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Introduction

Wind energy can be harnessed through both horizontal and vertical axis wind turbines, each converting kinetic energy into mechanical and electrical power. Among vertical-axis designs, two principal categories are distinguished: drag-based devices, represented by the Savonius rotor, and lift-based configurations, encompassing Troposkein and H-shaped Darrieus turbines [1, 2]. The latter are notable for their structural simplicity, quiet operation, insensitivity to wind direction, and minimal servicing demands, positioning them as attractive candidates for urban energy applications. Nevertheless, H-Darrieus rotors present inherent drawbacks, namely poor self-starting performance and a relatively modest power coefficient.

A range of strategies has been explored to address these shortcomings, including modifications to blade geometry and count, integration of supplementary flow control elements, and broader aerodynamic optimization. Experimental work by Mazarbhuiya et al. demonstrated that adopting the thicker NACA 63-415 profile yields a 4.34% improvement in C_p [3], while numerical investigations by Mabrouk and Hami highlighted the aerodynamic benefits of a three-bladed arrangement [4]. Dominy et al. further reported enhanced self-starting characteristics through design refinements [5]. Beyond conventional configurations, alternative layout concepts are under consideration, including the strategic siting of VAWTs within building wake regions to exploit accelerated flow.

The experimental investigation of aerodynamic characteristics was carried out in the T-1-M wind tunnel, as shown in Figure 1. The tests of a three-bladed Darrieus-type vertical axis wind turbine were conducted in an aerodynamic laboratory using two fabricated rotor models. The wind tunnel provides a controlled airflow through the test section where the wind turbine model is installed. The dimensions of the test section are 0.5 m × 0.5 m in cross-section and 0.8 m in length. The airflow velocity generated by the fan was measured using a digital anemometer and varied within the range of 3–15 m/s.

Rotational speed was recorded using an infrared tachometer. The rotor was placed near the outlet to ensure uniform flow and reduce blockage effects. A three-component aerodynamic balance was used to measure forces and moments acting on the model.



Fig. 1. . Experimental model of a wind turbine with a three-bladed rotor:
(a) rotor with modified asymmetric blades (test configuration);
(b) rotor with symmetric blades (baseline configuration).

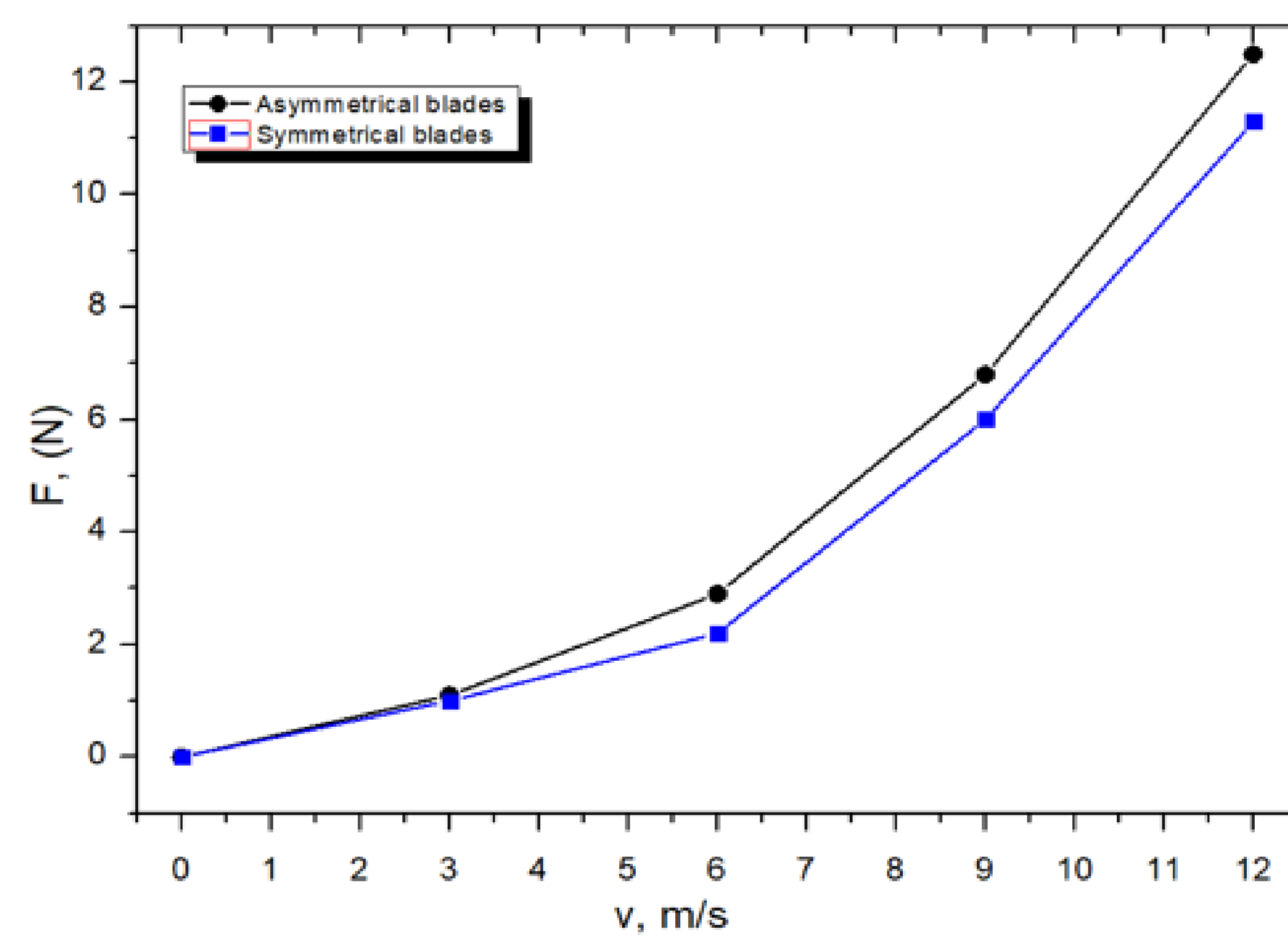


Fig. 2. Dependence of rotor torque on wind speed for the wind turbine model

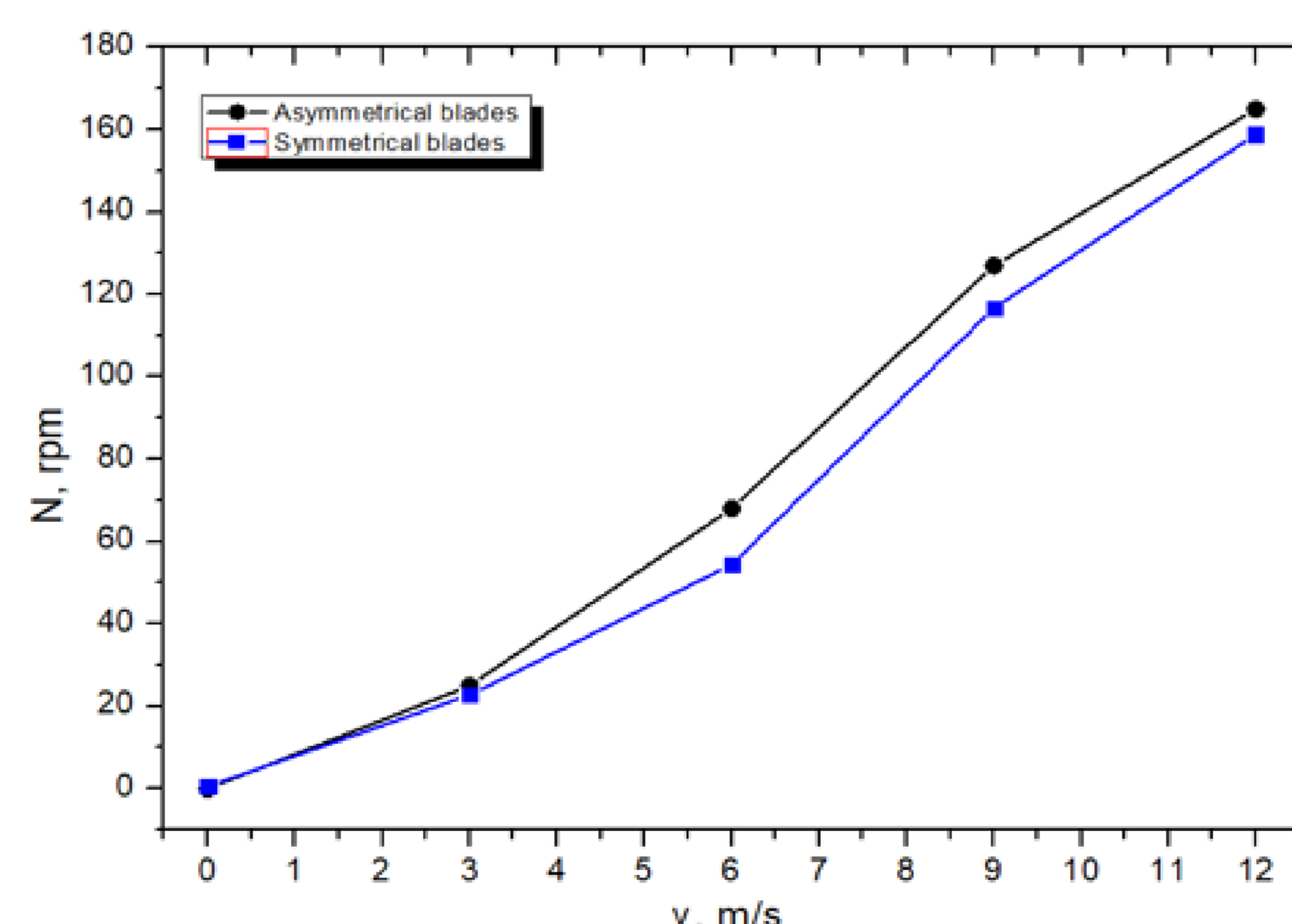


Fig. 3. Effect of wind speed on rotor rotational speed

The performance of a wind turbine is commonly evaluated using the power coefficient, a dimensionless parameter that represents the efficiency of converting the kinetic energy of the airflow into mechanical energy at the rotor shaft. It is calculated as follows:

$$C_p = \frac{N_r - N_c}{N_{of}}$$

where $N_c = m M_c \omega_c$ – is the rotational power of the rotor; m – is the number of blades; M_c – is the aerodynamic force acting on the blades during rotation; and ω_c – is the angular velocity.

The tip speed ratio (TSR) is defined as the ratio of the tangential velocity of the blade tips to the velocity of the incoming airflow.

$$\lambda_p = \frac{2\pi R n}{60V}$$

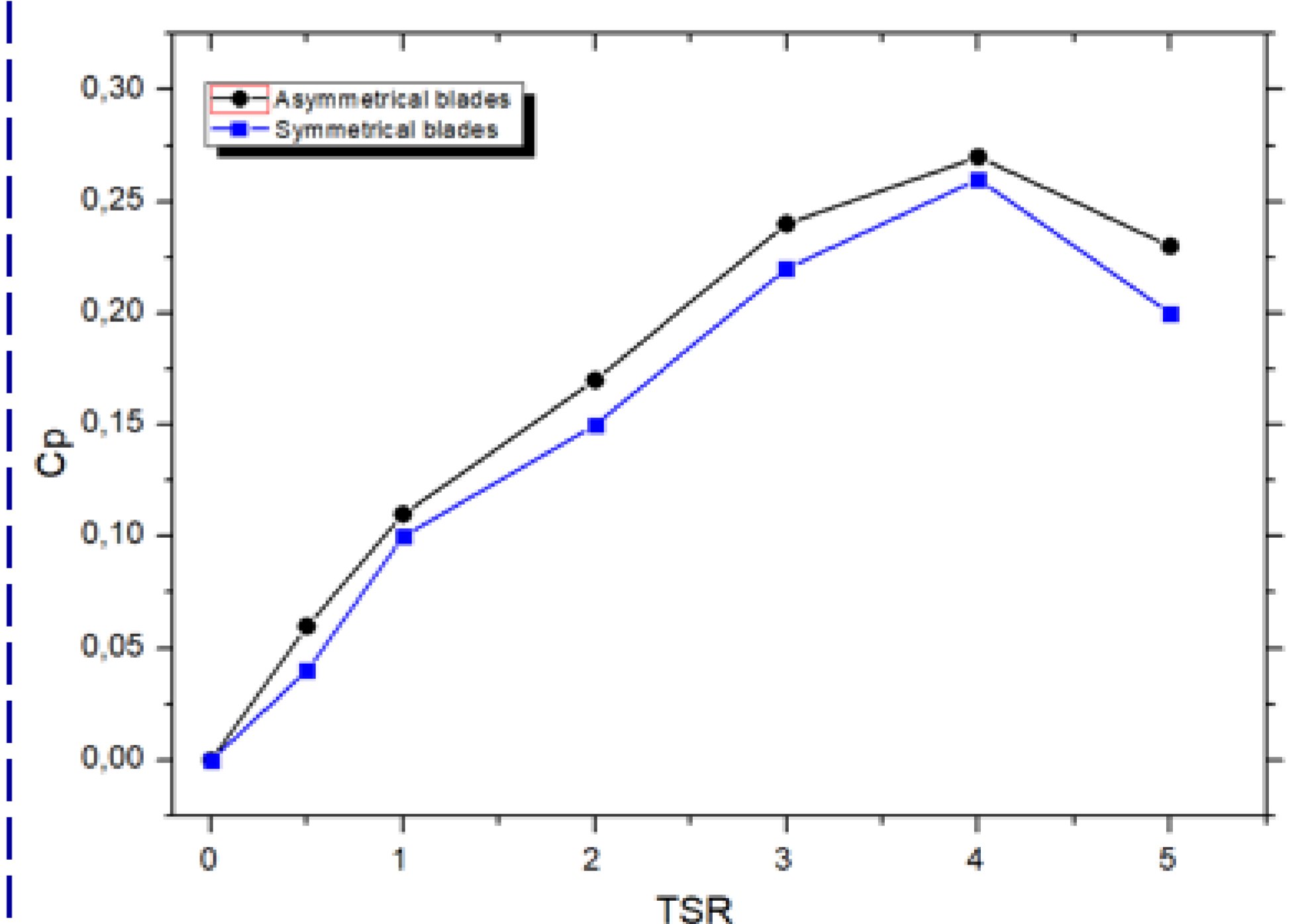


Fig. 4 Variation of the power coefficient with tip speed ratio

Conclusions

This study compares the aerodynamic performance of a three-bladed Darrieus vertical axis wind turbine with symmetric and modified asymmetric blades. Wind tunnel experiments across various airflow velocities show that asymmetric blades improve torque, rotational speed, and start-up performance, especially at higher wind speeds. Both configurations reach maximum power coefficient (C_p) at $TSR \approx 4$, but the asymmetric design consistently achieves higher C_p values, indicating better efficiency. Overall, asymmetric blades enhance start-up and energy performance and offer strong potential for further turbine optimization.

References

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