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(71) Applicant(s):
Michael Torr Todman
Quince Cottage, Ladbroke, SOUTHAM, Warwickshire, CV47 2BT, United Kingdom

(72) Inventor(s):
Michael Torr Todman
John Richard Carew Armstrong

(74) Agent and/or Address for Service:
Michael Torr Todman
Quince Cottage, Ladbroke, SOUTHAM, Warwickshire, CV47 2BT, United Kingdom

(51) INT CL:
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F03D 1/02 (2006.01)

(56) Documents Cited:
GB 2425328 A **WO 2001/034974 A1**
US 5151610 A **US 20050218656 A1**

(58) Field of Search:
UK CL (Edition X) **F1Q, F1T**
INT CL **F03D**
Other: **EPODOC, WPI**

(54) Abstract Title**: Multi rotor wind turbine**

(57) A wind turbine arrangement comprises a tower 5 and at least two arms 3 projecting outwards there from. A wind turbine 1, 2 is attached to an end of each arm 3, with means being provided to selectively lower each turbine 1, 2 towards the base of the tower 5 to allow for easier maintenance. The arms 3 may be rigid with one another and pivoted to the tower 5 such that each turbine can be lowered in turn. In this arrangement two or three arms 3 and wind turbines 1, 2 may be provided. Alternatively the arms may be independent from one another and as such may both be lowered at the same time. The turbines 1, 2 may also be lowered whilst the arms 3 remain in a substantially horizontal position. A method of control is also disclosed which can align the turbines 1, 2 with the wind direction by means of blade pitch adjustment. The tower 5 may be mounted on land or at sea.

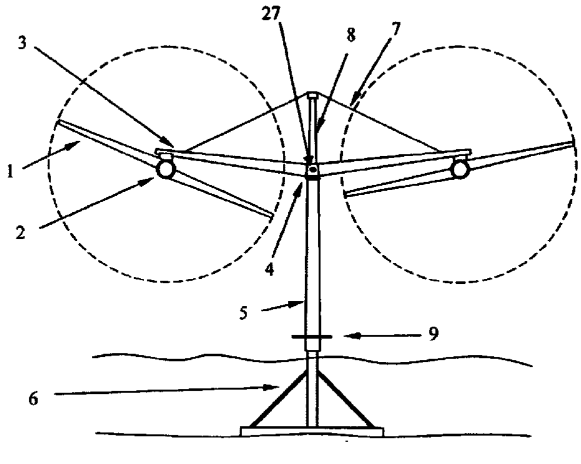

Figure 1

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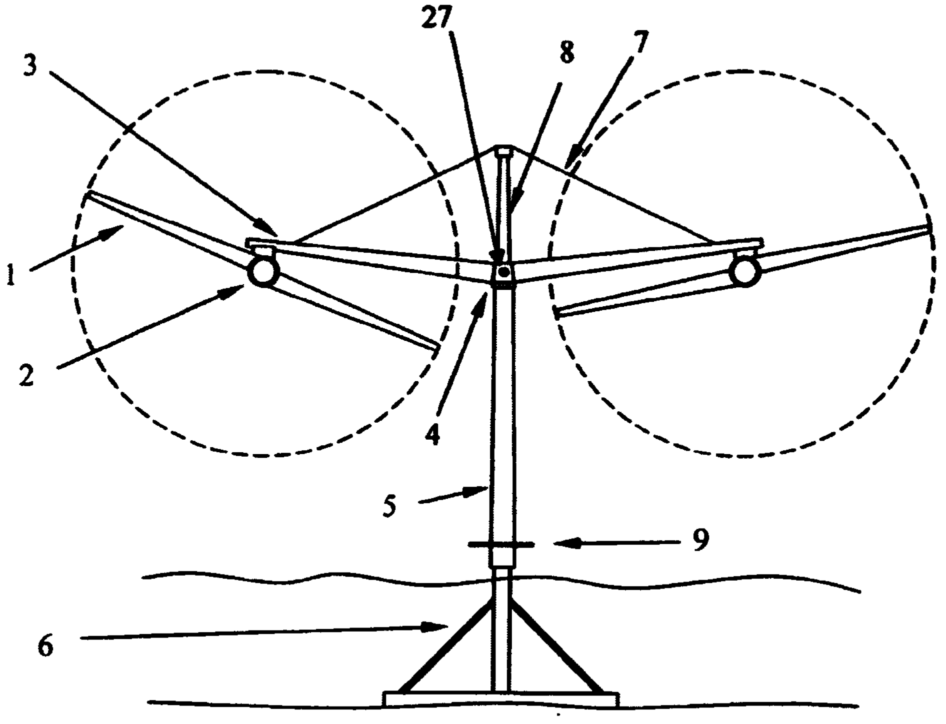

Figure 1

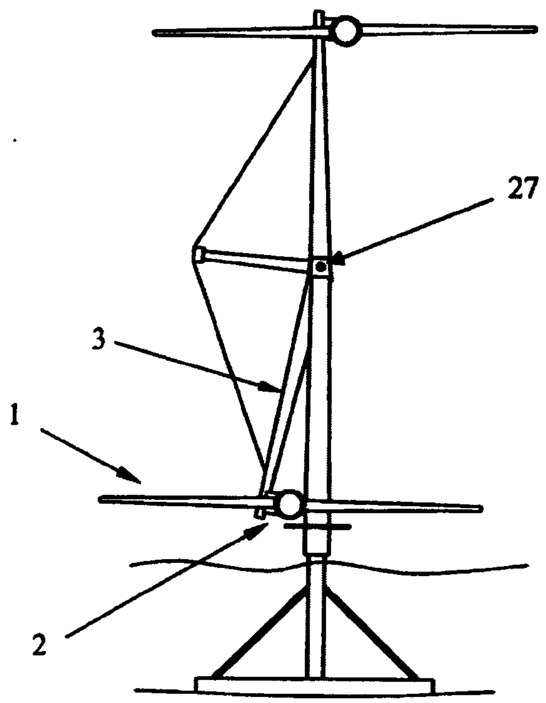

Figure 2

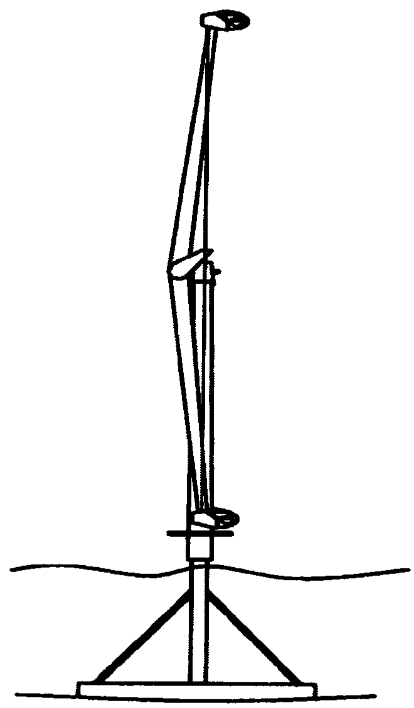

Figure 3

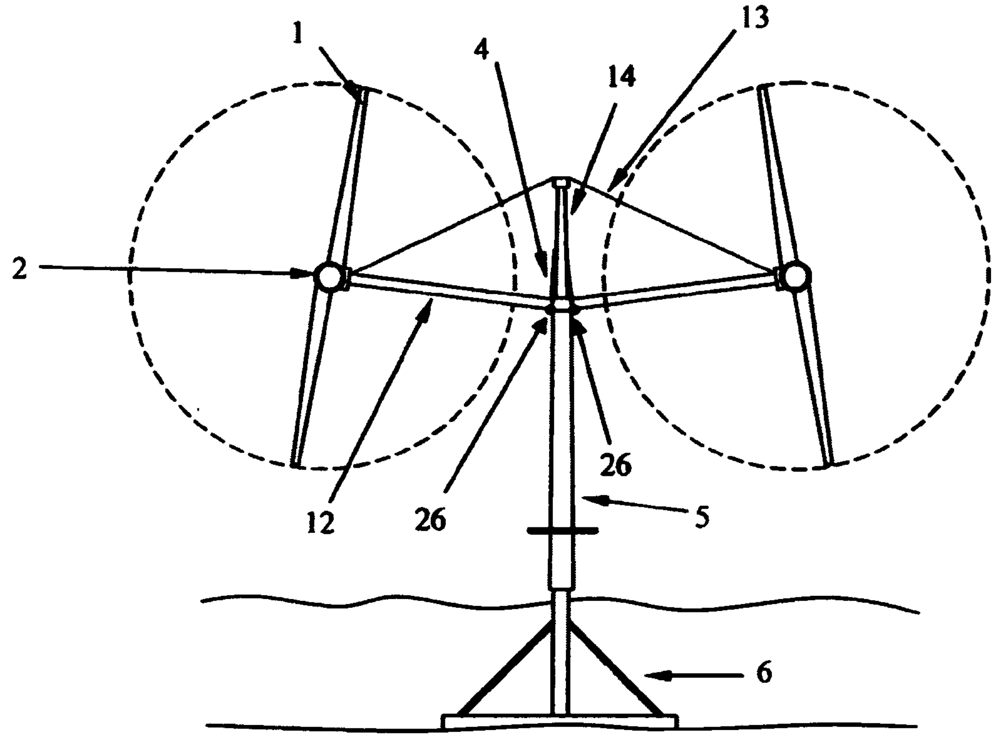

Figure 4

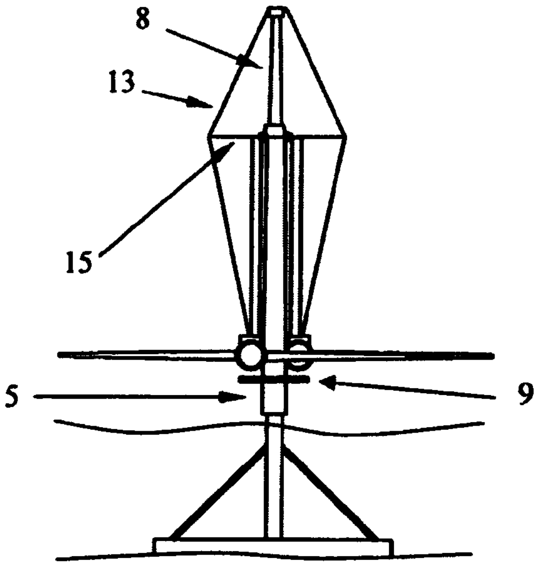

Figure 5

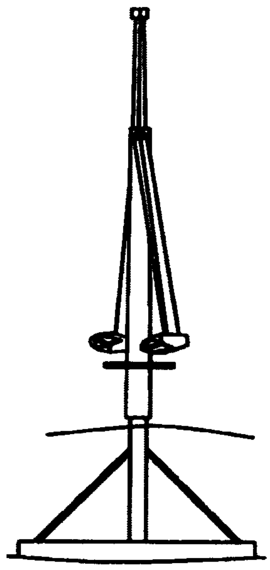

Figure 6

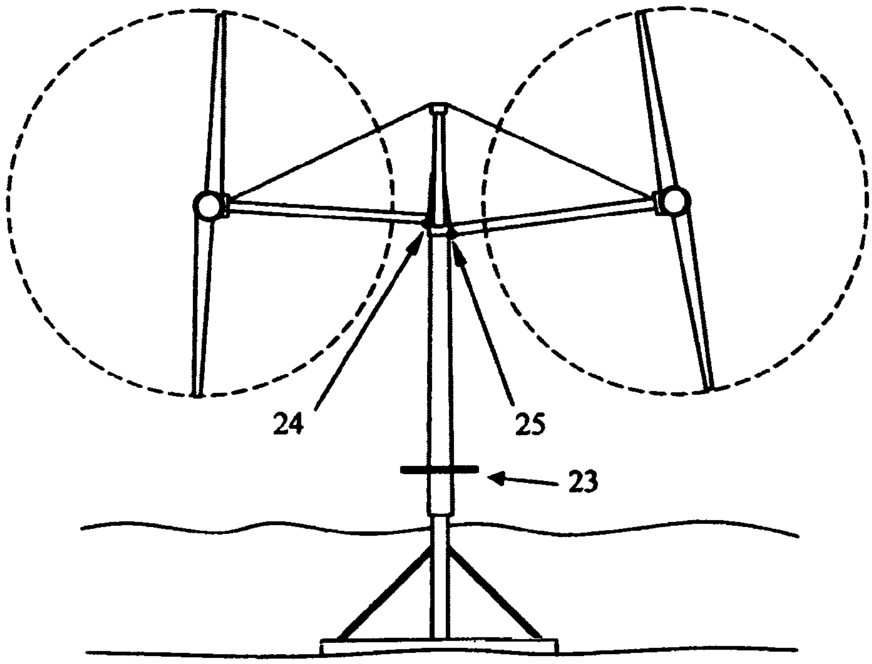

Figure 7

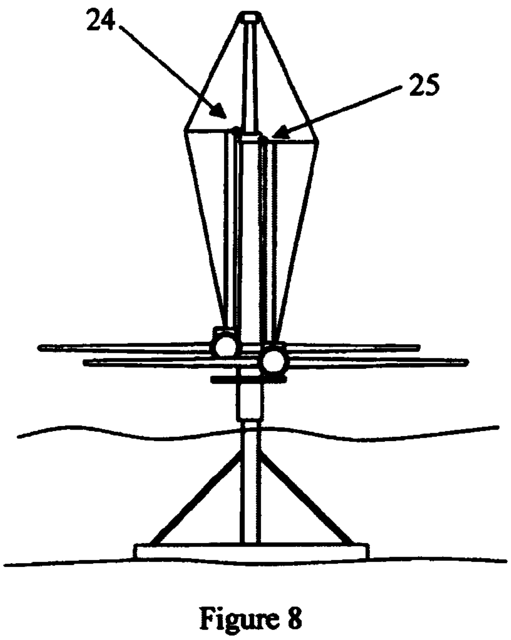

Figure 8

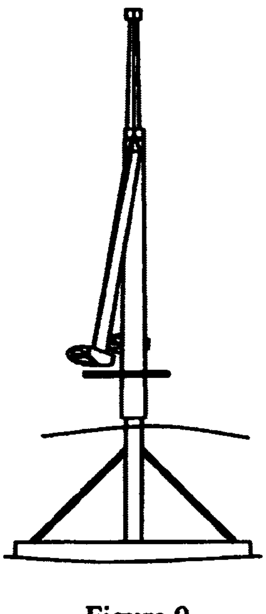

Figure 9

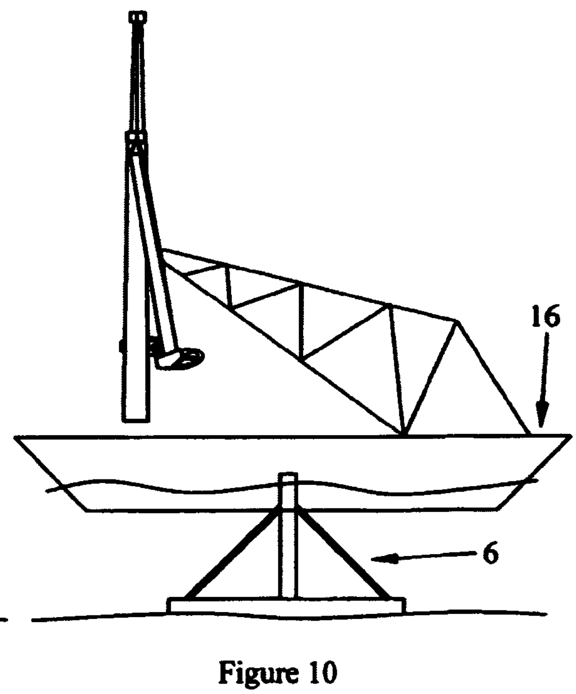

Figure 10

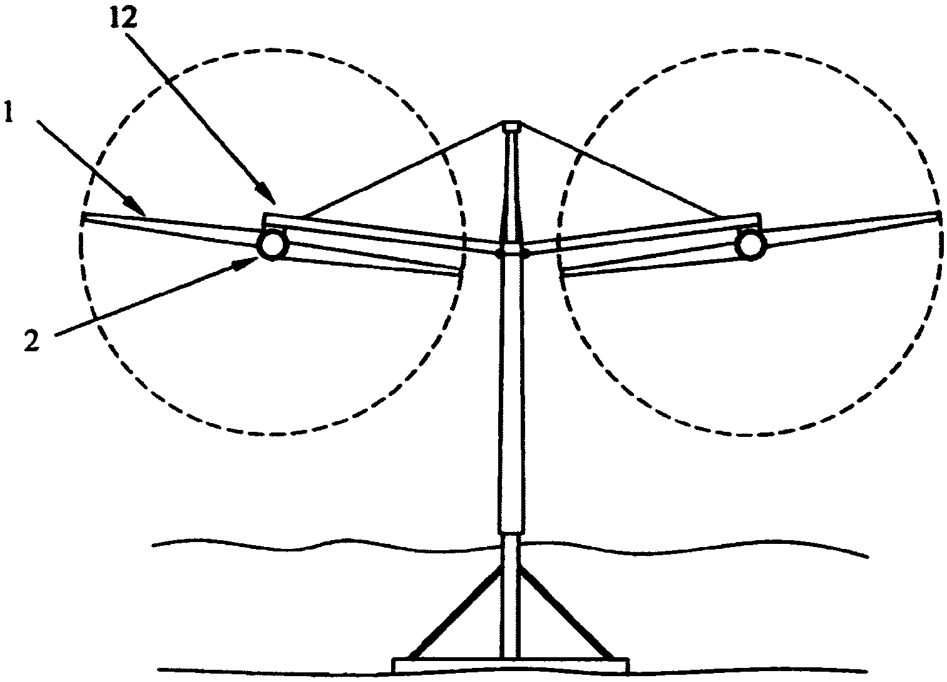

Figure 11

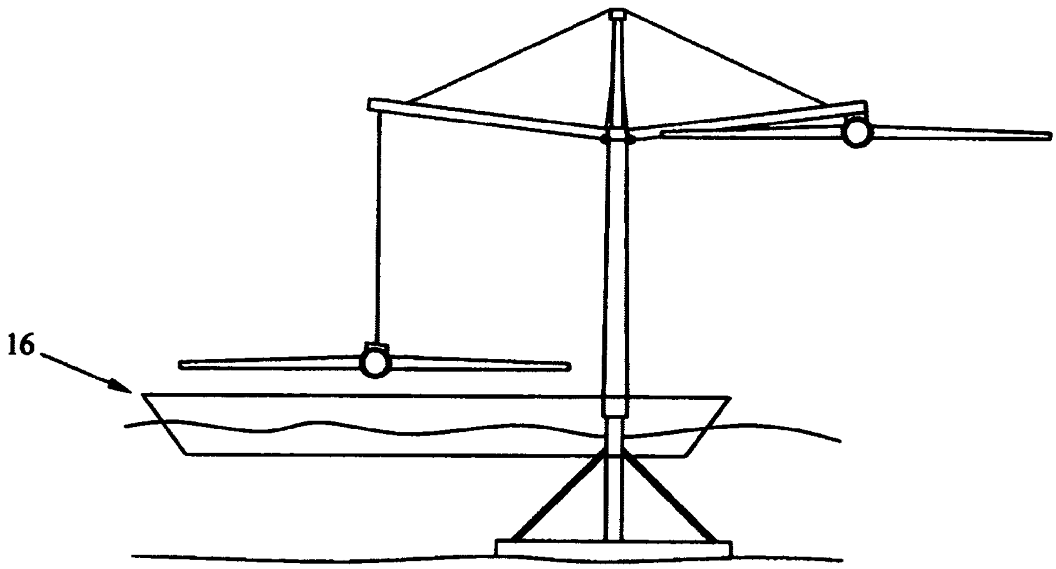

Figure 12

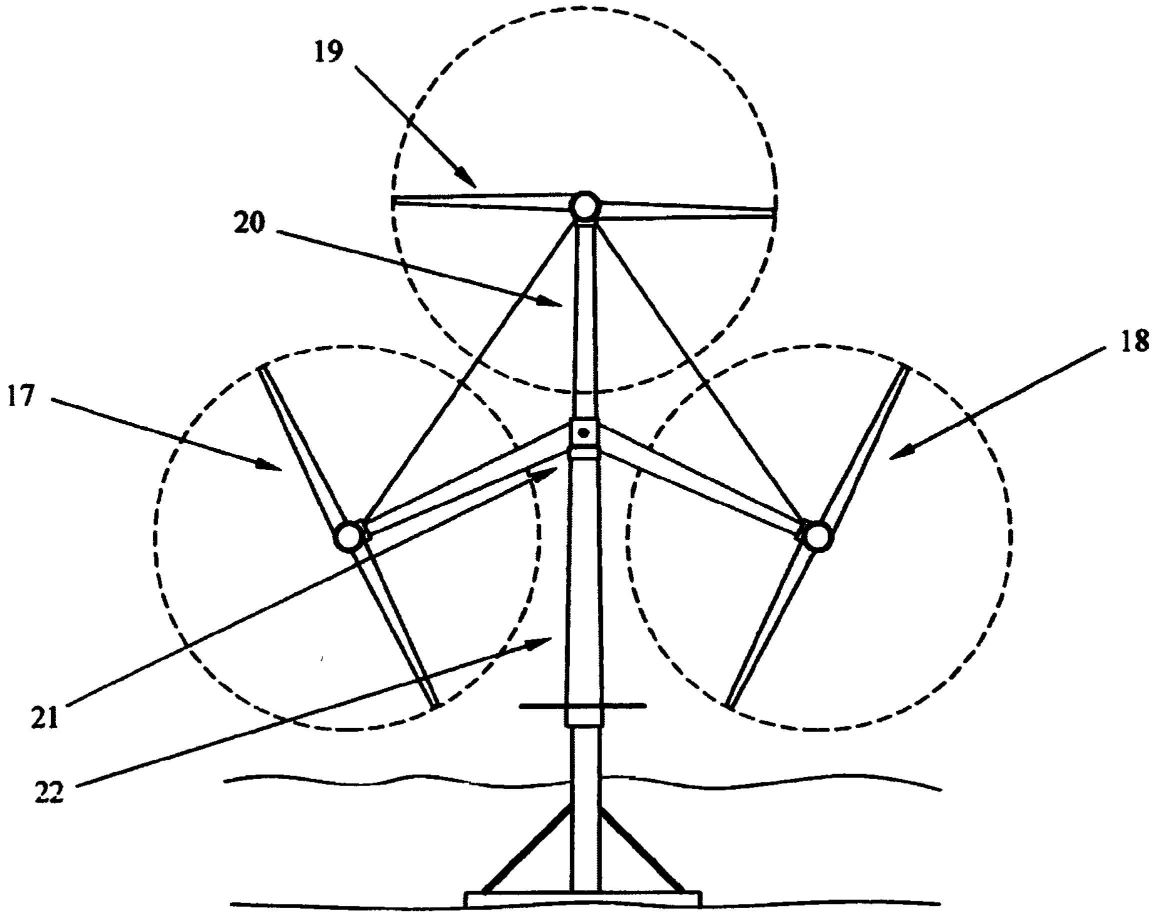

Figure 13

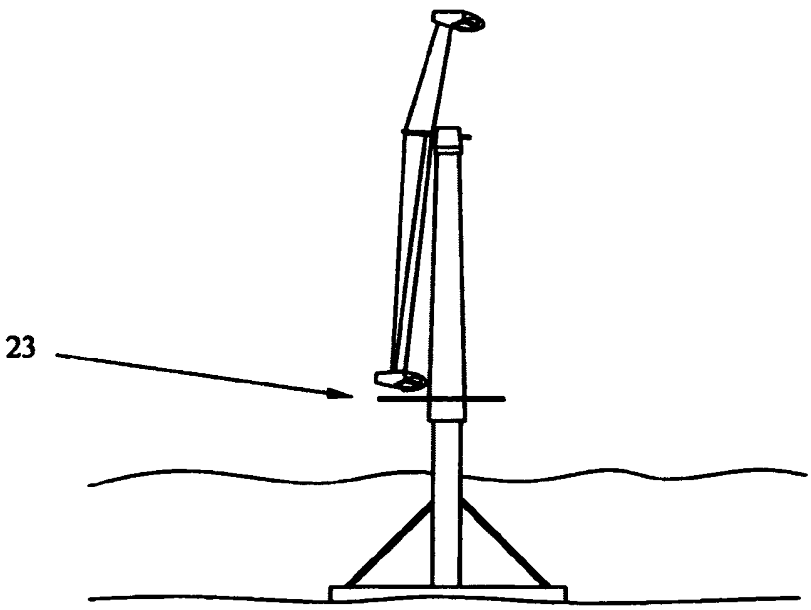

Figure 14

MULTI-ROTOR WIND TURBINE

This invention relates to large electricity-generating wind turbines, particularly but not exclusively for use offshore, and to the method of mounting the turbines to reduce the capital installed cost, costs of maintenance, and thus cost of energy produced.

It is well known that wind turbines developed for onshore use can be deployed offshore, given an appropriate gravity or piled base that can be used to put in place the tower of the wind turbine via such as a flanged connection joint situated above the high water point at the site. Typically, the turbines are erected using floating or jack-up cranes; or, in more recent developments, by floating out completely assembled tower-nacelle-rotor units fixed to the deck of a barge and lifted into place each as an entire assembly by very large floating or jack-up cranes such as described by Seegers and Holthausen (Reference 1).

The installation of large single-rotor wind turbines offshore – typically having rotors with three blades – is proving to be very expensive, because of the high capital cost and the high installation cost, involving as it does such large specialist crane equipment. Maintenance has also proven to be very expensive: in the event of a major component failure such as a blade, gearbox or generator, large floating jack-up cranes with the capacity to reach to the top of the support tower are again required and have to be brought in at substantial cost. Because there are few such cranes in existence, there can also be expensive delays both in installing new plant and in replacing that which has failed. These maintenance costs are said to add 25-30% to the cost of each unit of energy generated by offshore wind installations.

The aim of the invention is to reduce the installed capital cost per unit of energy generated as well as the practicality and ease of maintenance. Applied to a twin rotor configuration, whether onshore or offshore, this invention enables the rotor and nacelle units to be brought down close to sea level, where they are more easily handled, without the need for large cranes. The invention proposes a number of improvements for the operation of a twin rotor configuration, which will further enhance the economic viability compared to present day single rotor turbines.

Applied to wind turbines with 3 or more rotors, additional inventive features enable operation, installation and maintenance in such a way that the overall cost of energy may be further reduced.

Twin rotor configurations have been proposed in various references (see References 2-7). The present invention relates to an arrangement where twin rotors are mounted atop a single tower, such that the orientation into alignment with the wind of the rotors is controlled by regulating the thrust of one rotor with respect to the other, by the use of full or partial blade pitch control. The advantage of such a system is that the twin rotors double the energy capture area of the turbine without a corresponding doubling of the cost of the installation, since there is only a single tower, base and installation operation.

The key aspect of the invention is the method of mounting the rotors and nacelles on a swivelling cross-beam which can be rotated in a substantially vertical plane to bring either rotor/nacelle unit close to the tower base, allowing simple access to the rotors and nacelle machinery, and simplifying and making less costly installation and maintenance activities.

The specific advantages of the invention are: firstly the arrangement whereby the arms carrying the nacelle/rotor units brings these units down to near sea level and close to the tower is more practical than the one proposed by Alexandroff (Reference 2) – where the lowered arms end up substantially horizontal; and from the lowered position, components of the rotor or nacelle may be easily removed to a barge moored by the tower. Secondly, that in comparison to previous twin rotor proposals, the overturning loads on the yaw bearing, inasmuch as this is located at the top of the tower substantially at the same level as the rotors, are significantly reduced from previous proposals where the bearing is located near the ground.

With regard to wind turbines with 3 or more rotors, where the rotor area presented to the wind is large enough to be susceptible to differential wind shear of gusts, another aspect of this invention relates to a means of control whereby the pitch of the blades of each rotor are regulated to maintain an appropriate balance between the thrusts generated by the rotors; whether in the process of starting up, normal running or shutting down; so that the resulting bending loads on critical points on the structure are minimised.

According to the first aspect of this invention, the apparatus comprises of a tower fixed to the sea bed and protruding above the sea surface, upon the top of which is located a cross beam structure on which electricity generating turbines powered by the wind are mounted. A second aspect of the invention comprises a rotor mounted on an arm that can be rotated or moved to bring the rotor close to the sea level for ease of assembly or maintenance. A third aspect of the invention comprises a mechanism of struts and support stays actuated by electric or hydraulic power that can provide movement to the arm and turbine.

These and other features of the invention will be apparent from the following description of a preferred embodiment illustrated, by way of example only, in the accompanying drawings in which:

Figure 1 is a schematic view of one embodiment of the invention, showing a twin rotor turbine with the nacelle/rotor units mounted at opposite ends of a cross-beam

Figure 2 illustrates the embodiment of Figure 1 with one nacelle/rotor lowered to just above sea level

Figure 3 is a side view of Figure 2 showing the relative positioning of the lowered nacelle

Figure 4 shows an alternative embodiment of the invention, with two nacelle/rotor units mounted on individual pivoted arms

Figure 5 illustrates the embodiment of Figure 4 with the rotors lowered to just above sea level

Figure 6 illustrates the embodiment of Figures 4 and 5 from the side view, showing how the rotors stow one in front of the tower and one behind

Figure 7 illustrates an alternative embodiment with arm pivot points displaced vertically one from the other

Figure 8 illustrates the embodiment of Figure 7 with arms lowered, showing how the rotors stow with one nacelle higher than the other

Figure 9 illustrates the embodiment of Figure 7 and 8 from the side view, showing how the rotors stow in front of the tower

Figure 10 illustrates the embodiments of Figures 4 and 7 showing how the entire tower, arms, nacelles and rotors may be lifted into place from a barge

Figure 11 illustrates an alternative embodiment with the nacelle/rotor units supported below the cross arms

Figure 12 further illustrates the embodiment of Figure 11 showing how one nacelle/rotor unit may be lowered to a barge

Figure 13 illustrates an alternative embodiment with three nacelle/rotor units supported on a three-arm structure

Figure 14 further illustrates the embodiment of Figure 13, showing a side view with the three-arm assembly rotated to lower a nacelle to a platform.

According to the arrangement illustrated in **Figure 1**, rotors 1 and nacelles 2 are supported on a crossbeam 3 which is mounted by a pivot 27 to a yaw bearing unit 4 that can turn in a horizontal plane to follow the wind. The yaw bearing unit 4 is mounted atop a tower 5 located on a subsea base 6. The crossbeam 3 may be supported by stays 7 attached to a central column 8. In the preferred embodiment the rotors 1 are both mounted upwind of crossbeam 3 so that the rotor blades turn in a predominantly undisturbed airflow. The rotors preferably rotate in opposite directions so as that their torques decrease rather than increase the gravity loads on cross-beam 3. It is also envisaged that it can be arranged for the rotors to rotate in the same direction. Crossbeam 3 may be profiled so as to minimise even further disturbance to the upstream airflow on the rotor. The rotors may either be fixed or teetered with respect to the hub of the drive transmission.

The cross-beam with rotors and drive units can preferably be arranged so that the centre of gravity of the rotatable assembly is located close to the centre of the tower so as to minimise gravity moments on the yaw bearing.

In another aspect of this invention, the rotors may be arranged to run downwind of the supporting crossbeam 3. In this case it will be desirable to profile the arms so as to reduce disturbance to the airflow striking the downwind rotor blades

Figure 2 shows how crossbeam 3 may be rotated to a near-vertical alignment so that one nacelle/rotor unit lies alongside the main tower a short distance above the sea surface where it can conveniently be accessed for removal or replacement. The main access platform 9 may be positioned to be at a convenient height for working on the nacelle or rotor. A lifting jib-arm attached to the tower may be used to remove components from the nacelle or rotor and lower to them to a moored boat for replacement.

It will be noted that this arrangement makes possible the approximately even distribution of component masses about the yaw bearing so that overturning moments are kept low – for example from **Figures 2 and 3**, it can be seen that crossbeam 3 is raked forward at its outer ends so that the lower part is located behind the tower near its pivot point, but in front of the tower at its outer end where the lower rotor 1 and nacelle 2 are carried.

In the embodiment illustrated in **Figure 4**, rotors 1 and nacelles 2 are supported on near-horizontal arms 12 which are in turn located via a hinge system 26 to a yaw bearing unit 4 that can turn to follow the wind. The yaw bearing unit 4 is mounted atop a tower 5 located on a subsea base 6. The arms 12 are supported by stays 13 attached to a central column 14. In the preferred embodiment, rotors 1 are both mounted upwind of the supporting arms 12 so that the rotor blades turn in a predominantly undisturbed airflow. The rotors preferably rotate in opposite directions so as that their torques decrease rather than increase the gravity loads on arms 12, but it is envisaged that the rotors can also be arranged to rotate in the same direction. Arms 12 may be profiled so as to minimise even further disturbance to the upstream air flow on the rotor. The rotors may either be fixed or teetered with respect to the hub of the drive transmission.

In another aspect of this invention, the rotors may be arranged to run downwind of supporting arms 12. In this case it will be desirable to profile the arms so as to reduce disturbance to the airflow striking the downwind rotor blades.

Figure 5 shows how arms 12 may be lowered by stays 13 to a near-vertical alignment alongside the main tower with the rotor/nacelle units carried a short distance above the sea surface where they can conveniently be accessed for removal or replacement via platform 9. Struts 15, cantilevered from the inboard ends of arms 12 assist the stability and control of this process. The stays 13 may be operated by electric winch and cable from within the tower causing a change in length and thus the position the arms are drawn to. This can be in unison or as separate actions thus lowering one arm or the other. The initial installation of the rotor/nacelle units can be accomplished by attaching the rotor/nacelle to the arms and then raising them to the operating position. Platforms 9 may be constructed and attached to the main tower to provide a safe working area above the wave tops and as a convenient temporary location of the rotor/nacelle units. An alternative method of actuating the arm movement can be by such as hydraulic rams acting to move central column 14 vertically and react against a fixed length stay thus causing the stay cable to pull the arms up or allow them to be lowered.

Figure 6 further shows how with reference to Figures 4 and 5, the axes of the pivots on yaw unit 4 carrying arms 3 are arranged so that the nacelles and rotors are lowered fore and aft of the tower so as not to clash either with the tower or with each other.

Another aspect of this invention is illustrated in **Figure 7** where the pivots on yaw unit 4 are displaced vertically one from the other. The operational positions of the nacelles and rotors are arranged to still be symmetrical, but when lowered to near-sea level one nacelle/rotor unit fits behind and above the other, both in front of (or both behind) the tower. This is illustrated in **Figures 8 and 9**. This effect can also be achieved by differential spacing of the pivots away from the tower – thus keeping the arms 12 in the same plane when largely horizontal.

From all the positions described, components of the rotor or nacelle may be removed to a barge moored by the tower.

Figure 10 illustrates a further advantage of this arrangement; whereby the tower and arms, nacelles and rotors in their lowered positions are lifted as a single unit from the deck of a barge 16 on to the pre-prepared subsea base 6. The advantage of this arrangement over the traditional single turbine lift described above is that the centre of gravity of the assembly is now so low that a smaller reach crane can be used to carry out the lift, with lower resulting cost and the greater availability of suitable means.

Figure 11 shows a further embodiment of the invention where the rotors 1 and nacelles 2 are supported underneath arms 12 to facilitate them being lifted or removed individually by winches mounted temporarily or permanently to the turbine structure.

Figure 12 shows how, in the embodiment of Figure 11, the rotor and nacelle unit may be lowered to a barge 16 for removal or maintenance. Alternatively the rotor and nacelle may be removed directly to a vessel or attached platform when the arm 12 is in the lowered vertical position.

In another aspect of this invention, three bladed rotors rather than two-bladed rotors may be fitted. Lowering of the arms to the side of the tower will then require removal of one blade so that the other two may be parked pointing upwards for full lowering.

In another aspect of this invention, and referring to the arrangement illustrated in Figure 1, the yaw about the tower of the crossarm 3 or arms 12 carrying the nacelle and rotor units is controlled at zero or low wind speed by yaw drives fitted between the arms and the top of the tower. These allow for initial positioning of the rotors into the wind as the rotors start up, for cable unwinding and for fixing of the yaw for safe maintenance access. At higher windspeeds, with both rotors turning, the yaw is released or over-ridden by controlling the differential thrust moments of the rotors about the yaw axis.

The approach to three-rotor turbines is illustrated by **Figure 13**. In this embodiment, two nacelle/rotor units 17 and 18 are mounted symmetrically about the yaw axis and the third nacelle/rotor unit 19 in line with it. The arms 20 carrying the nacelle/rotor units are joined rigidly together and mounted by a pivot to the yaw bearing 21 atop tower 22. The pivot enables the entire arm/rotor/nacelle assembly to be rotated for purposes of erection, maintenance or disassembly. The pivot carrying the arms is angled so that at least one of the side nacelle/rotor units passes behind the tower so that rotation may continue to bring the top rotor down to the level of the maintenance platform.

Figure 14 shows the side view, in which one side nacelle/rotor unit is passing behind the tower. When in the position for nacelle or rotor maintenance, access can be obtained from platform 23.

Four or more rotors can be accommodated by combinations of one or more crossarms with one or more pivoted arms according to the methods described herein for two or three rotor turbines.

In another aspect of this invention, the correct orientation of the rotors to the prevailing wind is controlled by an algorithm regulating blade pitch. This allows alignment with the wind by for instance measurement of rotor speed, power level, blade pitch angle, absolute nacelle orientation about a vertical axis, and wind direction error (ie wind direction relative to the rotor axis). In near-fixed-speed rotor operation (usually fixed speed operation with controlled slip), pitch is controlled so as to spill power from the rotor moving into the wind, as detected by the yaw error signal. The measurement of absolute yaw position is necessary to ensure damping of the response so that unacceptable oscillations about the yaw axis do not develop. It can also be used to moderate the power-spilling response so that energy loss from blade pitching is minimised. In variable speed operation, the rotational speed of the rotor moving into the wind can be reduced so as to limit thrust so that energy is not lost through blade pitching. In this case the algorithm will rely on rotor speed and power measurements in addition to those of pitch, absolute yaw, and yaw error.

In the case of off-power operation, for instance while starting or stopping the rotors, the differential thrusts on the rotor may be calculated from measurement of rotor speed, rotor acceleration and pitch angle; and reduced by making balancing adjustments to pitch angle as before. It will be appreciated that when a rotor is working to maximise power, its thrust is also near to maximum, so that to achieve thrust balance between two rotors it will generally be required to reduce the thrust of the one generating the most power.

With regard to control of rotor thrust for yaw alignment and differential load reduction when three rotors are used, it is another aspect of this invention that thrust balance can be achieved between the rotors so that not only do the side rotors balance each other to achieve alignment with the wind, but that the third rotor balances its thrust with respect to the side rotors so that the pitching moments of the three rotors are balanced about the yaw bearing. In the turbine illustrated in **Figure 13**, for example may be applied to the control of the pitch of rotors 17 and 18 by the means described above for two rotors so that all three rotors are steered in alignment with the wind direction. In addition, in order to reduce the bending loads at yaw bearing 21, the thrust of rotor 19 with respect to rotors 17 and 18 can also be adjusted so that the thrusts balance. The methods described are used so that the thrusts balance under conditions of start-up, normal generating operation, and shut-down. As before, in very light winds or with the rotors stopped, the yaw position may be held by a light duty drive which may be over-ridden or released when differential rotor thrust exceeds a predetermined magnitude.

A combination of all the features covered in this patent can be envisaged for some applications.

References

1. Seegers and Holthausen:- Method and apparatus for placing at least one wind turbine on open water; *UK Patent* **GB2390632B**

2. Alexandroff:- Aerogenerator Birotor; *European Patent* **EP0761964A1,** *1996* (lapsed)

3. Deijl:- Windkraftanlage; *German Patent* **DE3113247A1,** *1982*

4. Honnef:- Windkraftmaschine, deren Treibflugelspitzen durch einen Radkranz miteinander in Verbindung stehen; *German Patent* **DE549618C1,** *1932*

5. Freidmund:- Bezeichnung des Gegenstandes Windkraftanlage; *German Patent* **DE9419057**, *1994*

6. Struble:- Improvements in Wind Motor Power Plants; *UK Patent* **GB331683**, *1930.*

CLAIMS

1. A wind turbine comprising a tower to the top of which a cross beam structure is mounted by means of a yaw bearing and pivoting connection and that carries two or more electricity generating turbine rotors mounted at the extremities and whose position can be adjusted from normal operating height to a position close to the base of the tower.

2. A wind turbine according to claim 1 whose turbine generators can be lowered close to sea level by an inbuilt mechanism to facilitate build, maintenance or repair.

3. A wind turbine according to claim 1 whose electricity generating turbines can be accessed for build, maintenance or repair without recourse to specialist jack-leg high lift crane vessels.

4. A wind turbine according to claim 1 where two or more rotors are mounted atop a single tower

5. A wind turbine according to claim 1 having three blades per rotor or two blades per rotor which may be teetered or non-teetered.

6. A wind turbine structure according to any of the previous claims that mounts generators on cross arms that can be rotated independently in a substantially vertical plane to bring the turbine rotors close to the tower base

7. A wind turbine tower that includes a platform close to the base but above wave height that enable full access to turbine rotors when lowered by the apparatus as described in claim 1.

8. A wind turbine tower that includes a platform close to the base but above wave height that allows the transfer of equipment from an attending vessel to the structure without recourse to high lift cranes.

9. A cross arm support system acting as a solid beam mounted atop a tower carrying two electricity generating turbines at its extremities that can pivot about a central point thus moving from a horizontal position to a generally vertical position and thus bringing each turbine in turn close to the base.

10. A cross arm support system comprising two half arms mounted atop a tower and carrying electricity generating turbines at their extremities that can independently pivot about a point thus moving from a horizontal position to a generally vertical position and thus bringing a turbine close to the base.

11. A mechanism that can actuate a cross arm structure as described in claim 10 and cause it to rotate by means of adjustment to the lengths of tension support cables.

12. A mechanism that can actuate a cross arm structure as described in claim 10 and cause it to rotate by means of height adjustment to a support cable by means of a hydraulic or otherwise actuated vertically acting ram.

13. A three arm support system acting as a rigid structure mounted atop a tower carrying three electricity generating turbines at each arms extremities that can pivot about a central point thus revolving the assembly and bringing one or other rotors to a position close to the tower base.

14. A three arm support system as in claim 13 but that maintains the overall centre of mass substantially acting vertically down on the centre of the tower.

15. A three arm support system as in claim 13 that pivots about a central point in a manner that enables the side turbine generators to pass to the rear of the tower without collision or interference with the tower and thus bring the top most turbine rotor to the base whilst maintaining the centre of mass substantially acting vertically down on the centre of the tower.

16. A wind turbine comprising two or more rotors where the pitch of the blades or part thereof is regulated to control the aerodynamic thrust forces of the rotors so that they maintain heading into the wind by an algorithm taking input from some or all of measurements from each rotor of pitch angle, rotor speed, wind speed, wind direction, nacelle orientation.

17. A wind turbine where the pitch of the blades or part thereof is controlled to maintain heading into the wind and to minimise overturning moments on the yaw bearing by an algorithm taking input from some or all of measurements from each rotor of pitch angle, rotor speed, wind speed, wind direction, nacelle orientation

18. A wind turbine in accordance with the preceding claims where the turbine rotors can be mounted either upwind or downwind of the cross arm or multi rotor structure.

19. A wind turbine in accordance with the preceding claims where the cross arm or multi turbine structure is shaped such as to minimise the aerodynamic effect onto the turbine blading when the turbines are mounted downstream of the wind direction

20. A wind turbine comprising all or some of the above claims and that can also be used on land based applications.

AMENDMENTS TO THE CLAIMS HAVE BEEN FILED AS FOLLOWS

AMENDED CLAIMS

1. A wind turbine comprising a tower to the top of which a cross beam structure is mounted by means of a yaw bearing and pivoting connection and that carries two or more electricity generating turbine rotors mounted at the extremities and whose position can be adjusted from normal operating height to a position close to the base of the tower and that the rotors are aligned with the wind direction by means of variation of the rotor blade pitch angle.

2. A wind turbine comprising two or more rotors where the pitch of the blades or part thereof is regulated to control the aerodynamic thrust forces of the rotors so that they maintain heading into the wind by an algorithm taking input from some or all of measurements from each rotor of pitch angle, rotor speed, wind speed, wind direction, nacelle orientation.

3. A wind turbine where the pitch of the blades or part thereof is controlled to maintain heading into the wind and to minimise overturning moments on the yaw bearing by an algorithm taking input from some or all of measurements from each rotor of pitch angle, rotor speed, wind speed, wind direction, nacelle orientation

4. A cross arm support system comprising two half arms mounted atop a tower and carrying electricity generating turbines at their extremities that can independently pivot about a point thus moving from a horizontal position to a generally vertical position and thus bringing a turbine close to the base.

5. A mechanism that can actuate a cross arm structure as described in claim 10 and cause it to rotate by means of adjustment to the lengths of tension support cables.

6. A mechanism that can actuate a cross arm structure as described in claim 4 and cause it to rotate by means of height adjustment to a support cable by means of a hydraulic or otherwise actuated vertically acting ram.

7. A wind turbine structure that mounts generators on cross arms that can be rotated independently in a substantially vertical plane to bring the turbine rotors close to the tower base

8. A wind turbine tower that includes a platform close to the base but above wave height that enable full access to turbine rotors when lowered by the apparatus as described in claim 4.

9. A wind turbine tower that includes a platform close to the base but above wave height that allows the transfer of equipment from an attending vessel to the structure without recourse to high lift cranes.

10. A wind turbine comprising all or some of the above claims and that can also be used on land based applications.

Application No:	GB0623079.1	**Examiner:**	Alex Swaffer
Claims searched:	1-20	**Date of search:**	10 March 2008

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-5, 9, 13-15, 18-20	US2005/218656 A1 (Wobben): See figures 1-4 in particular.
X	1-5, 9, 13-15, 18-20	WO01/34974 A1 (Aerolift Patent BV): See figures 1 and 2 in particular.
X	1-5, 9, 18-20	US5151610 A (St Germain): See figure 1 in particular.
X	1-5, 18-20	GB2425328 A (Marine Current Turbines Ltd): See figures 1A & 1B, and page 7 lines 2-22 in particular.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

F1Q; F1T

Worldwide search of patent documents classified in the following areas of the IPC

F03D

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI

International Classification:

Subclass	Subgroup	Valid From
F03D	0011/04	01/01/2006
F03D	0001/00	01/01/2006
F03D	0001/02	01/01/2006