Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

Design and Feasibility Analysis of Small-Scale Wind Turbines

Sachin Bansal, Pankaj Kumar Pandey
Amity University Rajasthan Jaipur-303002

Abstract - The rapid growth of population, industrialization, and urban development has significantly increased global energy consumption, leading to excessive dependence on fossil fuels and associated environmental challenges such as greenhouse gas emissions and climate change. In response to these concerns, renewable energy technologies, especially wind energy, have emerged as sustainable alternatives for clean and decentralized power generation. This study investigates the performance and feasibility of a vertical axis small-scale wind turbine (VSWT) installed at Jaichandpura village, Jaipur, Rajasthan under moderate wind conditions. The experimental turbine consisted of four FRP blades and was evaluated at wind speeds ranging from 3-8 m/s. Field observations indicated an average wind velocity of 5.75 m/s, while the maximum wind power density achieved was 31 3.6 W/m² at 8 m/s wind speed. The turbine generated a maximum energy output of 21 1 .68 Wh with an overall system efficiency of approximately 45%. The findings indicate that the proposed VSWT system is technically suitable for decentralized rural electrification and small-scale energy applications. Furthermore, the study highlights the potential integration of small-scale wind systems with hybrid renewable technologies to enhance energy reliability in remote regions. The proposed work contributes toward sustainable energy development and supports Sustainable Development Goal (SDG) 7: Affordable and Clean Energy, as well as SDG 1 3: Climate Action.

Keywords: small-scale wind turbine, sustainable rural development, energy efficiency, wind energy, feasibility analysis

INTRODUCTION

Energy is an essential aspect of economic growth and social improvement, and the world's need for energy has grown tremendously because of fast population expansion, urbanization, industrialization, and technological breakthroughs that lead to a dependency on fossil fuels [1 ,2]. Fossil fuels are widely used, but they have serious negative effects on the environment and human health, such as air pollution, greenhouse gas emissions, and climate change. As a result, the shift to environmentally friendly and sustainable energy sources is imperative. India's economy is one of the fastest growing in the world, and it will be difficult to meet its growing energy needs while maintaining environmental sustainability. Initiative and regulations put up by Ministry of New and Renewable Energy (MNRE) has increased the utilization of renewable energy especially wind energy in India. The renewable energy plays an important role in the production of 475 GW of energy generated as of 2025 in India [3]. Keeping in view of Sustainable Development Goals (SDG), about 1 70% growth has been reported during last decay put India commitment for the clean and sustainable energy transition. With a wind energy capacity exceeding 50 GW (GWEC, 2024), India becomes the world's leading producers of wind energy. States like Tamil Nadu, Gujarat, Karnataka, Maharashtra, Andhra Pradesh, and Rajasthan together produces about 90-95% of all wind power generation. Due to its abundance of land, advantageous wind regimes, and robust renewable energy policies, Rajasthan became the leader in wind energy growth. Rajasthan contributed over 57.35 billion units (BU) of power from renewable energy sources as of 2024-2025, making up roughly 1 4.21 % of all renewable generation in India. Rajasthan is one of the top states, making a substantial contribution to India's total wind power production. All things considered, India's wind energy industry has great growth potential and is anticipated to be crucial to reaching the nation's goal of 500 GW of non-fossil fuel capacity by 2030, supporting sustainable development and climate change mitigation objectives [4]. For these kinds of applications, small-scale wind turbines (SWTs), which are generally classified as turbines with a capacity of less than 1 00 kW, have become a viable option [5]. Small scale wind turbines have many advantages such as lower transmission losses, better energy access, and increased energy security. SWTs when combined with renewable energy technologies can provide steady electricity [6]. Wind turbine effectiveness dependent on variables such as blade geometry, tip speed ratio, airfoil properties, wind speed distribution, sufficient wind resources and site selection [7]. Average wind speed, wind direction, topographical characteristics, and closeness to load centers are the main factors for installations of SWTs [8]. The design and viability analysis of small-scale wind turbines for decentralized energy applications are the main objectives of this project. The atmospheric boundary layer (ABL)[9] plays a critical role in wind energy applications because wind speed and turbulence vary with height due

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

to surface roughness and thermal effects. Small-scale wind turbines operating near ground level are significantly influenced by ABL characteristics. Rajasthan provides suitable conditions for decentralized wind energy systems due to favorable wind regimes, open terrain, and increasing renewable energy investments. However, limited studies have focused on rooftop vertical axis wind turbines under villages conditions as an energy management application in Rajasthan, which represents a major research gap addressed in the present study. To assess the practical application of such systems under wind conditions, a case study of Jaichandpura village in Jaipur, Rajasthan, is taken into consideration. The study intends to examine the potential of small wind turbines in promoting rural electricity and sustainable development, analyze the technical design factors, and evaluate the installation viability.

MATERIALS AND METHODS

Methodology

The present study focuses on the design, testing, and feasibility evaluation of a small-scale wind turbine (SWT) under moderate wind conditions. The vertical axis small-scale wind turbine was installed on a rooftop at Jaichandpura village, Jaipur, Rajasthan at a height of approximately 3.35 m. The turbine consisted of four FRP blades connected to a generator system. Wind speed data were recorded at regular intervals using field measurements. Unlike horizontal axis wind turbines, VAWTs can accept wind from all directions without requiring yaw mechanisms, making them suitable for decentralized applications. The turbine consisted of the following major components: (a) Four FRP (Fiber Reinforced Plastic) blades (b) Rotor shaft (c) Mild steel support structure (d) Permanent magnet DC generator (e) Battery storage unit
(f) Charge controller and inverter system. The schematic diagram has been shown in Figure *1*.

Principle of Wind Energy - Conversion of kinetic energy into mechanical energy by applying rotor blades and then converting the energy into electrical energy through a generator is the principle of wind energy [1 0]. The wind power is calculated using equation 1 :

$$P = 0.5\rho AV^3 \text{----------} 1$$

where:
P= power in wind (W)
ρ= air density (1 .225 kg/m³) A=
swept area (m²)
V= wind velocity (m/s)

$$Pm = Cp \times Pw __ 2$$

The actual output power is calculated using equation (2) where Pm- mechanical power extracted by the turbine (W), Cp is the power coefficient, Pw- total wind power (W). This coefficient changes with the wind speed and the design of the wind turbine. Practically, the power coefficient is between 0.4 and 0.45 [1 1].

The total energy generated over time is calculated using equation 3:

$$E = P \times t \text{---------} 3$$

where:
E= energy (Wh)
P= power output (W) t=
time (hours)

Efficiency of System is calculated using equation 4

\(η)=P_{output/P_{input\times1 00\) ---------- 4

Poutput- The useful power generated or the work successfully completed by the machine. Pinput- The total power supplied to the system to make it run.

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

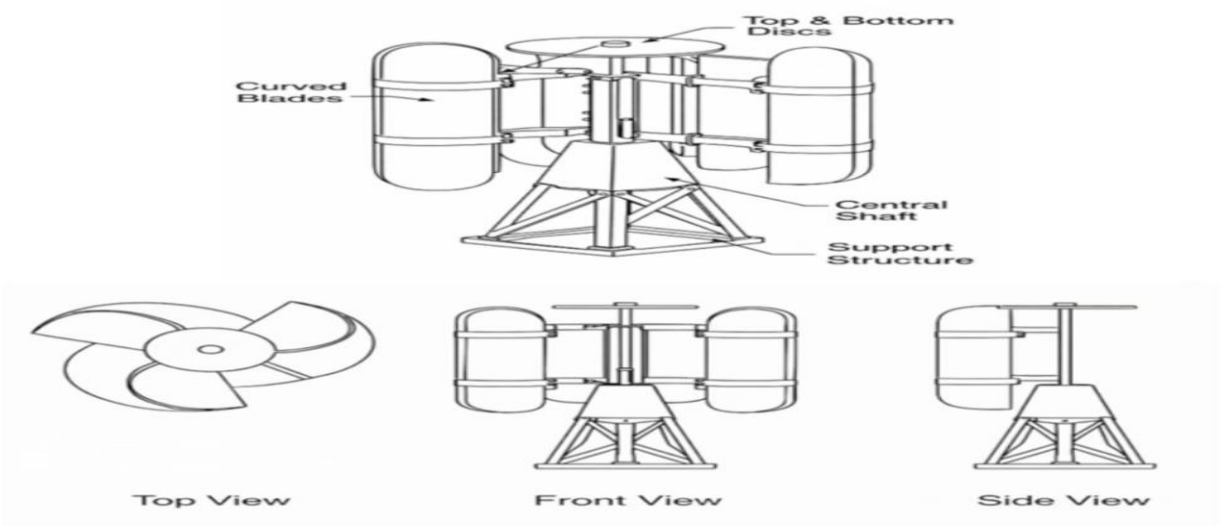


Figure 1: Schematic view of vertical axis wind turbine

FIGURE 1 : Schematic view of vertical axis wind turbine

RESULTS AND DISCUSSION

Results and Discussion- The performance analysis of the vertical axis small-scale wind turbine (VSWT) was carried out under actual environmental conditions at Jaichandpura village, Jaipur, Rajasthan. The study primarily focused on evaluating wind characteristics, power generation capability, energy output, system efficiency, and the overall feasibility of decentralized wind energy applications in rural areas.

Design of vertical axis small axis wind turbine (VSWT)-

The VSWT is designed to generate electrical power for rural homes using available wind energy. The system converts the kinetic energy of wind into electrical energy and stores it for later use. It consists of rotor blades, hub and shaft, generator/alternator, tower, charge controller, battery bank, inverter. The technical details include 0.3 KW windmill vertical axis consists of four numbers of FRP blades, PM alternator, design of hybrid of Darrieus-Savonius vertical axis wind turbine, tubular pole/pedestal of 0.5m, charge controller- input 3ph AC and output 1 2V DC, 25 amps rating with display.

Effect of time with wind speed-

Figure*2*illustrates the variation of wind speed recorded during the experimental testing period at Jaichandpura Village, Jaipur, Rajasthan. The wind speed exhibited temporal fluctuations due to changing atmospheric conditions, surface roughness, and turbulence associated with the Atmospheric Boundary Layer (ABL). The measured wind speed ranged from 3.0 to 8.0 m/s, with an average value of 5.75 m/s throughout the monitoring period. At the beginning of the observation period, wind speed remained relatively low (approximately 3-4 m/s), resulting in limited turbine rotation and lower electrical power generation. As the day progressed, the wind velocity gradually increased and reached a peak value of 8 m/s, corresponding to the highest recorded power density of 31 3.6 W/m² and maximum energy generation of 21 1 .68 Wh. Following the peak period, wind speed showed moderate fluctuations before gradually decreasing during the later hours of the day. Overall, Figure*2*confirms that wind speed variability has a direct influence on turbine performance and energy production. The results emphasize the importance of long-term wind resource assessment and proper site selection for improving the efficiency and reliability of small-scale wind energy systems. These wind conditions are considered suitable for the operation of small-scale wind turbines; particularly vertical axis turbines designed for low and moderate wind speed environments. The experimental results revealed that turbine performance was strongly dependent on wind velocity due to the cubic relationship between wind speed and power output.

Effect of wind speed

The power as a function of wind speed is shown in fig *3*. The theoretical power available in wind was estimated to use standard

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

wind power equations, while actual power generation was determined through turbine output measurements. At lower wind speeds (3-4 m/s), the turbine generated limited power output, which was sufficient only for small electrical loads such as LED lighting and mobile charging. However, as wind speed increased beyond 5 m/s, the power output increased significantly. The turbine achieved its maximum power density of approximately 31 3.6 W/m² at a wind speed of 8 m/s. Similarly, the maximum energy generated during the testing period was found to be 21 1 .68 Wh, indicating the capability of the system to support basic household energy demands. It shows that as wind speed increases the power per unit swept area also increases and reaches up to a maximum value of 31 3.6 W/m2 at a wind speed of 8 m/s.

Efficiency and energy of wind turbine- Using the equation 4, the overall system efficiency was calculated to be approximately 45% which falls within the acceptable range reported for small-scale vertical axis wind turbines in previous studies. The relatively good efficiency obtained in this study may be attributed to the aerodynamic design of the blades, low mechanical losses, and favourable rooftop wind conditions. Compared with conventional horizontal axis wind turbines (HAWTs), the VSWT showed better operational stability under turbulent wind conditions and did not require wind direction alignment mechanisms. [1] reported that small-scale vertical axis wind turbines operating under low wind conditions generally achieve efficiencies ranging between 35-50%, depending on blade configuration and site conditions. Similarly, [4,11] highlighted that small wind turbines become economically feasible in rural regions where grid connectivity is limited and renewable energy integration is encouraged.

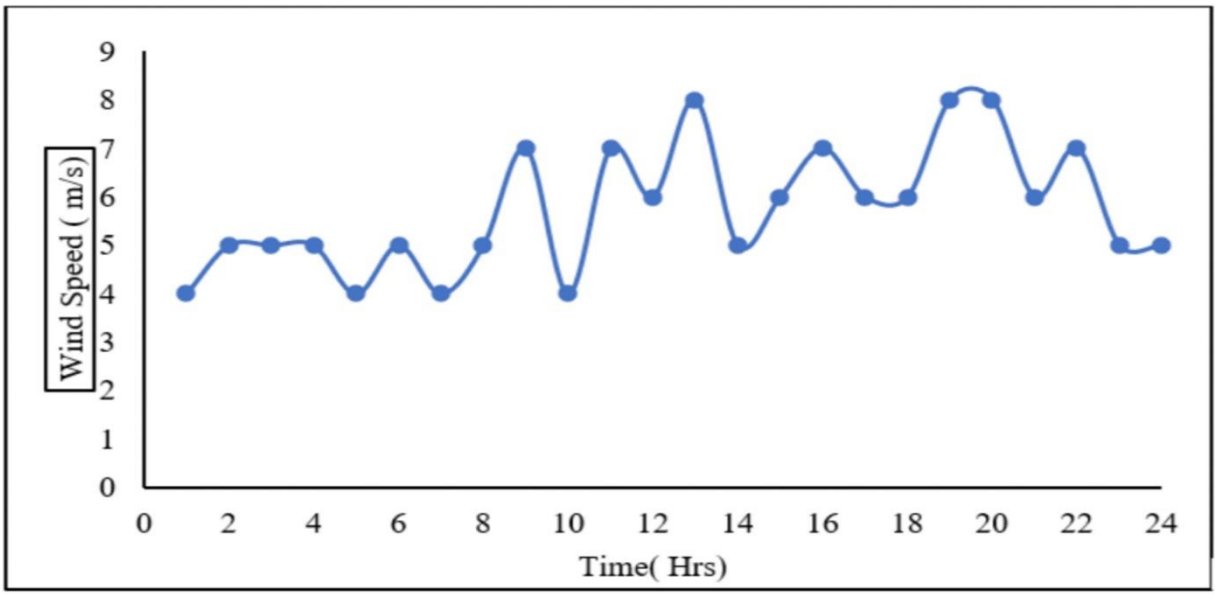


Figure 2: - Effect of time on Wind speed

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

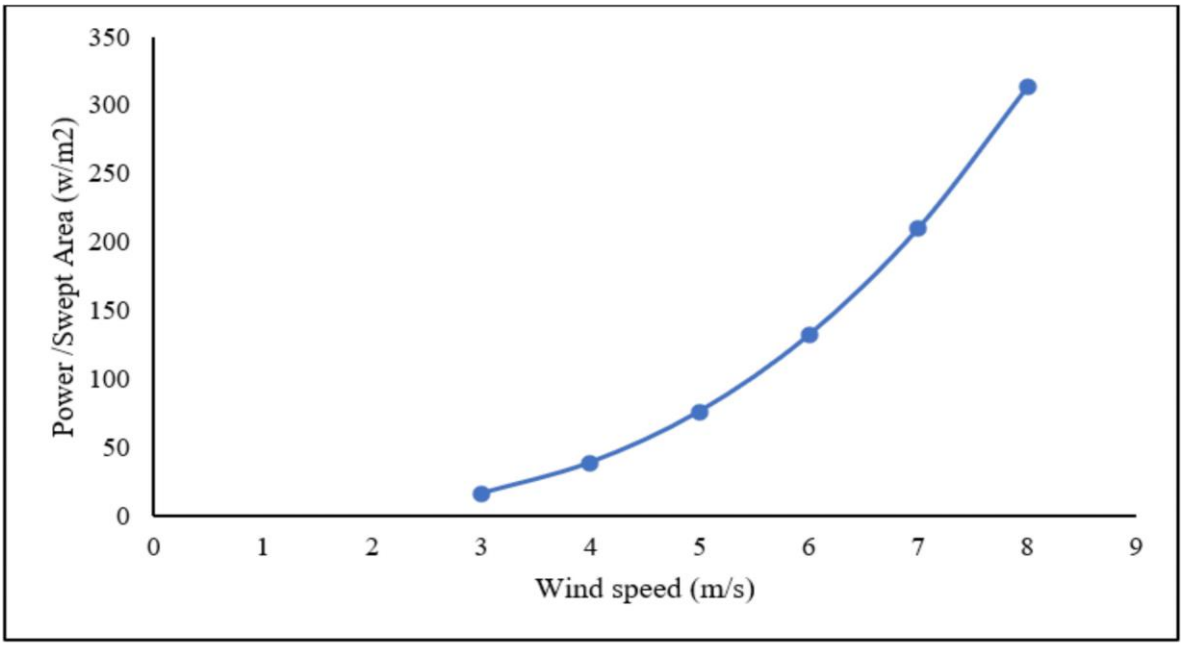


Figure 3: - Effect of wind speed on Power output

CONCLUSIONS

This study presents the design and feasibility analysis of vertical axis small-scale wind turbines (VSWTs) for decentralized energy generation, with a specific focus on rural applications. The selection of the Vertical Axis Wind Turbine(VAWTs) over the Horizontal Axis Wind Turbine(HAWTs) for small-scale rural applications is due to that VAWTs are capable of accepting wind from any direction without requiring a yaw mechanism, have better self-starting capability at low wind speeds (depending on the design), are easier to install and maintain due to ground-level placement of major components, generate lower noise, and are more suitable for turbulent and multidirectional wind conditions commonly found in rural and built environments. Although VAWTs generally have lower peak aerodynamic efficiency than HAWTs, their operational simplicity, reliability, and satisfactory power output under low to moderate wind speed conditions make them a feasible choice for decentralized small-scale electricity generation. The VSWTs has efficiently harness wind energy having wind speed ranging from 3 to 8m/s. These types of VSWTs can be suitable for rural areas required less amount of energy. The estimated energy output will fulfil the need of rural homes by combining with energy storage or hybrid systems. The wind turbine installed has the long operational life (20-25 years) and low maintenance costs improve overall cost-effectiveness. Overall, the results confirm that small-scale vertical axis wind turbines can serve as an effective and sustainable decentralized energy solution for rural electrification. The proposed system supports clean energy generation, reduces dependence on fossil fuels, and contributes toward achieving Sustainable Development Goal (SDG) 7: Affordable and Clean Energy and SDG 1 3: Climate Action.

REFERENCES

[1] Basack S, Dutta S: Installation and performance study of a vertical-axis wind turbine prototype model.Sustainability. 2022, 1 4:1 0.3390/su1 4231 6084
[2] Ouerghi FH, Omri M, Abdel A, Taloba AI, El-: RMA:Feasibility evaluation of wind energy as a sustainable energy resource.Alexandria Eng J.. 1 06:227-239. 1 0.1 01 6/j.aej.2024.06.055.
[3] Ministry of New and Renewable Energy. Renewable energy statistics 2024-25. https://cdnbbsr.s3waas.gov.in/s371 6e1 b8c6cd1 7b771 da77391 355749f3/uploads/2025/1 1 /20251 1 061 627678782.pdf.
[4] Hosseinalizadeh R, Shafiei A, Farid S: Economic analysis of small wind turbines in residential energy sector in Iran. Sustain Energy Technol Assessments. 20:58-71 . 1 0.1 01 6/j.seta.201 7.02.01 8.
[5] Athraa Ali Kadhem, Wahab NIA, Ahmed N Abdalla: Wind energy generation assessment at specific sites in a peninsula in malaysia based on reliability indices. Processes.. 201 9, 7:1 0.3390/pr7070399
[6] Kułyk P, Augustowski Ł: Economic profitability of a hybrid approach to powering residual households from natural sources in two wind zones of the lubuskie voivodeship in poland. Energies. 1 4:1 0.3390/en1 421 6869
[7] Matcha A, Abhilasha TR: India ' s net zero journey : a decade of sustainable progress - 201 3 to 2023. International Journal of Science and Research.. 2024, 1 3:284-294. 1 0.21 275/SR249241 1 1 201

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

[8] Wagh AS, Naik P: Design and analysis of a small-scale horizontal axis wind turbine for rural power generation. Journal of Engineering and Technology Management. 34:6-1 0.
[9] Stull, R. B: An Introduction to Boundary Layer Meteorology . springer, 1 988. 1 0.1 007/978-94-009-3027-8
[10] 1 0. Lumbera MP, Encarnacion JIB : Design optimization of small-scale horizontal-axis wind turbines using genetic algorithm to minimize co2 emissions.. Chemical Engineering Transactions. 2025, 253-258. 1 0.3303/CET251 20043
[11] 1 1 . Ruzi NA, Rosly NH: : Conceptual design and analysis of small-scale wind turbine for household usage in malaysia. Progress in Aerospace and Aviation Technology. 2023, 3:28-36. 1 0.30880/paat.2023.03.02.004

(This work is licensed under a Creative Commons Attribution 4.0 International License.)