TITLE: WIND TURBINE

DESCRIPTION

The present invention relates to a novel wind turbine for use in generating electricity.

Wind turbines for converting wind power into useable electricity are well known in the art as a viable unlimited or renewable energy source. Conventional wind turbines generally comprise a set of aerodynamic blades attached to a hub which is usually supported by a mast. However, the energy that may be extracted from the air by such a conventional wind turbine is severely limited (as discussed below).

Wind turbines extract energy from the air that they are able to draw through their blades. The energy that can be extracted from the air is proportional to, and thus limited by, the area which is swept out by the blades. Conventional wind turbines suffer from a strict limit on blade radius dictated by mast height, and accordingly energy extraction is limited. Conventional wind turbines also suffer from severe fatigue loading of the blades as they move through a wind gradient or if the turbine disc is not exactly normal to the wind flow. A further adverse loading characteristic of prior art designs is the generation of a large overturning moment at the base of the mast. Furthermore, prior art designs generally have the generating machinery in a housing at the top of the mast which, in addition to adding to the expense and difficulty of installation of the wind turbine, compromises accessibility for servicing the generating machinery.

In accordance with the above, the present applicants have identified the need for an improved wind turbine which overcomes, or at least alleviates, some of the problems associated with the prior art.

In accordance with the present invention, there is provided a wind turbine comprising: a base unit including a rotatable input shaft for coupling to a load, the rotatable input shaft defining a rotation axis; and a kite assembly comprising a glider part configured to be propelled by wind power and a tether coupling the glider part to the input shaft, the kite assembly being configured to guide movement of the glider part in a path spaced from and around the rotation axis when propelled by wind power and thereby rotate the rotatable input shaft.

In this way, a wind turbine is provided in which part of the kite assembly (i.e. the glider part) flies clear of the base of the turbine, thereby allowing the area swept out by the path of gliding part to be very much greater than could be achieved by a conventional wind turbine of comparable size to the base unit of the present invention. A wind turbine built in accordance with the present invention may be used to generate electricity (e.g. to supply electricity to an electrical-power grid) or to provide mechanical power (e.g. by coupling the wind turbine to a propeller to provide propulsion for a ship).

The gliding part may be described as a captive glider which is configured to be flown in a similar manner to a kite. Aerodynamically, the gliding part may serve exactly the same function as a conventional turbine blade. However, unlike in a conventional blade turbine, the gliding part may be configured to operate at great distance from the fixed supporting structure (i.e. base unit) and may therefore sweep out a considerably greater area of air than a conventional blade turbine. When deployed, the glider part may fly in an approximately circular path downwind of the base unit.

The glider part may comprise a body having a plurality of wing sections (e.g. on each lateral side of the body) and may further comprise a tail section having a similar aerodynamic configuration to that of a conventional glider.

The base unit may comprise a load or a mechanical coupling to a load. The load or coupling may be connected, either directly or via gearing, to the input shaft.

In one embodiment, the glider part may be coupled to the base unit via a plurality of tethers (e.g. a pair of tethers). In this way, the orientation of the glider parts relative to the wind may be more easily controlled.

The (or each) tether may be of variable length. For example, a tether control means may be provided for varying the distance between the glider part and the base unit. For example, the tether control means may be configured to increase and decrease the length of the tether. In this way, the kite assembly may be deployed to suit a variety of wind conditions (e.g. different wind speeds).

The (or each) tether may comprise a flexible line (e.g. cable). In one embodiment, the tether control means may comprise a drum around which at least a portion of the flexible line (e.g. cable) may be wound, the drum being configured to advance (e.g. pay out) a length of the flexible line (and so increase the tether length) as the drum is rotated in a first direction relative to the tether, and to retract (e.g. reel-in) the length of flexible line when the drum is rotated in a second direction relative to the tether opposite to the first direction. The drum may be coupled (e.g. mounted) to the rotatable input shaft.

The distance between the glider part and the base unit may be varied in dependence upon tension in the tether. For example, the tether control means may be configured to increase or decrease the length of the tether as a result of the degree of tension in the linkage (e.g. relative to the load). In this way, the kite assembly may be configured to be self-deploying, with optimum positioning of the glider part occurring automatically as wind conditions change.

The tension in the tether may be controlled by varying the load on the rotatable input shaft. For example, the input shaft may be coupled to the load via output gearing, and the load may be varied by varying the output gearing.

The base unit may comprise a rotatable support for coupling the base unit to the kite assembly, the rotatable support being configured to rotate in sympathy with the kite assembly around the rotation axis. The rotatable support may be coupled to the tether in a location spaced from the rotation axis of the input shaft.

When the base unit further comprises the tether control means with the drum for controlling tether length, the rotatable support and drum may be configured to rotate co-axially. If the torque provided by tension in the tether exceeds the torque provided by the load, the drum will rotate relative to the rotatable support and increase the length of the tether. Similarly, as the torque provided by the load exceeds the torque provided by tension in the linkage, the drum will rotate relative to the rotatable support and decrease the length of the tether.

In addition, the rotatable support may be configured to support the glider part before deployment (i.e. before the glider part flies away from the base unit).

The wind turbine may further comprise a second kite assembly equivalent to the first-mentioned kite assembly. Thus, the glider part of each kite assembly may be coupled to the input shaft via its respective tether. The pair of glider parts may be configured to fly in a substantially circular path and may be configured to fly approximately 180^{o} out of phase with one another, generating a couple. The plurality of glider parts may be supported by opposing lateral sides of the rotatable support.

In addition to the first-mentioned and second kite assemblies, the wind turbine may further comprise one or more additional kite assemblies equivalent to the first-mentioned kite assembly. The kite assemblies may be spaced to retain an approximately rotationally symmetric configuration.

An embodiment of the present invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 shows a schematic view of a wind turbine embodying the present invention in its un-deployed configuration;

Figure 2 shows a schematic view of the wind turbine of Figure 1 in a deployed configuration;

Figure 3 shows a schematic cross-sectional view of a base unit and rotatable support of the wind turbine of Figure 1;

Figure 4 shows a schematic view of the rotatable support and kite assemblies; and

Figure 5 shows a schematic view of one glider part in its un-deployed position.

Figures 1-5 show a wind turbine 10 comprising a base unit 20 including a rotatable input shaft 30 for coupling to a load 35 and a pair of kite assemblies 40, the rotatable input shaft defining a rotation axis AA. Each kite assembly 40 comprises a glider part 50 coupled via a pair of flexible cables 60 to the input shaft 30. Each glider part 50 comprises a body 51 having a pair of wing sections 52 disposed on lateral sides thereof, and a tail section 54 comprising a pair of tail wing sections 56 and a fin 58.

The input shaft 30 is mounted in a rotatable housing 38 which is configured to rotate relative to the base unit 20 (around a substantially vertical axis). The input shaft 30 also includes a drum 80 configured to carry both pairs of cables 60, the drum 80 being configured to rotate in sympathy with the input shaft 30.

The base unit 20 includes the load 35, and the load 35 is connected to the input shaft 30 via output gearing 70. In use, the rotatable housing 38 is configured to rotate to allow the kite assemblies 40 to be orientated downwind of the base unit 20.

As shown in Figure 1, the glider parts 50 are mounted in an un-deployed position on lateral sides (e.g. limbs) of a rotatable support 90. The rotatable support 90 is rotatably mounted to rotatable mounting 38 by means of a bearing assembly 39. The rotatable support 90 includes an elongate collar 95 for receiving the input shaft 30. Bearings 97 allow the input shaft 30 to move relative to the rotatable support. Cables 60 engage rotatable support 90 and, in use, the rotatable support 90 is configured to rotate in sympathy with the glider parts 50 around the rotation axis AA.

In Figure 2, the pair of glider parts 50 are shown in a deployed position downwind of the base unit 20. The pair of glider parts 50 are configured to follow a substantially circular path R whilst the cables 60 are under tension.

As can be seen from Figure 5, the glider parts 50 may comprise docking means (e.g. legs 59) configured to engage a set of rollers 100 mounted on the rotatable support 90. The docking means (e.g. legs 59) may be mounted to the glider parts 50 via hinges (not shown). The flexible cables 60 may attached to their respective glider parts 50 via the docking means.

The set of rollers 100 allow the glider parts 50 limited freedom to pitch and roll when the glider parts 50 are supported by the rotatable support 90 in their un-deployed position. In this way, when wind passes across the glider parts 50, surfaces of the tail 54 of each glider part 50 will cause its respective glider to pitch such as to place the wing sections 52 at a reduced angle to the apparent wind in much the same manner as a variable pitch propeller. This allows the glider parts 50 to generate a force to initiate rotation of the rotatable support 90 in its bearing assembly 39.

As the rotational speed of the glider parts 50 increases, so does the apparent wind experienced by the glider parts 50 and hence the surfaces of their tails will tend to maintain the glider parts 50 at an angle of attack to the apparent wind. As the force increases so does the centripetal force, this allows the roll freedom of the rotational support 90 to take effect and both glider parts 50 move laterally outward from the centre of rotation. The geometry of the rotatable support 90 is configured to roll the glider parts 50 to allow the generation of a force component towards the overall rotational axis of the input shaft.

When sufficient force is generated for lift-off of the glider parts 50 to occur, the four-bar chain roll geometry (see below) is still preserved by the cables 60. The result is that the glider parts 50 are aerodynamically constrained to adopt an approximately circular flight path R at a distance downwind of the base unit 20. With the glider parts 50 flying in this manner, torque is transmitted via tension in the cables 60 and the glider parts 50 will lead the rotatable support 90 by a small angle (generally but not exclusively less than ten degrees).

Each glider part 50, in combination with flexible cables 60 and rotatable support 90, forms a four-bar chain roll geometry which comprises the following four limbs: a first limb defined by the departure points of the cables 60 from the rotatable support 90; second and third limbs defined by the cables 60 between the departure points from the rotatable support and the hinged attachment points on the glider part 50; and a forth limb defined by the glider part 50 between the two hinged attachment points.

The second and third limbs defined by the cables (e.g. cable plus leg 59) are of approximately similar length regardless of the distance between the glider part 50 and the rotatable support 90. In use, the first limb (defined by the cable separation at the rotatable support 90) will generally be longer than the forth limb (defined by the two hinged attachments for the legs 59 on glider part 50).

If the glider part 50 is moved away from the rotational axis of the rotatable support 90, the glider part 50 will be rolled towards the rotational axis in the same manner as if it was still resting on the rotatable support 90 and will thus generate a restoring force towards the rotational axis. The four bar chain geometry thus described may be preserved regardless of the degree of cable extension.

The rotating cables may be configured to describe a substantially cone-like shape by a suitable balance of glider part roll with offset from the rotational axis and cable tension which both provide forces towards the rotational axis and the centripetal accelerations which provide a force away from that axis. The glider parts 50, being stable about their own yaw axes, will thus tend to follow an approximately circular flight path R controlled by this balance of aerodynamic and inertial forces.

To illustrate the method by which torque transmission to the load 35 is integrated with the pay-out/reel-in of the cables 60, reference should be made to Figure 3. The glider parts 50 are restrained on the rotatable support 90 by tension within the cables 60. This tension is directly controlled by the load 35 via the output gearing 70. As the torque provided by the tension in the cables 60 increases to the point at which it exceeds that provided by the load 35, the drum 80 rotates relative to the rotatable support 90 and pays out additional lengths of cables 60. The length of cable 60 payed out is controlled by the cable available and/or by direct control of the load 35. If the cables 60 are fully payed out, the rotatable support and drum will rotate together at the same speed if the cables are under tension.

To retrieve the kite assemblies 40, the load torque is increased (or the torque generated by the kite assemblies 40 falls to below that reacted by the load) and the drum 80 will then rotate more slowly than the rotatable support 90 causing the drum 80 to achieve rotation relative to the rotatable support 90 and thus wind-in the glider parts 50.

Advantages of the present invention

The fundamental principle behind the concept of the present invention is that the area swept out by the path of the rigs is very much greater than could be achieved by a conventional wind turbine of similar size to the un-deployed unit. Power capacity of a turbine is directly proportional to area swept by the blades and hence, for a similar level of cost/complexity, this concept has the ability to deliver a much greater power output than a conventional wind turbine. The blade efficiency of a conventional turbine is now very high, typically in excess of 80% of the extractable energy being delivered to the load. This concept will not deliver anywhere near this efficiency due to the cables and losses incurred as a result of the rigs needing to generate additional forces to maintain a near circular flight path. However, the vast area swept, and hence energy extracted, by the flying rigs is sufficient to render these losses unimportant. Therefore, although the efficiency is lower than a conventional turbine the effectiveness for a roughly equal amount of engineering effort is much greater.

Benefits of the present invention include:

1. The base unit, not being subjected to the full air speed of the rigs when in full operation, need not be optimised for low wind resistance, it can therefore be fairly crude and cheap.

2. As the line of force applied to the base unit is close to the mounting plane of the unit a much smaller overturning moment is generated than would be expected from a conventional turbine of equivalent power. This make mounting on a mobile or floating platform possible rather than rigid anchorage to the ground. This opens the possibility of exploitation of deep water locations currently closed to state of the art turbines.

3. As the present invention does not require a mast and the aerodynamic elements are displaced from the base unit in operation, they can operate at a much greater altitude above a mounting surface than a conventional turbine blade. This allows the higher wind speed away from the ground boundary layer to be exploited.

4. Power capability of any wind energy extraction device is directly proportional to the cross section of airstream that is influenced by the device. This concept allow a huge cross section to be exploited for a modestly proportioned base unit. Preliminary calculations based on this effective area indicate power output of five to ten times the output of an equivalently proportioned conventional turbine could be achieved. Accordingly, although the aerodynamic efficiency of present invention may not be as high as

some conventional wind turbines, the present invention has a very high potential effectiveness.

5. Since the rigs can be payed out or reeled in simply by varying the load torque, the area swept by the turbine can also be varied at will. This allows the unit to be tuned for a very wide range of wind conditions unlike with a conventional wind turbine which is capped at a limit output above a threshold speed and, ultimately, is shut down in stronger winds. A wind turbine in accordance with the present invention should therefore achieve a much higher utilisation than more traditional designs.