

DOUBLE ROTATION WIND TURBINE

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Abstract. The study evaluates the efficiency of Lenz-type vertical-axis wind turbines (VAWTs), which offer potential advantages for small-scale and urban applications due to their simplicity, low noise, and ability to capture wind from any direction. The Lenz turbine, characterized by its distinctively curved blades, is designed to optimize the lift-to-drag ratio, potentially enhancing energy capture compared to traditional Savonius or Darrieus designs. This research employs computational fluid dynamics (CFD) methods to assess the aerodynamic performance and energy efficiency of the Lenz turbine. 2D CFD simulations were performed using ANSYS Fluent to analyze airflow patterns and pressure distributions around the turbine blades, providing deeper insights into the aerodynamic interactions. Results indicated that the Lenz turbine exhibited higher efficiency at lower wind speeds compared to conventional designs, achieving a peak power coefficient of 0.3, which is notably high for VAWTs. The Double Rotation Wind Turbine innovation aims to create a wind energy conversion system of the vertical wind turbine type that uses the Lenz profile for the blades. The turbine has as its main novelty the overlapping arrangement of the two rotors, which rotate in opposite directions, thus obtaining a double speed at the electric generator. The combination of lift and drag forces, optimized by the blade curvature, contributed to this performance enhancement. Additionally, the turbine demonstrated robust self-starting capabilities and maintained stable operation in fluctuating wind conditions. The study concludes that the Double Rotation Lenz-type turbines can be a viable option for decentralized energy generation in urban environments, especially in regions with moderate wind resources.

Keywords: wind turbine, Lenz, numerical simulation, vorticity magnitude, tip speed ratio.

Introduction

Wind turbines are a high-performance technology for harnessing wind energy, and quantifying their efficiency is crucial to enhance performance and reduce energy costs. As the demand for renewable energy increases, wind energy is emerging as a dominant force in the world energy mix [1].

The classical theory offers a simplified analytical approach to determine the efficiency of wind turbines basically based on Betz Law and momentum theory [2]. It makes simplifying assumptions and fails to accurately depict complex aerodynamic phenomena such as turbulence and eddy interactions.

Vertical Axis Wind Turbines (VAWTs) have been investigated as an alternative to Horizontal Axis Wind Turbines (HAWTs) due to their potential advantages in urban and turbulent wind setting. VAWTs perform better in changing wind conditions because their blades can catch wind from all directions. The Darrieus and Savonius designs are among the most extensively researched VAWTs, having different aerodynamic properties and efficiency.

Anton Lenz designed the Lenz type VAWT, which has a distinctive blade layout that distinguishes it from more typical designs. The authors of [3] conducted a basic study of the Lenz type VAWT, highlighting its potential benefits in terms of efficiency and operational stability. The Lenz type employs blades organized to efficiently harness wind energy while avoiding some of the difficulties associated with other VAWT designs, such as turbulence and drag [4].

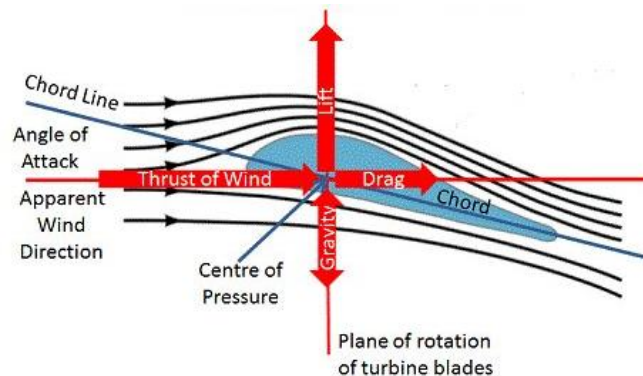


Fig. 1. Aerodynamic lift and drag force on the blade [5]

In Figure 1 are illustrated the lift and drag forces on wind turbine blade and how the airfoil shape and direction of the wind produce torque for power production. The wind strikes the blade at an angle of attack to the chord line (a straight line connecting the leading and trailing edges). This encounter generates two main aerodynamic forces: lift perpendicular to the wind direction (this is the main force responsible for spinning the blade) and drag in the same direction as the wind and opposing the movement of the blade.

The wind drag force manifests itself as a horizontal force component and one that assists in energy extraction. Even though the point of pressure is the point upon which the resultant aerodynamic force acts, gravity and the plane along which the turbine revolves are incorporated to place the forces the turbine feels when rotating into perspective.

Computational Fluid Dynamics (CFD) is a numerical method to simulate fluid flow and evaluate in detail the aerodynamic performance of wind turbines. CFD is different from BEM and classical theory because it accounts for intricate effects such as vortex effects, turbulence, and flow separation. The Navier-Stokes equations are the governing equations for the simulation of CFD, which describe the motion of fluids:

$$\rho \left(\frac{\partial v}{\partial t} + v \cdot \nabla v \right) = -\nabla p + \mu \nabla^2 v + f, \quad (1)$$

where v – fluid velocity field,
 ρ – fluid density,
 p – pressure,
 μ – dynamic viscosity,
 f – body forces, such as gravity.

CFD simulations allow for detailed, high-resolution modelling of the interactions between wind turbine blades and the wind, providing insights into blade shape optimization, turbine spacing, and the effects of vortex interaction [5-7]. The image below shows a computational fluid dynamics (CFD) simulation showing the magnitude of vorticity around a wind turbine rotor. The colour scale on the left indicates the magnitude of vorticity (in s^{-1}), from blue (low) to red (high). The circular boundary represents the area swept by the rotor, with the turbine hub at the centre. Regions of high vorticity (yellow, red) appear near the blade tips and behind them, indicating strong vortex shedding - typical of rotating blades. The downstream structure behind the rotor exhibits complex flow interactions that are crucial for understanding trailing losses, turbine efficiency, and turbine spacing in wind farms. These flow patterns are important in evaluating aerodynamic performance and in load predictions.

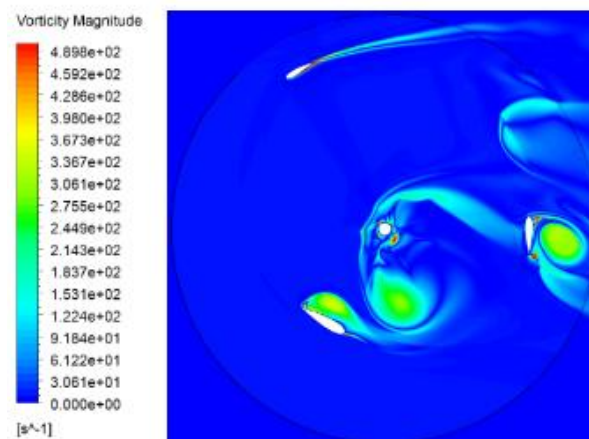


Fig. 2. CFD simulation showing wind flow over turbine blades [3]

Recent advances in wind turbine performance evaluation have led to the development of hybrid models, which combine the advantages of BEM theory and CFD simulations. These hybrid models allow for rapid performance estimates (from BEM) while providing accurate aerodynamic analysis (from CFD). In addition, Artificial Intelligence (AI) [8] and Machine Learning (ML) [9] are used to analyze large data sets, predict turbine performance, and optimize operational parameters. CFD allows

the prediction of aerodynamic forces on wind turbine blades, including lift and drag [10], [11]. The main challenge in wind turbine CFD is to capture the effects of turbulence, the transient nature of the wind, and the interaction of the rotating turbine blades with the wind. Fig. 3 illustrates the computational grid used to simulate the flow over the airfoil of a wind turbine blade, showing several zoom levels from the domain scale to the blade surface. The global grid view (a) shows the overall computational domain, with a fine grid resolution concentrated around the airfoil (centre) and coarser cells in the opposite direction. This is a typical grid structure, designed to save computational resources. The in-focus region (b) is a zoomed-in view of the refined area surrounding the airfoil. A tighter grid grouping can be observed, especially where accurate flow prediction (e.g., vortex generation) is crucial. The airfoil neighbourhood (c) shows unstructured grid elements around the airfoil, capturing the complex boundary layer behaviour and flow separation zones, while the airfoil surface grid (d) is a further zoom in close to the airfoil surface with dense triangular grid elements, essential for resolving the boundary layer flow. Finally, the LE and TE insets show close-ups of the leading edge (LE) and trailing edge (TE), which feature an extremely fine grid – essential for accurate modelling of pressure gradients and flow separation.

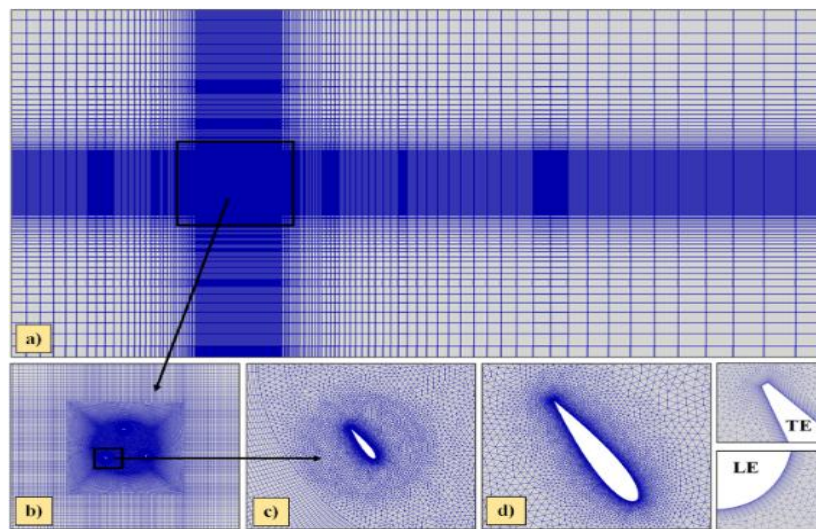


Fig. 3. **Hybrid computational grid for a vertical axis wind turbine of type H:** a – structured stationary domain; b – blocks around the rotational domain; c – fine unstructured grids inside the rotational domain; d – grid density on the blade surfaces, leading edge (LE) and trailing edge (TE), [12]

In this article, the efficiency of a new vertical axis wind turbine configuration consisting of two counter-rotating Lenz-type wind turbines which is tested in a wind tunnel was numerically analyzed. The analysis was performed using CFD methods.

Materials and methods

For the development of the counter-rotating vertical axis turbine, its operating parameters were established. This wind turbine is vertical axis and it is of the Lenz type [4], based on the drag force. The system of vertical axis wind turbines with dual counter-rotating rotor (Fig. 4), consisting of an upper rotor (1) formed by a set of Lenz-2 type blades (2), which rotates in one direction and a lower rotor (13) with a second set of Lenz-2 type blades [3] (11), mounted coaxially and rotating in the opposite direction, having coaxial counter-rotating axes (4) which allow the independent rotation of the two sets of blades, characterized in that the coaxial counter-rotating axes (4) are connected to a double-rotation electric generator (6) which stator and rotor rotate in opposite directions to obtain a double relative speed, thus optimizing the mechanical conversion into electricity and which is provided with a conductive slip ring with inductive coupling (8) which makes possible the contactless transfer of electrical energy from the generator to the electrical box on the support being fixed to the turbine support pole (12) by means of a support flange (7) comprising vibration damping mechanisms (3) and (10) on which UFC type oscillating bearings are mounted, fixed to the turbine support column (12) by means of support flanges (5) and (9), to reduce mechanical stresses.

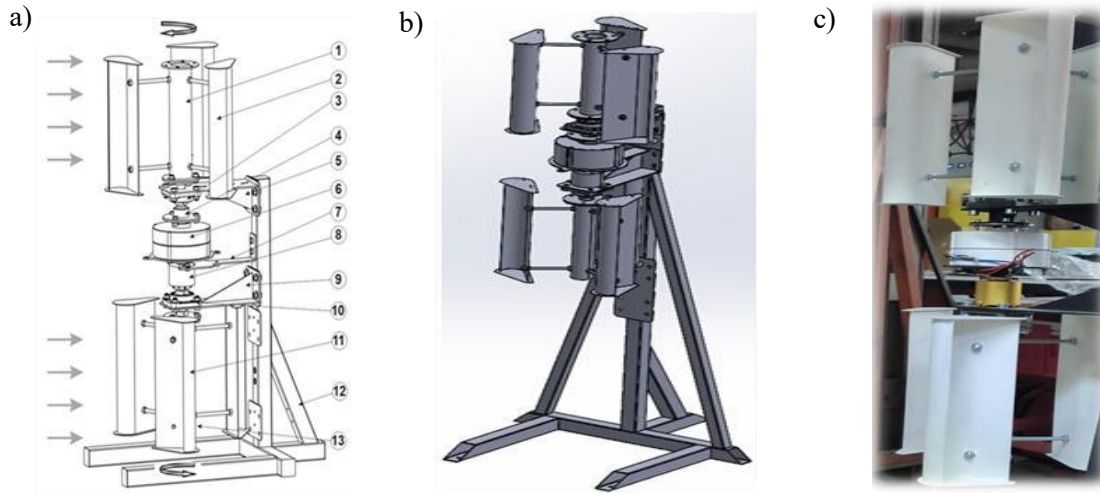


Fig. 4. CAD model and wind turbine Lenz type counter-rotating: a – wireframe view; b – 3D model; c – physical object

The power coefficient (performance) C_p is determined from the wind power at the turbine shaft. The equations below represent the formula for estimating the power of a wind turbine.

$$P_{wind} = \frac{1}{2} \rho \cdot S \cdot V_{\infty}^3 \cdot C_p, \tag{3}$$

where P_{wind} – wind power;
 ρ – air density, $1.225 \text{ kg}\cdot\text{m}^{-3}$;
 S – reference surface, m^2 ;
 V_{∞} – wind speed;
 C_p – power coefficient.

C_{pT} represents the power coefficient (turbine):

$$C_{pT} = \frac{P_T}{P_{wind}} = \frac{M \cdot \omega}{\frac{1}{2} \rho S V_{\infty}^3} = \frac{\frac{1}{2} \rho S V_{\infty}^2 L C_m \omega}{\frac{1}{2} \rho S V_{\infty}^3} = C_m \frac{L \cdot \omega}{V_{\infty}} = C_m \cdot \lambda < 0.593, \tag{4}$$

where P_T – turbine mechanical power from P_{wind} (available wind power);
 M – torque (moment);
 ω – angular velocity;
 C_m – torque coefficient;
 L – characteristic length, defined as the diameter or chord depending on formulation, (L = Radius), but in my equation for VAWT it acts as the moment arm;
 λ – tip speed ratio (TSR).

To determine the turbine blade chord length, the relative solidity of the turbine rotor radius was expressed, resulting in the parameters in Table 1.

Table 1

Operating parameters for vertical axis wind turbine

TSR	$\omega, \text{rad}\cdot\text{s}^{-1}$	$\Delta t, \text{s (2 deg)}$	N, rpm
0.2	16	0.002182	152.788746
0.4	32	0.001091	305.577491
0.6	48	0.000727	458.366237
0.8	64	0.000545	611.154982
1.0	80	0.000436	763.943728
1.2	96	0.000364	916.732473

Constant values: for the wind turbine: diameter $D = 0.3$ m, height $H = 0.6$ m, $c = 0.12$ m, $N = 3$ (blade number); wind speed $v = 12$ m·s⁻¹.

Testing in wind tunnel

For the Lenz VAWT, C_p is not constant, but strongly depends on TSR, in the test campaign we started from calibrating the demonstrator with that of the CFD model. The theoretical operating parameters for the vertical axis wind turbine are presented in Table 1, according to which we have turbine speeds corresponding to various wind values. Turbine was experimentally tested in a wind tunnel (Fig. 5, 6). For adjustment, the wind speed in the tunnel was fixed and the electrical loads of the consumer were varied to reach the number of speeds corresponding to the TSR curves. Using calibrated measuring devices, the following are determined: rotation speeds, shaft torque and number of revolutions per minute.

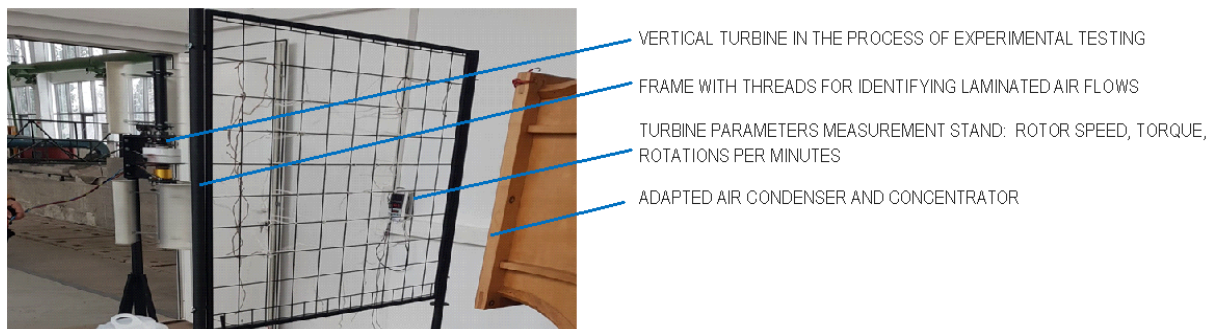


Fig. 5. Wind turbine being tested



Fig. 6. General view of the wind tunnel stand

With the help of the frequency converter, predetermined values for the wind are obtained. Top speed ratio (TSR) was not imposed directly by controlling the wind speed, but by regulating the electrical load connected to the generator. This load-controlled method of control allows for the establishment of distinct operating modes for the same air flow speed. Loading the turbine with loads causes a current and a voltage at the generator terminals. The experimental stage included recording the measured values for the parameters: rotor speed, voltage and electric current, wind speed.

Results

In the post-testing stage of the wind tunnel testing data obtained were analyzed. The graphs (Fig. 7) represent the variation of the power coefficient C_p (a) and the mechanical torque (b) as functions of wind speed. On the X axis is represented the wind, on the Y axis is represented the power and, respectively, the torque coefficient (C_p), which measures the momentum generated in relation to the available wind energy. Each curve corresponds to a different TSR value, ranging from 0.4 to 1.

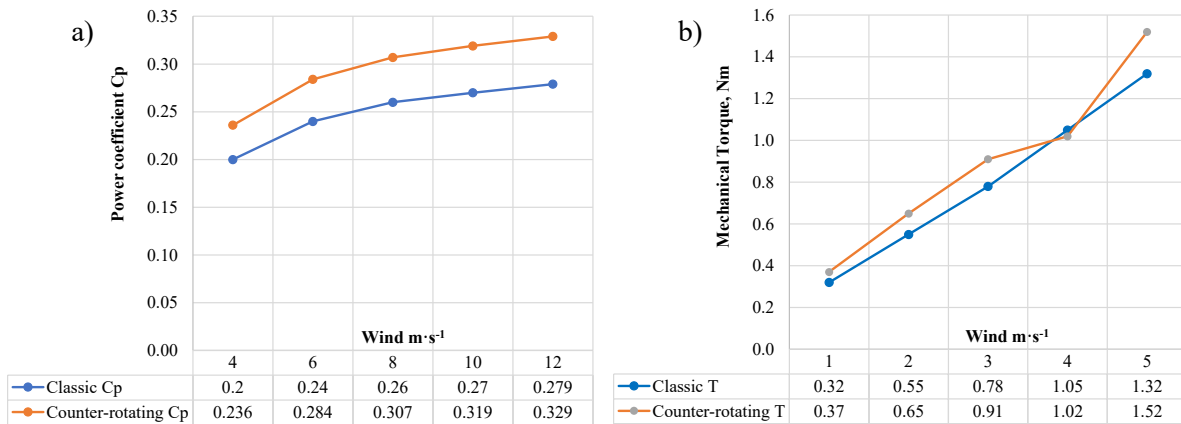


Fig. 7. Variation of the power coefficient C_p (a) and the mechanical torque (b) for different values of wind

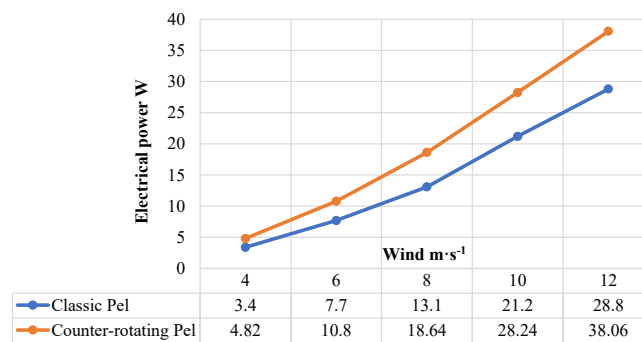


Fig. 8. Variation of electrical power at $TSR = 0.6$

Following this step, the turbine operating characteristic was obtained, which consists of the graphic representation for electrical power as a function (Fig. 8): green is the counter-rotating Lenz turbine, the red line represents the classical Lenz. On the X axis is represented the wind and on the Y axis is represented the electrical power (P_e) of the vertical axis wind turbine. TSR series (tip speed ratio 0.2; 0.4; 0.6; 0.8). At lower TSRs (0.2; 0.4), the power factor exhibits more pronounced peaks and troughs. As TSR increases, the peaks become less sharp and the curve smooths out. The highest C_t values appears to be close to TSRs of 0.2 and 0.4, indicating a good performance even at these low TSRs.

Conclusions

This research presented an investigation of a novel vertical axis wind turbine (VAWT) design featuring two Lenz-type turbines rotating in opposite directions. The objective of the study was the aerodynamic performance and flow features of this new configuration.

Experiments were conducted at a steady wind speed of 4-12 $m \cdot s^{-1}$ and a range of changing tip speed ratios (TSR) from 0.2 up to 1.

Torque fluctuation throughout a full revolution was analyzed for each TSR. The results show that under low TSRs (i.e., 0.2-0.4), the turbine experienced high torque fluctuations due to dominant unsteady flow effects and periodic flow separation. As TSR increased, the torque behaviour became stabilized, with the optimal performance at 0.6, which represented an optimal operating range for the configuration. The counter-rotation arrangement appeared to reduce the torque asymmetry and phase lag between the two turbines, resulting in a smoother mechanical output.

Experimental tests have demonstrated that the analyzed Lenz turbine presents the following main characteristics: starting capacity at low wind speeds, of approximately 4–6 $m \cdot s^{-1}$, due to the high mechanical torque developed by the rotor; a clear dependence of the delivered electric power on the air flow speed, with an evolution close to the theoretical cubic relationship; the existence of an optimal operating regime corresponding to a peak speed ratio (TSR) of approximately 0.6; obtaining a maximum power coefficient of 0.28 and 0.33 for the counter-rotating, competitive value for low-power vertical

axis wind turbines. These results confirm that the counter-rotating Lenz turbine is superior to the classic one and is suitable for use in decentralized applications, especially in areas with weak or moderate wind regimes.

In conclusion, the proposed turbine concept design has positive aerodynamic characteristics, including stable torque generation and constructive vortex interactions under the design operating conditions. The findings confirm the feasibility of the configuration as an efficient and compact wind energy product for distributed power systems, particularly for variable direction and moderate wind speed conditions.

Author contributions

This article represents the subject of Adrian PANDELE's Doctoral thesis, the contributions of the other authors are: Bogdan Ovidiu DURAN, CAD design and simulation, Dragos Mihail PREDA-model execution and experimental tests, Gheorghe VOICU – coordinating teacher.

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