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Wind Traditional Turbine Engines key Point Development of Power Efficiency

Author

Dr. Faleh Hasian Al-Dosari

Saad Al Abdulla academy for Security Science Kuwait

Co-Author

Dr. Sherif Ibrahim. Abouellail

Kuwait University Faculty of Engineering

Abstract

Wind energy is an important and promising source of clean and renewable power, but the efficiency of wind turbines is limited by various factors. As the demand for energy continues to grow and the need to transition to more sustainable sources becomes more urgent, improving the efficiency of wind turbines is a critical research area. In recent years, researchers have investigated various approaches to improving wind turbine efficiency, including the design of more aerodynamic blades, the use of advanced materials, and the development of sophisticated control systems. However, there is still much work to be done to further

Increase the efficiency of wind turbines. This research aims to study ways to improve wind turbine efficiency by optimizing turbine design, investigating the impact of external factors on turbine performance, and developing new energy storage technologies to make wind energy more reliable and accessible. Ultimately, increasing the efficiency of wind turbines can help to reduce the cost of wind energy and make it a more feasible and competitive alternative to traditional energy sources.

Keywords : Sustainability , Cost reduction , Control system , Energy storage technologies , Aerodynamic blade

I Introduction

Wind energy is becoming an increasingly important source of renewable power in the world as countries seek to reduce their reliance on fossil fuels and mitigate the impacts of climate change. Wind turbines are used to convert the kinetic energy of wind into electrical energy, but their efficiency is limited by various factors such as wind speed, turbulence, and the design of the turbine blades. Improving the efficiency of wind turbines is therefore a critical research area, as it can help to increase the amount of electricity generated and reduce the cost of wind energy(Xu, Kewei & Zha, Gecheng. (2021)).

In recent years, there has been a growing interest in developing new technologies and techniques to improve the efficiency of wind turbine engines. Researchers around the world have investigated various approaches, including the design of more aerodynamic blades, the use of advanced materials, and the development of sophisticated control systems.

These efforts have resulted in significant improvements in the performance of wind

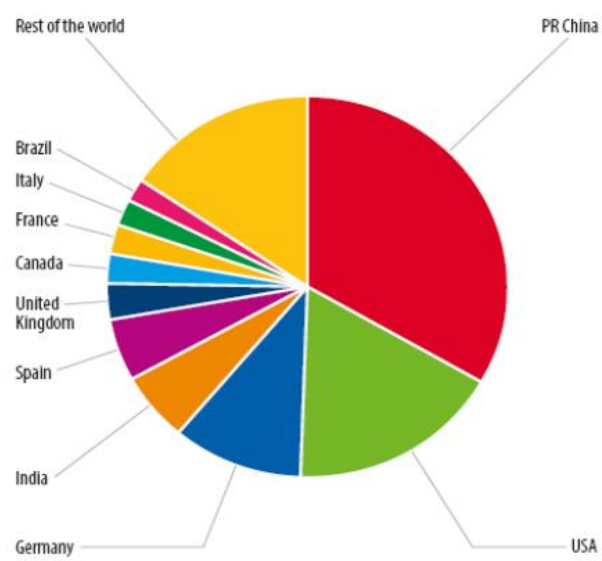

Figure (1) Wind Power across the world

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turbines, but there is still much work to be done to further increase their efficiency. (T. N. Fattal , 2018).

The climate change becomes an increasing problem, the acceptance of wind energy is crucial Beginning in the 1970s, the world began to experience an energy crisis due to its over-reliance on fossil fuels. There was a need to find and accept new ways to produce energy. This has led to the acceptance of unconventional energy sources such as hydro, geothermal, wind, and solar energy (Shimizu, et, al, (2022).

Wind turbines are increasingly recognized as a vital renewable energy source in the modern era. As human consumption of traditional power sources continues, there is a risk that future generations will face a scarcity of available resources, not to mention the environmental damage caused by their use. It is therefore imperative that we seek out new sources of energy that can meet the growing demand for power. Renewable energy is an alternative source of energy that occurs naturally and is theoretically inexhaustible (Bošnjaković et, al 2022).

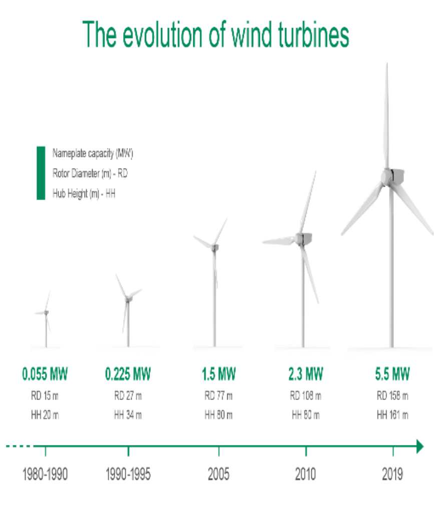

Figure (2) Evolution of wind turbines

The development of more efficient wind turbines has important implications for the global transition to renewable energy. By improving the efficiency of wind turbines, we can increase the amount of renewable energy that we can generate, reduce greenhouse gas emissions, and contribute to a more sustainable future. As such, the research and development of more efficient wind turbine engines is a critical area of focus for scientists, engineers, and policymakers around the world.

I Problem Statement

The global energy demand is increasing rapidly with the growth of population and industrialization. At the same time, the negative impact of traditional energy sources on the environment, such as air and water pollution, global warming, and climate change, is becoming increasingly evident and urgent. As a result, there is a growing need for alternative energy sources that are clean, renewable, and sustainable.

Wind energy is one of the most promising sources of clean and renewable energy. However, the efficiency of wind turbines, which capture the kinetic energy of wind and convert it into electrical energy, is limited by several factors. For example, the wind speed is not constant, and turbines have to operate in varying wind conditions. Additionally, turbulence, caused by the interaction of wind with the surrounding environment, can reduce the efficiency of turbines. Moreover, the design of turbine blades, which convert the kinetic energy of wind into mechanical energy, can also limit the efficiency of turbines.

The low efficiency of wind turbines translates into lower power output and increased costs, which can make wind energy less competitive compared to traditional energy sources. Therefore, researchers and engineers are working on various approaches to improve the efficiency of wind turbines, such as optimizing the design of turbine blades, developing advanced control systems, and exploring new wind turbine technologies.

Improving the efficiency of wind turbine engines is a crucial challenge that requires a multidisciplinary approach and collaboration between various stakeholders, including researchers, engineers, policymakers, and the public. The development of wind energy is essential to meet the growing energy demand and reduce the environmental impact of traditional energy sources, and improving the efficiency of wind turbines is a vital step towards achieving a sustainable and clean energy future. (Mone C, Hand et ,al , 2016).

II Research Objective

The current research studies to improving the efficiency of wind turbine engines by achieving this.

- Increase the amount of energy generated by wind turbines while reducing costs.
- Develop more advanced control systems for wind turbines to optimize

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performance based on changing wind conditions.

- Improve the aerodynamics of wind turbine blades to increase their efficiency.
- Use advanced materials and manufacturing techniques to reduce the weight of turbine components and improve their durability.
- Develop new energy storage technologies to make wind energy more reliable and accessible.
- Make wind energy a more viable and competitive alternative to traditional energy sources.
- Reduce the environmental impact of energy generation by reducing greenhouse gas emissions and other harmful pollutants

III Literature Review

The article by (Khameneh and Tadjfar (2016)) explores a new approach to enhance the efficiency of wind turbines by using synthetic jets. However, the study also discusses the main factors that affect wind turbine engine efficiency, including the design of the turbine blades, control systems, and materials used in construction. The authors summarize the findings of previous studies on these factors and their impact on the wind turbine efficiency. They highlight that the design of the turbine blades plays a critical role in determining the aerodynamic performance of the wind turbine. In addition, control systems are essential for optimizing the operation of a wind turbine in response to changing wind conditions. Finally, the materials used in construction can affect the weight and durability of the wind turbine, which can impact its efficiency and lifespan. The study identified several gaps in the literature that the research addresses. These include the need for more research on the use of synthetic jets to enhance wind turbine efficiency, the need for more research on control systems that can adapt to changing wind conditions, and the need for more research on the use of new materials, such as composites, in wind turbine construction. The article by (Rahimi , 2018)) discusses the improvement of the energy conversion efficiency and damping of wind turbine response in grid-connected Doubly Fed Induction Generator (DFIG) based wind

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turbines. This study improved the performance of wind turbines by proposing a new control strategy for the DFIG system. The study has several gaps that could be addressed in future research. First, the study focused on a specific type of wind turbine technology (DFIG), and it is unclear whether the proposed control strategy would be applicable to other types of wind turbines. Second, the study did not consider the effects of varying wind speeds on the performance of the wind turbine. Third, the study did not investigate the economic feasibility of the proposed control strategy. the article discusses a new control strategy for DFIG-based wind turbines to improve their energy conversion efficiency and damping of response. The proposed control strategy is shown to be effective in simulations, but there are gaps in the study that need to be addressed in future research. The paper "Improvement of Wind Turbine Efficiency by Using Synthetic Jets" by (Khameneh and Tadjfar) published in 2016, proposes the use of synthetic jets to improve the efficiency of wind turbines.

The authors begin by introducing the concept of synthetic jets, which are small-scale, high-frequency fluidic actuators that can be used to control the flow of air over a surface. They explain that by adding synthetic jets to the blades of a wind turbine, it is possible to control the boundary layer and delay the onset of turbulence, resulting in increased efficiency.

The paper then describes a series of experiments that were conducted to test the effectiveness of synthetic jets on wind turbine blades. The experiments were carried out using a wind tunnel and a model wind turbine blade, and the results showed that the addition of synthetic jets led to a significant increase in efficiency.

The authors conclude that the use of synthetic jets can improve the efficiency of wind turbines, and that further research is needed to explore the optimal design and placement of synthetic jets on wind turbine blades. They also note that the use of synthetic jets may be particularly beneficial in areas with low wind speeds, where traditional wind turbines are less effective.

This paper provides an interesting and innovative approach to improving the wind turbine efficiency, and highlights the potential benefits of using synthetic jets in wind turbine design. The paper titled "Improvement of energy conversion efficiency and damping of wind turbine response in grid connected DFIG based wind turbines" by (Rahimi, published in the International Journal of Electrical Power & Energy Systems in 2018) , presents a study on improving the energy conversion efficiency and damping of wind turbine response in grid-connected doubly fed induction generator (DFIG) based wind turbines.

The paper begins by introducing the concept of DFIG-based wind turbines and their advantages over other types of wind turbines. The author then discusses the challenges associated with DFIG-based wind turbines, including the need for an improved energy conversion efficiency and damping of the turbine response.

This paper presents a comprehensive study on the use of a variety of techniques to improve the energy conversion efficiency and damping of wind turbine response in DFIG-based wind turbines. These include the use of advanced control techniques such as model predictive control and adaptive fuzzy control, to optimize the performance of the turbine and reduce energy losses. The paper also discusses the use of passive techniques, such as the use of tuned mass dampers, to reduce the response of the turbine to external disturbances and improve overall stability.

The results of this study show that the use of advanced control techniques and passive techniques can significantly improve the energy conversion efficiency and damping of wind turbine response in DFIG-based wind turbines. The study also highlights the importance of considering the dynamic behavior of wind turbines in the design of control systems and the selection of passive damping techniques.

This paper provides valuable insights into the challenges associated with DFIG-based wind turbines and the techniques that can be used to improve their performance. The study is crucial to researchers and practitioners in the field of renewable

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energy, as it provides a roadmap for improving the efficiency and stability of wind turbines, thereby contributing to the development of sustainable energy sources.

The article by (Yang et al. (2020) focuses on improving the ambient temperature of wind turbine engine rooms. Researchers note that the temperature in these rooms can impact the performance and efficiency of wind turbines. High temperatures can lead to overheating of the turbine components ; which can reduce their lifespan and increase maintenance costs. The article proposes a method for improving the ambient temperature of wind turbine engine rooms using a heat pipe heat exchanger. The researchers conducted experiments to evaluate the effectiveness of this method and found that it can significantly reduce the temperature in the engine room. This article highlights the importance of considering ambient temperature in the design and operation of wind turbines. The proposed method for improving the ambient temperature of wind turbine engine rooms can help to increase the lifespan of turbine components and reduce maintenance costs. Overall, this study demonstrates the need for continued research into the impact of ambient temperature on wind turbine performance and the development of effective solutions for managing temperature in wind turbine engine rooms (Jathi, N.Y., Shaik, et , al . (2020).

The article by (Yang et al. (2020) focuses on the improvement of ambient temperature in wind turbine engine rooms. This study aims to optimize the thermal management of wind turbine engine rooms to improve their efficiency and prolong their lifespan. The authors discuss several factors that affect the ambient temperature in wind turbine engine rooms, including the design of the ventilation system, the thermal insulation of the engine room, and the use of cooling systems such as air conditioning or heat exchangers. They highlight that the ventilation system design is critical for maintaining a suitable temperature range in the engine room, and that proper insulation can help reduce heat loss and improve energy efficiency. They also discuss the use of cooling systems to regulate the ambient temperature in the engine room. This study

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summarizes the findings of previous research on these factors and their impact on the ambient temperature in wind turbine engine rooms. The authors highlight the importance of optimizing the ventilation system design, improving the thermal insulation of the engine room, and using efficient cooling systems to maintain an appropriate temperature range. The authors identify gaps in the literature related to the optimization of thermal management in wind turbine engine rooms. These include the need for more research on the impact of different ventilation system designs on the ambient temperature, the need for more research on the use of alternative cooling systems, and the need for more research on the optimization of thermal insulation in wind turbine engine rooms.

This study (Goman et al. (2021) improved the efficiency of Darrieus wind turbines by optimizing their aerodynamic performance. The study identified several factors that affect the wind turbine efficiency, including the design of turbine blades, control systems, the materials used in construction. The design of turbine blades is critical to the efficiency of wind turbines. The study found that the shape and curvature of the blades can significantly impact turbine performance. In particular, the researchers found that blade shape affects the lift and drag forces acting on the blades, which can impact the turbine efficiency. This study optimized the blade design to improve aerodynamics and reduce weight, thereby increasing the efficiency of the wind turbine. This study identified a gap in the literature regarding the optimal blade shape and length for different wind conditions. Additionally, the study investigated the use of new materials and manufacturing techniques to improve turbine performance. The objective of the study was to improve the efficiency of Darrieus wind turbines by optimizing their aerodynamic performance, thereby increasing the amount of electricity generated and reducing the cost of wind energy (Singh and Sundaram's (2021)) The article discusses the importance of efficient and safe performance of wind turbine generator components for better annual energy production. The recent high-efficiency generator and motor designs have

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led to less cooling capacity, which has resulted in higher bearing temperatures and premature bearing failure. Grease lubrication deterioration is the leading cause of bearing failure, and the service life of grease lubrication is closely associated with the operating temperature. To address this issue, the article presents the recent experiments on an air-cooled squirrel cage induction generator to address inadequate and imbalanced bearing cooling. The article recommends updates to the IC6A1A6 cooled generator design and corresponding standards to ensure optimal bearing life and generator reliability. This article suggests that a proactive plan based on the recommendations in the article can help to secure safe wind turbine-generator operation and avoid issues similar to those observed with IEEE standard 841 high-efficiency motors used in refineries, where a study confirmed that the motors are at greater risk.

The article by (Goman, Dreus, Rozhkevych, and Heti (2021)) focuses on the aerodynamic improvement of Darrieus wind turbines. The study notes that Darrieus wind turbines are a promising source of renewable energy but can be improved through aerodynamic design modifications. The study uses a computational fluid dynamics approach to simulate the flow around a Darrieus wind turbine and identify areas for improvement. The study focuses on the use of winglets, which are small aerodynamic devices that can improve the performance of the turbine. The study finds that the use of winglets can significantly improve the aerodynamic performance of Darrieus wind turbines, particularly in terms of increasing the power coefficient and reducing the drag coefficient. The study notes that these improvements can lead to increased energy production and reduced costs. The researchers note that these findings have important implications for the design and operation of Darrieus wind turbines. The study suggests that the use of winglets can help to improve the efficiency and reduce the environmental impact of wind power. the article provides insights into the aerodynamic improvement of Darrieus wind turbines. The study offers important implications for designers and engineers seeking to improve the

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performance and sustainability of renewable energy sources.

The article by (Alcayde, Hernández-Escobedo, Muñoz-Rodríguez, and Perea-Moreno (2022)) examines worldwide research trends on optimizing wind turbine efficiency. The study notes that wind power is a key source of renewable energy, but the efficiency of wind turbines can be improved through research and development. The study uses a bibliometric analysis approach, drawing on data from the Web of Science database to identify research trends and patterns in the field of wind turbine efficiency. The study analyzes publications from 2000 to 2020, focusing on key themes and research areas. The study finds that research on wind turbine efficiency has grown rapidly in recent years, with a focus on areas such as blade design, control systems, and optimization algorithms. The study notes that these areas are critical for improving the efficiency of wind turbines and reducing the cost of wind power. The researchers note that these findings have important implications for policymakers and investors seeking to promote renewable energy. The study suggests that policies aimed at promoting research and development in wind turbine efficiency can help to drive innovation and reduce the cost of renewable energy. the article provides insights into worldwide research trends on optimizing wind turbine efficiency. The study offers important implications for policymakers and investors seeking to promote renewable energy and reduce the environmental impact of energy production

The article by **(**Sosnina et al. (2022) provides a review of the technologies used to improve the efficiency of Wind Diesel Hybrid Systems (WDHS) and reduce fuel consumption. The study focuses on the main factors that affect wind turbine engine efficiency, including the design of the turbine blades, the control systems, and the materials used in construction. The authors summarize the findings of previous studies on these factors and their impact on wind turbine efficiency. They highlight that the design of the turbine blades plays a crucial role in determining the aerodynamic performance of the wind turbine and, therefore, its efficiency. Control systems are

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also critical, as they can optimize the operation of the wind turbine in response to changing wind conditions. Finally, the materials used in construction can affect the weight and durability of the wind turbine, which can impact its efficiency and lifespan. The study identifies several gaps in the literature, which the authors aim to address. These include a lack of systematic analysis of the impact of blade design on wind turbine efficiency, the need for more research on control systems that can adapt to changing wind conditions, and the need for more research on the use of new materials, such as composites, in wind turbine construction.

IV Methodology

Improving the efficiency of wind turbine engines is an important goal as it can lead to a reduction in the cost of energy production and make wind energy more competitive with other forms of energy generation. To achieve this goal, various techniques have been proposed and tested in recent years. In this section, we will provide an overview of the methodology that can be used to improve the efficiency of wind turbine engines**.**

1- Blade Damage

studies on the damage to the composite material and adhesive interface in wind turbine blades subjected to structural testing have been available for some time. Static and cyclic loads applied during full-scale testing can result in various forms of damage, such as adhesive layer failure, laminate delamination, debonding at skin/core interfaces, splitting along fibers, in-plane compressive failure, gelcoat/skin debonding, and cracks in the gelcoat (Sareen, A et , al 2014) . Damage in the primary load-bearing laminates, such as the main spar and laminates at the leading and trailing edges, is particularly concerning. Fortunately, composite materials are damage-tolerant. Nonetheless, a significant issue is that precise information on the damages found in operating wind farms is lacking. Many of the damage modes that occur in wind turbine blades are not easily detectable as they do not originate from external surfaces and may not be visible. For instance, wrinkles in thick composite parts

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can lead to compression failure and delamination, and cracks and delamination can also begin from processing details such as ply-drops that cause local stress concentration. Cracks at trailing edge bondlines may be visible, but it can be difficult to assess their extent into the composite structure.

In addition to structural loading effects, wind turbine blades can also be damaged by lightning strikes, physical impacts, and surface erosion conditions during operation. Although operators of wind farms take measures to minimize exposure to storm conditions, over a 25-year service life, it is expected that wind turbine blades will accumulate signs of damage.

Blades are particularly vulnerable to lightning strikes, and all blades have a lightning protection system to reduce the effect of such strikes when they occur. However, scorching damage and cracking around the lightning attraction point of a blade, as well as spar rupture, separation, and surface tearing in more extreme cases, are still common.

One of the most significant damage forms observed in operating turbine blades is caused by airborne particulates impacting and eroding the leading edge, especially towards the tip where velocities are higher. This rough surface can degrade the aerodynamic performance of the blade and reduce power production. If left unrepaired, structural damage to the laminate material will soon develop, requiring a longer and more complex repair effort (Battisti, L et , al 2015).

Icing is another issue that can occur under low-temperature weather conditions, resulting in the accumulation of ice on the blade surface. In extreme cases, icing can stop the operation of the turbine, but before that, it can disrupt the aerodynamics of the blade, reduce energy generation, and unbalance the load distribution in the system, reducing the structural fatigue lifetime (Garolera, A.C.; Madsen et , al , 2016).

2- Blade aerodynamics

Blade aerodynamics is a complex field that plays a significant role in the design and performance of wind turbines.

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Wind tunnel experiments are typically used to study the aerodynamics of wind turbine blades, where scaled-down models of the blades are tested in a controlled wind flow. These experiments can provide valuable data on the lift, drag, and other aerodynamic forces acting on the blades, allowing engineers to optimize the blade shape and dimensions for maximum energy production.

The airfoil or cross-section of the blade also plays a critical role in determining the aerodynamic performance of the blade. Different airfoil shapes generate different amounts of lift and drag, affecting the overall efficiency of the blade. Engineers use computational methods such as computational fluid dynamics (CFD) to simulate the airflow around the blades and predict the lift and drag coefficients for different airfoil shapes. This information can be used to design blades that are optimized for specific wind conditions and energy production goals. The aerodynamics of wind turbines at the rotor surface also exhibit unique phenomena such as the formation of tip vortices and wake turbulence. Tip vortices are created at the tips of the blades as the high-pressure air from the bottom of the blade moves around to the low-pressure region above the blade. These vortices can cause significant energy loss and increase the noise generated by the turbine. Wake turbulence is created by the blades as they move through the air, and can affect the performance of downstream turbines. Understanding and minimizing these phenomena is an important aspect of wind turbine design and optimization.

3- Boundary Layer Separation

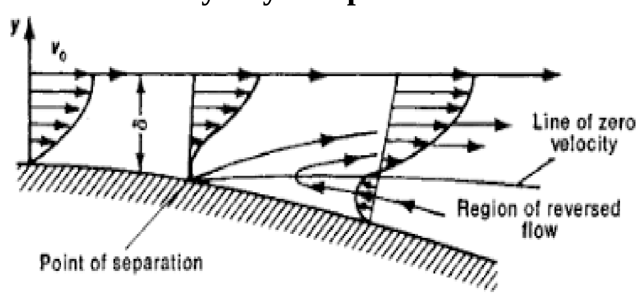

Figure (3) Separation of Flow over a Curved Surface

Boundary layer separation is an important phenomenon in fluid dynamics that can have significant effects on the aerodynamic performance of wind turbine blades. As mentioned, the boundary layer is the thin layer of fluid that flows along the surface of a body, such as the surface of a wind turbine blade. The boundary layer thickness increases as the fluid flows along the surface, and eventually, it can become thick enough that the velocity of the fluid near the surface decreases to zero (Goman, O.G.,et , al . (2021).

When the pressure gradient in the flow is favorable, the fluid can continue to flow smoothly along the surface, with the boundary layer remaining attached to the surface. However, when the pressure gradient becomes adverse, the fluid has to work harder to overcome the pressure hill, and the velocity of the fluid near the surface decreases further. Eventually, the velocity near the surface can become zero, causing the boundary layer to separate from the surface of the blade.

When the boundary layer separates from the surface of the blade, it can cause a significant increase in drag and a decrease in lift, reducing the overall aerodynamic efficiency of the blade. This can lead to reduced energy production and increased mechanical loads on the turbine. Engineers use various techniques, such as vortex generators and changes to the blade shape, to mitigate the effects of boundary layer separation and improve the aerodynamic performance of wind turbine blades.

4- Vortex Generator

The vortex created by the VG mixes high-energy air from above the boundary layer with low-energy air from the boundary layer, delaying the onset of separation and reducing the size of the separated region. This improves the lift-to-drag ratio of the blade and reduces drag, thereby increasing the efficiency of the wind turbine.

The effectiveness of VGs in mitigating the effects of boundary layer separation depends on the size, shape, and orientation of the VGs, as well as the wind conditions and the design of the blade. The number and spacing of VGs, as well as their angle of attack, can also affect their performance.

VGs are a relatively simple and cost-effective technique for improving the aerodynamic performance of wind turbine blades. They can be retrofitted onto existing blades or incorporated into the design of new blades. However, the use of VGs can also increase the noise generated by the

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wind turbine, as the vortices shed by the VGs can create turbulent flow and noise. Therefore, the design and placement of VGs must be carefully considered to balance their aerodynamic benefits with the potential increase in noise levels.

The use of vortex generators (VGs) on wind turbine blades can increase the aerodynamic performance of the blades by delaying boundary layer separation and reducing drag. However, as mentioned, VGs can also increase the noise generated by the wind turbine, particularly in low wind speed conditions.

There are several techniques that can be used to reduce the noise generated by VGs on wind turbine blades. One approach is to modify the shape and design of the VGs to reduce the turbulence and noise generated by the vortices shed by the VGs. For example, adding a small lip or tab to the trailing edge of the VG can help to smooth out the flow and reduce the turbulence and noise generated by the vortices. Another approach is to modify the placement and orientation of the VGs on the blade. For example, staggering the VGs in an alternating pattern or changing the angle of attack of the VGs can help reduce the noise generated by the vortices.

In addition to these design modifications, it may be possible to reduce the noise generated by VGs through the use of active flow control techniques. For example, plasma actuators or synthetic jets can be used to manipulate the flow around the VGs and reduce the turbulence and noise generated by the vortices.

5- Dimensions of Blades

The dimensions of wind turbine blades have a significant impact on the aerodynamic performance of the blades and the overall energy production of the wind

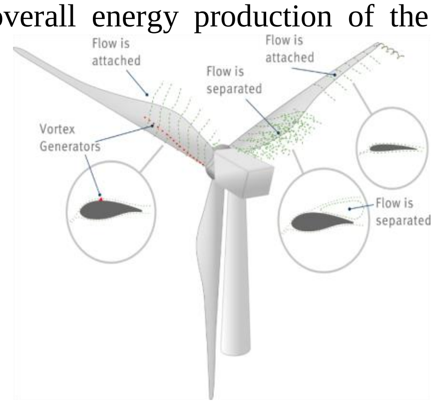

Figure (4) Wind turbine blade vortex generator

turbine. The design of the blade is a complex process that involves balancing

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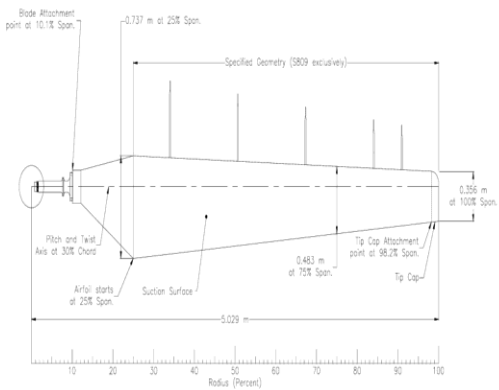

Figure (5) Blade planform dimensions

aerodynamic performance, structural integrity, and cost considerations.

The shape of the airfoil, or cross-section, of the blade is a critical design parameter that affects the lift and drag characteristics of the blade. Different airfoil shapes have different lift and drag coefficients, and the choice of airfoil shape will depend on factors such as wind velocity, blade length, and the desired energy production (Sugimori, J., Oda, S., Hasegawa, Y., & Ushijima, T. (2019.

The length of the blade is also an important design parameter, as it affects the swept area of the turbine. The swept area is the area covered by the blades as they rotate, and is directly proportional to the amount of energy that can be extracted from the wind. Longer blades generally have a larger swept area and can generate more energy, but longer blades also increase the loads on the turbine and can be more expensive to manufacture (Vikulin, A.V., Yaroslavtsev, N.L (2018).

The root diameter and section length of the blade are also critical design parameters that affect the structural integrity of the blade. The root diameter is the diameter of the blade at the point where it is attached to the hub, and the section length refers to the length of each section of the blade between the root and the tip. The choice of root diameter and section length will depend on factors such as the wind velocity, blade length, and the desired structural properties of the blade (Viswam, R., & Sankar, S. (2015).

Finally, the chord length of the blade is another important design parameter that affects the aerodynamic performance of the blade. The chord length is the width of the blade at a given point along its length, and affects the lift and drag characteristics of the blade. The chord length can be varied along the length of the blade to optimize its

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performance under different wind conditions.

The design of wind turbine blades is a complex process that involves balancing aerodynamic performance, structural integrity, and cost considerations. The dimensions of the blade, including the shape of the airfoil, blade length, root diameter,

section length, and chord length, are critical design parameters that must be carefully considered to ensure optimal performance of the wind turbine (Yang, G., Shiming, F., Baoliang, L., & Xuemin, L. (2020) .

6- The Airfoil of Blade

The airfoil of a wind turbine blade is designed to increase lift forces and reduce drag. It is not just a shape, but an engineered design that is optimized for aerodynamic performance.

The airfoil is constructed with A longer upper surface, which causes The wind to travel a greater distance over the top surface (Bošnjaković, M., Katinić, M., Sánta, R., & Marić, D. (2022). This, in turn, increases the velocity of the air over the surface, leading to a lower pressure zone on the upper side of the blade. The resulting difference in pressure causes lift forces to act perpendicular to the blade profile. There is a wide variety of airfoil structures used for wind turbine blades, as reported by NREL. The S 818 series is a commonly used standard airfoil for this purpose. In order to simplify the modelling process and overcome limitations, only a single airfoil structure is utilized instead of the three airfoils typically used in standard wind turbine blades. This airfoil structure is obtained from the NREL site, which provides coordinates for standard airfoils. Despite this limitation, the efficiency analysis of the wind turbine is not affected and can be accurately determined (Oda, S., Hasegawa, et , al (2015)

7- Length of Blade

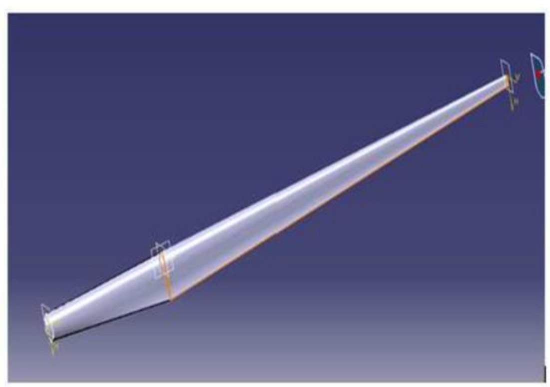

Figure (6) Wind blade drawn in Catia v2.5 without vortex

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The length of a wind turbine blade is a critical factor that determines the amount of area swept by the blade. This, in turn, has a significant impact on the wind speed in a particular area. The power extraction of the wind turbine also depends on the swept area of the blade, which is directly proportional to the diameter of the blade. Therefore, the length of the blade plays a crucial role in determining the overall power extraction of the wind turbine. In the present scenario, the length of the wind turbine blade is selected as 23m, and the rated wind speed is set at 12m/s. These values have been carefully chosen to optimize the performance of the wind turbine. The dimensions of the vortex generator (VG) are selected based on the chord length and angle of attack. The height of the VG is typically between 1 to 2% of the chord length, the length is between 2 to 3% of the chord length, and the angle of attack is between 15 and 20 degrees. The spacing between the VGs should be 10 times the height. In this case, a rectangular-type VG is used and placed at the higher camber length of the airfoil section, before the point of separation. The dimensions of the VG used in this experiment are selected based on the highest chord length, with a height of 35mm, length of 60mm, and spacing of 350mm. The VG is placed at the point of separation, with the height of the vortex matching the height of the boundary layer. In blade 1, the separation is found to be at the center of the chord, so the VG is placed at the center line of the chord, extending towards the tip (Marinić-Kragić, I., P. et , al (2022)

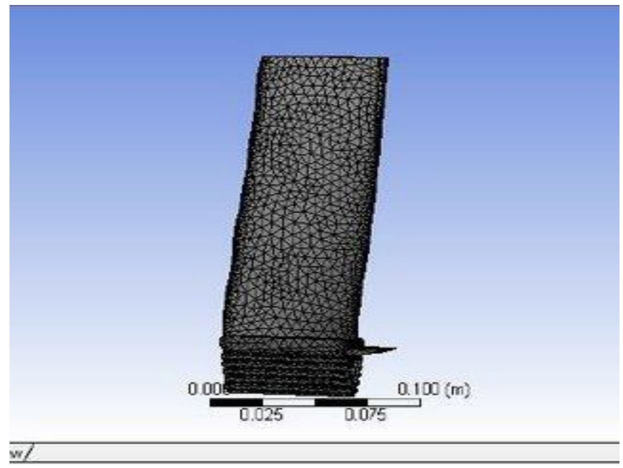
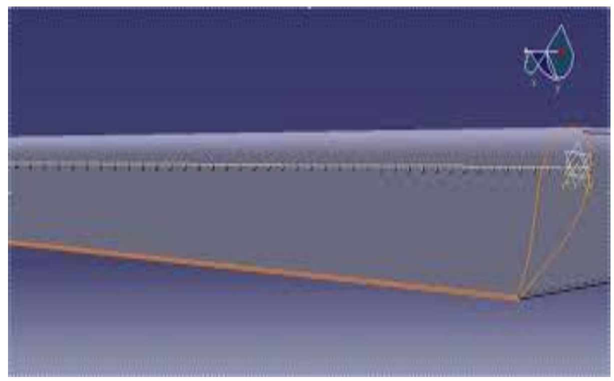


Figure (8) Meshing of the Blade and Fluid Volume

To simulate the wind turbine, Catia v2.5 by Dassault systems is used to design the wind blade according to the required dimensions. Ansys Fluent v12.0 is used to simulate the atmospheric conditions in the computer. A fluid volume is created and defined as fluid around the wind blade design, and the atmospheric conditions are simulated inside this volume(Mishnaevsky et , al 2009). The boundary is applied as fluid for analysis, and Boolean is used to create a thin wall layer over the wind blade. The wind blade is subtracted from the boundary layer using Boolean to provide a thin wall over the blade, and the resulting structure is sent for meshing (Sugimori, J., Oda, S., Hasegawa, Y., & Ushijima, T. (2019) The process of meshing is a crucial step in building the structure. It involves converting the CAD drawing into a structure built with small geometric structures known as meshes. These meshes act as the smallest areas where the simulation concentrates. The accuracy of the simulation depends on the quality of the meshing. Increasing the number of meshes can improve the accuracy of the simulation, but it also increases the calculation time. Therefore, finding the right balance between accuracy and computational resources is critical. Mesh generation is a critical aspect of the engineering solution and requires careful consideration to ensure the accuracy and efficiency of the simulation. Excessive meshing can lead to longer solving times and higher risk of errors.

The mesh used to model the structure can come in different forms, such as tetrahedrons, polygons, or triangles. Each element of the mesh is analyzed using Finite Element Analysis (FEA) in Computational Fluid Dynamics (CFD) Every mesh



represents the smallest area used for analysis. Careful consideration is required to determine the most appropriate mesh for the simulation, balancing the accuracy of the results with the computational resources available (Xu, K., & Zha, G. (2021).

V Results

The k-ε iteration method is a widely used turbulence model in computational fluid dynamics (CFD) simulations. It calculates the turbulent kinetic energy and its dissipation rate at each point in the flow field to model the effects of turbulence on the flow. The default set values for the k-ε model in Fluent are generally suitable for a

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wide range of applications, but they may need to be adjusted for specific cases to achieve accurate results.

The introduction of vortex generators (VGs) over the blades is a common technique for improving the aerodynamic performance of wind turbine blades. As mentioned earlier, VGs can delay boundary layer separation and reduce drag, resulting in increased lift and power generation. By placing VGs at the separation point, the lift can be increased to a limited extent, further enhancing blade efficiency.

However, the effectiveness of VGs depends on their shape, size, spacing, and orientation on the blade surface. Modifying these parameters can further improve the aerodynamic performance of the blade. For example, changing the shape and angle of attack of the VGs can help optimize the vortices shed by the VGs and improve their effectiveness in delaying boundary layer separation. Adjusting the spacing and orientation of the VGs can also affect their performance, as it can alter the flow patterns around the blade and the shedding of vortices.

Figure (7) Wind Blade Equipped with Vortex Generator

VI Discussion

wind turbine design is a complex and multidisciplinary process that involves careful consideration of many factors, including blade aerodynamics, boundary layer separation, vortex generators, dimensions of blades, airfoil design, blade length, materials, manufacturing processes, and environmental conditions. By optimizing these factors, wind turbine designers can achieve the maximum power extraction from the wind and improve the efficiency and reliability of wind energy generation.

The above text highlights several important aspects of wind turbine design, including blade aerodynamics, boundary layer separation, vortex generators, blade dimensions, airfoil design, and blade length. The text also discusses the importance of meshing in the simulation process and the use of computational fluid dynamics (CFD) to analyze wind turbine performance. One of the key takeaways from this text is the importance of blade design in wind turbine performance. The shape, length, and dimensions of the blade all play a critical role in determining the efficiency of the wind turbine.

Accurate design parameters are necessary to optimize the performance of the wind turbine and ensure maximum power extraction from the wind. Another important aspect of wind turbine design discussed in this text is the use of vortex generators. These devices can help improve blade efficiency by delaying the boundary layer separation and increasing lift forces. However, the placement, shape, and the angle of the attack of vortex generators must be carefully considered to achieve optimal results. The discussion of meshing highlights the importance of balancing accuracy and computational resources in the simulation process. Excessive meshing can lead to longer solving times and a higher risk of errors, while too few meshes can result in inaccurate simulations. Therefore, careful consideration is required to determine the most appropriate mesh for the simulation. 0wind turbine design is a complex and multidisciplinary process that requires careful consideration of a variety of factors. The aerodynamics of the blade, boundary layer separation, vortex generators, dimensions of blades, airfoil design, and blade length all play critical roles in determining the efficiency and performance of the wind turbine. The use of CFD and meshing can help optimize wind turbine design and ensure maximum power extraction from the wind.

In addition to the design parameters mentioned, another important aspect of wind turbine design that was not discussed in the previous text is the materials used in the construction of the blades. The materials used must be strong, durable, and lightweight to withstand the stresses and strains of wind turbine operation. Common materials used in wind turbine blades include fiberglass, carbon fiber, and composite materials.

The manufacturing process is also a critical consideration in wind turbine design. Blades must be manufactured to precise specifications and tolerances to ensure optimal performance and reliability. The manufacturing process must also be cost-

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effective to ensure that wind energy remains competitive with other forms of energy generation. Furthermore, the location and environmental conditions of the wind turbine must also be considered during the design process. Wind conditions, terrain, and climate can all affect the performance and efficiency of the wind turbine. The wind turbine must be designed to withstand extreme weather conditions such as high winds, lightning strikes, and icing.

VII Conclusion

In conclusion, wind turbine design is a complex and multidisciplinary process that requires careful consideration of several factors. The aerodynamics of the blade, boundary layer separation, vortex generators, dimensions of blades, airfoil design, and blade length all play critical roles in determining the efficiency and performance of the wind turbine. Accurate design parameters are necessary to optimize the performance of the wind turbine and ensure the maximum power extraction from the wind. The use of computational fluid dynamics (CFD) and meshing can help optimize wind turbine design and ensure accurate simulations of wind turbine performance. However, balancing accuracy and computational resources is crucial in the meshing process to achieve accurate and efficient simulations. wind turbine design requires a thorough understanding of aerodynamics and a multidisciplinary approach to optimize performance. With the increasing demand for renewable energy sources, the optimization of wind turbine design is essential for the efficient and reliable generation of wind power

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