Design and Fabrication of a Portable Vertical Axis Wind Turbine for Sustainable Off-Grid Power Generation

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***ABSTRACT*-This paper provides the design and manufacture of a transportable vertical axis wind turbine. reviewing the operation of the Vertical Axis Wind Turbine (VAWT), the state of technology, cutting-edge modelling findings, and probable future paths for VAWTs. The importance of VAWT to the present energy problem has been emphasized. One can envision that humanity will live on a world with wind power turbines and solar power panels given the current modern energy crisis. Wind energy has been implemented as a reliable and efficient new source of energy. Although vertical axis wind turbines (VAWTs) are more cost or material-effective than horizontal axis wind turbines (HAWTs), the VAWTs presently do not generate enough electricity due to many responsible factors.**

1. INTRODUCTION

The futuristic need-based topic in the world right now is renewable energy. Most of the existing conventional fossil fuel storage was quickly eradicated, and no reserves were seen in future if this rate will continuous. Besides from energy production from fossil fuels may result environmental concerns, like greenhouse gas emissions, climate degradation and acid rain. [12] The use of renewable energy sources is crucial in cases like this. Energy that is produced from renewable resources like wind power, sunlight energy, raining water, sea waves, tides, and geothermal heat resources are known as renewable energy. Typically, four separate sectors receive electricity from renewable sources. They are transportation, rural (off-grid) energy services, air heating, water temperature changes during summer and winter and electricity generating. [7] For instance, Iceland and Norway already use renewable energy to produce their electricity. Many nations have established a target of obtaining 100% renewable energy in the future. For instance, the Danish government has decided to convert the whole energy supply (electricity, transportation, and heating/cooling) to renewable energy by the year 2050. A promising renewable energy source has been discovered as wind energy. Many countries have recognized the benefits of wind power and have developed regulations to guarantee that it plays a bigger part in the world's energy supplies.[11]

1.1 Wind

The difference in atmospheric pressure is what causes the wind to blow. Air particles travel from the high-pressure end to the low-pressure end as a result of the difference in atmospheric pressure. Air molecules are subject to the Coriolis effect while moving, with the exception of the precise equator.[2] According to the wind's force and direction of blowing, the winds are frequently referred to. Gusts are discrete, high-speed wind bursts. Squalls are strong winds of medium duration. Winds that linger for a long time go by various names, including breeze, gale, storm, and hurricane [2].

1.2 Wind Power

By using all energy generated by winds energy to run and start an electric generator. Wind turbines generate electricity. The generator produces energy and transfers it from the tower to a transformer that is available before switching the exit voltage typically around 700 V to the national grid (33000 V) or for personal. Comparative study of VAWT and HAWT gives us overview based on different factors as following: -

	Horizontal axis wind turbine (HAWT)	Vertical axis wind turbine (VAWT)
Tower sway	Large	Small
Yaw mechanism	Yes	No
Self-starting	Yes	No
Overall Set-up Formation	Complex	Simple
Generator location	Not on ground	On ground
Height from ground	Large	Small
Blade's operation space	Large	Small
Noise produced	high	Relatively Less
Wind direction	Dependent	Independent
Obstruction for birds	High	Less
Ideal efficiency	50–60%	More than 70%

For both large-scale and small scale and separated power generation examples, wind power generation is an essential and alternative energysource. Making it flexible and scalable is one of wind energy's resources major adoptable advantages. Applications can frequentlybe found in both massive wind farms and dispersed power generation. Utilizing wind energy has the added benefit of reducing reliance on fossil fuels. With enormous, mostly untapped wind power resources people moving from 20th century to 21st century with an ambitious drive to being a part of the development of wind power-based technology and further minimize its costs, to generate new jobs in the renewable sector and to improve environmental quality. Theworld and falling wind energy costs. Onshore wind is a more affordable source of electricity than coal or gas-fired power stations. Although offshore farms have less of an aesthetic impact than onshore farms and offshore wind is more stable and powerful than onshore wind, the expenses of building and maintenance are significantly greater offshore.

1.3 Wind Potential in India

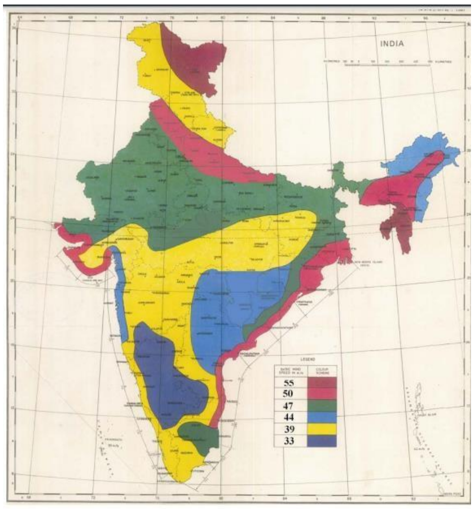


Figure 12. Suggested modification of design wind speed map of India.

Figure 1: Map representation of average wind speed in different region of India.

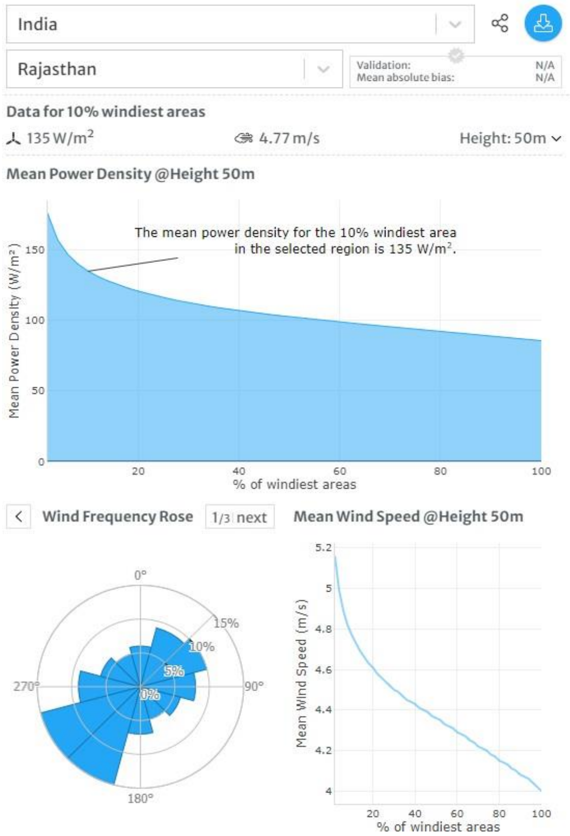


Figure 2: Wind data at altitude 50 m in Rajasthan

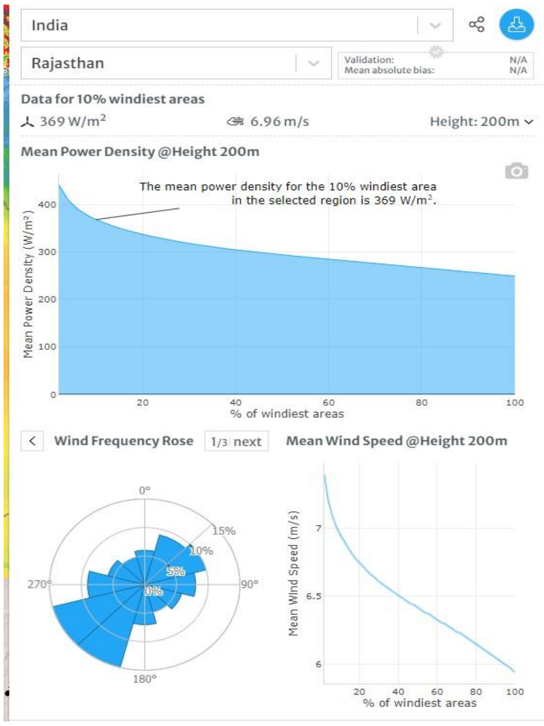


Figure 3 Wind data at altitude 100m in Rajasthan [1]

Our vertical windmill was developed considering the average wind blowing speed in different area of

Rajasthan, India, and the wind data used here was obtained from the global wind atlas.

Metropolitan cities	Altitude(m)	Wind speed
Delhi	50	3.76
	100	4.49
	150	5.04
Mumbai	50	4.26
	100	4.57
	150	5.13
Chennai	50	4.99
	100	6.14
	150	6.4
Bengaluru	50	5.06
	100	6.13
	150	6.77
Kolkata	50	4.14
	100	5.06
	150	5.77

Figure 4: Wind speed of 5 Major metropolitan Cities

Methodology

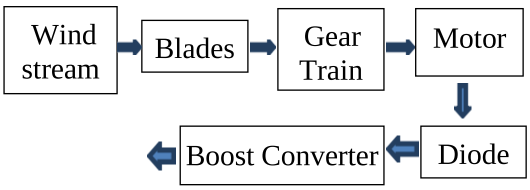


Figure 5: Block diagram/ Flow Diagram of the wind turbine

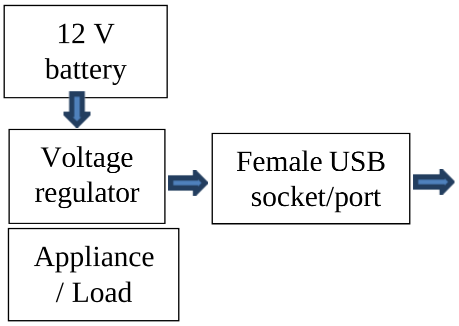


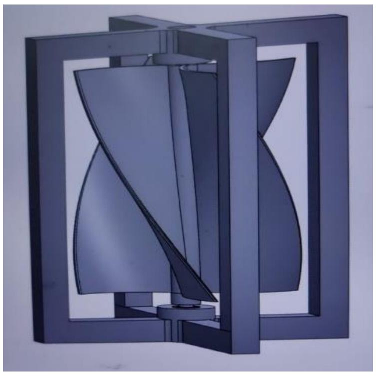
Figure 6: Designed VAWT blades

2.1 Wind Blade Design

With respect to generating a portable mobile charger by a multidirectional wind turbine, lots off methods have been carried out (PMDWT). The research's block diagram is displayed in Figure 1. The design and manufacturing of a wind turbine's blade is the initial step. The blade design affects a portable wind turbine's efficiency.[3] The ideal bald' design should take into account the wind flow behavior around the airfoil while the wind turbine is stationary and be suitable for air stream resistance. The design of the multidirectional wind turbine used in this study is depicted in Figure 2. For the best move of wind energy into rotation, the blade is built on a swirl shape.[6].Because it is simpler to construct and disassemble, the frame was created in the Lego manner.

So that the VAWT requires less and less wind power to rotate, blade design is crucial and should be done appropriately. The content Used in making blades 3D Printing specifications

Material Temperature = 200 degree CSize: 250mm x 250 mm x 300 mm



Some Design Results of blade

Blade Diameter = 15cmBlade Height = 21cm Blade Thickness = 3mm
Blade Curve = 0.25 revolutionTotal Span = 21 cm

Swept Area = (S) = 2.131 m^2
Power coefficient (Pw) = 0.205 for wind speed of2m/s
Blade Chord (C) = 6.69
Blade Curvature Angle = 40 degrees
Solidity = 2.66
Model type use SAVANIOUS

To design the blades, the following parameters were considered: [6]

- Swept area
- Power and power coefficient
- Tip speed ratio
- Blade chord
- Number of blades
- Solidity
- Initial angle of attack

Aerodynamic performance determines how efficiently rotors operate; hence it is necessary to use the right design to maximize this force. Friction also produces an opposing drag force that must be reduced as it opposes the motion of the blade.[6] The number of blades will have an impact on the turbine's power output. Depending on the blades' function, a portable phone charger should have a minimum of two blades [4]. Blades must be controlled while moving at a high rate of speed but with little torque. Usually, there are four. Blades, as this generates sufficient torque beyond managing more weight that would delay the spinning. Pumps that blow air require a lot of speed but minimum torque. Morestability is achieved by rotors with an even blades number that minimum required four blades. The number of blades required for a wind power turbine based on its torque [13]. The ProJet SD 3000 3D printer was used to create the blade process after the number of blades was selected. Figure 3 depicts the blade's design. Three probes have been used for the capability testing in order to measure the voltage levels that thePMDWT produces at various wind speeds. The 3 probes.

(a)

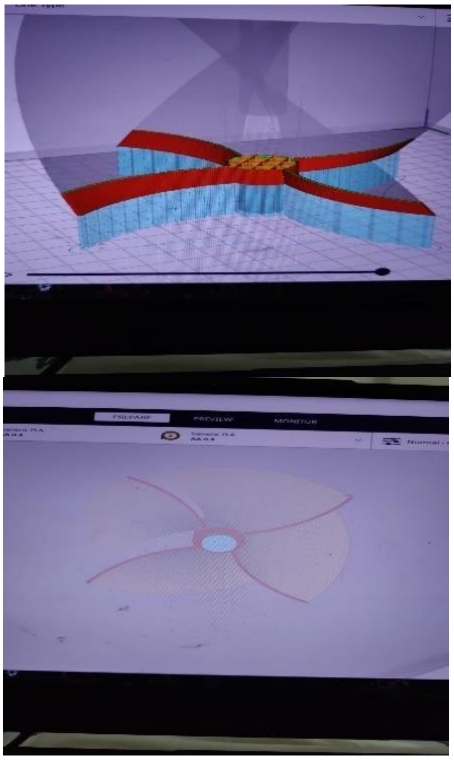


Figure 5A(a) Design of blades and support analysis (b) Top view of blades during analysis

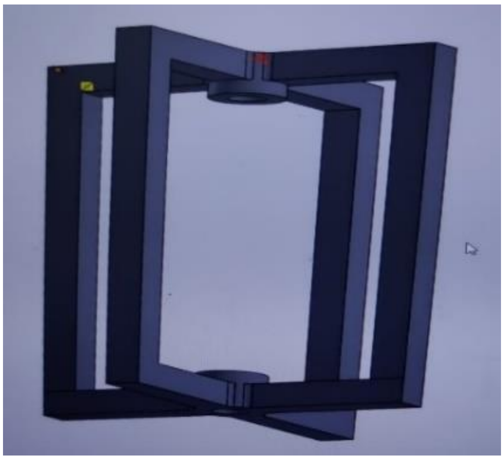


Figure 6: Frame design of VAWT

In order to maintain the speed, rpm, and torque as well as balance the reaction forces during working conditions, this design was made employing solid works.

2.2 Frame Design

A Frame is a rigid structure which sustains the load of the turbine's blades keeping the structure stationary and fixed at its place. Frame design is crucial to eliminate vibrational losses of the turbine as it provides structural support to the blades during the operation of the turbine.

A frame is an assemblage of rigid components, at least one of which must be a multi-force member, designed to serve as a fixed support for a load. A grouping of stiff parts intended to perform mechanical work by converting one set of input loading forces into another set of output forces is referred to as a machine.[9]

2.3 Pulley System

The pulley system was later replaced with the gear train having gear ratio as 1:4. This was done to overcome the inability of the pulley to produce sufficient torque to rotate the motor shaft which will produce the required electricity.

The speed ratio of a pulley system is the ratio of the rotational speed of the driving pulley to the driven pulley.
It can be calculated using the following formula:

$$\textbf{Speed Ratio} = \mathbf{N2 / N1}$$

where N1 is the rotational speed of the driving pulley and N2 is the rotational speed of the driven pulley.
If the pulleys have different diameters, you can also calculate the speed ratio using the following formula:

$$\textbf{Speed Ratio} = \mathbf{D1 / D2}$$

where D1 is the diameter of the driving pulley and D2 is the diameter of the driven pulley. Or chain, the speed ratio will also depend on the diameter of the belt or chain pulleys, as well as the distance between the pulleys. The speed ratio will be affected by these factors, in addition to the diameters of the pulleys themselves.

The pulley system is used in VAWT to manage the RPM and help in provide the required torque for the motor as pulley system failed, we used gear train.

2.4 Gear Train

Using gear train that has mechanical components of a system created by managing gears on a structure such that all mesh together.

Gear teeth are meticulously engineered to guarantee continuous contact between the pitch circles of meshing gears, preventing any obstructions and enabling a smooth transmission of motion through the synchronized motion of the teeth. An example of a feature of gears and train created by gears is:

- The relationship between the gear ratios of interlocking gears establishes both the speed ratio and the mechanical advantage of the gear assembly.
- A planetary gear mechanism offers substantial gear reduction within a space-efficient configuration.
- It is feasible to create gear teeth for non-circular gears that maintain torque transmission with fluidity.
- The speed ratios for chain and belt drives are calculated using the same principles as those for gear systems, as exemplified in bicycle gearing.

The Antikythera mechanism from Greece and the south-pointing chariot from China stand as some of the earliest instances where rotational motion was conveyed through the interaction of toothed wheels. Depictions of gear trains with cylindrical teeth can be observed in the artworks and diagrams of the Renaissance scholar Georgios Agricola. [11]. A common gear design with a constant speed ratio was produced by the use of involute teeth.

The types of gear trains are:

- Simple gear train.
- Compound gear train.
- Reverted gear train.
- Epicyclic gear train.

2.4.1 Compound Gear System

Compound gear trains employ multiple sets of meshing gears and find application when substantial speed variations are necessary or when various outputs need to move at distinct velocities.

To make the compound gear train, four gears were first designed in SOLIDWORKS software and were then fabricated using a 3D printer.

By Gear formula,

N1/N2 = T2/T1

N2/N3 = T4/T3

(N2=N3)

N3/N4 = T4/T3

Now,

T1=40 and T2=20

N1/N2= 20/40 = 0.5

N1 = (0.5) N2 …. (i)

Similarly

T4=10

N3/N4=T4/T3

N3/N4 = 10/20

N3/N4 = 0.5

N3 = 0.5 N4 ..(ii)

Substituting value of N3

N1= (0.5) N2

N1 = (0.5) *(0.5) N4

Or,

where D1 is the diameter of the driving pulley and D2 is the diameter of the driven pulley. Or chain, the speed ratio will also depend on the diameter of the belt or chain pulleys, as well as the distance between the pulleys. The speed ratio will be affected by these factors, in addition to the diameters of the pulleys themselves.

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Substituting value of N3

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$N1 = (0.5) *(0.5) N4$

Or,

$N1=N4/4$

So,

$N1/N4 = 1/4$

Hence **Gear ratio is 1:4**

The specifications of each gear are as follows:

For **Gear 1**
Module =2.5
Pressure Angle =14.5

Spur gear
Face width=10mm
Teeth (N1) = 40 Bore = 10mm

For Gear 2 and 3
Module =2.5
Pressure Angle =14.5

Spur gear
Face Width =10mm Teeth (N2&N3) =20
Bore = 10mm

For Gear 4
Module =2.5
Pressure Angle =14.5
Face width = 10mm Spur gear
Teeth (N4) =10
Bore = 10mm

2.4.3 Spur Gear

Spur gear is a cylindrical shaped toothed component used in VAWT to transfer mechanical motion aswell as control speed, power, and torque. These simple gears are cost-effective, durable, reliable and provide a positive, constant speed drive to facilitate daily windmill operations. There are four gears used in the operation for the proper power transmission.

$$M_g = N1 / N4$$

Where M_g is Gear Ratio and **N1** is teeth of spur gearand,

N2 is the teeth of driven gear. After design and calculation.

$$M_g = 1/4$$

Where the pitch diameters are

$$D1 = 10 \text{ cm}$$
$$D2 = D3 = 5 \text{ cm}$$
$$D4 = 2.5 \text{ cm}$$

Bore Diameter (d),

d = 10mm = 1 cm

Compound gear train is used to transmit power and design in such a way that it delivers the required rpm and torque to the DC motor

2.6 DC Motor

Figure 8: 1000 RPM 12V Low Noise Geared DC Motor

A type of rotary electric motor known as a direct current (DC) motor converts direct current (DC) electrical energy into mechanical energy. The most common types rely on the magnetic fields that are induced when electricity flows through a coil. Almost all types of DC motors have an inbuilt electromechanical or electronic mechanism that periodically reverses the direction of current in a specific section of the motor.
Motor is operating at 1000 RPM and 12V output. With a Rated Torque (kg-m) of 0.3 and a Stall Torque (kg-cm) of 1.5, this motor is utilized as a current generator. The motor is 32 mm diameter and 75 mm length. Its shaft length (mm) and diameter (mm) are both six.

2.7 DC to DC Boost Convertor

Figure 9: Boost Convertor

The boost converter is employed to increase the input voltage to meet the requirements of a load, effectively stepping up the voltage. It achieves this by storing energy in an inductor and then delivering it to the load at an elevated voltage. This brief overview highlights common errors individuals make when using boost regulators.

2.8 Diode 5408

A power rectifier diode having a voltage drop of 1V and a maximum forward current of 3A is the 1N5408. It is frequently employed in rectifying or switching applications. The 1N5408 diode's specs are as follows: Drop in Forward Voltage: 1V (at 3A) 3A of forward current subject in the near future, according to study on VAWTs. The introduction of their research findings to the nation would benefit national growth.

Figure 10: Diode 5408

2.9 Voltage regulator

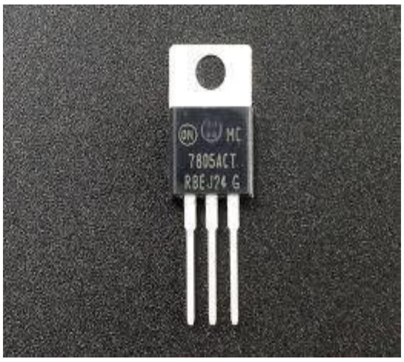

Figure 11: Voltage Regulator

A system known as voltage regulator 7805 is made to automatically maintain a constant voltage. A voltage regulator might employ negative feedback or a simple feed-forward topology. It might include electrical components or an electromechanical device. Depending on the design, it may be used to manage one or more AC or DC voltages.[10] Due to variations in the circuit, no voltage source can produce a constant output. Voltage regulators are used to obtain a constant and steady output. Voltage regulator integrated circuits (ICs) are electronic devices used to control voltage. We can talk about the IC 7805 right now.[4]

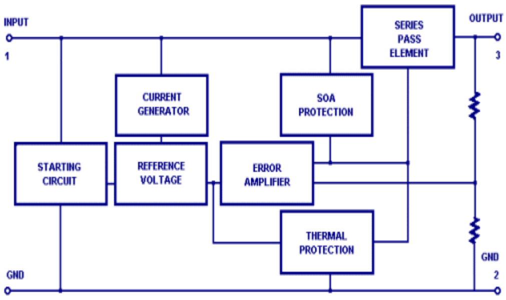

Figure 12: Internal circuit of a 7805 Regulator

The 78xx series encompasses various voltage regulator ICs, and one such IC is the 7805, which is a fixed linear voltage regulator. The "78xx" series designation indicates the specific fixed output voltage, with the 7805 delivering a +5V DC regulated power supply. Additionally, the 7805 IC features provisions for attaching a heat sink to manage heat dissipation. This voltage regulator's threshold limit is 35V, and any input voltage less than or equal to that will result in a constant output of 5V from the IC [5]. [Image. Source: rigacci.org]

2.10 12V Battery, 3 4V batteries

Electrical batteries that can be charged, discharged, and recharged repeatedly include rechargeable batteries, storage batteries, secondary cells, and energy accumulators. In contrast, a primary or disposable battery is given to the user fully charged and is disposed of after usage. One or more electrochemical cells make up its structure.[8] When something builds up and energy is stored by a reversible electrochemical process. Rechargeable batteries come in a wide range of shapes and capacities, from button cells to megawatt systems connected to stabilize an electrical distribution network. Lead-acid, zinc-air, nickel-cadmium (NiCd), nickel-metal hydride (NiMH), lithium-ion (Li-ion), lithium iron phosphate (LiFePO4), and lithium-ion polymer (Li-ion) are among the electrode materials and electrolytes utilized.

Wind rotor	Rated Voltage	14V
	Rotor diameter	20 cm
	Swept area	1 m^2 (1 m*1 m)
	Gear box type	4 Spur gear Compound Gear Train
	Brake	Not required
Generator	Generator type	DC generator
	Electric Transmission	Geared
Turbine blade	Blade type	Savonius, J-type(drag)
	Blade number	3
	Blade material	Resin 3D Printing
Blade dimension	Length	38 cm
	Cup radius	0.126 m
Boost Voltage Converter	XL6009 Operating Volts	2V to 25V DC
Voltage Regulator	LM7805 Output Current	1 A

DC Appliances Run in 14 V Supply

1. Chargers
2. Fans
3. LED lights

4. Shaver
5. Smart watch
6. Smartphones
7. Bluetooth Speakers
8. DVD Players

TEST RESULT

In order to determine the effectiveness of the products that were manufactured, two different tests were performed to evaluate. The types of testing which has been performed to check the output voltage of a Vertical Axis Wind Turbine are:

1. Motor Testing.
2. Multi meter Testing

Motor Testing: In this test, wind was blown at constant speed over the blades, rpm of the blades at two points were measured via Tachometer.

Table 2: Motor Testing

SNo.	DC Voltage Output	Rpm in Gear 1	Rpm at Motor shaft
1.	2V	40	60
2.	5V	63	99
3.	7V	76	168
4.	9V	87	261
5.	12V	94	282

Multimeter Testing: Under this test, the multimeter was kept at various junctions within the circuit to measure the voltage generated via wind turbine. Some of the results of the test are mentioned in the table below:

Table 3: Multimeter Testing

S No.	Location	Voltage (V)
1.	Output of Motor/ Input of Boost Converter	2.4V
2.	Output of Boost Converter/ Input of Voltage Regulator	14V
3.	Output of Voltage Regulator	12V
4.	Input to Battery	12V via Diode

3. CONCLUSION

In the near future, local governments in India and various other nations will face a most of challenges stemming from the depletion of non-renewable energy resources. As a response all are increasingly turning to alternative energy sources such as wind, solar, tidal, rain, wave, geothermal heat, and more to address their energy needs. as a result. If we could make the Vertical Axis Wind Turbines (VAWTs) more effective, the government would gain a lot. Anywhere they can, they can generate electricity and use VAWTs, reducing CO2 emissions and helping the economy in the process. According to research on VAWTs, there will probably be a big advancement in this area in the near future. The dissemination of their research's results would aid in the development of the country.

The focus on making Vertical Axis Wind Turbines (VAWTs) more efficient could yield substantial benefits for governments. By strategically deploying VAWTs, they can harness electricity generation across diverse locations, mitigating CO_2 emissions and concurrently bolstering the economy. Anticipated advancements in VAWT technology signify a promising future for this sector. Disseminating the outcomes of research in this domain can significantly contribute to the country's progress by fostering innovation and sustainable energy development.

The dissemination of research findings on VAWTs is crucial for the country's development. Sharing the outcomes of this research would contribute to the collective knowledge base, facilitating informed decision-making by policymakers. This, in turn, would play a pivotal role in steering the nation towards a more sustainable and energy-efficient future. Efforts to improve the effectiveness of VAWTs could prove instrumental in advancing the government's agenda. By strategically deploying these turbines wherever feasible, governments can harness electricity generation, consequently curbing CO_2 emissions and fostering economic growth. Ongoing research in the field of VAWTs suggests that substantial advancements are on the horizon, promising a positive impact on energy production and environmental sustainability.

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