US 20070269311A1

(19) United States
(12) Patent Application Publication
Browning
(10) Pub. No.: US 2007/0269311 A1
(43) Pub. Date: Nov. 22, 2007

(54) WIND TURBINE AND SUPPORT STRUCTURE AND METHOD OF CONTROLLING THE ROTATIONAL SPEED OF SUCH WIND TURBINE

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(21) Appl. No.: 11/800,399

(22) Filed: May 3, 2007

Related U.S. Application Data

(60) Provisional application No. 60/797,332, filed on May 3, 2006.

Publication Classification

(51) Int. Cl.
B63H 1/06 (2006.01)
(52) U.S. Cl. .... 416/132 B

(57) ABSTRACT

A wind turbine system and a method for controlling a rotational speed of a rotor of such wind turbine system are provided. The system included a wind turbine having a rotor having airfoils having an orientation relative to wind and a rotational axis. The system further includes a structure supporting the wind turbine above ground. The support structure is coupled to the ground. The structure has first portion closer to the wind turbine and a second portion farther from the wind turbine. The first portion will move farther in response to the wind acting across the structure than said second portion causing the turbine rotational axis to tilt. The method includes tilting the rotor rotational axis about an angle, and varying the angle in response to changes of the wind force.

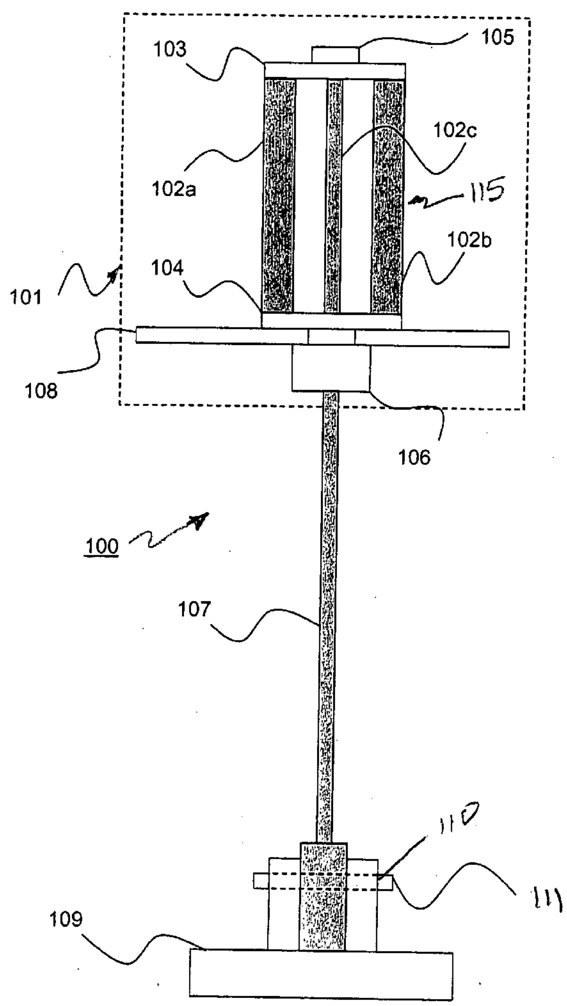


FIG 1

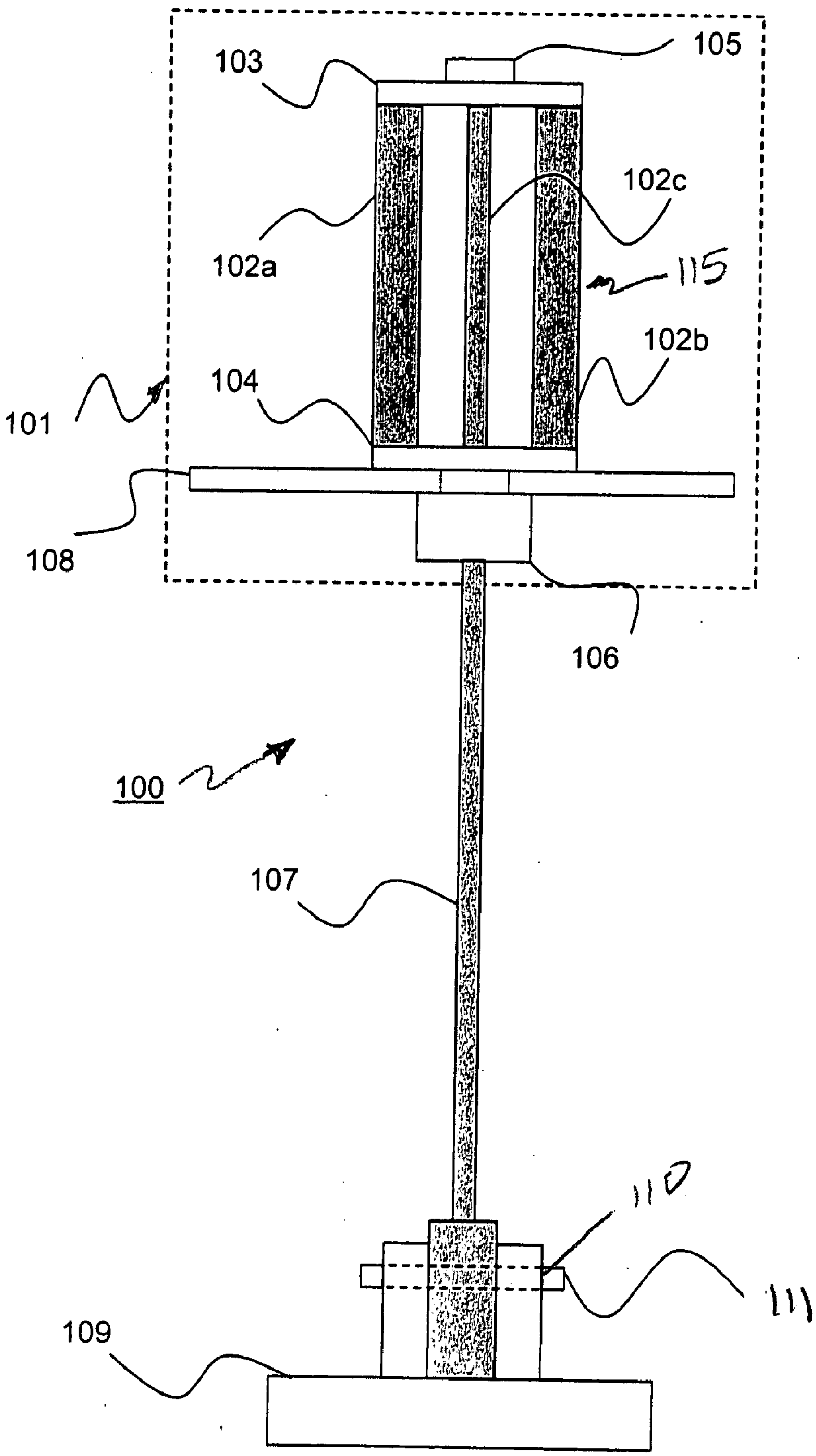


FIG 2

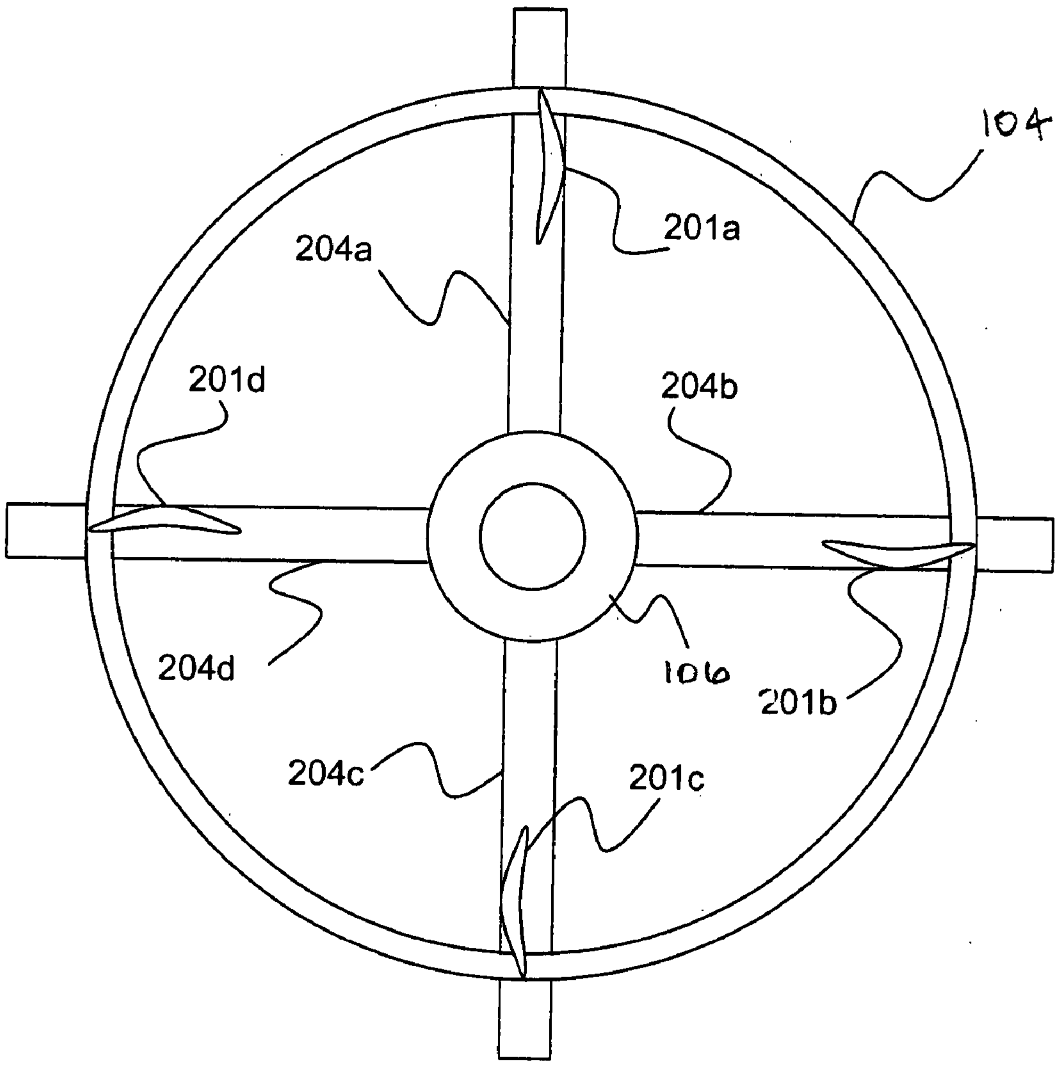


FIG 3

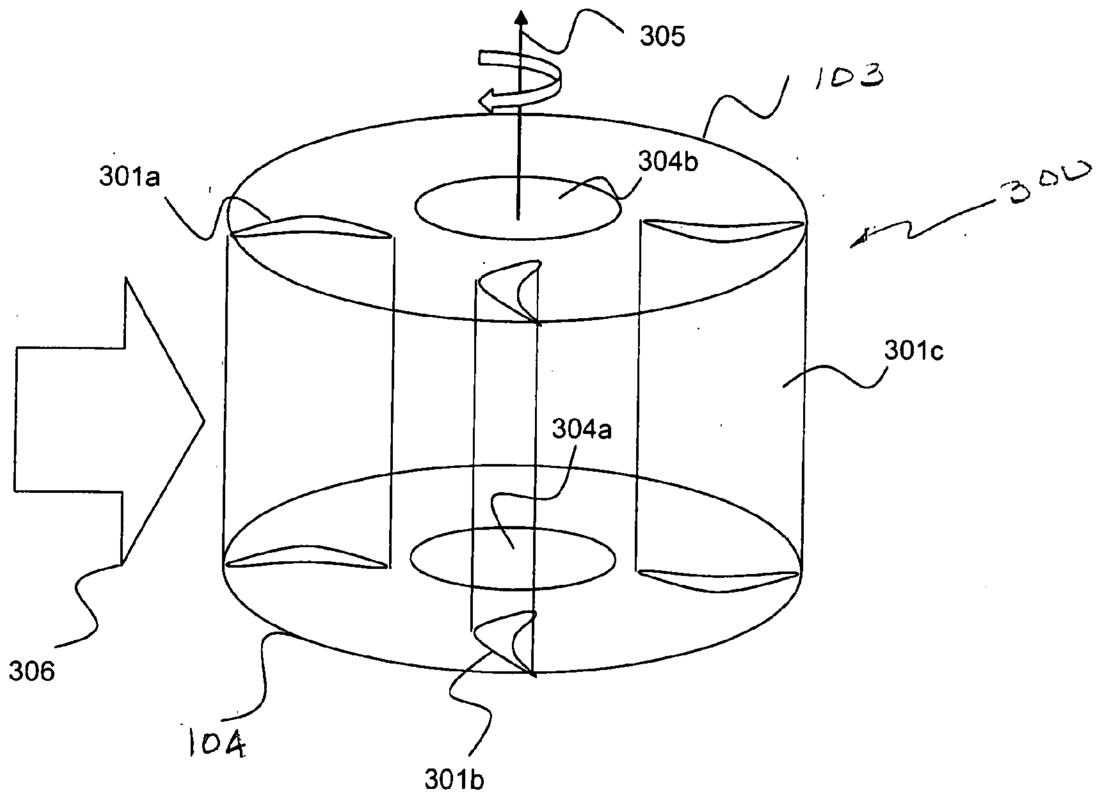


FIG 4

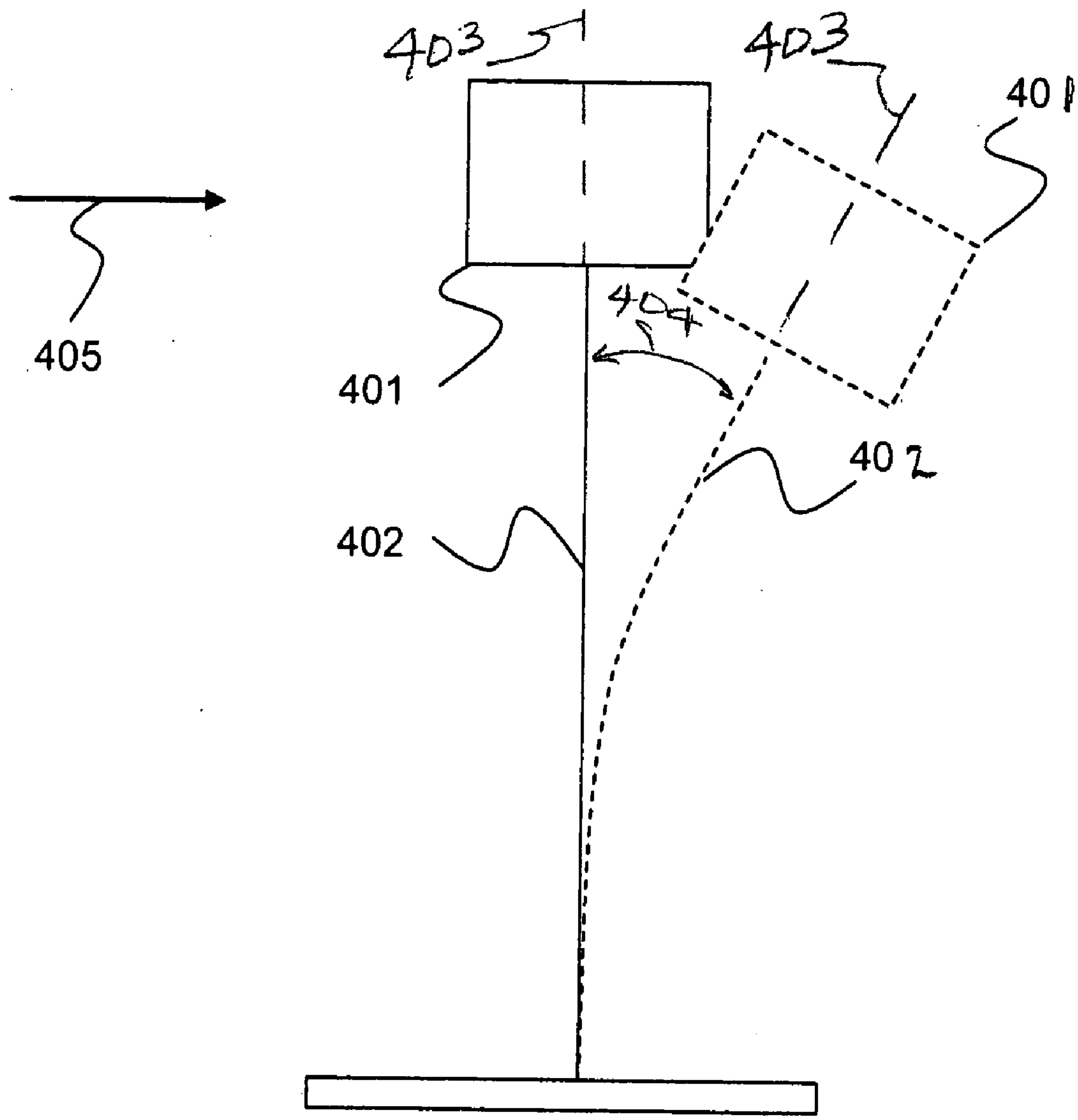


FIG 5

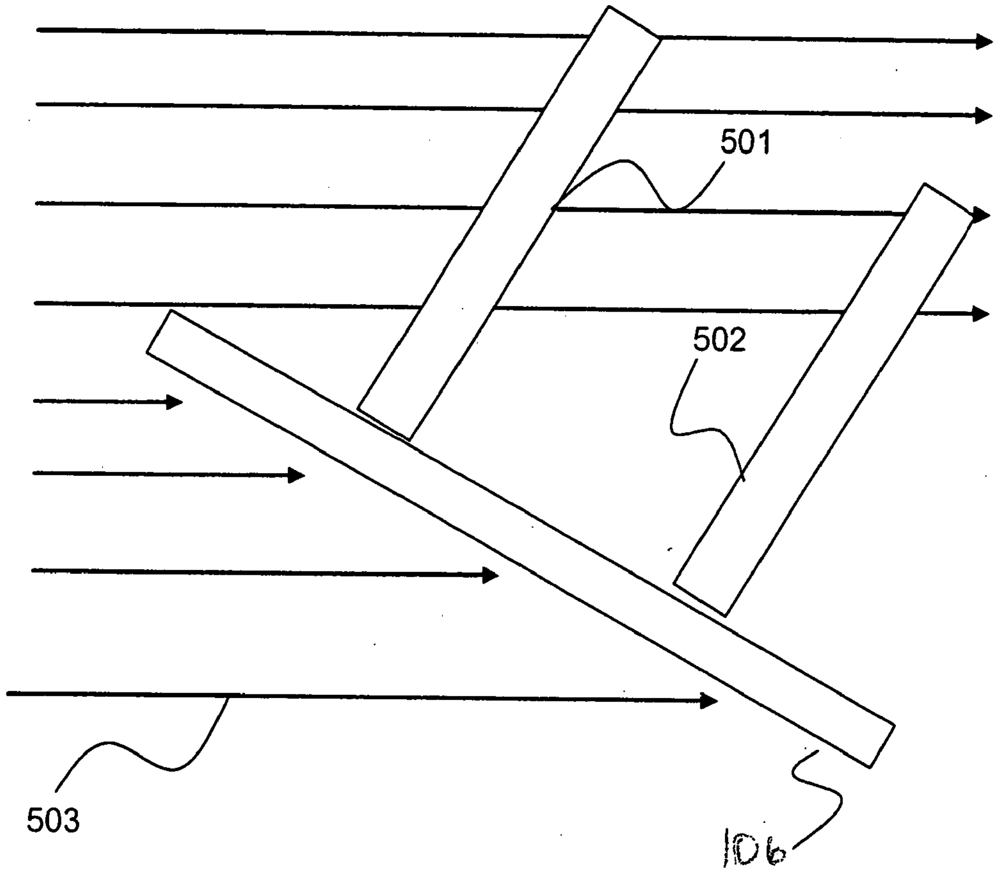
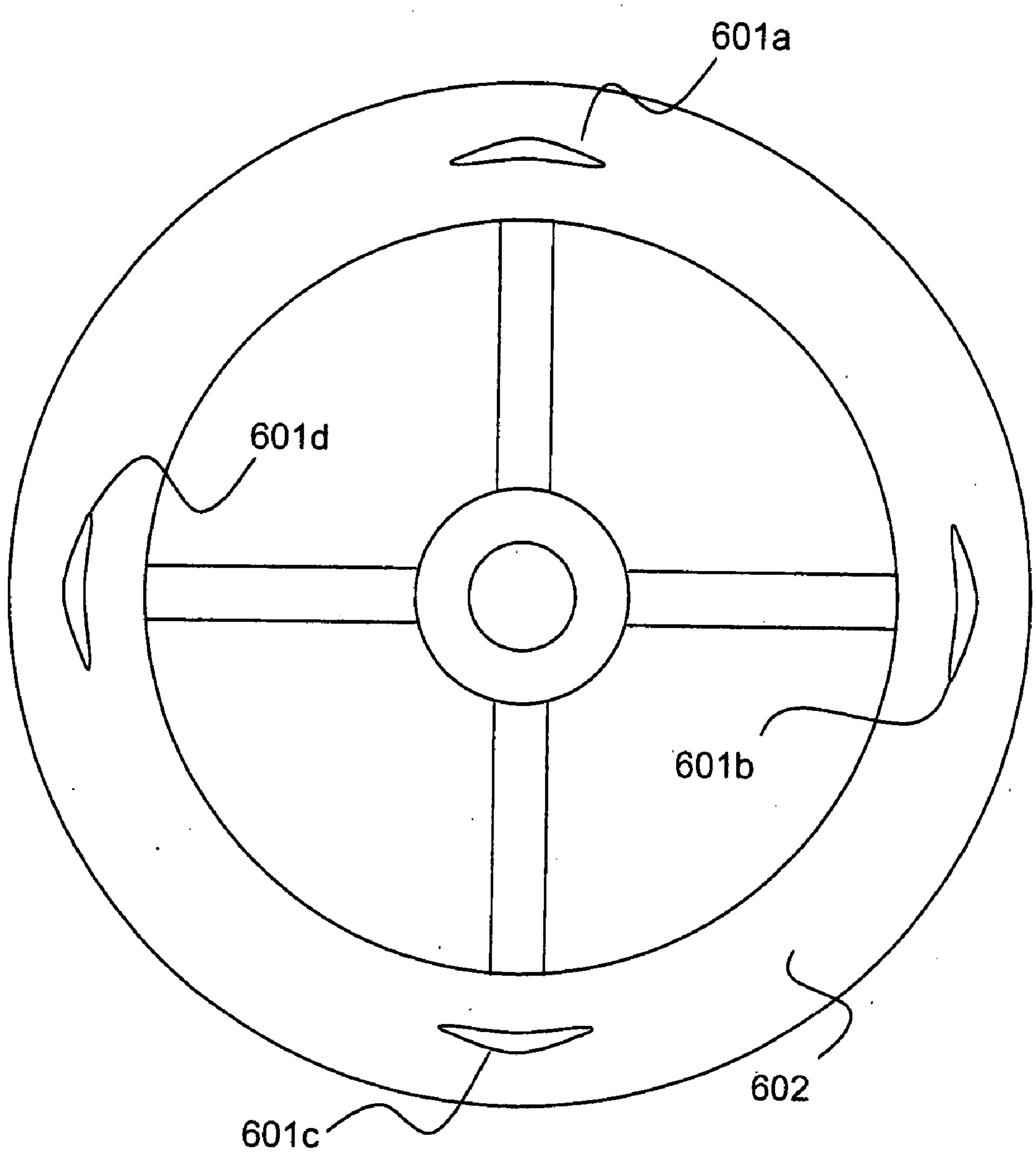


FIG 6



WIND TURBINE AND SUPPORT STRUCTURE AND METHOD OF CONTROLLING THE ROTATIONAL SPEED OF SUCH WIND TURBINE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is based upon and claims priority of a U.S. Provisional Application, Ser. No. 60/797,332 filed on May 3, 2006, the contents of which are fully incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention relates generally to vertical wind turbines, and more particularly to a vertical wind turbine with a support capable of flexing and/or pivoting. Wind turbines of various designs are in use in converting wind energy to electrical energy. Designs variations include wind turbines with horizontal axes, vertical axes, drag propulsion, aerodynamic lift, turbines, and sails. Horizontal axis wind turbines typically include a tall tower and a propeller or fan-like rotor mounted at the top of the tower for rotation about an axis substantially parallel to the earth's surface. Vertical wind turbines are more varied with cups, half cylinders, eggbeater like blades, flat blades, paddles, or airfoils (individually or collectively referred to herein as "airfoils") rotating around a vertical axis. A vertical wind turbine may have a rotor with airfoils which may be fixed or movable and rotating about a central shaft. A plurality of airfoils mounted on stationary rings may surround the rotor and serve to direct and compress air from the wind before is directed at the rotor airfoils. Vertical axis wind turbines are divided generally into lift- and drag-types.

[0003] The advantage of the horizontal wind turbine is in the design of the propeller like turbine. The blades of the horizontal wind turbine are typically airfoils which provide lift. The lifting blades can spin faster than the air flow, and indeed may be supersonic at the tips, thus providing high efficiency and high rotation speed for generating electricity. A disadvantage of the horizontal axis wind turbine lies in the fact that the rotor must face either into or away from the direction of the wind and a yaw mechanism is required to rotate the rotor about the vertical axis of the tower to keep the rotor in proper alignment with the wind flow. Since a mechanical means of delivering power to the ground could cause the rotor to yaw out of alignment with the wind, energy conversion devices, such as generators; power transmission equipment; and related equipment are typically also mounted atop the tower. A structurally robust and costly tower is required to support the weight of the elevated equipment. Maintenance of horizontal axis turbines can be complex and costly because the equipment is located at the top of the tower. While horizontal axis wind turbine installations are relatively complex and expensive, they are the most common wind turbine configurations in current use.

[0004] The advantage of the vertical axis wind turbine is that its exposure remains constant regardless of the wind direction. A great deal of the cost of wind turbines results from high strength materials that are used to withstand high stresses, which result from the high speed at which they operate. Wind turbines are also subject to very high amplitude and high frequency vibrations, which result in fatigue to the various components of the wind turbines. To minimize these vibrations, the airfoils and other rotational components of these systems must be perfectly balanced. Additionally, wind turbines are exposed to adverse weather conditions such as high winds, snow, ice, and ultraviolet radiation. Substantial engineering and maintenance resources have to be devoted to the design and operation of these wind turbines so that they can withstand the multitude of forces, as well as the adverse conditions, to which they will be subjected. Wind turbines are often severely damaged by high wind conditions.

[0005] Wind turbines have a relatively small range of wind speeds within which they will operate efficiently, typically 20 to 40 miles per hour. At lower speeds the electricity generation is inefficient and at higher speeds the rotor is exceeding its safe operating limit and must be damped electrically to prevent damage. Obviously, the necessity for such a high minimum wind speed greatly reduce the geographical areas where wind turbines can be used economically. Additionally, the necessity for providing the highest average wind speeds over the time of operation requires the wind turbines being set high above the ground on very tall masts. Tall masts further increase the cost of installation and maintenance. Consequently, a wind generating power source that operates over a wide range of wind speeds, with low capital, installation, and maintenance costs is desirable.

SUMMARY OF THE INVENTION

[0006] The present invention relates generally to vertical wind turbines, and more particularly to a vertical wind turbine with a support assembly, and more particularly to a support assembly that minimizes damage in high gusting winds, and more particularly to a support structure that is a monopole, and more particularly to a monopole that is formed from a glass fiber composite, and more particularly a pultruded glass fiber composite. In another exemplary embodiment of the invention the vertical wind turbine is supported by an elevating support structure that flexes or pivots during wind gusts. In yet another exemplary embodiment of the invention the flexing of the support assembly under a high wind load reduces the efficiency of the vertical wind turbine and thus regulates the rotational speed of the wind turbine. In a further exemplary embodiment of the invention the design of the wind turbine rotor and the wind resistance of the rotor base plate are tuned to regulate the rotational speed of the wind turbine under differing wind conditions.

[0007] In an exemplary embodiment a wind turbine system is provided. The system included a wind turbine having a rotor having airfoils and a rotational axis. The system further includes a structure supporting the wind turbine above ground. The support structure is coupled to the ground. The structure has first portion closer to the wind turbine and a second portion farther from the wind turbine. The first portion will move farther in response to a wind acting across the structure than the second portion causing the turbine rotational axis to tilt. In another exemplary embodiment, the structure is a flexible structure and has a flexibility allowing for the first portion to move farther than the second portion in response to the wind. In yet another exemplary embodiment, the structure is coupled to a base with a flexible member and the base is coupled to the ground. In one exemplary embodiment, the flexible member is a spring. In yet another exemplary embodiment, the wind turbine is a vertical wind turbine and the rotational axis when not tilted is generally vertical. In yet a further exemplary embodiment, the structure includes a flexible shaft which flexes in response to the wind whereby the first portion moves father than the second portion. In another exemplary embodiment, the shaft formed from a glass fiber composite. In another exemplary embodiment, the shaft if pultruded.

[0008] In yet another exemplary embodiment, the system further includes a shadowing structure, or a means, coupled the turbine for blocking a portion of the wind from reaching the wind turbine rotor when the rotational axis is tilted. In another exemplary embodiment, the portion of the wind being blocked increases as the flexing of the shaft increases. In a further exemplary embodiment, the shadowing structure defines a base of the rotor on which the airfoils are mounted. In yet a further exemplary embodiment, the structure is pivotably coupled to a member coupled to the ground.

[0009] In another exemplary embodiment a method is provided for controlling a rotational speed of a vertical wind turbine rotor mounted on a support structure and rotating about a generally vertical rotational axis by being exposed to wind having a force, the rotor having airfoils exposed to the wind. The method includes tilting the rotor rotational axis about an angle, and varying the angle in response to changes of the wind force. In another exemplary embodiment, varying includes increasing the angle when the wind force increases. In a further exemplary embodiment, the method also includes blocking a portion of the wind from acting on the rotor as the angle increases for controlling the amount of force exerted on the rotor by the wind. In yet another exemplary embodiment, the method further includes increasing the wind portion being blocked as the wind force increases. In yet a further exemplary embodiment, tilting the rotational axis includes pivoting the support structure relative to the ground for tilting the rotational axis. In another exemplary embodiment, tilting included flexing the support structure for tilting the rotational axis. In yet another exemplary embodiment, tilting includes decreasing a rotational efficiency of the rotor for a given wind speed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The invention will be better understood and the objects and advantages of the present invention will become apparent when consideration is given to the following detailed description thereof. Such description makes reference to the annexed drawings wherein:

[0011] FIG. **1** is a illustration of the wind turbine assembly;

[0012] FIG. **2** illustrates in top view of a vertical wind turbine rotor with the upper base plate removed;

[0013] FIG. **3** illustrates schematically a rotor in perspective view having a plurality of airfoils attached to bottom and top base plates;

[0014] FIG. **4** illustrates schematically the tilting action of the wind turbine assembly under low and high wind conditions;

[0015] FIG. **5** illustrates schematically the wind shadowing during the tilting action of the wind turbine assembly under high wind conditions; and

[0016] FIG. **6** illustrates in plan view an alternative arrangement of a plurality of airfoils on a base plate of a vertical wind turbine.

DETAILED DESCRIPTION OF THE INVENTION

[0017] Referring to FIGS. **1** through **6**, wherein like reference numerals refer to like components in the various views, there is illustrated therein a new and improved vertical wind turbine assembly. In an exemplary embodiment, a wind turbine assembly generating electricity with lower capital, installation, and maintenance costs is provided. In one exemplary embodiment, a vertical wind turbine elevated on a supporting structure that has a high compliancy is provided. In an exemplary embodiment, the supporting structure is a monopole that is capable of elastically bending. In another exemplary embodiment, the monopole is a lightweight composite pole, and may be formed as a glass/resin pultruded composite. In another exemplary embodiment of the invention, a vertical turbine rotor is provided that has attachments that provide wind shadowing on the rotor airfoils when the supporting structure is bending under wind load.

[0018] It should be noted that the terms "upper,""lower,""above" and "below" as used herein are relative terms to describe the relative location of parts and not the exact locations of such parts. For example, an "upper" part may be lower than a "lower" part.

[0019] FIG. **1** illustrates an exemplary embodiment vertical wind turbine assembly **100**. The assembly includes a vertical wind turbine **101** having a vertical wind turbine rotor **115** including a plurality of airfoils **102***a, b, c,* an upper base plate **103** and a lower base plate **104**. The upper base plate **103** and the lower base plate **104** support the airfoils **102***a, b, c* and hold them in the correct orientation. The turbine is mounted on a supporting structure such as a monopole **107**. The upper base plate **103** has an upper central cylindrical bearing **105** and the lower base plate **104** has lower central cylindrical bearing **106** that allows the vertical wind turbine rotor **115** to rotate relative to the monopole **107**. In the shown exemplary embodiment, the vertical turbine is mounted on the monopole **107** via the lower central cylindrical bearing **106**. The lower central bearing **106** may incorporate an electrical generating device which when rotated by the rotor generates electric energy. Other types of bearings may also be used. A wind shadowing structure **108**, such as a plate is attached underneath the airfoils **102***a, b, c.* In an exemplary embodiment the shadowing structure is attached below the lower base plate. The wind turbine assembly **100** may incorporates a plinth **109** coupled to the monopole that is used to anchor the assembly to the ground. In the arrangement shown in FIG. **1** the plinth **109** allows the monopole **107** to be raised and lowered by pivotable connecting the monopole to the plinth at pivot point **110**. A member **111** may be used to pivotably couple the monopole to the plinth. It alternate exemplary embodiments, a simple hole in a base or other arrangement for mounting the monopole can be substituted for the plinth **109**.

[0020] FIG. **2** illustrates in plan how a plurality of symmetric airfoils **201***a, b, c, d* can be arranged on a rotor base of an exemplary embodiment rotor of a vertical wind turbine. The plurality of symmetric airfoils **201***a, b, c, d* in an exemplary embodiment have the same size and shape and are equidistantly spaced around a rotor base support such as the rotor lower base plate **104**. The lower base plate is coupled to the lower cylindrical bearing **106** by means of axial spokes **204***a, b, c, d*. The axial spokes **204***a, b, c, d* also act as devices to shadow the symmetric airfoils **201***a, b, c, d* when the rotor is tilted with respect to the wind direction. While four symmetric airfoils **201***a, b, c, d* are illustrated in FIG. **2** it can be appreciated that numerous alternative arrangements of airfoils and number of airfoils are possible. It should be noted that the upper and lower base plates may be solid or ring-like annular plates.

[0021] FIG. **3** is a simplified illustration of how the base plates and airfoils are arranged to form a rotor **300** of an exemplary embodiment vertical wind turbine. Only three conventional airfoils **301***a, b, c* are shown attached at their ends to the upper base plate **103** and to the lower base plate **104**. The two base plates **103**, **104** shown are annular, i.e., they have central circular holes **304***a, b* to allow for the attachment of bearings, such the upper bearing **105** and the lower bearing **106**, around a central shaft (not shown) along the axis **305**. Wind blowing against the conventional airfoils **301***a, b, c* from the side in the direction **306** will cause the rotor **300** to rotate around the central axis **305**. As the wind speed increases greater force will be applied both to the rotation around the axis **305** and to the side of the rotor assembly in the wind direction **306**.

[0022] FIG. **4** schematically illustrates the action of a wind turbine **401** supported by an exemplary embodiment flexible monopole **402** in a high wind. The original position of the wind turbine **401** supported by a schematic monopole **402** is illustrated for low wind conditions. At higher wind conditions the new position of the wind turbine **401** with a flexed monopole **402** is shown in dashed. As the monopole flexes (i.e., bends, in relation to the ground, a rotational axis **403** of the rotor tilts at an angle **404**. The tilted angle **404** of the rotational axis places the wind turbine **403** in a new position such that it is at an angle to the wind direction **405** and thus is not driven so efficiently. In other words, as the rotational axis tilts, the rotational efficiency of the rotor for a given wind speed decreases. In this regard, the rotational speed of the rotor is controlled when the wind speed increases. The angle of tilt **404** increases as the wind force increases. The angle may also be controlled by controlling the flexibility of the supporting structure or monopole **402**.

[0023] FIG. **5** illustrates an exemplary embodiment wind shadowing during the tilting action of the wind turbine assembly under high wind conditions. A windward airfoil **501** and a lee airfoil **502** are partly shadowed from the wind **503** by the shadowing structure **106**. This reduces the wind force acting on the windward airfoil **501** and the lee airfoil **502**. The speed of rotation of the rotor is thereby reduced. It will be apparent to those ordinarily skilled in the art that a large number of arrangements of shadowing structures are possible.

[0024] FIG. **6** illustrates in plan an alternative exemplary arrangement of a plurality of non radial airfoils **601***a, b, c, d* on the lower extended base plate **602** in a vertical wind turbine rotor assembly. The extended base plate extends radially outward beyond the airfoils. The extended base plate **602** acts to shadow the non radial airfoils **601***a, b, c, d* from the wind when the rotor is tilted. In this regard, the lowered extended base plate may be used to shadow the wind and reduce the wind force acting on the rotor as the rotor is tilted.

[0025] An exemplary material for the monopole **107** is pultruded glass fiber/resin composite. Glass fiber composite has the advantage of being considerably more elastic than steel but with a similar strength and much lower weight. As the modulus of elasticity of a composite can be modulated by the use of different types of glass fibers an appropriate flexibility for the monopole can be obtained for different wind turbine designs. Further glass fiber also does not work harden when it is flexed thus leading to an extended lifetime. Also the geometry of the monopole may be varied as necessary for obtaining a desired flexibility.

[0026] A very lightweight rotor assembly is desired and an exemplary material for the airfoils is also pultruded glass fiber, both for high strength and low weight. It would be expected that a glass fiber composite would also be used for the base plates and other parts, again reducing the weight of the entire wind turbine assembly.

[0027] As the wind turbine tilted at an angle to the wind, its rotational speed will be reduced compared to a directly upright vertical wind turbine at right angles to the wind. This change in angle means that as the wind velocity increases and the flexing of the monopole increases due to the sideways force then the speed of the wind turbine can be regulated to a degree between limits. As the force flexing the monopole has a component largely from the size of the wind turbine a stiffer pole is needed for a larger wind turbine. As this is a complex system experiments may be necessary to design the most appropriate flexure of the monopole given the design parameters of the wind turbine and the generator. Furthermore, the flexure may be controlled by using a wind turbine having a desired weight. For example, the weight of the turbine may be reduced if necessary by forming components of the turbine rotor such as the airfoils from composite materials such as fiberglass In an exemplary embodiment, in extremely high winds an exemplary monopole will be flexed until the wind turbine is no longer facing the wind and the main force will be acting on the wind shadowing devices.

[0028] The exemplary flexible elevating support structure has been described herein by way of a monopole, the support structure can have different geometries and can be made in a large variety of desired sizes. A monopole has however the advantage of being axially symmetric and therefore will have the same flexural dynamics whatever the wind direction. In other exemplary embodiments, a spring or other elastic or flexible structure may be used which is coupled to the ground and to the support structure to assist with the flexing. i.e., bending of the support structure relative to the ground so as to control the rotational speed of the wind turbine rotor. For example member **111** shown in FIG. **1** may be a rotational spring. With this embodiment, the support structure pivots relative to the ground when exposed to wind force. With this embodiment, the support structure may be very stiff and not flexible. Furthermore with this embodiment, the tilt angle **404** for a given wind force may be controlled by using springs of different stiffness. In other exemplary embodiments, the support structure may be coupled to a plinth or other base that anchors the structure to the ground using a ball bearing or other type of bearing that would allow the support structure to pivot in any direction. One or more springs or other flexible members may be used to resist such pivoting. Furthermore, spring may be required when the support structure is relatively short so as to aid in the bending of the structure relative to the ground.

[0029] The wind turbine apparatus of the invention can be made in a large variety of desired sizes with alternative embodiments of a lightweight rotor assembly. While exemplary embodiment vertical wind turbines illustrated in FIGS. **1**, **2** and **3** for use in combination with the exemplary embodiment supporting structure, other alternative wind turbine types can be used with the principle of tilt to regulate rotational speed.

[0030] As can be seen an exemplary embodiment support structure flexes during wind gusts thus reducing the rotational efficiency of the vertical wind turbine for a given wind speed and thus regulating the rotational speed of the wind turbine. Furthermore, the wind turbine rotor and the wind resistance of the rotor lower base plate further regulate the rotational speed of the wind turbine under differing wind conditions by blocking a portion of the wind reaching the rotor. In addition, the wind shadowing structure also blocks a portion of the wind reaching the rotor as the wind speed increases, thus reducing the wind force acting on the rotor and controlling the rotor speed. Moreover, the airfoils may be attached to the wind turbine rotor to regulate the rotational speed of the wind turbine under differing wind conditions.

[0031] The apparatus of this invention is fully functional for generating electrical energy even in very high wind conditions. Yet, the apparatus is capable of generating electrical energy even at low wind speeds.

[0032] The above disclosure is sufficient to enable one of ordinary skill in the art to practice the invention, and provides the best mode of practicing the invention presently contemplated by the inventor. While there is provided herein a full and complete disclosure of exemplary embodiments of this invention, it is not desired to limit the invention to the exact construction, dimensional relationships, and operation shown and described. Various modifications, alternative constructions, changes and equivalents will readily occur to those skilled in the art and may be employed, as suitable, without departing from the true spirit and scope of the invention. Such changes might involve alternative materials, components, structural arrangements, sizes, shapes, forms, functions, operational features or the like.

What is claimed is:

1. A wind turbine system comprising:

a wind turbine having a rotor having airfoils and a rotational axis; and

a structure supporting the wind turbine above ground, said structure being coupled to the ground, wherein said structure has first portion closer to the wind turbine and a second portion farther from the wind turbine, wherein said first portion will move farther in response to a wind acting across said structure than said second portion causing said turbine rotational axis to tilt.

2. The wind turbine system as recited in claim 1 wherein said structure is a flexible structure comprising a flexibility allowing for said first portion to move farther than said second portion in response to said wind.

3. The wind turbine system as recited in claim 1 wherein said structure is coupled to a base with a flexible member, said base being coupled to the ground.

4. The wind turbine system as recited in claim 3 wherein said flexible member is a spring.

5. The wind turbine system as recited in claim 1 wherein said wind turbine is a vertical wind turbine and wherein the rotation axis when not tilted is generally vertical.

6. The wind turbine system as recited in claim 5 wherein said structure comprises a flexible shaft, wherein said shaft flexes in response to said wind whereby said first portion moves father than said second portion.

7. The wind turbine system as recited in claim 6 further comprising a shadowing structure coupled the turbine for blocking a portion of the wind from reaching said wind turbine rotor when said rotational axis is tilted.

8. The wind turbine system as recited in claim 7 wherein said portion of the wind being blocked increases as the flexing of said shaft increases.

9. The wind turbine system as recited in claim 7 wherein said shadowing structure defines a base of said rotor on which said airfoils are mounted.

10. The wind turbine system as recited in claim 1 further comprising a shadowing means for blocking a portion of the wind from reaching said wind turbine rotor when said rotational axis is tilted.

11. The wind turbine system as recited in claim 10 wherein said shadowing means will block larger portion of the wind as the wind speed increases.

12. The wind turbine system as recited in claim 1 wherein said structure comprises a flexible shaft formed from a glass fiber composite, wherein said shaft flexes in response to said wind whereby said first portion moves father than said second portion.

13. The wind turbine system as recited in claim 12 wherein said shaft is pultruded.

14. The wind turbine as system as recited in claim 1 wherein said structure is pivotably coupled to a member coupled to the ground.

15. A method for controlling a rotational speed of a vertical wind turbine rotor mounted on a support structure and rotating about a generally vertical rotational axis by being exposed to wind having a force, said rotor comprising airfoils exposed to the wind, the method comprising:

tilting said rotor rotational axis about an angle; and

varying said angle in response to changes of said wind force.

16. The method as recited in claim 15 wherein varying comprises increasing said angle when said wind force increases.

17. The method as recited in claim 15 wherein said tilting comprises decreasing a rotational efficiency of said rotor for a given wind speed.

18. The method as recited in claim 15 father comprising blocking a portion of the wind from acting on said rotor as the angle increases for controlling the amount of force exerted on said rotor by said wind.

19. The method as recited in claim 17 further comprising increasing said wind portion being blocked as said wind force increases.

20. The method as recited in claim 15 wherein titling said rotational axis comprises pivoting said support structure relative to the ground for tilting said rotational axis.

21. The method as recited in claim 15 wherein said tilting comprises flexing said structure for tilting said rotational axis.

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