

# Recent Advancements in Wind Energy: An Overview

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**ABSTRACT:** Wind energy is a form of renewable energy with high potential. The researchers are working to innovate new designs, machines, materials, and technologies to produce power from wind energy efficiently. This overview aims to briefly discuss some of the recent advancements in wind energy production. These are related to materials, technology, machines, and structural and design advancements. Wind energy can play a vital role in world energy supplies. Advancements and innovations in the field of wind energy generation can help in its effective production.

**KEYWORDS:** Renewable Energy, Wind Energy, Wind Turbine, Offshore Wind Energy, Onshore Wind Energy, Recent Advancements, Sustainable Power Generation.

## I. INTRODUCTION

There is a constant increase in the demand for energy worldwide with the increase in population and industrialization. Earlier fossil fuels were the primary energy source to meet the power requirements, but their extensive use has caused environmental problems and rapid depletion of their resources [1,2]. Renewable energy emerged as a potential energy source that can help reduce the dependence on fossil fuels to meet energy requirements. Renewable energy is derived from sun, winds, water, or tides and is naturally replenished.

Wind energy is a form of renewable energy which uses wind power to generate electricity. So, it converts the kinetic energy of air to electric energy. The wind turbines consist of blades that rotate from the wind power. This rotational energy is transferred to a generator, which produces electric energy [2,3]. Wind energy was historically used for sailboats and windmills. However, now they are used for power generation and are considered one of the cheapest forms of

energy. The advantages of wind energy include its low cost, less requirement of space, easy management, ecofriendly nature, and renewable nature. Disadvantages include the variable nature of this energy (as it can't be produced on demand), un-aesthetic nature, noise production during blade movement, and impact on local wildlife [4].

Wind farms can be located on land (onshore) or in the sea (offshore). The overall cost of establishing offshore farms is higher, but they have a greater capacity for power production and lower visual influence. On the other hand, the cost of production of onshore wind farms is lower, but they have a higher visual influence [5].

According to the available data, wind energy contributed to 7.8% of the world's energy supplies [6]. This form of energy has high potential. Data reveals that wind energy grew by 10% in the year 2023 [6]. With such a high growth potential, researchers are working to innovate new designs, machines, materials, and technologies to efficiently produce power from wind energy. This overview briefly discusses some of the recent advancements in wind energy production.

## II. METHODOLOGY

We searched two academic search databases (Google Scholar and Research Gate) to retrieve recent articles relevant to our study. The keywords used for the search were renewable energy, wind energy, turbine, offshore wind energy, wind turbine, onshore wind energy, recent advancements, and Sustainable power generation.

## III. ADVANCEMENTS IN WIND ENERGY GENERATION

- 1) **Advancements in The Materials Aspect**
- A) **Advanced protective coatings on wind turbines:** Nanotechnology-based anti-corrosion coatings prevent corrosion, anti-

icing coatings, along with de-icing technologies, prevent ice deposition, and aerodynamic coatings prevent air drag and optimize airflow. These coatings improve the durability and overall efficiency of wind turbines [7-9].

**B) Advancements in wind energy harvesting materials:** Piezoelectric materials like lead zirconate-titanate, polymers of Polyvinylidene fluoride, and other lead-free materials are some of the advanced options for producing power for electric machines based on low energy [1]. These materials pose challenges in designing and practical applicability [1,2].

**C) Advancements in wind turbine blade materials:** Advanced composite materials like glass fiber-reinforced polymers and carbon fiber-reinforced polymers are lightweight and possess excellent mechanical properties, thus allowing for the fabrication of longer blades, leading to more power production due to more wind capturing [7,10].

## 2) Technological Advancements

**A) Use of machine learning and deep learning technologies:** They enhance the functioning proficiency of offshore wind turbines [3]. This technology aids in multiple ways, which include: i) prediction/forecasting of wind speed, long-term weather conditions, faults, power output, and bending strain [3]. ii) optimizing functioning and maintenance, diagnosis of faults, and conservation and generation of energy [3,11].

**B) Installation of smart sensors:** Smart sensors can be installed in turbines at various locations, such as blades, gearbox, and nacelle. They collect important operational data, monitor the conditions of the components, guide timely maintenance, and reduce turbine damage [7, 12].

**C) Wireless sensor networks:** Their use improves connectivity and allow uninterrupted data transmission even in harsh weather conditions [13].

## 3) Advancements in Machines

**A) Smart grid systems:** These grids monitor and control power flow and increase energy efficiency [14]. These grids can help in forecasting energy requirements and thus play a crucial role in managing electricity supply to urban areas as conventional fuels and batteries cannot store sufficient to meet the requirements [14,15].

**B) Advancements in energy storage technologies:** Wind energy is intermittent in nature, so to achieve consistent power delivery, it is vital that its storage be efficient [14]. The introduction of AI-integrated Battery energy storage systems [16] and hybrid energy storage systems [17] can help enhance the efficacy of wind power storage.

## 4) Structural and Design Advancements

**A) Advancements in blade design:** The use of hybrid composites allows manufacturers to customize blade designs based on needs, thus improving the machine's efficiency [18].

**B) Turbines with longer blades and taller towers:** This is possible with the use of composite-based materials for blade construction, which provide a balance between size and weight. High-strength steel and advanced alloys help construct taller towers [9,19].

**C) Advancements in Foundation designs:** Use of new foundation designs like floating platforms and monopoles to support the installation of wind turbines in deeper waters in offshore areas [19].

**D) Advancements in Power cables:** Use of dynamic power cables fabricated from newer materials having newer designs for reliable connectivity and uninterrupted power delivery from offshore installations [20].

## Challenges and Future Prospects

Challenges include high initial costs involved in research and development and concerns related to the long-term reliability and durability of newer materials. Future prospects include, Use of shape memory alloys and nanomaterials for fabrication of towers and blades [7], Use of biodegradable materials for manufacturing various components of wind turbines thus minimizing adverse effects on environment due to production and installation of wind energy turbines [7], and Investigating different blade shapes, rotor sizes and configurations to improve performance of wing turbines [21].

## IV. CONCLUSION

Wind energy has great potential and can play a vital role in world energy supplies. Advancements and innovations in wind energy generation can help ensure its effective production.

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