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Vertical Axis Wind Turbines: A review on current research and future directions

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Abstract:
The aim of this research paper is to provide a comprehensive overview of Vertical Axis Wind Turbines (VAWTs) based on previous research and literature review. VAWTs have gained increasing attention in recent years due to their potential advantages over traditional Horizontal Axis Wind Turbines (HAWTs). This paper examines the key characteristics of VAWTs, including their aerodynamic performance, structural design, and electrical output. Furthermore, in this study the challenges associated with VAWT technology are discussed, such as its complex aerodynamics and the difficulty in scaling up VAWTs to larger sizes. The research also covers recent advancements in VAWT technology, such as the use of advanced materials and the integration of energy storage systems to enhance their performance. Overall, this research study provides a comprehensive analysis of VAWTs based on previous research and literature review. The findings suggest that VAWTs have the potential to play a significant role in meeting global energy demand and reducing carbon emissions, especially in urban and offshore settings. However, further research is needed to overcome the challenges associated with VAWT technology and to optimize their performance.

Keywords: Vertical axis wind turbines, aerodynamics, structural design, performance, research gap, research methodology

Introduction:

Wind energy has emerged as a clean and renewable source of electricity with significant potential to address the global energy crisis and reduce greenhouse gas emissions. Horizontal axis wind turbines (HAWTs) have dominated the wind energy industry due to their high efficiency and power generation capabilities. However, HAWTs have limitations in urban and decentralized environments due to their large size, noise, and visual impact. Vertical axis wind turbines (VAWTs), on the other hand, offer advantages such as compact size, lower noise, and omnidirectional wind capturing capabilities, making them suitable for urban and decentralized applications. VAWTs have been studied extensively in recent years, but there are still research gaps that need to be addressed to optimize their performance, reliability, and economic feasibility. This paper aims to bridge the research gap by critically analyzing the existing literature on VAWTs, identifying research gaps, proposing hypotheses, and suggesting future research directions.

Literature Review:

Vertical axis wind turbines (VAWTs) have gained attention as an alternative source of renewable energy. Bakhshai and Menetrier (2004) proposed a new configuration of VAWT that integrates Savonius and Darrieus rotors. They tested a prototype of the design and reported the performance evaluation results. Paraschivoiu (2005) presented a comprehensive overview of aerodynamic theories, principles, and computational tools employed in VAWT design, covering blade design, structural analysis, and control strategies. Mohanraj et al. (2007) conducted a comparative study of Darrieus, Savonius, and H-Darrieus turbines' power output, torque, and efficiency. Singh and Singh (2008) reviewed various wind turbine types, components, and recent developments in blade, generator, and control systems. Kim et al. (2009) analyzed the effect of blade shape on a VAWT's efficiency, concluding that twisted blades perform better than straight or curved blades. Akwa and Carrio (2010) simulated a VAWT with a variable pitch angle and optimized its design parameters for improved energy capture efficiency. Chen and Lee (2011) reviewed VAWT's development history, advantages, and limitations, and highlighted the research efforts made to improve their performance and reliability. Ferreira et al. (2012) developed a dynamic model for VAWTs for hydrokinetic energy conversion. Kishore and Sreenivasan (2013) analyzed the progress made in wind energy research and identified future research areas. Bhattarai and Perera (2014) evaluated the performance of a VAWT by measuring power output, torque, and wind speed characteristics.

VAWT's design affects their efficiency and power generation capacity. The study by Bakhshai and Menetrier (2004) proposed a new VAWT configuration that integrates Savonius and Darrieus rotors. Paraschivoiu's (2005) book provided a comprehensive overview of VAWT design principles, computational tools, and theories, while Chen and Lee (2011) reviewed VAWT's development history and research status. Kim et al. (2009) showed that twisted blades improved the VAWT's efficiency compared to straight or curved blades. Akwa and Carrio (2010) optimized the VAWT's design parameters for improved energy capture efficiency by simulating a VAWT with a variable pitch angle. Ferreira et al. (2012) developed a dynamic model for VAWTs for hydrokinetic energy conversion. Bhattarai and Perera (2014) evaluated the performance of a VAWT by measuring power output, torque, and wind speed characteristics.

Mohanraj et al. (2007) conducted a comparative study of Darrieus, Savonius, and H-Darrieus turbines and found that each type had its advantages and disadvantages. Meanwhile, Singh and Singh (2008) reviewed various wind turbine types, components, and recent developments in blade, generator, and control systems. Kishore and Sreenivasan (2013) analyzed the progress made in wind energy research and identified future research areas, including modeling VAWTs for hydrokinetic energy conversion (Ferreira et al., 2012) and improving their efficiency through blade design (Kim et al., 2009).Lee and Jang (2015) examined the impact of the number of blades on VAWT performance, concluding that a two-bladed configuration performed better than a three-bladed configuration. Hong and Kim (2016) presented a new design for a VAWT and investigated its power generation characteristics. Chowdhury, Kumar, and Kumar (2017) provided a comprehensive review of VAWT design and development, highlighting the key design parameters, performance characteristics, and challenges associated with their development.

Mustafa and Saqr (2018) used computational fluid dynamics (CFD) to optimize the design of a Darrieus VAWT and improve its efficiency. Allahyari et al. (2018) investigated the performance of a straight-bladed VAWT using experimental and numerical methods, evaluating the effects of blade number and chord length on power and torque characteristics. Faza et al. (2018) conducted an experimental and numerical study of a new design of Darrieus-Savonius hybrid VAWT, comparing it with a conventional Darrieus wind turbine. Islam, Islam, and Hasanuzzaman (2019) focused on an experimental investigation of a Darrieus VAWT, evaluating its performance in terms of power coefficient, torque coefficient, and blade tip speed ratio. Kumar and Kumar (2020) provided a review of VAWT technology, highlighting the challenges and opportunities associated with their use as a sustainable energy source for micro power generation. Finally, Ali and Iqbal (2021) explored the aerodynamic principles governing VAWT performance, including the lift and drag forces acting on the blades, the effect of blade geometry and airfoil shape on performance, and the impact of blade rotation on the flow of air. Overall, these studies provide valuable insights into VAWT design, performance, and potential use as a sustainable energy source.Overall, these studies have contributed significantly to the understanding of VAWTs and their potential as a sustainable energy source. They have covered various topics related to VAWT design, operation, and maintenance, such as aerodynamic theories, structural analysis, control strategies, and blade design. The studies have also highlighted the importance of optimizing VAWT design parameters for improved technology.

Research Gap:

Although there has been considerable research on VAWTs, there are still several research gaps that need to be addressed. These include:

1. Limited understanding of VAWT aerodynamics: Despite numerous studies, the aerodynamics of VAWTs are not yet fully understood, particularly in complex flow conditions, dynamic stall, and unsteady loads. Further research is needed to improve the understanding of VAWT aerodynamics to optimize their performance.

2. Lack of optimized structural design: The structural design of VAWTs is crucial for their performance and reliability. However, there is a research gap in optimizing the structural design of VAWTs, considering factors such as material fatigue, structural dynamics, and maintenance requirements.

3. Insufficient economic feasibility analysis: Although economic feasibility studies of VAWTs have been conducted, there is a need for further research to assess their cost-effectiveness, considering factors such as installation, operation, and maintenance costs, and their integration into the electrical grid.

Objectives:

The objectives of this research paper are:

1. To critically analyze the current state of research on VAWTs, including aerodynamics, structural design, performance analysis, and applications.

2. To identify research gaps in VAWT research, including aerodynamics, structural design, and economic feasibility, based on the existing literature.

3. To propose hypotheses for further investigation into VAWT aerodynamics, structural design, and economic feasibility.

4. To suggest future research directions to fill the identified research gaps and optimize the performance and reliability of VAWTs.

Hypothesis

Based on the literature review, the following hypotheses are proposed:

1. The aerodynamic performance of VAWTs can be optimized through the investigation of complex flow patterns, dynamic stall, and unsteady loads, leading to improved power output and efficiency.

2. The structural design of VAWTs can be optimized by considering factors such as material fatigue, structural dynamics, and maintenance requirements, leading to increased reliability and lifespan.

3. Economic feasibility of VAWTs can be improved through further research on cost-effective installation, operation, and maintenance, and their integration into the electrical grid, leading to increased competitiveness with HAWTs.

Research Methodology

This research paper will follow a systematic review approach to critically analyze the existing literature on VAWTs. The methodology will include the following steps:

1. Literature search: A comprehensive search of relevant literature will be conducted in online databases, journals, and conference proceedings to collect articles, papers, and reports related to VAWTs, focusing on aerodynamics, structural design, performance analysis, and applications.

2. Data analysis: The collected literature will be analyzed to identify research gaps and trends in VAWT research, including areas that require further investigation and optimization.

3. Simulation-based investigations: Numerical simulations and computational analyses will be conducted to investigate the aerodynamic performance, structural design, and economic feasibility of VAWTs, based on the identified research gaps and hypotheses.

Results

The results of this research paper are expected to contribute to the understanding of VAWTs and provide valuable insights for the development of more efficient and reliable VAWT systems. The findings of this research may include:

1. Improved understanding of VAWT aerodynamics, including complex flow patterns, dynamic stall, and unsteady loads, leading to optimized aerodynamic performance.

2. Optimization of VAWT structural design, considering factors such as material fatigue, structural dynamics, and maintenance requirements, leading to increased reliability and lifespan.

3. Insights into the economic feasibility of VAWTs, including cost-effective installation, operation, and maintenance, and their integration into the electrical grid, leading to increased competitiveness with HAWTs.

Conclusion/Discussion

In conclusion, the incorporation of VAWTs in self-sustaining rapid transit systems is a promising solution to reduce the carbon footprint of transportation and generate clean energy. The integration of VAWTs can provide a continuous source of renewable energy for powering the transportation system, which can significantly reduce the reliance on non-renewable energy sources. The VAWTs can be installed in various locations along the transit route, and their design can be customized to suit the specific requirements of the transit system. Therefore, it is recommended that policymakers and urban planners consider the integration of VAWTs in self-sustaining rapid transit systems to enhance sustainability and reduce carbon emissions.

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