DESIGN AND FABRICATION OF COMBINED SAVONIUS AND DARRIEUS WIND TURBINE

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Abstract – *In this design, an attempt is made to use the advantage of Darrieus and Savonius rotors, to work on the overall effectiveness of the affair power. This combined wind turbine with a Darrieus rotor provides the main power, starting power is handed by the Savonius rotor. At low wind pets the Savonius rotor starts rotating, pulling alongside it the Darrieus rotor. At the point when the Darrieus rotor reaches its critical speed, it starts rotating at a faster speed. Presently, for a analogous low wind speed, both the Savonius rotor and Darrieus rotors rotate at their own pets, the affair of which will be fed to a one input epicyclic gear box, so that an enhanced affair will be attained from the gear box. The combined Savonius- Darrieus rotor can increase the wind turbine effectiveness in low wind speed and also enable tone-starting in Darrieus turbine. Hence, analysis of this design performance of the system is done.*

Key Words: Darrieus and Savonius rotor, Critical speed, , etc (Minimum 5 to 8 key words)…

1. INTRODUCTION

Winds are an outcome due to the earth's equatorial regions receiving more alternative solar energy than the Polar Regions and these sets up enormous convection flows in the atmosphere. In few areas of the planet, wind energy has proactively developed to be thought asa mainstream energy source. It is the most economical solution to the world's ever rising energy requirements. It's a clean energy and consumes no fuel. Wind energy can contribute majorly in satisfying the world's need for clean and renewable energy in the coming years. The energy that may be extracted from the wind is directly proportional to the cube of the wind speed. Thus, an understanding of the wind characteristics (like velocity, direction, and variation) adds to every aspects of wind energy generation, from the identification of suitable places to predictions of the economic viability of wind farms, to the design of the wind turbines themselves. The most striking wind characteristic is its random nature. The wind varies highly in, both geographically and temporally.

1.1 Wind Turbines

A wind turbine is a device that converts the wind's kinetic energy into electrical energy. Wind turbines can be manufactured in wide scopes of sizes, with either horizontal or vertical configuration of the axes. It is assessed that huge number of large wind turbines, when installed grouply known as wind farms, can generate more than 700 Gigawatts of power, with 70 GW adding every year. Wind energy are an increasingly crucial source of intermittent renewable energy, and are utilized in several countries to bring down the energy costs and diminish the reliance on fossil fuels, for generating electrical energy.

1.2 Vertical Axis Wind Turbine

Wind turbines that are set on a vertical axis, free to rotate, are called as vertical axis wind turbines (VAWT). Recently, VAWTs are gaining popularity due to the interest of people in producing eco-friendly energy solutions. Small companies, all over the world have been advertising these new devices such as Helix Wind, Urban Green Energy, and Wind spire. As, VAWTs are small, quiet, easy to install, can take wind from any direction, and operate efficiently in turbulent wind conditions, a new area in wind turbine research has opened up to meet the energy demands of individuals, willing to take control and put resources into small wind energy technology.

A vertical axis wind turbines are classified into two types, they are

- Savonius Wind Turbine
- Darrieus Wind Turbine

1.3 Savonius Wind Turbine

Savonius wind turbines shown in Fig 1, are a type of vertical-axis wind turbine(VAWT), used for converting the wind's force into rotational torque, on a rotating shaft. The turbine consists of a number of aero foiled shaped leaves usually, but not always vertically mounted on a rotating shaft. They are either ground stationed or connected in several airborne systems. Savonius turbines extract much less of the wind's power, than other similarly-sized lift- type turbines. Much of the swept area of a Savonius rotor may be

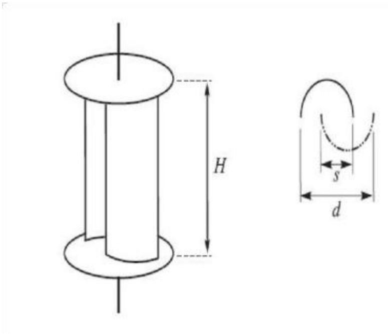


Fig -1: Savonius wind turbine

around the ground, if it has a small mount without an extended post, making the overall energy extraction less efficient due to the lower wind speeds available at lower altitudes. Savonius turbines are used whenever cost or reliability is much more considerable parameters than efficiency. They are also used for the self-starting mechanism of a turbine without any external mechanical aid.

1.4 Overlapping Savonius Rotors

A simple modification, done to the Savonius rotor is to overlap the leaves of the wind turbine or rotors, permitting air to flow between each of the sides, which dominantly increases the wind turbine's efficiency. This study concluded that, the two stage overlapping Savonius rotor as shown in Fig 2 was the most efficient wind turbine among the different combinations of the Savonius wind turbine rotors tested. This also allows the turbine to be started with wind from any direction because the offsetting rotors or stages ensures that either one of the buckets are usually in the direction of the wind.

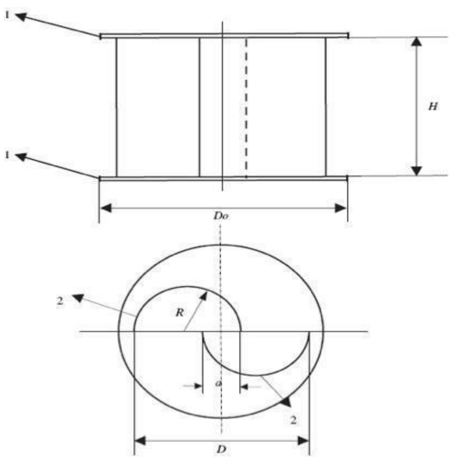


Fig -2: Overlapping Savonius rotors

1.5 Darrieus Wind Turbine

It is type of vertical axis wind turbine (VAWT) used to produce electricity from the wind energy. The turbine contains several curved aero foil shaped blades, mounted on a free to rotate shaft. The curvature of the blades permits the blade to be stressed only at high rotating speeds. There are many difficulties in safe guarding the Darrieus type wind turbine from extreme wind conditions and in making it self-starting. The shape of the leaves present in the Darrieus type wind turbines could be of two types

- Egg-Beater type rotors
- H-rotor type rotors

1.6 Egg-Beater Type Darrieus Wind Turbine

This type of Darrieus wind turbine consists of two curved blades that are vertically positioned and rotating around a vertical shaft. This Darrieus wind turbine is a kind of VAWT. Unlike the Savonius type wind turbine, the Darrieus type is a lift-type VAWT. Instead of gathering the air streams within its cups, the turbines will drag around along with wind. Darrieus type wind turbine utilizes the lift force of the wind which is created through the air stream striking the aero foiled shaped rotors to make rotations around the shaft.

Fig -3: Egg-Beater Type Darrieus Wind Turbine

1.7 H-Rotor Type Darrieus Wind Turbine

The H-rotor type Darrieus wind turbine contains straight and vertically oriented rotors rather than the standard shapes that have curved blades directly, horizontal structures connect the blades or rotors and the shaft. The orientation of these structures is typically on the ends or the center of the blades as shown in Fig 4. One of the major and crucial characteristics of this type vertical axis wind turbine is that it has the ability to collect the wind from different directions. Moreover, straightforward and simple design of the rotors leads to easy manufacturing of the wind turbine, which ultimately leads to easy installation and maintenance.

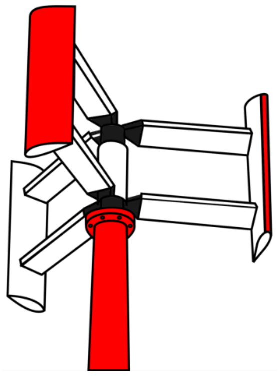
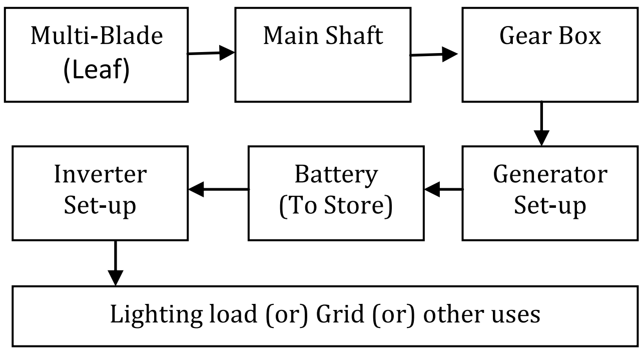


Fig -4: H-Rotor Type Darrieus Wind Turbine

1.8 Methodology



2. LITERATURE SURVEY

[1] Anurag Kumar et al describes briefly about the hybrid rotor system which has been available in different configurations. Many attempts have been made to achieve a good start-up torque for the hybrid rotor consisting the Savonius type rotor. Hence, Savonius rotors provide the self-starting ability.

[2] Nawfal M. Ali et al studies showed experimentally and numerically what is the effect of the combination between the two types of wind turbines (Savonius and Darrieus). The main conclusions were "The performance of the hybrid Wind mill case is better than the other cases. At low wind velocity, there is increased power co-efficient and torque co-efficient and can be self-started at a lower wind velocity too. The overall efficiency of extracting the wind power for the Hybrid Wind mill is economically feasible for larger structures".

[3] Parth Rathod et al evident that the power output of vertical axis wind turbine for two blades (Savonius rotors) with two stages, is maximum. It is also observed that when Darrieus H type rotors are constructed above the S type Savonius rotors, then power output increases with respect to the velocity of wind.

[4] Mr.Jaimin Patel et al shows that Vertical axis wind turbine (Savonius wind turbine) is easier to construct, low cost in manufacture, requires less maintenance, less space availability and most important provides free & green energy. The result from the literature shows that two blade Savonius rotor is more efficient than the three blade setup. It can play an important role in villages for producing renewable and free energy. Also, it can reduce the pollution created bythe fossil fuels to produce electricity. Hence, it is very useful for household application.

[5] M. Douak, Z et al concludes that "The rotor height does not affect the power coefficient as it appears in the expressions of both the produced and maximum available power. However, it does affect the value of the starting torque and the power. Both of these values increase with the value of height." Hence, Darrieus Rotors require external starting power or aid, with increased rotor height, to generate electricity efficiently.

3. COMPONENTS DESCRIPTION

3.1 Bearing

Here Deep Groove Ball Bearing is selected as needed for withstanding the desired load. Ball bearing SKF 6201 with 20 mm bore diameter is selected to fit the shaft size (20 mm).

Type	Deep Groove Ball Bearing
Bearing Diameter	20 mm
Width of bearing	15 mm
Static load capacity	4800 kgf
Dynamic load capacity	6400 kgf
Maximum Speed	5000 rpm

Fig-5: Bearing

3.2 Shaft

Shaft with diameter 20 mm is selected for our project as this size of rod weighs light and can withstand considerable stresses and strains.

Fig-6: Shaft

Diameter	20 mm
Length	915 mm
Weight	2.26 kg
Material	Mild Steel
Young's Modulus	2.1 x 10^5 N/mm^2

3.3 Frame

The frame for our project is created by welding in L angles according to our requirements.

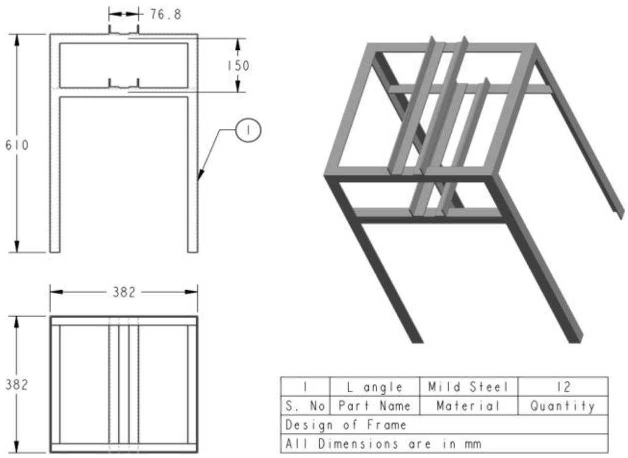


Fig-7: Frame

3.4 Bearing Cap

Fig-8: Bearing Cap

Diameter	58 mm
Thickness	20 mm
Material	Mild Steel

3.5 Sheet Plate

Length	610 mm & 305 mm
Thickness	1mm
Breadth	204 mm
Material	Mild Steel

Fig-9: Sheet Plate

3.6 Round Plate

MS Plates are used in our project to mount the Darrieus type vertical wind turbine. Mild steel Plates are used as they are ductile, weld able and easy to install. The plate is drilled to produce a hole of about 20 mm to fit it in the shaft.

Fig-10: Round Plate

3.7 Spur Gear (Pinion and Wheel)

Fig-11: Pinion

Fig-12: Wheel

Contents	Pinion	Wheel
Material	Cast Iron	Cast Iron
Outer Diameter	160 mm	40 mm
Inner Diameter	20 mm	20 mm
No. of Teeth	86	22
Module	3 mm	3 mm

3.8 Battery

Lead acid batteries are generally used because of their power to weight ratio and their low cost. Inside a lead-acid battery, the positive and negative electrodes consist of a group of plates welded to a connecting strap. The plates are immersed in the electrolyte, consisting of 8 parts of water to

3 parts of concentrated sulfuric acid.The battery used in our project is AP-BTX5L lead acid battery with Voltage – 12 V and Power Output at 5 A-h.

Fig-13: Battery

Type	Lead Acid Battery
Model Number	AP-BTX5L
Voltage	12 V
Electric Charge	5 A-h

3.9 Alternator

Fig-14: Alternator

Type	Permanent Magnet
Power Output	1.5 W
Voltage Produced	12 V at 200 rpm

3.10 Inverter

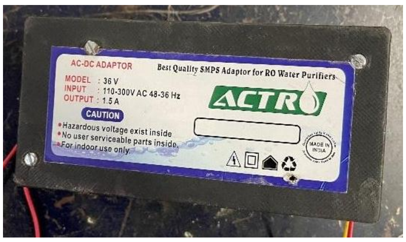


Fig-15: Inverter

Input	12 V DC
Output	220 V AC
Power Output	40 W

4. DESIGN OF THE TURBINE

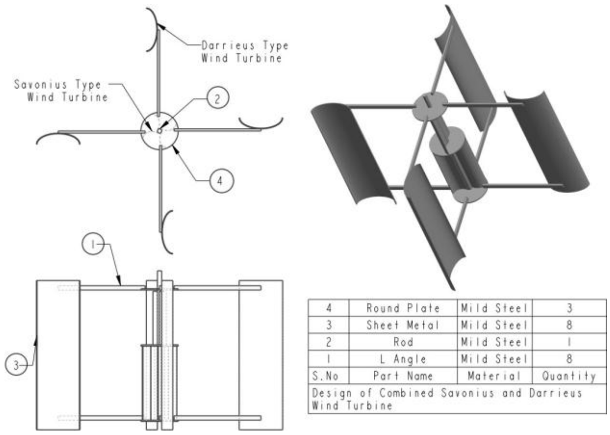


Fig-16: Design of the combined Savonius and Darrieus Wind Turbine

4. 1 Assembled view of the turbine

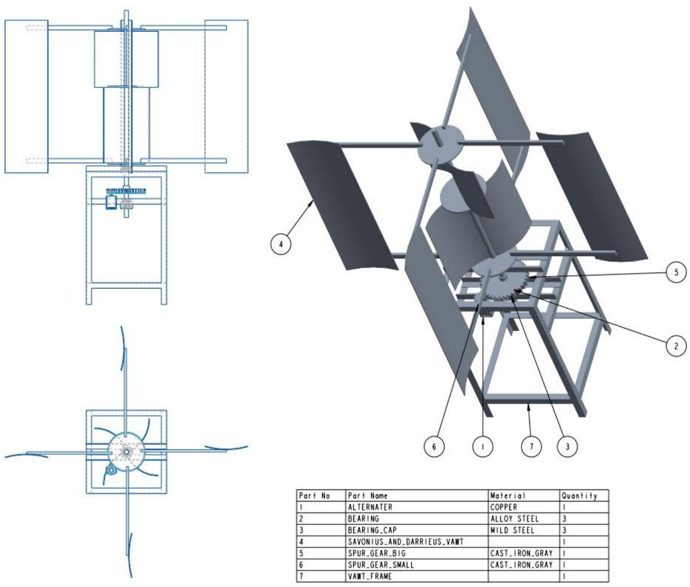


Fig-17: Wind Turbine Assembly

Fig-18: Final Assembly view of Wind Turbine

5. TESTING AND CALCULATION

5.1 Testing

The wind turbine setup was tested from wind speeds varying from 5 m/s to 35 m/s and was also tested for its starting wind speed also. The test run results for both Savonius setup alone and the combined Savonius and Darrieus wind turbine is as shown in the table 1 and 2 below.

Table -1: Test run results for Savonius Wind turbine setup alone

Wind Speed (in m/s)	Respective speed of the wind turbine setup (in rpm)
5	10
10	20
15	40
20	74
22.5	88
25	105
30	123
35	154

From this test run we can clearly conclude that the Savonius wind turbine setup alone, automatically starts to rotate at the wind speed of 5 m/s. Though the Savonius wind turbine setup helps to self-start the entire wind turbine without any starting up mechanical aid, it doesn't perform well at higher wind speeds. Next, the Combined Savonius and Darrieus wind turbine setup was tested at the wind tunnel. The results were as shown in the table 2 below.

Table -2: Test run results for combined Savonius and Darrieus Wind turbine setup alone

Wind Speed (in m/s)	Respective speed of the wind turbine setup (in rpm)
7.5	15
10	23
15	40
17.5	48
20	58
25	70
30	105
35	120

We can clearly see that the combined Savonius and Darrieus wind turbine setup automatically starts up at the wind speed of 7.5 m/s. The starting speed of combined Savonius and Darrieus wind turbine is a little bit higher than Savonius wind turbine setup alone, is because of the added weight of the Darrieus wind turbine setup made. Darrieus wind turbine require even more higher wind speed and a large swept area or diameter of the rotor, for providing even more higher rotational speeds and higher efficiency. Having recorded these values, the Efficiency of the Wind turbine is found out by Calculations.

5.2 Efficiency Calculation

Trail 1 (For Velocity 10 m/s)

$P_{avail} = \frac{\rho \pi D^2 V^3}{8}$

$P_{avail} = \frac{1.225 \times \pi \times 0.8128^2 \times 10^3}{8}$

$\mathbf{P_{avail} = 317.806\ watts}$

Considering power factor to be C_p = 0.4,

$P_{actual} = P_{avail} \times C_p$

P_{actual} = 317.806 x 0.4 = **127.122 watts**

Considering the power losses in the turbine,

Wake loss – 1 %; Mechanical Loss – 2 %; Electrical Loss – 1.5 %; other losses – 1 %

Total Power Loss = 127.122 x 4.5 % = 127.122 x 0.045 = **5.72 watts**

Therefore, the actual power after all the losses is,

P_{actual} = 127.122 – 5.72 = 121.402 watts

Therefore, Efficiency of the wind turbine $= \frac{P_{actual}}{P_{avail}} x100$

$= \frac{121.402}{317.806} x100$ = **38.18%**

Trail 2 (For Velocity 15m/s)

$P_{avail} = \frac{\rho \pi D^2 V^3}{8}$

$P_{avail} = \frac{1.225 \times \pi \times 0.8128^2 \times 15^3}{8}$

$\mathbf{P_{avail} = 1072.598 watts}$

Considering power factor to be C_p = 0.4,

$P_{actual} = P_{avail} \times C_p$

P_{actual} = 1072.598 x 0.4 = **429.039 watts**

Considering the power losses in the turbine,
Wake loss – 1 %
Mechanical Loss – 2 %
Electrical Loss – 1.5 %
Other losses – 1 %
Total Power Loss = 429.039 x 4.5 % = 429.039 x 0.045 = **19.30 watts**
Therefore, the actual power after all the losses is,
P_{actual} = 429.039 – 19.30 = 409.739 watts
Therefore, Efficiency of the wind turbine = $\frac{P_{actual}}{P_{avail}} x100$
$= \frac{409.739}{1072.598} x100 =$ **38.20%**

5.3 Torque Calculation

Torque generated by the wind turbine is found out using the Tip speed ratio of the wind turbine and by determining its angular velocity. We know that,
Blade tip speed = $\frac{\text{Rotational speed x } \pi \text{ x D}}{60}$
Then, the angular velocity of the wind turbine at different wind speeds is found out andit is then tabulated.
Tip speed ratio of the wind turbine = $\frac{\text{Velocity at the tip speed}}{\text{Velocity of the wind}}$
Hence, using the Angular velocity, found above, and the wind speed, the tip speed ratiofor various wind speeds is found and then tabulated.
Radius of the Wind turbine = 0.4064 m

Table -3: Tip speed ratio for respective wind speeds

Wind Speed (in m/s)	Wind turbine Speed (in rpm)	Tip Speed (in m/s)	Tip Speed ratio
7.5	15	0.6388	0.085
10	23	0.9788	0.097
15	40	1.7023	0.113
17.5	48	2.0427	0.116
20	58	2.4683	0.123
25	70	2.9791	0.119
30	105	4.4686	0.148
35	120	5.1069	0.145

The torque generated by the wind turbine is calculated by the given formula,

$$T = \frac{P \text{ x } 30}{N \text{ x } \pi}$$

Table -4: Torque Produced for respective wind speeds

Wind Speed (in m/s)	Wind turbine Speed (in rpm)	Actual power after the losses P (in W)	Torque produced (in Nm)
7.5	15	51.216	32.605
10	23	121.40	40.401
15	40	409.739	97.817
17.5	48	650.639	129.440
20	58	970.515	159.788
25	70	1896.906	258.773
30	105	3277.855	298.106
35	120	5205.120	414.210

Thus, we have calculated and found out the Torque produced by the wind mill at variouswind speeds, and the efficiency of the Combined Wind turbine was found out.

6. ADVANTAGES AND APPLICATIONS

6.1 Advantages

- It is a renewable source of energy.
- Better utilization of wind power.
- The Savonius wind turbine setup attached in the combined wind turbine, helpsin the Self-starting of the wind turbine at a wind speed of 7.5 m/s, hence startingto produce electricity at wind speed around 10 m/s only.
- The major advantage of this wind turbine design is that it can accept wind from any direction, hence eliminating steering the setup into the wind.
- The Combination of Savonius and Darrieus wind turbine has helped to achieve higher efficiency than usual vertical axis wind turbines.
- As this machine has vertical axis symmetry, it eliminates yaw control requirement for its rotor to capture wind energy. A comparatively simple shaft axis support is required as well as ground level power output delivery due to the presence of a vertical shaft. Hence, allowing easier access and serviceability.
- The tip speed ratio and power coefficient are considerably better than those of the Savonius wind turbines setup alone but are still less than the values of a modern horizontal-axis, three-bladed propeller rotor.

- Construction and manufacturing of this wind turbine is simple.
- VAWT's can be installed in more versatile locations such as - on roofs, alonghighways, in parking lots, etc.
- Combined Wind turbine can be scaled more easily – designs for producing frommilli-watts to mega-watts of power.
- Combined Wind turbine on a small scale setup can be utilized to produce a few kilowatts of electricity, and is less costly too.
- Combined wind turbine on a large scale setup, costs can be competitive higher and lower costs could be attained by mass production.
- It can have low maintenance downtime, as the wind turbine is closer to ground and can be accessed easily.

6.2 Applications

- Wind-turbine generators have been built on a wide scope of power outputs, rangingfrom kilowatt to a few thousand mega-watts.
- Wind turbines producing low power can generate sufficient electricity for space heating or cooling and for can be utilized for domestic applications.
- Applications of more powerful wind turbines producing power up to about 50 kW, can be utilized for operating irrigation pumps, navigational signal, etc.
- Wind turbines producing power in the intermediate power range, roughly about 5 to 50 kW can supply electricity to isolated areas.

7. CONCLUSIONS

Wind turbine technology has demonstrated the potential to harness electricity from the wind power, and to contribute to the ever-rising energy demands of the world. If the correct locations with suitable wind characteristics were fully utilized, they could contribute to the production of electricity, and supply the ever growing demand for electricity in this growing world.

Our Project is designed, fabricated and tested for performance at various wind speeds, onthe basis to produce a combined vertical axis wind turbine, to create its own characteristics. The advantage of the self-starting Savonius type wind turbine is combined along with the highly efficient Darrieus wind turbine, to increase its efficiency at low wind speeds. This design has helped to make the Darrieus wind turbine self-starting at low wind speeds such as 7.5 m/s and produce uninterrupted electricity supply at a speed of 10 m/s. Thus, the project of designing and Fabrication of the Combined Savonius and Darrieus wind turbine has been successfully done.

Future Scope

- The design of the wind turbine leaves can be changed into a more efficient aero foilstructure to increase its efficiency.
- Different materials, with lesser overall weight, can be selected and used to create the structural features of the wind turbine, to be more efficient at even lower wind speeds.
- Total area of wind capture can be increased by scaling the model, to capture even morewind and produce electricity at greater efficiency.
- Larger generators can be coupled with the up scaled model of the wind turbine to produce more power.

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