Application Scenarios of Long-duration Energy Storage Technologies in Novel Power Systems

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ABSTRACT

New power systems, dominated by renewable energy sources, face challenges such as output volatility, randomness, and insufficient system flexibility resulting from the high proportion of renewable energy grid integration. Long-duration energy storage technology has become a key supporting means. This paper reviews the types and characteristics of mechanical energy storage, electrochemical energy storage, and other emerging long-duration energy storage technologies. It focuses on analyzing their application scenarios in achieving power balance and energy time shifting on the grid side, improving renewable energy absorption and output smoothing on the power supply side, and supporting peak-valley arbitrage and power supply reliability on the user side. The paper also discusses the role and adaptability of various technologies in multi-timescale regulation, providing technical references for building a clean, low-carbon, safe, and efficient new power system.

Keywords: Long-Duration Energy Storage, New Power Systems, Mechanical Energy Storage, Electrochemical Energy Storage, Application Scenarios

1. INTRODUCTION

1.1 Current Status and Challenges of New Power System Development

The new power system is based on new energy sources and is accelerating its transformation towards clean, low-carbon, safe and efficient. By the end of 2022, China's non-fossil energy installed capacity reached 1.27 billion kilowatts, accounting for 49% of the total installed capacity, exceeding the installed capacity of coal-fired power; wind power and photovoltaic power generation installed capacity reached 760 million kilowatts, accounting for 14% of the total power generation. The grid's cross-regional transmission capacity has been improved, and the characteristics of intelligent interconnection have emerged. The power supply guarantee capacity and green and low-carbon transformation have been continuously promoted. However, the high proportion of new energy grid connection brings severe challenges. The intermittent, random and volatile output of new energy sources has increased the difficulty of system balance, the regulation capacity is insufficient, the problem of wind and solar curtailment still exists in some areas, the pressure of power balance has increased, the risk of safe and stable operation has increased, and the problems of shortage of flexible resources and rising costs are prominent [1][2].

1.2 Necessity of Long-Term Energy Storage Technology

Under the new power system, the large-scale access of new energy requires energy storage to provide multi-time scale regulation capabilities. Long-term energy storage can realize energy time shift, smooth out power output fluctuations, and improve the level of new energy consumption, which is the core support for ensuring system stability and reliability [3]. With the increase in the penetration rate of renewable energy, short-term energy storage is difficult to meet the cross-day and cross-seasonal balance needs. Long-term energy storage has become an indispensable key technology for building a new power system by improving system flexibility, reducing power curtailment, and supporting the integration of source, grid, load and storage [4].

2. TYPES AND CHARACTERISTICS OF LONG-TERM ENERGY STORAGE TECHNOLOGIES

2.1 Mechanical Energy Storage Technology

Mechanical energy storage technology, as one of the core types of long-term energy storage, mainly includes pumped hydro storage, compressed air storage, gravity storage and flywheel storage. In new power systems, pumped hydro storage

technology is highly mature, has large capacity and long-term discharge characteristics, and can effectively realize energy time shift across days and even seasons, supporting high proportion of new energy consumption and system balance. Compressed air storage has the advantages of flexible site selection, relatively low cost and environmental friendliness. It achieves large-scale energy storage through compressed air and is suitable for grid-side peak and valley regulation and new energy output smoothing [5]. With the increase of new energy penetration rate, mechanical energy storage has become an indispensable technical support for building new power systems by improving system flexibility and reliability. Its large-scale application can significantly reduce wind and solar curtailment rate and ensure safe and stable power supply [6].

2.2 Electrochemical Energy Storage Technology

Electrochemical energy storage technology is represented by flow batteries and sodium-ion batteries in the field of long-term energy storage. It has the characteristics of moderate energy density, long cycle life and strong scalability. In the new power system, the all-vanadium redox flow battery achieves power and capacity decoupling through electrolyte separation, which is suitable for multi-hour to cross-day balance regulation and improves the utilization rate of new energy [7]. Sodium-ion batteries have become a long-term energy storage alternative to lithium -ion batteries due to their abundant resources, low cost and high safety, and can support the integrated operation of source, grid, load and storage. This type of technology meets the needs of the new power system for long-term regulation capability by optimizing the material system and system integration, effectively alleviates the cross-season balance problem that is difficult to cover by short-term energy storage, and promotes the power system to transform towards clean and low-carbon.

2.3 Other Emerging Technologies

Other emerging long-term energy storage technologies include hydrogen energy storage, thermal energy storage and gravity energy storage, which focus on seasonal and ultra-long-term scale regulation. In new power systems, hydrogen energy storage achieves chemical energy storage by producing hydrogen through water electrolysis, which can realize cross-seasonal energy transfer and support the large-scale consumption of renewable energy. Gravity energy storage stores energy in the form of mechanical potential energy, and has the characteristics of flexible site selection, long life and great potential for cost reduction, and is suitable for long-term balance in distributed scenarios [8]. Technologies such as thermal energy storage further enrich the technical route, improve the system flexibility through multi-energy complementarity, and become an important supplement for new power systems to cope with extreme events and the challenges of high proportion of new energy.

3. APPLICATION SCENARIOS OF LONG-TERM ENERGY STORAGE TECHNOLOGY IN NEW POWER SYSTEMS

3.1 Application Scenarios on the Power Grid Side

The grid side is a crucial application area for long-duration energy storage technology, primarily undertaking system-level power balancing and energy time-shifting functions. In new power systems, long-duration energy storage can effectively mitigate output fluctuations caused by large-scale centralized grid connection of new energy sources. Through cross-day or cross-week energy storage and release, it alleviates grid peak-shaving pressure and improves system operational flexibility. The combination of mechanical and electrochemical energy storage can support the stable operation of ultra-high-voltage transmission channels, reduce wind and solar curtailment, and ensure the safe and stable power supply of regional power grids. Furthermore, in extreme weather or sudden fault situations, long-duration energy storage can provide long-term backup capacity, maintain grid frequency and voltage stability, and avoid the risk of large-scale blackouts. By participating in the ancillary services market, long-duration energy storage can also optimize the grid investment structure, delay or reduce the construction of new peak-shaving power sources, and achieve economical and efficient system regulation.

3.2 Power Supply Side Application Scenarios

Power- side applications focus on the local balancing and consumption of new energy power generation bases. Long-duration energy storage, operating in conjunction with wind, solar, and other renewable energy power plants, can achieve output smoothing and peak shaving, effectively increasing the utilization hours of new energy power generation and reducing the impact of high energy consumption and high-power generation capacity on power-side stability. Mechanical energy storage is suitable for seasonal regulation in large-scale bases, while electrochemical energy storage is suitable for multi-period optimization within a single day. In the integrated generation-grid-load-storage model, long-duration energy

storage helps the power supply side achieve self-balancing, reducing long-distance transmission losses and wasted power, and supporting efficient integration of distributed new energy sources. Simultaneously, by combining with emerging technologies such as hydrogen energy storage, the cross-seasonal energy storage capacity of the power supply side can be further expanded, promoting the transformation of new energy bases into multi-energy complementary integrated energy bases.

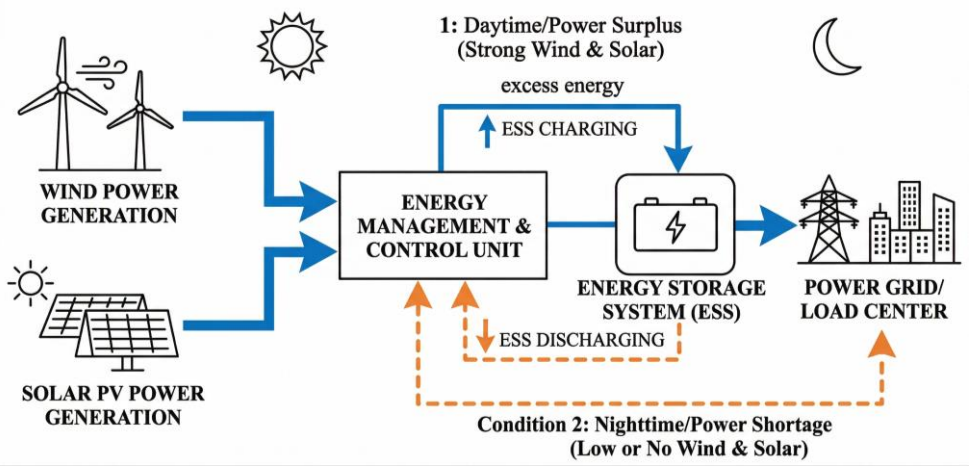

Figure 1. Schematic diagram of integrated wind, solar and energy storage power supply side.

The integration of wind, solar, and energy storage on the power supply side is one of the important application scenarios for long-term energy storage (Figure 1). Wind power, photovoltaic power plants, and long-term energy storage devices are integrated in the same site. During the day or when there is strong wind and strong sunlight, excess electricity is charged and stored through the energy storage system. At night or when there is low output, the energy storage system discharges to smooth the power output, achieve local balance and high proportion of consumption, and improve the efficiency of new energy utilization.

3.3 User -side application scenarios

User-side applications primarily serve the demand response and self-sufficiency needs of industrial parks, large commercial buildings, and distributed users. Long-duration energy storage helps users achieve peak-valley electricity price arbitrage, reducing electricity costs, while providing long-term backup power during grid power outages to ensure the continuous operation of critical loads. Electrochemical energy storage has become the mainstream choice for user-side applications due to its fast response speed and flexible modular deployment.

In new power systems, long-term energy storage on the user side can also participate in demand-side response and the construction of virtual power plants, enhancing the overall flexibility of the system through aggregation effects and promoting coordinated optimization of power generation, grid, load, and storage. In the future, as energy storage costs continue to decline, this scenario will further drive terminal electrification and user-side energy transformation, achieving a green and low-carbon energy consumption model.

4. CONCLUSION

The new power system, dominated by new energy sources, faces challenges such as output volatility, insufficient system flexibility, and difficulties in safe and stable operation due to the high proportion of renewable energy integrated into the grid. Long-duration energy storage technology serves as a key support, utilizing mechanical energy storage, electrochemical energy storage, and other emerging technologies to achieve power balance and energy time-shifting on the grid side, enhance the absorption capacity of new energy sources on the power generation side, and support demand response and self-sufficiency on the user side, significantly improving system regulation capabilities and reliability. Various technological approaches each have their advantages, collectively forming a multi-timescale, multi-scenario adaptable energy storage system, providing strong support for building a clean, low-carbon, safe, and efficient new power system.

In the future, with technological advancements and cost reductions, long-duration energy storage will play a greater role in the integration of power generation, grid, load, and storage, driving the power system's transition to a higher proportion of renewable energy. Strengthening technological innovation, policy guidance, and market mechanism development will further unleash the potential of long-duration energy storage, making a significant contribution to achieving the goal of carbon peaking and carbon neutrality.

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