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Design and Development of Vertical Axis Wind Turbine

Amol Ghule[1], Pandurang Shendage[2], Sanket Chavan[3], Prashant Shirsat[4], Tanishq Naik[5]

Assistant Professor, Department of Mechanical Engineering[1]

B.E (Mechanical Engineering) Final Year Students[2,3,4,5]

Adsul Technical Campus, Chas, Ahmednagar, India

Abstract: *This paper is related to design and development of vertical axis wind turbine. This is a part of final year project of department of mechanical engineering, Adsul Technical Campus, Chas. The design and development of vertical axis wind turbines have gained significant attention in recent years due to their potential to harness wind energy in urban and remote areas. This study aims to explore the various aspects of designing and developing a vertical axis wind turbine, including the aerodynamic considerations, structural design, and material selection. By optimizing the design and enhancing the efficiency of vertical axis wind turbines, this research contributes to the advancement of sustainable energy solutions. Moreover, the integration of vertical axis wind turbines into urban landscapes presents a promising opportunity for decentralized power generation. The findings of this study have the potential to impact the renewable energy sector and address the growing demand for clean energy sources.*

Keywords: Development, Design, Vertical Axis Wind Turbine, Aerodynamic

I. INTRODUCTION

Vertical axis wind turbines have garnered considerable interest in the field of renewable energy due to their unique design and potential applications in urban and remote areas. The ability to harness wind energy in varying environmental conditions makes VAWTs an attractive option for sustainable power generation. As the demand for clean energy continues to rise, the development and optimization of VAWTs have become imperative in addressing the energy needs of both urban and remote communities.[1]

This study delves into the intricate aspects of designing and developing vertical axis wind turbines, with a specific focus on aerodynamic considerations, structural design, and material selection. By exploring these key elements, the research endeavors to contribute to the enhancement of VAWT efficiency and overall performance, thereby advancing sustainable energy solutions. Additionally, the integration of VAWTs into urban landscapes holds promise for decentralized power generation, presenting an innovative approach to meeting the growing energy demands of populated areas.[2]

Figure 1: Vertical Axis Turbine.

As the global push for renewable energy intensifies, the findings of this study have the potential to significantly impact the renewable energy sector, providing valuable insights into the advancement of clean energy sources. By addressing the challenges and opportunities associated with VAWT design and development, this research aims to pave the way for a more sustainable and environmentally conscious future.[3]

In the context of vertical axis wind turbine design, understanding the intricate aerodynamic considerations is crucial for optimizing performance and efficiency. The aerodynamic aspects encompass various factors such as airflow patterns, blade design, and the interaction between the blades and the wind. A detailed analysis of these elements is essential for enhancing the overall effectiveness of VAWTs in harnessing wind energy.[4]

In the realm of airflow patterns, researchers have delved into the nuances of wind behavior in relation to VAWTs, considering factors such as turbulence, wind speed variations, and the influence of surrounding structures. By gaining insights into these complex airflow dynamics, designers can tailor the VAWT configuration to maximize energy capture while minimizing turbulence-induced stress on the turbine.[5]

Furthermore, the design of VAWT blades plays a pivotal role in dictating performance. Various blade profiles, such as straight, curved, or twisted designs, have been investigated to determine their efficiency in different wind conditions. Additionally, the integration of smart materials and advanced composites in blade construction has emerged as a focal point in enhancing aerodynamic performance and structural integrity.[6]

The interaction between VAWT blades and the wind presents a multifaceted area of study, encompassing phenomena such as aerodynamic loading, wake interference, and the optimization of blade pitch angles. Analyzing these interactions provides valuable insights into mitigating aerodynamic losses and improving energy extraction from the wind, ultimately contributing to the overall advancement of VAWT technology.[1]

By delving into these detailed aerodynamic considerations, this research seeks to offer a comprehensive understanding of the complexities involved in designing VAWTs for optimal performance. The in-depth exploration of aerodynamic factors is instrumental in driving advancements in VAWT technology, thereby fostering the realization of sustainable and efficient wind energy solutions.[4]

II. LITERATURE SURVEY

The literature on vertical axis wind turbine design and development encompasses a wide array of studies and research efforts, reflecting the growing interest and significance of VAWTs in the renewable energy sector. One prominent aspect that emerges from the existing literature is the emphasis on aerodynamic considerations as a crucial factor in optimizing VAWT performance.[7]

Numerous research studies have focused on delving into the complexities of airflow patterns, blade designs, and the interaction between blades and the wind. These investigations have contributed to a comprehensive understanding of the aerodynamic principles governing VAWT operation and have paved the way for innovative advancements in turbine efficiency.[4]

Moreover, the literature highlights the significance of material selection and structural design in enhancing the durability and reliability of VAWTs. Studies have explored the utilization of advanced composites and smart materials to improve the aerodynamic performance and structural integrity of VAWT blades, offering valuable insights into the potential for further innovation in material science for wind turbine applications.[8]

Another notable aspect illuminated by the existing literature is the integration of VAWTs into urban landscapes for decentralized power generation. This trend underscores the potential for VAWTs to address the energy needs of populated areas while providing a visually unobtrusive and sustainable energy solution.[9]

In addition to the technical aspects, the literature also addresses the economic and environmental implications of VAWT deployment. Cost-benefit analyses, life cycle assessments, and environmental impact evaluations have been integral in assessing the viability and sustainability of VAWTs, contributing to a comprehensive understanding of their potential role in the broader context of renewable energy deployment.[10]

As the global demand for clean energy escalates, the existing literature serves as a valuable repository of knowledge, offering insights that can inform and inspire further advancements in VAWT technology. This review of existing literature provides a foundational understanding of the multifaceted considerations surrounding VAWT design and development, setting the stage for the comprehensive investigation and innovation in the realm of vertical axis wind turbines.

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III. METHODOLOGY

The methodology for designing and developing vertical axis wind turbines involves a multifaceted approach encompassing aerodynamic considerations, structural design, material selection, and integration into urban landscapes. This section provides a detailed insight into the comprehensive methodology adopted for this research, highlighting the depth of the investigative process and the scope of the study.

Figure 2: Vertical Axis Turbine Making

1. Literature Review: The methodology begins with an extensive literature review on vertical axis wind turbines.This step involves a thorough examination of existing research papers, journal articles, and technical reports to gain a comprehensive understanding of the current state of VAWT technology, including its applications, challenges, and potential for further innovation. The focus of the literature review is on identifying the key parameters and design considerations for VAWTs, as well as the latest advancements and trends in the field. By synthesizing information from diverse sources, this research aims to build upon the existing knowledge base and contribute to the advancement of VAWT technology.

2. Aerodynamic Analysis: Following the literature review, the methodology entails a detailed aerodynamic analysis of VAWT design principles and performance optimization. This involves computational fluid dynamics simulations and wind tunnel experiments to investigate airflow patterns, blade designs, and the interaction between the turbine and the wind. By employing advanced aerodynamic analysis techniques, this research seeks to gain deeper insights into the intricacies of VAWT operation and identify opportunities for enhancing its efficiency.

3. Blade Design and Material Selection: The next phase of the methodology focuses on blade design and material selection, crucial elements that significantly influence VAWT performance. Utilizing computational modeling and structural analysis, the research aims to evaluate various blade profiles, material compositions, and smart material integration to enhance aerodynamic performance and durability.

4. Urban Integration and Environmental Impact Assessment: As VAWTs increasingly find application in urban environments, this research incorporates a comprehensive assessment of the integration of VAWTs into urban landscapes and their environmental impact. Factors such as visual aesthetics, noise levels, and local wind characteristics are considered to optimize the placement and operation of VAWTs in urban settings while ensuring minimal environmental impact.

5. Prototype Development and Testing: The methodology culminates in the development of VAWT prototypes based on the insights gained from the preceding phases. Prototypes are subjected to rigorous testing under real-world conditions to validate their performance, efficiency, and structural integrity. The results of the testing phase contribute to the refinement of VAWT design and facilitate the translation of research findings into practical applications.

By meticulously following this comprehensive methodology, this research endeavours to make significant contributions to the field of vertical axis wind turbine design and development. The holistic approach employed in this study aims to address the technical, environmental, and societal aspects of VAWT deployment, ultimately fostering the advancement of sustainable wind energy solutions.

IV. CFD ANALYSIS

The utilization of Computational Fluid Dynamics analysis in the study of vertical axis wind turbines is pivotal in gaining a comprehensive understanding of the aerodynamic principles governing VAWT operation. CFD simulations provide an in-depth insight into airflow patterns, velocity distribution, and pressure gradients around the VAWT rotor. By leveraging advanced CFD techniques, this study aims to delve into the intricacies of VAWT aerodynamics, including the assessment of drag and lift forces acting on the turbine blades, the influence of turbulence on overall performance, and the impact of varying wind speeds and directions.

Furthermore, the CFD analysis facilitates the optimization of VAWT design by enabling the exploration of numerous blade configurations and shapes, leading to the identification of geometries that enhance energy capture and minimize aerodynamic losses. This detailed analysis also encompasses the investigation of flow separation, vortex shedding, and the alleviation of stall conditions, crucial factors in maximizing VAWT efficiency and reliability.

In addition to static simulations, transient CFD analyses are conducted to assess the unsteady behavior of airflow around the VAWT throughout its operational cycles. This dynamic understanding is essential in developing robust designs capable of withstanding fluctuating wind conditions while maintaining stable and efficient performance.

The integration of CFD analysis into this comprehensive research methodology exemplifies the commitment to exploring the intricate aerodynamics of VAWTs, laying the foundation for innovative advancements in turbine efficiency and performance. This in-depth analysis not only contributes to the academic understanding of VAWT technology but also holds significant implications for practical applications in the renewable energy sector.

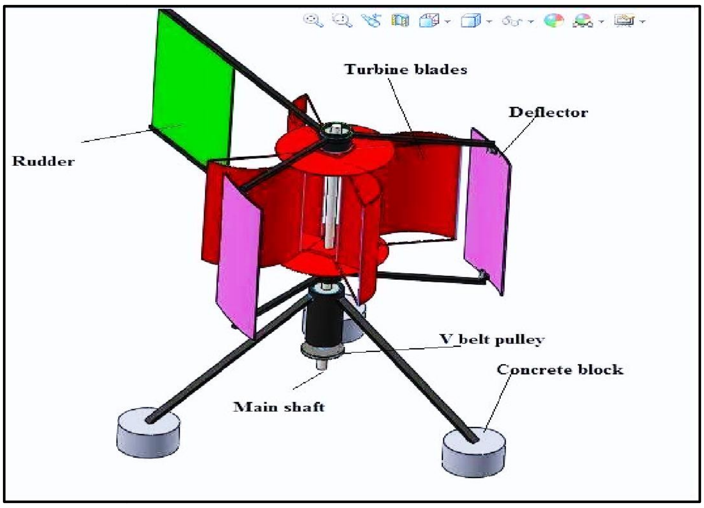

Figure 2: Solid Works 3D model of the Vertical Axis Wind Turbine

In order to develop this project, the calculations were done with CFD, which is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyse. This software gives the power to simulate flows, heat and mass transfer, moving bodies, etc., through computer modelling.

In order to obtain an approximate solution numerically, a discretization method have to be used to approximate the differential equations by a system of algebraic equations, which can later be solved with the help of a computer. The approximations are applied to small domains in time and/or space. The accuracy of numerical solutions depends on the quality of the discretization used as much as the accuracy of experimental data depends on the quality of the tools used.

It is important to bear in mind that numerical results are always approximate because there are reasons for differences between computed results and reality like:

The differential equations might contain approximations or idealizations.
The approximations made in the discretization process.
Iterative methods are used in solving the discretizated equations. So, unless they are run for a very long time, the exact solution of the discretizated equations is not produced.
Discretization errors can be reduced by using more accurate interpolation or approximations or by applying the approximations to smaller regions, but this usually increases the time and cost of obtaining the solution.
Compromise is needed in solving the discretised equations. Direct solvers, which obtain accurate solutions, are not very much used because they are too expensive. Otherwise iterative methods are more common but the errors produced by stopping the iteration process too soon need to be taken into account.

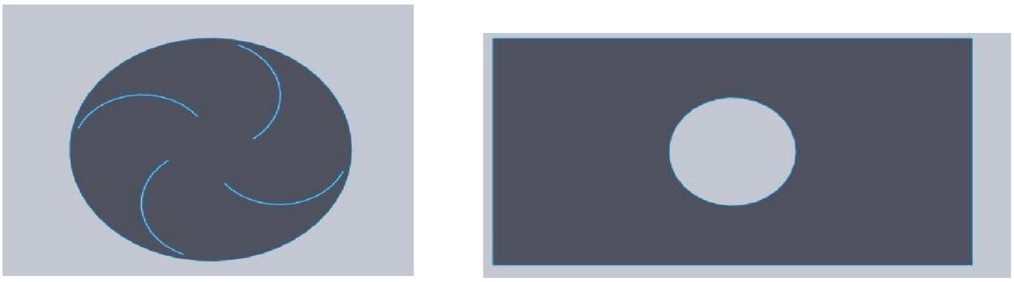

Figure 2: Solid works 2D drawing of rotating region and boundary layer respectively

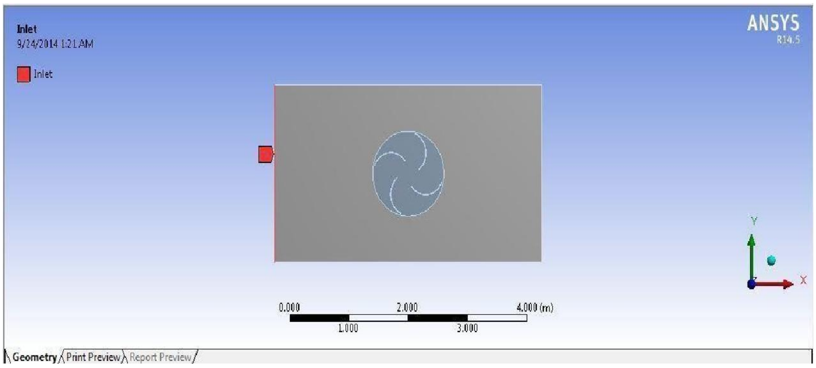

Figure 3: Defined working area.

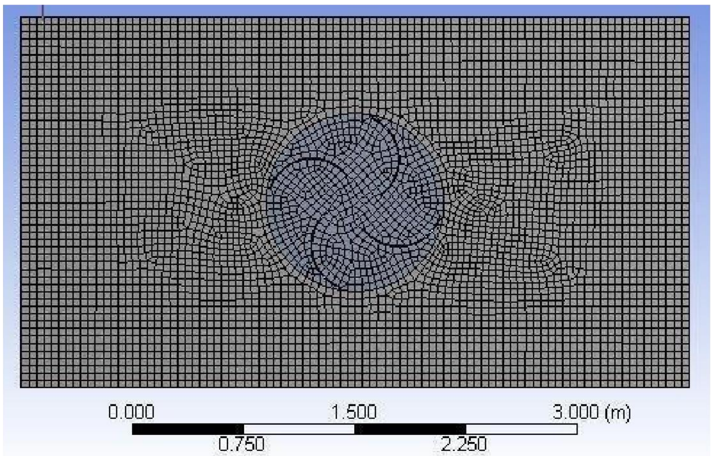

Figure 4: Final Mesh file

V. RESULTS AND DISCUSSION

We used fluent simulated data for selecting the best wind turbine blades quantity in this section. We checked 2 to 6 turbine blades with respect to air velocity 1ms-1 – 10ms-1. We found that, 4 turbine blades are more efficient than others. Here we used constant 60 rpm value for the various wind speeds.By using simulated data, we can draw the

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graphs. By using that graphs, we can simply identify which turbine blades are more suitable than others.Total moment coefficient Vs. velocity & Total force coefficient Vs. Velocity graphs are shown in the below figures.

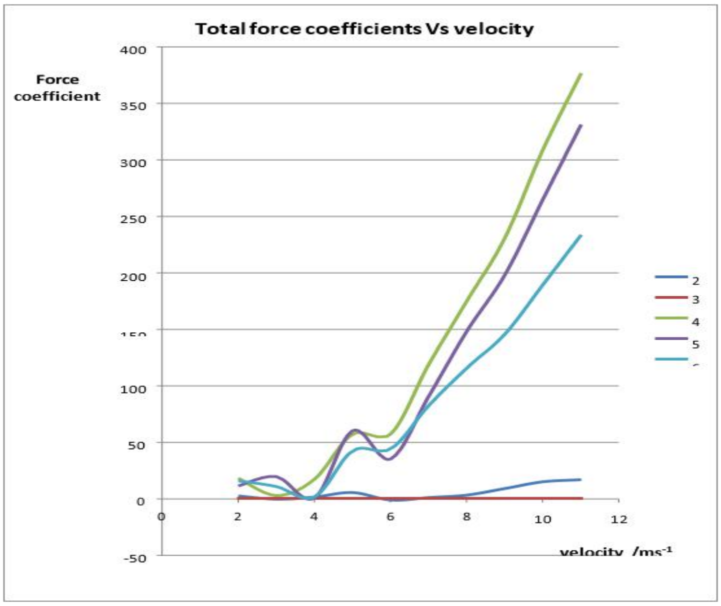

Figure 5: Total force coefficients Vs velocity with different blades

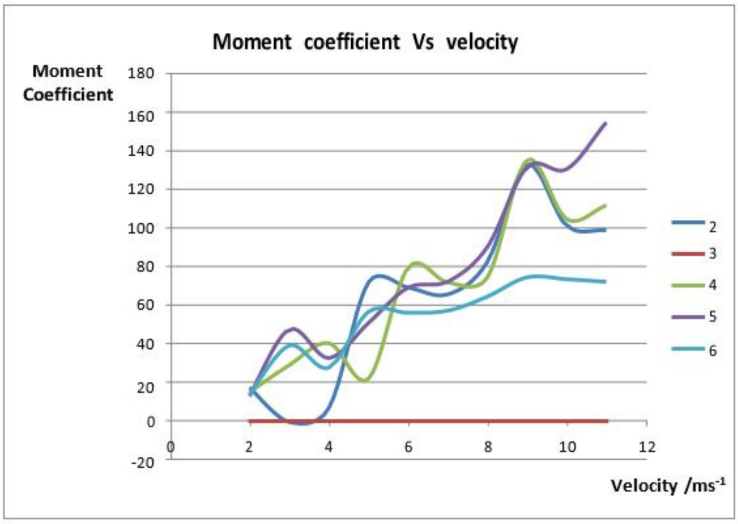

Figure 6: Moment coefficient Vs velocity with different blades

Above graphs are drawn in the constant 60 rpm rotational speed of the wind turbine. We can see that 4 turbine blades have higher force and higher moment on the blades with increasing speed of the wind. When we increased the rpm of the wind turbine we can see 4 turbine blades have higher force and moment on the blades.And also, in fabrication process it is easy to balance 4 turbine blades. By considering all of these facts we chose 4 wind turbine blades for our project.

VI. CONCLUSION

While these works are being completed a huge amount of knowledge has been collected and vast area in the CFD field has to be explored. Sometimes weeks have been spent for solving problems in fluent which encountered in simulations. Throughout the simulation process more than 400 simulations have been done and each simulation was spent around 1-2 hours' time to be simulated. In order to does that more than 600 hours have to be spent only in simulations. For those simulations more than 50 meshes have been drawn. In the case of simulations most of the Laptops available easily were hardly fulfilled the requirement of the software. So the simulating speed had been reduced. So, lot more time has to be spent on it. For some problems came across some areas of the software had to be explored. Those problems were unique problems for user to user. Then there wasn't enough information in internet too. Then the new areas had to be explored with great courage. So it is all about learning new and challenging things.As the results were presented with respect to Cp, then it also had to be rearranged and process the data that had been obtained by the simulations. So the data had to be recorded correctly and in a proper manner for the easiness of the reading and processing. But at the end we could manage to finish the simulation part within the time period that it is allocated.In the fabrication process lot of knowledge has been grabbed about the practical aspects and how to do certain things in workshop. We were given money for the project. That was very helpful to achieve our primary goal.In the testing, weather was not much helpful. Sometimes very powerful winds blew around even 10 m/s at once. Sometimes it was barely around 1-2m/s. Sometimes the rain also came to the party and it made all the things wet in few seconds. But at the end all those things were belong to the learning curve and the lessons they have taught were the most valuable and important things to the future. Sometimes the courage that was improved during the simulation period helped when the fabrication and testing were going on. So all along they all were good lessons.

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