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(54) TURBINE FLUID VELOCITY FIELD MEASUREMENT

MESSUNG DER STRÖMUNGSGESCHWINDIGKEITSFELDES EINER TURBINE

MESURE SUR LE TERRAIN DE LA VITESSE D’UN FLUIDE DE TURBINE

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- **None**

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Description

[0001] The present disclosure relates to turbine fluid velocity field measurement, and in particular to new systems and methods for Doppler velocimetry measurement of a fluid velocity field.

Background

[0002] A turbine is a machine that comprises a rotary element that moves under pressure of fluid flow to generate useful work which is usually the generation of electricity. Fluid may be gas or liquid or other non-solid phases. One example of a turbine is a wind turbine. When a wind turbine is mentioned in the present disclosure, the fluid concerned is the air, and wind is the flow of air. Wind turbines are commonly horizontal axis or vertical axis, although other types of design have been proposed. The present disclosure can apply to any type of turbine.

[0003] A horizontal axis wind turbine is well known to someone skilled in the art. The method of Doppler anemometry is also well known to an individual skilled in the art. It will be appreciated that LIDAR (Light Detection and Ranging) Doppler anemometry systems may employ range gated, pulsed laser beams or alternatively focused continuous wave (CW) laser beams, typically employing substantially co-located emitter and receiver optics, in order to measure velocity components of radial extent along the laser beam direction.

[0004] It will be appreciated that emitter and receiver optics do not necessarily need to be substantially co-located and that bi-static configurations may employ emitter and receiver optics substantially displaced from each other.

[0005] A person skilled in the art will be familiar with the design of horizontal axis wind turbine including a nacelle housing mounted atop a vertical tower and containing a near-horizontal axis rotating shaft driven by a rotor system attached to the nacelle at a hub from which protrude a plurality of aerodynamically designed blades. A person skilled in the art will also be familiar with pitch control systems which may rotate or pitch the blades through different angles about their longitudinal axes radiating laterally from the near-horizontal drive train axis. It is known that such systems may include a low speed shaft, gearbox and one or more high speed shafts driving generators, or alternatively that the system may be of direct drive type without need for gearbox and high speed shaft. Alternatively, it is also known that hydraulic drive train designs may be implemented within a wind turbine. A person skilled in the art will be familiar with designs where the nacelle housing may be driven to rotate or yaw around a vertical axis such that the rotor axis aligns substantially with the wind direction and the turbine may be driven to face into or away from the wind. It will be appreciated that all the aforementioned drive train types make use of control systems dependent upon wind speed and wind direction measurements and that the usual measurement method currently employed makes use of wind vane or anemometry instruments mounted on the wind turbine nacelle.

[0006] Present nacelle mounted Doppler anemometry or LIDAR systems for horizontal axis wind turbines sample only the radial line of sight wind velocity at a given point. However, the three dimensional wind velocity field variation is significant to the operation of a wind turbine. Present techniques collect wind velocity component information by use of a plurality of divergent beams but this results in collection of different velocity components at widely separated points in the incident wind field. The present techniques may make the assumption that the wind velocity field is substantially parallel and uniform. Since it is well known that substantial variation in wind field is possible across a wind turbine rotor swept area this assumption of uniformity or averaging of the wind field leads to a degradation of information resolution and precludes the possibility of detailed measurement of a variable wind velocity vector field.

[0007] Measurement of turbulence intensity at a point in space within a given time-averaging period, defined as the standard deviation of wind speed samples divided by the average of the wind speed samples within the time-averaging period, will also be subject to increased measurement error when velocity components are sampled not at the intended measurement point but substantially displaced from the intended measurement point. The standard deviation is then calculated over a data population extending in space as well as over the time-averaging period. It is noted that classical spinning cup or ultrasonic anemometry involves the collection of data substantially at a single point in space.

[0008] Various measurement systems have been proposed, in US2012/0051907 (ROGERS); GB2477529 (VESTAS); EP1460266 (MITSUBISHI); WO2011/096928 (CATCH THE WIND); US2012/0274937 (HAYS); and US2013/0162974 (DAKIN); but these all suffer from one or more disadvantages. Therefore a new fluid velocity measurement system would be beneficial.

[0009] US 8810796 describes a light processing method.

Summary of the Disclosure

[0010] The invention relates to a measurement system as defined by claim 1, a measurement method as defined by independent claim 14 and a computer program product as defined by independent claim 15. Further embodiments are defined by the dependent claims.

Detailed Description

[0011] A new sensor design will be beneficial where the design enables three dimensional wind velocity sampling at one or more points in space and that this can be achieved through the intersection or convergence of beams from spatially separated sources.

[0012] A receiver measures a Doppler shift of the reflected or scattered beams, and a processor determines a fluid velocity at the measurement point where the beams converge based on the measured Doppler shift. The beam sources may be referred to as "Doppler beam sources" where they are used as part of a Doppler measurement system.

[0013] The fluid velocity measurement can be made by beam sources mounted on the turbine. Preferably they are mounted on component parts of the turbine which can adjust their position to take account of changing direction of fluid flow. This is advantageous because the beam sources then naturally tend to point along a fluid flow axis (either upstream or downstream of the turbine).

[0014] In the example of a horizontal axis wind turbine (HAWT), the beam sources may for example be mounted on a nacelle, rotor hub or turbine blade(s); or on associated frames or extension components as described elsewhere.

[0015] For example, a HAWT nacelle or rotor hub is typically controlled (by a set of yaw motors) so as to point substantially into the wind, so if all beam sources are mounted on these components one can conveniently avoid the situation where the HAWT (support) tower would obscure potential measurement points from the beam sources, receivers or transceivers.

[0016] There can be another advantage of employing beam sources and receivers in the reference frame of the rotor on the grounds that this is the reference frame of the blades which means that measurements made within this reference frame give a "direct measurement" of the wind velocity relative to any given blade section. This relative velocity determines the angle of attack and relative wind speed which governs the lift coefficient and drag coefficient of the blade element.

[0017] By using scanning techniques, within or without the rotating reference frame of the rotor hub, it is possible to sequentially employ simultaneously converging beams to sample three dimensional wind velocity at one or more points, where the beam sources are all based upon the wind turbine nacelle, rotor hub or blades but where the beam sources are substantially separated from one another.

[0018] The separation of the Doppler beam sources is important in order to adequately resolve the three orthogonal velocity components. It will be appreciated that three mutually nonparallel beams are sufficient to form a basis for specifying a three dimensional vector.

[0019] Therefore three non-parallel Doppler measurements of radial speed of an object may be combined to specify the three-dimensional velocity of the object. Three non-parallel Doppler measurements at a beam intersection point therefore provide three-dimensional velocity measurement of aerosol or other particle velocity which may be taken to indicate the wind velocity at that measurement point, the aerosol or other particle being carried by the wind at or near the local wind velocity.

[0020] Employing beam sources on the wind turbine nacelle, rotor hub or rotor blades means that beam sources yaw or rotate about a vertical axis as does the wind turbine nacelle and rotor assembly such that it faces generally into the wind. This enables the three-dimensional measurement or sampling of the incident wind velocity vector field ahead of the turbine and its blades.

[0021] Similarly beam sources can be employed to measure at one or more points behind the wind turbine, at points within its wake, or in fact at any chosen position relative to the wind turbine.

[0022] It could be possible to employ three orthogonal beams originating from points on the rotor hub, radial extension of the hub or blades, the blades themselves, or an associated frame such that the intersection point lies at a point on the rotor axis of rotation at some fixed range in front of the turbine. This arrangement enables the direct measurement of the orthogonal wind velocity vector components and could be achieved with staring beams and no need for beam steering. The range at which such beams could be made to intersect orthogonally would be limited by the extent of the rotor diameter. Measurements at greater ranges could be obtained also with staring intersecting beams, being of fixed position within the frame of reference of the rotor, where the beams converge with acute angles less than 90 degrees.

[0023] Wind turbine control systems and control philosophy demand accurate incident wind speed and incident wind direction measurement inputs. However, wind speed and direction measurements are typically provided by nacelle mounted wind vanes, cup anemometers or ultrasonic anemometers. Correction factors or transfer function parameters are used to transform the nacelle measurements into upwind measurement estimates.

[0024] The position of such instruments on the nacelle, behind the rotor and subject to wind flow streamlines around the nacelle including bow wave and wake effects, gives rise to errors in estimating the upwind quantities. Therefore an additional advantage of a nacelle LIDAR system, employing converging beams for improved measurement accuracy, is to provide direct more accurate measurement of the upwind quantities, thus enabling more accurate adherence to the wind turbine control philosophy.

[0025] Wind turbine yaw misalignment due to inaccurate wind direction measurement can cause significant power losses. Therefore improved wind direction data, provided by more accurate nacelle mounted LIDAR employing converging beams, can increase wind turbine output by offering improved yaw alignment with the wind direction.

[0026] Nacelle mounted LIDAR enables characterisation of future wind conditions incident at the wind turbine and rotor through measurements made upwind of the turbine. More accurate nacelle LIDAR measurements, by use of converging beams, can enable more effective assessment of future wind conditions, thereby improving the effectiveness of possible control system response.

[0027] Advance knowledge of extreme wind conditions such as gusts or extreme wind shear events allows a wind turbine control system to adjust control parameters in order to avoid the associated increased loads on wind turbine components. Therefore more accurate nacelle mounted LIDAR employing converging beams enables more effective wind turbine load control.

[0028] Advance knowledge of incident wind conditions may be employed by predictive collective or independent pitch control. Therefore more accurate nacelle mounted LIDAR employing converging beams enables more effective pitch control.

[0029] In order to resolve three dimensional wind velocity components at a specific point within the wind field it is necessary to intersect at least three beams. More than three beams may be provided in order to allow for simultaneous multiple measurement. In other words, a plurality of measurement points may be measured at any one time.

[0030] If the beams are almost parallel then they are essentially measuring the same radial line of sight velocity component and little or no information is obtained on the lateral velocity components. Therefore it is preferred that the beams will have large angle between them and that they should converge or intersect at a given measurement point in space, which can be achieved by large spatial displacement between their respective beam sources along with suitable beam direction control.

[0031] The disclosure comprises a plurality of beams emitted from beam sources which are within or mounted on those horizontal axis wind turbine components which yaw or rotate around a vertical axis as the wind turbine is controlled to face into the wind.

[0032] Such components include the wind turbine nacelle, rotor hub or rotor blades. The beam sources are substantially displaced from one another and the beams are aimed towards the measurement point such that they intersect or converge at the measurement point, thereby enabling radial Doppler velocimetry along at least three non-parallel axes in order to reconstruct the three-dimensional wind velocity at the measurement point. Each beam measurement range may be independently controlled by use of focusing optics or by use of range gate timing.

[0033] Preferably the beam source is a laser. Each beam source may be substantially co-located with a receiver-detector system allowing radial velocity measurement along the beam axis and at the measurement point.

[0034] Beam sources can be of a number of different types. In one embodiment doped optical fibre lasers may be employed. These may be chosen to operate with wavelength and power which is considered safe for the human eye. However it is appreciated that other types of laser and optics could be employed including semiconductor lasers, pumped optical cavity lasers, mirrors, lenses, etc.

[0035] It will be appreciated that a laser source may or may not be co-located with one or more laser beam telescopes. For instance it would be possible to transmit and/or amplify laser beams via system of mirrors or optical fibres from wind turbine base or nacelle through to wind turbine rotor hub and also into wind turbine blades. Components such as optical slip ring or other may be employed in the system if required. Therefore laser beams may be directed or transmitted from telescopes or optical windows at any required location on or within the wind turbine subcomponents such as base/transition piece, tower, nacelle, rotor hub, rotor blades, etc.

[0036] Radiation from the laser source may be replicated or split in order to provide an optical reference of known frequency which can be mixed with or interfered with the reflected beam. The reflected beam is reflected from particles, aerosols or molecules within the air which are considered to be travelling with the same velocity as the wind. Mixing or interference of the reflected beam frequency with the reference frequency enables the Doppler shift in frequency to be measured. The reference frequency or the reflected frequency may also be shifted by a known amount prior to mixing. The Doppler shift in frequency indicates the relative velocity of the reflecting particle, aerosol or molecule. This principle is used to infer the wind velocity component along a given Doppler beam measurement line of sight.

[0037] In case there is a measured or known statistical relationship indicating a difference in wind velocity with velocity of such particles, aerosols or molecules borne on the wind then a corresponding correction factor may be applied to the measured Doppler velocity in order to correct the measurement towards the true wind velocity. A similar technique could be employed for turbines which operate in liquid or other fluids.

[0038] A novelty of this disclosure lies within the fact that nacelle or rotor mounted beam sources are made to converge at the measurement point allowing co-located measurement of independent components of the wind velocity vector, whereas existing nacelle mounted LIDAR Doppler velocimetry methods employ diverging beams which sense the independent wind velocity components at different locations in space, or else simply collect data on the radial wind speed component alone using a single beam.

[0039] An advantage of employing convergent beams from beam sources on the nacelle or rotor is that accurate three-dimensional wind velocity samples can be measured upwind of the wind turbine rotor, irrespective of the turbine yaw position.

[0040] A "point" will in practice be an intersection region having a size defined by the size or focus of the beams. For a Continuous Wave (CW) laser system an adjustable focusing system would normally be employed in order to make Doppler measurement at a given focus range; or where a pulsed laser system is used the pulse length and timing gate resolution will determine the range-resolution at which Doppler measurement can be made at a series of different ranges (for a series of timing gates according to the speed of light travelling to and back from the measurement range).

[0041] In air, normally a pulsed system would be employed over long range (e.g. 50m to some kilometres) whereas a CW system could be better employed over short range (e.g. less than 100m) since the range resolution of CW system can be very good at low range - of order 1 metre or less, while typical pulsed systems would have range resolution perhaps around 10 metres.

[0042] This means that a CW system could be very good for close in accurate measurements to be used for quick pitch adjustments or for feeding into active surface control such as controllable blade flaps.

[0043] These considerations depend on the laser wavelength and/or the pulse or range gate wavelength. We are normally talking about 1.5 to 2 micrometre wavelength which is "eye safe".

[0044] According to the invention the Doppler beams may be deliberately steered such that they be made to intersect at various chosen measurement points. This may be with or without deliberate dwell times of the beam scanning system / steering system per measurement point. Through successive measurements this allows the sampling of the varying wind velocity field at different relative upwind ranges, heights and lateral displacements from the wind turbine rotor hub centre. This measurement information may be used to feed into the wind turbine control system for reasons including improved adherence to wind turbine control philosophy, improved wind turbine performance monitoring, improved yaw control, anticipatory or predictive control as well as load management or protection against extreme events within the incident wind velocity field.

[0045] In another example embodiment of the disclosure one or more fixed beams relative to the rotor hub sweep out one or more cones as the rotor rotates and such beams are intersected by fixed or scanning beams emanating from telescopes mounted on/in the nacelle/tower/base, or elsewhere. For instance if the rotor is rotating slowly at just 6 rpm (one rotation every 10 seconds) then one of ten independent beams fixed relative to the rotor hub could be arranged to intersect any given point on their swept cone once every second giving a measurement frequency of 1 Hz. In case of additional fixed or scanning beams intersecting the same point then it would be possible to reconstruct a three dimensional wind velocity vector at that measurement point.

[0046] The means of beam scanning may for example employ a rotating turret with optical window where the beam is scanned by means of system of one or more rotating and/or fixed mirrors and/or by means of one or more rotating and/or fixed prism/lens. However, it will be appreciated that other methods of beam steering can be employed.

[0047] It is possible to measure a three-dimensional map of the wind field by arranging for a series of measurement samples to be collected at a chosen set of points across the field of measurement. In a preferred embodiment three scanning beams emanating from the nacelle and/or hub and/or rotor blades are individually steered such that they intersect at the same point in time and space (at the measurement point) and that this process is repeated at successive measurement points sampled across the chosen measurement field.

[0048] In one example embodiment a set of measurement points are chosen such that they are as close to the rotor plane as possible but separated by a distance which is calculated to allow pitch systems or other actuators (e.g. active surface/flaps actuators) to prepare for the imminent wind field about to impinge on the blades.

[0049] In one example embodiment a set of measurement points are chosen so as to sample the wind field at a significant distance in front of the wind turbine rotor, such as at 2.5 rotor diameters distance in accordance with the notion that measuring at such a distance in front of the rotor may be considered a "free stream" measurement.

[0050] In one example embodiment the scanning points are arranged so as to densely sample the wind field across the entire rotor in order to provide measurements which contribute to a rotor averaged wind speed measurement for rotor averaged power curve assessment or other purpose.

[0051] In one example embodiment sets of measurement points may be collected at multiple ranges in order to check for the persistence of potentially damaging wind features such as extreme turbulence, localised eddies, gusts, or other features with the potential to enable warning flags of increasing severity in case a damaging feature persists and approaches the wind turbine, and eventually an alarm to initiate shutdown or alternative protective measures such as through pitch control.

[0052] In general the disclosure allows for the measurement at multiple ranges and points throughout the incident fluid field in order to simultaneously characterise the fluid field for multiple different purposes.

[0053] Wind maps may be constructed which are planar sections through the overall wind field such as a plane parallel to the rotor plane at one or more distance in front of the rotor. In general a wind velocity map may include a plurality of samples throughout the incident or surrounding wind field.

[0054] In general a scanning system that controls the beam sources is programmable such that any set of measurement points may be successively and/or simultaneously sampled for one or more specific purposes.

[0055] The principles of the disclosure are not limited to measurements upstream of a turbine and may equally be applied in measuring behind/downstream of the turbine in order to characterise wake conditions, which may impinge on another turbine.

[0056] Wake information collected by this means may allow for the deflection, diversion or deliberate alteration of the wake (or wake conditions such as turbulence) such that it could be deflected or directed away from other turbines.

[0057] Very accurate milliradian beam steering of lasers is possible with existing equipment, employing galvanometers, MEMS gratings, micro-mirrors, decentred lens arrays, rotating wedges or other beam steering systems.

[0058] When mounting a LIDAR steering system on/in a wind turbine nacelle then the nacelle motion would need to be measured and accounted for - for example using MEMS accelerometers or other equivalent methods. Similarly, when mounting on/in the rotor hub then rotor rotation angle also needs to be measured and taken into account; and when mounting on a pitching blade section then blade pitch also needs to be accounted for. If a blade section is also flexing then further sensing or beam steering correction may be required.

[0059] Multiple transformations/corrections can be applied to account for all possible degrees of motion, and are combined into a resultant command signal for the beam steering actuators whatever they may be.

[0060] In one example embodiment the design of hub and blade connection is itself modified and a fixed, non-pitching extension piece is inserted between the hub and the blade mounting point beyond which the blade is permitted to pitch. This design enables the beam sources to be mounted on the rotor at substantially greater radii from the rotor rotation axis whilst avoiding being subject to blade pitch motion which could affect beam steering capability. The large radii from the rotor rotation axis enables pairs of such sources to be separated with large baseline, thereby facilitating improved three-dimensional velocity measurement through resolution of orthogonal wind velocity components. This design may also benefit from the possible use of shorter blades required to provide a given torque.

[0061] In another example embodiment the wind turbine has three blades and each pitching blade is mounted on a fixed, non-pitching extension piece with the three beams each staring in a fixed direction with respect to the rotor reference frame such that they intersect substantially orthogonally on the rotor axis. This design enables a single three-dimensional velocity measurement at a fixed location within the frame of reference of the rotor. Additional beams can be intersected at different fixed positions within the reference frame of the rotor, both on the rotor axis itself and displaced from the rotor axis. This arrangement can conveniently gather three-dimensional measurements of the extended wind velocity field ahead of the wind turbine rotor, with passive scanning by making use of the rotor rotation.

[0062] In one example embodiment the measurement locations can be fixed or steered such that they are aimed at points in the wind field anticipated to engage imminently with a wind turbine blade, thus contributing to the blade tip speed control or predictive blade pitch control. In this case it may be beneficial to employ additional Doppler beam sources mounted at the rear of the wind turbine nacelle, on or within the top, bottom or sides of the nacelle housing, as well as rotor hub or blade mounted beams converging at the measurement point.

Figure 1 shows components of a typical horizontal axis wind turbine including tower 1, nacelle 2, rotor hub 3, blades 4 and nacelle mounted anemometry 11.

Figure 2 illustrates the front view of the wind turbine which is presented to the wind, and shows an example of how a plurality of Doppler beam sources 5 could be arranged to be mounted on the top, bottom and sides of the nacelle 2 and that it could be possible to arrange their beams to intersect at a given measurement point 6.

Figure 3 again shows the front view of the wind turbine but where a plurality of Doppler beam sources are mounted on the rotating rotor hub 3 in order to avoid obstruction of the beams by the passing rotor blades 4 when the beams are arranged to intersect at a given measurement point 6.

Figure 4 shows an example involving a new method of blade mounting where the blade mounting points are not at the rotor hub itself but at the end of cylindrical or alternatively shaped tubing 12 extending radially outward from the rotor hub 3 and enabling the positioning of Doppler beam sources 5 on the rotor but with base line separation greater than the rotor hub diameter. Employing the fixed, not-pitching extension tube sections 12 ensures that the Doppler beam sources do not rotate additionally around the pitch axis which could hinder or complicate the intersection of their beams at the measurement point

Figure 5 illustrates the possibility of scanning the beams in order that they successively and simultaneously converge at a series of measurement points which can be arranged in a regular grid or otherwise and may be at different ranges in front of the wind turbine. In this figure the beam sources are shown to be mounted on or within the pitching blades themselves implying that blade pitch, as well as rotor rotation, would need to be accounted for in scanning.

Figure 6 illustrates a scanning method which makes use of the rotation of the rotor in which case it is possible to converge the beams at a fixed point relative in the frame of reference of the rotor hub but that this allows successive data collection at numerous points on a circular locus.

Figure 7 illustrates the possibility of employing multiple fixed beams from sources 5 on the rotor hub or extensions thereof which may intercept orthogonally at a point 14 on the rotor axis, or converge with acute angles further upwind at a point 15 also on the rotor axis, or that fixed or scanning beams may be made to intersect at points 16 displaced from the rotor axis which may or may not be points in the incident wind field which may imminently be engaged by a blade. In the case where measurement point 16 is close in to the rotor blade plane then it could be beneficial to employ further beams from sources mounted toward the rear of the nacelle either on top, below or on the side of the nacelle housing, in order to adequately resolve the component of wind velocity parallel to the rotor axis.

[0063] Various improvements and modifications can be made without departing from the scope of the appended claims.

[0064] For example, it will be appreciated that many different beam source mounting points, frames or inclusion points are possible within the claims of this disclosure. The figures shown are just a few examples.

Claims

1. A measurement system comprising:

   a plurality of beam sources (5) mounted on a wind turbine and arranged such that beams from the beam sources (5) intersect at a measurement point (6) which is upstream or downstream of the wind turbine with respect to the flow direction of a fluid that drives the wind turbine;
   one or more receivers for measuring a Doppler shift of reflected or scattered beams;
   a processor for determining a fluid velocity at the measurement point (6) based on the measured Doppler shift.

2. The system of claim 1, wherein the wind turbine is a horizontal axis or vertical axis wind turbine.

3. The system of claim 2, wherein one or more beam sources (5) are mounted:

   on or in a nacelle housing (2), or on or in a fixed frame extending from the nacelle housing (2); and/or
   on or in a rotor hub (3), or on or in a fixed frame extending from the rotor hub (3); and/or
   on or in one or more rotor blades (4) or in a fixed frame extending from one or more rotor blades (4).

4. The system of any preceding claim, wherein beam sources (5) are provided at a plurality of wind turbines and have their beams independently directed such that they converge or intersect at the measurement point (6).

5. The system of any of claims 3 to 4, comprising a beam source control system which is arranged to select particular beams which best lend themselves to providing samples at particular positions without being intersected by the passage of the rotor blades (4), nacelle (2) or tower, thereby allowing for uninterrupted measurement and freeing up any alternative beams in order that they may simultaneously be employed towards alternative measurement positions.

6. The system of claim 5, wherein the beam scanning method may change according to an operational state of the wind turbine allowing for the possibility of employing the rotation of the rotor blades (4) for beam scanning when the rotor rotates but switching to an alternative measurement mode when the rotor ceases to rotate.

7. The system of any preceding claim, comprising a beam steerer that can be controlled to vary the measurement point (6), comprising a control system which provides necessary signals to the individual beam steering or deflection systems, based upon one or more of: sensor input knowledge and calculation of relative positions of sources, component orientation and alignment information, relative position and velocity of geographic, rotor and blade pitch reference frames, yaw angles, rotor angle, blade pitch angles, rotor speed, wind velocity and/or wind direction.

8. The system of claim 7, wherein one or more of:

   nacelle yaw angle;
   tower bending;
   nacelle bending;
   rotor rotation angle;
   blade bending; and
   blade pitch angle;

   are taken into account for beam steering accuracy purpose.

9. The system of any preceding claim, wherein the beam sources (5) are arranged to measure a fluid velocity field at a succession of sampling or measurement points (6) in order to provide data samples indicating the spatial variation of the fluid velocity field or its characteristics.

10. The system of any of claims 3 to 9 when dependent on Claim 2, wherein a control system is arranged to combine the velocimetry data with inputs from additional sensors collecting one or more of: wind turbine operational data, power performance data, wind conditions data, noise data, condition monitoring data, vibration data, blade bending moment data or tower bending moment data, and wherein the control system employs the available data in order to calculate and actuate altered turbine control parameters.

11. The system of any preceding claim, wherein velocimetry data is employed to provide wind field mapping, which can be used for predicting output of wind farm for grid management purpose or for energy storage control purpose or for co-generation management whereby wind farm output is combined with the output of another generator, one possible object being to deliver accurate power prediction/forecasting for electricity grid management or energy trading purpose.

12. The system of any preceding claim, wherein the wind velocity measurements are used to alter the wind turbine inclination or tilt control; the wind turbine axis orientation may be adjusted in order to account for varying non-horizontal wind velocity, preferably within a margin of safety to avoid the risk of blade collision against a tower; and wherein a rotor hub (3) may be moved forward from a substantially horizontal axis wind turbine tower in order to allow for greater rotor axis tilt variation for matching wind conditions.

13. The system of any preceding claim, wherein the beam sources (5) and receivers comprise LIDAR beam sources and receivers; RADAR beam sources and receivers; SODAR beam sources and receivers; or SONAR beam sources and receivers.

14. A measurement method comprising:

emitting beams from a plurality of beam sources (5) on a wind turbine such that beams from the beam sources (5) intersect at a measurement point (6) which is upstream or downstream of the wind turbine with respect to the flow direction of a fluid that drives the wind turbine;
receiving a Doppler shift of reflected or scattered beams; and
determining a fluid velocity at the measurement point (6) based on the measured Doppler shift.

15. A computer program product comprising instructions to cause the measurement system of Claim 1 to execute the steps of the method of Claim 14.

Patentansprüche

1. Messsystem, umfassend:

eine Vielzahl von Strahlenquellen (5), die an einer Windturbine angebracht und so eingerichtet sind, dass sich die Strahlen von den Strahlenquellen (5) an einem Messpunkt (6) schneiden, der in Bezug auf die Strömungsrichtung eines Fluids, das die Windturbine antreibt, stromaufwärts oder stromabwärts der Windturbine liegt;
einen oder mehrere Empfänger zur Messung der Dopplerverschiebung der reflektierten oder gestreuten Strahlen;
einen Prozessor zum Bestimmen einer Fluidgeschwindigkeit am Messpunkt (6) basierend auf der gemessenen Dopplerverschiebung.

2. System nach Anspruch 1, wobei die Windturbine eine Windturbine mit horizontaler oder vertikaler Achse ist.

3. System nach Anspruch 2, wobei eine oder mehrere Strahlenquellen (5) angebracht sind:

auf oder in einem Gondelgehäuse (2) oder auf oder in einem festen Rahmen, der sich von dem Gondelgehäuse (2) erstreckt; und/oder
auf oder in einer Rotornabe (3) oder auf oder in einem festen Rahmen, der sich von der Rotornabe aus erstreckt (3); und/oder
auf oder in einem oder mehreren Rotorblättern (4) oder
in einem festen Rahmen, der sich von einem oder mehreren Rotorblättern (4) erstreckt.

4. System nach einem der vorstehenden Ansprüche, wobei Strahlenquellen (5) an einer Vielzahl von Windturbinen bereitgestellt sind und ihre Strahlen unabhängig voneinander so lenken, dass sie am Messpunkt (6) konvergieren oder sich schneiden.

5. System nach einem der Ansprüche 3 bis 4, umfassend ein System zur Steuerung von Strahlenquellen, das so eingerichtet ist, dass es bestimmte Strahlen auswählt, die sich am besten dazu eignen, Proben an bestimmten Positionen bereitzustellen, ohne von der Passage der Rotorblätter (4), der Gondel (2) oder des Turms durchschnitten zu werden, wodurch eine ununterbrochene Messung ermöglicht wird und alle alternativen Strahlen frei werden, so dass sie gleichzeitig für alternative Messpositionen eingesetzt werden können.

6. System nach Anspruch 5, wobei sich das Verfahren zur Strahlabtastung je nach Betriebszustand der Windturbine ändern kann, wodurch ermöglicht wird, die Drehung der Rotorblätter (4) zur Strahlabtastung zu nutzen, wenn sich der Rotor dreht, aber auf einen alternativen Messmodus umzuschalten, wenn sich der Rotor nicht mehr dreht.

7. System nach einem der vorstehenden Ansprüche, umfassend eine Strahlumlenkung, die so gesteuert werden kann, dass sie den Messpunkt (6) verändert, umfassend ein Steuersystem, das die erforderlichen Signale für die einzelnen Strahlumlenkungs- oder -ablenkungssysteme bereitstellt, basierend auf einem oder mehreren der Folgenden: Kenntnis der Sensoreingänge und Berechnung der relativen Positionen der Quellen, Informationen über die Orientierung und Ausrichtung von Komponenten, relative Position und Geschwindigkeit von geografischen, Rotor- und Blattanstell-Referenzrahmen, Gierwinkel, Rotorwinkel, Blattanstellwinkel, Rotorgeschwindigkeit, Windgeschwindigkeit und/oder Windrichtung.

8. System nach Anspruch 7, wobei eines oder mehrere der Folgenden:

Gondelgierwinkel;
Turmbiegung;
Gondelbiegung;
Rotordrehwinkel;
Blattbiegung; und
Blattanstellwinkel;
für die Genauigkeit der Strahlumlenkung berücksichtigt werden.

9. System nach einem der vorstehenden Ansprüche, wobei die Strahlenquellen (5) so eingerichtet sind, dass sie ein Fluidgeschwindigkeitsfeld an einer Folge von Probenahme- oder Messpunkten (6) messen, um Datenproben bereitzustellen, die die räumliche Veränderung des Fluidgeschwindigkeitsfeldes oder seiner Eigenschaften anzeigen.

10. System nach einem der Ansprüche 3 bis 9, wenn es von Anspruch 2 abhängt, wobei ein Steuersystem eingerichtet ist, um die Geschwindigkeitsmessdaten mit Eingaben von zusätzlichen Sensoren zu kombinieren, die eines oder mehrere der Folgenden erfassen: Betriebsdaten der Windturbine, Energieleistungsdaten, Windbedingungsdaten, Geräuschdaten, Zustandsüberwachungsdaten, Schwingungsdaten, Blattbiegemomentdaten oder Turmbiegemomentdaten, und wobei das Steuersystem die verfügbaren Daten verwendet, um geänderte Turbinensteuerparameter zu berechnen und zu steuern.

11. System nach einem der vorstehenden Ansprüche, wobei Geschwindigkeitsmessdaten zur Bereitstellung von Windfeldkartierung eingesetzt werden, die zur Vorhersage der Leistung eines Windparks zum Zwecke der Stromnetzverwaltung oder zur Steuerung der Energiespeicherung oder zur Steuerung der Kraft-Wärme-Kopplung verwendet werden kann, wobei die Leistung eines Windparks mit der Leistung eines anderen Generators kombiniert wird, wobei ein mögliches Ziel darin besteht, eine genaue Leistungsvorhersage/-prognose für die Stromnetzverwaltung oder für den Energiehandel zu liefern.

12. System nach einem der vorstehenden Ansprüche, wobei die Windgeschwindigkeitsmessungen verwendet werden, um die Neigung der Windturbine oder die Steuerung der Schrägstellung zu ändern; die Ausrichtung der Windturbinenachse angepasst werden kann, um variierende nicht-horizontale Windgeschwindigkeiten zu berücksichtigen, bevorzugt innerhalb einer Sicherheitsspanne, um das Risiko einer Blattkollision mit einem Turm zu vermeiden; und wobei eine Rotornabe (3) von einem Windturbinenturm mit im Wesentlichen horizontaler Achse nach vorne bewegt werden kann, um eine größere Variation der Rotorachsenneigung für übereinstimmende Windbedingungen zu ermöglichen.

13. System nach einem der vorstehenden Ansprüche, wobei die Strahlenquellen (5) und -empfänger LIDAR-Strahlenquellen und -empfänger, RADAR-Strahlenquellen und - empfänger, SODAR-Strahlenquellen und -empfänger oder SONAR-Strahlenquellen und - empfänger umfassen.

14. Messverfahren, umfassend:

Emittieren von Strahlen aus einer Vielzahl von Strahlquellen (5) an einer Windturbine, so dass sich die Strahlen aus den Strahlquellen (5) an einem Messpunkt (6) schneiden, der in Bezug auf die Strömungsrichtung eines Fluids, das die Windturbine antreibt, stromaufwärts oder stromabwärts der Windkraftanlage liegt;
Empfangen einer Dopplerverschiebung der reflektierten oder gestreuten Strahlen; und
Bestimmen einer Fluidgeschwindigkeit an dem Messpunkt (6) basierend auf der gemessenen Dopplerverschiebung.

15. Computerprogrammprodukt, das Anweisungen umfasst, um das Messsystem nach Anspruch 1 zu veranlassen, die Schritte des Verfahrens nach Anspruch 14 auszuführen.

Revendications

1. Système de mesure comprenant :

une pluralité de sources de faisceau (5) montées sur une éolienne et agencées de sorte que des faisceaux provenant des sources de faisceau (5) se croisent à un point de mesure (6) qui est en amont ou en aval de l'éolienne par rapport à la direction d'écoulement d'un fluide qui entraîne l'éolienne ;
un ou plusieurs récepteurs pour mesurer un décalage Doppler de faisceaux réfléchis ou diffusés ;
un processeur pour déterminer une vitesse de fluide au point de mesure (6) sur la base du décalage Doppler mesuré.

2. Système selon la revendication 1, dans lequel l'éolienne est une éolienne à axe horizontal ou à axe vertical.

3. Système selon la revendication 2, dans lequel une ou plusieurs sources de faisceau (5) sont montées :

sur ou dans un logement de nacelle (2), ou sur ou dans un cadre fixe s'étendant depuis le logement de nacelle (2) ; et/ou
sur ou dans un moyeu de rotor (3), ou sur ou dans un cadre fixe s'étendant depuis le moyeu de rotor

(3) ; et/ou

sur ou dans une ou plusieurs pales de rotor (4) ou
dans un cadre fixe s'étendant depuis une ou plusieurs pales de rotor (4).

4. Système selon l'une quelconque des revendications précédentes, dans lequel des sources de faisceau (5) sont prévues à une pluralité d'éoliennes et ont leurs faisceaux dirigés indépendamment de sorte qu'ils convergent ou se croisent au point de mesure (6).

5. Système selon la revendication 3 ou 4, comprenant un système de commande de source de faisceau qui est agencé pour sélectionner des faisceaux particuliers qui se prêtent le mieux à fournir des échantillons à des positions particulières sans être croisés par le passage des pales de rotor (4), une nacelle (2) ou une tour, en permettant de ce fait une mesure ininterrompue et en libérant des faisceaux alternatifs pour qu'ils puissent être employés simultanément vers des positions de mesure alternatives.

6. Système selon la revendication 5, dans lequel le procédé de balayage de faisceau peut changer en fonction d'un état de fonctionnement de l'éolienne en permettant la possibilité d'employer la rotation des pales de rotor (4) pour un balayage de faisceau lorsque le rotor tourne mais en commutant dans un mode de mesure alternatif lorsque le rotor cesse de tourner.

7. Système selon l'une quelconque des revendications précédentes, comprenant un dispositif de direction de faisceau qui peut être commandé pour faire varier le point de mesure (6), comprenant un système de commande qui fournit des signaux nécessaires aux systèmes de direction ou de déviation de faisceaux individuels, sur la base d'un ou plusieurs parmi : une connaissance d'entrée de capteur et un calcul de positions relatives de sources, des informations d'orientation et d'alignement de composants, une position relative et une vitesse de cadres de référence géographiques, de rotor et de pas de pale, des angles de lacet, un angle de rotor, des angles de pas de pale, une vitesse de rotor, une vitesse du vent et/ou une direction du vent.

8. Système selon la revendication 7, dans lequel un ou plusieurs parmi :

angle de lacet de nacelle ;
courbure de tour ;
courbure de nacelle ;
angle de rotation de rotor ;
courbure de pale ; et
angle de pas de pale ;
sont pris en compte à des fins de précision de direction de faisceau.

9. Système selon l'une quelconque des revendications précédentes, dans lequel les sources de faisceau (5) sont agencées pour mesurer un champ de vitesse de fluide à une succession de points d'échantillonnage ou de mesure (6) afin de fournir des échantillons de données indiquant la variation spatiale du champ de vitesse de fluide ou ses caractéristiques.

10. Système selon l'une quelconque des revendications 3 à 9 dépendant de la revendication 2, dans lequel un système de commande est agencé pour combiner les données de vélocimétrie avec des entrées de capteurs supplémentaires collectant une ou plusieurs parmi : données opérationnelles d'éolienne, données de performance de puissance, données de conditions du vent, données de bruit, données de surveillance de conditions, données de vibrations, données de moment de flexion de pale ou données de moment de flexion de tour, et dans lequel le système de commande emploie les données disponibles pour calculer et actionner des paramètres de commande d'éolienne altérés.

11. Système selon l'une quelconque des revendications précédentes, dans lequel des données de vélocimétrie sont employées pour fournir une cartographie de champ de vent, qui peut être utilisée pour prédire une sortie de parc éolien à des fins de gestion de réseau ou à des fins de commande de stockage d'énergie ou pour une gestion de cogénération de telle manière qu'une sortie de parc éolien soit combinée à la sortie d'un autre générateur, un objet possible étant de fournir une prédiction/prévision de puissance précise à des fins de gestion de réseau électrique ou à des fins de négoce d'énergie.

12. Système selon l'une quelconque des revendications précédentes, dans lequel les mesures de vitesse du vent sont utilisées pour altérer la commande d'inclinaison ou de pente d'éolienne ; l'orientation d'axe d'éolienne peut être ajustée afin de tenir compte d'une vitesse variable du vent non horizontal, de préférence à l'intérieur d'une marge de sécurité pour éviter le risque de collision de pale contre une tour : et dans lequel un moyeu de rotor (3) peut être avancé depuis une tour d'éolienne à axe sensiblement horizontal afin de permettre une plus grande variation d'inclinaison d'axe de rotor en fonction des conditions du vent.

13. Système selon l'une quelconque des revendications précédentes, dans lequel les sources de faisceau (5) et les récepteurs comprennent des sources de faisceau et des récepteurs LIDAR ; des sources de faisceau et des récepteurs RADAR ; des sources de faisceau et des récepteurs SODAR ; ou des sources de faisceau et des récepteurs SONAR.

14. Procédé de mesure comprenant :

l'émission de faisceaux depuis une pluralité de sources de faisceau (5) sur une éolienne de sorte que des faisceaux provenant des sources de faisceau (5) se croisent à un point de mesure (6) qui est en amont ou en aval de l'éolienne par rapport à la direction d'écoulement d'un fluide qui entraîne l'éolienne ;
la réception d'un décalage Doppler de faisceaux réfléchis ou diffusés ; et
la détermination d'une vitesse de fluide au point de mesure (6) sur la base du décalage Doppler mesuré.

15. Produit de programme d'ordinateur comprenant des instructions pour amener le système de mesure selon la revendication 1 à exécuter les étapes du procédé selon la revendication 14.

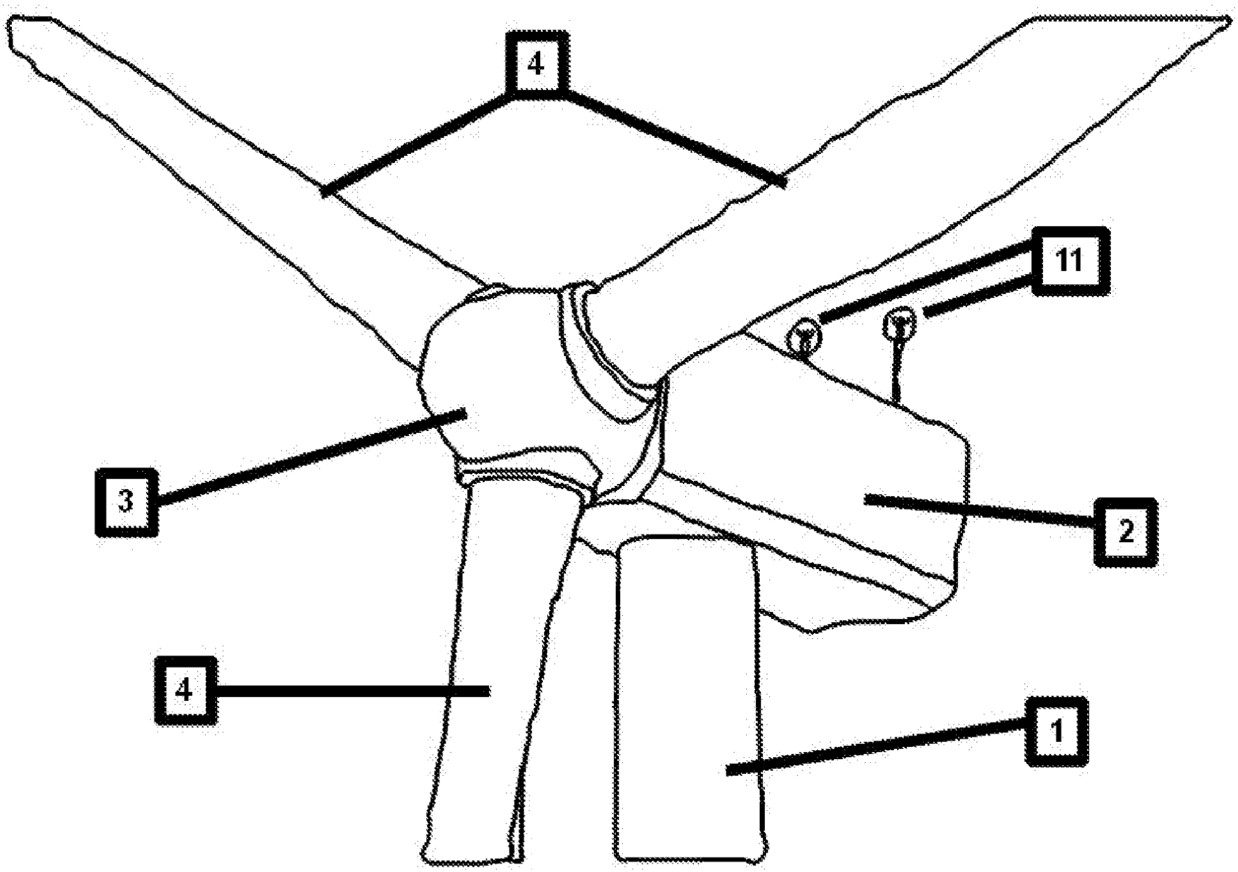

Figure 1

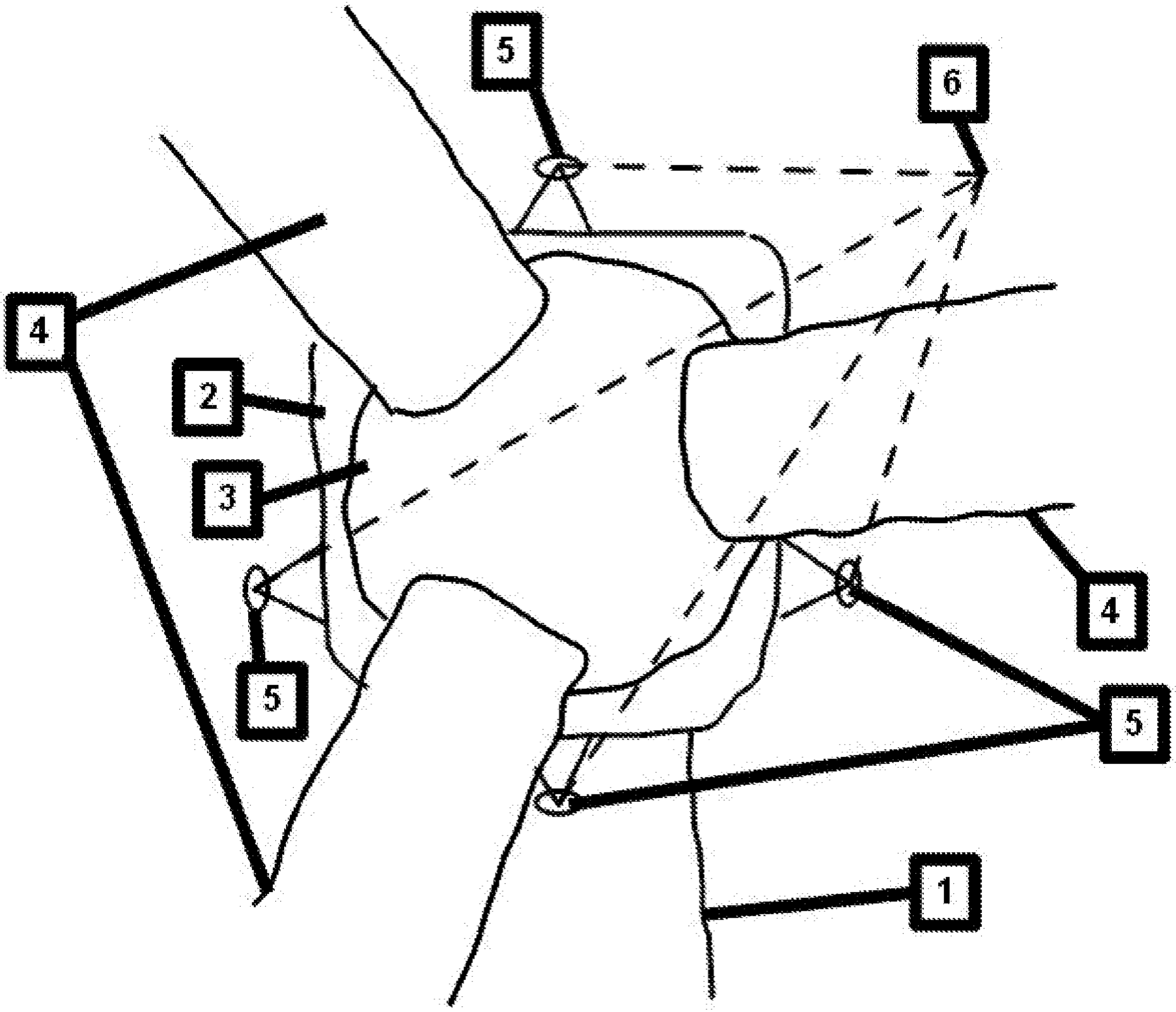

Figure 2

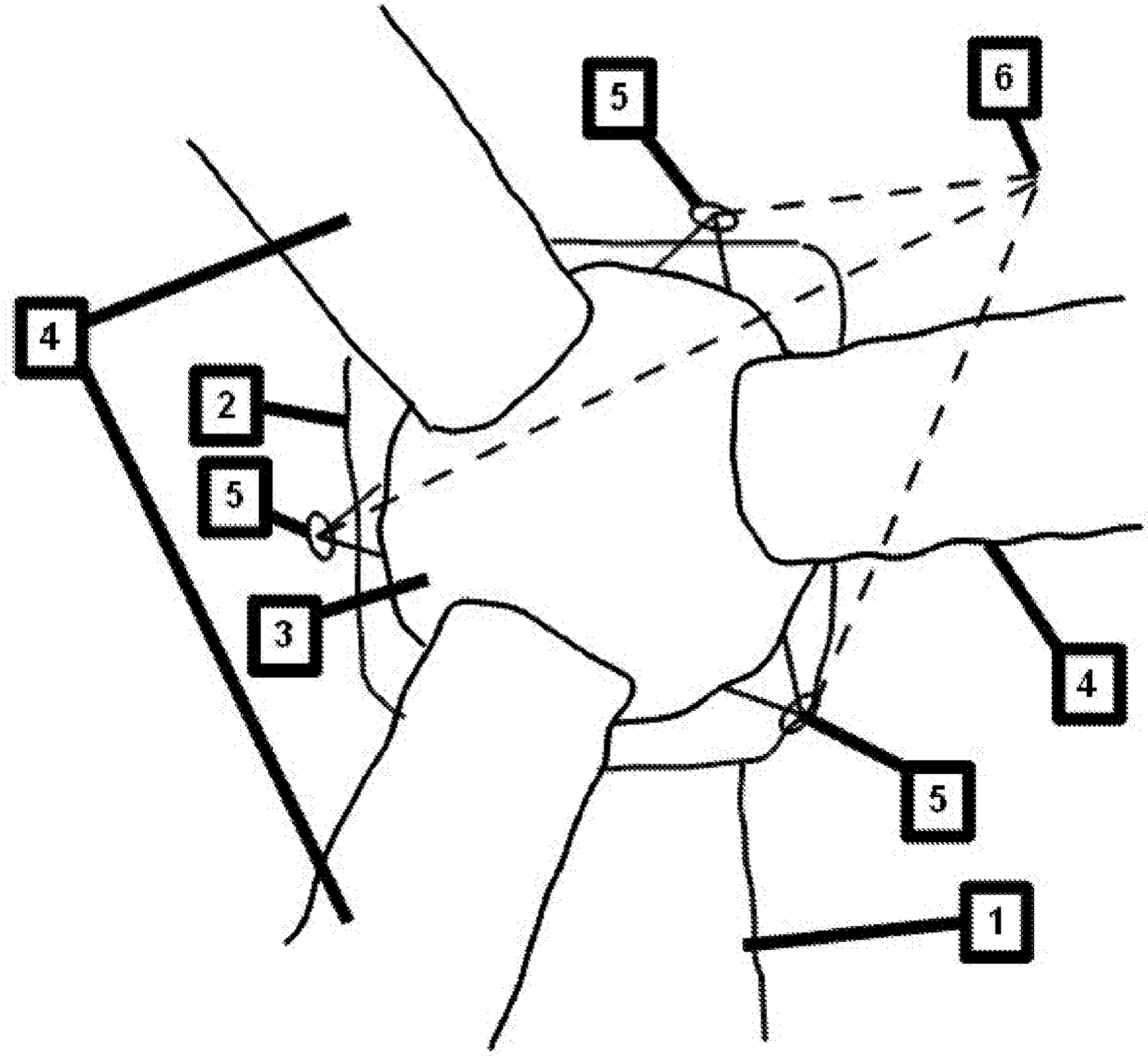

Figure 3

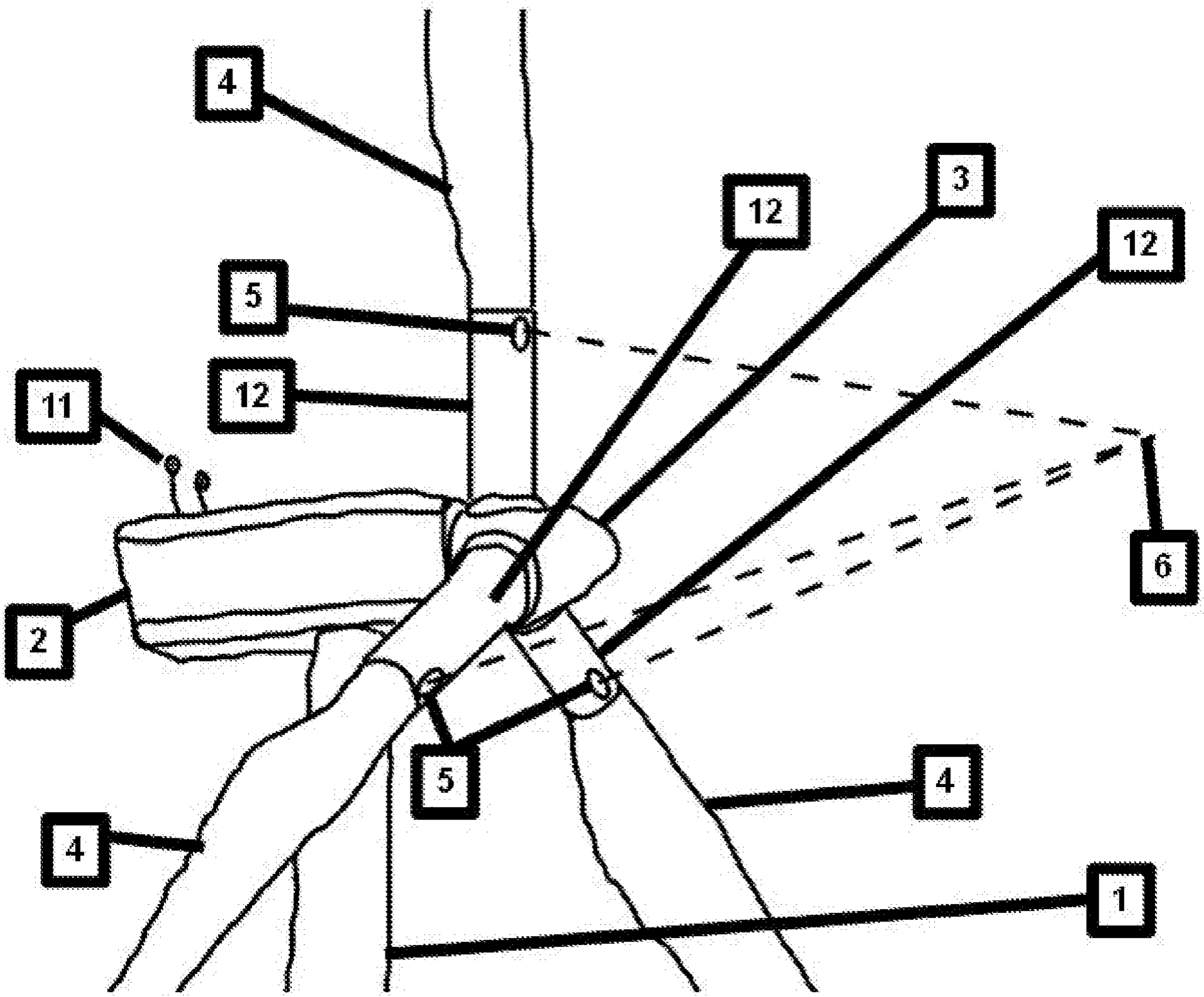

Figure 4

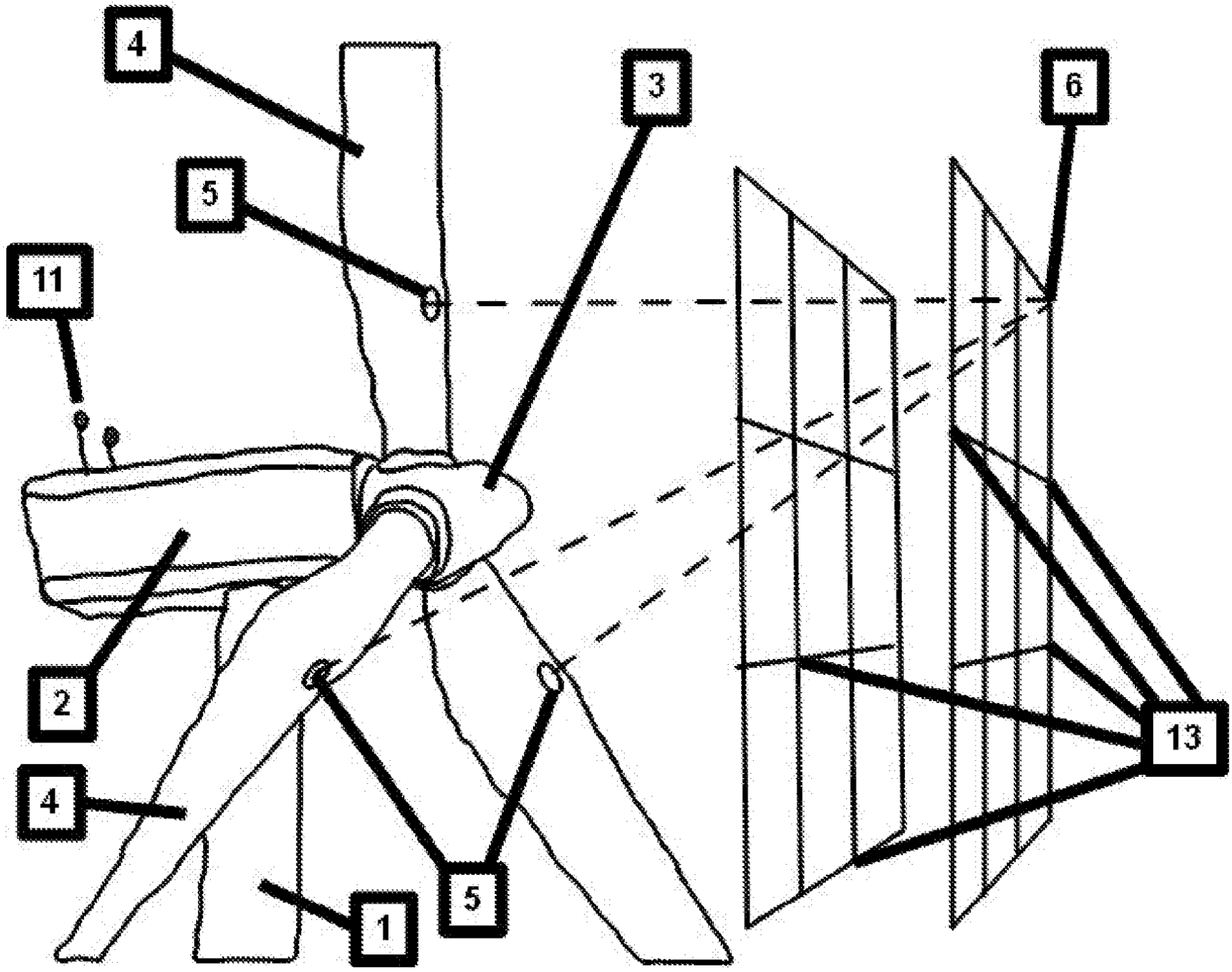

Figure 5

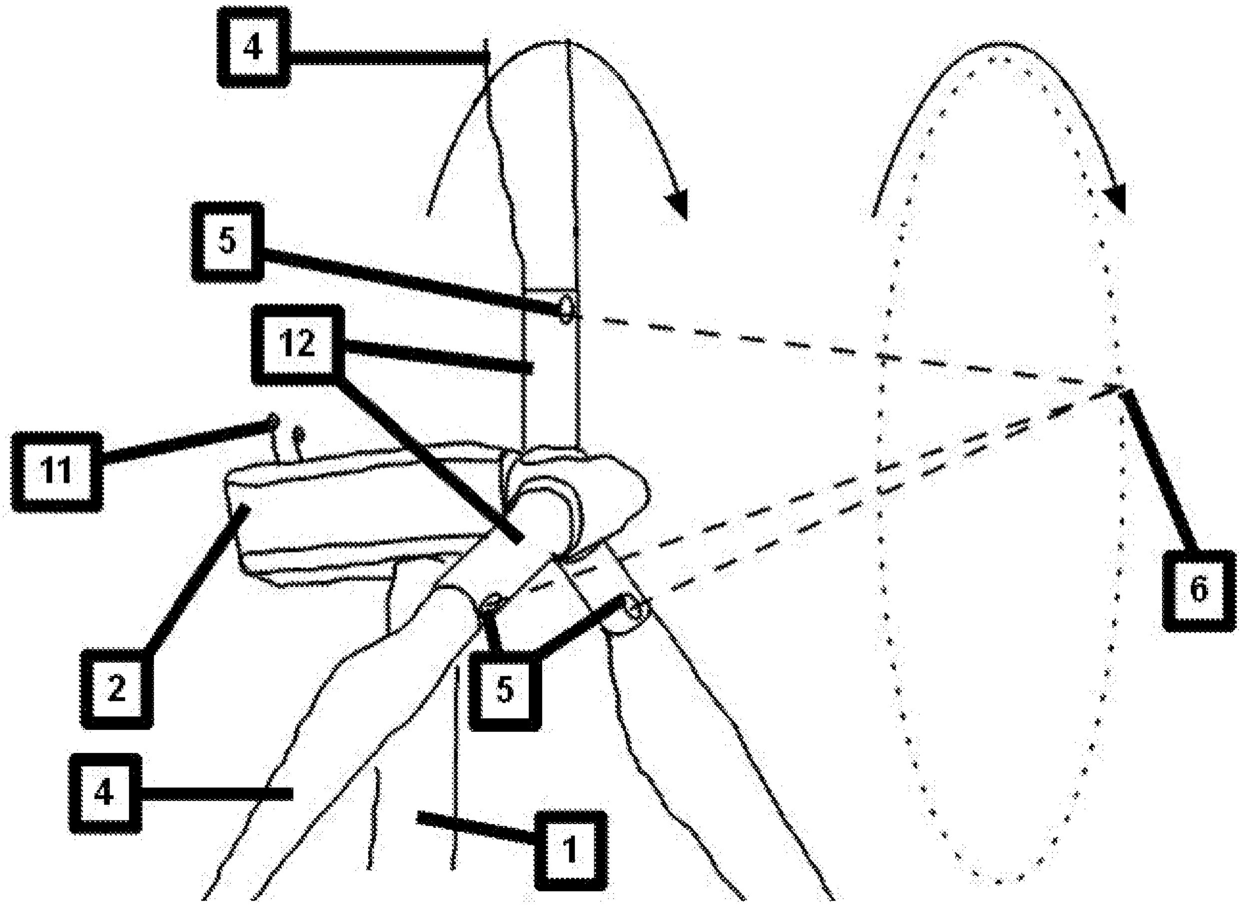

Figure 6

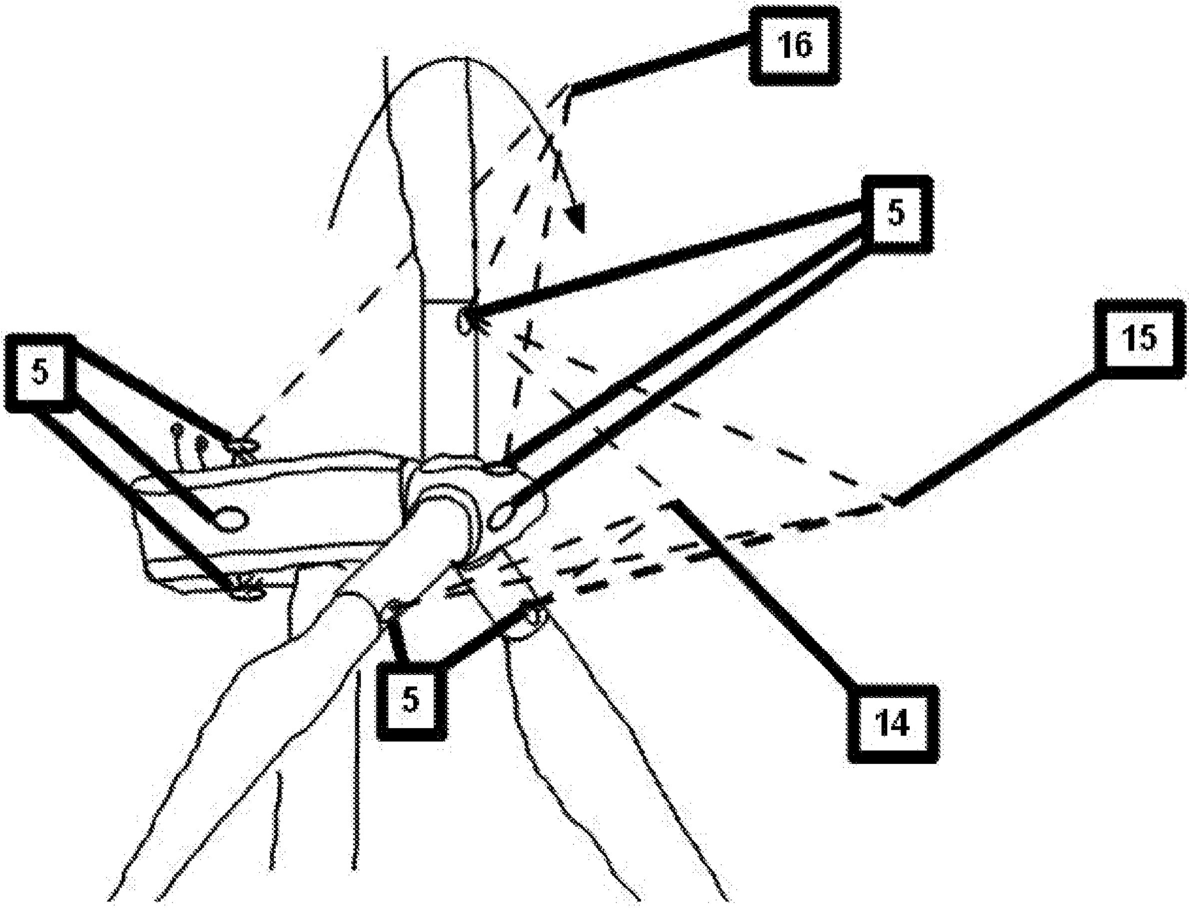

Figure 7

REFERENCES CITED IN THE DESCRIPTION

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