AN INVESTIGATION OF THE EFFECTS OF WIND VELOCITY ON THE PERFORMANCE OF TURBINES AND GENERATORS

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Abstract

The objective of this study is to compare wind speed fluctuations at elevations of 4, 6, and 8 meters over the course of twenty-four hours. The analysis procedure aims to assess the disparity between generator and turbine velocities while operating load-free and with wind speed. The research findings indicate that the maximum wind speed of 3.3 m/s was observed at an altitude of 8 meters. Conversely, the minimum wind speed of approximately 2.4 m/s was measured at an altitude of 4 meters. Moreover, the turbine speed rises in the absence of a load, reaching a maximum speed of 3.9 meters per second. The results indicate notable disparities in wind speed and distinctions between turbines and generators, with an average rotational speed difference of 3.74 RPM. Further investigation in the fields of atmospheric science and renewable energy technology may be prompted by the new insights provided by these findings regarding wind dynamics and energy conversion at the study site. In the context of efficient energy conversion, the significance of the correlation between wind speed and generator rotation speed is underscored by the evaluation of generator performance via current and voltage measurements.

Keywords: wind velocity, generator, turbine velocity, speed

1. Introduction

Research and development efforts have focused on sustainable energy technologies like integrating wind turbines. Modern smart grids integrate renewable energy sources like wind power with modern communication, control, and information technologies [1]. Wind energy is intermittent and variable. Therefore, hybrid energy systems provide a reliable electrical supply [2]. These systems use hydro, solar PV, and wind turbines. Researchers have also investigated hybrid clean energy systems, which use energy storage devices and advanced energy management strategies to address intermittent power generation and wind power integration issues [3]. These advances show ongoing efforts to overcome hurdles and optimize wind energy capacity as part of the sustainable energy shift.

Scaling renewable energy requires wind turbines. They are necessary for switching to solar, hydro, renewable energy sources, and other sustainable solutions. An essential part of the renewable energy portfolio, wind power is clean, abundant, and becoming more competitive. Wind turbine technology has improved wind power generating efficiency and dependability, maximizing wind energy use [1]. Integration of wind turbines with intelligent grid infrastructure has increased renewable energy system efficiency [1]. Investors evaluating wind energy systems must carefully select wind turbines to optimize wind energy production [4]. Wind turbines are crucial to renewable energy development.

Utilizing wind power is possible with a wind turbine. Small-scale, Savonius, and inverse taper wind turbines exist. Small wind turbines can produce 500 watts or less. However, vertical axis Savonius wind turbines use drag forces to catch and deflect wind to generate power. Airfoil cross-sectional profiles are used to design inverse taper wind turbines, which grow toward the tip. These turbines generate clean, sustainable wind power [5][6]. Understanding the relationship between wind speed, turbine speed, and generator is crucial to wind turbine power

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generation. Wind speed affects turbine rotational speed and generator output. The generator's performance depends on its operating and ambient temperatures. The generator's output power is often governed by its rotor speed or frequency [7]. Induction generators use reactive power when wind speed drops below or increases above the cut-in speed [8].

Wind speed and electrical output affect starting torque and heat generation in a vertical axis wind turbine (VAWT) with a PMSG. Magnet skew and other approaches diminish starting torque [9]. Analyzing the association between crucial turbine operating metrics and fault types can also identify wind turbine generating system defects. PMI and LSSVM can perform this [10][11]. These results demonstrate the intricacy and interaction of wind speed, turbine speed, and generator in wind turbines.

The electrical grid has challenges when integrating wind turbines. Wind instability may cause power generation to varying, which is a significant issue. This intermittentity may require assistance matching energy supply and demand. Thus, grid operators need alternate power sources or energy storage to maintain grid stability [12]. Wind farms are scattered across different regions and must convey their electricity to populous areas, which can strain the grid infrastructure. Improvements and transmission line expenditures are often needed [13].

Wind energy's intermittent nature requires effective energy management and storage technology, a significant barrier to grid integration [3]. These limits underscore the need for advanced grid technology and energy management systems to fully utilize wind energy in transitioning to a more sustainable energy system. Wind turbine integration into the electrical grid may be solved in numerous ways. Hybrid energy systems may help. These systems use solar PV, hydro, and wind turbines to deliver reliable electricity [15]. Modern grid technology provides sophisticated management, communication, and information technologies to handle intermittent and unpredictable renewable energy sources like wind power [1].

Investors can use adaptive hybrid multi-criteria decision-making methods to maximize efficiency in choosing the finest wind turbines for onshore and offshore wind farm planning [16]. Energy management and storage technology like batteries may help integrate wind power into the power system and reduce its erratic nature [3]. These methods assist overcome wind turbine grid integration challenges, enabling a more dependable and ecologically beneficial energy supply.

Researchers have also been very interested in improving wind turbine technology. Renewable energy sources like wind turbines are significant, and their reliability and efficiency have improved. The efficiency of renewable energy systems has increased since smart grid infrastructure was added to wind turbines. The challenges in integrating wind turbines into the power grid are still substantial. Wind variability can result in irregular electricity production, necessitating efficient energy management tactics and energy storage innovations to uphold grid stability. Enhancing the electric network infrastructure is necessary to transmit electricity from wind farms to residential areas.

As a result, learning about energy management, storage technology, and how to connect power grids is very important for making the transition to a more eco-friendly energy system go more smoothly. Innovative approaches to overcoming obstacles to integrating wind turbine networks are proposed as part of this research, which seeks to increase knowledge of the intricate relationship between wind speed, wind turbines, and generators.

2. Method

The speed of the wind is the first factor in the wind turbine system, as it is this factor that may cause the fans in the ceiling to spin. Since the voltage generated by the ceiling fan motor is in the form of alternating current (AC), it must first undergo rectifying before entering the voltage and current accumulator. In order to maintain a constant voltage, a controller must receive the rectifier circuit's output voltage and current. The used accumulator operates at 12

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volts direct current (DC). The generator's output voltage must be equal to or slightly higher than 12 volts DC in order to charge the accumulator. A generator's current or voltage is directly proportional to its rotational speed.

Consequently, a controller is required to maintain the generator's output voltage at 12 volts DC or slightly higher. This is essential to ensure that the accumulator can be charged safely by the voltage output of the generator. The controller's voltage and current output influence the accumulator's charging period. The rate at which the accumulator is filled depends on the magnitude of the current generated and the output from the voltage regulator. This is true as long as the generator output voltage equals or slightly above 12 volts DC. The wholly charged accumulator must undergo voltage and current conversion through an inverter before providing power to AC loads or electrical devices operating on AC. Data gathering is conducted both under loaded and unloaded conditions.

The existing Savonius wind turbine was used as a basis for the development of the tool that was produced. Utilizing a ceiling fan motor as a generator that is capable of producing energy from the movement of the rotor is the method by which this instrument is constructed. The Savonius wind turbine frame and ceiling fan motor are depicted in **Fig.1** and **Fig.2**, respectively, in the design drawings.

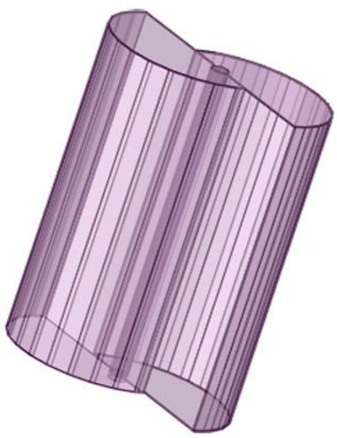

Figure 1. Dimension of The Frame

The process of retrieving data involves the utilization of a load, namely the connection of the ceiling fan motor to the adapter, battery, and inverter. Meanwhile, the ceiling fan motor remains unconnected to an adapter or any other device without a load. The data was gathered by employing a multimeter to quantify the power generated during the operation of the generator under wind conditions and by using a tachometer to measure the rotational speed (RPM) of the windmill.

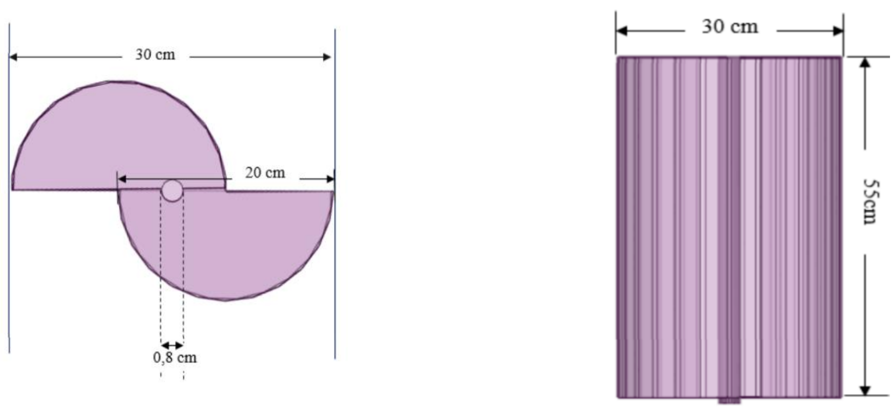

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Figure 2. The following is a dimensional framework drawing for a) blade dimensions and b) turbine dimensions.

A tachometer measures the rotation of the wind turbine and ceiling fan motor (generator). The ceiling fan motor generates alternating current (AC), and its output current and voltage may be measured using an avometer. The rectifier circuit receives the output of the ceiling fan motor as its input. The rectifier circuit converts alternating current (AC) and current into direct current (DC) voltage and current. Subsequently, the rectifier circuit's output is fed as input to the controller, where the voltage is regulated to charge the accumulator. AC load testing is conducted when the accumulator is disconnected from the wind turbine. An inverter converts the direct current (DC) voltage and current from the accumulator into alternating current (AC), rendering it suitable for electrical equipment.

3. Results And Discussion

The relationship between the speed and direction of wind has a diverse impact on several aspects of wind power generation. A thorough investigation has shed light on the intricate dynamics involved, showing that changes in wind direction at higher altitudes, known as directional wind shear, and differences in wind speed can significantly impact the efficiency of wind turbines. These shear events have been noticed to display a daily cycle, changing in various patterns as wind speeds increase.

Moreover, inquiries have emphasized the crucial significance of wind direction shear and speed shear in the suboptimal operation of turbines, especially during periods marked by sudden increases in energy demand. Significantly, cases with significant directional shear but moderate speed shear were shown to contribute to less-than-ideal performance. This effect becomes most noticeable during periods of increasing electrical consumption.

Furthermore, the relationship between wind speed and direction gets much more complex when considering the variation in wind direction at different heights. This is an important issue to consider when analyzing the performance of turbines. The variability of wind speed and wind direction throughout the area covered by the turbine blades is influenced by the vertical distribution of wind, also known as shear. This phenomenon can result in either suboptimal or superoptimal power generation, depending on the characteristics of the variations in the wind's vertical profile.

A fundamental requirement for the comprehension and optimization of wind energy generation is an all-encompassing comprehension of the complex interplay between wind speed and wind direction. This connection is crucial, substantially impacting wind turbines' overall efficiency and efficacy in harvesting renewable energy.

The nuances of wind speed were investigated by meticulously collecting a 24-hour dataset, which is depicted in **Fig. 3**. The dataset specifically examines variations in wind speed at height differentials of 4, 6, and 8 meters. The detailed study provides a convincing understanding of the changing patterns of wind behavior over the observation period.

Significantly, the highest recorded wind velocity of 3.3 m/s occurred during the third data collection period, as illustrated in **Fig. 3c)** The aforementioned peak velocity was measured from an altitude of 8 meters. Interestingly, a slight variation from the highest wind speed was seen at a height of 6 meters, measuring 3.2 m/s over the same period of data collection, as shown in **Fig. 3b)**. This slight difference highlights the complicated connection between wind speeds at various heights, suggesting a complex interaction of atmospheric elements.

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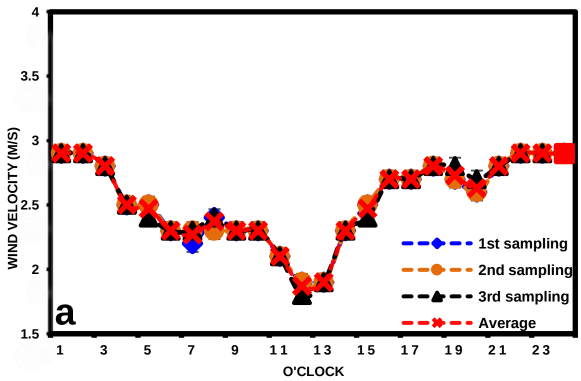
Simultaneously, at a lower altitude of 4 meters, the measured wind speed displayed a different pattern. The minimum wind speed recorded in this sample was around 2.4 m/s, providing insights into the significant differences in wind patterns at different altitudes, as shown in **Fig. 3a)**. The lower threshold of 4 meters serves as both a baseline for comparison and a crucial reference point for directing and informing future data gathering efforts. Clarifying these variations in wind speed based on height enhances our comprehension of the complex mechanics that influence wind patterns and emphasizes the importance of precise data gathering at different heights. This thorough research provides a basis for improving our understanding of wind behavior, allowing for more detailed and focused inquiries in atmospheric sciences.

The complex correlation between wind velocity and the dynamic interaction of turbine and generator speeds is crucial in efficiently using wind energy for electricity production. The intricate interplay is affected by several aspects, encompassing the turbine's intrinsic design attributes, the generator's effectiveness, and the existing loading circumstances. When the scenario is evaluated in the absence of demand, the turbine's operational efficiency is significantly impacted by its response to fluctuating wind velocities. During periods of low wind velocity, the turbine may face difficulties in attaining an ideal rotating speed to harness and transform wind power efficiently. As the velocity of the wind rises, the turbine is anticipated to adapt its speed, ideally achieving an optimal rotational velocity that maximizes the extraction of power from the wind resource at hand. Nevertheless, when the generator encounters little to no resistance, there is a potential danger of exceeding the optimal speed under extreme wind conditions. In order to reduce this danger and protect the turbine from potential harm, control systems are frequently incorporated to regulate the speed of the turbine.

Incorporating the process of loading into the equation profoundly modifies the dynamics. Once the generator is connected and a load is provided, the turbine must now face the extra resistance caused by the generator. This connection requires a careful equilibrium between the rotational velocity of the turbine and the electrical demand on the generator. In order to optimize the extraction of wind energy and meet the electrical load requirements, the turbine has to dynamically adapt its speed in response to the rising wind speed. The complex interaction between the turbine and generator during operation highlights the need for advanced control systems, which frequently incorporate pitch and yaw mechanisms. These systems are crucial for optimizing blade angles and rotor direction, ensuring the turbine performs at its best in different wind situations.



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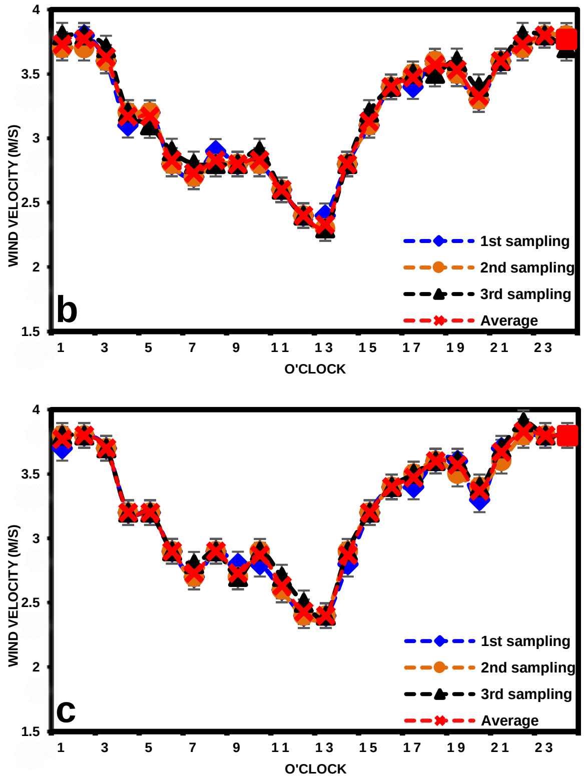

Figure 3. The wind velocity is recorded at three elevations: a) 4 meters, b) 6 meters, and c) 8 meters.

The speed differences between the generator and turbine, when loaded and unloaded, are shown in **Fig. 4**. The majority of the data indicate an elevation in turbine velocity when operating without a load. A direct correlation is observed when the rise in wind speed aligns with the speed of the turbine. **Fig. 4a)** demonstrates the disparity in turbine and generator speeds under loading and non-loading conditions at low wind speeds of 2.4 m/s. The observed difference is 3.4 RPM, with the non-loading speed measuring 93.2 RPM and the loading speed measuring 89.8 RPM. On the contrary, the greatest wind speed recorded was 3.9 m/s, resulting in a difference of 5.4 RPM. The unloaded value was estimated at 134.2 RPM, while the loaded value was 128.8 RPM. **Fig. 4c)** shows the disparity in turbine and generator speed between loading and non-loading conditions at low wind speeds, namely 2.5 m/s.

The observed difference is 3.4 RPM, with a non-loading speed of 93.2 RPM and a loading speed of 89.8 RPM. On the contrary, the greatest wind speed recorded is 3.9 m/s, with a difference of 8.1 RPM. The figure obtained without loading is 134.2 RPM, whereas the value with weight is 126.1 RPM. **Fig. 4b)** indicates the disparity in turbine and generator speeds under loading and non-loading conditions at low wind speeds, namely 2.4 m/s. The observed difference is 4.4 RPM, with the non-loading speed measuring 96.7 RPM and the loading speed measuring 92.3 RPM. On the contrary, the greatest wind speed recorded was 3.9 m/s, with a difference of 8.1 RPM.

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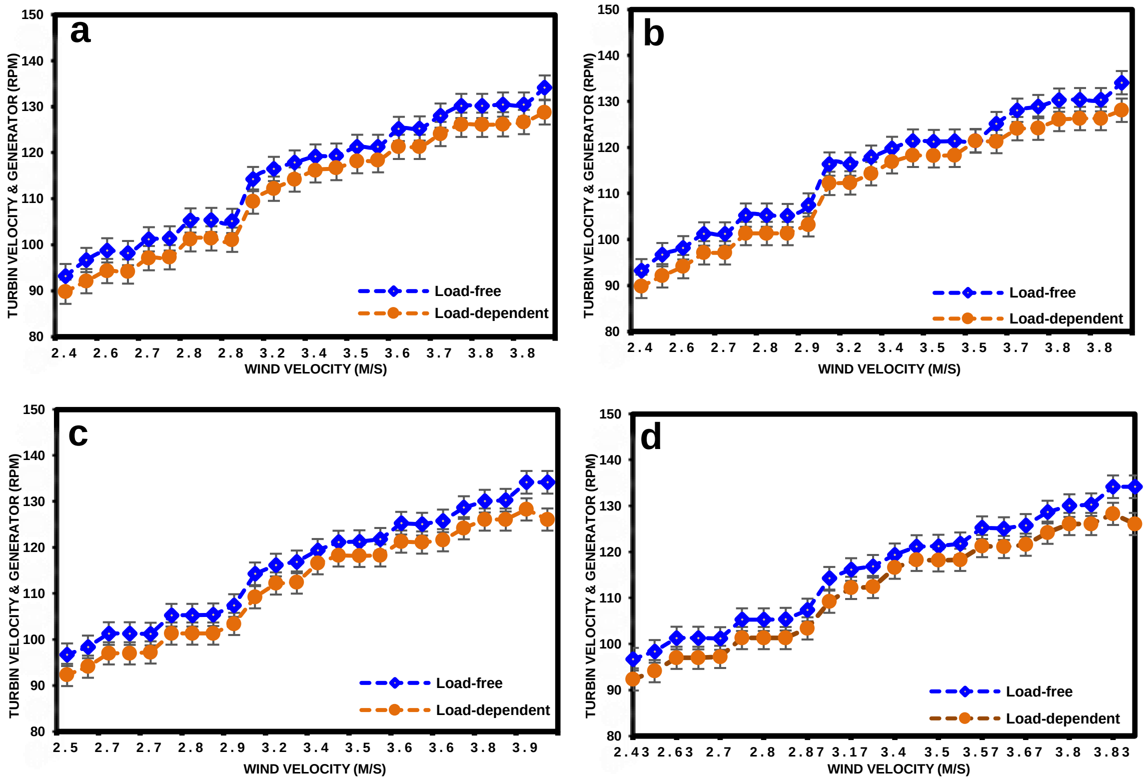

Figure 4. The following variables are considered: a) the initial data, b) the second data, c) the third data, and d) the mean value of all data, which represent variations in wind speed in relation to turbine and generator speed with and without loading.

The figure obtained without loading was 134.1 RPM, while the value with weight was 128.1 RPM. **Fig. 4d)** displays the average discrepancy in the speed of the turbine and generator when loaded and unloaded at low wind speeds, namely 2.43 m/s. The obtained difference is 3.74 RPM, with the unloaded value being 94.37 RPM and the loaded value being 90.63 RPM. On the contrary, the greatest wind speed recorded was 3.9 m/s, resulting in a difference of 5.77 RPM. The unloaded value was measured at 134.17 RPM, while the loaded value was 128.4 RPM.

Furthermore, it is important to mention that the analysis of wind speed's influence on generator output is evident through the observable manifestations of current (measured in milliamperes) and voltage (expressed in volts). Upon careful examination of **Fig. 5**, a fascinating result becomes apparent, indicating a significant level of consistency in the voltage and current values generated, even when the experimental tests were carried out at different time intervals. The consistent use of output settings highlights the dependability and consistency of the generator's performance under different wind situations.

A discernible pattern emerges when examining the details of the first data gathering, as seen in **Fig. 5a)**. The generator produced a voltage of 10.5 V and a current of 7.5 mA while the wind speed was at its lowest point of 2.4 m/s. In contrast, when the wind speed reached its maximum value of 3.9 m/s in the same dataset, the generator exhibited a higher voltage output of 16.4 V and a current of 11.2 mA. It is worth mentioning that the generator consistently performed well, demonstrating its capacity to adapt and be efficient in all settings, despite the varying wind speeds.

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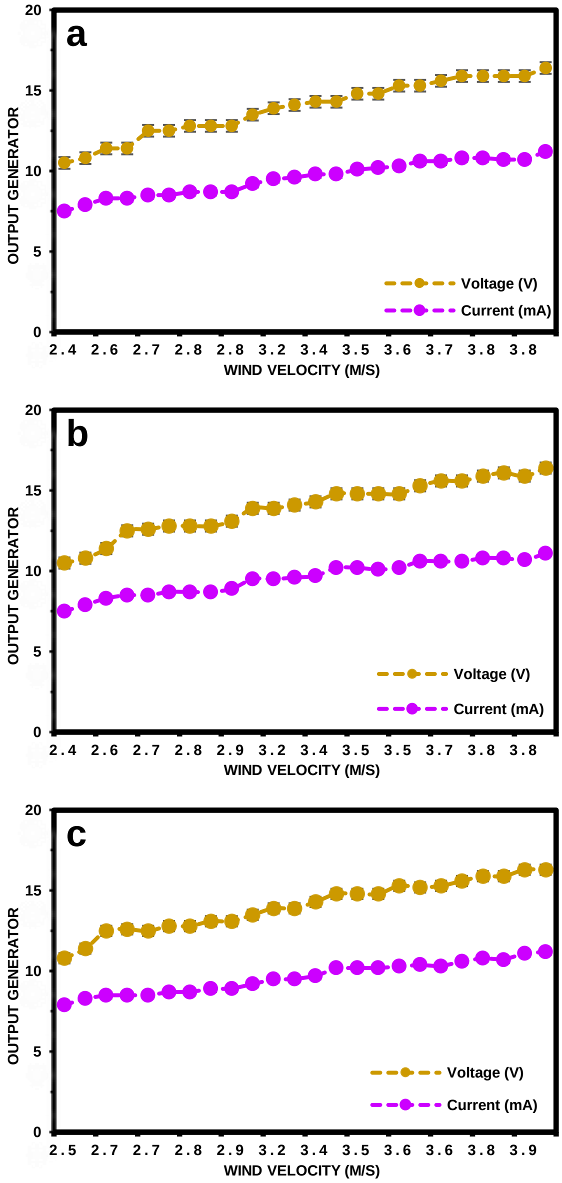

Figure 5. Variations in wind speed lead to adjustments in the current and voltage values produced by the generator concerning a) the initial data collection, b) the subsequent data, and c) the third data.

Similarly, the second batch of data (**Fig. 5b**) mirrors the patterns identified in the initial dataset. The generator consistently maintains its performance, as seen by the lowest voltage and current values recorded at a wind speed of 2.4 m/s (10.5 V and 7.5 mA, respectively), and the maximum values recorded at a wind speed of 3.9 m/s (16.4 V and 11.1 mA, respectively). These results align well with the initial dataset. This repeat of data reinforces the comprehension of the generator's consistent reaction to varying wind velocities. Upon further examination of the third set of data, depicted in **Fig. 3c)**, small discrepancies become apparent, providing a greater understanding of the intricate correlation between wind speed and generator output. The minimum voltage was observed at a wind speed of 2.5 m/s, measuring 10.8 V, with a corresponding current of 7.9 mA. Conversely, when the wind speed reached its maximum at 3.9 m/s, it generated an output voltage of 16.3 V and a current of 11.2 mA. The subtle variations emphasize the complex relationship between wind and generator, demonstrating that even small fluctuations in wind velocity can result in noticeable modifications in electrical production.

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Overall, the thorough examination of how wind speed affects generator output, as indicated by current and voltage measurements, demonstrates consistent and adaptable performance in different wind situations. The complex information extracted from the many datasets highlights the strength and significance of the generator, emphasizing the need for such research to enhance the efficiency of wind energy conversion systems.

The correlation between the wind velocity and the generator's rotational speed is pivotal in converting energy. The speed of the generator is closely connected to the turbine's rotational speed and is directly affected by the wind speed and prevailing loading conditions. Power output efficacy may be compromised when the generator fails to achieve maximum speed due to reduced wind velocities. Nevertheless, when the wind's velocity escalates, the generator's speed likewise elevates, hence facilitating a more proficient and potent creation of electricity. Given the effects of burden on both, it is apparent that the electrical demand, grid requirements, and storage system constraints significantly influence the performance of the turbine and generator. The turbine's speed must be adjusted to meet the increased loading, which affects the generator's speed. Achieving a careful equilibrium between loading circumstances and turbine-generator dynamics is crucial for maximizing power production and guaranteeing the durability and dependability of the overall wind energy conversion system.

4. Conclusion

In order to examine the fluctuations in wind speed at elevations of 4, 6, and 8 meters, a 24-hour dataset was gathered. The analysis revealed that the maximum recorded wind speed was 3.3 m/s at a height of 8 meters, with a little fluctuation noted at 6 meters. The wind speed measured at a height of 4 meters reached a minimum of around 2.4 m/s, suggesting notable variations in wind behavior at varying elevations. The investigation also identified disparities in speed between the generator and turbine under loaded and empty conditions. A significant proportion of the data suggested that turbine velocity increased in the absence of a burden. The investigation also revealed discrepancies in the speeds of turbines and generators when subjected to loading and non-loading scenarios at low wind velocities. The maximum measured wind speed was 3.9 meters per second, with a corresponding difference of 5.4 revolutions per minute. The mean difference in rotational speed between the turbine and generator under low wind conditions, both when the generator is loaded and unloaded, was 3.74 RPM. This research serves as a foundation for enhancing our comprehension of wind dynamics and facilitating more intricate and targeted investigations in the field of atmospheric sciences.

The impact of wind speed on generator output is clearly demonstrated by measuring current and voltage. The generator regularly exhibits high performance across varying wind conditions, showcasing its adaptability and efficiency. The generator exhibits steady and flexible performance, even in the presence of fluctuating wind speeds. The generator exhibits constant performance across various wind speeds, with the minimum voltage and current values at 2.4 m/s and the greatest at 3.9 m/s. The intricate correlation between wind and generator is apparent in the nuanced fluctuations detected in the third batch of data. The relationship between wind velocity and generator rotational speed is vital in the process of converting energy. The efficiency of power output is affected when the generator is unable to reach its maximum speed owing to lower wind velocities. The turbine's velocity must be modified to accommodate the heightened load, thereby impacting the speed of the generator. Optimizing power generation and preserving the long-term reliability of the wind energy conversion system requires a delicate balance between loading conditions and the dynamics of the turbine generator.

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