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Optimizing Small-Scale Wind Energy Generation: Site-Specific Wind Speed Analysis and Turbine Placement Strategies

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ABSTRACT

Wind is an effective renewable power source suitable for localized electricity production when regional environmental factors have substantial impact on system output. The research studies the best wind turbine placement through wind speed variability studies conducted with calibrated anemometers and data loggers that assess site conditions. A data-based assessment method creates the research's main contribution which facilitates the optimization of wind power potential measurement for enhanced energy efficiency. The research methodology includes continuous Vantage Pro2 equipment together with anemometers at different heights for wind speed observation while performing accuracy-based calibration analysis. The research shows that elevating the turbine from seven meters to ten meters leads to a 12 percent growth in the amount of power produced. The power output of wind energy decreases as wind speed changes because of environmental conditions so proper installation locations become essential. Energy performance increases best when selecting sites which feature reliable and elevated wind speeds. This research provides useful knowledge about enhancing decentralized power generation through wind energy but it cannot be easily scaled up to bigger systems. The study demonstrates that specific site assessments together with practical recommendations will enhance the efficiency of small-scale wind energy systems.

1. Introduction

The industrial evolution of economies creates energy demand which serves as a fundamental contributor to development achievements through per capita consumption measurements [1]-[4]. The increasing speed of global energy consumption along with dwindling fossil fuel stocks has created an instant need for sustainable renewable sources of energy [2]. Energizing the economy with fossil fuels causes accelerated depleting resources and worsens air quality by emitting greenhouse gases which create climate change impacts besides environmental degradation [3]. Research teams and industry sectors together with governments have started investigating alternate power generation options in order to build a future based on sustainable and clean energy systems [4].

Wind energy proves itself as a leading renewable alternative among solar, hydro, biomass and geothermal power because it offers plentiful resources alongside minimal environmental consequences and continuously decreasing price tags [5]. The motion-based wind energy produces unmatched renewable power which frees us from fossil fuel dependence while causing minimum environmental strain [6]. The transformation of wind energy into electrical power happens through wind turbines that possess rotor blades as well as a hub and nacelle containing a generator and gearbox and utilize a tower to reach suitable wind altitudes [7]. The two primary variants of wind turbines exist as horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines (VAWTs). Large-scale power generation relies on HAWTs because they operate efficiently but VAWTs become the better choice for small-scale and urban locations requiring performance in turbulent winds and multiple wind directions [8].

Technical advancements of wind energy systems since the 1990s have noticeably enhanced turbine operational capabilities along with size and power output features. Contemporary wind turbine technology includes residential units which deliver less than 10 kW but also encompasses power plants larger than 5 MW that operate as community electricity suppliers [9]. According to reports the worldwide wind power capacity showed dramatic growth to reach 369,553 MW in 2014 and continues to expand through advancements in turbine dimensions as well as efficiency and power grid readiness [10]. Research articles about wind energy resource evaluation generally depend on past data which requires modern analytical methods to reassess both technical capabilities and present-day wind potential [11].

Wind energy adoption faces substantial barriers because of the factors such as intermittency and grid constraints as well as economic feasibility [12]. The operational effectiveness of wind power systems mainly depends on the selected site's location and wind speed regularity and its interaction with terrain elements [13]. The consistency of wind patterns at offshore wind farms provides better and more steady wind flow for power generation which enhances operational performance compared to surface-based wind turbines. Organizations need to invest greater capital and develop advanced infrastructure systems to accomplish offshore projects while conducting maintenance operations [14]-[15]. Wind farms installed onshore are usually less expensive yet launch financial conflicts against landowners and need thorough wind power assessments before starting projects [16].

Proper assessment of wind resources remains essential for developing the most optimal wind energy systems. The assessment of wind speed together with direction and frequency durations requires specialized instruments such as anemometers and data loggers to correctly determine the viability of wind turbine deployment for a specified site [17]. Various factors affect the accuracy of wind speed measurement through effects on anemometer height changes between stations and instrument measurement inconsistencies with their placement sites [18]. The proper assessment of wind energy requires regular instrument calibration because it helps eliminate measurement errors as documented in research [19]. Collecting and analyzing data using sensor technologies together with real-time analytics systems has become a proposed method for wind energy resource administration improvement and improved power output optimization [20].

The assessment of wind energy potential through this study depends on wind speed index-controlled experiments conducted with wind tunnel testing [21]-[26]. Laboratory wind measurements rely on a combination of a data acquisition system together with a wind speed measurement device which enables researchers to study wind performance under different environmental conditions [27]-[34]. The data-driven system helps determine power generation capacity along with the best locations for wind turbines and specific project feasibility assessments in wind energy ventures [35]-[40]. Wind energy evaluations benefit from calibration procedures which aid accuracy measurements and improve reliability according to previous research findings [41]-[45].

The study brings major contributions to wind energy assessment science. The study demonstrates an experimental wind energy analysis through wind tunnel testing which allows systemic turbine performance assessment under diverse wind conditions [46]-[49]. The research demonstrates how accurate wind measurement methods need calibration processes that reduce measurement inaccuracies. The research demonstrates practical information about deploying small-scale wind power systems for decentralized and distributed energy systems applications. This study tackles important elements which adds to present discussions on renewable energy optimization while backing worldwide adoption of sustainable green energy systems [50]-[53].

2. Wind Turbine

A wind turbine transforms the kinetic energy from the wind-driven windmill into electrical energy. When the wind rotates the windmill, it also rotates the turbine, which is connected mechanically and produces electrical energy. The system is widely used in society, as it produces zero negative waste. To calculate the wind power produced by the windmill, Equation (1) is used [22].

$$P = \frac{1}{2}\rho v^3 \tag{1}$$

2.1. Simulink Design

Fig. 1 shows the block diagram of the wind turbine using Simulink in MATLAB software. In order to implement the model, a wind turbine induction generator is chosen to determine the parameter output, such as voltage, current, power, and motor speed value from the output. Fig. 2 displays the characteristics of the wind turbine. The graph establishes the output base at a wind speed of 2 m/s. Turbine output power is proportional to wind speed, as shown in Fig. 3.

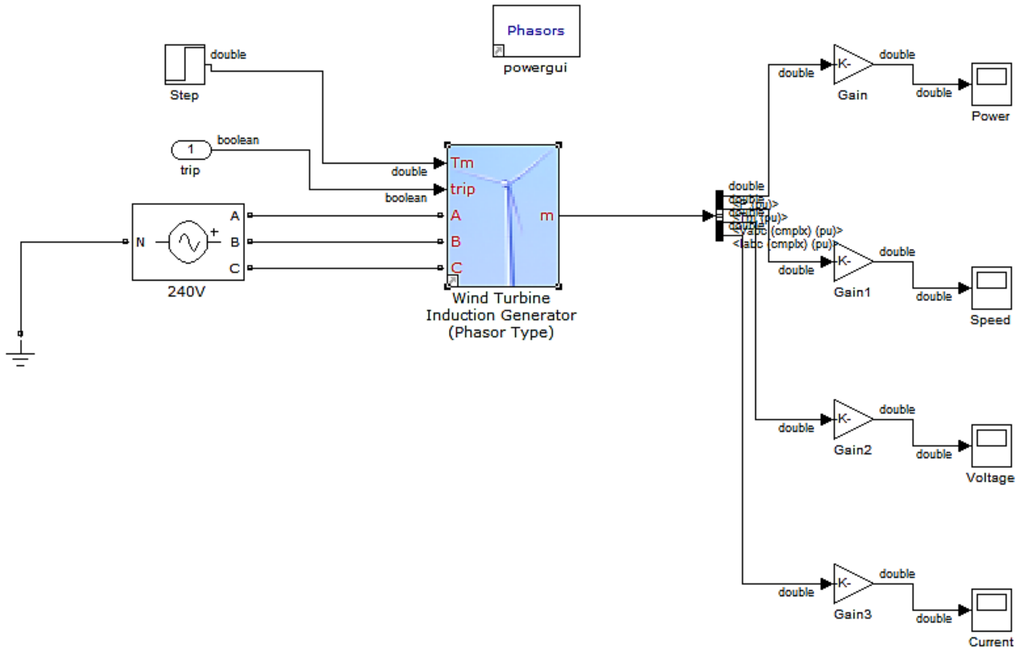

Fig. 1. Block diagram of wind turbine

3. Methodology

To complete the research given, two methods have been used, and the algorithm illustrated in Fig. 4 is implemented. As presented, the proposed method takes the data by using a data logger and

Vantage Pro 2 (which connects with a data logger), from which the data can be downloaded at the final year project laboratory by using Weather Link software. And, a calibrated anemometer is utilized as a tool to take readings of the speed of wind manually. The anemometer and Vantage Pro 2 readings are compared for accurate calibration of Vantage Pro 2.

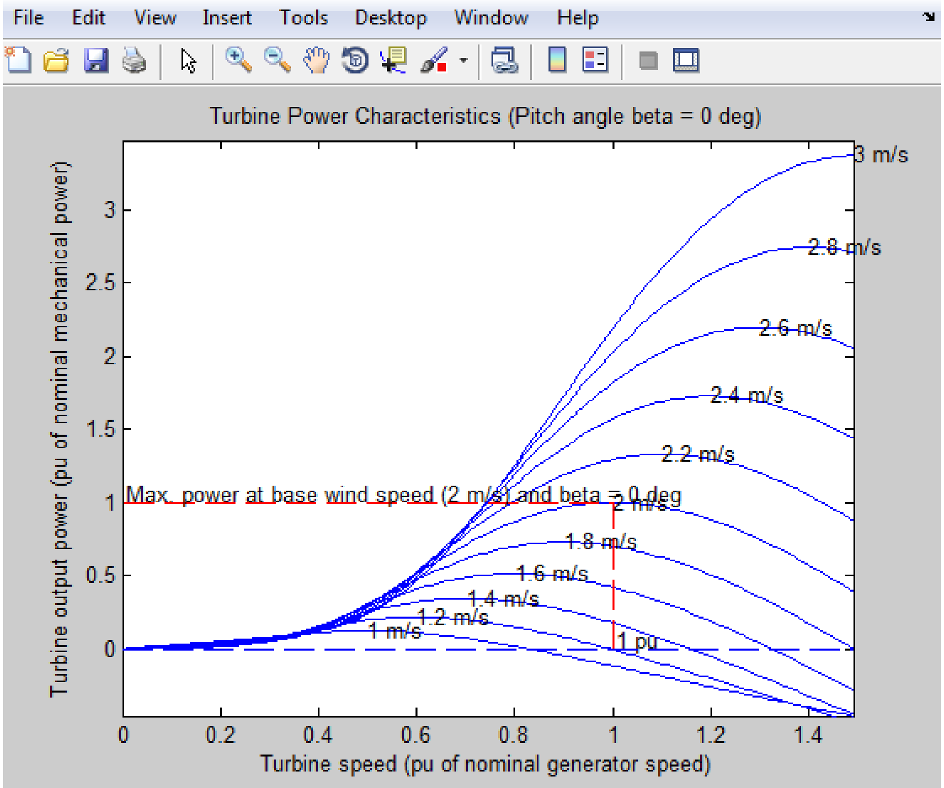

Fig. 2. Wind turbine characteristic

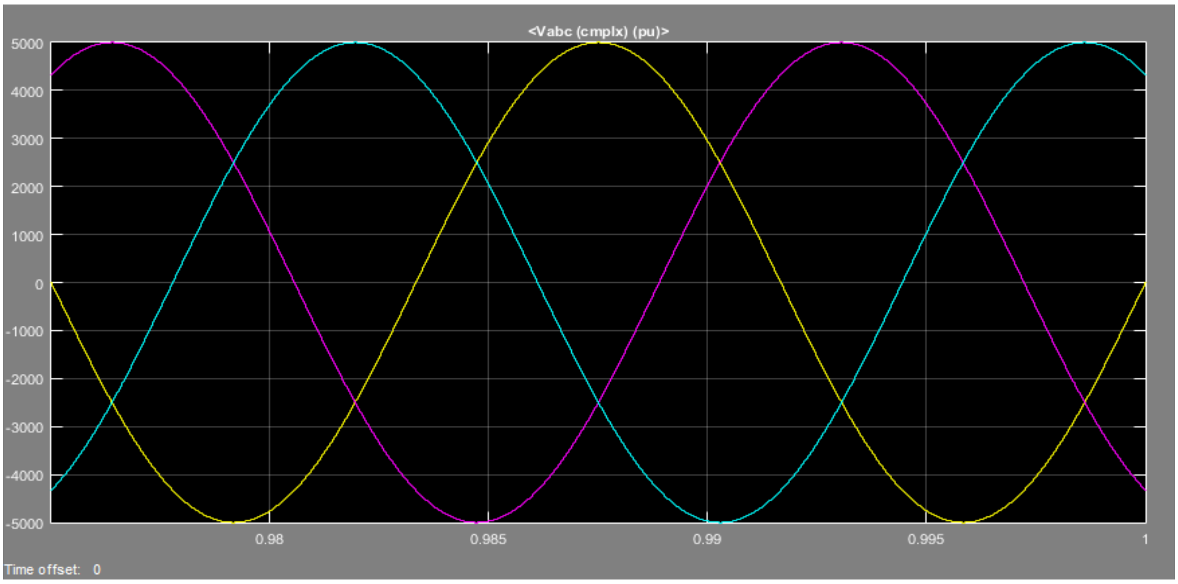

Fig. 3. Waveform of phase voltage

3.1. Proposed Method: Data logger and Vantage Pro 2

A data logger is an electronic gadget that records information after some time or in connection to an area either with an implicit instrument or sensor or by means of outer instruments and sensors. Increasingly, but not exclusively, data loggers rely on a digital processor (or PC). They are, for the most part, small, battery-controlled, compact, and outfitted with a microchip, interior memory for data storage, and sensors. A data logger interface with PC, and use programming to actuate the data logger and see and investigate the gathered information, while others have a local interface device (keypad, LCD) and can be utilized as a stand-alone device.

Vantage Pro2 is equipment that displays the data that records from a data logger, via cable or wireless, and the data logger is located on the wind turbine, as shown in Fig. 5. Vantage Pro2 console's features are given in Fig. 6. With conditional settings of features, the equipment displays the graph and alarm function that interface to a computer using the Weather Link software. In Fig. 7 the experimental setup is given for the Vantage Pro2 observed wind turbine setup at Al-Huwaija Technical Institute, NTU, Iraq.

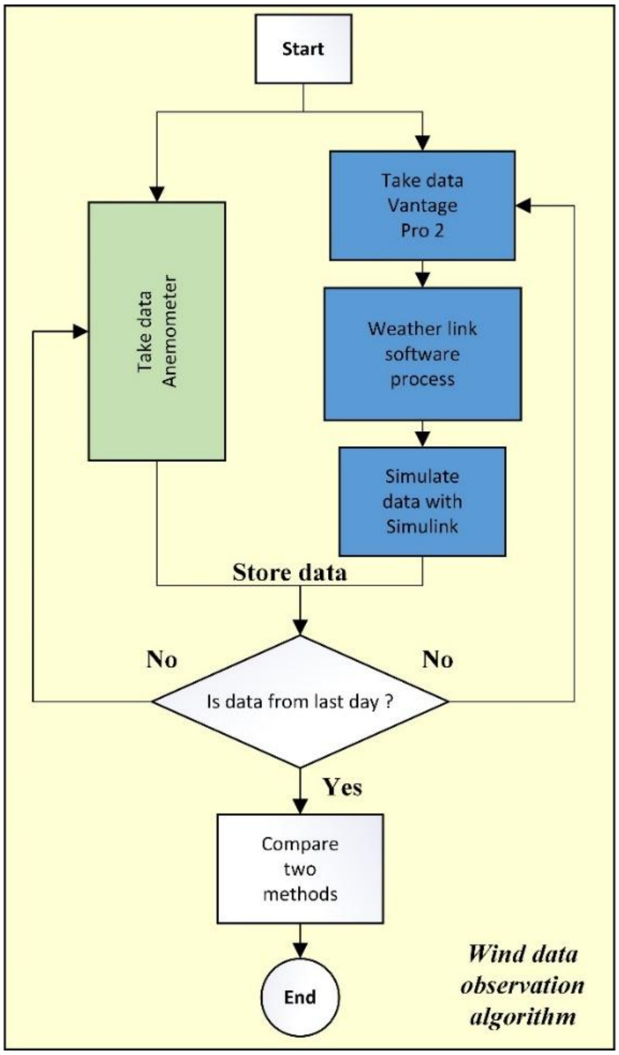

Fig. 4. Wind data observation algorithm

How to take a reading of wind speed in Vantage Pro2 is illustrated as in following steps:

- Press WIND
- The wind speed will display on the screen (m.p.h, km/h, m/s, and knots)
- The screen will display the 10-minute average wind speed
- An arrow in the compass rose means the direction of the current wind
- Press WIND for the second time will display the direction of the wind in degree
- Each additional press WIND will display between wind speed and wind direction in degrees.

How to take reading of temperature (outside/inside) in Vantage Pro2 is illustrated as in following steps:

- Press TEMP (outside temperature) temperature will appear on the screen in degree Fahrenheit (^oF) or degree Celsius (^oC).
- Press TEMP second times (inside temperature) any additional press TEMP will display temperature readings for any optional temperature.

The Vantage Pro 2 must be calibrated for accurate weather data collecting. Wind speed sensor calibration instructions for the Vantage Pro 2 is given as following:

- Firstly, a reference anemometer (used in Section 3.2) must be used. This anemometer must be certified and calibrated.
- Conduct a comparison of the wind speed measurements obtained from the Vantage Pro 2 to those from a certified, calibrated anemometer. This evaluation must take place under conditions of constant and consistent wind.
- Adjust the calibration parameters on the weather station console. The Vantage Pro 2 allows user to multiply the wind speed calibration factor.
- Adjust the multiplier to match Vantage Pro 2 and reference anemometer readings.

Fig. 5. Data logger for wind turbine

3.2. Calibrated Anemometer

An anemometer is an instrument that measures the rate of the wind or of another streaming liquid. The most essential kind of anemometer comprises a progression of glasses mounted toward the end of arms that turn in the wind. In the structure, the anemometer likewise shows the bearing of the wind. The data of wind speed can be taken manually by hand. Fig. 8 and Fig. 9 illustrate the process of gathering wind speed data with anemometer at Al-Huwaija Technical Institute, NTU, Iraq.

Fig. 6. Vantage Pro2 with computer connection

Fig. 7. Vantage Pro2 observed wind turbine setup

Fig. 8. Anemometer handheld

Fig. 9. Taking the wind speed in two different directions

4. Result and Discussion

Al-Huwaija Technical Institute, NTU, Iraq conducted the wind speed data measurement process, as Table 1 demonstrates. All the data was collected every hour starting from 1 a.m. on 1st October until 11p.m. on 1st December 2024 as shown in Fig. 10 and Fig. 11. Totally, the measurement process was approximately conducted for two months in October and November 2024. The condition of the weather was taken into account as it effects the variation of the wind speed from the data logger equipment. The paper also compares anemometer testing that combines site measurement data.

Table 1. Average wind speed power from data logger

Wind speed vi (m/s)	**Hours vi per month**	**Fraction of Hours vi**	**vi * Fraction Hours vi**	$(vi)^3$	$(vi)^3$ *** Fraction Hours vi**
0.00	57	0.0777	0.0000	0.00	0.000
0.40	49	0.0668	0.0267	0.06	0.004
0.80	1	0.0014	0.0011	0.51	0.001
0.90	67	0.0913	0.0822	0.73	0.067
1.30	84	0.1144	0.1488	2.20	0.251
1.80	75	0.1022	0.1839	5.83	0.564
2.20	106	0.1444	0.3177	10.65	1.538
2.70	87	0.1185	0.3200	19.68	2.333
3.10	86	0.1172	0.3632	29.79	3.490
3.60	62	0.0845	0.3041	46.66	3.941
3.70	3	0.0041	0.0151	50.65	0.207
4.00	36	0.0490	0.1962	64.00	3.139
4.50	11	0.0150	0.0674	91.13	1.366
4.90	10	0.0136	0.0668	117.65	1.603
Total	734	1.0000	2.09	439.54	18.54

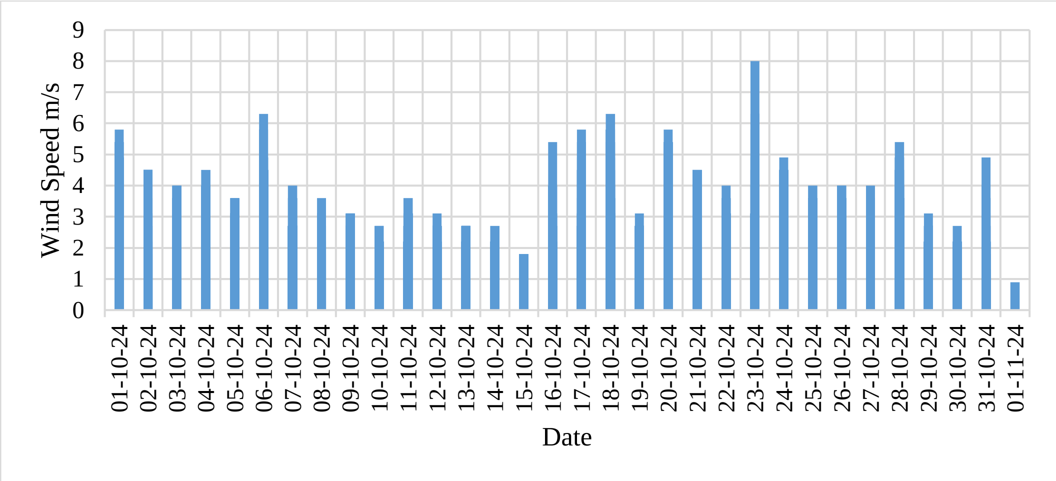

Fig. 10. Daily measured average wind speed data (October)

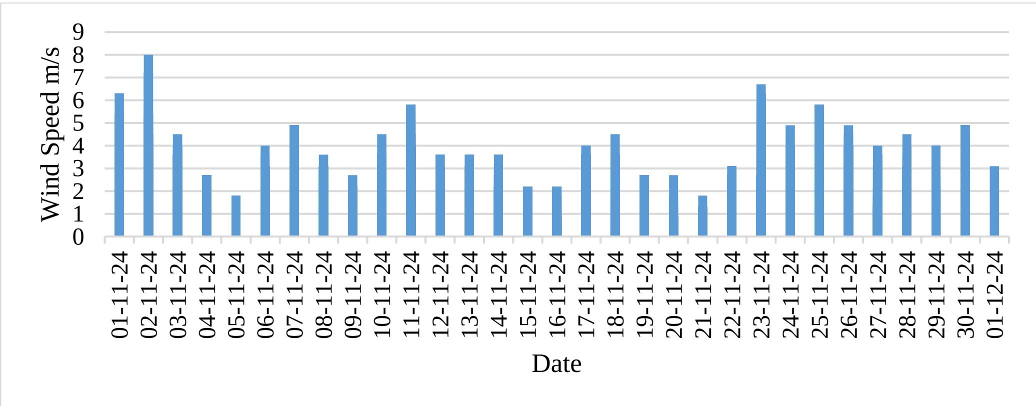

Fig. 11. Daily measured average wind speed data (November)

Fig. 10 and Fig. 11 shows the trend analysis of site data and wind histogram showing hours that the wind blows at each speed. The average windspeed is Equation (2):

$$V_{avg} = \sum_i [vi.(Fraction.of.hours\ @vi)] = 2.09m/s \tag{2}$$

The average value of V^3 is Equation (3):

$$(V)^3 avg = \sum_i [vi^3.(Fraction.of.hours\ @vi)] = 18.54m/s \tag{3}$$

The average power in the wind is Equation (4):

$$P_{avg} = \frac{1}{2}\rho * (v)^3 avg = 0.5 * 1.165 * 18.54 = 10.80/m^2 \tag{4}$$

In Fig. 12, the calculated average power for October and November Al-Huwaija Technical Institute is 11.36 W/m^2. The air density is ρ = 1.165 kg/m^3. However, the average power could be miscalculated using just the average wind speed. For example, the wind speed using the 2.09 m/s Equation (5).

The pattern of average wind speed is analysis as shown in Fig. 13. Thus, the average wind speed increased significantly on 19th November compared to other days. The impact of output is depending the uncertain weather of surrounding conditions, which is cloudy, rainy, or sunny day. The same situation happened when the higher average wind speed was blowing during cloudy conditions.

$$P_{avg(wrong)} = \frac{1}{2}\rho * (V)^3 avg = 0.5 * 1.165 * (2.09)^3 = 5.32/m^2 \tag{5}$$

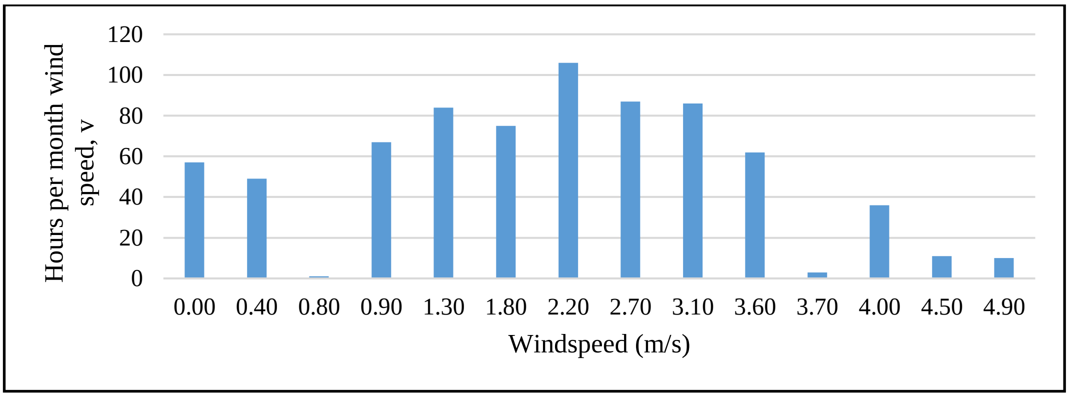

Fig. 12. Wind histogram showing hours at each wind speed site data (October and November)

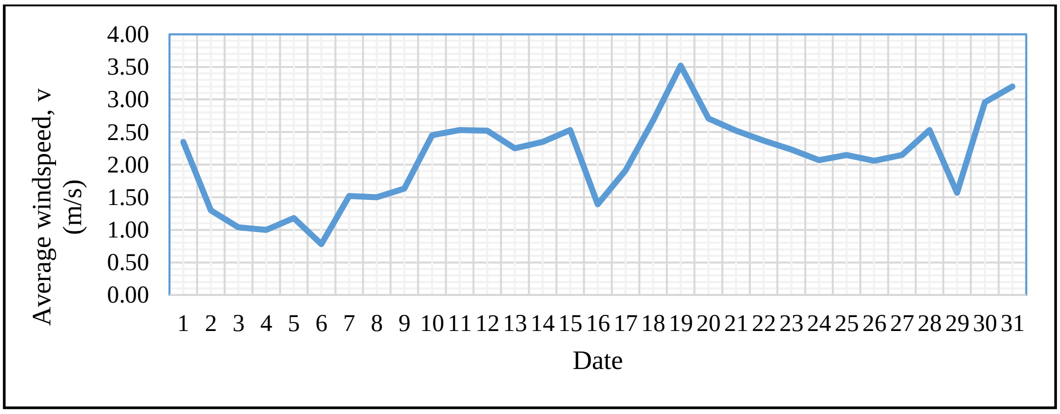

Fig. 13. Wind speed versus time of day (November)

The wind's power is directly proportionate to its average speed. Consequently, to achieve greater maximum power from winds, it is advisable to install it on a taller tower. The influence of surface roughness on wind velocity is as follows in Equation (6):

$$(\frac{V}{V_0} = \left(\frac{H}{H_0}\right)^a \tag{6}$$

Where:

V = windspeed at height H

Vo = windspeed at height Ho (reference height of 5m)

α = friction coefficient

An anemometer mounted at height of 7 m above a surface with smooth hard ground shows a windspeed of 2.09 m/s. Estimate the windspeed if the tower height is 10m and the specific power in the wind can be generated. Assume that, α for smooth hard ground is 0.10. Then, air density is ρ = 1.165 kg/m^3. Rearrange equation 1.5 to solve windspeed at 10m in Equation (7).

$$V_{10} = 2.09 * \left(\frac{10}{7}\right)^{0.1} - 2.17m/s \tag{7}$$

Specific power in the wind will be in Equation (8):

$$P_{10} = \frac{1}{2}\rho * (V)^3 avg = 0.5 * 1.165 * (2.17)^3 = 5.95W/m^2 \tag{8}$$

From the result obtained, power in the wind at 10m is 5.95 W/m^2. Since, to consider the relative power of the wind at height H versus the power at the reference height of Ho can be determine in Equation (9) and (10). The power in the wind proportional the height tower is about 12% increment from 7m to 10m.

$$\left(\frac{P}{P_o}\right) = \left(\frac{{}^1/_2\,\rho A v^3}{{}^1/_2\,\rho A {v_0}^3}\right) = \left(\frac{v}{v_0}\right)^3 = \left(\frac{H}{H_0}\right)^{3a} \tag{9}$$

$$\left(\frac{P}{P_o}\right) = \left(\frac{v}{v_0}\right)^3 = \left(\frac{2.17}{2.09}\right)^3 = 1.12 \tag{10}$$

5. Recommendation

The experimental process encounters a large number of major challenges, affecting the functionality and effectiveness of wind turbines. First of all, wind speed in Al-Huwaija Technical Institute is generally weak, and so the turbines often do not run at their optimal capacity so as to produce the necessary amount of electricity giving very low electricity production. Further this problem is reinforced by the fact the turbine blades themselves can also generate significant noise, potentially, in disturbance to those communities and wildlife nearby. Also, the blades could be dangerous to besides biodiversity, to constellation of wildlife, organic structure birds, which could be killed if its collision with the moving blades. Furthermore, the placement of turbines is usually located far away from major cities where the electricity is actually required, causing the installation of long and expensive transmission lines to transport the power, and increasing further the cost of the wind energy infrastructure.

To overcome these challenges and increase the efficiency of wind turbines, it is vital to obtain more accurate and valuable wind slope data to determine the very best area for turbine installation. This information can be used to identify areas where a consistent high wind speeds, enabling turbines to be run in these locations to a maximum capacity of energy. Additionally, to achieve better accuracy of wind speed measurement, a real wind turbine mounted with real blades can be adopted as a more faithful option of traditional anemometers, practicing in attributable measurement which depicting the full variety of power producing by wind. These actions could greatly improve the efficiency and cost-benefit level of wind energy systems.

6. Conclusion

The analysis confirms that specific wind readings at locations play a vital part in achieving peak efficiency from small-scale wind power systems. Analyses of wind velocity data with power density calculations (e.g., 11.36 W/m² yield important findings about how environmental elements affect turbine energy production. Wind power installations should focus on sites which maintain consistently vigorous and steady wind speeds because they offer the most effective locations for wind energy development. The need for thorough feasibility evaluations becomes evident because they analyze both seasonal wind changes and local conditions of land elevations and temperature patterns before implementing wind turbines.

This research demonstrates that choosing the correct turbine site location stands out as a crucial discovery. An appropriate placement location results in energy efficiency by reducing turbulence together with minimizing wind shear effects. The research points toward raising turbines to higher heights because this reduces friction losses in ground-level conditions particularly among low-wind speed areas. These survey results will advance the development of small-scale wind energy technology because these systems hold great potential to generate power off-grid in rural places.

The research contains various constraints which merit recognition. Relying only on short-term wind speed measurements might fail to represent long-term wind patterns thus affecting the overall result validity. Human-involvement in reading anemometer data leads to the risk of obtaining inaccurate measurement results. Upcoming studies in this domain should use automated logging systems to gather continuous wind data while improving both precision and reliability of their measurements. The evaluation of wind speed and power density in this study should be complemented by an assessment of essential components such as turbine lifespan and maintenance demands and environmental impact analysis when creating wind energy installations.

Going for-wards, several directions for further investigation can additionally refine and extend these results. The final say goes to the next phase of researches the influence of the layouts of the advanced turbine blade and the layers on productivity boosters. Moreover, incorporating machine learning methods for predictive wind model can increase the accuracy of site selection, more accurate wind resource assessment. The economic viability of small-scale wind systems needs to be investigated, especially inside the frame of grid integration together with hybrid renewable energy systems that bring wind, solar as well as battery storage options.

In summary, this research contributes to the expanding dataset of small-scale wind energy optimization research through offering data-based knowledge concerning wind resource assessment and turbine location strategies. By taking into account existing site-specific conditions and incorporating cutting–knowledge methodologies, later research can foster the progress in wind energy utilization, contributing to the growth to a more sustainable renewable energy future.

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References

[1] B. Ayar, Z. G. Yalçın, M. Dağ, "Rüzgârı hasat etmek: Türkiye'de rüzgâr enerjisinin fizibilitesi ve gelişmeleri üzerine bir araştırma," *Avrupa Bilim ve Teknoloji Dergisi*, vol. 49, pp. 43-49, 2023, https://doi.org/10.31590/ejosat.1261573.

[2] A. Rosato, A. Perrotta, L. Maffei, "Commercial small-scale horizontal and vertical wind turbines: A comprehensive review of geometry, materials, costs and performance," *Energies*, vol. 17, no. 13, p. 3125, 2024, https://doi.org/10.3390/en17133125.

[3] I. C. Gil-García, A. Fernández-Guillamón, Á. H. Montes-Torres, "Innovation in clean energy from man-made wind and small-wind generation," *Scientific Reports*, vol. 14, no. 1, p. 22932, 2024, https://doi.org/10.1038/s41598-024-74141-w.

[4] A. Shahid, F. Plaum, T. Korõtko and A. Rosin, "AI Technologies and Their Applications in Small-Scale Electric Power Systems," *IEEE Access*, vol. 12, pp. 109984-110001, 2024, https://doi.org/10.1109/ACCESS.2024.3440067.

[5] B. Mendi, M. Pattnaik, G. Srungavarapu, "A single current sensor based adaptive step size MPPT control of a small scale variable speed wind energy conversion system," *Applied Energy*, vol. 357, p. 122492, 2024, https://doi.org/10.1016/j.apenergy.2023.122492.

[6] R. Figaj, "Energy and Economic Sustainability of a Small-Scale Hybrid Renewable Energy System Powered by Biogas, Solar Energy, and Wind," *Energies*, vol. 17, no. 3, p. 706, 2024, https://doi.org/10.3390/en17030706.

[7] O. Apata, P. N. Bokoro, G. Sharma, "Integration of small-scale wind turbines in sustainable and energy efficient buildings," *Natural Energy, Lighting, and Ventilation in Sustainable Buildings*, pp. 111-129, 2023, https://doi.org/10.1007/978-3-031-41148-9_6.

[8] B. Y. Kassa, A. T. Baheta, A. Beyene, "Current trends and innovations in enhancing the aerodynamic performance of small-scale, horizontal axis wind turbines: A review," *ASME Open Journal of Engineering*, vol. 3, p. 031001, 2024, https://doi.org/10.1115/1.4064141.

[9] L. Zemite, J. Kozadajevs, L. Jansons, I. Bode, E. Dzelzitis, K. Palkova, "Integrating Renewable Energy Solutions in Small-Scale Industrial Facilities," *Energies*, vol. 17, no. 11, p. 2792, 2024, https://doi.org/10.3390/en17112792.

[10] Y. Li, W. Jiang, G. Zhang, L. Shu, "Wind turbine fault diagnosis based on transfer learning and convolutional autoencoder with small-scale data," *Renewable Energy*, vol. 171, pp. 103-115, 2021, https://doi.org/10.1016/j.renene.2021.01.143.

[11] M. Martín-Betancor, J. Osorio, A. Ruíz-García, I. Nuez, "Technical-economic limitations of floating offshore wind energy generation in small isolated island power systems without energy storage: Case study in the Canary Islands," *Energy Policy*, vol. 188, p. 114056, 2024, https://doi.org/10.1016/j.enpol.2024.114056.

[12] X. Liu, D. Zhao, N. L. Oo, "CFD investigation on wind power harvesting from small-scale wind turbines for powering residential buildings in New Zealand," *Journal of the Royal Society of New Zealand*, pp. 1-28, 2024, https://doi.org/10.1080/03036758.2024.2323488.

[13] A. Ghigo, E. Petracca, G. Mangia, G. Giorgi, G. Bracco, "Development of a floating vertical axis wind turbine for the mediterranean sea," *Journal of Physics: Conference Series*, vol. 2745, no. 1, p. 012008, 2024, https://doi.org/10.1088/1742-6596/2745/1/012008.

[14] A. Vallati, M. Di Matteo, L. Pompei, F. Nardecchia, C. V. Fiorini, "Mitigation of renewable energy source production variability in residential stock through small-scale gas–liquid energy storage technology application," *Processes*, vol. 12, no. 4, p. 655, 2024, https://doi.org/10.3390/pr12040655.

[15] D. Keisar, V. Freger, D. Greenblatt, "Direct wind-powered vertical axis brackish water desalination system," *Desalination*, vol. 570, p. 117060, 2024, https://doi.org/10.1016/j.desal.2023.117060.

[16] R. Heredia-Fonseca, S. Kumar, S. Ghosh, J. Thakur, A. Bhattacharya, "Modeling a 100% renewable energy pathway in developing Countries: A case study of State of Goa, India," *Energy Conversion and Management*, vol. 315, p. 118800, 2024, https://doi.org/10.1016/j.enconman.2024.118800.

[17] A. F. Olivera, E. Chica, H. A. Colorado, "Design and manufacturing with 3D printing and life cycle analysis of a recyclable polymer-based H-Darrieus wind turbine," *Engineered Science*, vol. 31, p. 1156, 2024, http://dx.doi.org/10.30919/es1156.

[18] V. Adomavicius, G. Simkoniene, A. Dedenok, "Usefulness of Small-Scale Stand-Alone Hybrid Solar-Wind Power Plants in Rural Areas," *Engineering for Rural Development*, pp. 601-607, 2024, https://doi.org/10.22616/ERDev.2024.23.TF111.

[19] C. Azorin-Molina *et al*., "Biases in wind speed measurements due to anemometer changes," *Atmospheric Research*, vol. 289, p. 106771, 2023, https://doi.org/10.1016/j.atmosres.2023.106771.

[20] Ç. Ersin, A. Öz, "Remote Monitoring of Wind Speed and Produced Voltage Measured by Anemometer," *Avrupa Bilim ve Teknoloji Dergisi*, vol. 31, pp. 986-990, 2021, https://doi.org/10.31590/ejosat.1019527.

[21] S. Liu, Q. Li, B. Lu, J. He, "Analysis of NREL-5MW wind turbine wake under varied incoming turbulence conditions," *Renewable Energy*, vol. 224, p. 120136, 2024, https://doi.org/10.1016/j.renene.2024.120136.

[22] A. Setiawan *et al.*, "Opportunity Assessment of Virtual Power Plant Implementation for Sustainable Renewable Energy Development in Indonesia Power System Network," *Sustainability*, vol. 16, no. 5, p. 1721, 2024, https://doi.org/10.3390/su16051721.

[23] R. McKenna *et al.*, "System impacts of wind energy developments: Key research challenges and opportunities," *Joule*, vol. 9, no. 1, p. 101799, 2025, https://doi.org/10.1016/j.joule.2024.11.016.

[24] C. Shen, Z. B. Li, F. Liu, H. W. Chen, D. Chen, "A robust reduction in near-surface wind speed after volcanic eruptions: Implications for wind energy generation," *The Innovation*, vol. 6, no. 1, p. 100734, 2025, https://doi.org/10.1016/j.xinn.2024.100734.

[25] E. Ramalho *et al.*, "Understanding wind Energy Economic externalities impacts: A systematic literature review," *Renewable and Sustainable Energy Reviews*, vol. 209, p. 115120, 2025, https://doi.org/10.1016/j.rser.2024.115120.

[26] T. A. Taha *et al.*, "Enhancing Multilevel Inverter Performance: A Novel Dung Beetle Optimizer-based Selective Harmonic Elimination Approach," *Journal of Robotics and Control (JRC)*, vol. 5, no. 4, pp. 944-953, 2024, https://doi.org/10.18196/jrc.v5i4.21722.

[27] N. B. Altinpulluk, D. Altinpulluk, M. Yildirim, S. Zhao, F. Qiu, A. Greco, "A survey on degradation modeling, prognosis, and prognostics-driven maintenance in wind energy systems," *Renewable and Sustainable Energy Reviews*, vol. 211, p. 115281, 2025, https://doi.org/10.1016/j.rser.2024.115281.

[28] S. Liu *et al.*, "Advances in urban wind resource development and wind energy harvesters," *Renewable and Sustainable Energy Reviews*, vol. 207, p. 114943, 2025, https://doi.org/10.1016/j.rser.2024.114943.

[29] T. A. Taha, H. I. Zaynal, A. S. T. Hussain, H. Desa, F. H. Taha, "Definite time over-current protection on transmission line using MATLAB/Simulink," *Bulletin of Electrical Engineering and Informatics*, vol. 13, no. 2, pp. 713-723, 2024, https://doi.org/10.11591/eei.v13i2.5301.

[30] A. A. Galarza-Chavez, J. L. Martinez-Rodriguez, R. F. Domínguez-Cruz, E. López-Garza, A. B. Rios-Alvarado, "Multi-step wind energy forecasting in the Mexican Isthmus using machine and deep learning," *Energy Reports*, vol. 13, pp. 1-15, 2025, https://doi.org/10.1016/j.egyr.2024.11.074.

[31] A. A. Mas'ud, I. Seidu, S. Salisu, U. Musa, H. Z. AlGarni, M. Bajaj, I. Zaitsev, "Wind energy assessment and hybrid micro-grid optimization for selected regions of Saudi Arabia," *Scientific Reports*, vol. 15, no. 1, p. 1376, 2025, https://doi.org/10.1038/s41598-025-85616-9.

[32] A. S. T. Hussain, "Unlocking solar potential: advancements in automated solar tracking systems for enhanced energy utilization," *Journal of Robotics and Control (JRC)*, vol. 5, no. 4, pp. 1018-1027, 2024, https://doi.org/10.18196/jrc.v5i4.19931.

[33] O. K. Ahmed, S. Algburi, M. A. Jasim, T. A. Taha, A. M. Saleh, K. F. Yassin, "Experimental assessment of the effect of black dye and water depth on the performance of PV/solar distiller," *Desalination and Water Treatment*, vol. 318, p. 100317, 2024, https://doi.org/10.1016/j.dwt.2024.100317.

[34] P. Shakya, M. Thomas, A. C. Seibi, M. Shekaramiz, M. S. Masoum, "Fluid-structure interaction and life prediction of small-scale damaged horizontal axis wind turbine blades," *Results in Engineering*, vol. 23, p. 102388, 2024, https://doi.org/10.1016/j.rineng.2024.102388.

[35] T. A. Taha, M. K. Hassan, H. I. Zaynal, N. I. A. Wahab, "Big data for smart grid: a case study," *Big Data Analytics Framework for Smart Grids*, pp. 142-180, 2024, https://doi.org/10.1201/9781032665399-8.

[36] A. S. T. Hussain, D. Z. Ghafoor, S. A. Ahmed, T. A. Taha, "Smart inverter for low power application based hybrid power system," *AIP Conference Proceedings*, vol. 2787, no. 1, p. 050022, 2023, https://doi.org/10.1063/5.0150294.

[37] T. A. Taha, A. S. T. Hussain, K. A. Taha, "Design solar thermal energy harvesting system," *AIP Conference Proceedings*, vol. 2591, no. 1, p. 030041, 2023, https://doi.org/10.1063/5.0119752.

[38] M. A. Sharif, "Numerical simulation of a ground-supported solar panel PV array subjected to periodic flow," *NTU Journal of Renewable Energy*, vol. 1, no. 1, pp. 50-55, 2021, https://doi.org/10.56286/ntujre.v1i1.23.

[39] M. Sun *et al*., "A novel small-scale H-type Darrieus vertical axis wind turbine manufactured of carbon fiber reinforced composites," *Renewable Energy*, vol. 238, p. 121923, 2025, https://doi.org/10.1016/j.renene.2024.121923.

[40] C. Sreenu, G. Mallesham, T. C. Shekar, S. R. Salkuti, "High Gain Quasi Z-Source Converters with Artificial Bee Colony Control for Grid-Integrated Solar-Wind Energy Sources," *Green Energy and Intelligent Transportation*, p. 100264, 2025, https://doi.org/10.1016/j.geits.2025.100264.

[41] O. H. Mohammed, D. K. Hashim, M. Y. Suliman, "The Optimal Energy Management Methods of The Hybrid Power System," *NTU Journal of Renewable Energy*, vol. 4, no. 1, pp. 7-17, 2023, https://doi.org/10.56286/ntujre.v4i1.401.

[42] N. H. Aziz, "Load Frequency Control With Renewable Energy Sources Using Practical Swarm Optimization Based On PID," *NTU Journal of Renewable Energy*, vol. 5, no. 1, pp. 61-73, 2023, https://doi.org/10.56286/ntujre.v5i1.563.

[43] T. Atyia, M. Qasim, "Evaluating the impact of weather conditions on the effectiveness and performance of PV solar systems and inverters," *NTU Journal of Renewable Energy*, vol. 5, no. 1, pp. 34-46, 2023, https://doi.org/10.56286/ntujre.v5i1.551.

[44] L. Onwuemezie, H. G. Darabkhani, "Biohydrogen production from solar and wind assisted AF-MEC coupled with MFC, PEM electrolysis of H2O and H2 fuel cell for small-scale applications," *Renewable Energy*, vol. 224, p. 120160, 2024, https://doi.org/10.1016/j.renene.2024.120160.

[45] O. Gaidai, F. Wang, J. Sheng, Y. Zhu, A. Ashraf, Y. Cao, "State-of-the-art Gaidai hypersurface risk assessment for semi-submersible wind turbines, accounting for memory effects," *Energy Conversion and Management: X*, vol. 26, p. 100946, 2025, https://doi.org/10.1016/j.ecmx.2025.100946.

[46] A. D. Verma, P. Gaur, A. Tomar, "Low-voltage synchronized BPF-based cascaded VSI controller in solar-wind powered small-scale isolated hybrid microgrid for rural electrification," *Energy*, vol. 309, p. 133141, 2024, https://doi.org/10.1016/j.energy.2024.133141.

[47] H. Farooki *et al*., "A Closer Look at Small-scale Magnetic Flux Ropes in the Solar Wind at 1 au: Results from Improved Automated Detection," *The Astrophysical Journal Supplement Series*, vol. 271, no. 2, p. 42, 2024, https://doi.org/10.3847/1538-4365/ad24e1.

[48] K. Naik, N. Sahoo, "Aerodynamic performance and starting torque enhancement of small-scale Darrieus type straight-bladed vertical axis wind turbines with J-shaped airfoil," *Journal of Renewable and Sustainable Energy*, vol. 16, no. 3, p. 033304, 2024, https://doi.org/10.1063/5.0203557.

[49] F. Mechnane, S. Drid, N. Nait-Said, L. Chrifi-Alaoui, "Robust Current Control of a Small-Scale Wind–Photovoltaic Hybrid System Based on the Multiport DC Converter," *Applied Sciences*, vol. 13, no. 12, p. 7047, 2023, https://doi.org/10.3390/app13127047.

[50] T. J. Zaremba, J. R. Minder, K. Friedrich, "Small-scale wind fluctuations within melting layers of winter storms: results from WINTRE-MIX," *Journal of the Atmospheric Sciences*, vol. 82, no. 3, pp. 457-482, 2025, https://doi.org/10.1175/JAS-D-24-0087.1.

[51] M. Borunda, R. Garduno, J. de la Cruz Soto, R. A. F. Díaz, "Intelligent Control of an Experimental Small-Scale Wind Turbine," *Energies*, vol. 17, no. 22, pp. 1-32, 2024, https://doi.org/10.3390/en17225656.

[52] Z. Zhao *et al*., "Harmonics propagation and interaction evaluation in small-scale wind farms and hydroelectric generating systems," *ISA transactions*, vol. 129, pp. 334-344, 2022, https://doi.org/10.1016/j.isatra.2022.02.050.

[53] A. Eltayesh *et al*., "Experimental and numerical investigation of the effect of blade number on the aerodynamic performance of a small-scale horizontal axis wind turbine," *Alexandria Engineering Journal*, vol. 60, no. 4, pp. 3931-3944, 2021, https://doi.org/10.1016/j.aej.2021.02.048.