Design And Analysis of Modern Vertical Axis Wind Turbine (VAWT)

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Abstract- *With traditional energy sources running low, the world is turning more towards renewable energy, particularly wind power. But current wind turbines have their flaws. Enter the wind turbine tree, a potential solution to these issues. This study looks at various research papers on different wind turbine designs. After analysing them all, it's clear that wind turbine trees with Savonius blades are better than traditional bladed turbines. They take up less space and produce the same amount of power. This paper explores these findings and suggests that wind turbine trees could be the future of wind energy..*

Keywords- Renewable Energy, Wind Turbine, wind Turbine Tree, Vertical axis wind turbine (VAWT), Horizontal axis wind turbine (HAWT), Computational fluid Dynamics (CFD).

INTRODUCTION

In wind power generation, there are two main methods: rotational wind harvesting and oscillation wind harvesting. They both convert wind energy into electricity, but they work differently. Rotational wind harvesting is like what we see in traditional windmills. The spinning blades turn a shaft connected to a gearbox, which then transfers the energy to a generator. This generator changes the spinning motion into usable electricity. Wind energy technology has become really important in recent years. But traditional wind turbines are expensive to make, heavy, and hard to maintain. However, wind power is expected to play a big role in electricity production in the future. That's why energy policies around the world are encouraging the development of wind turbines and their technology.

HISTORY

The history of wind turbine development spans millennia, reflecting humanity's enduring quest to harness the power of the wind for various purposes. Ancient civilizations, including the Persians, Egyptians, and Chinese, employed simple windmills for tasks like grinding grain and pumping water as early as 2000 BCE. These early windmills typically featured vertical-axis designs and were essential to agricultural and industrial activities. However, it was not until the late 19th century that wind turbines began to transition towards electricity generation. In 1887, Scottish engineer James Blyth erected the first known electricity-generating wind turbine in Marykirk , Scotland. Blyth's design utilized cloth sails mounted on a lattice tower to power his holiday home, marking a significant milestone in wind turbine history.

Subsequent innovations by pioneers such as Danish scientist Poul la Cour and American engineer Charles F. Brush propelled wind turbine technology forward. La Cour's experiments in the early 20th century laid the foundation for modern wind turbines, with his multi-blade designs contributing to Denmark's widespread adoption of wind power for electricity generation. The mid-20th century saw the emergence of horizontal-axis wind turbines (HAWTs), pioneered by engineers like Palmer Putnam in the United States. These early HAWTs, featuring two or three blades mounted on a horizontal axis, played a crucial role in the growth of wind power during the 1970s energy crisis.

Throughout the latter half of the 20th century and into the 21st century, wind turbine technology experienced rapid advancements driven by innovations in materials, manufacturing processes, and control systems. The introduction of fiberglass blades, variable-speed generators, and advanced pitch control mechanisms significantly improved the efficiency, reliability, and cost-effectiveness of wind turbines.

Today, wind power stands as one of the fastest-growing sources of renewable energy worldwide, with modern wind turbines capable of generating significant amounts of electricity at competitive costs.

The history of wind turbine development reflects humanity's relentless pursuit of sustainable energy solutions and underscores the ongoing innovation and progress in the field of renewable energy.

LITERATURE SURVEY

Understanding the design theory and materials used in wind turbine blades is crucial for project implementation. This paper offers insights into both aspects, providing valuable information necessary for the effective design and construction of wind turbines. By addressing these fundamental components, engineers and researchers can better navigate the complexities of wind turbine development, ultimately facilitating the successful harnessing of wind energy for sustainable power generation.

DESIGN OF BLADES FOR WIND TURBINES

S.M. Rehman. et al. gives review on an innovative approach to wind turbine design is explored, focusing on the orientation of leaf-shaped blades to maximize energy generation efficiency by an impressive 70%. This novel blade design aims to achieve higher power output while utilizing minimal land space and without relying on heavy, large blades traditionally associated with wind turbines. Such a design breakthrough holds immense promise for various urban and commercial settings, including hotels, parking areas, public parks, malls, high-rise buildings, and small industries. By effectively harnessing wind energy in these environments, this pioneering approach offers a sustainable solution to meet energy demands while minimizing environmental impact and spatial constraints. Rehman's review paper highlights the potential of this blade orientation strategy to revolutionize wind energy utilization in diverse urban landscapes, paving the way for widespread adoption of wind turbines in previously inaccessible or underutilized spaces.[1].

Mukesh Kumar Rathore. et al. gives brief review on significant focus is placed on optimizing the performance of wind turbines through the application of the Aero Savonius blade design, particularly in the context of wind tree installations. The paper delves into the development and evaluation of a new Aero Leaf design, which emerged after extensive simulation studies employing Computational Fluid Dynamics (CFD) techniques.

The primary objective behind this innovative design is to enhance the absorption of wind energy efficiently. Specifically, Rathore and the research team aimed to cultivate wind flow from any direction, even at low speeds as minimal as 3.3 m/s, thereby achieving a remarkable coefficient of performance of 12.9%. This targeted approach addresses the challenges posed by low wind speed situations, which are common in many regions. By harnessing wind energy effectively under such conditions, the Aero Leaf design offers a promising solution to enhance the viability and sustainability of wind energy generation. Rathore's review paper underscores the potential of this blade design to revolutionize wind energy utilization, particularly in areas with suboptimal wind conditions, and sets the stage for further advancements in wind turbine technology [2].

M. Salman Siddiqul et al. study conducted on the performance of the H-type vertical axis wind turbine (VAWT) under the influence of turbulence intensity and rapid changes in wind direction reveals significant insights into the behaviour of these turbines in real-world conditions. Through computational fluid dynamics (CFD) simulations, various aspects affecting turbine performance were analysed, focusing on the impact of fluid turbulence on the resultant torque.

Turbulence intensity, a key parameter in wind dynamics, plays a critical role in the efficiency and stability of VAWTs. The findings of the study indicate that turbulence can cause fluctuations in the resultant torque of the H-type VAWT, with variations ranging from 23% to 33% compared to scenarios with no turbulence. This variation underscores the sensitivity of VAWTs to atmospheric turbulence and its implications for power generation.

Furthermore, the study highlights the effect of rapid changes in wind direction on turbine performance. Sudden shifts in wind direction can lead to dynamic loads on the turbine blades, affecting their aerodynamic efficiency and, consequently, the resultant torque. By examining these dynamics through CFD simulations, a deeper understanding of how turbulence and wind direction changes influence VAWT performance is attained. Overall, the study underscores the importance of considering turbulence intensity and wind direction variability in the design and operation of VAWTs. The insights gained from this research contribute to optimizing VAWT performance and enhancing their reliability in diverse environmental conditions, thereby advancing the utilization of wind energy for sustainable power generation [3].

Dowoan Han et.al. gives review on a comprehensive performance test was conducted on a Helical type vertical axis wind turbine (VAWT) specifically designed for urban environments. The turbine was optimized with a low tip speed ratio of 1.1 and targeted for operation at a wind speed of 9m/s. The dimensions of the turbine were determined through meticulous analysis, employing the NACA0018 blade profile under the IEC61400-2 Protocol model.

The performance evaluation included a detailed study of the lift and drag characteristics of the blade with respect to the angle of attack, facilitated by computational fluid dynamics (CFD) simulations. These simulations enabled the assessment of the turbine's average power output, revealing a remarkable 5.9% increase compared to predictions from the mathematical model. Specifically, the turbine demonstrated an average power output of 114.7 W, surpassing the anticipated 100 W output.

This meticulous performance evaluation not only validates the effectiveness of the Helical type VAWT design but also underscores the importance of utilizing advanced simulation techniques for optimizing turbine performance. Such findings hold significant implications for the development of efficient wind energy systems tailored for urban settings, where space and environmental considerations are paramount [4].

Sahishnu R. Shah et.al. performance analysis of vertical axis wind turbine (VAWT) Savonius rotor blades is meticulously examined, particularly focusing on their rotation characteristics across various blade designs: straight, curved, twisted, and air foil-shaped. Through the lens of a comprehensive mathematical model encompassing parameters such as power coefficient, tip speed ratio, and the intricacies of mechanical and electrical components, the study aims to elucidate the economic viability of VAWT systems, particularly through the optimization of blade shapes.

The investigation reveals a nuanced understanding of blade performance, with straight blades demonstrating suboptimal effectiveness compared to their twisted counterparts. This finding underscores the significance of blade design in enhancing turbine efficiency and power generation capacity. By employing mathematical models, the study estimates a substantial electricity generation of approximately 7838 kWh, translating into an estimated revenue of $845.51. Such projections illuminate the tangible economic benefits achievable through the strategic manipulation of blade configurations, thereby contributing valuable insights to the field of wind energy utilization and fostering advancements in renewable energy technologies [5]

S. Mohammed et.al conduct an in-depth performance study on Vertical Axis Wind Turbines (VAWTs) tailored for low wind speeds is presented. The study focuses on the utilization of an H-type rotor design optimized for operation in low wind conditions. Notably, the turbine blades are crafted from lightweight aluminum sheets, ensuring optimal performance within a specified wind speed range of 2.5 to 6.5 m/s.

By leveraging this specialized rotor design and material composition, the study aims to harness wind energy efficiently in environments characterized by low wind speeds. Through rigorous analysis and experimentation, the paper estimates that this VAWT configuration can generate a power output of approximately 25 watts. Such findings are indicative of the turbine's ability to extract energy effectively from modest wind resources, thereby offering a promising solution for energy generation in regions with predominantly low wind conditions

Overall, the review paper by S. Mohammed provides valuable insights into the development and optimization of VAWT systems tailored for low wind speed environments. By showcasing the efficacy of the H-type rotor design and lightweight aluminum blade construction, the study contributes to the advancement of renewable energy technologies, particularly in addressing the challenges associated with low wind speed regions [6].

MATERIAL USED IN WIND TURBINE BLADES.

Mohammed et.al conduct an in-depth performance study on Vertical Axis Wind Turbines (VAWTs) tailored for low wind speeds is presented are crafted from lightweight aluminum sheets, ensuring optimal performance within a specified wind speed range of 2.5 to 6.5 m/s. Utilizing this unique rotor design and material composition, the research attempts to effectively capture wind energy in low-wind settings. The study predicts that this VAWT arrangement can produce an output of about 25 watts through thorough analysis and experimentation. These results show that the turbine can efficiently extract energy from limited wind resources, which makes it a viable option for energy generation in areas with generally low wind conditions.

All things considered, S. Mohammed's review study offers insightful information about the design and improvement of VAWT systems suited for low wind speed conditions. The study makes a significant contribution to the development of renewable energy technologies by demonstrating the effectiveness of the H-type rotor design and lightweight aluminium blade manufacture, especially in addressing the difficulties associated with low wind speed regions[6].

S.M. Rehaman et al. investigate a novel method of producing wind power using the Aero Leaf Wind Turbine in their study. Acknowledging the limitations of restricted land area and the requirement to reduce the weight and upkeep expenses customarily linked with wind turbine blades, the study team presents an innovative solution: Nylon fibre leaf-shaped blades. This novel design that deviates from traditional turbine blades has great potential to increase the efficiency of power generation in small spaces. The Aero Leaf structure's use of nylon fibre makes the blades incredibly light, allowing the turbine to function well even in spaces with little space. The lighter weight also helps to minimize maintenance needs, which increases the turbine's economic viability.
All things considered, the research done by S.M. Rehaman and colleagues highlights how revolutionary the Aero Leaf Wind Turbine can be in the field of wind energy production. Contributing to the global shift towards renewable energy sources, the research creates new opportunities for sustainable energy production by developing a design that optimizes power output while minimizing land footprint and maintenance costs[1].

METHODOLOGY

To thoroughly review wind turbine trees, we systematically collected and analysed data. We began with an extensive search through academic databases, engineering journals, and industry reports, using keywords like "wind turbine tree" and "renewable energy in urban environments." We also examined patents and technical documents for the latest insights. Criteria were set to select studies based on relevance, publication date, and language. We then evaluated the credibility and quality of the chosen studies, considering factors like experimental rigor and validity of results. Ethical considerations, such as proper citation practices, were paramount throughout. Finally, we synthesized the data to identify key trends and challenges in wind turbine tree technology, aiming to provide a comprehensive overview of their potential as sustainable energy solutions in urban areas.

WIND TURBINE TREE WITH SAVORIES WIND TURBINE

In their research, A.P. Avhad et al. delved into the design and manufacturing of wind turbine trees utilizing the Savonius type, each unit capacity of around 300 watts.

These innovative wind turbine trees feature a robust structure crafted from galvanized steel, ensuring resilience and durability in diverse environmental conditions. Complementing this sturdy framework, the turbine blades are expertly fashioned from aluminium, combining lightweight construction with durability. This versatile design makes wind turbine trees ideal for deployment in various locations such as stadiums, streets, and buildings. Their ability to harness wind energy efficiently in urban settings holds promise for enhancing sustainability and reducing reliance on traditional energy sources. The findings of A.P. Avhad et al.'s study represent a significant step forward in the advancement of renewable energy solutions, offering a practical and environmentally friendly option for power generation in urban environments.

FUTURE SCOPE

Looking ahead, wind turbine trees hold great promise for transforming urban landscapes with clean energy. As technology progresses, there are exciting opportunities to make these structures even better. Researchers can work on improving their efficiency and making them stronger. With advancements in materials, we might see lighter yet tougher components. Smart technology can also be added, helping to monitor performance and manage energy better. Exploring new ways to place wind turbine trees, like on buildings or in parks, could make them more common in cities. By working together, scientists, engineers, and city planners can overcome challenges and make wind turbine trees a big part of our clean energy future.

PROPOSED WORK

We have recently created a novel blade design for vertical axis wind turbines (VAWT) by using a multidisciplinary approach that includes blade analysis, computational fluid dynamics (CFD) simulations, mathematical calculations, and experimental research. Our methodical procedure involved producing important parts including the shaft, UC 204 bearing, permanent magnet generator, gears, and aluminium sheet, using the NACA0018 air foil blade as a point of reference. Our prototype VAWT performs admirably, producing an impressive 50 watts at a wind speed of 4.5 m/s. This review article presents our all-encompassing approach and highlights the technological developments in VAWT, which open the door to increased wind energy generating efficiency and sustainability.

A. **Design Points to Remember:** Determine the precise design factors that your VAWT should take into account, such as:
Design of blades (quantity, form, material) diameter of the rotor Tower height and design Type and capacity of the generator Control systems environmental element (turbulence, wind speed, etc.)
financial limitations

B. **Calculus-Base Modelling:**
Create mathematical models that explain the VAWT system's electrical, structural, and aerodynamic properties. Equations for structural analysis, electrical generation, and blade element momentum theory (BEMT) may be involved in this.

C. **CAD, or computer-aided design:**
Make intricate 3D models of the tower, nacelle, rotor, and blades of the VAWT using CAD software. Make sure the design satisfies the needs for aerodynamics and structure.

D. **Analysis and Simulation:**
Utilizing computational fluid dynamics (CFD) tools, run simulations to assess the aerodynamic performance of the VAWT and examine the airflow surrounding it. Take into account variables like engine output, torque, drag, and lift.

E. **Assessment of Performance:**
Analysed the VAWT design's performance using important parameters like power coefficient, tip-speed ratio, and annual energy generation. Verify the design assumptions by comparing the performance to benchmarks.

F. **Cost and Feasibility Study Analysis:**
To determine the capital and operating expenses related to the VAWT system's production, installation, and upkeep, perform a cost analysis. To determine the project's economic viability, do a feasibility study.

G. **Development of Prototypes (Optional):**
If possible, construct a smaller version of the VAWT prototype to confirm the concept of design and outcomes of the experiments. Gather information from prototype testing to improve the design and confirm performance estimates.

SETUP FOR AN EXPERIMENT

fig 1.VAWT

CONCLUSION

Generating energy is crucial , and wind power is incredibly valuable. However, to make wind energy system better, we need to address factors like cost material weight, space needed , wind speed. These factors affects how well the system works overall. By focusing and minimizing this factors, we can improve the efficiency and effectiveness of wind power. System , Making them more accessible and beneficial for everyone.

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