LITEREATURE REVIEW ON THE GLOBAL WIND TURBINE PROPELLER TYPES

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Abstract. *The global energy crisis and the urgency of climate change mitigation, encourage the use of renewable energy, one of which is wind energy. The efficiency of the conversion of wind energy into electricity is very dependent on the design of the wind turbine propeller. This study aims to conduct a comprehensive literature study of various types of wind turbine propellers that have been developed and used globally, especially in the context of small-scale turbines for household needs. The method used is descriptive-qualitative literature study by examining various scientific sources, such as international journals, technical books, and reports of energy institutions. The results of the study show that there are several main types of propellers, namely Horizontal Axis Wind Turbine (HAWT), Vertical Axis Wind Turbine (VAWT), multi-blade, and Helical Blade, each with characteristics Aerodynamics, excellence, and its own limitations. The analysis also shows that the design of the propeller is efficient, simple, and low-cost is needed for the use of wind energy on a household scale, especially in tropical regions such as Indonesia. This research is expected to be a reference for the development of a mini wind turbine that is applicable, affordable, and sustainable.*

Keywords: *Aerodynamic efficiency, design bar, literature study, propeller, renewable energy, wind turbine*

1. INTRODUCTION

The global energy crisis and climate change are driving the transition from fossil fuels to renewable energy sources. Wind energy is one of the strategic solutions because it is clean, abundant, and has low operating costs. Wind turbines convert wind energy into electrical energy through propellers that capture and convert wind energy into mechanical motion. The performance of wind turbines is highly dependent on the design of the propeller, including the number of blades, and angle of inclination relative to the wind direction. Electricity generated by wind turbines is one of the cleanest methods of energy production and has been widely adopted globally, with a total installed capacity of 906 gigawatts (GW) (Putra et al., 2019). This technology has produced a variety of propeller designs tailored to geographical conditions, and power requirements. However, most innovations still focus on expensive and complex industrial-scale wind turbines, making their application at the household level challenging, especially in remote areas not yet connected to the national grid (Laka et al., 2024). One of the main obstacles is the high cost of small- scale wind turbines on the market. One of their main drawbacks is that the noise generated by wind turbines significantly affects nearby households. Therefore, it is important to predict noise levels from various turbines and modify their designs to ensure public safety. A study is needed to find efficient, affordable, and locally suitable designs and production processes for small-scale wind turbines (Junaidin, 2017). Demand for small-scale renewable energy technology continues to increase as public awareness of energy independence grows. This study is structured as a literature review to identify propeller designs that are efficient, easy to produce, and suitable for tropical wind conditions such as those in Indonesia. The results are expected to encourage the development of inexpensive and sustainable residential wind turbines (Anjani et al., 2024).

2. LITERATURE REVIEW

Wind energy is a type of renewable energy generated from the movement of air due to atmospheric pressure differences caused by uneven heating by sunlight. Wind kinetic energy is harnessed through wind turbines that convert it into electrical energy using the principle of energy conversion with blades, rotors, and generators. This process is influenced by aerodynamic principles and is equipped with yaw control and pitch control systems for efficiency. There are two types of turbines based on location: onshore and offshore. Onshore turbines are easier to build and maintain, while offshore turbines capture stronger winds but require significant costs. The efficiency and capacity of turbines continue to improve (Nuryanti et al., 2021).

2.1 Wind Turbine Type

a. Horizontal Axis Wind Turbine (HAWT)

Wind energy is a type of renewable energy generated from the movement of air due to atmospheric pressure differences caused by uneven heating by sunlight. Wind kinetic energy is harnessed through wind turbines that convert it into electrical energy using the principle of energy conversion with blades, rotors, and generators. This process is influenced by aerodynamic principles and is equipped with yaw control and pitch control systems for efficiency. There are two types of turbines based on location: onshore and offshore. Onshore turbines are easier to build and maintain, while offshore turbines capture stronger winds but require significant costs. The efficiency and capacity of turbines continue to improve (Nuryanti et al., 2021).

b. Vertical Axis Wind Turbine (VAWT)

Vertical axis wind turbines (VAWT) have a shaft that is perpendicular to the ground and can capture wind from all directions without using a yaw system. The two main types are Darrieus (H-shaped or egg-shaped) and Savonius (half- cylindrical blades that utilize drag force). VAWTs are suitable for areas with variable wind directions, especially in urban areas. Although their efficiency is lower than that of HAWTs, VAWTs are easy to maintain because the generator and gearbox are close to the ground. The rotor surrounds the shaft and operates based on lift or drag forces. Their drawbacks include low efficiency and the need for initial thrust (Mahmuddin et al., 2019).

c. Multi-blade Wind Turbine

Multi-blade wind turbines have more than three short blades arranged in a circle on the rotor. These turbines work on the principle of drag and operate at low speeds with high torque, making them suitable for direct mechanical applications such as water pumping in rural areas, rather than electricity generation. Their efficiency in converting wind energy into electricity is lower than that of modern turbines like HAWTs. However, the main advantage of multi-blade turbines is their operational stability in weak and unstable winds, making them reliable for simple energy needs in remote areas (Amin & Kaloko, 2024).

d. Helical Blade Turbine

Helical blade wind turbines are a variant of vertical axis wind turbines (VAWT) that use spiral or helical blades. This design was developed to reduce the torque fluctuations and vibrations commonly found in conventional VAWTs, resulting in smoother and more stable rotation. Its advantages make this turbine suitable for use in noise-sensitive environments, such as urban areas or institutions. Although its operating principle is similar to that of a conventional VAWT, the helical shape allows the turbine to operate more efficiently in low wind conditions and unpredictable wind directions. However, the complexity of the design and higher production costs pose significant challenges to its implementation (Divakaran et al., 2020).

2.2 How Wind Turbines Work

Wind turbines convert the kinetic energy of wind into electrical energy. The wind turns the blades, creating mechanical energy that is transmitted through the shaft and gearbox to the generator. The generator converts this into electricity using the principle of electromagnetic induction. Two forces influence the operation of the blades: lift force, which is perpendicular to the wind flow and is the primary source of rotation (especially in HAWTs), and drag force, which is parallel to the wind flow and is generally minimized, except in drag-based turbines such as Savonius turbines. Turbine efficiency is influenced by blade design (length, airfoil, angle of attack, material) and environmental factors (wind speed and direction). Technologies such as yaw systems and pitch control are used in HAWTs to optimize performance. The success of a turbine depends on aerodynamic design, mechanical systems, and controls suited to local conditions (Khusnawati et al., 2022) and (Muchlisinalahuddin, 2021).

2.3 Comparison of Peformance and Global Application of Wind Turbines

a. Horizontal Axis Wind Turbie (HAWT)

Horizontal Axis Wind Turbines (HAWT) are the most used type of wind turbine worldwide, especially for large-scale energy production in areas such as coastlines, deserts, and highlands. Their long, slender blades provide high energy conversion efficiency, especially in areas with stable winds. According to Khammas's study (2006), HAWT efficiency can exceed 70%, higher than that of VAWT (50– 60%). However, HAWTs require a yaw system to track wind direction and face installation and maintenance challenges, making them more suitable for locations with adequate infrastructure and open areas (Al-Rawajfeh & Gomaa, 2023a).77

b. Vertical Axis Wind Turbine (VAWT)

Vertical Axis Wind Turbines (VAWTs) are designed to capture wind from all directions without the need for a yaw system, making them suitable for urban areas, densely populated settlements, or regions with turbulent winds. The generator and gearbox being located close to the ground facilitates maintenance. Although its efficiency is lower compared to HAWT—approximately 25% lower according to Gomaa et al. (2023)—VAWT can produce higher torque and operate optimally atlow wind speeds and varying wind directions. This makes them ideal for use in urban areas (Safarov & Mamedov, 2021).

c. Multi-blade Wind Turbine

Multi-blade wind turbines are generally used for non-electric purposes, such as pumping water in remote areas. These turbines rely on drag force and function optimally at low wind speeds. Their efficiency for electricity production is very low due to the less aerodynamic shape of their blades. However, their advantage lies in their simplicity of construction and their ability to operate in weak wind conditions (Sulaiman et al., 2023).

d. Helical Blade Turbine

Wind turbines with helical blades are an advancement of VAWTs that reduce torque fluctuations, improve rotational stability, and reduce noise, making them suitable for sensitive environments such as residential areas and schools. This research shows improved aerodynamic performance and noise reduction compared to straight blades. However, this design poses challenges in terms of cost and production complexity. The selection of wind turbines globally isinfluenced by efficiency, cost, maintenance, durability, and ecological impact. Developed countries like Denmark and the US prefer HAWTs, while developing countries opt for VAWTs or small turbines for local needs (Dwi Fikako et al., 2023).

3. RESEARCH METHODS

This research is a descriptive qualitative study with a literature review approach. Data was collected through reviewing journals, conference proceedings, technical reports, and books discussing various types of wind turbine blades globally. The research was conducted online and through literature study, without laboratory or field activities, during the period from June to October 2025.

Figure 1. Flow chart

3.1 Problem identification

At this stage, the author identified that although wind turbines have been widely used in various parts of the world, information about the differences in blade design, performance, and characteristics has not been thoroughly studied in a single scientific document. Therefore, this topic is considered important to review, especially as an effort to support the development of renewable energy through a deeper understanding of wind turbine propeller technology.

3.2 Global Literature Studies

After the topic and issues were determined, a literature study was conducted on various scientific references from around the world. The author collected data and information from scientific journals, conference articles, technical books, and reports from international energy agencies. The main focus at this stage was to identify the designs of wind turbine blades that have been developed and used, as well as their performance and technical innovations in various regions with different wind characteristics.

a. Classification of Wind Turbine Blade Types

1) The results of the literature study were then classified into several main categories, such as: Types of turbines according to shaft direction (horizontal and vertical shafts)
2) Number of propeller blades (one, two, three, or more).
3) Materials used (fiberglass, metal, composite, etc.)

b. Application (onshore and offshore).

This classification aims to help readers understand the various propeller designs that have been developed and used globally.

3.3 Analysis and Comparison

After the data was collected and classified, an analysis was conducted on each type of propeller based on aerodynamic efficiency, structural strength, production costs, and suitability to environmental conditions. In addition, comparisons were made between designs from various countries or regions to reveal the advantages and disadvantages of each type of propeller, as well as the factors that influence their selection.

3.4 Result and Discussion

This section presents the results of the literature study. The author discusses the main findings for each type of propeller studied and provides an interpretation of current trends and directions in wind turbine propeller technology. This discussion also covers opportunities and challenges in developing more efficient propeller designs in the future.

4. RESULTS AND DISCUSSION

This literature review was conducted by collecting scientific articles related to research on wind turbine blades. The literature was searched online through the Google website using the keywords “wind turbine global” and through the Google Scholar website using the keywords “horizontal axis wind turbine” and also through the ScienceDirect website using the keywords “vertical axis wind turbine.” The search on the Google website yielded 50 articles, but only 10 were closely related and further analyzed in this study. The search on the Google Scholar website yielded 100 articles, but only 15 were closely related. The search on the ScienceDirect website yielded 200 articles, but only 12 were closely related and further analyzed in this study.

From collecting scientific articles through internet searches, we got 20 articles that are closely related to the discussion of wind turbine blades, namely:

Table 1.

No	Blades Type	Materials	Number Of Blades	Advantages and Disadvantages
1	H- Darrieus (VAWT) (Olivera et al. 2025)	PLA	3 blade	Biodegradable, easy to print UV sensitive, low strength
2	Morphing Blade (Multistable) (Riley et al. 2025).	CFRP (Carbon Fiber Reinforced Polymer) + CNT	3 blade	• Very strong, lightweight, long life adaptive shape High cost, design complexity
3	Mikro HAWT (horizontal (Kadhim et al., 2025)	Komposit (SG6041– 6043)	3 blade	High start-up torque, efficient at low wind speeds Sensitive to wind speed variations, performance decreases if overdesigned
4	Savonius (VAWT) (AlRawajfeh & Gomaa, 2023b)	Fiberglass, termoplastik , logam	2-3 blade	• Simple construction, high initial torque Low efficiency (~16%), poor aerodynamic performance
5	Darrieus Φ (Sandia 34m) (Möllerström et al., 2019).	Aluminium	2 blade	• High efficiency (Cp 0.43), modular design for research Foundation cracks, metal fatigue
6	Savonius + Airfoil Deflector (Rajpar et al. 2021).	NACA 001 airfoil (logam/komposit)	2 blade	Increases Cp by up to 50%, self starting, high efficiency Requires angle of attack (AOA) adjustment complicated to fabricate
7	VAWT H-Rotor (Ramadhani, 2021).	Fiberglass dan logam	2-6 blade	Easy to apply in low wind areas Adding more blades reduces power efficiency
8	VAWT (Vertical Axis Wind Turbine) (Ulinuha & Ubaidillah, 2021)	Material berbahan ringan	4 blade	• The generator is easy to maintain because it is located at the bottom Portable Lower efficiency compared toHAWT

9	HAWT tipe Taperless (Nursidik et al., 2021)	Kayu mahoni	3 blade	• Lightweight, strong, corrosior resistant, easy to shape Wood can warp if left in the sun fo too long
10	VAWT (Vertical Axis Winc Turbine), tipe Savonius (Monika et al., 2024).	spesifik untul bilah (hanya sistem dar komponen elektronik)	5 blade	Suitable for low winds Lower efficiency compared tc horizontal types
11	HAWT (Horizontal Axis Wind Turbine) (Prasetiyc et al., 2020).	Airfoil naca 6409	10 blade	Can utilize exhaust air from the condenser and high torque Rotational speed decreases if there are too many blades
12	HAWT (Horizontal Axis Winc Turbine) (Kassa et al. 2024).	SG6043, NACA4412	1-3 blade	• High efficiency (Cp can reach 0.6 and stable at various wind speeds Performance decreases at low Re if the design is not optimal anc sensitive to wind without yaw
13	Horizontal Axis Winc Turbine	Tidak disebutkar	3 blade	High efficiency with a power coefficient of up to 0.4
	(HAWT) (Altmimi et al., 2022).	secara spalit		Susceptible to vertical winc fluctuations
14	Horizontal Axis Winc Turbine (HAWT) (Gao et al., 2021).	Tidak disebutkar secara eksplisit	2-3 blade	Using the Actuator Line Model (ALM with LES simulation for high precisior Complex and time- consuming computation
15	Horizontal-Axis Winc Turbine (HAWT) (Castellani et al. 2019).	Material komposit ringar seperti fiberglass atau karbon	2 blade	• More accurate simulation with anisotropic models anc better predictions in yaw conditions • Decreased performance at large yaw angles and high simulation anc computational complexity
16	Horizontal-Axis Winc Turbine (HAWT) dar Vertical-Axis Wind Turbine (VAWT) (Khandakar & Kashem 2020).	fiberglass dar struktur berbasis komposit ringan	2-3 blade	HAWT: high efficiency, long durability, suitable for large-scale power generation and VAWT: no yaw required, suitable in areas of variable winds HAWT: high cost, requires yaw mechanism and VAWT: low efficiency, difficult to self-start, higher cost per kWh
17	Horizontal Axis Winc Turbine (HAWT) (Prabowoputra et al., 2020).	Aluminum Alloy dan Natura Composite	3 blade	High stability and high energy conversion efficiency Requires yaw drive and Requires a strong suppor structure and high maintenance costs

18	Horizontal Axis Wind Turbine (HAWT) (Shankar et al.,n.d.)	Polyvinyl Chloride (PVC)	4 blade	• Can operate at low wind speeds with high torque Lower efficiency compared to largescale turbines, sensitivity to wind direction
19	Horizontal Axis Wind Turbine (HAWT) dan Vertical Axis Wind Turbine (VAWT) (Eftekhari et al., 2021b).	Tidak dijelaskan secara spesifik	HAWT 3 blade VAWT 2-4 blade	HAWT: high efficiency, suitable for large scale and VAWT can receive wind from all directions, quieter suitable for urban areas HAWT: high efficiency, suitable for large scale and VAWT can receive wind from all directions, quieter suitable for urban areas
20	Horizont al Axis (Pramono et al. 2023).	GFRP dan CFRP	3 blade	Strong and lightweight Difficult to recycle

Based on a review of 20 articles analyzed, the development of wind turbine blade design shows significant diversity, both in terms of turbine type (HAWT and VAWT), materials, fabrication methods, and applications and performance.

1. Types and Configurations of Propeller

In general, wind turbines are divided into two main types, namely Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT). HAWTs tend to be more efficient because they utilize wind direction directly, while VAWTs are superior in terms of installation and operation in areas with unpredictable wind directions. Blade designs also vary, ranging from taperless, morphing blades, Savonius, to H-Rotor and Φ-Darrieus. The Savonius type is suitable for low wind speeds and urban environments, while the H-Darrieus and HRotor types are more commonly used for modular applications or laboratory-scale projects.

2. Material and Structural Characteristics

The materials used in wind turbines vary widely, ranging from biodegradable polymers (PLA), PVC, thermoplastic and thermoset composites, fiberglass, to CFRP/GFRP. The choice of materials affects the efficiency, durability, and recyclability of turbines. Composite materials such as CFRP and GFRP are often chosen for high- performance applications in large-scale turbines, but the main challenges are the difficulty in recycling and relatively high costs. Some studies emphasize the use of lightweight and easy-to-process materials like mahogany wood, PLA, and others for small-scale applications or laboratory prototypes. Additionally, advanced materials like CNT and special metal alloys are used to enhance structural adaptability and the lifespan of the blades.

3. Manufacturing Process and Simulation

The methods used to manufacture blades include conventional techniques such as manual cutting (wooden/PVC blocks), resin infusion and autoclave, as well as modern technique such us 3D Printing technology (Abd Halim et al., 2023). .The use of simulation software such as QBlade, CFD URANS, and LES is very important in the design process and validation of turbine aerodynamic performance. Studies by Altmimi et al. and Gao et al. demonstrate how numerical modeling and yaw effect simulations can enhance performance prediction and wake control accuracy of turbines. Experimental approaches are also conducted through direct field performance tests or laboratory-scale experiments, as performed by Kadhim et al. and Monika et al.

4. Energy Function and Efficiency

All writings emphasize that the main function of propellers is to convert wind kinetic energy into electrical energy. However, their efficiency and intended use vary. Micro turbines such as those developed (Kadhim et al. 2025) and (Ulinuha and Ubaidillah 2021) are designed for household and portable use, while larger designs such as the Sandia 34m are more focused on research and medium to large-scale energy production. Additional features such as morphing blades and airfoil deflectors indicate a trend toward innovative adaptive designs that can significantly improve the power coefficient (Cp). However, these innovations come with challenges related to design complexity and high costs. Based on the analysis of the four points above, the best blade type for residential-scale applications is the HAWT blade type, which uses SG6041-6043 composite materials and a three-blade configuration. The turbine is designed to produce high initial torque and operate optimally at low wind speeds, making it suitable for urban and residential areas.

Thus, the results of this study indicate that the suitable turbine type for residential and rural applications is the H-Rotor (VAWT) type, which features a vertical axis design, making it suitable for areas with fluctuating or inconsistent wind speeds, such as urban environments or rural areas. This turbine uses three blades made of fiberglass or lightweight plastic composite material for efficiency and ease of production. Meanwhile, there is also the HAWT turbine type, which is equally good, but the HAWT turbine requires relatively high wind speeds and is significantly more expensive compared to the VAWT. The conclusion is that in this study, the VAWT is an excellent choice for residential-scale applications with low to moderate wind speeds. Its simple design, adequate efficiency, and ease of manufacturing and maintenance make it a practical and economical solution for small household energy needs.

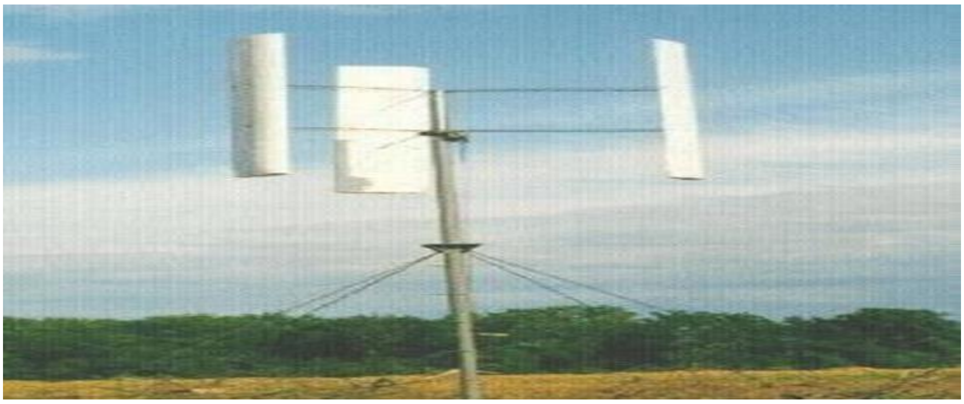

Figure 2.

CONCLUSION

The conclusions of the articles discussed show that wind turbines, both VAWT and HAWT types, have advantages and disadvantages in terms of efficiency and application. VAWT types are simpler and do not require a yaw system, but their efficiency is lower. Meanwhile, HAWT types are more efficient but require a yaw mechanism and are more expensive. The materials used vary, ranging from lightweight composites such as CFRP and PLA to metals such as aluminum, each of which has advantages in terms of strength and durability, but also disadvantages in terms of cost and complexity. The materials used vary, ranging from lightweight composites such as CFRP and PLA to metals like aluminum, each of which has advantages in terms of strength and durability, but also drawbacks in terms of cost and complexity. The manufacturing process for turbines varies, using methods such as 3D printing, resin infusion, and CFD-based simulation for design optimization. Wind turbines convert wind energy into electricity, suitable for both small-scale and large-scale applications, with further research needed to improve efficiency and material durability. The results of this study indicate that the most suitable blade type for residential and rural applications is the H-Rotor (VAWT) blade, which features a vertical axis design, making it suitable for areas with fluctuating or inconsistent wind speeds, such as urban environments or rural areas.

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