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Research Article

Analysis of the Economic Impacts of Optimal Management of Large-Scale Energy Storage Facilities

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Abstract

Due to technological advances, today it is possible to upgrade large-scale energy storage plants. The modern architecture and technology of these power plants facilitate the possibility of optimal use of renewable energy sources and, as a result, significantly reduce energy costs and increase energy efficiency. Also, by using artificial intelligence and optimization algorithms, the performance and operation of energy storage plants can be improved. In this article, the management of large energy storage power plants is discussed. This article presents innovative measures in the management of these power plants, which include limitations on the number of times of charging and discharging. In addition, the cuckoo search algorithm is used as a powerful and efficient method in solving the proposed model. This algorithm can find global optimal solutions and can be effective in improving the efficiency and increasing the profitability of large energy storage power plants. The simulation results show that the use of this approach in the management of large-scale energy storage plants brings significant economic effects. These impacts include reducing energy costs, increasing productivity, greater independence from fossil fuel sources, maintaining the stability of the power grid, and improving the performance of the power transmission system.

Keywords: Large-scale energy storage power plants, distribution substation, evolutionary algorithm, optimization.

Highlights

- Use of energy storage power plants as an innovative solution in optimizing energy management and smart grids.
- Utilizing the cuckoo search algorithm as a robust method to enhance the efficiency of energy storage power plants.
- Providing an economic optimization approach for optimal planning of large-scale storage system planning.

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1. Introduction

The management of large-scale energy storage plants has become increasingly important with the advancements in technology that facilitate the optimal use of renewable energy sources. These modern energy storage systems significantly reduce energy costs and improve energy efficiency, contributing to more sustainable energy solutions (References [1], [2], [3]). The implementation of artificial intelligence and optimization algorithms can further enhance the performance and operations of these plants. This paper explores the innovative management of large-scale energy storage facilities, focusing on optimizing charge and discharge processes using the Cuckoo Search Algorithm (CSA).

The CSA is known for its robustness and efficiency in finding global optimal solutions, making it suitable for improving the efficiency and profitability of large-scale energy storage plants (References [4], [5], [6]). Prior studies have highlighted the economic benefits of such optimization methods, including reduced energy costs, increased efficiency, and enhanced grid stability (References [7], [8]). However, challenges such as the limited number of charge and discharge cycles necessitate innovative management strategies (References [9], [10]). This study aims to address these challenges by leveraging the CSA to optimize the performance and profitability of energy storage plants, thereby contributing to more sustainable and efficient energy management solutions.

2. Innovation and contributions

This paper makes significant contributions to the field of energy storage management by introducing advanced methods to enhance the efficiency and coordination of large-scale energy storage plants. The key contributions and innovations of this research are as follows:

1. **Development of a New Optimization Model**: The paper presents a novel optimization model designed specifically for the integrated management of large-scale energy storage plants. This model incorporates various management options, including controlling the frequency of charge and discharge cycles, which is critical for maintaining the longevity and efficiency of energy storage systems.
2. **Application of the Cuckoo Search Algorithm**: The study employs the Cuckoo Search Algorithm (CSA), a robust and efficient optimization technique, to solve the proposed model. The CSA is selected for its superior ability to find global optimal solutions, outperforming other existing algorithms. This ensures that the management of energy storage plants is optimized to the highest possible standards, leading to increased efficiency and profitability.

These innovations collectively contribute to the development of more sustainable and cost-effective energy storage solutions, addressing current challenges in the management of large-scale energy storage systems. The integration of advanced optimization techniques and comprehensive management strategies represents a significant advancement in the field, with potential applications in various energy distribution networks.

3. Materials and Methods

In this section, we present a case study to validate the proposed model and evaluate its performance under various conditions. The load and price data utilized for this analysis are sourced from reference [11]. For this study, the energy storage system considered is the vanadium redox battery (VRB), as detailed in [11]. To solve the proposed mathematical model, we employ the Cuckoo Search Algorithm, a robust optimization technique known for its efficacy in finding global optimal solutions.

The computations are performed on a laptop equipped with a 2.4 GHz processor and 12 GB of RAM. This setup allows for the efficient execution of the Cuckoo Search Algorithm and facilitates the comprehensive analysis of the model's performance across different scenarios. The results from this case study are used to assess the effectiveness and accuracy of the proposed model in managing large-scale energy storage systems.

4. Results and Discussion

The results of the simulations reveal significant differences between scenarios with and without restrictions on the number of charge and discharge cycles for the energy storage system.

Without any operational constraints, the system achieves a total profit of $6289, with a peak discharge power of 12,850 kW and a peak charge power of 6650 kW. This indicates that the system can operate at its maximum discharge capability and generate substantial revenue when not restricted by the frequency of charge and discharge cycles.

In contrast, when restrictions on charge and discharge cycles are applied, the total profit drops to $3680. The peak discharge power is reduced to 6285 kW, demonstrating a decrease in the system's maximum discharge capability. The peak charge power remains unchanged at 6650 kW, showing that charge capacity is not affected by the restrictions.

These findings underscore the impact of operational constraints on the system's performance and profitability. The absence of restrictions allows for greater revenue and peak discharge power, while limitations lead to reduced profits and a lower discharge capacity. This comparison highlights the trade-offs between operational flexibility and financial returns in managing large-scale energy storage systems.

5. Conclusion

In this paper, an economic approach to energy management in substations with energy storage systems is presented, incorporating management options for controlling charge and discharge cycles. The proposed model offers several advantages, including sufficient flexibility regarding the allowable number of charge and discharge events. Solved using the Cuckoo Search Algorithm, the model demonstrates significant improvements over traditional optimization methods such as Particle Swarm Optimization (PSO), Genetic Algorithms (GA), and Grey Wolf Algorithm (GWA).

The results indicate that the proposed algorithm significantly enhances profitability compared to these conventional methods. In both scenarios analyzed, the proposed algorithm achieved the best results and improved the objective function more effectively

than the alternatives. The performance of the proposed algorithm led to an increase in profit, achieving a total of $6289, whereas the best result obtained with PSO was $5349, representing a 17% improvement.
Overall, the proposed algorithm has shown a substantial enhancement in the charge and discharge management of energy storage systems. It proves to be a more reliable and efficient optimization method, offering notable improvements in profitability and system performance. The proposed approach is therefore recommended as an effective and dependable solution for optimizing the operation of large-scale energy storage systems.

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Appendix

Table 1. Energy storage plant parameters

Parameter	Value
Type	VRB
Efficiency (%)	70
Peak Cost ($/kW)	426
Energy Cost ($/kWh)	100
Fixed Operation Cost ($/kW/year)	9
Capital Investment ($)	300,000
Parameter	Value

Table 2. The results of simulation and comparison of different modes

Mode	Profit ($)	Peak Discharge Power (kW)	Peak Charge Power (kW)
First	6289	12850	6650
Second	3680	6285	6650

Table 3. Comparison of the proposed algorithm with other methods

Method	Proposed Algorithm	PSO	GA	GWA
Objective Function in First Mode (USD)	6289	5349	5198	6041
Objective Function in Second Mode (USD)	3680	2780	2470	3454

Declaration of Competing Interest: Authors do not have conflict of interest. The content of the paper is approved by the authors.

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