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(72) Inventor; and
(71) Applicant : ALMAZAN ACEBO, Jorge [ES/ES]; Paseo Pamplona 4-6, 10, E-50004 Zaragoza (ES).

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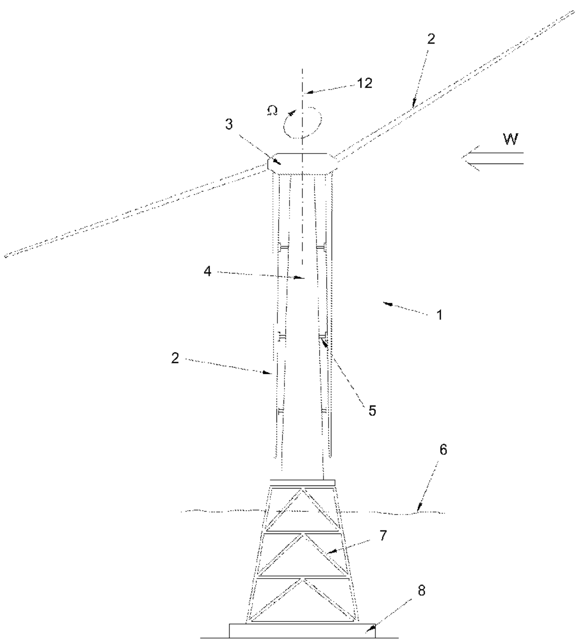

FIG. 1

(57) Abstract: The wind turbine has a rotor which is rotatably, around a substantially vertical rotational axis, and functionally coupled to a stator for generating energy. The rotor comprises at least one blade, and a rotor frame for supporting the blades. The wind turbine is characterized in that, in operation of the wind turbine, the blades are freely pivotally coupled to the rotor frame in at least flapping.

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WIND TURBINE

The present invention concerns a vertical axis turbine suitable for a large scale configuration, particularly, though not exclusively, a wind turbine.

The main types of currently available wind turbines can be classified into two groups according to the rotor orientation with respect to the wind in operation of the turbine. First: horizontal axis wind turbines, so called HAWTs, which are the most widespread in use. The rotor plane of the HAWT remains substantially perpendicular to the wind direction; i.e., vertical to the reference surface (ground, sea, etc.) on which the turbine is built. Second: vertical axis wind turbines, so called VAWTs. The rotor axis of the VAWT remains substantially perpendicular to the wind direction; i.e., perpendicular to the reference surface.

Different types of VAWT are well known. They can be classified into four families: "Darrieus", "Savonius", "H-rotor" and "V-rotor." They are basically distinguished from each other by the shape and arrangement of their rotor blades.

Hereinafter, the term "large scale wind turbine" refers to a wind turbine with a rotor provided with a maximum diameter greater than 100 m, which is approximately equivalent to a rated power greater than 1 MW (assuming an average wind speed of about 15 m/s in operation of the wind turbine).

In terms of size, the largest HAWTs currently known in operation reach about 120 m rotor diameter and 120 m height from the reference surface to the nacelle, providing a rated power of approximately 5 MW.

In the last 25 years, the size of the HAWT built has been almost doubled. The reason for this development and for it being advantageous to build a wind turbine as large as possible lies primarily in the fact that the larger the wind turbine is, the more the rated power is significantly increased without proportionally affecting the cost of its construction and maintenance.

Offshore wind turbines are a special case, where the superiority of large scale wind turbines is especially true, considering the added difficulty in their construction and maintenance per se. In recent years, this kind of wind turbine has proliferated, mainly due to the offshore wind quality.

The height of the wind turbine, measured from the reference surface to the nacelle, must obviously be greater than the radius of the HAWT rotor, which imposes a limitation of the HAWTs against the VAWT, due to the fact that being located at a higher distance above the base surface involves a higher cost of construction and maintenance. However, it should be borne in mind that increasing the height provides higher rated power since wind speed significantly increases with altitude.

Large scale HAWTs present some problems in the current state of the art. One of the most critical problems is the structural fatigue of the blades. In HAWTs, taking into account that the rotor blades rotate in a substantially vertical plane, the direction of the weight force acting on the blade varies as the rotor rotates, causing the blade weight stresses to vary cyclically. The structural fatigue occurs as a consequence of such cyclic weight stresses. For this reason, increasing the size of the wind turbine considerably and proportionally makes the rotor more vulnerable to structural fatigue.

By contrast, in VAWTs the problem of weight structural fatigue is not present. This is because in a VAWT the weight force remains substantially in the same direction relative to the blade as it rotates, therefore not causing cyclic stresses on the blade.

However, this does not imply the total absence of cyclic stresses on the VAWT blades; there are other cyclic stresses that are basically due to the asymmetry of the aerodynamic forces acting on the blade during its rotation, genuine of the VAWT.

Nevertheless, resistance to structural fatigue caused by aerodynamic forces in VAWTs, has the advantage, compared with that caused by the force of weight in HAWTs, that the former does not depend significantly on the size of the wind turbine. This makes VAWTs seem promising as a solution in the state of the art for large scale application.

In terms of performance and power rating of the VAWT compared to the HAWT, the comparison should be done between wind turbines that have the same equivalent rotor area. The “equivalent rotor area” is defined hereinafter as the area of the surface that results from projecting the swept surface by the rotor blades onto a plane perpendicular to the wind direction (e.g. according to this definition, the equivalent rotor area of a HAWT is essentially equal to the rotor area). In the current state of the art, the rated power of the VAWT is only slightly lower than the rated power of the HAWT with an equivalent rotor area. One reason for this may be the lower usage and technological development that VAWTs have received compared to HAWTs so far.

The most powerful VAWT known ever built is the "Eolo". It is a "Darrieus" type with a height of approximately 100 m and a rated power of about 2.5 MW. No other VAWT that has reached a greater or equal rated power is known to exist. In terms of size of the "Darrieus" wind turbine, it has the disadvantage that, since its blades are vertical catenary shaped, the equivalent rotor area is determined by the height of the turbine, which substantially limits the equivalent rotor area in comparison with other wind turbines.

In the “V-rotor" type, the blades are attached to the rotor at the blade roots and extended at an angle in a vertical plane; i.e., in a plane perpendicular to the reference surface. This configuration allows the "V-rotor" type to provide an equivalent rotor area greater than that of the "Darrieus" type given a similar design dimension of the blades (blade length of the “V-rotor” vs. height of the “Darrieus”). Thus, a "V-rotor" which had an inclination of the blades of preferably 45 degrees would maximize the equivalent rotor area and hence the turbine's rated power. Another technical aspect in favour of the “V-rotor” is its manufacturing simplicity of the blades due to their geometry.

In the US patent document **US-4168439** a wind turbine is described as being suitable for a large scale configuration.

Additionally, there are other known advantages of VAWTs against HAWTs, prompting the utilisation of VAWTs in large scale configurations.

One of these advantages of VAWTs, and in particular of the "V-rotor" type, is that they are omnidirectional. This means that the wind turbine can work regardless of the wind direction and therefore it does not require a yaw system to turn the rotor into the wind as in a HAWT. This obviously implies advantages in reliability and cost of operation and maintenance of the wind turbines.

A second inherent advantage of VAWTs is that they do not affect RADAR systems, which is not the case for HAWTs.

However, on the other hand, large scale VAWTs and particularly "V-rotor" wind turbines present a number of technical problems in the current state of the art.

A first problem is the aforementioned structural fatigue cause by cyclic stresses from aerodynamic forces. A second known problem comes, like the above, from the asymmetry of the aerodynamic forces acting on the rotor. Aerodynamic forces generated in stationary operation of the wind turbine result in a static overall moment on the rotor that tends to overturn it (overturning moment).

The overturning moment can help increase the negative effect of cyclic stresses due to the aerodynamic forces, thus significantly deteriorating the structural fatigue resistance of both the rotor and the turbine's foundation. The overturning moment can also damage the rotor bearing. In fact, these were the main reasons for the failure of the “Eolo" wind turbine, which led to it being shut down in the late 90's.

Finally, the presence of the overturning moment may also affect the stability of the structure of the wind turbine - either it is a floating or a fixed structure.

The International patent publication **WO-2006/054091** describes a "V rotor" wind turbine suitable for a large configuration wherein a solution to minimize the technical problem of the overturning moment is provided. This solution consists of incorporating an outer wing attached transversely to the blade, or a number of wings at different distances along the blade from the tip thereof. This invention is currently under development in the United Kingdom under the name of NOVA (standing for "Novel Offshore Vertical Axis"). Different models of large scale NOVA wind turbines have been studied up to a height of 100 m and 300 m rotor diameter, estimating a rated power up to about 10 MW.

Large scale VAWTs known in the prior art have the problem of poorly avoiding the structural fatigue caused by aerodynamic forces and the existence of the overturning moment throughout the operation range of the wind turbine.

Purpose of the present invention is to provide a VAWT with an improved structural resistance and stability, particularly fatigue resistance, and to avoid the negative overturning moment effects. In addition, it is an object of the invention to provide a wind turbine with an improved power rating compared to current wind turbines with equivalent size. Notwithstanding these objects of the invention are regardless the size of the wind turbine, the invention aims to provide a VAWT especially suitable for a large configuration.

In order to overcome the mentioned shortcomings of the prior art and to obtain the above and other purposes and advantages, the invention provides the technical features and effects described below.

The present invention refers to a wind turbine with a rotor coupled rotatably to a stator, around a substantially vertical rotational axis, and functionally for generating energy. The rotor includes at least one blade and a rotor frame for supporting the blades.

The invention is characterised in that, in operation of the wind turbine, the blades are freely pivotally coupled to the rotor frame in at least flapping.

The freely pivotally coupling of the blade to the rotor frame (hereinafter called “blade coupling”) may be additionally in lagging. This coupling freedom would be necessary for example to release the high gyroscopic inertial forces that would act on the coupling when the wind turbine is large.

The blade coupling may be a spherically coupling to the rotor frame, which allows flapping, lagging and pitch motion of the blade at the same time.

In particular, the blades may be freely pivotally connected to the rotor frame. This can be realized for example by means of a flapping hinge and optionally a lagging hinge in the same connection, or alternatively by means of a ball joint.

Optionally, the blade coupling to the rotor frame may be located at the root of the blade.

The provision of a freely pivotally coupling in at least flapping eliminates the stress concentration that would occur in the root of the blade if it were a cantilever coupling and avoids structural fatigue and. This property would significantly improve the structural resistance of the blade and therefore allowing providing oversized rotors according to one object of the invention.

In an aspect of the invention, the blade coupling may comprise a blade damping system. The blade damping system may include at least one damper (e.g. hydraulic, pneumatic or frictional), at least one spring or at least one counterweight, in a manner known by the person skilled in the art.

The **US-2484291** patent document mentions the technical effect of articulating in flapping the blade to suppress the overturning moment and relieve stresses at the root of the blade, when the articulation is substantially coincident with the axis of rotation of the rotor. In the patent document **US-4197056**, which refers to a large scale HAWT, the technical effect of providing a flapping articulation at the root of the blade to relieve bending stresses is also considered. However, is not known this technical effect as applied to VAWTs according to the features of the present invention, which involves a distinguished concept of wind turbine, with a distinguished operation and performance in particular, as it will be exposed as follows.

The motion of the turbine blades of the invention in operation of the wind turbine is such that with a rotational speed (Ω) of the rotor and a wind speed (W) fixed, the blades adopt a given neutral position forming a constant cone angle (β) on a vertically and laterally inclined plane, in an inclination angle (ε) and a sideslip angle (δ), respectively (Fig. 5). Those blade motion parameters (β, ε and δ), that determine the movement of the blades depend on constrains of the wind turbine rotor, such as: length, inertia, mass, plan geometry and twist of the blade, aerofoil, number of blades, etc.

Concerning the motion of the turbine blades, It is noted that another advantage of the wind turbines according to the present invention, because of the freely pivotally blade coupling, is its capability to absorb wind gusts or sudden changes in speed and direction of the wind on the rotor. In the invention, these gusts of wind, instead of causing dynamic overloads on the structure, as in conventional wind turbines, only cause a deviation in the neutral position of the rotor, which tends to be self stabilised.

Additionally, the present invention intends to apply the technical effect of the rotor adopting an inclination angle (ε) naturally into the wind, thereby providing the capability to generate more power. This effect is obviously much more noticeable the larger the size of the rotor and therefore can be very significant in large scale wind turbines even when the inclination angle (ε) is small. It would be possible to select an appropriate combination of constrains of the rotor that determine the motion of the blades to maximize the inclination angle (ε) and thus the power rating of the wind turbine. Additionally, this technical effect also provides the capability to the VAWT of the invention to be omnitidirectional; i.e., self-adjustable into the direction of the wind.

In relation to the above mentioned technical effect it can be seen that the sideslip angle (δ) can penalise to certain extent the capability of the turbine to extract power, since, as shown in Figure 5, the apparent wind speed would be reduced by a factor of cos(δ). The present invention also incorporates a solution to this problem. This solution is based on the technical feature that the radius of the blade coupling, i.e., the radius segment of the rotor passing through the blade coupling, is forming an angle oblique to the axis of flapping. With this feature it would be possible to delay or advance the sideslip angle (δ) and thus to compensate said penalisation.

Another aspect of the invention is that the rotor frame may be movable with respect to the stator, so that for instance by tilting the rotor frame substantially upwardly into the wind a significant increase in the capability of the turbine to extract power can be obtained.

In order to achieve this function, the stator of the invention's wind turbine may comprise a stator frame movably coupled to a base frame, via a hereinafter called “stator frame coupling”. In this case, the functionally rotor coupling to the stator for generating energy of the wind turbine would be via the rotor frame to the stator frame. Particularly, the stator frame may be pivotally coupled to the base frame so as to permit the stator frame being tilted or turned with respect to the base frame. In this case, the stator frame coupling may include a central support of the stator frame functionally connected to the stator frame for allowing the motion with respect to the base frame thereof.

In another aspect of the invention, the stator frame coupling may comprise a stator frame damping system for damping the motion (e.g. tilting or turning) of the stator frame with respect to the base frame. The stator frame damping system may include at least one damper (e.g. hydraulic, pneumatic or frictional), at least one spring or at least one counterweight, in a manner known by the person skilled in the art.

Alternatively or complementary, the stator frame coupling may comprise a stator frame actuation system for effecting the motion of the rotor frame (e.g. tilting or turning). The stator frame actuation system may include at least one actuator (e.g. hydraulic, pneumatic or electric).

Optionally, the stator frame coupling may include a turnable frame with respect to the base frame.

The invention also contemplates that at least one element of the stator frame coupling (e.g. an actuator) may belong both to the stator frame damping system and the stator frame actuation system, continuously or discretionally performing both corresponding functions.

Optionally, the stator frame coupling may comprise a hexapod actuator system.

The stator frame coupling system may constitute, by means of the stator frame damping system or the stator frame actuation system or the combination of both, a passive or an active rotor stabilization or control system. The stabilization or control system may additionally comprise sensors such as wind speed and direction sensors and rotational speed tachometers for obtaining and processing such information mechanically or electronically to stabilize or control the wind turbine, as a function of constrains of the wind turbine rotor, in a manner known by a person skilled in the art. Optionally, the stabilization or control system may be implemented in rotor pitch, rotor roll or rotor yaw, i.e. with respect to a rotor frame axis system with the roll axis being horizontal and pointing to the direction the wind is blowing from, the pitch axis being horizontal and perpendicular to the roll axis, and the yaw axis being perpendicular to the roll axis and the pitch axis.

Another technical feature of the present invention is based on that the freely pivotally blade coupling may be located at an offset distance from the vertical rotational axis for providing stability to the rotor blade. Those skilled in the art could determine an adequate offset distance by for instance modelling the rotor blade as a beam, in particular from the paper **"Vibrations of a rotating beam", Jay L. Lipeles, Journal of the American Helicopter Society. 11 (1966), pp. 17-24**. Accordingly, stability can also be improved by conveniently ballasting the blade. Generally, it has found to be suitable an offset distance within the interval comprising approximately 5% to 25% of the blade length, more preferably about 15%.

On the contrary, if the blade coupling is substantially coincident with the rotational axis, it can theoretically eliminate the problem of the presence of the overturning moment since the aerodynamic forces obviously would not produce a significant overall overturning moment on the rotor. However this feature alone would not allow enhancing stability according to the above.

Consequently it is desirable to provide a wind turbine according to the invention wherein both effects of improving stability and reducing the overturning moment are satisfied at the same time. The present invention also provides a solution to that problem by making possible to device or select a stator frame coupling or a blade coupling offset distance to balance the rotor frame at a given tilting angle (α) utilizing the overturning moment which acts on the offset distance coupling blade rotor. Thus, it is possible for example to maximize the power generation by tilting the rotor up to a given tilting angle (α) by the action of the overturning moment. Accordingly, it can be selected a stator frame damping system (passive balancing) or a stator frame actuation system (active balancing).

Moreover, the invention contemplates the incorporation of a built-in generator in the rotor and stator itself; for example a linear induction generator. These generators allow electrical energy to be extracted directly, consequently reducing the total weight of the rotor, since for example the need for gearboxes and gears is avoided thus being suitable for a large configuration wind turbine. However, other alternatives are also considered such as a conventional electric generator directly connected to the rotor frame axis or via gearing. The patent document **US-5758911** shows an example of a built-in generator applied to a VAWT. On the other hand, in the patent document **US-7425772** different ways of realisation of this type of electric generator can be found. Accordingly, another technical feature included in the present invention is the provision of levitation elements (e.g. permanent magnets or electromagnets), allowing the prevention of friction on the rotor functionally coupling to the stator for generating energy.

According to another aspect of the invention, in a parking state the blades of the wind turbine may remain suspended vertically from the rotor frame. In that state, the invention may include an anchoring (e.g. a clamp or a vacuum sucker) for anchoring the blade to ensure its immobility when is not in operation. Once anchored, the vulnerability of the wind turbine to high winds and storms would be reduced. This effect can be enhanced by parking the blades in a position such that aerodynamic forces do not significantly affect to the blade, for example by extrados or intrados of the blade facing the tower.

Regarding the operation of the wind turbine according to the invention, in order to start the operation of the wind turbine the generator of the wind turbine may be used, but fed with electricity, therefore operating as a motor up to reach the operation rotational speed (autorotation speed). It is also possible with the invention to provide a self starting wind turbine from the parking position by aerodynamically configuring the blades (e.g. with an adequate blade pitch angle) so as to provide enough lift or drag to start rotating.

Any number of blades may be utilised in the wind turbine according to the present invention; preferably, from one to a maximum which would be conditioned by the performance of the rotor. As for the arrangement of the blades on the rotor, it may be suitable that they be arranged in radially opposite pairs to provide a substantially balanced rotor.

With respect to control and brake of the rotor, the wind turbine of the invention can be fitted with any type of known devices for wind turbines, including aerodynamic type devices (e.g. ailerons, flaps, airbrakes and devices for changing the blade pitch) or mechanical type devices.

The wind turbine assembly can be made on a tower built up on ground or reference surface, or on a floating platform.

The invention is illustrated by way of example in more detail with reference to the accompanying diagrammatic drawings in which:

Figure 1	is an overall view of an embodiment of wind turbine according to the invention.
Figure 2	represents a prior art "V-Rotor" type VAWT.
Figure 3	represents a first realization of an embodiment of wind turbine according to the invention.
Figure 4	represents a second realization of an embodiment of wind turbine according to the invention.
Figure 5	depicts a diagram illustrating the blade motion in a wind turbine according to the invention.

With reference to the Figure 1, a wind turbine is indicated overall by 1 and represents a large scale offshore VAWT embodiment according to the present invention. The embodiment can be selected as having two rectangular shaped blades 2 of 100 m of length by 10 m of chord each, with a NACA 0012 aerofoil and a rotational speed (Ω) of 3 rpm in operation of the wind turbine.

In operation of the wind turbine 1, the blades 2 adopt a neutral position (dashed line). In parking, the blades 2 remain suspended and immobilised by anchoring 5, for example by means of a vacuum sucker device. The nacelle 3 of the wind turbine 1, where the rotor 10 is located in, is supported on the tower 4, which is fixed to an undersea foundation 8 through an undersea structure 7.

Figure 2 represents the prior art "V-Rotor" type VAWT in operation of the turbine, wherein the blades 2 are fixed to the rotor frame 15. The rotor 10 is rotatably, around a substantially vertical rotational axis 12, and functionally coupled to a stator 11 for generating energy via a bearing 14 and a generator 13. The rotor 15 comprises two blades 2, and a rotor frame 15 for supporting the blades 2. The blades 2 are fixed to the rotor frame 15.

Figure 3 and 4 represent schematically two different realizations of the embodiment according to the invention in operation of the wind turbine 1, showing the neutral position adopted by the rotor 10 into the direction of the wind. In contrast, the two blades 2 are freely pivotally coupled to the rotor frame 15 by means of a flapping hinge 20 and a lagging hinge 21. Dashed lines and solid lines intend to represent the flapping motion of the blades 2, not to scale. The embodiment of Figure 4 is distinguished from the embodiment of Figure 3 in that the stator 11 of the latter comprises a stator frame 30 and a base frame 31. The base frame 15 is tiltable in a tilting angle (α). The illustrated embodiment incorporates actuators 32 and a central support 40, as stator frame coupling means for tilting the stator frame 30.

Finally, Figure 5 represents diagrammatically the blade motion in a wind turbine according to the invention and explained above.

The embodiment described above is given by way of example only, and various other modifications will be apparent to persons skilled in the art without departing from the scope of the invention, as defined by the appended claims.

List of references and symbols

1	wind turbine
2	blade
3	nacelle
4	tower
5	anchoring
6	sea reference surface
7	undersea structure
8	undersea foundation
10	rotor
11	stator
12	rotational axis
13	generator
14	bearing
15	rotor frame
20	flapping hinge
21	lagging hinge
30	stator frame
31	base frame
32	actuator
40	central support

W	wind speed
Ω	rotational speed
α	tilting angle
β	cone angle
δ	sideslip angle
ε	inclination angle

CLAIMS

1. **A WIND TURBINE**, specially a large scale wind turbine; having a rotor which is rotatably, around a substantially vertical rotational axis, and functionally coupled to a stator for generating energy; the rotor comprising: at least one blade, and a rotor frame for supporting the blades; **characterized in that**, in operation of the wind turbine, the blades are freely pivotally coupled to the rotor frame in at least flapping.

2. **A WIND TURBINE**, according to Claim 1; **characterized in that**, in operation of the wind turbine, the blades are freely pivotally coupled to the rotor frame in flapping and lagging.

3. **A WIND TURBINE**, according to Claim 1; **characterized in that**, in operation of the wind turbine, the blades are freely spherically coupled to the rotor frame.

4. **A WIND TURBINE**, according to any one of Claims 1 to 3; **characterized in that**, in operation of the wind turbine, the blades are freely pivotally connected to the rotor frame.

5. **A WIND TURBINE**, according to any one of Claims 1 to 3; **characterized in that** the blade coupling comprises a blade damping system.

6. **A WIND TURBINE**, according to any one of Claims 1 to 5; **characterized in that**: the stator comprises a stator frame and a base frame; the stator frame is movably coupled to the base frame so as to permit the stator frame being moved with respect to the base frame; the rotor being functionally coupled to the stator for generating energy via the rotor frame and the stator frame.

7. **A WIND TURBINE**, according to Claim 6; **characterized in that**: the stator comprises a stator frame and a base frame; the stator frame is pivotally coupled to the base frame so as to permit the stator frame being tilted or turned with respect to the base frame; the rotor being functionally coupled to the stator for generating energy via the rotor frame and the stator frame.

8. **A WIND TURBINE**, according to any one of Claims 6 or 7; **characterized in that** the stator frame coupling comprises a stator frame damping system.

9. **A WIND TURBINE**, according to any one of Claims 6 to 8; **characterized in that** the stator frame coupling comprises a stator frame actuation system.

10. **A WIND TURBINE**, according to any one of Claims 6 to 9; **characterized in that** the stator frame coupling includes a central support which is functionally connected to the stator frame for allowing the motion of the stator frame with respect to the base frame.

11. **WIND TURBINE**, according to any one of Claims 6 to 10; **characterized in that** the stator frame coupling comprises an hexapod actuator system.

12. **A WIND TURBINE**, according to any one of Claims 1 to 11; **characterized in that** the blade coupling is located at the root of the blade.

13. **A WIND TURBINE**, according to any one of Claims 1 to 12; **characterized in that** the blade coupling is located at an offset distance from the rotational axis.

14. **A WIND TURBINE**, according to Claim 13; **characterized in that** the radius of the blade coupling is forming an angle oblique to the axis of flapping.

15. **WIND TURBINE**, according to any one of Claims 1 to 14; **characterized in that** the rotor functional coupling to the stator for generating energy comprises a linear induction generator.

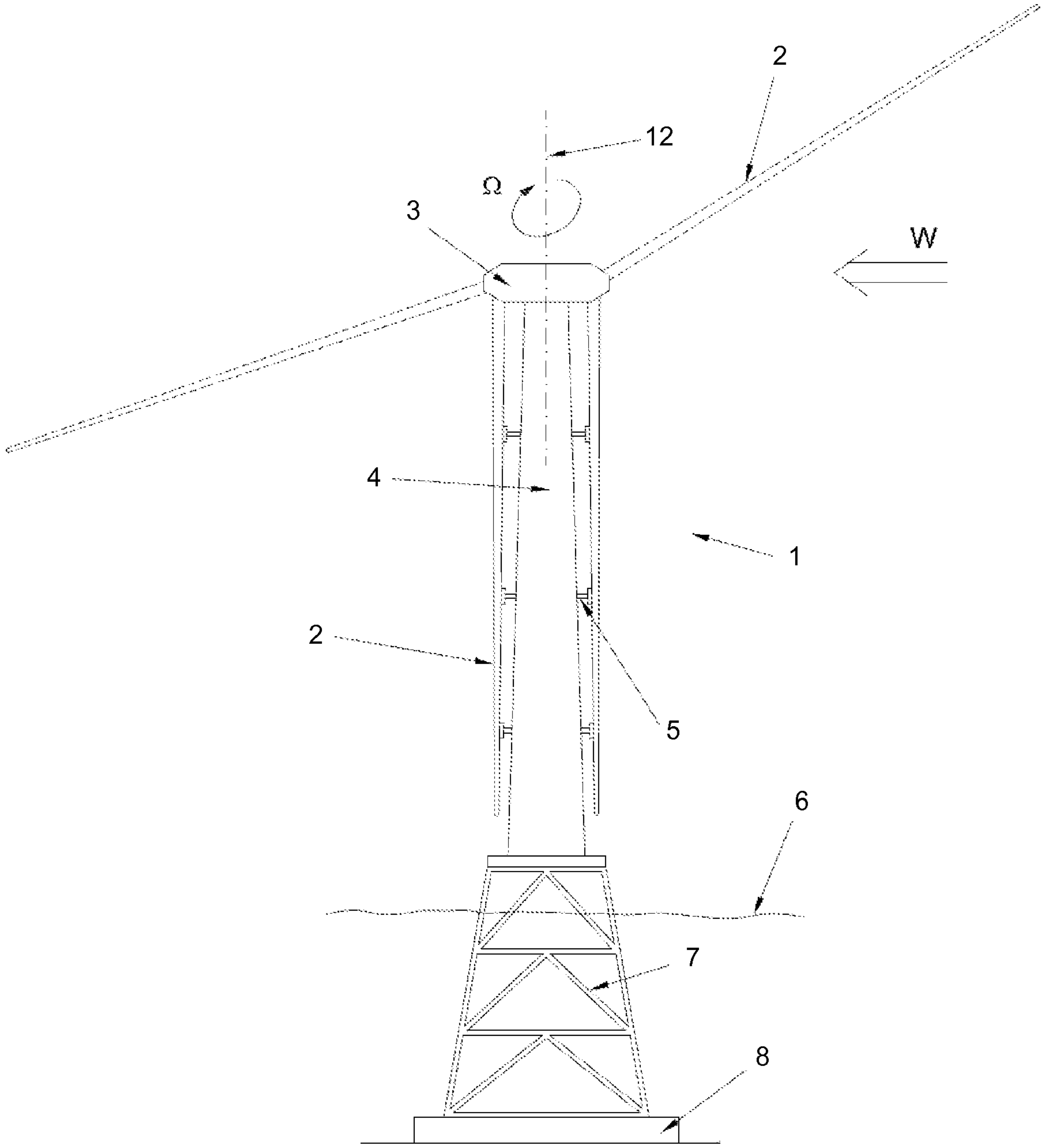

FIG. 1

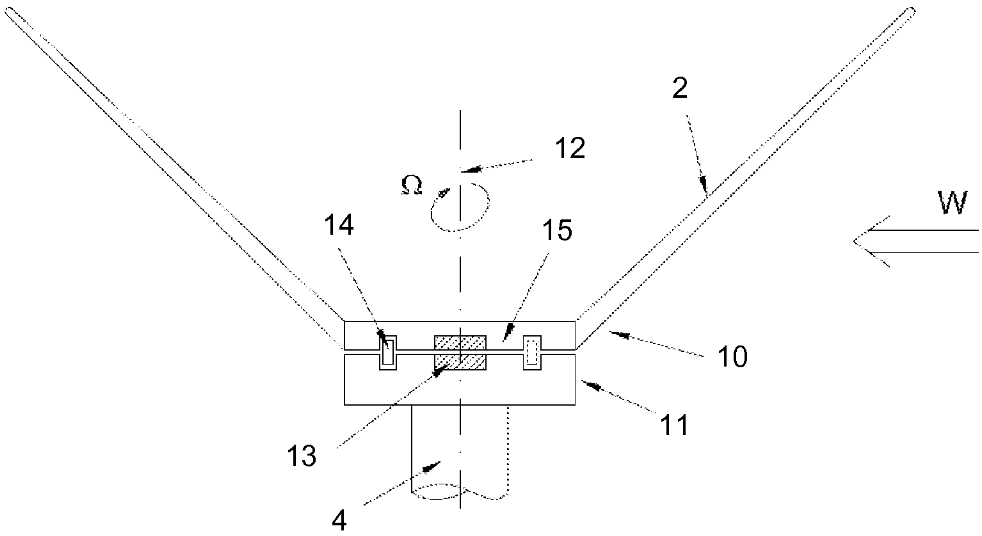

FIG. 2

PRIOR ART

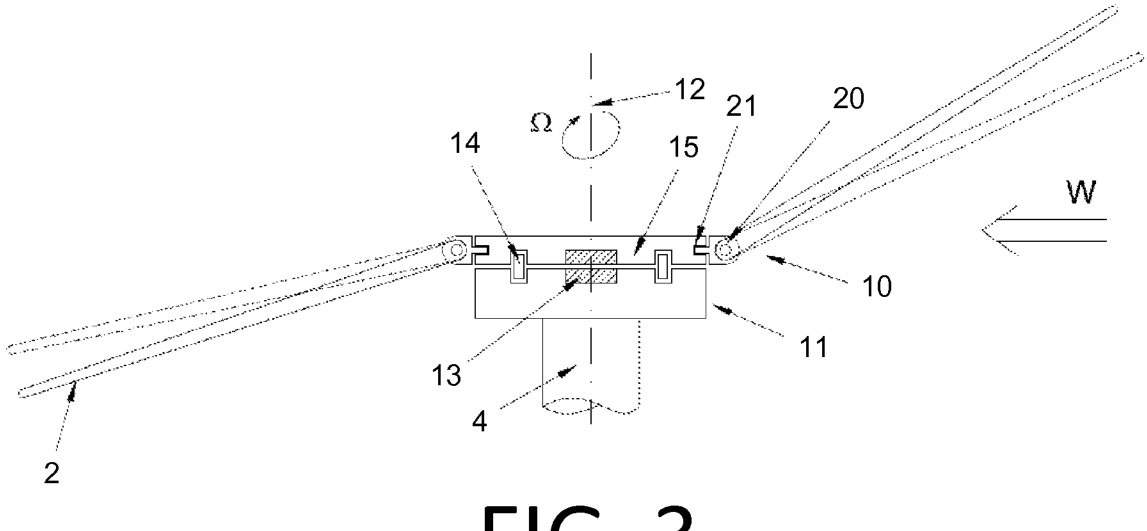

FIG. 3

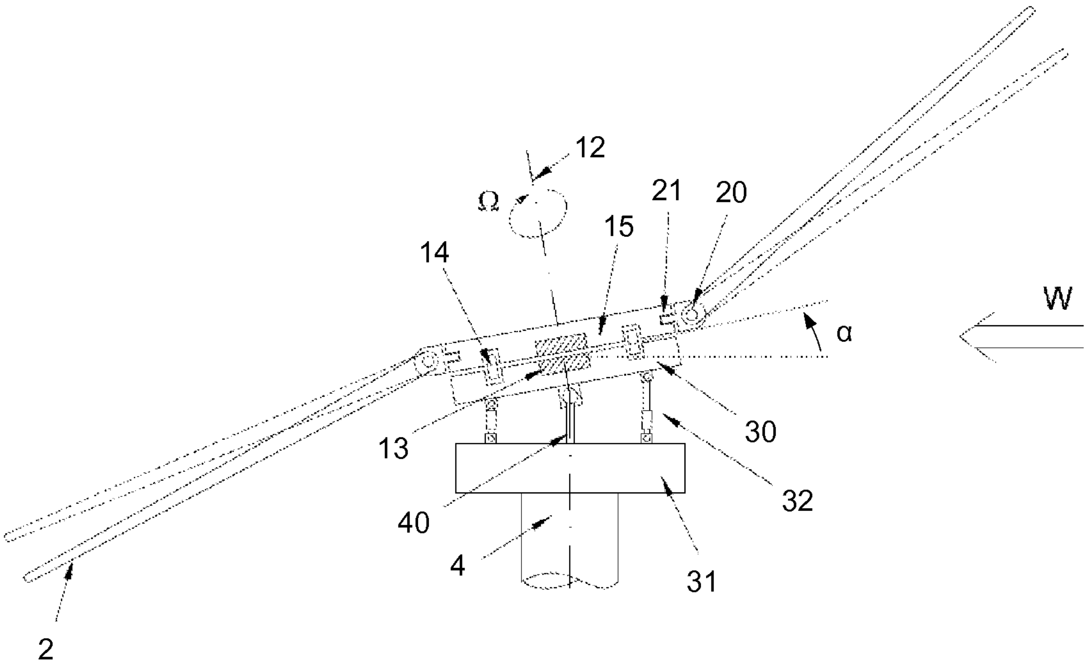

FIG. 4

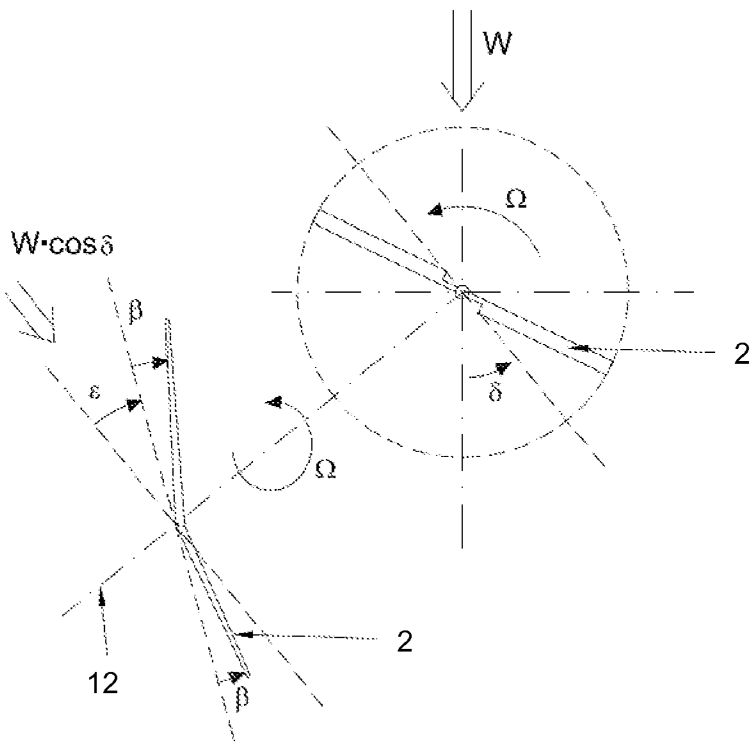

FIG. 5