Design and analysis of vertical axis wind turbine on highway

Ms. Pradnya Telang[1], Anvit Morey[2], Akshar Bandagale[3], Pritesh Pawar[4], Ruturaj Bhogle[5]

[1]Asst. Professor, Department of Civil Engineering, New Horizon Institute of Technology and Management, Maharashtra, India
[2]B.E student, Department of Civil Engineering, New Horizon Institute of Technology and Management, Maharashtra, India
[3]B.E student, Department of Civil Engineering, New Horizon Institute of Technology and Management, Maharashtra, India
[4]B.E student, Department of Civil Engineering, New Horizon Institute of Technology and Management, Maharashtra, India
[5]B.E student, Department of Civil Engineering, New Horizon Institute of Technology and Management, Maharashtra, India

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Abstract - *In the face of a rapidly growing global population, our energy demands are skyrocketing exponentially. Projections indicate that within the next nine years, the energy requirements will double, posing a significant challenge. Compounding this issue is the looming threat of global warming, an existential crisis exacerbated by the escalating carbon emissions resulting from human activities. As our planet steadily warms with each passing decade, it becomes imperative to address the root cause of this environmental peril – carbon emissions. Notably, traditional energy generation methods, particularly from nuclear power plants and fossil fuel-driven vehicles, contribute significantly to this predicament. With fossil fuel reserves depleting, an urgent exploration of sustainable alternatives for long-term energy generation is paramount. Wind energy – a renewable and zero-carbon source that holds immense promise. While wind mills have graced our landscapes for over a century, the exploration of vertical axial wind turbines (VAWT), specifically the Savonius type, remains relatively uncharted territory. This report delves into the viability of Savonius-type VAWTs and introduces a groundbreaking concept of twisted blades and aimed at enhancing turbine efficiency through experimental approaches.*

Key Words: *Wind Energy, Wind turbines, VAWT, Savonius, Darrieus.*

1.INTRODUCTION

With the advancement of technology, the rate of energy consumption is rising daily. The amount of energy consumed worldwide has grown by almost a third since 2000 and is expected to do so for some time to come. In 2018, the worldwide energy demand climbed by 2.9%. If nothing changes, by 2040, the global energy consumption is expected to reach 740 million tera joules, or an extra 30% growth. It is becoming increasingly difficult to generate energy with non-renewable resources at this rate. In many nations, wind turbines are employed as a more cost-effective and less-reliant source of intermittent renewable energy to offset rising fossil fuel prices.

1.1 Vertical Axis Wind Turbine

Vertical-axis wind turbines have the main rotor shaft arranged vertically This configuration has the benefit of not requiring the turbine to face the wind in order for it to function, which is useful in locations where wind direction is very variable, like when the turbine is integrated into a building. In order to improve accessibility for maintenance, the generator and gearbox can also be positioned close to the ground by using a direct drive from the rotor assembly to the ground-based gearbox. The advantages of VAWTs versus horizontal-axis wind turbines are numerous. They can be located closer to the ground, where the wind speed is lower, so they don't need as much wind to generate power. They can be installed in a variety of settings and require less maintenance because they are closer to the ground.

1.2 Types of Vertical Axis Wind Turbine

Savonius Wind Turbine

Vertical Axis Wind Turbine (VAWT) of drag type is the Savonius wind turbine. The typical design consists of a revolving shaft that catches the incoming wind with two or three scoops. It is utilized when dependability is more crucial than efficiency because of its straightforward and sturdy form and rather poor efficiency. Approximately only half of a Savonius wind turbine creates positive torque; the other half moves against the wind and produces negative torque, which contributes to the turbine's low efficiency.

Darrieus Wind Turbine

A vertical axis wind turbine (VAWT) of the lift type is the Darrieus wind turbine. A set of curved airfoil blades with their tips fixed to a revolving shaft were part of the original concept. On the other hand, other designs—known as H-rotor or Giro mill Derrius wind turbines—use vertical airfoils. Additionally, by distributing the torque uniformly throughout the revolution, the Darrieus wind turbine's blades can be formed into a helix to lessen the torque ripple impact on the turbine. The Darrieus wind turbines are lift-type devices, meaning they can harness wind energy more efficiently than drag-type wind turbines like the Savonius wind turbine.

2. Literature Review

1. Design and development of Vertical Axis Wind Turbine (2017)

   Professors Samir Deshmukh and Sagar Charthal conducted an extensive investigation into the design and development of Vertical Axis Wind Turbines (VAWTs). Their study compares VAWTs with Horizontal Axis Wind Turbines (HAWTs), highlighting the growing popularity of VAWTs for power generation. While HAWTs have been utilized for many years, they require higher wind speeds for optimal performance compared to VAWTs, which can generate electrical energy efficiently even at lower wind speeds. The efficiency of VAWTs exceeds 70%, as demonstrated in this study.The paper elaborates on the intricate design of aerofoil blades, emphasizing their efficiency at various angles. Results indicate that the blades achieve maximum power output at a 90° angle. Additionally, the authors incorporate the concept of magnetic levitation at the shaft's base to suspend the turbine, thereby reducing friction.This research provides valuable insights into the design and fabrication of complex aerofoil blades for VAWTs. Vertical Axis Wind Turbines offer a promising future for wind power generation, surpassing the output of conventional HAWTs. Consequently, the paper concludes that VAWTs can generate more power with higher efficiency, even at low wind velocities, suggesting the potential for this technology to replace current wind farm technologies entirely.

2. Vertical Axis Wind Turbine for Highway Application (2016)

   Saurabh Arun Kulkarni and Prof. M. R. Birajdar present a study in this paper focusing on the dimensions of various parts of a vertical axis wind turbine (VAWT), the materials used, and the fabrication process involved. The model was designed to capture wind from all directions and underwent testing, resulting in a power output of 28 watts at a wind speed of 6 m/sec. The paper suggests that the efficiency of the VAWT can be enhanced by altering the size and shape of the blades. It is noted that this model has the potential to generate more energy on faster routes and can be utilized to power street lights. Notably, the model was constructed at a very low cost, primarily due to the use of plastic for the blades.

3. Power Generation by Using Highway Vertical Axis Wind Mill (2017)

   N. Venkata Subbaiah and M.L.S Deva Kumar present a study in this paper focusing on the number of blades used in vertical axis wind turbines (VAWTs), the angle of the blades, and the maximum rotational speed of the blades. They find that a turbine equipped with three Savonius blades curved at an angle of 104° achieves a maximum speed of 473.5 RPM. The maximum speed of the generator is 500 RPM, which, when fully operational, yields an output of 14.5 kW. The authors suggest that implementing this method on all National Highways could result in significant power generation. They emphasize the importance of carefully selecting the blade profile to minimize losses and enhance power generation efficiency. Additionally, they propose hybridizing the model by adding solar panels on top to further increase its efficiency.

4. Design, modeling and economic performance of a vertical axis wind turbine (2018)

   Sahishnu R. Shah, Rakesh Kumar, Kaamran Raahemifar, and Alan S. Fung explore the feasibility of implementing Vertical Axis Wind Turbines (VAWTs) in urban settings, such as on the ground or building roofs. They highlight that developing appropriate VAWT designs could lead to widespread acceptance of these machines on a large scale. The main aim of their research was to design and model a small-scale VAWT capable of meeting the power needs of low-demand applications.The study investigates two novel shapes of Savonius rotor blades, comparing their rotational performance with conventional straight and curved blades.

   MATLAB simulation is employed to create a mathematical model incorporating wind power coefficient, tip speed ratio, and various mechanical and electrical components. The model is validated using measured results from the developed turbine. Their objectives include analyzing turbine blade shapes, devising a mathematical algorithm, and evaluating the techno-economic performance of the new curved blade design. The model predicts that the proposed turbine can generate an annual energy output of 7838 kWh, resulting in an annual electricity cost saving of $846.51 in Ontario, based on an electricity price of $0.108/kWh.

3. Site selected for testing of model

3.1 General

Highways offer significant wind potential for turbine operation due to the high volume of vehicle traffic. This untapped energy source can be harnessed for power generation purposes. The turbines will be strategically placed on highway medians to capture wind flow from both directions effectively. Wind speed measurements were conducted using an Anemometer, a device designed to gauge wind speed and direction.

All the parameters were gathered from the designated location, specifically **"NH 48, Varsova Road, near Metro De Royale Multicuisine Family Restaurant," situated in Thane, Maharashtra.**

3.2 Site Parameters

Table -1: Different Parameters of site

Sr no.	Parameters	Results
1	Average Wind Speed	5.17 m/sec
2	Humidity	75% to 80%
3	Rainfall	More than 80mm
4	Average Temperature	35° Celsius
5	Number of vehicles passing per minute	30-41

4. Proposed Model

Fig -1: Proposed Model of Twisted blade Vertical Axis Wind turbine

Fig -2: Proposed Model of Curved blade Vertical Axis Wind turbine

5. Design Of Model

The design of model is based on the study of different research papers regarding Vertical Axis Wind Turbine.

Table -2: Detailed specifications of Vertical Axis Wind Turbine

Sr no.	Particular	Specifications & Material Used
1	Blade (twisted & curved)	230 mm x 900 mm Aluminium
2	Rod	1524 mm Mild Steel
3	Holding Frame	800 mm x 800 mm Aluminium square pipe
4	Aluminium square pipe	20 mm x 20 mm
5	Blade Holder	120° Mild Steel
6	Diameter of Bearing	Internal- 26 mm Outer – 47 mm Height -12 mm
7	Motor	24 DC, Rpm of 9000
8	Multimeter	DT830D - 1000V DC/750V AC Digital Multimeter
9	Gear	ratio 1: 2
10	Anemometer	Measures wind speed in mph, ft/min, Km/h, m/s

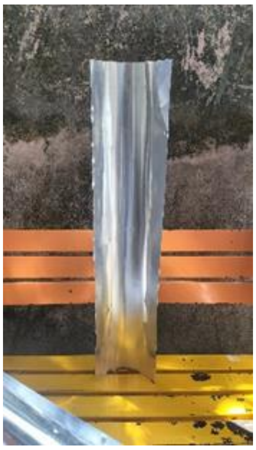

Fig -3: Curved Blade for Vertical Axis Wind Turbine

Fig -4: Twisted Blade for Vertical Axis Wind Turbine

Fig -4: Rod

Fig -5: Holding Frame / Stand

Fig -6: Bearing

Fig -7: Gear Assembly

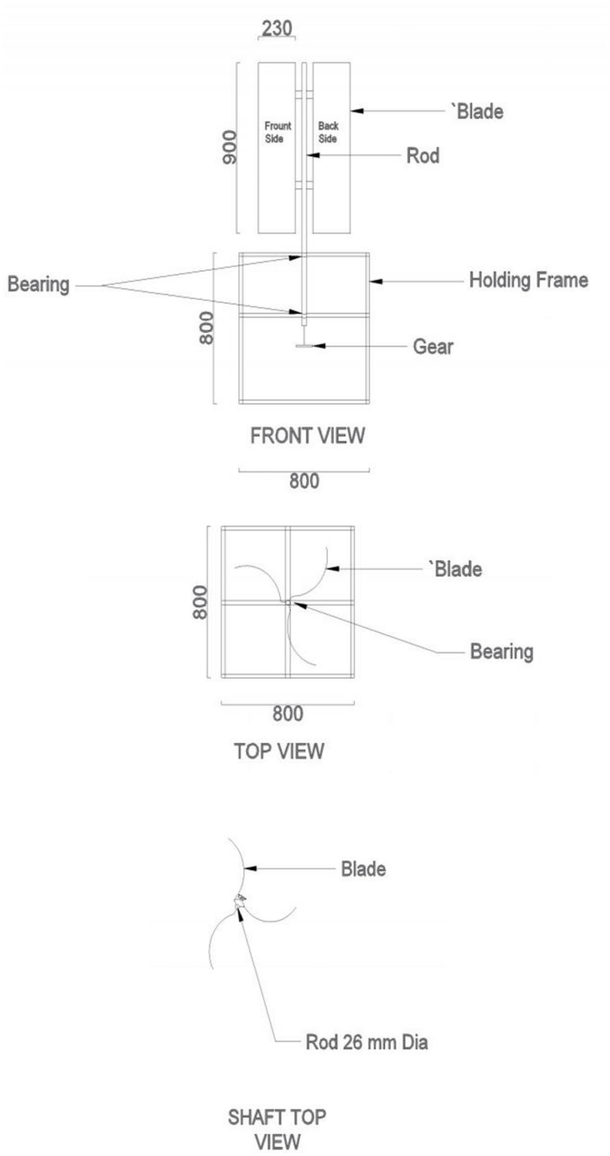

Fig -8: 2D Design of Vertical Axis Wind Turbine on AutoCAD

6. Fabrication Process

1. The initial shaping processes
2. Blade Bending, Twisting and cutting
3. Welding Process
4. Surface finishing

7. Theoretical Power Calculation

The power in the wind can be calculated using the principles of kinetics. Operating on the premise of transforming the wind's kinetic energy into mechanical energy, the wind turbine subsequently converts this mechanical energy into electrical energy. The power produced by the turbine's rotation is determined by multiplying the voltage and current.

Power (watt) = Voltage x Current

For highways, the average wind speed per minute and the number of vehicles passing each minute were recorded over a period of 15 minutes. Additionally, the corresponding voltage and current for the average wind speed were noted. By multiplying the voltage, current, and the number of vehicles, the power generated for the 15-minute interval was calculated.

Power generated per hour = power generated in 15 minutes x 4

The power generated per hour, day, and year can be computed using the same formula by multiplying it with the respective time factors.

Suppose we have per hour power output reading then the one-day reading can be given as:

Power generated per day = power/hour x 24

Again, for one year the readings can be given as:

Power generated per year = Power generated/day x 365

8. Testing And Results

The tests were conducted for 15 minutes on the selected location.

Sr no.	Time	Average number of vehicles per minute per side	Average Wind speed (m/sec)	Voltage (V)	Current (A)	Watt (voltage x Ampere)	Watt (per minute)
1	02:30	40	4.2	1.77	0.16	0.283	16.98
2	02:31	37	5.4	1.85	0.165	0.305	18.3
3	02:32	41	4.5	1.81	0.162	0.293	17.58
4	02:33	34	5.2	1.83	0.164	0.3	18
5	02:34	38	3.2	1.6	0.169	0.271	16.27
6	02:35	43	3.8	1.73	0.163	0.282	16.9
7	02:36	36	4.2	1.78	0.165	0.294	17.64
8	02:37	38	5.5	1.86	0.167	0.31	18.62
9	02:38	39	6.3	1.92	0.173	0.332	19.92
10	02:39	41	6.6	1.94	0.179	0.347	20.83
11	02:40	30	4.8	1.81	0.163	0.296	17.76
12	02:41	34	5.5	1.86	0.167	0.31	18.62
13	02:42	31	3.4	1.64	0.17	0.279	16.75
14	02:43	39	3.9	1.75	0.161	0.283	16.99
15	02:44	42	6.5	1.93	0.178	0.344	20.64
Power Generated in 15 minutes							271.8 Watt = 0.2718 KW

Fig -9: Data Collected for Curved Blade VAWT

Sr no.	Time	Average number of vehicles per minute per side	Average Wind speed	Voltage (V)	Current (A)	Watt (voltage x Ampere)	Watt (per minute)
1	03:10	41	3.4	1.64	0.17	0.2788	16.728
2	03:11	45	3.9	1.75	0.161	0.2818	16.905
3	03:12	39	6.5	1.93	0.178	0.3435	20.6124
4	03:13	38	6.2	1.92	0.171	0.3283	19.6992
5	03:14	42	4.1	1.77	0.162	0.2867	17.2044
6	03:15	41	5.3	1.84	0.166	0.3054	18.3264
7	03:16	39	5.9	1.88	0.177	0.3328	19.9656
8	03:17	43	7.2	1.99	0.184	0.3662	21.9696
9	03:18	41	4.1	1.77	0.162	0.2867	17.2044
10	03:19	30	3.5	1.67	0.168	0.2806	16.8336
11	03:20	35	4.2	1.78	0.163	0.2901	17.4084
12	03:21	36	5.7	1.87	0.169	0.316	18.9618
13	03:22	42	6.6	1.94	0.179	0.3473	20.8356
14	03:23	32	5.7	1.87	0.171	0.3198	19.1862
15	03:24	37	4.3	1.78	0.165	0.2937	17.622
Power Generated in 15 minutes							279.463 Watt = 0.2794 KW

Fig -10: Data Collected for Twisted Blade VAWT

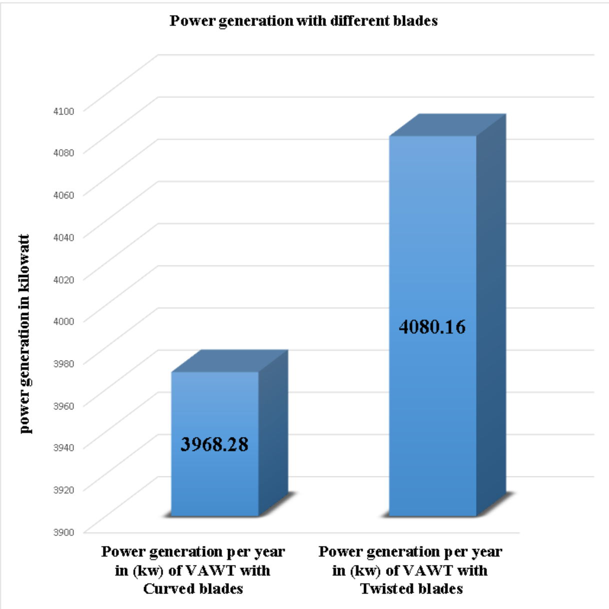

Chart -1: Comparison of Power Generation between Curved blade VAWT and Twisted blade VAWT

Calculations of power generated

- **Curved Blade** generates electricity of 1087.2 Watt per hour.
- So, if the model runs for 10 hrs. per day it generates electricity of 10872 watt per day.
- For 1 year = 10872 x 365 = 3968280 Watts = 3968.28 KW/ year.
- **Twisted Blade** generates electricity of 1117.852 Watt per hour.
- So, if the model runs for 10 hrs. per day it generates electricity of 11178.52 Watt per day.
- For 1 year = 11178.52 x 365 = 4080159.8 watts = 4080.16 KW/ year.
- **In India, the average rate per unit is Rs 5.3.**
- Therefore,
- **For curved blade,**
- Rate of power generated per year = 3968.28 x 5.3 = **Rs 21031.89**
- **For twisted blade,**
- Rate of power generated per year = 4080.16 x 5.3 = **Rs 21624.89**

9. Cost Analysis

Sr no.	Parts of VAWT (vertical axis wind turbine)	Price (Rs)
1	Shaft	400
2	Aluminium sheet	700
3	Bearing	200
4	DC motor	300
5	Multimeter	350
7	Gear	200
8	Aanemometer	1000
9	Aaluminium square pipe	500
10	Fabrication work	2650
11	Transportation	200
Total		RS 6500/-

Fig -12: Manufacturing cost of Vertical Axis Wind Turbine

The total manufacturing cost of this model is

RS 6500/-

10. CONCLUSIONS

The project extensively investigated and analyzed two distinct blade designs, curved and twisted, for Savonius-type vertical axis wind turbines. The model underwent rigorous testing on-site to evaluate its efficiency. Results revealed that the twisted blade VAWT outperforms the curved blade variant, yielding 1117.852 Watt per hour of electricity compared to 1087.2 Watt per hour. The application of twisted blade VAWT on highways holds significant promise, particularly in illuminating street lights.

Moreover, the project's economic viability is underscored by its ability to recoup manufacturing costs within a year. This demonstrates the project's potential for providing a cost-effective renewable energy solution. The findings underscore the significance of vertical axis wind turbines as a valuable contributor to the renewable energy landscape.

In conclusion, this research underscores the potential of vertical axis wind turbines in leveraging various blade designs to generate clean and sustainable energy.

11. FUTURE SCOPE

A stable foundation is essential for optimizing the efficiency of vertical axis wind turbines (VAWT). Additionally, hybridization of VAWT can be accomplished by integrating solar panels, thereby harnessing energy from multiple renewable sources. Furthermore, incorporating a rain gauge to measure precipitation levels at specific locations can provide valuable data for system optimization and maintenance. To mitigate potential corrosion caused by rainfall, the turbine model can be coated with a thin layer of plastic as a protective measure. These strategies aim to enhance the reliability and longevity of VAWT systems while maximizing their energy output.

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BIOGRAPHIES

Ms. Pradnya Telang
"Asst. Professor, Department of Civil Engineering, New Horizon Institute of Technology and Management, Maharashtra, India"

Anvit Morey
"B.E student, Department of Civil Engineering, New Horizon Institute of Technology and Management, Maharashtra, India"

Akshar Bandagale
"B.E student, Department of Civil Engineering, New Horizon Institute of Technology and Management, Maharashtra, India"

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