CHAPTER I
INTRODUCTION

1.1 Background

The world's electricity demand is still predominantly met by fossil fuel-based energy sources, which generate high carbon emissions, while the contribution of low-carbon energy remains relatively limited. Dependence on fossil fuels has led to ecological imbalances and environmental degradation that are difficult to reverse. This situation has encouraged researchers worldwide to develop various renewable energy sources as an effort to reduce carbon emissions. Various approaches, including wind, solar, hydropower, geothermal, and biomass energy, continue to be developed as environmentally friendly alternatives (Farajyar et al., 2023).

Energy-related challenges in Indonesia are becoming increasingly complex due to the high level of emissions in urban areas. In particular, Surabaya contributes up to 3.7 million tons of CO_2 annually, with 82.12% originating from the transportation sector. This condition highlights the urgent need for the implementation of low-carbon energy sources, such as wind energy, to support sustainable development and reduce greenhouse gas emissions (Mustikaningtyas & Winursita, 2016). The average wind speed in Surabaya ranges from 3 to 5 m/s (Soewarianto et al., 2022), Although this wind speed is relatively low, it still offers significant potential for the development of Savonius-type wind turbines, which are capable of operating efficiently under low wind speed conditions. Therefore, Savonius wind turbines can serve as a promising renewable energy solution to support the development of low-carbon cities (Putri et al., 2023).

Wind energy is one of the alternative energy sources in Indonesia, an archipelagic country located along the equator. As a renewable and environmentally friendly energy source, wind energy converts the kinetic energy of moving air into electrical energy through the use of wind turbines (Sudirman & Santoso, 2020). According to the Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG) in Padang, Indonesia has an average wind speed of approximately 3 m/s, which has the potential to be utilized for small-scale Wind Power Plants (PLTB – Pembangkit Listrik Tenaga Bayu) (Pratiwi & Yurian, 2021).

Horizontal-axis wind turbines are the most commonly developed type of wind turbine. However, for regions characterized by low average wind speeds, vertical-axis wind turbines are often preferred due to their distinct advantages, including the ability to operate independently of wind direction and their relatively simple design (Sudirman & Santoso, 2020). Despite these advantages, Savonius wind turbines still have limitations that continue to be the focus of ongoing research and development, particularly their relatively low Coefficient of Power (CoP). This limitation is attributed to several factors, including operation under relatively low wind speed conditions and the tendency for Savonius turbines to be installed at lower heights, where wind resources are generally less favorable (Arif, 2019; Zulianto & Siregar, 2019)

Previous studies on modifications to Savonius turbine geometries have shown that changes in blade shape can significantly influence the Coefficient of Power (CoP) and torque performance; however, the findings have not been entirely consistent. A study by (Shashikumar et al., 2021) compared a conventional Savonius turbine with a tapered-blade configuration under low-flow water conditions. The results indicated that, at certain taper ratios, the CoP decreased compared to the conventional design due to a reduction in the effective flow-capturing area and a less favorable pressure distribution. Research by (Mrigua et al., 2022) investigated blade shape modifications using a Computational Fluid Dynamics (CFD) approach. Their findings demonstrated performance improvements for several specific configurations; however, the study primarily focused on overall blade geometry modifications rather than a detailed analysis of the effect of taper ratio on static torque characteristics. Meanwhile (Soetanto et al., 2024) evaluated tapered and inverse-tapered blade designs for small-scale vertical-axis wind turbines and reported potential efficiency improvements under low wind speed conditions. Nevertheless, the study did not comprehensively examine the relationship between taper ratio variation, Coefficient of Power (CoP), and Coefficient of Static Torque (CTs) simultaneously.

This study focuses on analyzing the performance of a Savonius wind turbine with modified blade taper ratios. The turbine performance is evaluated using the Coefficient of Power (CoP) and Coefficient of Static Torque (CTs) through Computational Fluid Dynamics (CFD) simulations conducted in ANSYS Fluent. This approach enables a three-dimensional investigation of both geometric and operational turbine parameters, including taper ratio variations, wind speed, and blade shape factors, thereby providing a more comprehensive understanding of the influence of geometric modifications on the aerodynamic efficiency of Savonius turbines operating under low wind speed conditions..

Research on taper ratio variations in Savonius wind turbines is not only intended to improve aerodynamic performance through enhancements in the Coefficient of Power (CoP) and Coefficient of Static Torque (CTs), but also holds direct relevance to Indonesia’s energy transition efforts. This study has the potential to contribute to the development of more efficient wind energy conversion technologies for regions characterized by low wind speeds, thereby supporting the reduction of carbon emissions from the energy and urban transportation sectors..

1.2 Problem Formulation

1. How does the variation of the taper ratio affect the Coefficient of Power (CoP) of a Savonius wind turbine?
2. How does the variation of the taper ratio affect the Coefficient of Static Torque (CTs) of a Savonius wind turbine?
3. What is the relationship between taper ratio, Coefficient of Power (CoP), and Coefficient of Static Torque (CTs), and how can the optimum taper ratio (K) be identified to enhance the performance of a Savonius wind turbine?

1.3 Research Objectives

1. To analyze the effect of taper ratio variations on the performance of a Savonius wind turbine based on the Coefficient of Power (CoP).
2. To evaluate the relationship between taper ratio variations and the Coefficient of Static Torque (CTs) under low wind speed conditions.
3. To determine the optimum taper ratio (K) that can enhance the performance of a Savonius wind turbine and support the implementation of wind energy in Indonesia.

1.4 Research Scope

1. The study was conducted using three-dimensional (3D) simulations in ANSYS Fluent 2021 R2.
2. The study assumes ideal airflow conditions.
3. The working fluid is incompressible air with transient (unsteady) flow characteristics.
4. The rotor is analyzed under rotating conditions.
5. The analysis is performed for unidirectional external flow.
6. The simulations employ the sliding mesh method.
7. The realizable k–ε turbulence model is used in the simulations.
8. The simulations are conducted by neglecting the effects of heat transfer and gravitational forces.