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Performance Testing of a Small Self-Starting Vertical Axis Wind Turbine

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Abstract:- The presented research work focuses on utilizing wind energy for power production by developing a small-scale wind turbine, as an alternative to conventional energy sources like fossil fuels which are rapidly depleting and also harming the environment on global scale. In the undertaken work, a simple self-propelled vertically-mounted rotor turbine has been fabricated. An NACA0018 airfoil was selected for the prototype and the model was subjected to a dessert cooler at different speed for study and optimization of turbine for aerodynamic performance.

***Keywords**:- Wind turbine, HAWT, VAWT, aerodynamics, optimization.*

I. INTRODUCTION

Over the past 50 years, the average global temperature has increased, and this worldwide phenomenon is called Global Warming. As an alternative to fossil fuels, demand and attention for sustainable and renewable energy sources like hydroelectricity, tidal, solar, wind, wave, geothermal and bioenergy has increased all over the world. In recent times, wind energy being a clean, renewable and sustainable source gained a prime importance in power production. The terms wind energy or wind power describes the procedure where wind is used to produce electricity or mechanical power. The difference of pressure and temperature in atmospheric air causes them to flow and hence generates wind. Wind power involves conversion of kinetic energy of wind into electricity using wind turbines.

Wind turbines can be divided into two groups: vertical axis wind turbine (VAWT) and horizontal axis wind turbine (HAWT). HAWT has successfully evolved into amateur technology for wind energy to electricity conversion. At present, HAWT is applied on big to huge (large-scale) wind power plants. The depth of studies and recent works on VAWT are not as profound as those testing HAWT, primarily because HAWT has superior efficiency. However, VAWT also has its own advantages, during the rotation of the blades, the condition of receiving effects is better than that of HAWT, because the directions of the inertial force and gravity keep stable ever. Hence, the blades receive a fixed load, and accordingly have fatigue longevity longer than the HAWT.

II. PROBLEM FORMULATION

How Turbines Work: The wind applies two driving forces on the blades of a turbine; drag and lift. The velocity difference in wind creates a pressure differential. A low-pressure area is created on the leeward side, which pulls the airfoil in that direction. This is the Bernoulli's Principle. Drag and lift are the components of this force vector parallel to and perpendicular to the relative or apparent wind, respectively.

A. Turbine Power

The power of the wind is proportional to the natural wind speed, area of the segment of wind being considered, and air density. These variables follow the following relation-

$$P_w = \frac{1}{2}\rho A u^3$$

Where,
Pw - Power of the wind (W)
- Air density (kg/m3)
A - Area of a segment of the wind being considered (m2) U - Undisturbed wind speed (m/s)

With an ideal turbine, the mechanical power that can be obtained from the wind is given as

$$P = 2\pi \frac{NT}{60}$$

Where,
P - Mechanical Power of Turbine (W) N - Rotation Speed, rpm
T - Torque

Coefficient of Performance can be deduced from Turbine Power and Wind Power.

$$C_p = \frac{P}{P_w}$$

B. Design Parameters

Design Specifications

Rotor (R)	0.65 m
Blade Length (L)	0.5 m
Blade Chord	0.08 m
No of Blades (N)	6
Wind Speed	3 – 10 m/s
Mounted Stand Height	0.68 m

Table 1. Turbine Dimensions

Rotor (R) 0.65 m
Blade Length (L) 0.5 m
Blade chord 0.08 m
No of Blades (N) 6
Wind Speed 3 - 10 m/s
Mounted Stand Height 0.68 m

➢ *Airfoil Selection*

The airfoil is selected after considering the final thickness of the blade which is associated with its ability to withstand the loads and the availability and accessibility of airfoil data for angles of attack between -30 and 30º.

The selected airfoil is the NACA0018, whose aerodynamics characteristics were determined by implementing an airfoil property synthesizer code.

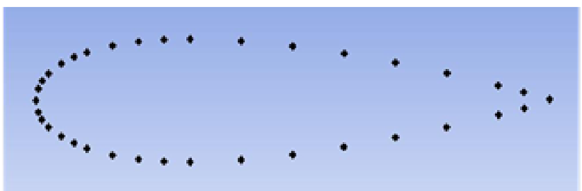

Fig. I: Airfoil Naca0018

III. FABRICATION OF THE MODEL

The VAWT requires airfoil blades with a rotor on a stand. The blades with airfoil cross-section profile of NACA0018 is fabricated with 24-guage Galvanized Iron sheet. The airfoil cross-section was made on cardboard and GI sheet was rolled around it to obtain the profile. The rotor and support arms are made of Galvanized Iron rod. The arms have screw holes at one end to hold airfoil blades and are welded on other side to the rotor. This setup is put over a tripod stand where rotor fits at the top of it with a rotary bearing. The stand frame is made of Mild Steel.

Fig 2:- Assembled Prototype of VAWT

IV. TEST SET-UP AND INSTRUMENTATION

A. *Experimental Set-up*

All the fabricated VAWT parts are assembled as shown in FIG. 2. The VAWT consists of 6 airfoil blades at angle of 600 each, screwed at extended arms of the rotor. The turbine set-up was kept at a distance from a dessert cooler which has a varying speed of 3m/s to 10.5m/s.

B. *Instrumentations*

Torque Measurement: In order to determine the aerodynamic performance of the turbine, a torque meter was used to measure the torque generated in the rotor by the wind.

Rotational Speed Measurement: In order to determine the rotational speed of the rotor, a digital tachometer was used to measure the rpm of the turbine.

V. RESULTS

The VAWT was subjected to a dessert cooler with varying speed between 3.5 m/s to 10 m/s. The torque and RPM of the turbine was measured by the instruments at different speed. Power outcome, co-efficient of power and tip-speed ratio were calculated using measured quantities. Here are shown some results at different wind speed.

➢ *At wind speed 3.5 m/s*

RPM	POWER	TSR	C_P
24	1.616	0.43	0.103
26	2.118	0.466	0.135
28	2.699	0.502	0.172
30	3.263	0.538	0.208
32	3.828	0.574	0.244
34	4.283	0.61	0.273
36	4.55	0.644	0.29

Table 2. Parameters at wind speed of 3.5 m/s

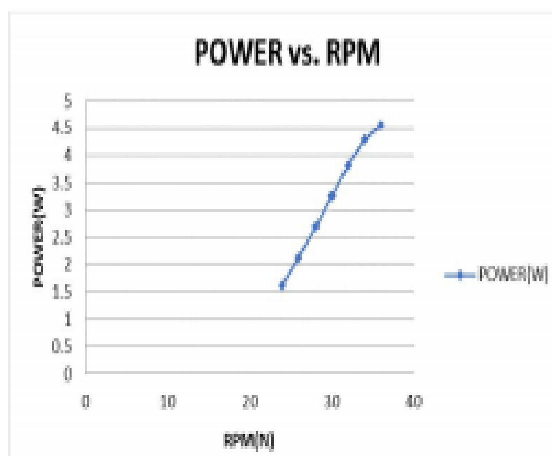

Fig 3:- Power vs RPM, at wind speed 3.5 m/s

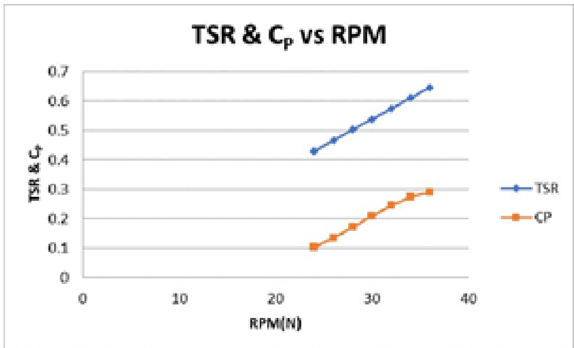

Fig 4:- TSR & Cp vs RPM, at wind speed 3.5 m/s

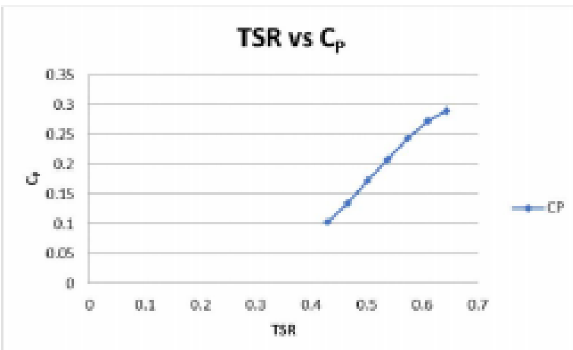

Fig 5:- TSR vs Cp, at wind speed 3.5 m/s

➢ *At wind speed 5 m/s*

RPM	POWER	TSR	C_P
46	6.419	0.577	0.14
49	8.023	0.615	0.175
54	8.848	0.678	0.193
60	9.995	0.753	0.218
65	10.82	0.816	0.236
69	11.829	0.866	0.258
74	13.617	0.928	0.297

Table 3. Parameters at Wind Speed of 5 M/S

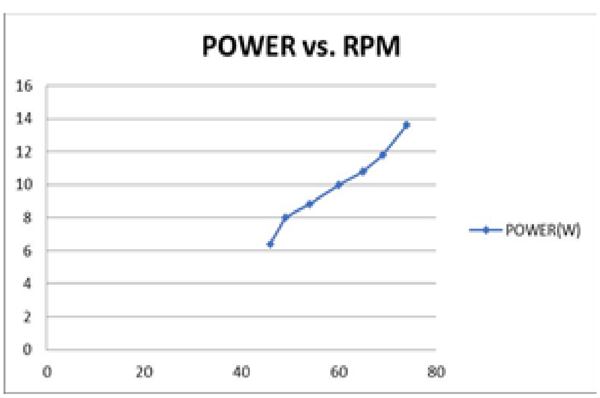

Fig 6:- Power Vs Rpm, at Wind Speed 5 M/S

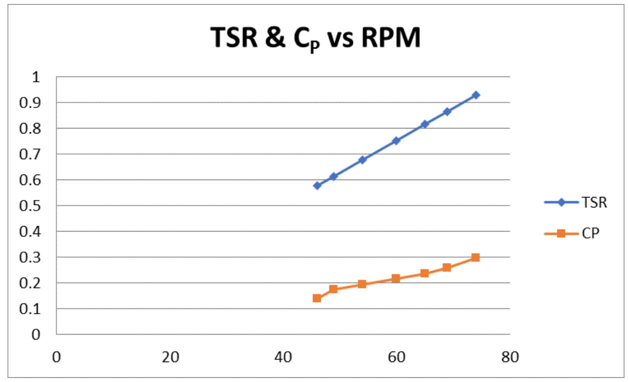

Fig 7:- TSR & C_P vs. RPM at wind speed 5 m/s

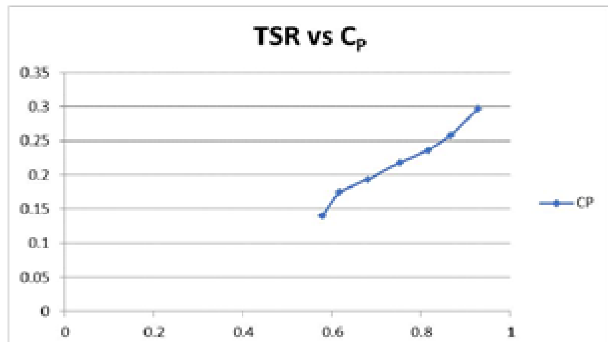

Fig 8:- TSR vs C_P at wind speed 5 m/s

RPM	POWER	TSR	CP
61	10.308	0.638	0.13
64	11.577	0.67	0.146
70	14.749	0.733	0.186
76	16.176	0.795	0.204
80	18.716	0.837	0.236
86	21.172	0.9	0.267

Table 4. Parameters at wind speed 6 m/s

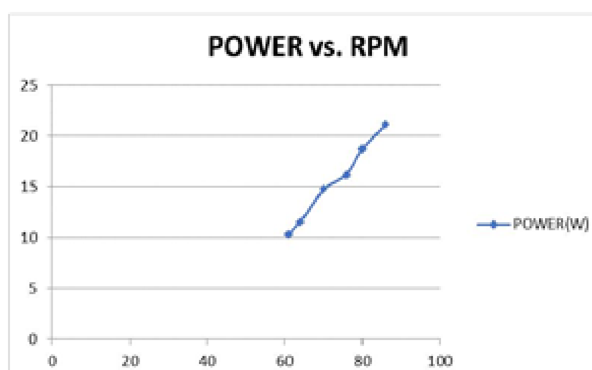

Fig 9:- Power vs. RPM at wind speed 6 m/s

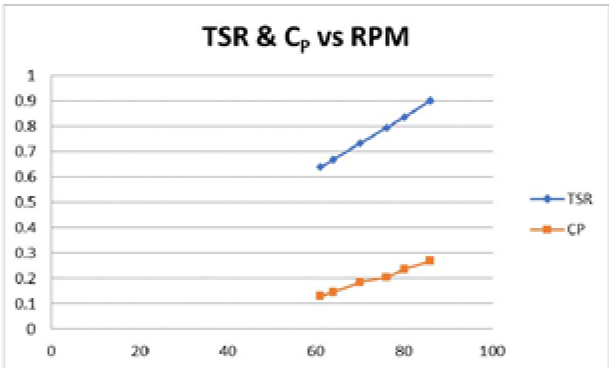

Fig 10:- TSR & Cp vs RPM, at wind speed 6 m/s

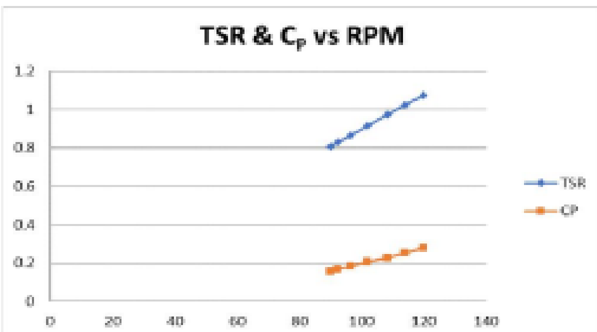

Fig 11. TSR & C_P vs. RPM at wind speed 6 m/s

➢ *At wind speed 7 m/s*

RPM	POWER	TSR	CP
90	19.744	0.807	0.157
92.5	21.253	0.829	0.169
96.4	23.139	0.864	0.184
101.8	25.906	0.913	0.206
108.3	28.547	0.972	0.227
114	31.69	1.022	0.252
119.8	35.086	1.074	0.279

Table 5. Parameters at wind speed of 7 m/s

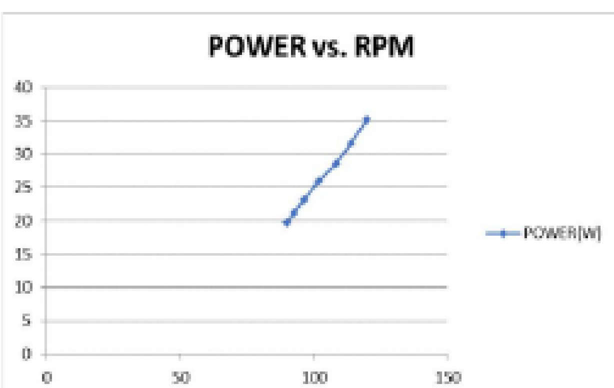

Fig 12. Power vs. RPM at wind speed 7 m/s

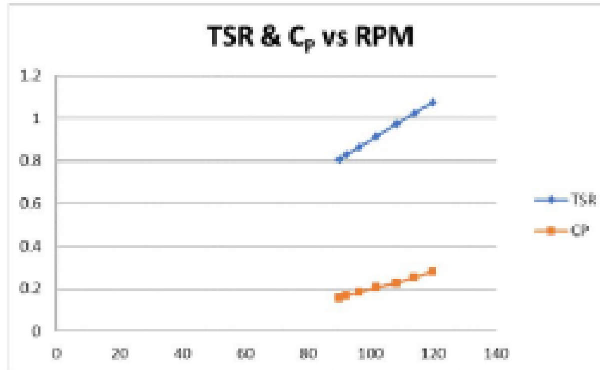

Fig 13:- TSR & Cp vs RPM, at wind speed 7 m/s

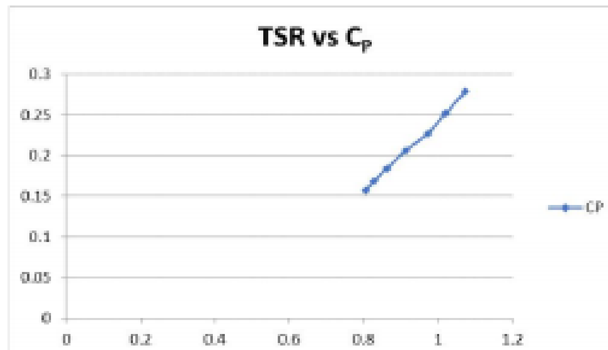

Fig 14:- TSR vs C_P at wind speed 7 m/s

➢ *At wind speed 8 m/s*

RPM	POWER	TSR	CP
115.5	30.808	0.906	0.164
118.1	34.001	0.927	0.181
119.8	36.819	0.94	0.196
120.7	39.073	0.947	0.208
123.3	41.14	0.968	0.219
125	46.399	0.981	0.247
127.2	49.217	0.999	0.262

Table 6. Parameters at wind speed of 8 m/s

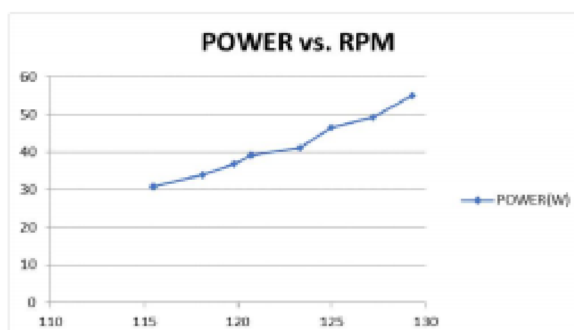

Fig 15:- POWER vs. RPM at wind speed of 8 m/s

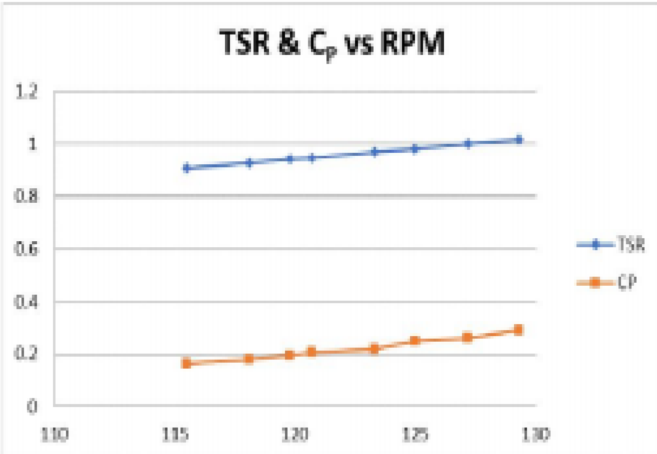

Fig 16:- TSR & Cp vs RPM, at wind speed 8 m/s

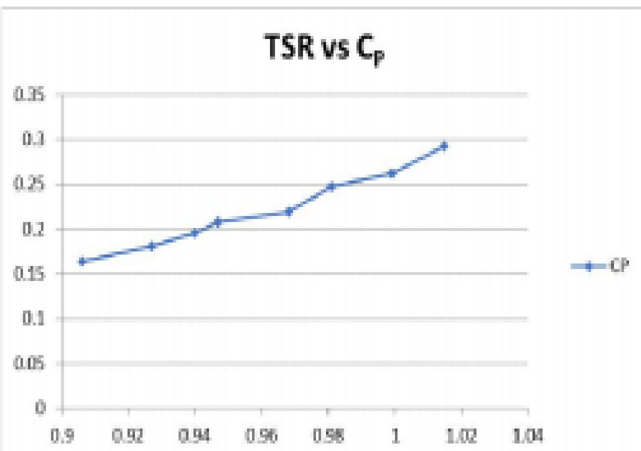

Fig 17:- TSR vs Cp, at wind speed 8 m/s

➢ *At wind speed 9 m/s*

RPM	POWER	TSR	CP
130.4	48.707	0.91	0.181
132.6	51.65	0.925	0.193
134.5	55.932	0.938	0.209
135.9	58.073	0.948	0.217
136.6	61.552	0.953	0.23
139.8	66.369	0.975	0.248
145.7	73.595	1.016	0.275
148.3	79.75	1.034	0.298

Table 7. Parameters at wind speed of 9 m/s

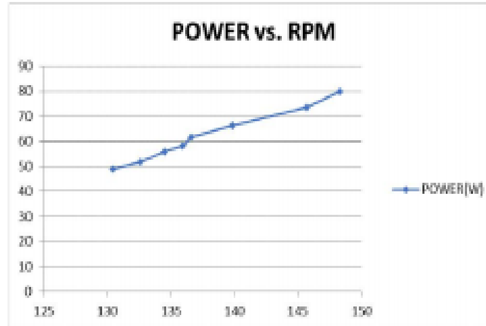

Fig 18:- POWER vs RPM at wind speed of 9 m/s

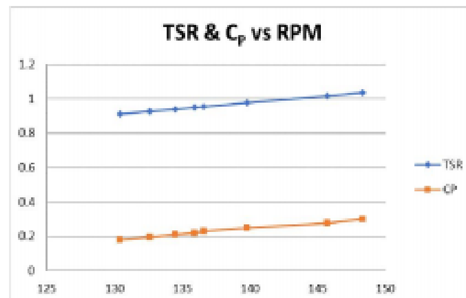

Fig 19:- TSR & C_P vs RPM at wind speed of 9 m/s

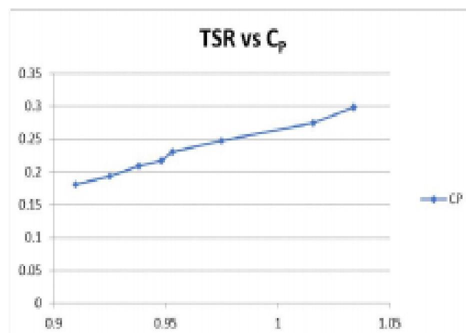

Fig 20:- TSR vs C_P at wind speed of 9 m/s

➢ *At wind speed of 10 m/s*

RPM	POWER	TSR	CP
147.2	78.125	0.924	0.213
149.4	80.324	0.938	0.219
152.7	86.192	0.959	0.235
153.5	90.594	0.964	0.247
155.3	97.196	0.975	0.265
157.7	102.33	0.99	0.279
159.6	109.42	1.002	0.298

Table 8. Parameter at wind speed of 10 m/s

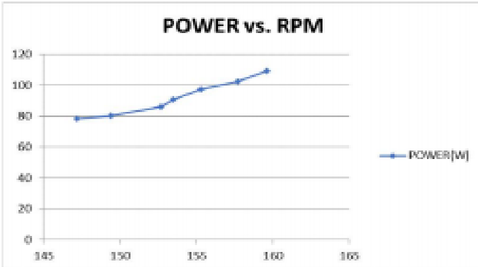

Fig 21:- POWER vs RPM at wind speed of 10 m/s

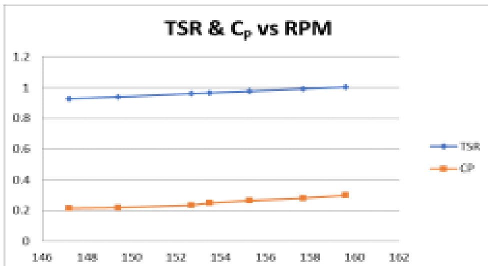

Fig 22:- TSR & C_P RPM at wind speed of 10 m/s

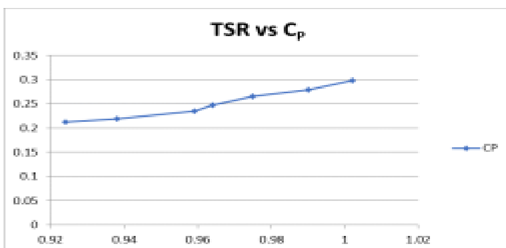

Fig 23:- TSR vs C_P at wind speed of 10 m/s

VI. CONCLUSION

The self-starting Vertical Axis Wind Turbine project was successful. However, it required some rearrangements and calculations for desired output. Initially, the 3-bladed prototype model in consideration having airfoil NACA0015 profile didn’t show any output. So, the airfoil profile and other design specifications were changed to NACA0018. The next resulted model showed us some work output but was not self-starting. The desired results were achieved by increasing the number of blades from 3 to 6. Under test condition, at highest wind speed the final prototype VAWT model generated over 100 W powers with 29.8% efficiency. The project shows the small-scale development of VAWT for power generation from wind energy. Such VAWT are low-cost and easy to fabricate models can be implemented at rooftops and farms at off-shore areas to produce electricity. This makes the VAWT at an overall basis a very fruitful and advantageous replacement to HAWT.

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