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REVIEW OF BATTERY TYPES AND APPLICATION TO WIND POWER GENERATION SYSTEM

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Abstract: The paper discusses diverse energy storage technologies, highlighting the limitations of lead-acid batteries and the emergence of cleaner alternatives such as lithium-ion batteries. It covers battery inspections, factors affecting battery life, and repurposing retired batteries. Additionally, it addresses challenges in wind power generation and the successful application of LL-type VRLA batteries in stabilizing power fluctuations.

Key words: battery life, battery management systems, energy storage technology, inspections of the battery, operating temperature, wind power generation system**.**

1. INTRODUCTION

Recent trends in the applications of batteries in the built environment are improving the efficiency of batteries and lowering costs. This paper introduces various types of battery technologies such as sodium sulfur, lithium ion, flow and lead acid batteries and discusses their models [1].

It is well known that the power delivered by the wind turbines fluctuates intensely due to the wind variability. Additionally, many of these generating sources will operate as distributed generators. When the power system grid connection is not available, these uncontrollable sources may operate in an island mode. In this case, disturbances such as wind fluctuation and load perturbation have adverse effects on grid frequency and voltage in completely isolated and relatively small power systems with significant penetration of wind generation. As a solution, the battery storage technologies can play a vital role in improving the power quality against voltage depressions and power interruptions and reliability of the power system [2].

In the world, some regions has a great wealth of renewable energy sources (RES), especially wind energies. These energies do not utilize to compensate for the increasing demand for electrical power. Also, the burden on transmission network is increasing at an unexpecting manner so that the transmission network becomes economically cheap. Furthermore, the depletion of fossil fuels and the rampant increase in the price of these fuels have resulted in increased interest to include RES for power productions [3].

In the middle of a continuous and exponential development of renewable energies trend, generated by the increasing price of the conventional fuels which are quickly draining, and facing the fact that we have tremendous messages sent by our polluted Planet, people returned its face to environment concerns [4].

2. TYPES OF BATTERIES

Lead-acid batteries are commonly used in energy systems. However, such batteries typically have a short life-span and may create pollutants during the production process. Thus, in the future, they will likely be replaced by cleaner energy storage devices. A nickel hydrogen battery works the same as a lead-acid battery. However, with increased use, its capacity will decrease. Its use has been restricted by the European Union (EU) because of the risk of heavy metal pollution [1].

A sodium sulfur battery is a type of molten-salt battery constructed from liquid sodium (Na) and sulfur (S) [5-6]. Sodium sulfur and flow batteries are regarded as the newest, most efficient types of electric storage batteries. These types of batteries have a large capacity and are widely employed in all kinds of applications. Sodium sulfur batteries have a high energy density and are very small and efficient which makes them easy to install and transport. However, such batteries need high temperature conditions in order to work properly. A flow battery has many systems and can store energy for a long time. This type of battery is currently in high commercial demand. [1]

The first non-rechargeable Lithium Ion (Li-ion) batteries became commercially available. Since lithium is the lightest of the metal elements, it also has the greatest electrochemical potential and thus provides the largest specific energy per weight. Lithium ion batteries are considered to have the greatest power battery system and potential for development. A lithium ion battery has a high energy density, can store energy for long periods of time, and does not produce pollution. Although it is almost always found in small electronics, its monomer level is never standard. The greatest concern with lithium ion batteries is that those having a large capacity also pose a considerable safety hazard. [1] In Recent years, with the rapid development of electric vehicles (EV) and hybrid electric vehicles (HEV), lithium-ion batteries have become the main way of energy storage for EV and HEV. [5]

A Lithium Polymer (LiPo) battery consists of several components [9-10]: A positive electrode consisting of LiCoO2 or LiMn2O4, a separator made of a liquid electrolyte that contains LiPF6 and organic solvents, as well as a negative electrode formed by carbon material. [1] It is developing an advanced lithium polymer rechargeable battery based on proprietary positive electrode chemistry. In one formulation, this electrode contains elemental sulfur, either free or in association with secondary materials that promote its utilization. Batteries based on this cathode chemistry offer high steady-state (>250 Wkg) and high peak power densities (3000 Wkg), in a low cost and environmentally benign format. High energy density, in excess of 500 Wh/kg (600 WM) can also be achieved. The high power and energy densities, along with the low toxicity and low cost of materials used in the PolyPlus solid-state cells make this battery exceptionally attractive for both hybrid and electric vehicles, and for consumer electronic applications.[6]

A nickel-metal hybrid (NiMH) battery is a rechargeable battery that has chemical reactions similar to the NickelCadmium (NiCd) battery. However, the nickel-metal hybrid battery has two to three times the capacity of the nickel- cadmium (NiCd) battery. This type of battery has a thin design and relatively good battery life. It is also very lightweight and safe to use. Unfortunately, NiMH batteries are more costly to manufacture than lithium-ion batteries [1]

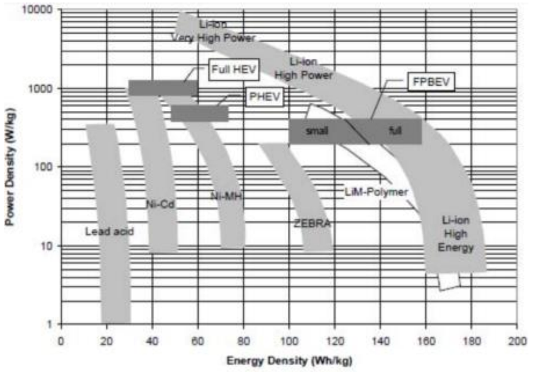

Figure 1 Shows the energy and power densities of different types of batteries

A Lithium Iron battery (LiFePO4) has the advantages of safety, long life, no pollution, high power density, and high coulombic efficiency (η) [1]. The change rates of the terminal voltage of a LiFePO4 battery from 20% to 80% of the state of charge (SOC) are very small; therefore, this battery can provide a stable voltage for load, but this can cause problems in applications such as SOC estimation. The cycle life of this battery is greater than 1000 times; hence, the battery cost should be low, but collecting data for developing state-of-health (SOH) estimation technology is problematic.[7]

Sealed Lead Acid (SLA) battery are sometimes referred to as VRLA (valve-regulated lead acid) batteries - most economical for larger power applications where weight is of lesser concern. The SLA is the prefemed choice in hospital equipment, wheelchairs, UPS systems and emergency lighting where its low energy density is of lesser importance. [8]

Reusable Alkaline battery - replaces disposable household batteries; suitable for low-power, low-cost applications. Its limited cycle life is compensated by low self-discharge, making this battery ideal for portable entertainment devices and flashlights. [8]

3. INSPECTIONS OF THE BATTERY

General Inspections. Inspection of the battery on a regular scheduled basis should include a check of the following:

(1) General cleanliness of the battery and battery area

(2) Float voltage

(3) Cells for cracks or electrolyte leakage

(4) Plates of cells (plates buckling. discoloring, grid cracks, or plate growth)

(5) Ambient temperature and ventilation equipment

(6) Pilot cell (if used) voltage. specific gravity. electrolyte temperature and level

(7) Terminals and connectors for evidence of corrosion

Note: A regular schedule for a nuclear plant Class I battery should be consistent with the inspection intervals described in IEEE Std 303-1971. Criteria for Class IE Electric Systems for Nuclear Power Generating Stations.

Quarterly Inspections. Quarterly inspections should include a check of the following:

(1) Specific gravity readings of each cell

(2) Voltage reading of each cell and total battery terminal voltage (cell voltages shall be post to post to include intercell connector)

(3) Electrolyte level of each cell

(4) Float voltage

(5) Temperature of electrolyte of representative cells (suggestion - every sixth cell) (6) Battery load with battery on float charge (charger current)

Yearly Inspections. Yearly inspections should include a check and record of the following:

(1) Cell condition (detailed visual inspectioil)

(2) Cell-to-cell and terminal detail connection resistance

(3) Integrity of battery rack

Special Inspection. Under any abnormal conditions or severe circumstances the inspection procedures listed in Quarterly Inspections and Yearly Inspections should be repeated.[9]

4. BATTERY LIFE, OPERATING TEMPERATURE

The location and arrangement of cells should result in no greater than a 3 ºC temperature differential between cells at a given time. Avoid conditions that result in spot heating or cooling, as temperature variations will cause the battery to become electrically unbalanced. Elevated temperature operation will shorten battery life. A general rule of thumb for lead-acid batteries is that prolonged use at elevated temperatures will reduce the battery life by approximately 50% for every 8 ºC above 25 ºC. Ni-Cd cells are less affected, with a life reduction of about 20% for the same temperature increase. Rated performance of cells are typically at 25 ºC. A location where this temperature can be maintained will contribute to optimum battery life, performance, and cost of operation. Extreme ambient temperatures should be avoided because low temperatures decrease battery capacity, while prolonged high temperatures shorten battery life and increase maintenance cost. Installation in a location with an ambient below the rated temperature will affect sizing.[10]

5. OPERATION PLANNING OF BATTERY MANAGEMENT SYSTEMS

Battery energy storage systems (BESSs) are an important method to store energy with their flexible configurations for different application requirements without geographical conditions. Their fast responses can simultaneously input or output active and/or reactive power. Compared with other energy systems, BESS has a relatively higher energy efficiency. The said advantages make BESS an irreplaceable option in centralized and distributed new energy integration, and ancillary grid operations. [11]

Large-scale energy storage applications require multiple lithium-ion battery packs operating in parallel, such applications comprise of renewable energy storage systems. The current technology to enable parallel operation of multiple battery packs is quite hardware intensive. It requires a separate pack management system operating as a master and battery management systems in each of the battery packs configured as slaves. This significantly affects the scalability of such systems as the number of battery packs that can be connected in parallel is completely dependent on the capacity of the master [12], [25].

Battery energy storage systems (BESSs) require a battery management system (BMS) to monitor and maintain safe, optimal operation of each battery pack and a system supervisory control (SSC) to monitor the full system. Batteries are dynamic in nature, constantly operating outside the equilibrium state during cycling. In addition, the situation worsens for the case of intercalation-based storage systems (e.g., Li chemistry) which operate as a closed system with very few measurable state variables, making it difficult to properly monitor the states of the battery and maintain safe operation. Furthermore, even under normal operation the battery packs of a BESS will degrade during cycling. This degradation can be accelerated by extreme charging patterns, increased temperature (both ambient and operating), overcharging, or undercharging. A basic BMS controls battery packs only to meet the power demand. However, smarter model-based BMSs can reduce the causes of degradation and improve the performance of the system. Predictive and adaptive BMSs based on models are especially important for large battery packs for applications such as electric vehicles and grid integration. While there are many possible solutions to the intricate problem of BESS control, Fig. 2 describes a general BESS–BMS structure used for implementation [13].

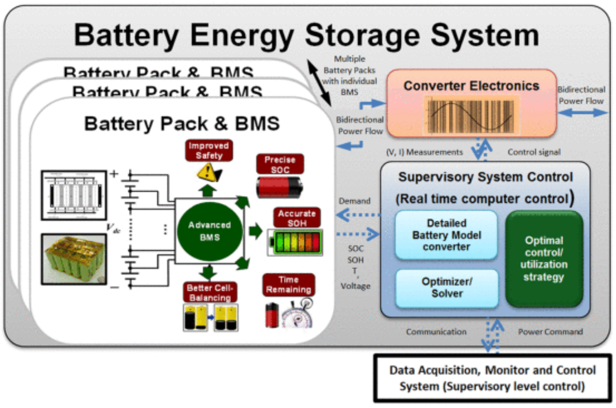

Figure 2 Schematic for the implementation of a battery pack and BMS into a BESS.

Valve regulated lead acid (VRLA) batteries widely used in substations still have large residual capacities when they are retired, so they can be reused in battery energy storage systems (BESS). The schematic of the reusing BESS is shown in Fig. 3 .The BMS can achieve the functions such as battery dynamic equalization, overvoltage/undervoltage protection of each battery cell, and automatic isolation of defective batteries. A battery energy storage system (BESS) using retired VRLA batteries is designed. During battery charging, the BMS can automatically switch between normal charging and equalizing charging according to the status information of each battery. During battery discharging, the BMS can accurately identify and isolate the defective batteries and try to repair them in the charging process. Thus, the stability and flexibility of the reusing BESS are improved. [14]

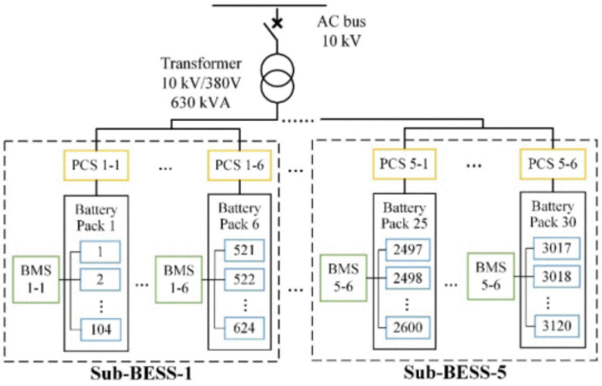

Figure 3 Schematic of the reusing BESS

For the wind power, the value of the power generated depends on the performance coefficient (CP) and the available wind speed. To maximize this output power, and as the wind speed is varying from time to time, the performance coefficient must be maximized and controlled. For the battery energy storage system conditions, the battery system should not be discharged to the minimum limit and charged to the maximum limits; because maximum charging and minimum discharging will cause a decrease in the life cycle of the battery system. Thus, in order to overcome this problem, the SOC should be controlled. Therefore, SOC must be lies between 0.3<SOC<0.8. The initial value of SOC is considered to be equal to 0.3. For the load system demand conditions, the load is manifested by the current it needs from the source the voltage of the wind turbine should be higher than the voltage of the battery system. [3]

6. THE APPLICATION OF VALVE-REGULATED LEAD ACID BATTERIES (VRLA SOCALLED LL-TYPE) TO WIND POWER GENERATION SYSTEM

Wind energy can be defined as the process by using the wind turbines to convert the kinetic energy in the wind into mechanical power. Once a wind turbine has converted the kinetic energy in the wind into rotational mechanical energy, that rotational energy is usually converted by a generator into electricity.[3] Wind power system should be managed so as to operate at optimal parameters, requiring the capture of wind energy with maximum efficiency.[15]-[17]

Electric power generation systems using renewable energy sources, such as wind power and photovoltaic power, a renewable and environmental friend energy source has an advantage without the greenhouse effect gas emission. The electric power output can be fluctuated by weather, however. This fluctuation is the essential problem of the renewable energy introduction. Instantaneous fluctuation causes the problem of the quality of a power grid, and a long period fluctuation causes the problem of the disturbance of the programmable power generation of a power grid. It is considered that these problems increase when the amount of electric power generation using renewable energy sources increases. In order to solve these problems, we need relaxation of instability of power output. The combination of the renewable energy system with a battery energy storage system is one of the solutions to solve the problem. These continuous fluctuation conditions are to cause the problem of battery life troubles by corrosion of positive grids, sulfation of negative active materials, stratification, partial deterioration, and primary capacity loss (PCL). Therefore, batteries hybridized to the wind power generation have to be operated under very severe conditions.[18]-[23]

The LL type battery has been applied to smoothing the fluctuations of the 1.2MW wind power generation system.

(1) The 0.1CA capacity of batteries of the LL type VRLA has been kept over 85% of its initial capacity before use in the wind power generation system.

(2) The sulfation, partial deteriorations, and PCL under the system operational conditions did not occur.

(3) The main failure mode of the batteries was the corrosion of positive grids.

(4) The life of batteries of the LL type VRLA applied to this system was evaluated to be 9 years.

(5) An expected life of more than 17 years of the VRLA battery, the LL-W type (table 1), has been developed for the use in the system of the wind power generation, by taking account of all the information on the LL type VRLA battery already applied to the wind power generation system. [18]

Table 1. Outline of developed battery (LL-W type)

Type		LL1500W
Voltage		2V
Capacity(10HR)		1500Ah
Installation direction		Horizontal position
Dimension	Height	507 mm
	Width	172 mm
	Length	437 mm
Weight		106 kg
Life expectancy (at 25 degrees)		17 years
Use range of SOC		SOC30-90%
Charge condition		Recommendation condition
Structure		Valve regulated lead acid battery

Isolated power system such as offshore wind turbine platform is characterized by limited generation capacity, large AC motor load, converters and cable connections. The factors have posed a big challenge to satisfy the requirements of many voltage, frequency and waveform distortion sensitive devices. During normal operation, the bus voltage and frequency variations should be limited to an acceptable range. The battery energy storage system (BESS) in windbattery hybrid generation comprises mainly of batteries and power conditioning system (PCS), and control of PCS is the key technology in BESS. [2]

A simplified one-line diagram of the considered electrical network is illustrated in Fig. 4. A 1.5MW DFIG (doubly fed induction generator) wind turbine is connected to point of common coupling (PCC) by means of a transformer, raising the voltage level from 0.69kV to 6.3kV, and BESS including NAS battery and PCS is integrated into the network at PCC through a step-up transformer of 0.07/6.3kV. The composite load of the offshore platform is 300kW, composed of dynamic load such as a 100kW high voltage motor of 6.3kV (PF=0.85) and static load such as 100kW high voltage power quality (PQ) load of 6.3kV and 100kW low voltage PQ load of 0.4kV (PF=0.8). Furthermore, a diesel generator served as standby power supply and a dump load must be included in order to maintain the isolated power system reliability at a desirable level. The PCS can regulate its power flow to keep the system voltage and frequency at a desired level during the disturbances from both utility side and demand side such as wind fluctuation and large AC motor start/stop. [2]

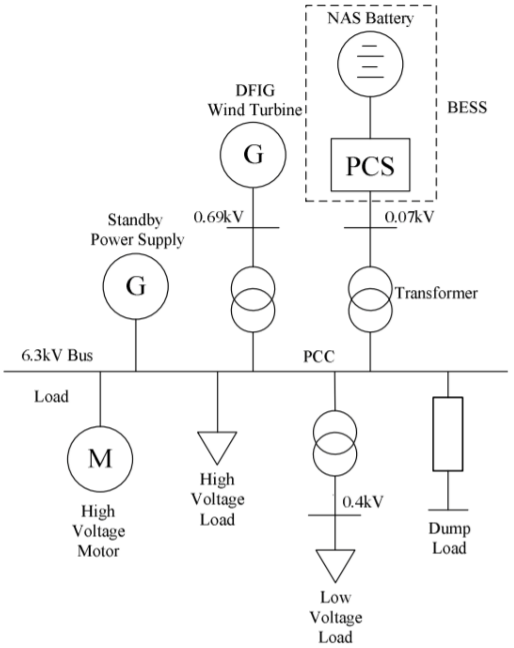

Figure 4 Simple circuit diagram of the offshore platform power system

7. THE ECONOMIC FEASIBILITY OF IMPLEMENTING VARIOUS BATTERY STORAGE SOLUTIONS

The economic feasibility of implementing various battery storage solutions in wind power systems is a complex issue that depends on multiple factors. Let's analyze the information provided in the text to discuss the economic aspects of these battery technologies:

Lead-Acid Batteries: The text mentions that lead-acid batteries have a short lifespan and can create pollutants during production. This could result in increased operational and environmental costs. As a result, they may become less economically viable in the long run, especially as cleaner alternatives become available.

Nickel Hydrogen Batteries: These batteries are compared to lead-acid batteries, but their capacity decreases with increased use. Moreover, they face restrictions due to heavy metal pollution concerns from the European Union. This indicates potential environmental and regulatory costs associated with their use, which could affect their economic feasibility.

Sodium Sulfur Batteries: These are described as efficient and having a high energy density, making them suitable for various applications. However, they require high-temperature conditions, which might increase operational costs. Their economic feasibility would depend on the specific application and the cost of maintaining the required temperature conditions.

Lithium-Ion Batteries: Lithium-ion batteries are praised for their high energy density, long-term energy storage capabilities, and lack of pollution. However, there's a mention of safety concerns, especially with larger capacity batteries. Addressing safety issues might entail additional costs.

Lithium Polymer Batteries: Lithium polymer batteries are highlighted for their high power and energy densities, making them attractive for various applications, including electric vehicles. However, the economic feasibility could be influenced by the cost of materials and production methods, as well as safety considerations.

Nickel-Metal Hybrid Batteries: These batteries are noted for their high capacity and safety. Still, they are considered more costly to manufacture than lithium-ion batteries, which could affect their economic viability, especially in cost-sensitive applications.

Sealed Lead Acid (SLA) Batteries: SLA batteries are mentioned as economical for larger power applications where weight is less of a concern. Their economic feasibility would depend on the specific application's requirements and the cost-effectiveness of SLA batteries compared to alternative technologies.

Reusable Alkaline Batteries: These batteries are described as suitable for low-power, low-cost applications. Their limited cycle life is compensated by low self-discharge, which could make them economically viable for certain portable devices.

In summary, the economic feasibility of implementing these battery storage solutions in wind power systems varies depending on factors such as battery lifespan, energy density, safety, environmental considerations, and application-specific requirements. Additionally, ongoing advancements in battery technology and changes in regulations can impact their economic viability. A thorough cost-benefit analysis would be necessary for each specific use case to determine the most economically advantageous battery technology [24].

8. FUTURE IMPLICATIONS, PARTICULARLY FOR WIND POWER SYSTEMS

The rapid advancements in battery technology hold several future implications, particularly for wind power systems:

Enhanced Energy Storage: Advanced battery technologies like lithium-ion, sodium-sulfur, and flow batteries offer higher energy densities and longer lifespans. This will allow wind power systems to store more energy efficiently, mitigating the intermittent nature of wind generation.

Improved Reliability: Batteries can act as grid stabilizers, providing a consistent power supply during fluctuations in wind energy production. This will enhance the reliability of wind power systems and reduce the need for backup fossil fuel generators.

Grid Integration: Battery energy storage facilitates better integration of wind power into the electrical grid. It enables the smooth injection of wind energy when it's abundant and its release during high-demand periods, thus reducing strain on the grid.

Sustainability: With a shift away from lead-acid batteries, which have environmental concerns, the adoption of cleaner energy storage devices will contribute to a more sustainable energy ecosystem, aligning with global environmental goals.

Cost Reduction: As battery technologies improve and economies of scale kick in, the cost of energy storage is likely to decrease. This will make wind power systems more cost-competitive with traditional fossil fuel-based energy sources.

Repurposing Retired Batteries: The text also highlights the reuse of retired batteries in energy storage systems. This practice can further reduce costs and environmental impact, extending the lifecycle of batteries.

Battery Management: The development of advanced Battery Management Systems (BMS) will play a critical role in optimizing battery performance, reducing degradation, and enhancing the overall efficiency of wind power systems.

Safety Considerations: As lithium-ion batteries become more prevalent in wind power systems, safety measures must be a top priority to mitigate the risk of fires or other hazards associated with high-capacity batteries.

Offshore Wind Farms: Battery technology can be especially beneficial for offshore wind farms, where energy storage can help overcome transmission challenges and stabilize power supply to onshore grids.

Market Growth: The increasing adoption of electric vehicles (EVs) and renewable energy sources, including wind power, will drive the demand for advanced batteries. This growing market will likely spur further innovations and cost reductions in battery technology.

In summary, rapid advancements in battery technology are poised to revolutionize the wind power industry. These developments promise increased efficiency, reliability, and sustainability, making wind power a more attractive and integral part of the global energy landscape. However, challenges related to safety, integration, and scalability must be carefully addressed as these technologies evolve.

9. CONCLUSIONS

In conclusion, the evolution of battery technologies within the context of wind power systems presents significant opportunities and challenges for the renewable energy sector. These trends have the following implications:

The ongoing development of various battery types, including sodium-sulfur, lithium-ion, flow, and lead-acid batteries, offers new avenues for optimizing energy storage solutions in wind power systems. These advancements promise increased efficiency, longer lifespan, and greater energy density.

Wind power, along with other renewable sources, is emerging as a vital component of the energy landscape. Battery storage systems are becoming indispensable in addressing the intermittent nature of wind energy, enabling more reliable and flexible power generation and distribution.

The global shift towards cleaner and more sustainable energy sources places an emphasis on environmentally responsible practices. Battery technologies that minimize pollution during production and operation, such as lithium-ion and lithium polymer batteries, align with these principles.

Safety concerns, particularly in relation to high-capacity lithium-ion batteries, require meticulous attention. Prioritizing safety measures, including thermal management and hazard prevention, is imperative to ensure the secure implementation of battery storage in wind power systems.

Evaluating the economic feasibility of deploying battery storage solutions in wind power projects is essential. Factors such as battery cost, performance, regulatory compliance, and environmental considerations must be thoroughly assessed to determine project-specific economic viability.

The future of battery technology in the wind power sector holds immense potential. These technological innovations have the capacity to significantly enhance energy storage capabilities, grid reliability, and cost-effectiveness, making renewable energy sources more competitive in the energy market.

Advanced Battery Management Systems (BMS) play a pivotal role in optimizing battery performance, ensuring longevity, and enhancing overall system efficiency. Continued research and development in BMS technology will be instrumental in realizing these benefits.

Battery technology is particularly advantageous for offshore wind farms, where energy transmission challenges can be mitigated. By stabilizing power supply and optimizing energy flow, batteries contribute to the success of these ambitious projects.

The increasing demand for electric vehicles (EVs) and the growing emphasis on clean energy sources, including wind power, are driving rapid market growth. These dynamics stimulate innovation and cost reductions in battery technology, benefiting both the renewable energy sector and EV manufacturers.

In conclusion, the integration of advanced battery storage solutions in wind power systems presents a transformative opportunity to revolutionize the energy landscape. While challenges exist, such as safety and economic considerations, the overarching potential for enhanced sustainability, reliability, and cost-efficiency makes these developments a cornerstone of future energy solutions. Success will require collaborative efforts across industries, ongoing research, and strategic investments to fully harness the benefits of evolving battery technologies in wind power systems.

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