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Characteristics and Performance of Vertical-Axis Wind Turbine (VAWT)

By Yongjian Gu

Abstract- There are two technologies of wind turbines. One is the horizontal-axis wind turbine (HAWT), which dominates the market of wind farms since the HAWT has a higher energy transfer efficiency. Another is the vertical-axis wind turbine (VAWT), which has unique characteristics to be able to compete with the HAWT, especially in application locations. This paper first introduces the working mechanism of the VAWT and presents different types of VAWTs. Then the paper lists the major difference between VAWTs and HAVTs. It is attractive that the VAWT doesn't need long length blades and a giant tower so that the VAWT doesn't require a large open area and can be applied in the areas of metropolitan, community, and resident. In these areas, VAWTs not only can efficiently utilize wind energy but also may have cosmetic effects for the buildings and surroundings. The paper reveals the unique characteristics of the VAWT: replaceable and stackable. The replaceable feature allows an existing VAWT to be altered to a different VAWT type amazingly and the stackable feature lets the VAWT be upgraded conveniently to meet the load requirements. In the paper, the author presents a novel design of the stackable VAWT, a green power tower (GPT).

Keywords: wind energy, vertical-axis wind turbine (VAWT).

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CHARACTERISTICSANDPERFORMANCEOFVERTICALAXISWINDTURBINEVAWT

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Characteristics and Performance of Vertical-Axis Wind Turbine (VAWT)

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Abstract- There are two technologies of wind turbines. One is the horizontal-axis wind turbine (HAWT), which dominates the market of wind farms since the HAWT has a higher energy transfer efficiency. Another is the vertical-axis wind turbine (VAWT), which has unique characteristics to be able to compete with the HAWT, especially in application locations. This paper first introduces the working mechanism of the VAWT and presents different types of VAWTs. Then the paper lists the major difference between VAWTs and HAVTs. It is attractive that the VAWT doesn't need long length blades and a giant tower so that the VAWT doesn't require a large open area and can be applied in the areas of metropolitan, community, and resident. In these areas, VAWTs not only can efficiently utilize wind energy but also may have cosmetic effects for the buildings and surroundings. The paper reveals the unique characteristics of the VAWT: replaceable and stackable. The replaceable feature allows an existing VAWT to be altered to a different VAWT type amazingly and the stackable feature lets the VAWT be upgraded conveniently to meet the load requirements. In the paper, the author presents a novel design of the stackable VAWT, a green power tower (GPT). The working principle of the GPT is described and performance data of the GPT are shown. The GPT can be installed on buildings, ships, towers, etc. The potential applications of the GPT are illustrated in the paper.

Keywords: wind energy, vertical-axis wind turbine (VAWT).

I. Introduction

A wind turbine is a device converting wind energy into useful power. There are two technologies of wind turbines: horizontal-axis wind turbine (HAWT) and vertical –axis wind turbine (VAWT). In a HAWT, the turbine shaft axis is parallel with the ground. While in a VAWT, the turbine shaft axis is perpendicular to the ground. Both turbines are shown in Figure 1.

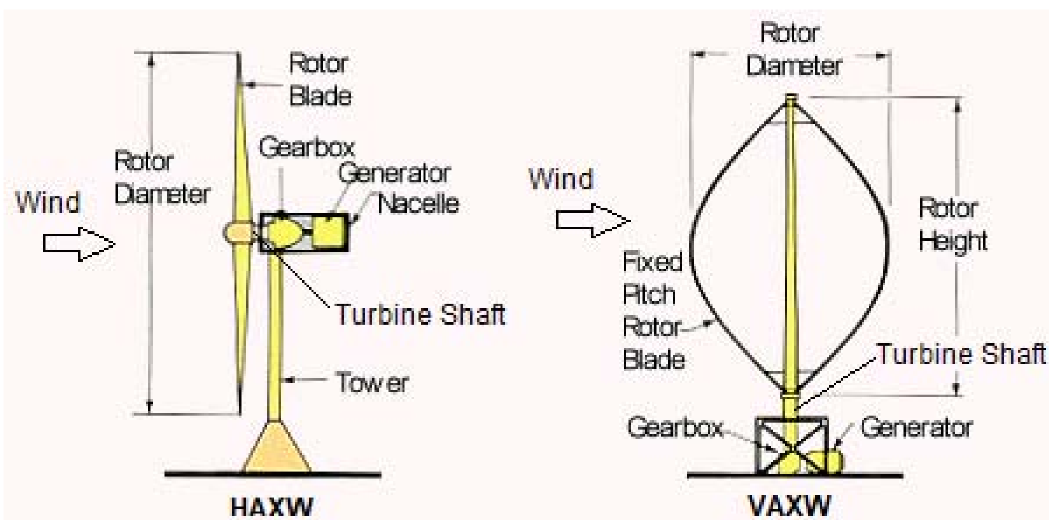

Fig. 1: HAWTs and VAWTs

In wind farm application, HAWTs are more popular than VAWTs since HAWTs have higher efficiency for the unit wind energy utilizationthan VAWTs. The working mechanism of two, nevertheless, HAWTs and VAWTs is the same - wind blowing the wind turbine blades converts the kinetic energy of the wind to mechanical energy (wind turbine shaft work). Then the wind turbine shaft drives a generator to convert the mechanical energy to electrical energy. Figure 2 illustrated the working principle of the VAWT.

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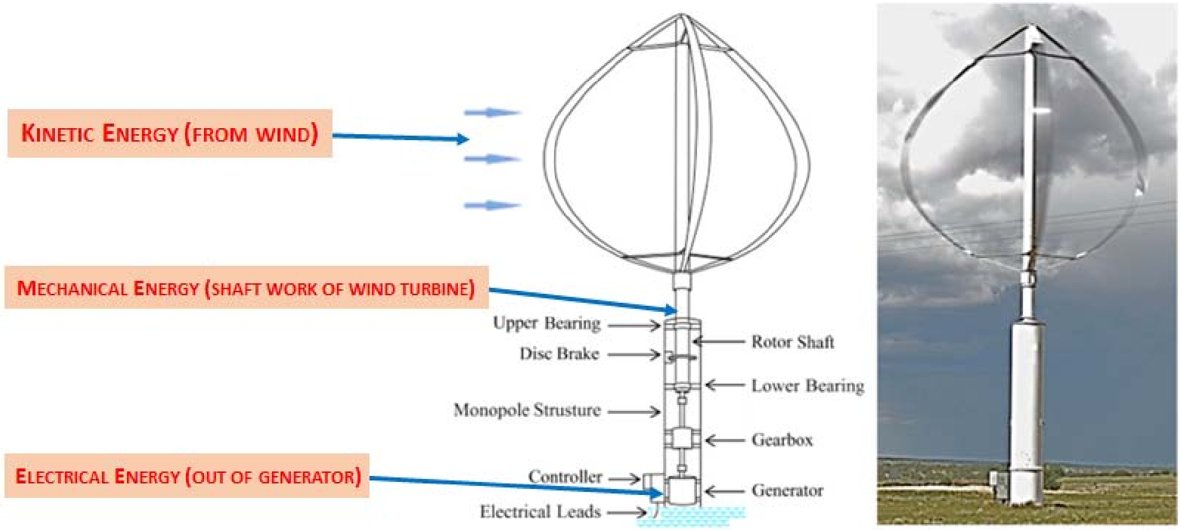

Fig. 2: Working Principle of VAWTs

In wind turbine history, the first wind turbine was VAWT dated back to the Egyptian civilization, where it was used in sailboats. In wind turbine development, various VAWT were designed. Figure 3 presents some of the VAWTs.

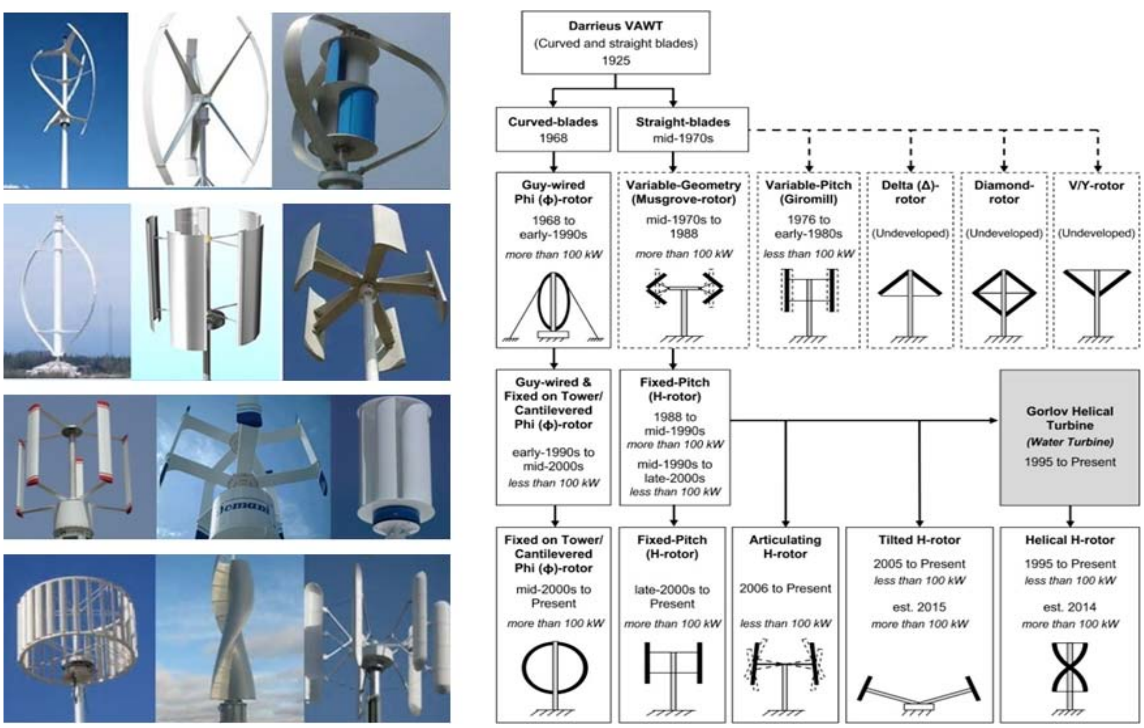

Fig. 3: Different VAWT designs

II. Difference Between HAWTs and VAWTs

Except the difference of the wind flow direction with the shaft axis, HAWTs and VAWTs have some differences and impacts in construction, economy, and environment. In HAWTs, the huge towers and large blades result in a high cost and trouble in the environment. After several decade of developments, HAWTs are becoming the bigger and the taller. The huge HAWTs are not suitable to locate in the areas of metropolitan, community, and resident, etc. Therefore, VAWTs become more attractive and practical in such areas. VAWTs are more convenient for installation and maintenance in which the electric system is on the ground. A summary of major differences between HAWTs and VAWTs are shown in Table 1.

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III. Advantages of VAWTs

From Table 1, it can be seen that HAWTs have advantages of efficiency and commercial availability; VAWTs, however, have the advantages which can compete with HAWTs, in application location, environment effect, etc.

Table 1: Major Difference between HAWTs and VAWTs

FACTOR	VAWT	HWAT
Power Generation Efficiency	50-60%. Less wind flow usage and partial blades are in operation	>70%. More wind flow usage and all brades are in operation. Less aerodynamic loss.
Blade Ratotion Speed	Quite Small. Lower weight of the blade.	Quite Large. Heavy weight of the blade.
Vibration Levels	Low. Symmetricity to the shaft.	High. Heavy blades on one end of the shaft.
Noise	0-10db. Due to low vibration level.	5-60db. Due to high vibration level.
Required Wind Speed	Fair. Because of the lower weight of the blades.	Strong. Because of the haveay weight of the blades.
Starting Wind Speed	Fair. Because of the lower weight of the blades.	Strong. Because of the haveay weight of the blades.
Wind Direction	No Effect. Can operate with wind from any direction.	Sensible. Has to turn around and fact to the wind direction
Effect on Enviroment	Small. Rotation area is small. Lower noise.	Large. Rotation Area is huge. Higher noise. There is design and manufacture standard. Their height makes them obtrusively visible across large areas, disruption the appearance of the landscape.
Commercial Availablility	Low. Has no standard.	High.
Installation Cost	Low. Major equipment is near ground.	High. Major equipment is on the tall tower. Massive towre construction is required to support the neary blades, gearbox, and generator. Tall tower are difficult to install, needing very tall and espernsive cranes, and skilled operation.
Maintenance Cost	Low. Major equipment is near ground.	High. Major equipment is on the tall tower.
Transportation Cost	Low. Small size of tower and blades.	High. Giant size of tower and blades. The tall towers and blades up to 90 meters long are difficult to transport. Transportation can be 20% of equipment costs.
Wind Farm Application	Few. Since efficiency is lower.	More. High efficiency is more attractive.

Figure 4 shows some locations and areas being suitable for VAWTs application. In 2010, two VAWTs were successfully installed on the Eiffel Tower, Paris, shown in Figure 5. They were installed 400 feet up on the 2nd tower level and provided 10,000 kWh of green electricity each year. It was an iconic application of the VAWT.

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Roadside/ Express Way Tunnel/ Bridge Building/ Residence Area

Fig. 4: Locations and Areas of VAWTs Application

Fig. 5: Two VAWTs on Eiffel Tower in Paris

IV. Characteristics of VAWTs

Most of VAWTs have unique characteristics: replaceable and stackable. The replaceable characteristic allows an existing VAWT to be altered to another type amazingly and the stackable characteristic lets the VAWT be upgraded conveniently to meet the load requirements. Figures 6 and 7 illustrate the two characteristics, respectively.

Fig. 6: Replaceable Characteristic of VAWTs

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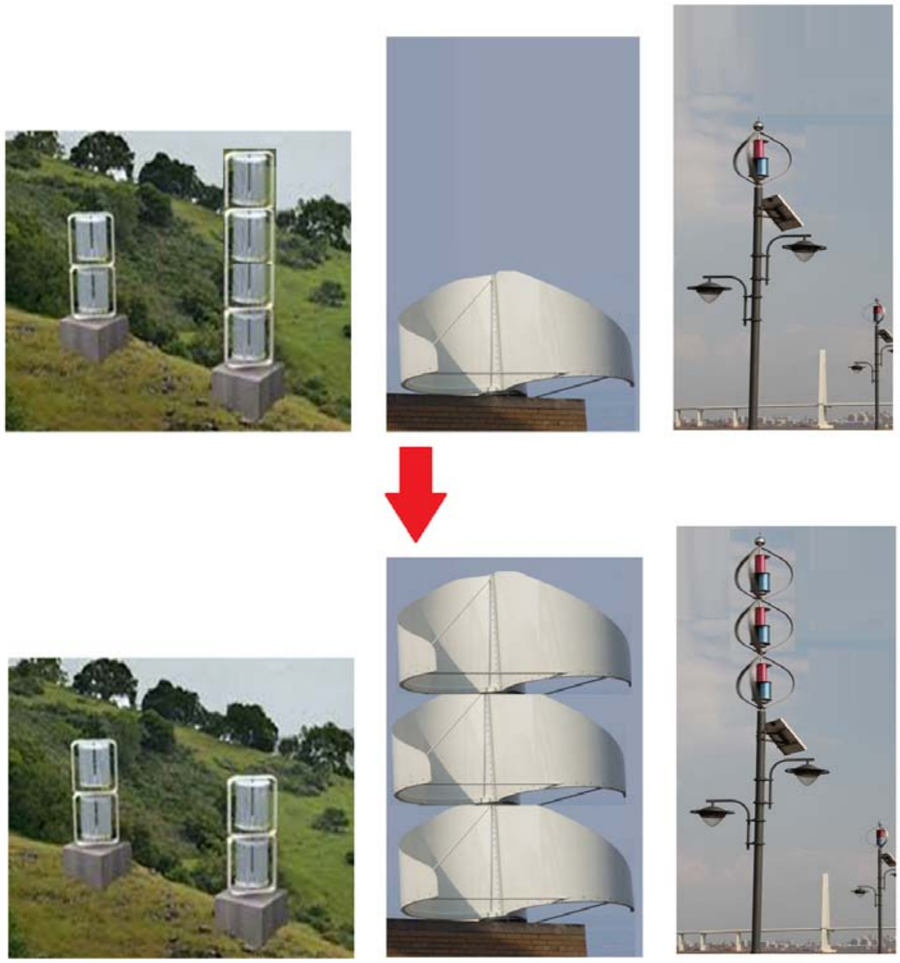

Fig. 7: Stackable Characteristic of VAWTs

V. A Novel Design of VAWT

Green power tower (GPT), a novel VAWT design, is developed. The GPT is a stackable type and has no exposed rotating components.

a) *Working Principle*

Figure 8 shows the configuration of the GPT. Air stream horizontally blows into the channels to drive the shaft by rotating turbine blades. The air stream will flow out on the top of the GPT. The GPT is packable and can have multiple levels to meet the power requirement. The shaft at the tower center drives the electric generator on the bottom.

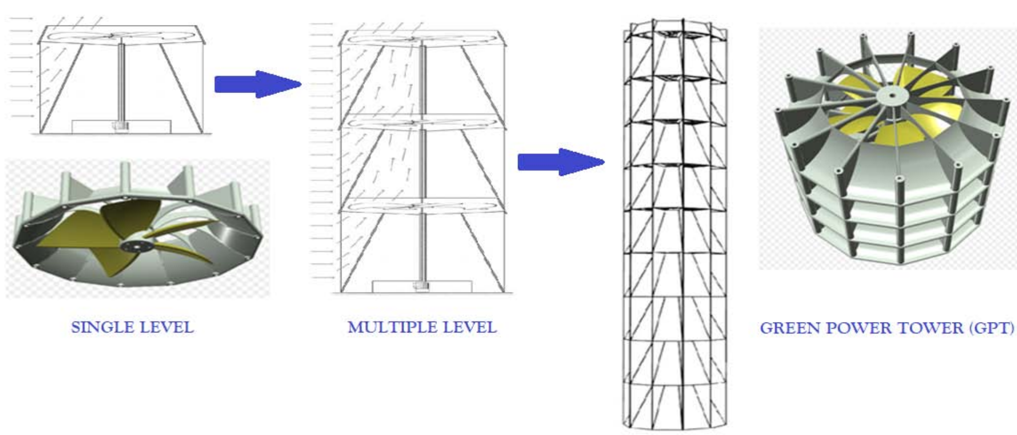

Fig. 8: Green Power Tower (GPT)

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b) GPT Performance Test

To evaluate the performance of the GPT, the scaled prototypes were built and tested with different wind blades. Figure 9 presents the tests conducted in the wind tunnel and at the site, respectively. At the site tests, the GPT was installed on the top of the moving vehicle. The driving speed of the vehicle is the velocity of the wind blowing.

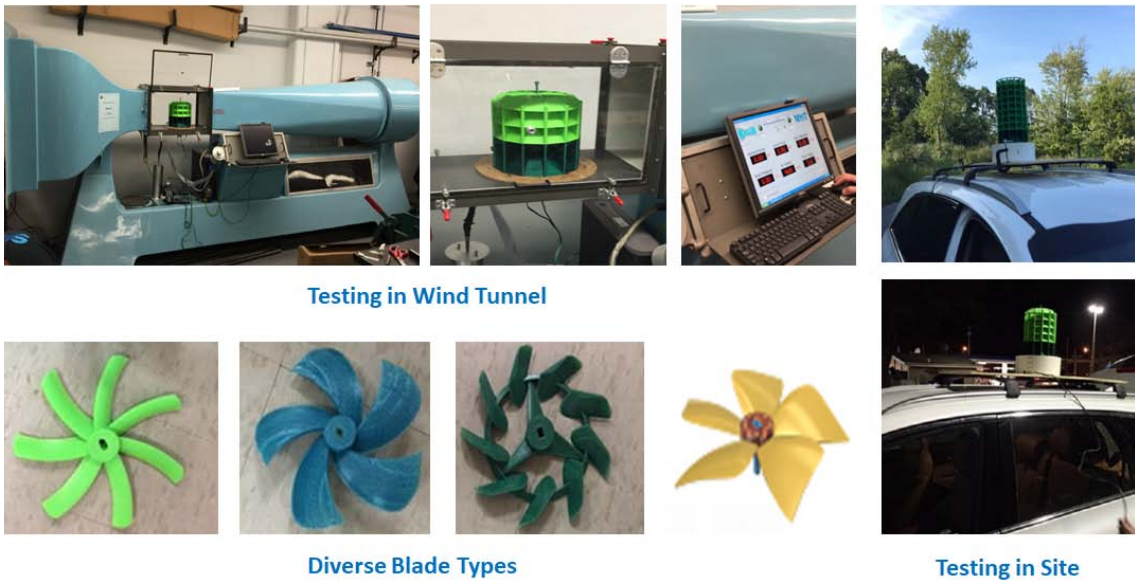

Fig. 9: Performance Testing

The GPT can be stacked to have multiple levels. In the tests, one, two, and three levels of GPTs were conducted to see the power generation capacity, tip speed ratio *TSR*, and power coefficient C_p of level impacts. *TSR* and C_p are defined by, respectively

$$TSR = \text{tip speed of blade/wind speed} = (2\pi r \times RPM)/60v \quad (1)$$

Where *r* – radius of wind blade (distance from wind shaft axis center to blade tip) (m)
RPM – are volution in per minute of wind blade
v – wind speed (m/s)

$$C_p = P_{out}/P_{in} = (V \times I)/P_{in} \quad (2)$$

Where P_{out} – power output from a wind turbine (kW)
P_{in} – thepower of the wind (kW), $P_{in} = \rho\pi d^2 v^3/8$
Ρ – density of air (kg/m^3)
d – diameter of wind turbine (m)
V – electrical voltage generated by a wind turbine(V)
I – electrical current generated by a wind turbine (A)

In the test, both *V* and *I* were measured by a multimeter, respectively.

c) Testing Results and Discussion

The tests were performed for both GPT and HAWT for comparison. The prototype data are listed in the following Table 2.

Table 2: Prototype Data in Test

Prototype	Radius (i.e., length of blade) (cm)	Swept Area (cm^2)
GPT- 1(One level)	9	255
GPT- 2(Two levels)	9	509
GPT- 3 (Three levels)	9	763
HAWT-1	12	450
HAWT-2	13	530

Test results of GPT performance and comparison are shown in Figure 10. The tests revealed all VAWTs performance were better than HAWTs. GPT-2 output power is about 200-250% higher than HAWT-2. These two prototypes are equivalent in terms of the swept area. The difference is about 104% when GPT-1

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and HAWT-1 are compared, although the swept area of GPT-1 is about 44% smaller than HAWT-1. It can also be observed that higher wind speed leads to a bigger gap between GPTs and HAWTs.

C_p converges on higher wind speeds. In lower wind speed, GPT with more levels outperforms the fewer number of levels, which was expected. There is also an irregular jump in GPT-1 for low wind speeds, which could be explained by the different cut-off speed of the system when there is only one level of GPT. The difference between GPT-2 and HAWT-2 in terms of C_P when wind speed is about 30 mph, is about 250%, where GPT-2 has a better performance.

The test data also indicates the in low wind speeds GPT-1 can have a better performance compared to the horizontal propeller of GPT, although in higher wind speeds it shows a negative impact.
It seems that VAWTs with small length blades have better performance and efficiency than HAWTs, which maybe be a reason HAWTs need large size and get larger and larger.

Large HAWTs may have more efficiency than VAWTs. Large HAWTs are more attractive in the application of wind farms in which large open area is available. Further study will be necessary to help with this evaluation.

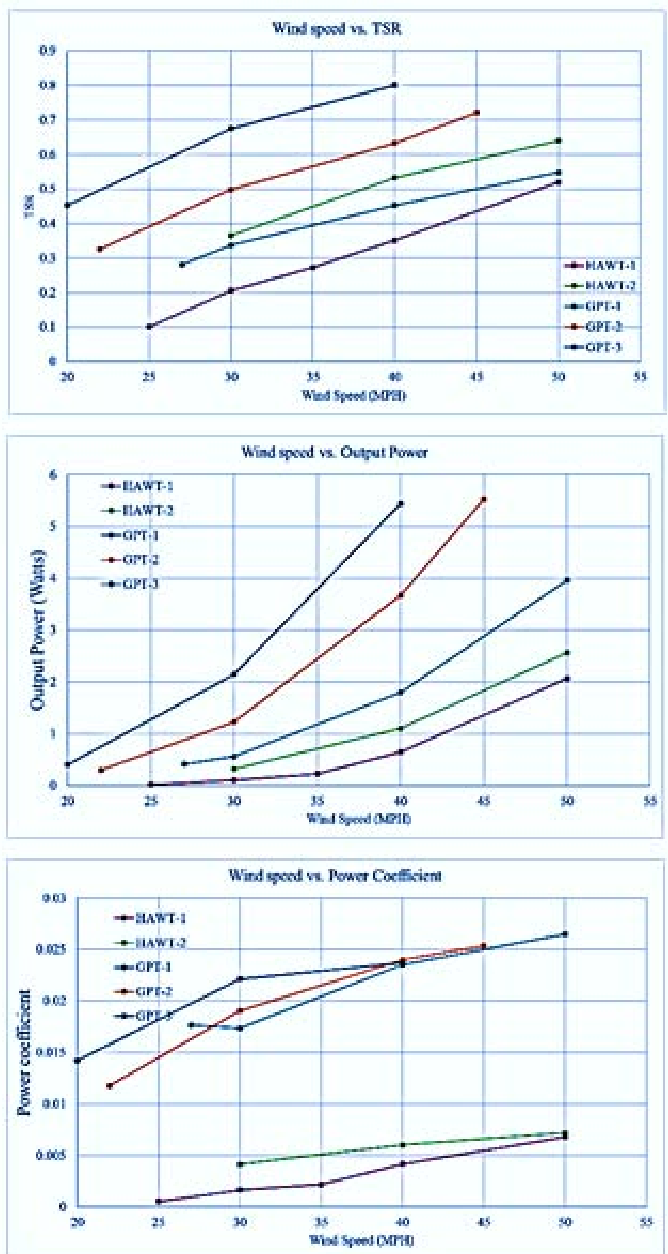

Fig. 10: Test Results and Comparison

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VI. Potential Application of GPT

The GPT has all advantages and characteristics of the VAWT. Also, the GPT doesn't have exposed rotating parts. All rotating parts are covered in enclosures. Therefore, the GPT is much safer than other VAWTs. The GPT can have many applications, for instance, on buildings, towers, and bridges, including wind farms. Some of the application is illustrated in Figure 11.

Fig. 11: Potential Applications of Green Power Tower (GPT)

VII. Summary

Comparing to HAVTs, VAWTs have advantages of without long length blades and giant towers and no needing large open areas so that VAWTs can be applied in the areas, such as metropolitan, community, and resident. In the areas, VAWTs not only can efficiently utilize the wind energy but also may have cosmetic effects for the buildings and surroundings.

Most of VAWTs have unique characteristics: replaceable and stackable. The replaceable character allows an existing VAWT to be altered to another type amazingly and the stackable character lets the VAWT be upgraded conveniently to meet the load requirements. The GPT, a novel VAWT design, has no exposed rotating components which are completely covered in enclosures. The GPT prototypes were tested and the performance was significant, which showed the GPT could extract more wind energy comparing to the similar size HAWTs. The novel VAWT can have many potential applications, such as on buildings, towers, and bridges, including wind farms.

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