching Reform Based on Multisim Virtual Simulation [J]. China Electric Power Education, 2022, (4): 77-78.

[8] Xu Kui. Teaching Design of Electrochemical Interface Energy Storage Virtual Simulation Based on Molecular Dynamics Simulation [J]. Educational Progress, 2024, 14(1): 495-502.

[9] Peng Jichang. New Teaching Model for Energy Storage Discipline Based on Virtual Simulation Technology [J]. Education and Teaching Forum, 2023, (17): 45-48.

[10] Ou Lijuan, Sun Aiming, Luo Jianxin, Liu Ning, Zhang Ping, Wang Jinjin. Thoughts and Exploration on Instrumental Analysis Experiment Teaching Reform Based on Virtual Simulation Technology [J]. Guangzhou Chemical Industry, 2020, 48(10): 179-180.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202501_8(1).0018

[11] Zhou Yue, Hai Xue, Ren Cuilan, Yin Yaru, Shang Kunlin, Lei Lei, Huai Ping. AISL: An Automated Simulation Program for XFEL Irradiation Damage Based on LAMMPS [J]. Nuclear Techniques, 2024, 47(4).

[12] Hu Haowei, Chu Wei, Fang Tingyong, Li Yun. Exploration of Teaching Reform of Thermal Power Plant Based on Virtual Simulation Experiment [J]. Western Quality Education, 2019, Vol. 5(3): 148-149.