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Development of a roof-mounted stand-alone wind turbine system for house-hold power generation

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Abstract

In recent years, the development of sustainable energy sources has attracted increasing interest due to worries about the environmental effects of greenhouse gas emissions. Renewable energy and technology may provide a solution to the persistent environmental issues that developing nations are currently experiencing. In this work, it has been demonstrated that the design, analysis, and implementation of the newly developed small roof-mounted stand-alone wind turbine systems for household energy production. It is specially designed for sites with low altitudes (12 m above ground) and low wind speeds (range of 1–12 m s^{-1}). The wind turbine system involves the mechanical design of the 3-blade rotor and its installation on a micro-capacity and self-contained 325 W wind turbine. The experimental analysis reveals that the peak power coefficient (C_P) is quite good, about 0.13, and the output power is 43.75 W. The comparative analysis is also done to validate that the results are consistent with micro-capacity systems that have been tested under similar conditions. This work provides insight into the development of roof-mounted stand-alone wind turbine systems, which have a lot of potential for green applications and to make up for people who don't have access to electricity.

1. Introduction

India has seen a massive jump in renewable energy, with 40% of the world's installed power coming from renewable sources by the end of 2022. This is almost half of the total capacity. The most dependable sources of renewable energy are the wind and the sun. The globe added over 295 GW of renewable energy in 2022, which was the year with the biggest rise. Out of which, the 75 GW share was of wind power. As per the Global Wind Energy Council (GWEC) report 2023, India is the 3rd most significant producer of wind turbine components globally [1]. The first wind power plant was installed in India in 1986 in Maharashtra, Gujarat and Tamil Nadu. As per the Government of India Ministry of power, India's total renewable power installed capacity is almost 168 GW by March 2023 [2]. India is 4th in the world in the wind power sector, with around 43 GW of installed capacity as of March 2023. Developed states like Maharashtra have almost 5 GW of installed wind capacity, Tamil Nadu has 9.6 GW and Gujarat has more than 8.5 GW [3]. Tamil Nadu and Gujarat are the two major contributors to India's wind-installed power capacity.

Wind is generated by temperature variations or uneven heating from the sun on the Earth's surface. Wind turbines are used to create energy from a natural source. Depending on the axis of rotation, they can be classified as Horizontal or Vertical axis. Horizontal axis turbines rotate parallel to the ground, while vertical axis turbines revolve perpendicularly [4]. The power generation capacity of wind turbines can be classified as Micro, Mini, Small, Medium, Large, or Ultra Large, depending on the size of the rotor and the generation capacity. There is no commonly accepted limit for this classification [5]. The wind turbine's size depends on the power it can produce at the wind's rated speed, which the wind turbine manufacturer specifies. Small wind turbines have a power capacity varying from 50 W to 15 kW, with a rotor diameter of between 0.5 and 10 m, above 15 kW. They are installed for commercial purposes and connected to networks. As defined by some researchers, micro-capacity wind turbines range from 4–250 W [4, 6]. The researchers noted that these types of micro-capacity turbines are typically mounted on roofs and are specifically designed for domestic applications [7]. However, only a limited amount of study has been conducted on the claim of micro-capacity sizes of wind turbines. The UK government had proposed to include micro-generation capabilities in roofing standards. It had set a target to have all new construction residences carbon-neutral by 2016. Micro-wind is one of the technologies in this sector that has the potential to be developed and widely adopted. However, there were only a few household systems, particularly in metropolitan areas. A larger number of micro wind turbines had previously been installed for educational purposes at institutions or environment centres, with horizontal axis turbines having power ratings in the range of 2.5–20 kW. However, in recent years, the small wind turbine industry has begun focusing on the market for smaller, building-integrated turbines with capacities below 1.5 kW. Additionally, there has been an emphasis on creating rooftop systems that are suitable for residential homes in metropolitan areas. The availability of these technologies has expanded the scope of Do It Oneself. Stores in the UK attract good interest from both the public and private sectors [8].

The urbanization is growing highly with an exponential increment in population. It demands high energy requirements in urban areas. In order to achieve the United Nations Sustainable Development localized micro-generation of energy from renewable sources within urban contexts can be extremely important. Wind energy utilisation in urban settings has been identified as a potential source of renewable energy production close to the end-user, even though wind energy usually originates from wind farms outside of metropolitan centers [9]. A performance study has been carried out on a wind tunnel experiment for the roof-mounted horizontal axis turbine and investigated the changes in performance curves and parameters with modification of roof edge shapes which is the latest investigation for roof-mounted systems [10]. An in-depth review of the literature on the analysis of micro-turbine installations on high-rise buildings has revealed that these structures act as towers. The author mentioned that these micro wind turbines were installed in nine states of India for domestic use [11]. The review presented a comprehensive overview of small-scale wind turbines, noting that the installation of a large wind farm has a considerable impact on the climate, thus making micro-turbines more suitable for home use [6]. A performance analysis of a small-scale horizontal axis wind turbine focused on the design of the rotor blades and the decrease in starting time as key parameters [12]. Additionally, a simplified blade design method was presented and fabricated with 3D printing technology for a 0.15 m rotor diameter wind turbine, setting a new concept for micro-size turbines [13]. A comparative study was conducted on a bio-inspired flexible centrifugal rotor blade design for a small wind turbine, proposing it as the preferred option over rigid rotor blade systems. This comparative study provided valuable attention to the design, fabrication and testing of micro-capacity wind turbines, as the previous studies prior to this review had been based on rigid blade systems [14]. The case study on the electrification of small villages in Ethiopia for small-capacity wind turbines addressed the new application of micro-to-small-size wind turbines [15]. The wind turbine blades' design begins with the airfoil's design and the distribution of the chord and twist angles. The design of wind turbine blades begins with the design of the airfoil and the distribution of the chord and twist angles. These parameters define the primary blade design, i.e., the aerodynamic shape of the blade along the span of the wind turbine (tapered) [16]. Giant wind turbine blades are designed by incorporating multiple airfoils in the span. In contrast, small-sized blades are designed with the same airframe throughout to reduce the overall cost [4, 16]. Large-size turbine airframes could not be incorporated into small and micro-size blades. The design of new airfoils and blades is continually being developed, based on the size of the turbine and environmental conditions. The QBlade tool has been used to create a new blade profile for micro-capacity size turbines (950 W) with a wind velocity of 7 m s^{-1}, and a computational investigation has revealed that this newly designed blade profile has superior power performance compared to the Boeing-Vertol V-13, NACA 2408, and other blade profiles [17]. Commercial wind turbines have been suggested as a solution to meet domestic energy needs while reducing carbon dioxide emissions from buildings. Small wind turbines have traditionally been used by farmers to produce electricity and pump water and are mounted to a tower. Micro-wind turbines are much smaller than these and have a power output below 3.5 kW. The power generated by micro-wind turbines is usually not enough to power a typical UK family. However, they can be used in conjunction with solar panels, as grid power or for specialised demand generation, like heating or water. Micro-wind turbines can also be installed on top of buildings. Currently, micro-wind has a low economic payback period of up to 10 years, making it unattractive to some buyers [18]. This paper provides an overview of the open-source wind turbine design concept that can be developed by using CAD software. It compares it to existing wind turbine concepts in terms of complexity, aerodynamic performance, and potential material options. It is intended to provide insight into the workability of building wind turbines with low initial investment costs and low economic risk, making the technology more attractive to a wider range of individuals.

The concept is intended to be installed in urban or lightly wooded areas, and the material options and qualities of the installation conditions will be discussed to gain a better understanding.

The literature review on micro-capacity HAWT shows that very few studies have been conducted theoretically and experimentally to extract power from such kinds of stand-alone systems for household power generation. Therefore, the research aims to generate usable electrical power from an experimental set-up of stand-alone HAWT of micro-capacity at low wind speed to run household appliances. This research work presents design and performance results of stand-alone micro-capacity wind turbines rated at 43 W with 1.4 m diameter, 3-bladed rotor designed for household power generation with an average wind speed of 7 m s^{-1}. The present theoretical and experimental study based on a newly developed in-house experimental test facility is primarily used for educational and research purposes at the institute. The theoretical and experimental study reports the obtained result for power coefficient stands marginally good for selected wind turbine installation sites.

2. Methodology

This study has selected Horizontal Axis Wind Turbines [HAWT] for roof mount, rather than Vertical Axis Turbines [VAWT]. The HAWT is commonly used for both onshore and offshore profit-oriented applications [19]. The classification of VAWT is done by Savonius and Darrieus [20]. [HAWT] are more aerodynamic, starting independently and having very few components at ground level [21]. The maximum capture of wind is possible in [HAWT], which is why it has a higher efficiency than [VAWT] [22]. Kinetic energy is used to revolve the turbine blades and transform them into electrical energy for home use. A large rotor shaft is connected to a gearbox, which drives the generator. In the case of a small-size rotor, the shaft of the rotor is connected directly to the generator. The governing equation of wind turbine power is provided below, based on the Betz limit reported in [4, 23], and well derived in [24].

$$P_O = \frac{1}{2} C_P \rho \, \pi r^2 V^3 \tag{1}$$

Where P_O = Power available at output
C_P = Power coefficient

$$C_P = \frac{P_O}{P_I} \tag{2}$$

P_I = Wind power input to the turbine

$$P_I = \frac{1}{2} \rho A V^3 \tag{3}$$

Where; $A = \pi r^2$ Swept area of rotor blade [m^2]
V = Wind speed [m s^{-1}]
ρ = Air density [kg m^{-3}]

The power coefficient is expressed as the ratio of the actual electrical power generated by the wind power input into the turbine. It indicates the entire efficiency of the wind turbine, which is most commonly used by the wind turbines industry [4, 23]. From the governing equation above, wind power is directly related to wind speed and increases with cubic power. However, the air density for a specific selected site does not change significantly as the height of the pole is fixed and the swept area for the specific design of the turbine must be constant. A turbine can only extract 59% efficiency according to the Betz limit, also known as maximum theoretical efficiency, which can be reduced by taking into account mechanical and electrical losses [4, 25].

2.1. Wind turbine design

The operational data required for the newly developed system is illustrated in (table 1).

2.1.1. Newly developed stand-alone system design

(1) Swept area of the turbine:

$$A = \pi r^2 = \pi \times 0.7^2 = 1.53 \ \mathrm{m}^2 \tag{4}$$

r : Length of the blade or radius of the rotor

Table 1. Specification and design parameters of newly developed system.

Operational data	
Span of the blade	0.7 m
Rotor diameter	1.4 m
Average wind speed	7 m s^{-1}
Cut in wind speed	1 m s^{-1}
Cut out wind speed	12 m s^{-1}
Design TSR	5
Rotor	
Numbers of Blade	3
Blade Material	Aluminum composite
Axis	Horizontal
Swept area	1.53 m^2
Rotational speed	75 rpm to 739 rpm
Generator	
Type	AC
Voltage	16 V
Rated Power output	100 watts
Rotational speed	50 to 500 rpm
Tower	
Type	Tubular mild steel
Outer Diameter	58 mm
Inner Diameter	50 mm
Height	3 m (Adjustable 1.5 to 3 m)
Base Frame	
(ISMC 100 mm × 50 mm)	Handling and transportation are quite portable as the design structure of the system is made adjustable.
Yaw Mechanism	Provided (System is made to orient in the direction of wind)

(2) Calculation of available wind power

$$P_I = \frac{1}{2}\rho\pi r^2 V^3$$

$$= \frac{1}{2} \times 1.225 \times \pi \times 0.7^2 \times 7^3 = 323.40W$$

(3) The power output equation with consideration of all efficiencies (η) of various other components (i.e. gearbox, generator) the equation 1st can be rewritten as:

$$P_O = C_P \eta \frac{1}{2}\rho\pi r^2 V^3 \tag{5}$$

Finding the efficiency of turbines (η), there's no one-size-fits-all approach to turbine efficiency, so different authors have suggested different efficiencies based on components or services. The turbine's efficiency (η) is calculated using mechanical, electrical, and blade aerodynamic efficiencies as given below [4, 26, 27].

$$\eta = (1 - K_M) \times (1 - K_E) \times (1 - K_{ET}) \times (1 - K_T) \times (1 - K_W) \tag{6}$$
$$= (1 - 0.003) \times (1 - 0.015) \times (1 - 0.1) \times (1 - 0.03) \times (1 - 0.1) = 0.77$$

Where;

$$K_M = mechanical \quad losses \quad of \quad blades \quad and \quad gearbox \quad (0 - 0.3\%)$$
$$K_E = electrical \quad losses \quad of \quad turbine \quad (1 - 1.5\%)$$
$$K_{ET} = \text{transmission electrical losses} \quad (3 - 10\%)$$
$$K_T = \text{turbine downtime losses due to maintenance} \quad (2 - 3\%)$$
$$K_W = \text{turbine wake losses}(3 - 10\%)$$

The turbine total efficiency (η_T) is calculated as:

Table 2. Assumptions and design parameters of newly developed stand-alone system.

Design parameters	
Type of turbine	HAWT
Length of blade	0.7 m
Wind speed	7 m s^{-1}
Available wind power	323 W
Power coefficient (C_P)	30%
Wake losses	10%
Output power before losses	87 W
Losses (Assumptions)	
Mechanical losses	0.3%
Electrical losses on turbine	1.5%
Transmission electrical losses	10%
Time out or down time of turbine (maintenance)	3%
Expected Output Power	
Total efficiency of turbine	23.15%
Output power with losses	75 W
Torque in the turbine blades	1.50 N-m
TSR	5
Revolutions per minutes	477 rpm

$$\eta_T = C_P\eta = 0.30 \times 0.77 = 0.231 = 23.1\% \tag{7}$$

Power coefficient C_P is typically between in the range of (30%–40%) [4, 27]

(4) Calculation of the power output

$$P_O = \eta_T P_I = 0.231 \times 323.40 \approx 75W \tag{8}$$

(5) The researchers [4, 24] reported the local tip speed ratio as:

$$N_{Rotor} = \frac{30}{\pi}\lambda\frac{V}{R} = \frac{30}{\pi} \times 5 \times \frac{7}{0.7} = 477rpm \tag{9}$$

Many researchers have reported experimental and simulation results for micro capacity wind turbines up to rotational speed of 500 rpm [6, 28].

(6) Torque in the turbine blades

$$T = \frac{P_O}{N}\frac{30}{\pi}$$
$$= \frac{75}{477} \times \frac{30}{\pi} = 1.50\ \ Nm \tag{10}$$

The above mathematical design model and assumptions in design calculations are represented in (table 2)

2.1.2. Blade design theories

There are three primary theories of blade design: blade element theory, blade momentum theory, and blade element momentum. Different researchers employ various blade design theories to their advantage. The blade element momentum theory is one of the most widely used theories, or BEM. Researchers have listed ten methods for determining the chord length distribution of rotor blades along their length [29]. Additionally, the researchers have briefly explained the Aerodynamic and General Momentum Theory for Small (HAWT). This theory has been accepted as a promising one for small wind turbine blade design [30, 31]. Aerodynamic rotor blades are designed to capture more wind energy. Research work on turbine design using tools such as QBlade has led to the emergence of new researchers in this field [17, 24]. The design of a rotor blade is relatively straightforward, and is commonly referred to as baseline blades, or rectangular blades. The components and system are all made from scrap material, and aluminium composite sheet is preferred. The shape of the blades is determined in solid works, and the raw machining operations are conducted in in-house workshops to obtain the desired shape and size of the rotor blades. The bolted joints are designed to facilitate assembly operations. To ensure the aerodynamic shape of the blades, a manual twisting angle is provided while mounting them on the rotor, which necessitates the expertise of operators. (figure 1) illustrates the CAD model of the rotor blade based

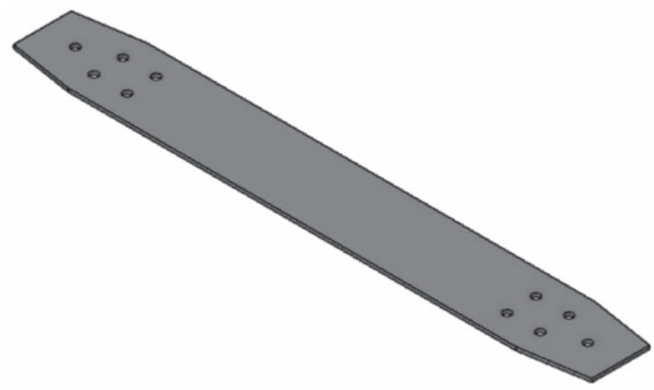

Figure 1. 3D rotor blade design using CAD tool.

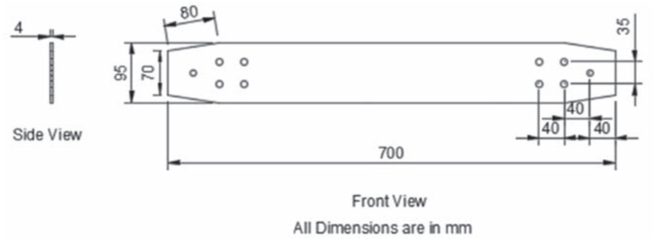

Figure 2. Rotor blade drafted dimensions in (mm).

Table 3. Design wind turbine rotor blade dimensions.

Design parameters	
Material	Aluminium composite sheet
Length (span)	700 mm
Thickness	4 mm
Width	95 mm
Bolt size diameter	10 mm
Weight of each blade	258 gm

on the rectangular profile shape known as the baseline blade, and (figure 2) illustrates the design dimensions and parameters of the rotor blade mentioned in (table 3).

2.1.3. Small-capacity size blade manufacturing methods

Different blade manufacturing methods include filament winding, pure wood blade, hand lay-up process, Injection moulding, and Resin transfer moulding. Filament winding is most widely used in the aerospace industry. It is used for small wind turbine blades. The material used is fiberglass composite [4, 32]. Pure wood blade is used for blades of 1m in size. The wood material is readily available. However, the issue with this method is the life of the blade components and the accuracy of maintaining the shape and size. It is difficult to achieve close tolerances [32]. The hand lay-up process requires skilled operators. It is very popular for the producing blades of fibres and epoxy composite. The fibres and clothes are accurately cut in the required shape and dimensions. It is placed by hand and infused with resin. The quality of the product entirely depends on the skill of the operators [33]. For small wind turbines with a rotor size under 200 m^2 and a power capacity of less than 50 Kw, the author has designed, manufactured, and installed a diffuser-augmented wind turbine (DAWT). This system is suitable for remote telecommunication applications [34]. The various researchers discussed various manufacturing methods that are dependent on the materials used for rotor blades. These materials range from fibres to composites and thermosets to thermoplastics, and the material properties were considered with design and recycling considerations [15, 35].

Figure 3. Manufactured rotor blades.

The gyroscopic and fatigue loading of a turbine blade are of the utmost importance, as they are caused by turbulent wind. Fatigue loading is defined as the accumulation of 10^7 cyclical loads over an average lifespan of 20 years. The key requirements for manufacturing these blades are high stiffness, low weight, resistance to fatigue load and geometric design and construction [36, 37]. (figure 3) illustrates manufactured rotor blades of aluminium composite material. Baseline blades are simpler to manufacture than complex airfoil designs, and are also more cost-effective in product design and manufacturing. To compare the efficiency of baseline blades and aerodynamics blades, the aerodynamics shape profile is higher in the baseline blades. Micro-capacity turbines require the aerodynamics blade profile. New researchers who self-fund for domestic applications can follow this baseline blade concept as it does not require add-on skills operators for manufacturing the product.

2.2. Installation site selection

Selecting the most suitable site to install a wind turbine is of paramount importance. A study of computational studies has been conducted to generate a blade profile appropriate for micro-sized turbines in the vicinity of Pune, India [38]. Small wind turbines are mainly used for domestic applications, or to be mounted on roofs to meet the electricity needs of homes and villages [39]. The following factors mentioned in (table 4) should be considered for the site selection.

2.3. Turbine components

Wind turbines are classified according to the rotor orientation and divided into Horizontal Axis Wind Turbines (HAWT), Vertical Axis Turbines (VAWT), and Three Bladed Turbine Systems (HAWT). HAWT is the most widely used and popular type of turbine. As the number of blades increases, the turbine's efficiency decreases slightly. However, this also leads to an increase in the cost of materials and manufacturing [42]. In this study, the author developed an in-house assembly for a new roof-mounted stand-alone wind turbine system. The following are the components or systems developed and installed at selected locations by the author: Upgrading in system, time being is the guiding principle of this research for the purposes of domestic need.

Figure 4. Turbine rotor system.

Table 4. Factors affecting wind turbine site selection.

Factors	Description	Reference
Wind speed (m s^{-1})	As the maximum annual average wind guest is twice the change in power eight times.	Site selection consideration for wind energy conversion [40]
Distance to road or railways	The site should have easy access for transportation of materials, structures, and heavy load machinery.	[40]
Slope	The slope should be less than 15%.	[41]
Altitude	The altitude of the site should be high, as at high altitude the wind speed is high. The micro size turbines should be installed on the roof mount to access the high wind speed.	Site selection consideration for wind energy conversion [40]
Land cost	To have a favourable land cost. It will drop down the total system cost. For micro-capacity size roof mounted systems are preferred.	
Obstructions free site	For the micro-capacity size, the site should be free of obstructions.	

(1) Turbine Rotor

(Figure 4) represents 3 bladed designed turbine rotor of roof mounted stand-alone system.

(2) Head & Yaw Assembly

(3) Base Frame Mount

(4) Wind Turbine Test Set-Up

(Figures 4–7) illustrate the newly designed and developed stand-alone wind turbine system. (figure 5) shows the Head and Yaw assembly, which is composed of two types of bearing rings (inner and outer yaw bearing rings) and yaw gears. The system is mounted on the upper side of the pole below the top plate, and an interlocking mechanism is used. (figure 6) shows the Base Frame System for the roof-mounted stand-alone wind turbine system, which is required to be 100 mm × 50 mm in dimension. This base frame is designed for easy handling and transportation. It is a heavy-weight system to reduce vibrations caused by rotary motion and heavy guest wind speeds, and there is provision for fixing the base frame on the ground. Finally, (figure 7) shows a complete roof-mounted wind turbine set-up at 12 m from the ground, with a tower height of 3 m. One special provision is that the tower is adjustable in height.

One can easily disassemble the entire system, and its handling and transportation are suitable for reinstalling high guest wind speeds. It is clear that wind energy is pollution-free and clean, though there are certain environmental impacts associated with it like, its life cycle, manufacturing, installation, transportation, and maintenance briefly introduced by [43]. Small wind turbines are coupled with synchronous generators [44]. These are called variable

Figure 5. Head and yaw assembly system.

Figure 6. Base frame system.

Figure 7. Tower with rotor and nacelle system.

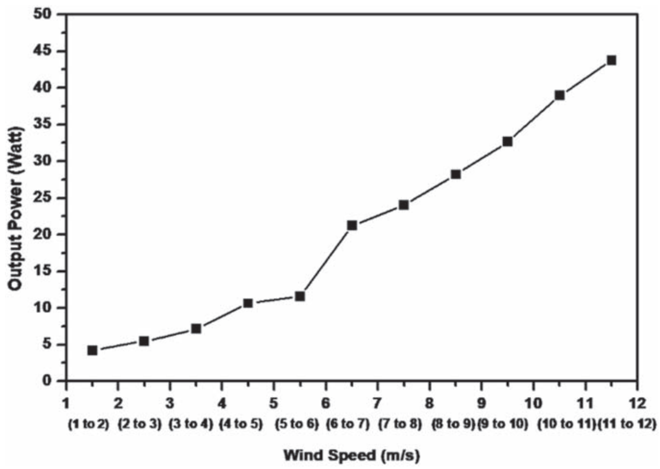

Figure 8. Powers (P) versus Wind Speed (V).

Table 5. Field test report of stand-alone wind turbine system.

Wind speed ($m\,s^{-1}$)	Rotational speed of shaft (rpm)	Voltage (V)	Current (A)	Output power (Watt)
1 to 2	55 to 68	3.5	1.2	4.2
2 to 3	72 to 96	3.9	1.4	5.46
3 to 4	101 to 129	4.2	1.7	7.14
4 to 5	135 to 156	5.6	1.9	10.64
5 to 6	162 to 178	6.1	2.2	11.59
6 to 7	182 to 210	8.5	2.5	21.25
7 to 8	220 to 249	8.9	2.7	24.03
8 to 9	260 to 292	9.4	3	28.2
9 to 10	301 to 340	10.2	3.2	32.64
10 to 11	352 to 378	11.8	3.3	38.94
11 to 12	382 to 402	12.5	3.5	43.75

speed generators. This can generate alternating current (AC). A pole of more than 15m is used as a supporting structure in small wind turbines. Tubular towers, guided wire towers, and tilted poles are the primary types of towers used due to their availability of materials, ease of installation, and ease of maintenance.

3. Results and discussions

A field test was conducted on the college campus terrace to determine the maximum wind speed achievable at the site. The selection of the site was based on the wind speed, and a survey of the anemometer was conducted. From the wind speed data analysis, the most suitable site was selected after collecting data. The selected site is free of obstructions. The maximum wind speed reported for the selected sites was 12 $m\,s^{-1}$, while the average wind speed was observed to be 7 $m\,s^{-1}$. Installation of wind turbines in areas with wind speeds of less than 5 $m\,s^{-1}$ is not economically viable. The power coefficient C_P of the wind turbines was determined from equations (11) and (12). For the power performance analysis, atmospheric pressure was assumed to be 101.325 kPa. A hot wire temperature probe was used to record the ambient temperature. The reported average value of the ambient temperature was 25 °C. The gas equation obtained from the equation showed an air density ratio of 1.18 ($kg\,m^{-3}$) [45, 46].

$$P_T = VI \tag{11}$$

$$C_P = \frac{P_T}{P_I} = \frac{VI}{\frac{1}{2}\rho A U^3} = \frac{12.5 \times 3.5}{323.40} = 0.13 \tag{12}$$

Hence peak power coefficient attained by the newly developed 3-bladed rotor stand-alone micro-capacity wind turbine at 12 $m\,s^{-1}$ wind speed was 0.13.

Where;

P_T: Wind turbine power (W)

Table 6. Comparative study on existing recent micro-capacity wind turbine systems.

Description	Rotor Size diameter (m)	Wind speed range (m s^{-1})	Power coefficient (C_P)	Airfoil and blade design profile
WiRE-01 [48]	0.15	5	0.4	Aerodynamic blade profile
500 W Archimedes spiral wind turbine (ASWT) [49]	1.5	5 to 12	0.25	Archimedes spiral blade profile
400 W Air-X marine turbine [46]	1.26	3 to 6	0.29	A low Reynolds number airfoil (AF300)
500 W multi-cross-section wind turbine blades [50]	1.27	1 to 6	0.040	NACA4412 and Multi-airfoils section
Newly developed Stand-alone micro-capacity INDWT-325 W (A current study)	1.4	1 to 12	0.13	Baseline blade profile- (Rectangular in shape)

P_I: Wind power (W)
V: Turbine voltage
I: Turbine current
U: Free stream velocity of the wind
ρ: density of air (kg m^{-3})
A : swept area of turbine (m^2)
Following readings have been reported in field testing:

Table 5 shows the field test results. The rated power obtained with 12.5 Volt AC capacity generators is 43.75 Watts (figure 8). As the wind speed increases, so does the power. The cut-in wind speed is 1 m s^{-1}, where the power starts to produce. The observed power at the cut-in speed is 4.2 watts. The cut-out wind speed, 12 m s^{-1}, is the point where power production comes to an end. At this point, the observed power is 43.75 watts. It can be inferred from the above information that the maximum peak power ratio of the new independent system is equal to 0.13.

The comparative study is carried out to validate the obtained results are in line with existing recent micro-capacity wind turbine systems under the same circumstances. The studies listed below align with a current study by the authors.

The blades were designed for low wind speed conditions, and field testing was conducted at a rate of 12.5 m s^{-1}. The power output was achieved as 400 W of 1.26 m blade diameter, with a power coefficient of 0.15 [46]. The wind turbine was designed for a power output of 3 kW and was constructed using seven arched thin airfoils with a blade diameter of 3.7 m at a speed of 10 m s^{-1}. The power coefficient was reported to be 0.14. The blades were produced using a glass fiber-reinforced plastic sheet [47]. Standard airfoil NACA 63–622 was used for small blades of wind turbine with a diameter of 3 m. The blades were made from Epoxy Carbon Fibre reinforced plastics. At a rated speed of 7.5 m s^{-1} and the power coefficient was 0.35 [26]. Some of the recently available micro-small capacity wind turbines are listed in (table 6).

A newly developed system is named as INDWT-325W, which means IND stands for the India the country name, WT stands wind turbine of 325 watt designed power capacity.

4. Conclusions

In this work, a newly developed roof-mounted stand-alone micro-capacity 3-bladed rotor has been designed for sites with low altitudes of 12 m above ground and low wind speeds in the range of 1–12 m s^{-1}. In order to get high lift and structural stability, the rectangular-shaped blades have been mounted on the 1.4 m-diameter rotor in this instance. The experimental analysis revealed that the micro-capacity turbine's output power and peak power coefficient are 43.75 W and 0.13, respectively. Additionally, the system is very cost-effective because of the basic blade profile and airfoil design, which are similar to VAWT.

Consequently, the micro-capacity turbine system might be particularly beneficial for urban locations without electricity access.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Future scope

A new, standalone system is developed from scrap material, which will improve the power output of turbines. Turbine blades will be designed based on the newly developed airfoil, and the design of gear boxes or synchronous alternators will further increase power output. Generator sizes up to 200 watts can be installed in order to take advantage of the turbine's maximum rated capacity. QBlade will enable researchers to select airfoils based on application and simulate different airfoils more accurately. This tool will save time and effort compared to wind tunnel testing and field testing, which require time, effort and money. Furthermore, the QBlade tool allows researchers to design and simulate at no cost under general public licenses. Furthermore, researchers can use an iterative algorithms and a trail-based approach to reach the optimal design of aerodynamics and rotor blades.

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Author contributions

Mr Minendra L Surve: Design and conception, experimental and computational work, interpretation of data, drafted the work and revised it Dr Prashant D Deshmukh: The data acquisition and analysis Dr Bharatbhushan S Kale: Conducting of the computational work Mr Akshay R Ghadge: Design of the work Mr Manish V Patil: Conducting of the experimental work.

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