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Utilization Of Wind Turbine Educational Kit as a Tool For Meaningful Learning

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Abstract

With the advent of the internet, access to information has become very rapid, consequently causing difficulties in assimilation and meaningful learning. Active methodologies aim to alter students' perceptions, allowing them to take the center stage in learning and favor meaningful learning. This article presents an evaluation of wind turbine kits used in the wind energy discipline of the Energy Engineering Course at the Faculty of Engineering and Sciences (FEC/UNESP), Rosana Campus, as a technological and experimental tool for knowledge construction. The objective of this work is to present control methods and the influence of blade profile and number on wind turbine performance, and shed light on the fact that allowing empirical activities during the learning process can significantly contribute to student education, whether in higher education or other learning phases. It is observed that an increase in the number of blades (testing two, three, and six blades) increases the power generated by the wind turbine, and altering the angle of attack can either break the turbine or at intermediate angles (28°), favoring energy generation. At the end of the process, it was observed that the use of commercial educational kits allowed students to intuitively explore the configurations of a wind turbine, increasing curiosity and their ability to assimilate theory. Therefore, the application of commercial kits or test prototypes developed within educational institutions is strongly recommended, as they facilitate meaningful learning in student education.

Keywords

Meaningful Learning — Wind Turbine Kit — Engineering Course — Energy Generation.

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1. Introduction

Amid globalization and technological advancements, we are increasingly dependent on electrical energy, whether at an industrial, commercial, or residential level. This reflects a concern among countries in creating new and efficient forms of energy generation based on renewable sources. According to the Brazilian Energy Balance (BEB) of 2022 [1], the installed generation capacity (measured in GW) grew by 3.9%, indicating an expansion in the demand for electrical energy. Wind energy represented 11% of the share of sources in the installed capacity. Furthermore, from 1970 to 2021, the Domestic Electricity Energy Supply (DEES) has increased from 45.7 to 679.2 TWh, showing an almost 15-fold increase in the supply of electrical energy within the national territory.

The growing global concern about environmental and energy-related factors has led to conferences and world meetings discussing how to address these issues. Aligned with the goals of the UN 2030 Agenda, which proposes 17 objectives to be followed and implemented by 2030 for a planet closely linked to Sustainable Development [2], the initiative to decouple fossil fuels as a global energy matrix has become a focus of investment. Nevertheless, fossil fuels continue to dominate the majority of investments and studies, owing to their widespread applicability and significant role in global goods and services [3]. Figure 1 illustrates the 17 objectives proposed by the UN in 2015 for the 2030 Agenda for Sustainable Development.

Figure 1. UN 2030 Agenda [2].

According to Junior [4], the overarching goal of all energy policies is to generate stability and socioeconomic development in society through regional structuring. He added that the creation of an energy policy is conditioned by the role of the state. Therefore, the development of an electric market focused on renewable energies with a solid foundation in sustainability concepts depends on the applicable public policies created by the state.

In this context, public policies such as Chapter VI in the Constitution of the Federative Republic of Brazil [5] are dedicated to the Environment and Law No. 9.795/99 [6], known as the National Environmental Education Project (PNEA), envision the democratization of environmental education. Additionally, the Ministry of Mines and Energy, in Law No. 10,438/2002 [6], created a Program for the Incentive of Alternative Sources of Electric Energy, encouraging autonomous enterprises to participate in renewable sources, and connecting them to the National Interconnected System (SIN). With Resolution No. 482/2012, the National Agency of Electric Energy (ANEEL) [7] regularized consumer access to small-scale renewable sources, such as micro- and mini-generation, incorporating a Distributed Generation (GD) system, which is based on an electrical compensation system that provides consumers with electricity credits that can be used later when surplus generation is fed into the grid, strengthened by the creation of the Distributed Generation Development Program (ProGD) established by ANEEL in 2015 [8–10].

According to Krasilchik [11], education should be structured in what is known as contextualized education, introducing the student to a combination of theoretical knowledge and practical methodologies, and facilitating learning through experiences closer to the situations they will encounter in the future [11]. Another factor that supports Myriam's argument is the perspective that knowledge comes from a generalized context and tends to unfold through the construction of a structured didactic sequence based on predefined pedagogical objectives [12].

Furthermore, according to the learning pyramid model structured by American psychiatrist William Glasser, first applied in 1946 by American Professor Edgar Dale, which is based on a segmented pyramid scheme of pedagogical study goals, starting at the top and unfolding to the base, showing the percentage of learning with each step. Figure 2 illustrates the scheme of the Glasser pyramid.

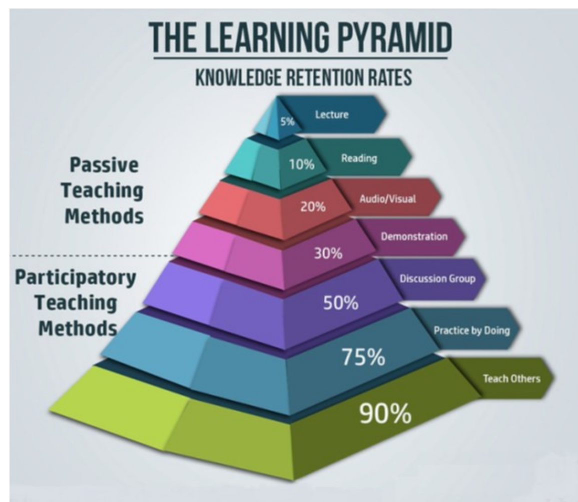

Figure 2. William Glasser's pyramid [13].

The presented model shows that within the active learning zone, the "Practice" segment is represented as one of the most important zones for study development. Therefore, analyzing the performance of a practical kit indicates its potential for use in developing the learning curve of students in elementary and higher education.

These facts align with the development of active methodologies that promote autonomy and the reconstruction of knowledge by students, placing them as protagonists and culminating in meaningful learning. These methodologies include problem-based learning, team-based learning, gamification, hybrid teaching (such as flipped classrooms), and case studies [14, 15].

Many studies have promoted the development of practical kits for educational purposes. The National Service for Industrial Training (SENAI) extensively studies this learning approach, as presented by Queiroz and Amorim Neto [16],

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with the development of a kit focused on basic engineering disciplines involving experimental physics. The procedure was based on the use of 2D and 3D geometric modeling software using CAD programming. Through modeling and construction of the equipment scale, computational simulation methods can be considered for data validation before creating a prototype. With the physical creation of the experiments, data were obtained. Thus, the kit could be tested, and with learning collections, deductions and comparisons of the results of using or not using a kit in this category could be made. Paraguay [17], also from SENAI, applied the development of didactic kits in the Bahia region in the logistics field using tools such as Kansei Engineering (KE) and the Permatus method (perception of materials by users), pointing out the importance of practical training combined with the presence of the teacher in student formation.

Júnior et al. [18] at the Federal Institute of Alagoas (IFAL) also conducted a study in this field, developing a project focused on electrical engineering with the development of a didactic kit for power electronics, using discarded materials from the college to develop a controlled rectifier. For the development of the kits, research was carried out on the survey of construction materials, the use of Proteus software to size the operation of the device, and the elaboration of the prototype.

Other studies on the development of pedagogical kits with a focus on renewable energy were carried out at the Federal Institute of Rio Grande do Sul [19], focusing on improving basic education (High School) through the development of three experiments, each focusing on a type of renewable energy, using CAD software for modeling and 3D printers for prototype creation. The first experiment focused on wind energy, with the printing of a miniature vertical-axis wind turbine connected to a protoboard to form a circuit. The second experiment focused on hydropower, with the production of miniature PVC pipes connected to a small pump and mini-generator. The last experiment was conducted in the field of solar energy using 3D printing of the solar support for the photovoltaic panel. The study is constantly improving based on feedback from the students who participated in the experiment.

Costa et al. [20] presented at the IX Brazilian Solar Energy Congress (CBENS) the construction of a small electrical circuit using microcontrollers, with the purpose of using to use the principle of solar energy to pump water from a small reservoir.

The use of commercial practical kits also permeates teaching and learning, especially in automation, such as the use of LEGO® MINDSTORMS®, which has a wide range of applications and experiments. For example, providing contact with engineering concepts among high school students with measurements and data collection associated with sensors for information receptivity (sound, touch, light, ultrasonic), didactically, with intuitive material, not depending on advanced knowledge in programming languages [21]. LEGO® MINDSTORMS® also has applications in higher education in control and automation engineering colleges, for example, based on the theoretical content observed and acquired during the course to apply in practice using the LEGO® kit in automation processes [22].

Thus, the objective of this study was to provide meaningful learning through the use of wind turbine kits, allowing observation of the influence of the number of blades and angle of attack, as well as the aerodynamics due to different profiles of wind turbine blades on the power generated in the turbines.

2. Methodology

The adopted kit was the wind energy kit from Horizon®, with tests using different types of wind turbine blades, angles of attack, circuit resistance, and number of blades available (Figure 3). Three different blade profiles were used, varying the number of blades to 2, 3, and 6 and angles of attack of 6 °, 28°, and 50 °. The tests were conducted at the Wind Energy Laboratory of São Paulo State University (UNESP), School of Engineering and Sciences, Rosana, Brazil.

Figure 3. Horizon Energy Box (FCJJ-40) [23].

2.1 Experimental assembly

The experimental setup (Figure 4) was assembled according to the manufacturer's manual by connecting the wind turbine to a resistor. A fan was aligned with the turbine to simulate natural winds. Connections were made by linking the turbine and multimeter to a protoboard and measuring the electrical voltage and current.

The power supplied by air was initially calculated using the kinetic energy equation Eq. (1), and considering air at a constant density, Eq. (2), 1,2754 kg/m^3, where the volume (vol) is given in relation to the cross-sectional area, $A_{section}$,

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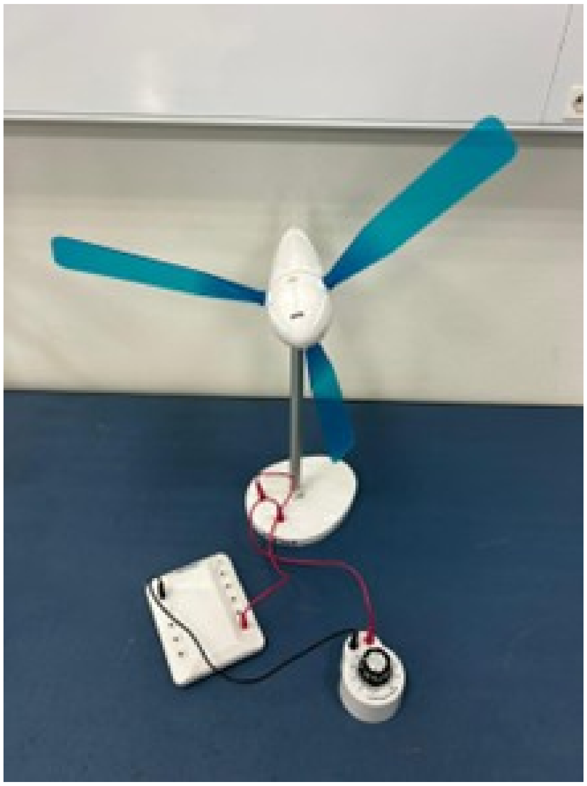

Figure 4. Experiment assembly. Author, 2024.

and the displacement in one dimension, x, Eq. (3). Thus, the supplied wind energy is given by Eq. (4), and dividing by the change in time, we obtain the power in Eq. (5).

$$E_c = \frac{1}{2} \cdot mv^2 \tag{1}$$

$$\rho = \frac{m}{vol} \Rightarrow m = \rho \cdot vol \tag{2}$$

$$vol = A_{\text{section}} \cdot x \tag{3}$$

$$E_c = \frac{1}{2} \cdot \rho_{ar} \cdot A_{\text{section}} x \cdot v^2 \tag{4}$$

$$P = \frac{1}{2} \cdot \rho_{ar} \cdot A_{\text{section}} v^3 \tag{5}$$

The wind speed was measured using an anemometer, and a velocity of v = 4.1 m/s. The average diameter of the blades was considered to be 37.5 cm, and the area is given by Eq. (6), with a value of A$_{section} = 0.1104m^2$.

$$A_{section} = \pi \cdot \frac{D^2}{4} \tag{6}$$

From Eq. (5) determines that the power delivered by the wind is P = 4.854 W. An electrical circuit was assembled to collect the results (Figure 5), where the real voltage source (ideal voltage source plus internal resistance) representing the entire wind turbine was connected in series with a rheostat (variable resistor fixed at 50).

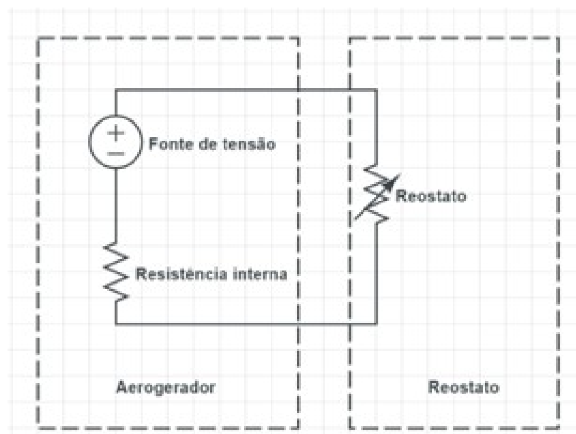

Figure 5. Electrical circuit representation. Author, 2024.

The measurements were performed using a digital multimeter, using the voltmeter and ammeter functions to determine the voltage drop across the rheostat for each resistance, thereby connecting it in parallel (Figure 6). To measure the voltage data, the circuit was willing in parallel to not reduce the voltage values, in the same way, to measure the current data, but the circuit was willing in series.

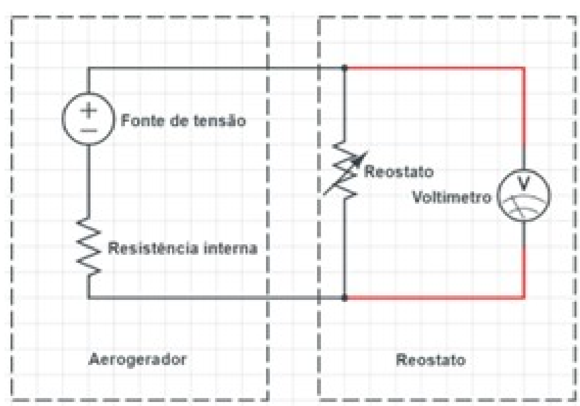

Figure 6. Association electrical circuit with voltmeter over a resistance Author, 2024.

The ammeter connection was connected in series to measure the current of the electrical circuit (Figure 7).

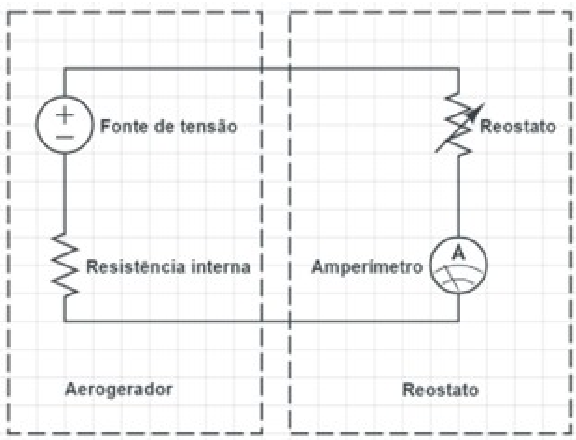

Figure 7. Association electrical circuit with ammeter over a resistance. Author, 2024.

After measuring the power generated for the three blade profiles by varying the number of blades (two, three, and six blades) and the angle of attack (6°, 28°, and 50°) with a resistance of 50 , the electrical power supplied to the resistor Eq. (7) is calculated as the product of the current passing through the circuit and the voltage difference across it, as represented by Eq. (7).

$$P[W] = v[V] \cdot i[A] \tag{7}$$

In Figure 8, the three types of wind turbine blades and the circuit assembly are visualized.

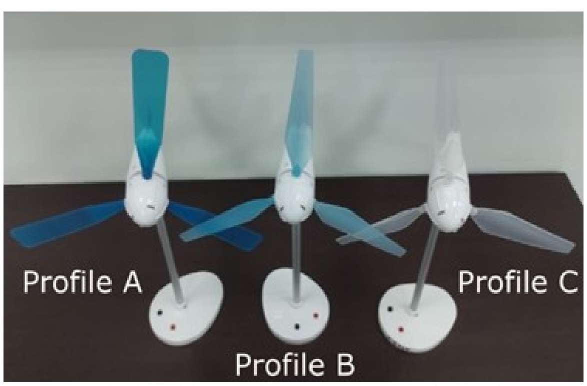

Figure 8. Wind turbines with the three profiles of blades. Author, 2024.

3. Results and Discussion

Based on the collected measurements and the calculation of electrical power, the power vs. Angle of Attack graphs were plotted (Figure 9).

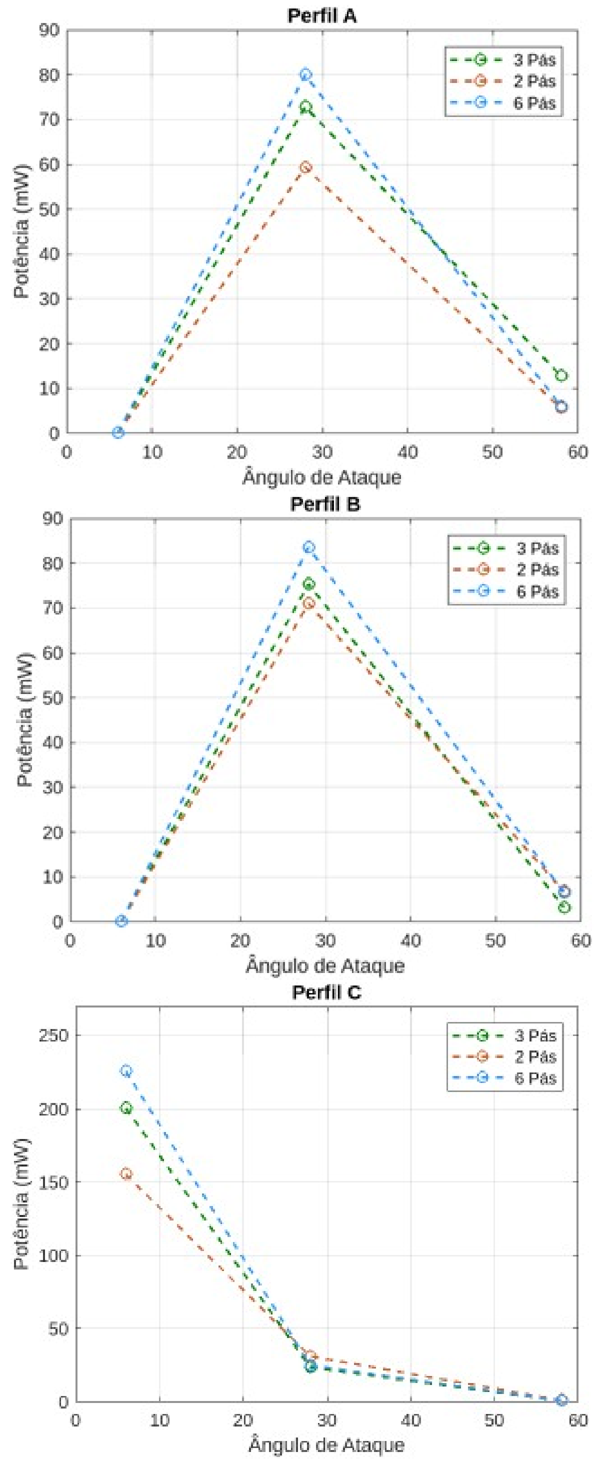

Figure 9. Power curve of profile (A), (B), (C) according to the tilt angle. Author, 2024.

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In profile A (Figure 9), regardless of the number of blades, for the smallest angle of attack of 6º, the turbine did not rotate, that is, it did not deliver any electrical power. For the configuration of 28º, the performance was much higher. For this angle of attack, the action of the lift force on the blades that promotes rotation is favored. For this angulation, it is possible to notice that the higher the number of blades, the greater the power generated by the wind turbine. For an angle of attack of 50º, the generated power was reduced again. This effect of changing the angle of attack for rotation control is used in wind turbines, described as pitch control. A similar evaluation was performed using blade profile B (Figure 9).

The behavior exhibited by this type of blade resembles that of profile A, showing only a slight variation in power when comparing configurations with three and two blades. Finally, the experiment was reproduced using blade profile C (Figure 9).

The behavior of blade profile C was different from that exhibited by the other profiles. In this case, it is noticeable that the higher the angle of attack, the lower the generated power. There were no significant differences when comparing angles of attack of 28º and 50º when changing the number of blades. However, for an angle of attack of 6º, there was an increase in the generated power proportional to the increase in the number of blades, reaching higher powers (between 150 and 250 mW) compared to profiles A (powers between 60 and 80 mW) and B (power between 70 and 80 mW).

Wind turbines with a large number of blades require a high starting torque. By reducing the number of blades and optimizing for three blades, the generated noise and required starting torque are reduced, allowing the use of smaller gearboxes (multipliers), and consequently obtaining lighter structures.

To better understand these results, it is necessary to conduct a study on the aerodynamics of the three types of profiles studied. The profiles are shown in Figure. 10.

Figure 10. Shape of each profile studied. Author, 2024.

Profile A (Figure 10 a) exhibited the worst performance in power generation owing to the lack of concavity in the blade profile, which worsens aerodynamics, resulting in increased drag force. Consequently, the number of rotations was lower, and smaller amounts of energy were generated. Profile B (Figure 10 b) presents a slight concavity, reducing the surface area and favoring airflow along the blade surface. This reduces the drag force, favoring the lift force action on the blades and consequently increasing turbine rotation. The unfavorable aerodynamics in these cases are overcome with increased angles of attack, allowing lift force action and consequently increasing the power generation. Finally, in the case of profile C, the concavity of the blade is increased, favoring air permeation and reducing air detachment from the surface, consequently decreasing vortex generation or turbulence after air passes through the turbine, and enhancing the lift force action responsible for producing rotation.

4. Conclusion

Through the study of the horizon kit, it was possible to understand the operating principle of a wind turbine, the influence of the number of blades, and the methods of rotation control. It was observed that increasing the number of blades increased the generated power; however, this was associated with an increase in the starting torque and noise generation. Changes in the angle of attack of the blades allowed for rotation control (preventing the turbine from rotating) and, depending on the blade profile, increased the power generation. Comparing the aerodynamics of different profiles, blades with greater concavity require smaller angles of attack, thus favoring rotation. Profiles A and B showed better performance with six blades at a 28º angle of attack, whereas profile C performed better with two blades at a 6º angle. The use of kits in experimental classes allows students to become protagonists in the construction of knowledge, facilitating, through observational means, an understanding of the process of energy conversion in horizontal-axis wind turbines.

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