The Development Current Situation and Future Expectation of Wind and Solar Energy Storage Technology

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Abstract. Wind and solar energy storage technology is a popular subject of current energy production and storage, which has got a lot of public attention recently. Some researchers have found that wind and solar energy storage technology can reduce the environmental pollution caused by electricity production to a certain degree. However, wind and solar energy storage technology still has a series of problems recently. For example, its output is unstable, which leads to the volatility and intermittent of its energy generation. What's more, the level of resources utilization is not so high. Hence, this text aims at researching the ability of smoothing output fluctuation by optimization of capacity configuration technology for wind and solar energy storage technology. By collecting the data of the level of energy utilization, running cost of the power grid and power loss rate after applying the optimization of capacity configuration technology and comparing them with the one without using it, the results indicates that after using the optimization of capacity configuration technology, the level of energy utilization of the power grid becomes higher. At the same time, the running cost and the power loss rate grew lower to a certain degree.

Keywords: Wind and solar energy, Microgrid system, Energy storage, Capacity configuration.

1. Introduction

With the advancement of social modernization, the global energy system is facing the superimposed test of "dual crises": on the one hand. Extreme climate events caused by global warming are becoming increasingly frequent. On the other hand, global demand for electricity has soared. The traditional methods of energy generation and energy storage can no longer meet the needs of society. Against this backdrop, wind and solar energy storage technologies have gradually stood out due to their advantages such as being clean, environmentally friendly and having high economic benefits, and have become the core path of global energy transition. The wind and solar energy storage technology has transformed from simple physical stacking, which relies empirical fixed-ratio storage allocation on to meet basic grid integration needs, to a policy-driven collaborative planning phase (characterized by policy refinement, scale expansion, and accelerated construction of wind-solar-storage integrated bases). And currently, it is entering the intelligent optimization stage, featuring digital upgrades such as grid-forming/full liquid-cooling technology applications, economic optimization through spot market utilization improvements, and multi-scenario adaptation with standardized solutions. However, the large-scale application of wind and solar energy storage technology is still limited by its fluctuating and unstable characteristics due to the fact that wind and photovoltaic power generation are easily affected by factors such as temperature and weather. At present, wind and solar energy storage technologies still have problems such as insufficient energy utilization rate and inability to match the electricity demand at the end of the user. Therefore, optimizing the energy allocation of wind, solar and energy storage and improving the utilization rate of wind and solar energy are of great significance for the intelligence and environmental protection of the power grid. This paper elaborates in detail on the characteristics of wind, solar and energy storage technologies. By analyzing and comparing the features, advantages and disadvantages of the three mainstream capacity configuration technologies of wind, solar and energy storage, it aims to respectively find the most suitable positions for the three technologies in the power grid and look forward to the future development of the three technologies.

2. The Features of Wind and Solar Energy Storage Technology

Wind and solar energy storage technology refers to a kind of new energy technology which combines wind power generation technology, photovoltaic power generation technology and energy storage technology. Wind and solar energy storage technology has been widely used in smart grid systems for being clean and eco-friendly and having strong adaptability, and high resource utilization rate. At the same time, because wind energy and solar energy can be easily affected by many factors such as climate and temperature, wind and solar energy storage technology also has disadvantages such as unstable output, volatility and intermittent of its energy generation. Therefore, optimizing the capacity configuration of wind and solar energy storage to match the power supply demand on the power consumption side is the top priority in the development of wind and solar energy storage technology.

3. Existing Capacity Configuration Optimization Techniques

3.1. Wind-Solar Hybrid Technology

Wind-solar hybrid technology refers to the technology that uses solar cell arrays and wind turbines to convert direct current into alternating current and store the generated electrical energy in battery packs. When consumers require electrical power, the inverter transforms the direct current (DC) that is stored within the battery unit into alternating current (AC) and then transmits it to the user's electrical load via the distribution line. This process enables the combined power generation from both the wind turbine and the solar cell panel system. That is, in spring and autumn of the year, wind power is mainly used for power generation, while in summer and winter, solar power is mainly used for power generation. At noon in a day, solar energy is mainly utilized for power generation. Wind power is mainly used for power generation at night. On rainy days, wind power is mainly used for power generation, while on sunny days, solar power is mainly utilized for power generation. The rest of the time, both are used for power generation simultaneously. Wind-solar hybrid technology has achieved the sustainable and full utilization of natural resources to the greatest extent, effectively reduced the waste of electric energy, and played a significant role in optimizing capacity configuration. As shown in Table 1, after the application of wind and solar energy storage technology, the number of power outages and operating costs in different scenarios have decreased, energy utilization rate has improved, and power supply has become more stable. It helps the power supply side to better serve the power consumption side. Simulation results from Ahmad have shown that the hybtid power system’s total yearly generation is 1509.85 GWh/year, and 7.83 % of them, which is from the PVstationand1391.7GWh/year (92.17%) generates from the wind farm. Furthermore, the control system consistently ensures that the hybrid power system operates at a unity power factor by maintaining the injected reactive power at a null value. Additionally, the voltage at the PCC (Point of Common Coupling) bus remains remarkably stable, regardless of fluctuations in weather conditions and variations in the amount of active power generated [1]. Zhuoli Zhao suggests that wind-solar hybrid technology is able to tackle different kinds of output oscillation [2].

Table 1. Comparison of performance indicators between traditional and multi-time-scale scheduling methods [3]

Performance indicators	Traditional	Multi-time-scale scheduling
Average power fluctuation range (%)	±20	±7
Annual power outage frequency (times)	12	2
Annual operating cost (ten thousand yuan)	850	680
Energy utilization rate (%)	75	88

Although wind-solar hybrid technology has made great contributions to optimizing the capacity configuration of wind and solar energy storage, there are also some disadvantages and difficulties which need to be solved and improved. For instance, though wind and solar energy theorically complement each other, accurately grasping and efficiently coordinating this complementarity for real-time power generation remains challenging. It is difficult to intelligently allocate power generation based on real-time energy comditions. In addition, wind-solar hybrid power generation is intermittent and fluctuating, resulting in unstable output electrical energy quality. Large-scale integration into the power grid can pose threat to the grid’s stability and safety, increasing the difficulty of grid scheduling and management. At last, the performance of wind-solar hybrid systems varies significantly under diffirent geographical and climatic conditions. For example, in special environments such as mountains, deserts, and oceans, device installation, maintenance, and system operation face unique challenges.

3.2. Distributed Energy Storage Technology

Distributed energy storage technology refers to the storage of energy through clean energy sources such as photovoltaic, wind power, or electricity in the power grid. The forms of stored energy can be electricity, heat, cold, potential energy, etc. Its system access locations are flexible. Currently, most of them are distributed in medium and low voltage configuration power grids, distributed generation microgrids, and user-side applications. Distributed energy storage systems can regulate grid loads, absorb peak power, input power when power supply suddenly drops, and locally store energy to alleviate power fluctuations caused by unstable production and output of renewable energy.

Xiangjun Li emphasizes that Battery Energy Storage Systems (BESS) significantly enhance the peak-shaving capability of energy systems. In the IEEE 33-node distribution network, BESS can effectively reduce the photovoltaic (PV) abandonment rate from 28.7% to as low as 8.4%. Not only that, but the Battery Energy Storage System (BESS) has significantly enhanced the system's voltage regulation capability, achieving an increase in the minimum voltage per unit value from 0.864 to 0.95. In addition to these technical advantages, BESS has made outstanding contributions to improving the system's economic performance, increasing the overall economic efficiency of the system by 3.1% [4]. Large-scale energy storage facilities are composed of many parallel-operating energy storage battery units, thus enabling the establishment of megawatt-level energy storage systems. Such equipment is typically called Large-scale Centralized Energy Storage (SES) power stations. This paper introduces a dynamic partitioning strategy based on this system, which subdivides the energy storage power station into small self-controlled and self-managed areas according to the actual needs of each part. According to Jianlin Li's study, this dynamic management method significantly improves the actual energy utilization efficiency of energy storage devices. Compared with traditional fixed strategies, it increases efficiency by about 20%. The combination of centralized SES power stations and renewable energy reduces the running costs of energy storage facilities. This integration not only enhances the operational income of each part which is involved but also makes the payback period for centralized SES power station investments shorter. Thus, this creates a beneficial win-win situation for all participating individuals [5]. Zeyneb Tanis's research shows that after adopting an energy storage virtualization model combined with a nonlinear programming multi-objective method, the system's energy storage costs are reduced by 18% and the usage of battery is propoted by 15-20% compared to the old methods. Additionally, introducing a Nash bargaining model in decentralized networks improves energy utilization efficiency by around 15%, especially during peak electricity demand periods, by ensuring response capability to energy flow fluctuations and improving energy transmission [6].

However, distributed energy storage technology still has obvious drawbacks. From a technical perspective, distributed energy storage systems require effective and reasonable integration and need to coordinate with various energy sources (such as solar and wind power) and central power grids. However, current system integration and optimization technologies are still immature, making it difficult for distributed energy storage systems to achieve efficient matching and coordinated operation between different parts. Therefore, system performance cannot be fully and effectively used. In addition, distributed energy storage systems have insufficient interaction abilities with power grids, making it difficult to efficiently tackle difficult problems such as the unstable energy output’s fluctuation. In the case of this kind of situation, the system often fails to accurately coordinate with the central grid's power generation output for energy storage and power release operations om time, seriously affecting the stability and reliability of the grid. In terms of safety, the main energy storage devices of distributed energy storage system are still batteries. And thermal runaway of batteries is a serious safety problem. If the battery is not kept well, the thermal runaway can lead to fire, explosion, and other safety accidents, causing danger to people and equipment. This has become a key factor restricting the development of electrochemical energy storage systems, and a critical factor affecting the development of distributed energy storage technology.

3.3. Microgrid System

A microgrid system is a small and integrated power generation and distribution framework composed of distributed energy resources, energy storage units, power conversion devices, loads, and monitoring and protection equipment. Unlike traditional centralized large-scale power grids, microgrids runs in a two-way interactive mode, balancing energy flow and improving energy efficiency while producing power. When the main grid loses control, microgrids can quickly disconnect from the utility grid and continue to provide critical loads with their stored energy. The development and expansion of microgrids is one of the necessary technologies and models for achieving distributed energy storage, significantly promoting the widespread integration of distributed energy resources, energy storage systems, and renewable energy sources, thereby ensuring more coordinated, highly reliable, and diversified energy supply for various loads. Youssef Akarne's research proposes a novel two-layer framework for communication microgrid management, which integrates photovoltaic systems (PVS), wind turbine systems (WTS), and battery energy storage systems (BSS) with the public power grid. This framework achieves a minimum state of charge (SOC) of 59.10%, surpassing the 57% of particle swarm optimization (PSO), 56% of genetic algorithm (GA), and the performance of non-optimized systems. Additionally, it reaches a maximum SOC of 89.98%. The SSAEMS (sine cosine algorithm-energy management system) under this framework achieves an SOC of 80%, demonstrating superior performance in energy utilization and energy storage management compared to PSO's 78% and GA's 77% [7]. Zhiyi Li pointed out that microgrids typically operate in parallel with the main grid but can quickly disconnect from the central grid and switch to island mode in case of abnormal situations (such as unstable energy output) to maintain local power supply through autonomous operation [8]. Liang Che emphasized that community microgrid structures enhance the reliability of community power systems and reduce grid operational costs. Each microgrid supplies power based on the rated voltage and capacity of the load, while also providing backup power for other microgrids within the community [9]. For example, a four-story office building with a roof area of 1,800 square meters and an office area of 4,000 square meters has an original fluorescent lighting load of approximately 18 kilowatts. Assuming an 8-hour daily operation, it consumes 144 kilowatt-hours of electricity, requiring a solar system with a peak capacity of about 45 kilowatts. The required solar panel area is approximately 400 square meters, corresponding to a roof area of about 600 square meters. With a 150 kWp capacity, the solar system on the engineering building alone can power all three four-story office buildings (totaling 12,000 m^2), or equivalently, a single 12-story high-rise office building with the same roof area [10].

The current development challenges of microgrid technology mainly focus on the following aspects: First of all, existing policies are primarily tailored to centralized power plants, lacking clear policy positioning for emerging entities such as distributed energy aggregators. This results in obstaclesvin grid connection approvals and electricity pricing mechanisms. Besides, micgrids incorporate both grid-forming and grid-connected distributed power sources, making traditional centralized control methods unsuitable. New distributed coordination and control technologies are required. Lastly, the intermittency and volatility of renewable energy sources pose significant challenges to the stable operation of microgrids, necessitating solutions for power generation forecasting, grid connection control, and protection technologies.

4. Comparison of Three Technologies

From a macro perspective, wind-solar hybrid technology regulates the reasonable allocation of large power grid capacity as a whole, while distributed energy storage technology and microgrid technology, from a micro perspective, achieve self-sufficiency as integral parts of the grid at the local level, share the power supply pressure of large power grids, and simultaneously prevent large-scale blackouts on the power consumption side due to grid overload. In terms of advantages and disadvantages, although wind-solar hybrid technology has advantages such as environmental cleanliness and high economic efficiency, it requires high hardware specifications and has complex load matching requirements. Distributed energy storage is a component of microgrid technology, and only when combined can they achieve optimal results. Table 2 clearly illustrates the difference between the three technologies by comparing their capacity, application scenario, advantages, and disadvantages. Overall, wind-solar hybrid technology regulates the whole, while distributed energy storage and microgrid technologies regulate local areas. As the three mainstream technologies currently optimizing wind-solar energy storage capacity allocation, they complement each other and are indispensable.

Table 2. Comparison of Three Technologies

	Capacity	Application scenario	Advantages	Disadvantages
Wind-solar hybrid technology	Large-scale	Power grid	Energy complementarity, stable power supply, and full resource utilization	Difficulty in coordinating energy complementarity, grid integration challenges, environmental adaptability
Distributed energy storage technology	Small-scale	User side	Enhance grid flexibility and reduce transmission costs	Difficulty in system integration and optimization, insufficient regulation and control capability, rish of thermal runaway
microgrid system	Small-scale	User side	Achieve diversified power supply to enhance grid flexibility	Poor policy synergy, heterogeneous energy coordination and control, high penetration of renewable energy

5. Trends and Future Prospects of Capacity Configuration in Wind-Solar Energy Storage

Nowadays, wind and solar energy storage technology has made certain progress, but there are still many deficiencies and challenges. In the future, humans are expected to improve the existing defects of wind and solar energy storage technology by integrating AI (especially machine learning and deep learning) with this technology. For example, through deep learning, AI can grasp the weather patterns of a certain area over the past 10 to 20 years, thereby accurately collecting wind and solar resource data and conducting effective analysis to achieve intelligent power generation allocation based on real-time energy conditions. Moreover, AI can also be used to monitor grid load status and equipment conditions, thus helping microgrids better coordinate and operate with the main grid. In the current electricity market environment, the capacity allocation of the main grid struggles to meet market demands. For instance, within a day, the grid generates the most electricity at noon when electricity prices are lower, but user demand is low, resulting in wasted excess electricity. In the evening, as user electricity consumption surges, so do electricity prices. Sometimes grid supply cannot keep up with demand, which is also not cost-effective for users. Therefore, through wind and solar energy storage technology, users can store electricity at noon for evening use, making it more economical for users and reducing evening power supply pressure for the grid, thus avoiding grid system paralysis. Meanwhile, wind and solar energy storage is expected to couple with other energy sources such as heat, cold, gas, and hydrogen, making grid power supply and energy storage develop towards more environmental protection and diversity.

6. Conclusion

This paper finds that the existing technologies for optimizing the capacity configuration of wind, solar and energy storage have, to a certain extent, improved the resource utilization rate of wind, solar and energy storage technologies, smoothed out the output fluctuations of wind, solar and energy storage, and effectively alleviated the problems of unstable output and inability to match well with the user side caused by the volatility and intermittency of the output of wind, solar and energy storage. This can be explained by the following fact: Firstly, the capacity optimization configuration technology flexibly adjusts the main power generation energy according to different temperatures and climates, enhancing the intelligence of the power grid and avoiding the waste and disposal of energy. Secondly, the capacity configuration technology should be optimized and regulated simultaneously at both macro and micro levels, as well as on the power supply side and in the power consumption measurement. It ensures the rational allocation of wind and solar energy storage capacity to the greatest extent.

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