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Study of the efficiency of a vortex wind turbine with an airflow concentrator

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ABSTRACT

This study investigates the aerodynamic performance of a vertical-axis vortex wind turbine equipped with a multi-channel airflow concentrator formed by logarithmically curved guide surfaces. The objective is to enhance airflow acceleration and controlled vortex formation under low-wind-speed conditions. Three-dimensional Reynolds-averaged Navier-Stokes (RANS) simulations with the standard k-epsilon turbulence model were used to analyze the flow field and turbine performance. At an inlet velocity of 2 m/s, the two-channel inflow condition produced a velocity amplification of approximately 10–12 times, corresponding to an outlet velocity of 20–24 m/s. The energy-performance analysis yielded a maximum estimated power coefficient of Cp=0.31 at a tip-speed ratio (TSR) of 1.25, corresponding to a rotor speed of 44.5 rpm, torque of 0.33 N·m, and mechanical output power of 1.55 W. The results demonstrate that logarithmically curved guide channels can combine airflow concentration with tangential flow generation and provide a distinct optimum operating region. The findings demonstrate the aerodynamic potential of the proposed concept, while wind-tunnel validation is required to confirm its practical performance.

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1. INTRODUCTION

Growing demand for renewable energy and the gradual depletion of traditional energy resources continue to accelerate the development of renewable energy technologies. Among these, wind energy remains one of the most mature and widely deployed solutions due to its scalability, environmental benefits, and ability to generate electricity without direct fuel consumption [1]–[3]. However, the performance of wind power

systems is significantly affected by local wind conditions, aerodynamic losses, and the efficiency of transferring kinetic energy from the incoming flow to the rotor.

Horizontal-axis wind turbines typically achieve high aerodynamic efficiency but require constant alignment with the wind direction and involve relatively complex support, control, and transmission systems [4], [5]. In contrast, vertical-axis wind turbines (VAWTs) can receive wind from various directions and offer simple design, compactness, and suitability for decentralized and urban applications [6], [7]. However, traditional Savonius and Darrieus turbines suffer from a number of aerodynamic limitations, including blade return losses, torque pulsation, flow separation, unstable start-up characteristics, and relatively low energy conversion efficiency at low speeds and highly variable wind conditions [8]–[11]. One approach to improving the performance of VAWTs is the use of diffusers, shrouds, guide vanes, and flow concentrators, which increase the local wind speed and direct a larger portion of the incoming airflow toward the rotor. Previous experimental and numerical studies have shown that properly designed wind turbines with diffusers can increase local flow speed and improve energy recovery [12]–[15]. However, the efficiency of such systems is highly dependent on the geometry of the diffuser or guide vane. Abrupt changes in flow direction, excessive constriction and poorly designed guide surfaces can lead to recirculation, pressure losses, flow separation, and uneven airflow to the rotor, thereby reducing the expected aerodynamic benefit [16], [17].

Vortex-based concepts offer an alternative approach by introducing a rotational component into the incoming airflow. A controlled vortex can increase the tangential velocity component and alter the aerodynamic load acting on the turbine rotor [18]. Research on vortex thrusters, curved ducts, and spiral guide structures has shown that smooth geometric curvature can promote organized rotational flow while reducing abrupt separation and excessive turbulence [19], [20]. Logarithmic or spiral guide geometries in particular are attractive because they can gradually redirect airflow into the rotor region while simultaneously generating a stable tangential component.

Despite these developments, an important research gap remains. Most VAWT configurations with diffusers are designed primarily to accelerate the axial component of the incoming wind, while relatively limited attention has been paid to compact concentrators that intentionally combine airflow acceleration with controlled tangential redirection before flow interaction with the rotor. Existing vortex-based concepts can also require complex geometries or operating conditions and often provide insufficient information on the relationship between guide channel configuration, vortex stability, and rotor velocity distribution. Therefore, there is a need for a simpler multi-channel concentrator geometry capable of creating a stable vortex structure while minimizing flow separation and aerodynamic losses.

The novelty of this study lies in the development of a multi-channel airflow concentrator with logarithmically curved guide surfaces, specifically designed for a VAWT. Unlike traditional diffuser configurations, which primarily increase the axial flow velocity, the proposed concentrator is designed to simultaneously accelerate and redirect the incoming airflow, thereby increasing the tangential velocity component and promoting the formation of a controlled vortex in the rotor region. The geometry is evaluated for various guide channel configurations to determine the arrangement that provides the most favorable flow organization.

Therefore, the objective of this study is to investigate the aerodynamic behavior of the proposed vortex wind turbine using mathematical modeling and 3D computational fluid dynamics (CFD). The study focuses on the influence of guide channel geometry on airflow acceleration, velocity distribution, vortex formation, and flow stability, and identifies a rational multi-channel configuration for further development. The obtained numerical results are subsequently used to evaluate the aerodynamic potential of the proposed design for compact wind turbines operating in low and variable wind speed conditions.

2. METHOD

The research methodology combines an analytical description of the aerodynamic processes in the airflow concentrator with three-dimensional modeling of the vortex flow in the turbine region using CFD. Numerical analysis was performed using the Reynolds-averaged Navier-Stokes (RANS) equations in conjunction with the $k-\varepsilon$ turbulence model. The methodology includes the formulation of governing aerodynamic equations, definition of the computational domain and boundary conditions, evaluation of various guide channel configurations, mesh independence assessment, and validation of the numerical approach based on literature results. The resulting velocity, pressure, and vortex flow characteristics were subsequently used to evaluate the aerodynamic performance of the proposed concentrator.

2.1. Fundamental equations of the mathematical model

The airflow through the concentrator was considered as an incompressible turbulent flow. The equations of motion were formulated using the RANS approach, which provides a practical basis for predicting

mean velocity and pressure fields in wind energy applications. Turbulence closure was achieved using the standard k-ε model due to its computational efficiency and proven applicability to engineering flows involving recirculation, curved channels, and high velocity gradients [21]–[23]. Aerodynamic computational modeling of airflow in a vortex wind turbine was performed using the RANS equation, as given in (1):

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + V\frac{\partial U}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \nu\left(\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2}\right) \quad (1)$$

where U and V are the longitudinal and vertical velocity components; ρ is the density; P is the pressure; ν is the kinematic viscosity coefficient; x and y are the longitudinal and transverse coordinates; and t is the time. The k–ε turbulence model was used to close the turbulent terms. The integral relations of the theory of turbulent jets (2) were used as an engineering approximation:

$$\int U\,dy = const \quad (2)$$
$$\int U^2\,dy = const$$

Here, U is the longitudinal velocity component and dy is the vertical integration step. Figure 1 shows a diagram of the wind velocity distribution as a function of the distance h from the guide walls.

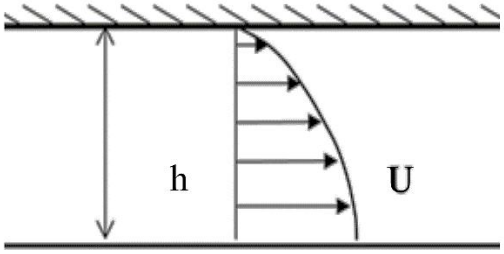


Figure 1. Wind speed distribution diagram

To obtain the calculated velocity distributions, (3) was used:

$$U = U_m + \frac{2}{\theta}\left(\frac{\Delta P}{\rho L}\right)^{1/2}\left[(y)^{\frac{1}{2}} - (h)^{\frac{1}{2}}\right] \quad (3)$$

where ΔP is the pressure difference in the wind turbine at height L; θ=0.4. The wind flow power is calculated using (4):

$$P = ½ * \rho * S * V^3 \quad (4)$$

where P is the wind flow power (W), ρ is the air density (1.228 kg/m^3 under normal conditions–room temperature +20 °C and a pressure of 760 mmHg), S is the cross-sectional area of the wind flow (m^2), and V is the wind speed (m/s). The net power output of the wind turbine is calculated using (5):

$$P_{\text{ВЭУ}} = C_p \cdot \frac{1}{2}\rho S V^3 \quad (5)$$

where C_p is the power coefficient, which depends on the rotor design. Standard aerodynamic relationships (6) were used to estimate the forces acting on the blades. The drag force acting on the wind turbine blades is calculated using (6):

$$P_x = ½ * Cx * S * \rho * (V - U)^2 \quad (6)$$

where Cx is the aerodynamic drag coefficient, U is the wind speed after the midsection of the body (in our case, the impeller). The wind energy utilization coefficient is calculated using (7):

$$\xi = C_x * \left(1 - \frac{U}{V}\right)^2 * U/V \quad (7)$$

For a real wind wheel, a more precise dependence (8) was used:

$$\xi = \xi t * \left[1 - \left(-\frac{r_0^2}{R^2}\right) - T_j - T_p - T_m\right] \quad (8)$$

where ξt is the theoretical wind energy utilization coefficient of a real wind turbine, T_j are the profile losses caused by the friction of air streams on the wing surface and depend only on the blade profile, T_p are the losses due to the torsion of the air stream behind the wind turbine, and T_m are the losses due to incomplete utilization of the wind turbine area. The speed was determined by (9):

$$Z = \frac{V_R}{u_0} = R * w / u_0 \quad (9)$$

where w is the angular velocity of the wind wheel. The torque generated by the wind turbine is calculated using (10):

$$M = C_M * M_{max} \quad (10)$$

where C_M is the torque coefficient. For an n-blade wind wheel, the optimal speed (11):

$$z_0 = \frac{4\pi}{n} \quad (11)$$

The amount of energy that a wind turbine generates over a given period of time can be determined as (12):

$$W = P_{\text{ВЭУ}} * t/1000, \quad (12)$$

where W is the amount of energy generated [kWh] and t is the estimated operating time of the wind turbine [h].

The coefficient 1000 is used to convert units of power from W to kW. When calculating wind farm performance, the mutual influence of wind turbines on each other within the wind farm (the "shadowing" effect) must be taken into account. Wind performance losses due to the turbulent wake behind the wind turbine rotor are determined using the PARK calculation module of WindPRO software. The basic equation used to calculate losses due to the wind shading effect on the rotor is as (13):

$$v = u[1 - \frac{2}{3}(\frac{R}{R+\alpha x})^2] \quad (13)$$

where v is the wind speed at a distance x behind the rotor, u is the natural wind speed before the rotor, R is the rotor radius, α is the speed reduction constant due to the turbulent wake, and 2/3 is the approximate value of the parameter C_t. The program uses the actual value of the parameter C_t for each interval of wind speed values in its calculations.

2.2. Numerical simulation of the vortex wind turbine design

Numerical simulation of the vortex wind turbine design was conducted to determine the optimal geometric parameters of the guide channels and evaluate the efficiency of vortex structured flow formation. The calculations were based on the Navier-Stokes equations for turbulent airflow and methods of free turbulent jet theory, which corresponds to approaches used in the analysis of aerodynamic and power plants of this type.

The geometry of the computational domain included a rectangular inlet channel, a smooth constriction, and a vortex formation region equipped with a system of guide channels. Various numbers of guide channels (2, 4, and 6) were considered, allowing for an analysis of the effect of the configuration on air jet acceleration, velocity distribution, and vortex motion stability. The shape of the guide channels corresponded to a logarithmic spiral line, previously developed in accordance with the requirements for minimizing recirculation zones and the location of regions of maximum pressure gradient. The calculation was performed in a three-dimensional setting using the k–ε turbulence model. The grid was refined in the channel constriction zone and along the walls, allowing for the accurate reproduction of the boundary layer and zones of high velocity gradient. A second-order unsteady-state scheme was used to integrate the equations, ensuring that steady-state conditions were reached after a series of time steps. Figure 2 shows the change in the airflow velocity contour along the concentrator channel wall at various points in time, and Figure 3 shows the velocity vector field. As can be seen from the figures, the flow is turbulent, with the velocity increasing by a factor of 6 at the channel constriction and by a factor of 8 in the area of airflow vortex.

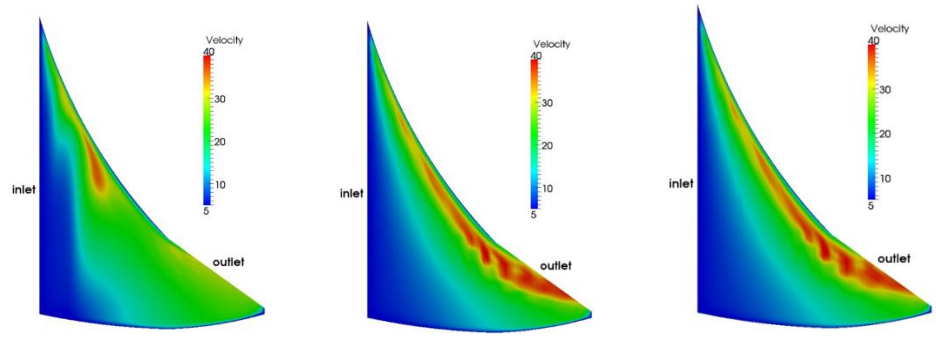


Figure 2. Velocity contours obtained at a blowing speed of 5 m/s at three different time points: t=0.005 s, t=0.038 s, and t=0.1 s

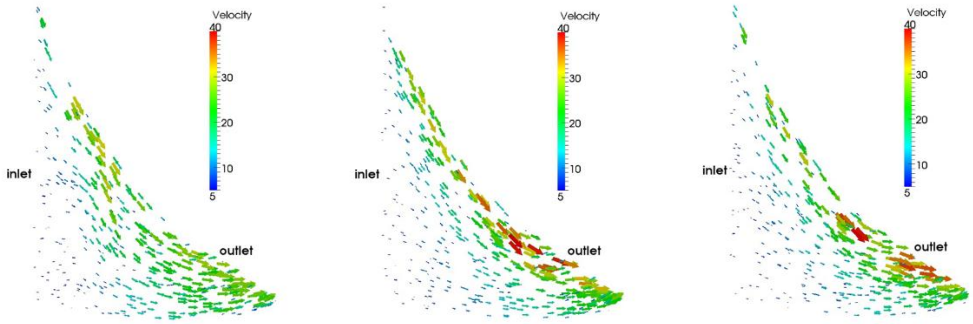


Figure 3. Velocity vector distributions obtained at a blowing speed of 5 m/s at three different time points: t=0.005 s, t=0.038 s, and t=0.1 s

A key aspect of the research is the numerical simulation results of vortex-turbulent flow in a six-channel vortex wind turbine. To thoroughly investigate air mass movement in the concentrator, two model problems are solved. The first problem involves simulating airflow in two concentrator channels at a constant velocity of 2 m/s, with the initial velocity vector field specified over the entire channel area. The second problem is devoted to a detailed simulation of airflow dynamics in a six-channel concentrator in the presence of wind flows from all six directions, which is not possible in practice. To solve these problems, initial and boundary conditions, as well as an inlet wind, were specified. The calculation results for the first model problem are shown in Figures 4 and 5 as isosurfaces for injection into two channels.

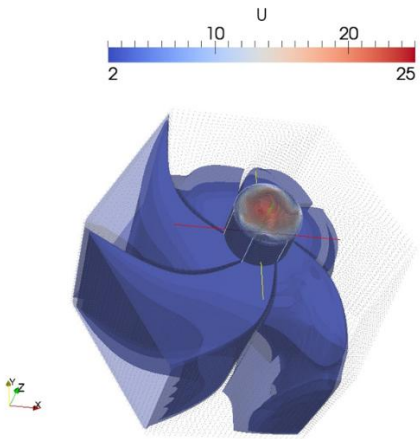


Figure 4. Two-channel inflow (westerly wind, 2 m/s, t=11 s): side oblique view of the velocity isosurfaces showing flow acceleration along the logarithmically curved guide surfaces

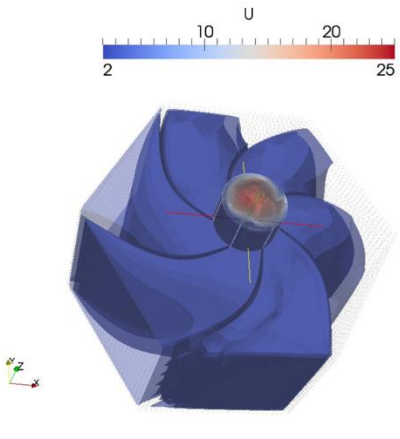


Figure 5. Two-channel inflow (westerly wind, 2 m/s, t=11 s): top view of the velocity isosurfaces showing the high-velocity vortex core formed in the central chamber

The second problem simulates flow in a six-channel vortex wind turbine with wind flows from all six directions. Figures 6 and 7 show the velocity isosurfaces for injection into the six concentrator channels at various time steps.

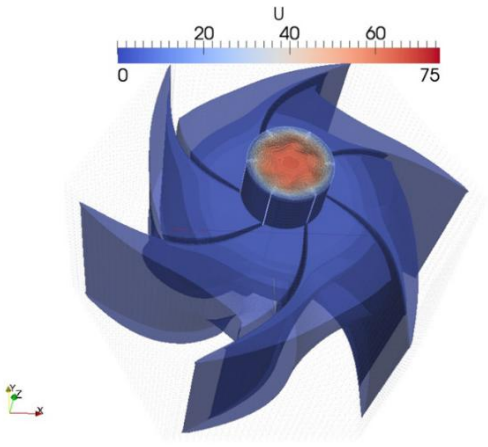


Figure 6. Six-channel inflow at the initial stage (t=8 s, inlet velocity 2 m/s): onset of vortex formation in the central chamber of the concentrator

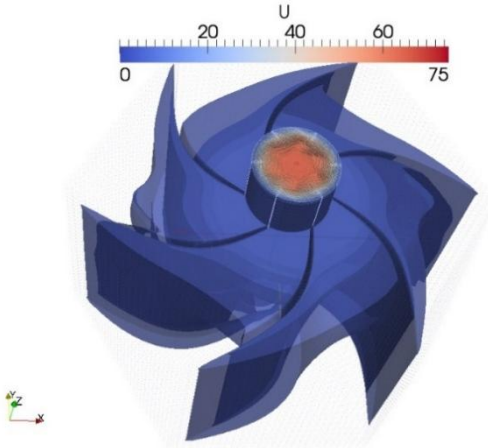


Figure 7. Six-channel inflow at the developed stage (t=29 s, inlet velocity 2 m/s): fully formed high-velocity vortex core at the concentrator outlet

Analysis of the calculated data shows that when blowing into two concentrator channels, the airflow velocity at the outlet increases by 10-12 times. The flow then reaches a steady state within 30 seconds. When examining the calculations for the second model problem, it can be concluded that the outlet velocity increases by 30 times in the presence of wind flows from all six directions. It should be noted that these studies are purely theoretical, as the initial velocity vector field was specified over all areas of the concentrator channels, and the airflow direction was set strictly toward the center of the concentrator from all six sides. However, numerical modeling of airflow movement in a wind turbine demonstrates the effectiveness of airflow concentrators. Experimental data from testing the six-channel concentrator design is required for further study of airflow behavior in the concentrator.

3. RESULTS AND DISCUSSION

The design of the vortex wind turbine was based on the results of numerical modeling of aerodynamic processes in the concentrator and wind wheel. The geometric parameters of the experimental model a concentrator diameter and height of 2000 mm and 1000 mm, a wind wheel diameter of 1072 mm, a stack height of 2000 mm, and a diameter of 500 mm were selected based on an analysis of the velocity distribution and flow patterns in various system configurations. Figure 8 shows a general sketch of the vortex wind turbine.

Simulation confirmed that optimizing the curved channels and blade profiles has a decisive impact on the formation of a stable vortex flow and an increase in exit velocity. Numerical experiments showed that when airflow is injected into two concentrator channels, the exit velocity increases severalfold, and a steady state is established within approximately 30 seconds. When airflow is simultaneously imposed through all six channels under the idealized multi-directional inflow condition, the numerical model predicts an outlet-velocity amplification of up to 30 times relative to the inlet velocity. This condition represents a theoretical upper-bound scenario rather than a realistic atmospheric operating state. These results demonstrate the high efficiency of using a multi-channel concentrator in a vortex wind turbine. Importantly, the numerical simulation was conducted under idealized conditions: the direction of the velocity vector was set strictly toward the center of the concentrator, and the velocity distribution across the inlet sections was uniform. Despite the theoretical nature of the calculations, the obtained data allows us to identify key patterns in the formation of vortex structures, determine the most favorable flow regimes, and select rational geometric design parameters. Based on the modeling results, several design options for curved blades and guide walls were proposed. Analysis of these options showed that the absence of flow overlap and a smooth change in wall curvature ensures the formation of a stable vortex core and minimizes aerodynamic losses. By comparing various geometries, the

optimal combination of blade shape and channel configuration was selected. Thus, the combination of mathematical modeling and parametric analysis enabled the creation of a viable vortex wind turbine design with increased wind energy conversion efficiency. The obtained results confirm the potential of concentrators and curved blade profiles for low- and medium-power wind turbines.

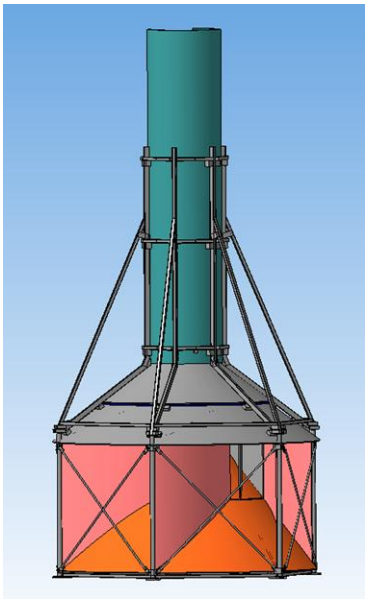


Figure 8. Sketch of a vortex wind turbine

To quantify the energy-conversion performance of the proposed six-channel vortex wind turbine, the aerodynamic characteristics were evaluated over a tip-speed ratio (TSR) range of 0.50–2.00. The analysis considered the rotor speed, aerodynamic torque, mechanical output power, and power coefficient (C_p) at an inlet wind velocity of 2 m/s. These parameters provide a more direct assessment of turbine performance than airflow-velocity amplification alone and allow the operating point associated with the highest energy conversion efficiency to be identified. The calculated performance characteristics are summarized in Table 1.

Table 1. Aerodynamic performance of the proposed six-channel vortex wind turbine at different TSRs

TSR, λ	Rotor speed (rpm)	Torque (N·m)	Output power (W)	C_p
0.50	17.8	0.34	0.64	0.13
0.75	26.7	0.39	1.09	0.22
1.00	35.6	0.39	1.46	0.29
1.25	44.5	0.33	1.55	0.31
1.50	53.4	0.26	1.35	0.27
1.75	62.4	0.18	1.01	0.20
2.00	71.3	0.11	0.64	0.13

As shown in Table 1, the power coefficient increased from 0.13 at a TSR of 0.50 to a maximum value of 0.31 at a TSR of 1.25, corresponding to a rotor speed of 44.5 rpm. At this operating point, the calculated torque and mechanical output power were 0.33 N·m and 1.55 W, respectively. Beyond the optimum TSR, C_p progressively decreased, reaching 0.13 at a TSR of 2.00, while the torque decreased to 0.11 N·m. The results therefore indicate the presence of a distinct optimum operating region and demonstrate that the aerodynamic flow modification produced by the concentrator can be expressed in terms of torque, mechanical power, and energy-conversion performance rather than airflow velocity alone. To define the rotational operating conditions used for the aerodynamic performance assessment, the rotor angular velocity and rotational speed were calculated for TSRs ranging from 0.50 to 2.00. The calculations were based on the proposed rotor radius of 0.536 m and a reference inlet wind velocity of 2 m/s. The corresponding operating parameters are presented in Table 2.

Table 2. Rotor kinematic parameters at different TSRs for an inlet wind velocity of 2 m/s

TSR	Angular velocity (rad/s)	Rotor speed (rpm)	Blade-tip speed (m/s)
0.50	1.866	17.8	1.00
0.75	2.799	26.7	1.50
1.00	3.731	35.6	2.00
1.25	4.664	44.5	2.50
1.50	5.597	53.4	3.00
1.75	6.530	62.4	3.50
2.00	7.463	71.3	4.00

As shown in Table 2, increasing the TSR from 0.50 to 2.00 results in a gradual increase in rotor speed from 17.8 to 71.3 rpm. The corresponding blade-tip velocity increases from 1.00 to 4.00 m/s, reflecting the direct relationship between TSR and rotor rotational speed. At a TSR of 1.25, which corresponds to the maximum estimated power coefficient reported in Table 1, the rotor operates at approximately 44.5 rpm with a blade-tip velocity of 2.50 m/s. This operating condition therefore represents the estimated optimum range for energy conversion under the considered inlet wind velocity of 2 m/s. Beyond this point, higher rotational speeds do not lead to an improvement in the estimated power coefficient, indicating that increasing TSR alone does not necessarily enhance turbine energy performance.

To further quantify the effect of the concentrator on airflow acceleration, the numerical results were compared for the two investigated inflow scenarios. The outlet velocity was derived from the reported velocity amplification ratio using the reference inlet velocity of 2 m/s. Table 3 summarizes the resulting velocity characteristics and distinguishes the directional two-channel case from the idealized simultaneous six-channel inflow condition.

Table 3. Reported airflow amplification under the investigated numerical inflow scenarios

Numerical scenario	V_{in} (m/s)	Reported amplification	Derived (V_{out}) (m/s)	Interpretation
Two-channel inflow	2.0	10–12×	20–24	Investigated directional inflow
Six-channel simultaneous inflow	2.0	30×	60	Idealized theoretical upper-bound condition

Table 3 shows that the two-channel inflow condition produced a velocity amplification of approximately 10–12 times, corresponding to a derived outlet velocity of 20–24 m/s for an inlet velocity of 2 m/s. Under the idealized six-channel simultaneous inflow condition, the reported amplification reached 30 times, corresponding to a theoretical outlet velocity of up to 60 m/s. However, this six-direction condition assumes that equal airflow enters simultaneously from all six directions and is directed toward the concentrator center; therefore, it should be interpreted as a theoretical upper-bound numerical scenario rather than as a directly attainable atmospheric operating condition. The comparison nevertheless demonstrates the strong sensitivity of vortex formation and local flow acceleration to the number and directional distribution of active concentrator channels.

Overall, the obtained results indicate that the aerodynamic effect of the proposed concentrator is associated not only with local airflow acceleration but also with the redistribution of the incoming flow into a pronounced tangential component around the rotor region. The observed C_p-TSR relationship demonstrates the existence of an optimum operating condition, with the maximum estimated power coefficient of 0.31 occurring at a TSR of 1.25, while the corresponding output power reaches 1.55 W. This behavior is generally consistent with the aerodynamic principles reported for diffuser-assisted and flow-concentrating wind turbines, where appropriate flow guidance can enhance the velocity available to the rotor and improve energy extraction [24], [25]. However, the proposed configuration differs from conventional diffuser-assisted systems because the logarithmically curved channels are intended to combine flow acceleration with controlled tangential redirection and vortex formation. The results should nevertheless be interpreted within the limitations of the present numerical framework, since the aerodynamic behavior was primarily evaluated using RANS-based CFD under controlled and partly idealized inflow conditions. Therefore, the reported performance demonstrates the aerodynamic potential of the proposed concept rather than experimentally verified full-scale turbine efficiency, and further wind-tunnel validation, higher-fidelity transient simulations, and structural–aerodynamic coupling studies are required to confirm its practical performance.

4. CONCLUSION

This study investigated the aerodynamic performance of a VAWT with a vortex flow, equipped with a multi-channel airflow concentrator formed by logarithmic curvature guide surfaces. The proposed

configuration was designed to combine airflow acceleration with controlled tangential redirection and vortex formation in the rotor region. Numerical analysis showed that the concentrator significantly modifies the internal flow field and promotes the formation of an organized rotational flow. Under the studied conditions of a two-channel inflow with an inlet velocity of 2 m/s, the recorded velocity increase was approximately 10–12 times, corresponding to an outlet velocity of 20–24 m/s. Under idealized conditions of simultaneous six-channel inflow, the numerical model predicted a theoretical upper increase of up to 30 times; this result should not be interpreted as a directly achievable value under natural atmospheric wind conditions.

The energy-performance assessment further showed that the aerodynamic benefit can be expressed in terms of rotor operating and energy-conversion parameters rather than airflow velocity alone. The maximum estimated power coefficient was C_p=0.31 at a TSR of 1.25, corresponding to a rotor speed of approximately 44.5 rpm, an aerodynamic torque of 0.33 N·m, and a mechanical output power of 1.55 W under the considered 2 m/s inlet condition. Increasing the TSR beyond 1.25 resulted in a progressive reduction in C_p, which decreased to 0.13 at TSR=2.00, indicating a distinct optimum operating region. These findings support the aerodynamic potential of the logarithmically curved multi-channel concentrator for compact vertical-axis wind-energy systems operating under low-wind-speed conditions.

Nevertheless, the present study has several limitations. The aerodynamic behavior was primarily evaluated using RANS-based CFD with the standard $k-\varepsilon$ turbulence model, and the investigated conditions included idealized inflow scenarios; therefore, the reported velocity amplification and estimated energy-performance parameters should not be regarded as experimentally verified full-scale turbine performance. In addition, transient vortex structures, detailed rotor wake interactions, structural deformation, and aeroelastic effects were not fully resolved within the present numerical framework. Future work will therefore focus on wind-tunnel testing of a scaled prototype to validate the predicted velocity field, torque, output power, and C_p–TSR characteristics. Higher-fidelity transient large-eddy simulation (LES) will be employed to improve the resolution of vortex formation and breakdown, while fluid structure interaction (FSI) analysis will be used to investigate aerodynamic loading, vibration, structural deformation, and possible aeroelastic effects. These developments will provide the experimental and multiphysics evidence required to assess the practical scalability and long-term performance of the proposed vortex wind turbine.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
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I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

[1] M. Essahraoui *et al.*, "Vertical axis wind turbines: A comprehensive critical review of aerodynamic theory, design configurations, performance analysis, and future perspectives," *Energies*, vol. 19, no. 11, p. 2544, 2026, doi: 10.3390/en19112544.

[2] U. Munir *et al.*, "Numerical analysis of off-axis wind and passive yaw control of an opposing airfoil paired motionless wind energy system," *Energy Conversion and Management: X*, p. 101207, 2025, doi: 10.1016/j.ecmx.2025.101207.

[3] T. Liang, C. Hu, W. Mo, and S. Watanabe, "A pressure-based actuator line approach for diffuser modeling in high-fidelity CFD of diffuser-augmented wind turbines," *Energy*, vol. 344, p. 140144, 2026, doi: 10.1016/j.energy.2026.140144.

[4] X. Xue *et al.*, "Advanced aerodynamic energy harvester based on the dual-cylinder vortex-induced vibration coupling effect," *Advanced Energy Materials*, vol. 15, no. 37, p. e02840, 2025, doi: 10.1002/aenm.202502840.

[5] L. Ibraheem *et al.*, "Enhancing energy yield in horizontal axis wind turbines via optimized tip speed ratio and intelligent power regulation techniques," *Terra Joule Journal*, vol. 1, no. 2, p. 6, 2025, doi: 10.64071/3080-5724.1014.

[6] Y. E. Qamch, A. A. Omar, K. Qaissi, W. Lahmili, and K. Bouchaala, "Bio-inspired owl airfoils for improved aerodynamic performance of small-scale wind turbines," in *Journal of Physics: Conference Series*, vol. 3224, no. 4, p. 042010, 2026, doi: 10.1088/1742-6596/3224/4/042010.

[7] A. Goyal, H. Biler, S. Schekman, M. Atkins, N. Cagney, and K. Sabnis, "Aerodynamic performance of a vertical-axis wind turbine at small scale: A design of experiments approach," in *Journal of Physics: Conference Series*, vol. 3224, no. 9, p. 092020, 2026, doi: 10.1088/1742-6596/3224/9/092020.

[8] İ. Özer, C. Tuncer, A. D. Alkan, L. Çolak, C. Şenol, and M. Çetinkaya, "Blade designs, generator systems, and contra-rotating architectures in vertical axis wind turbines: A review," *Electronic Letters on Science and Engineering*, vol. 22, no. 1, pp. 14–43, 2026.

[9] Y. R. Chen, H. Xiao, and H. Gan, "Resonance stability analysis method for power systems with high proportion of renewable energy," *IEEE Access*, vol. 14, pp. 78601–78613, 2026, doi: 10.1109/ACCESS.2026.3696016.

[10] T. Boutabba *et al.*, "Design of a small wind turbine emulator for testing power converters using dSPACE 1104," *International Journal of Robotics and Control Systems*, vol. 5, no. 2, pp. 698–712, 2025, doi: 10.31763/ijrcs.v5i2.1685.

[11] S. N. VB, S. S. Pillai, and P. PS, "Numerical simulation on the dynamic characteristics of VAWT with different cavity layouts," *International Journal of Numerical Methods for Heat & Fluid Flow*, vol. 35, no. 10, pp. 3605–3635, 2025, doi: 10.1108/HFF-10-2024-0803.

[12] H. F. Khaleel, R. N. Al-Kaby, and H. K. Rashid, "Aerodynamic performance optimisation of a Savonius VAWT for traffic wind energy harvesting," *African Journal of Applied Research*, vol. 12, no. 3, pp. 315–340, 2026, doi: 10.26437/qvvjrq90.

[13] A. Pandele, B. O. Duran, D. M. Preda, and G. Voicu, "Review of experimental research investigations and the working principle of small vertical axis wind turbines," *INMATEH—Agricultural Engineering*, vol. 76, no. 2, pp. 282–307, 2025, doi: 10.35633/inmateh-76-25.

[14] R. S. Vieira, A. Pavlovic, C. Fragassa, E. D. dos Santos, and A. P. Petry, "Complexity-aware design analysis of the efficiency in Darrieus vertical axis wind turbines," *Journal of Applied and Computational Mechanics*, vol. 11, no. 1, pp. 264–273, 2025, doi: 10.22055/jacm.2024.46304.4496.

[15] Y. Ohya and T. Karasudani, "A shrouded wind turbine generating high output power with wind-lens technology," *Energies*, vol. 3, no. 4, pp. 634–649, 2010, doi: 10.3390/en3040634.

[16] K. Abe and Y. Ohya, "An investigation of flow fields around flanged diffusers using CFD," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 92, no. 3–4, pp. 315–330, 2004, doi: 10.1016/j.jweia.2003.12.003.

[17] K. Abe *et al.*, "Experimental and numerical investigations of flow fields behind a small wind turbine with a flanged diffuser," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 93, no. 12, pp. 951–970, 2005, doi: 10.1016/j.jweia.2005.09.003.

[18] A. A. Yerzhan, Z. K. Kuralbayev, and G. D. Musapirova, "Solution of the problem of transient process in the circuit, whose nonlinear element I-V characteristic is a polynomial," *Life Science Journal*, vol. 11, no. S5, pp. 176–182, 2014.

[19] R. Nobile, M. Vahdati, J. F. Barlow, and A. Mewburn-Crook, "Unsteady flow simulation of a vertical axis augmented wind turbine: A two-dimensional study," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 125, pp. 168–179, 2014, doi: 10.1016/j.jweia.2013.12.005.

[20] S. A. Bahtaev, G. V. Bochkareva, and G. D. Musapirova, "Non-contact measurement meters of micro-sizes on coronary discharge," *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences*, vol. 4, no. 424, pp. 208–218, 2017.

[21] M. P. van der Laan, A. M. Forsting, and P. E. Réthoré, "A computational fluid dynamics surrogate model for wind turbine interaction including atmospheric stability," *Wind Energy Science*, vol. 11, no. 7, pp. 2647–2668, 2026, doi: 10.5194/wes-11-2647-2026.

[22] X. Chen, H. Zhang, Z. Zhang, Z. Shao, R. Ying, and X. Liu, "A three-dimensional analytical model for wind turbine wakes from near to far field: Incorporating atmospheric stability effects," *Energies*, vol. 19, no. 2, p. 467, 2026, doi: 10.3390/en19020467.

[23] J. C. Risco, M. P. van der Laan, M. M. Pedersen, A. Meyer Forsting, and P. E. Réthoré, "A RANS-based surrogate model for simulating wind turbine interaction," in *Journal of Physics: Conference Series*, vol. 2505, no. 1, p. 012016, 2023, doi: 10.1088/1742-6596/2505/1/012016.

[24] S. D. Karmakar and H. Chattopadhyay, "Numerical investigation of duct augmented vertical axis wind turbine with cambered airfoils," *Journal of Fluids Engineering*, vol. 147, no. 5, p. 051204, 2025, doi: 10.1115/1.4067276.

[25] G. M. Jorge-Saúl and E. C. Ernesto, "A systematic review of technological strategies to improve self-starting in H-type Darrieus VAWT," *Sustainability*, vol. 17, no. 17, p. 7878, 2025, doi: 10.3390/su17177878.

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