Airborne wind energy system.

The invention concerns an airborne wind energy system comprising a wind-engaging member with a bridle system connected to a tether. The tether is also connected to a tether storage device for dispensing and retracting the tether. An energy converting device is connected to the tether storage device. The system is also provided with a steering device to generate a steered movement of the wind engaging member and/or to steer the relative angle of the wind engaging member with respect to the tether. One or more control units are provided for steering the wind-engaging member and/or winding and unwinding the tether. The bridle system comprises power lines and steering lines. The tether is connected to the power lines. The steering device is provided between the tether and the steering lines. The invention also concerns a method to operate such system.
Airborne wind energy system

The invention concerns an airborne wind energy system comprising a wind-engaging member with a bridle system connected to a tether, a tether storage device for winding and unwinding the tether, an energy converting device connected to the tether storage device, a steering device to generate a steered movement of the wind engaging member and/or to steer the relative angle of the wind engaging member with respect to the tether, one or more control units for steering the wind-engaging member and/or winding and unwinding the tether. The invention also concerns a method for operating such wind energy system and a launch and landing system.

Airborne wind energy systems are designed to operate at higher altitudes than conventional tower-based wind energy systems. The wind-engaging members are typically rigid wings, flexible wings or aerostats. The wind-engaging member is tethered to a ground station. The ground station comprises a tether storage device, typically a winch, to wind and unwind the tether, and is connected to an energy converting device, typically a generator. During unwinding of the tether, the wind-engaging member is steered along a predetermined flight trajectory perpendicular to the wind direction. These cross wind flight manoeuvres generate a high traction force which is transferred by the winch to the generator where it is converted to electricity. When reaching the maximum tether length the wind engaging member is de-powered. This means that the relative angle of the wind-engaging member with respect to the apparent wind is reduced such that the traction force in the tether is minimized. Using the generator as a motor, the tether will then be wound onto the drum. Since the traction force during winding is substantially lower than during unwinding, the energy consumed is only a fraction of the energy generated during unwinding.

Such system is for instance known from US patent application 2007/0228738 (Wrage et al.). The steering device of this known system is situated between the tether and the bridle system. As the traction forces generated by the wind-engaging member are transmitted through the bridle system directly into
the steering device, this device needs to be powerful and strong. However, as the steering system will be airborne, such robust and powerful design will have a considerable negative influence on the flight dynamics and efficiency.

The present invention intends to solve one or more of the problems of the prior art as, among others, described above, and it is in particular an objective of the invention to provide an airborne wind energy system that provides a high energy output, that is easy to control and that is durable.

The airborne wind energy system according to the invention is characterized by one or several of the appended claims.

In a first aspect of the invention the bridle system of the wind-engaging member comprises power lines and steering lines. The power lines are connected directly to the tether and transmit most of the traction force generated by the wind-engaging member. The steering lines are connected to the steering device. The steering device is suspended to the tether. The separation of force transmission of the tether and the power lines on one hand and of the steering lines on the other hand allow individual optimization of both functions.

In an embodiment of the invention the steering device is provided with one or more drums for the steering lines. Rotation of the drums will, dependent on the direction of rotation, wind or unwind the steering lines and accordingly tighten or loosen the steering lines. In this way the wind-engaging member may be steered along a desired flight trajectory.

In a further aspect of the invention the steering device is provided with one or more depower drums connected to steering lines. The depower drum provides a certain pretension to the steering lines. By unwinding the depower drum, the steering lines will loosen simultaneously and the wind-engaging member will be depowered accordingly.

According to the invention the steering lines may be connected to the drum by steering tape. Such steering tape will facilitate winding and unwinding with optimal power transmission at the drum and optimal actuation characteristics.

In a further embodiment two or more steering lines are running through pulleys. The steering tape is provided on these
pulleys and the steering tape connects two or more steering
lines to the steering drum. The depower tape is connected to
the steering tape and the depower drum. This configuration pro-
vides an effective and responsive steering device with depower-
ing functionality. This is explained further below in the de-
scription explaining the attached figures.

The invention also provides that transverse suspension
lines are provided between the steering device and one or more
power lines. In this way the suspension of the steering device
is stabilized under all circumstances and weather conditions.

According to a further aspect of the invention the
steering device is wirelessly controllable from the ground. As
the steering system has a low power demand, it may be battery
operated and no separate wire for power supply between the
ground station and the steering device is required. The battery
may be charged by a small wind turbine attached to the steering
device. To establish the wireless connection between ground
station and steering device, the system may be equipped with
directed antennas. With such directed antennas a high data rate
may be achieved at low latency and with a low sensitivity for
other users of frequency bands. Additionally or alternatively,
the system may be equipped with omnidirectional antennas. In
case of temporary loss of tether tension, for instance due to
wind gusts, which may result in loss of direction and accord-
ingly loss of function of the directed antennas, the omnidirec-
tional antennas may act as substitute antennas providing a data
rate sufficient to ensure that the system remains airborne.

The invention also provides that the steering device
incorporates safety means. For instance, in the event of tether
rupture it is desirable that the wind-engaging member and the
steering device are returned to ground in a controlled way.
Safety means may include an additional line connecting the
tether with the wind-engaging member, essentially bypassing a
weak-link between tether and the steering device. In case that
the weak link breaks due to overload, the steering device de-
taches from the tether and swings below the wind-engaging mem-
ber, while the additional line stays connected to the wind-
engaging member which allows pulling the whole assembly safely
to the ground in a parachute mode. Additionally or alterna-
tively to the weak-link, a wirelessly controlled (pyrotechnic) cable cutter may be incorporated in the connection between the steering device and the tether. The steering device may, according to the invention, also be provided with crash protection. Such protection may be helpful during normal landing procedures and in particular in emergency situations such as crash landings, to prevent damage of the steering device. Typically, the protection comprises a casing of resilient material or a material with high energy absorption at impact.

In a further advantage embodiment, one or more power lines and/or steering lines are split up into two or more power lines respectively steering lines before connecting to the wind-engaging member. By splitting the power lines and providing several attachment points with the wind-engaging member, the traction force is more evenly distributed over the wind-engaging member. Local peak loads are thereby prevented. Although the forces in the steering lines are considerably lower, splitting of the steering lines will provide additional attachment points with the wind-engaging member, which will improve the steerability considerably. According to the invention, some or all split points of the power or steering lines may include pulleys which allow the bridle system to adapt for geometry changes due to rotation or deformation of the wind-engaging member. Accordingly, the induced stresses are minimized in the bridle system and the wind-engaging member. The invention also provides that the bridle system includes one or more span lines between the side parts of the leading edge of the wind-engaging member. A wind-engaging member, in particular an arc-shaped flexible membrane wing type kite, may collapse due to overload or due to a flow incident on the upper side, the suction side of the wing. This extreme situation may for instance be induced by strong wind gusts during reel-in of the wing. Wing collapse is mostly irreversible and leads to a crash. The application of the span line according to the invention promotes the stiffening of the construction and increases the collapsing resistance considerably.

According to a further aspect of the invention the tether storage device comprises a sled. The movement of the sled transverse to the incoming tether ensures evenly winding
of the tether. The functionality may be further enhanced by applying a 15 swivel, in particular by applying a swivel in combination with a sled. By separating the functions of force transmission by means of a single line tether from the steering by means of an airborne steering device, the sled or swivel movement will not substantially interfere with the steering of the wind-engaging member on a predetermined flight trajectory.

In a further embodiment of the invention the airborne wind energy system comprises a launch and recovery system. Such launch and recovery system will facilitate the lift off and landing of the wind-engaging member such that human intervention may not be necessary or may be reduced to a minimum. When not flying, the launch and recovery system of the invention maintains the wind-engaging member in an upside down position, with the tether completely retracted. In this retracted configuration, the effect of the tether weight is minimized, which allows launching of the wind-engaging member at low wind speeds. Only in the second phase of lifting off the tether weight will gain influence, however, at that stage the wind-engaging member will already have considerable height and will have picked up flight speed. The steering device is connected to the tether and supported by a cantilever at the initial stage of launching. In this way, the weight of the steering device will not affect the first stage of lift off. The just mentioned cantilever provides a suspension point sufficiently high to have the wind-engaging member with the bridle system freely suspended above the ground. Already at low wind speeds, the wind-engaging member can lift off sideways and fly into an upright position above the mounting point. As soon as the wind-engaging member has sufficient height and lift, the steering device will be released and the wind-engaging member may gain additional height. Even in mounted position the steering device will be able to steer the wind-engaging member to bring it in optimal position for lift-off.

The method of the invention for operating an airborne wind energy system comprises one or more of the following steps:

- alternately winding and unwinding the tether;
- monitoring the length of the unwound tether;
monitoring the tether force;
- when the length of the unwound tether has reached a maximum, the wind-engaging member is at least partly de-powered and if as a result thereof the tether force is sufficiently reduced, winding of the tether will start; and
- when the length of the unwound tether has reached a minimum, the wind-engaging member is powered and if as a result thereof the tether force has sufficiently increased, unwinding of the tether will start.

The airborne wind energy system is operated in a pumping cycle in order to generate net energy. The power generation and the flight dynamics are optimized by monitoring the tether force and the length of the unwound tether. The method of the invention may be further improved and refined by also monitoring the tether speed, in particular the axial speed. According to the invention the power output and the flight dynamics may even be further optimized by varying the tether speed in dependence of the tether force. In this way, in particular also wind fluctuations and gusts may be compensated for to avoid overload of the tether. To optimize the power output, the optimal set value of the tether speed can be calculated as a function of the tether force and/or the wind speed. Alternatively, the set value of the motor torque can be adjusted as a function of the measured tether force, speed and wind speed. Accordingly, a simple algorithm may be applied to control the system, which algorithm will apply one or more of the variables, tether force, tether length and tether speed. This can contribute to a robust control of the system.

The various aspects of the invention will now be described in more detail and will be elucidated, by way of example only, with reference to the accompanying drawing which shows in

- Figure 1, the airborne wind energy system according to the invention in perspective;
- Figure 2, the airborne wind energy system of figure 1 in unwinding respectively winding mode;
- Figure 3, the kite of the airborne wind energy system of figure 1, in schematic view;
- Figure 4, a schematic of the suspension of the steering device in the bridle system;

- Figure 5, an airborne wind energy system with a bridle system of which the power and the steering lines branch out in numerous lines connected to the wind-engaging member;

- Figure 6, a schematic view of the launch and recovery system;

- Figure 7a, the airborne wind energy system of figure 5, suspended at a cantilever; and

- Figure 7b, the airborne wind energy system of figure 7a, launched from the cantilever.

The airborne wind energy system of figure 1 consists of a ground station 1, a tether 2, a bridle system 3 and a wind engaging member 4. The ground station 1 comprises a tether storage device 5, an energy converting device 6, a battery/powerelectronics module 7 and a control center 8. In place of using a rechargeable battery for storing electrical energy, a mechanical energy storage device may be employed. The tether storage device is typically a drum. The energy converting device 6 may for instance be a generator connected to the drum. The battery/powerelectronics module 7 will store energy and supply energy to the grid. As the electric power is intermittently produced the battery or other storage device (for instance appropriate capacitors) is applied to balance the electric energy over the pumping cycle of the system. It stores the energy generated during unwinding of the tether and will release a small fraction of this energy for winding the tether, as hereinafter will be explained in more detail. Moreover, the battery will ensure a nominal electricity output also during periods in which the system is not generating energy. It is remarked that the storage capacity of the battery (or other storage device) can remain limited when simultaneously several airborne wind energy systems in accordance with the invention are applied that connect to such battery/storage device. The control center 8 may comprise several interconnected computers hosting different software components required for operating the airborne wind energy system 1. In addition, the control center 8 may comprise wireless modems to connect remote sensors, remote actuators and a steering device 19. The function
of the steering device 19 is further explained hereinafter with particular reference to figure 3.

The tether 2 transfers the traction force generated by the wind-engaging member 4 to the tether storage device 5. The tether 2 is typically made of a strong and lightweight plastic fiber and is connected to the bridle system 3 of the wind-engaging member 4. The connection of the tether 2 with the bridle system 3 will in general include additional safety features such as a metal-based weak link, which ruptures at a predefined maximum traction load, and a (pyrotechnic) cable cutter. Further a two-stage fabric-based shock absorber is provided as part of the safety mechanism that connects the tether (before any of the controlled rupture points) with the kite itself, thus bypassing the bridle system. The connection may also include a (not shown) sensor to measure tether force.

The wind-engaging member 4 as shown in figure 1 is a kite of the inflatable membrane wing type. Such inflatable membrane wing kite is robust and still sufficiently flexible to be optimal steerable.

In figure 2 the principle of power generation by the airborne wind energy system is shown. The system is operated in periodic pumping cycles, alternating between unwinding and winding of the tether 2. During unwinding the wind-engaging member 4 is steered along a predetermined flight trajectory transverse to the wind in order to optimize the traction force in the tether 2. Typically, the flight trajectory will be a figure-eight manoeuvre. When reaching the maximum tether length, the wind-engaging member 4 is de-powered. The wind-engaging member is de-powered by rotating the wind-engaging member 4 relative to the tether 2 by means of actuators in the steering device. The wind-engaging member 4 is then aligned with the apparent wind direction 11, i.e. the wind direction that the wing experiences during flight. The tether storage device 5 will start to retract the tether 2 and accordingly will bring the wind-engaging member 4 to its initial position. From there a new pumping cycle may start. The de-powering by rotating the wind-engaging member reduces the traction force during winding considerably and therefore the energy consumption during winding is only a fraction of the energy generated during
unwinding. Optimization of the power output requires an optimal synchronization of winding/unwinding and flight dynamics of the wind-engaging member.

The flight dynamics and the power generation are optimized by monitoring the tether force and the length of the deployed tether. The method of operating the airborne wind energy system of the invention may be further improved and refined by also monitoring the tether speed. The tether speed may, for instance, be varied in dependence of the tether force. In this way also wind fluctuations and gusts may be compensated for. Accordingly, an algorithm with only two or three variables (tether force, tether length and tether speed) may be applied to control the system. This can result in a robust control of the system. It may particularly be advantageous to optimize the power output of the system by controlling the tether speed as a function of the tether force and/or the wind speed. It is also possible to control the set value of the motor torque as a function of the measured tether force, tether speed and wind speed.

The tether 2 and the wind-engaging member 4 are shown in more detail in figure 3. The bridle 3 of the wind-engaging member 4 comprises, according to the invention, separate power-lines 11 and steering lines 16. The two power lines 11 are connected to tether 2. The power lines 11 are split into two lines 13, 14 that are attached to the leading edge of the tubular inflated frame of the wind-engaging member 4. It is also possible to split the two lines 13, 14 further two or three times before the leading edge of the wind engaging member 4 is reached. As a result of the multiple attachment points, the load is more evenly distributed over the leading edge and local peak loads in the tubular frame are reduced. In the shown configuration the lines 13 and 14 are actually the two ends of one and the same line that runs through pulley 15, which is attached to the tip of line 11. The pulley provides a uniform distribution of the force to the two lines 13 and 14 and it allows the bridle system layout to adjust to the changing three-dimensional geometry of the rotating wind-engaging member 4.

The bridle 3 of the wind-engaging member 4 also comprises two steering lines 16. In similar way as the power
lines, the steering lines 16 are split into two lines 17, 18. The lines 17 and 18 are connected to the left and right tips of the wind-engaging member 4. Also the lines 17 and 18 are actually the two ends of a single line running through a pulley 15 which is attached to the tip of steering line 16. The application of the pulley 15 and the lines 17 and 18 provides for a uniform distribution of forces and prevents peak loads. Moreover, the application of the lines 17 and 18 enhances the steering sensitivity of the wind-engaging member 4.

The steering lines 16 are connected to the steering device 19. The steering device 19 is connected by line 20 to the tether 2. The tensile forces in the steering lines 16, 17, 18 are considerably lower than the forces in the power lines 11. Also the power requirements for the steering device 19 are reduced which allows for a lightweight and efficient design. Moreover the separation of force transmission of the tether and the power lines 11, 13, 14 on one hand and of the steering lines 16, 17, 18 on the other hand allow individual optimization of both functions. The steering device 19 will selectively wind, respectively unwind the steering lines 16 to steer the wind-engaging member 4 along a predetermined glide path and to optimize the traction force in the tether 2. By winding or unwinding both lines 16 at the same time the wind-engaging member 4 will rotate relatively to the tether 2, as shown in figure 2, and the wind-engaging member 4 will accordingly be powered, respectively de-powered.

The bridle system 3 also comprises a span line 21. The span line 21 connects the leading edge sections of the left and right part of the wind-engaging member 4. Adding this tension element increases the collapsing resistance considerably. It is known that in particular wind-engaging members of the arc-shaped flexible membrane wing type may collapse due to flow incident on the upper side, the suction side, of the wing. Such a local flow situation with negative angle of attack can be induced by strong wind gusts during reeling of the tether 2. Wing collapse is mostly irreversible and leads to a crash of the wind-engaging member. Such collapse risk is however considerably reduced by applying the span line 21.

As the steering system 19 has a low power demand, it
may be battery operated and no separate wire for power supply between the ground station and the steering device 19 is required. The battery may be charged by a small wind turbine mounted on or near to the steering device. Moreover, the steering device 19 may be controlled wirelessly. Accordingly, no communication wire is required between the steering device 19 and the ground station. The system may be provided with directed antennas. With such directed antennas a high data rate may be achieved at low latency and with a low sensitivity for other users of the employed frequency bands. Additionally or alternatively, the airborne wind energy system may be provided with omnidirectional antennas. In case of temporary loss of tether tension, for instance due to wind gusts, which may result in loss of direction and accordingly loss of function of the directed antennas, the omnidirectional antennas may act as substitute antennas providing a data rate sufficient to ensure maintenance of control authority such that the system remains airborne.

The suspension of the steering device 19 in the bridle system 3 is shown in more detail in figure 4. The steering device 19 is connected by line 20 to the tether 2. Between the steering device 19 and the power lines 11 two transverse suspension lines 36 are provided. The steering device 19 is provided with two drums, a steering drum 34 and a depower drum 35. Steering tapes 32 are actuated by the steering drum 34. The steering tapes 32 are connected with pulley line 31. This pulley line 31 is connected to the steering lines 16 by pulleys 40. A depower tape 33 is provided on depower drum 35 and the depower tape is also connected to the pulley line 31 between the two pulleys 40. The shown configuration is reliable, efficient, fast and strong. By rotating the steering drum 34 the wind-engaging member 4 may be steered along a desired flight trajectory. Rotation of the depower drum 35 will, depended on the rotation direction, result in depowering respectively powering of the wind-engaging member.

The connection of the steering device 19 and the power lines 11 to the tether 2 is also equipped with safety means. The purpose of the safety means, the weak link 39 and the pyrotechnic cable cutter 38, is essentially to provide a controlled
rupture point in the tether 2. The function of the safety line 22 is to connect the wind-engaging member to the tether 2 if the weak link 39 ruptures or the cable cutter 38 is activated. The pyrotechnic cable cutter is for the event that something in the bridle system or anywhere else on the wind-engaging member breaks, essentially to reconfigure the system into a pulled payload parachute mode. Rupture of the weak link 39 or activation of the cable cutter 38 will detach the steering unit 19 together with the power lines 11 from the tether 2 such that only the safety line 22 remains attached to the tether 2. Much of this safety line 22 is stored in a pocket to the side of the steering device 19, however, it is actually not connected to the steering device 19. In this (not shown) pocket the safety line 22 is rolled up, including also a ripcord shock absorber 37. In case the weak link 39 ruptures or the cable cutter 38 is activated, the steering device 19 is detached and because of its mass swings below the wind-engaging member 4. The wind-engaging member 4 is flying free for a short moment, until caught by the safety line 22, which is, as a result of the dynamics of the wind-engaging member, ripped from the pocket. The shock-absorber 37 is used to slow down the wind-engaging member 4, avoiding rupture of the safety line 22. The steering device 19 may, according to the invention, also be provided with crash protection. Such protection may be helpful during normal landing procedures, to prevent damage of the steering device 19, however, in particular also in emergency situations such as crash landings. Typically, the protection comprises a casing of resilient material or a material with high energy absorption at impact.

In figure 5 an airborne wind energy system is shown with a bridle system of which the power and the steering lines branch out in numerous lines connected to the wind-engaging member. Such configuration with a branch out of numerous lines will in practice be most suitable because of the even distribution of power and steering forces.

The tether storage device 5 as shown in figure 6 is placed on a sled 23, which may be moved transverse to the incoming tether. The sled movement ensures evenly winding of the tether 2. This functionality may be further enhanced by apply-
ing a swivel 24 that follows the tether 2 and allows proper
guidance of the tether into the tether storage device 5. By
separating the functions of force transmission by means of a
single line tether from the steering by means of an airborne
steering device, the sled or swivel movement will not substan-
tially interfere with the predetermined flight trajectory.

The airborne wind energy system as shown in figure 6
also comprises a launch and recovery system 25. Such launch and
recovery system 25 will facilitate the lift off and landing
of the wind-engaging member 4 such that human intervention may
not be necessary or may be reduced to a minimum. The launch and
recovery system 25 comprises a cantilever construction 26, 27
and maintains the wind-engaging member 4 in an upside down po-
sition with the tether almost completely retracted. The wind-
engaging member 4 will lift off sideways and move into an up-
right position above the mounting point. In this way, initial-
ly, the effect of the weight of the tether 2 on the dynamics of
the wind-engaging member 4 is minimized, which allows launching
at low wind speeds. The wind-engaging member 4 is releasable
mounted by the steering device 19 to the suspension point of
the cantilever 27. In this way, also the weight of the steering
device 19 will not affect the first stage of lift off. Only in
the second phase of lifting off the weight of the tether 2 will
gain influence, however, at that stage the wind-engaging member
4 will already have considerable height. As soon as the wind-
engaging member 4 has sufficient height and lift, the steering
device 19 will be released and the wind-engaging member 4 may
gain additional height. Even in mounted position the steering
device 19 will be able to steer the wind-engaging member and
bring it in optimal position for lift-off.

A different configuration of the launch and recovery
system is shown in part in the figures 7a and 7b. The tether 2
is slideable connected to the top of the pole 27. The wind-
engaging member 4, the bridle system 3 and the steering device
19 are suspended upside down when the tether is almost entirely
retracted (figure 7a). For launching, the wind engaging member
is steered through a sideways sweeping maneuver to reach an up-
right position above the top of the pole 27. Once this position
is reached, the tether 2 is released and the wind-engaging mem-
ber can further gain altitude (figure 7b). The tether 2 is guided at the top of the pole 27 by a movable pulley.

To the person skilled in art it is obvious that the above given embodiments represent only a few of the many possible variations in which the airborne wind energy system according to the invention may be embodied. Therefore, the embodiments given here must be understood as an elucidation to the appended claims without limiting the scope of the invention. Within the protective scope numerous variations are conceivable. For instance the wind-engaging member is not restricted to kites in general or kites of the inflatable membrane wing type in particular. Also other types of wind-engaging member are possible. As another example, the system may have two control units, one to control the winding and the other to control the steering. These control units may function independently or in cooperation. For instance, the control unit for the winding may be located at the ground station, where the control unit for the steering system is included in the steering system. The wind-engaging member may be provided with several types of sensors to provide information concerning the dynamic state, the position and the environmental conditions of the wind-engaging member.
CONCLUSIES

1. Vliegend windenergie system omvattende een windvange
gend element (4) met een tuigsysteem (3) verbonden met een ka
bel (2), een wikkelinrichting (5) om de kabel (2) op- en af te wik
kelen, een energieomzetter (6) verbonden met de wikkelen
richting (5), een stuurinrichting (19) om een gestuurde bewe
ging van het windvange de element (4) te bewerkstelligen en/of om de relatieve hoek tussen het windvange de element (4) en de
ekabel (2) in te stellen,
eén of meer regelelementen (8) voor het sturen van het windvange de element (4) en/of voor het op-
en afwikkelen van de kabel (2), met het kenmerk, dat het tuig-
systeem (3) krachtlijnen (11) en stuurlijnen (16) omvat, dat de
krachtlijnen (11) zijn verbonden met de kabel (2), dat de
stuurlijnen (16) zijn verbonden met de stuurinrichting (19) en
dat de stuurinrichting (19) is verbonden met de kabel (2).

2. Vliegend windenergie system volgens conclusie 1,
met het kenmerk, dat de stuurinrichting (19) is voorzien van één of meer stuurspillen (34) voor de stuurlijnen (16).

3. Vliegend windenergie system volgens conclusie 1 of
2, met het kenmerk, dat de stuurinrichting (19) is voorzien
van één of meer ontlastingspillen (35) voor de stuurlijnen
(16).

4. Vliegend windenergie system volgens conclusie 2 of
3, met het kenmerk, dat de stuurlijnen (16) door middel van een stuurbane (32) of een ontlastingsband (33) zijn verbonden
met een spil (34,35).

5. Vliegend windenergie system volgens conclusie 4,
met het kenmerk, dat twee of meer stuurlijnen (16) zijn ver-
bonden met een katrol (40), dat de stuurbane (31,32) is aange-
bracht op de katrollen (40), dat de stuurbane (31,32) twee of
meer stuurlijnen (16) verbindt met een stuurspil (34) en dat een ontlastingsband (33) is aangebracht tussen de stuurbane
(31,32) en de ontlastingsspil (35).

6. Vliegend windenergie system volgens één van de
voorgaande conclusies, met het kenmerk, dat tussen de stuurin-
richting (19) en de krachtlijnen (11) één of meer zijophan-
lijnen (36) zijn aangebracht.
7. Vliegend windenergie system volgens één van de voorgaande conclusies, met het kenmerk, dat de stuurinrichting (19) draadloos vanaf de grond instelbaar is.

8. Vliegend windenergie system volgens conclusie 7, met het kenmerk, dat het systeem is voorzien van gerichte antennes.

9. Vliegend windenergie system volgens conclusie 7, met het kenmerk, dat het systeem is voorzien van omgevingsantennes.

10. Vliegend windenergie system volgens één van de voorgaande conclusies, met het kenmerk, dat de stuurinrichting (19) door een batterij van energie wordt voorzien.

11. Vliegend windenergie system volgens conclusie 10, met het kenmerk, dat de stuurinrichting is voorzien van een windturbine om de batterij op te laden.

12. Vliegend windenergie system volgens één van de voorgaande conclusies, met het kenmerk, dat het systeem is voorzien van veiligheidselementen (22, 38, 39).

13. Vliegend windenergie system volgens conclusie 12, met het kenmerk, dat de veiligheidselementen een additionele lijn (22) omvatten die de kabel (2) met het windvangende element (4) verbindt.

14. Vliegend windenergie system volgens conclusie 12 of 13, met het kenmerk, dat de veiligheidselementen een draadloze kabelsnijder (38) omvatten.

15. Vliegend windenergie system volgens één van de voorgaande conclusies, met het kenmerk, dat de stuurinrichting (19) is voorzien van botsprotectie.


17. Vliegend windenergie system volgens conclusie 16, met het kenmerk, dat het splitsingspunt van de kracht- of stuurlijn (11, 16) een katrol (40) omvat.

18. Vliegend windenergie system volgens één van de voorgaande conclusies, met het kenmerk, dat het tuigsysteem
een of meer spanlijnen (21) omvat tussen de zijden van de voorrand van het windvangende element (4).

19. Vliegend windenergie system volgens één van de voorgaande conclusies, met het kenmerk, dat wikkelinrichting (5) een slee (23) omvat.

20. Vliegend windenergie system volgens één van de voorgaande conclusies, met het kenmerk, dat de wikkelinrichting (5) een draaikop (24) omvat.


22. Vliegend windenergie system volgens conclusie 21, met het kenmerk, dat de installatie (25) voor het lanceren en terugkeren van het windvangende element (4), het windvangende element (4) en het tuigsysteem (3) in omgekeerde positie houdt, bij een vrijwel gewikkelde kabel (2).

23. Vliegend windenergie system volgens conclusie 21, met het kenmerk, dat het windvangende element (4) door middel van de stuurinrichting (19) losneembaar kan worden opgehangen in de installatie (25) voor het lanceren en terugkeren van het windvangende element (4).

24. Vliegend windenergie system volgens één van de conclusies 21-23, met het kenmerk, dat de installatie (25) een draagarm (26, 27) omvat.

25. Werkwijze voor het bedrijven van een vliegend windenergie system, omvattende één of meer van de volgende stappen:
- het beurtelings op- en afwikkelen van de kabel (2);
- het bewaken van de lengte van het afgewikkelde deel van de kabel (2);
- het bewaken van de kabelspanning;
- wanneer de lengte van de kabel (2) een zeker maximum heeft bereikt, wordt het windvangende element (4) ten minste gedeeltelijk ontlast en wanneer als gevolg daarvan de kabelspanning voldoende is afgenomen, wordt begonnen met het opwikkelen van de kabel (2); en
- wanneer de lengte van de kabel (2) een zeker minimum heeft bereikt, wordt het windvangende element (4) weer belast en
wanneer als gevolg daarvan de kabelspanning voldoende is toege- 
genomen, wordt begonnen met het afwikkelen van de kabel (2).


27. Werkwijze volgens conclusie 26, met het kenmerk, dat de kabelsnelheid wordt gevarieerd in afhankelijkheid de optimale kabelspanning en/of een optimale vluchtdynamiek.
<table>
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<th>KENMERK VAN DE AANVRAGER OF VAN DE GEMACHTIGDE</th>
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Aanvrager (Naam)

Technische Universiteit Delft

Datum van het verzoek voor een onderzoek van internationaal type

20-10-2012

Door de Instantie voor Internationaal Onderzoek aan het verzoek voor een onderzoek van internationaal type toegekend nr.

SN 59026

I. CLASSIFICATIE VAN HET ONDERWERP (bij toepassing van verschillende classificaties, alle classificatiesymbolen opgeven)

Volgens de internationale classificatie (IPC)

F03D5/00 B63B35/79

II. ONDERZochte GEBIEDEN VAN DE TECHNIEK

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<th>Classificatiesysteem</th>
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Onderzochte andere documentatie dan de minimum documentatie, voor zover dergelijke documenten in de onderzochte gebieden zijn opgenomen

III. GEEN ONDERZOEK MOGELIJK VOOR BEPAALDE CONCLUSIES (opmerkingen op aanvullingsblad)

IV. GEBREK AAN EENHEID VAN UITVINDING (opmerkingen op aanvullingsblad)

Form PCT/ISA 201 A (11/2000)
ONDERZOEKSRAPPORT BETREFFENDE HET RESULTAAT VAN HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE

Nummer van het verzoek om een onderzoek naar de stand van de techniek: NL 2009528

A. CLASSIFICATIE VAN HET ONDERWERP

INV. F03D5/00 B63B35/79

A. VOLGENS DE INTERNATIONALE CLASSIFICATIE VAN OCTROOIEN (IPC) OF ZELF VOLGENS DE NATIONALE CLASSIFICATIE ALS VOLGENS DE IPC.

B. Onderzochte gebieden van de techniek

F03D B63B

C. Onderzochte andere documentatie dan de minimum documentatie, voor dergelijke documenten, voor zover dergelijke documenten in de onderzochte gebieden zijn opgenomen

EPO-Internal, WPI Data

C. VAN BELANG GEACHTE DOCUMENTEN

<table>
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<th>Categorie</th>
<th>Geciteerde documenten, eventueel met aanduiding van speciaal van belang zijnde passages</th>
<th>Van belang voor conclusie nr.</th>
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<tr>
<td>X</td>
<td>GB 2 469 740 A (KITETECH ENERGY SYSTEMS LTD [GB]) 27 oktober 2010 (2010-10-27) * figuur 3 *</td>
<td>1,2,4, 7-11,4, 25</td>
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Datum waarop het onderzoek naar de stand van de techniek van internationaal type werd voltooid: 5 juni 2013

Naam en adres van de instantie:
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-3040, Fax: (+31-70) 340-3016

De bevoegde ambtenaar: Jucker, Chava
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| X         | EP 2 066 554 A2 (SKYSAILS GMBH & CO KG [DE] SKYSAILS GMBH [DE])
10 juni 2009 (2009-06-10)
* alineas [0001], [0002], [0027] - [0029], [0044] - [0052], [0058] - [0062]; figuren 1-5 * |
|           | -----                                                                                   | 1,2,4, 10,12, 13,16,17       |
| X         | NL 1 015 028 C2 (WUBBO JOHANNES OCKELS [NL]) 30 oktober 2001 (2001-10-30)
* bladzijde 2, regels 10-30 *
* bladzijde 5, regel 25 - bladzijde 7, regel 2; figuren 1, 2 * |
<p>|           | -----                                                                                   | 1,7,8, 16,17                 |</p>
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This opinion contains indications relating to the following items:

- Box No. I  Basis of the opinion
- Box No. II  Priority
- Box No. III  Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- Box No. IV  Lack of unity of invention
- Box No. V  Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- Box No. VI  Certain documents cited
- Box No. VII  Certain defects in the application
- Box No. VIII  Certain observations on the application
Box No. I  Basis of this opinion

1. This opinion has been established on the basis of the latest set of claims filed before the start of the search.

2. With regard to any nucleotide and/or amino acid sequence disclosed in the application and necessary to the claimed invention, this opinion has been established on the basis of:
   a. type of material:
      - [ ] a sequence listing
      - [ ] table(s) related to the sequence listing
   b. format of material:
      - [ ] on paper
      - [ ] in electronic form
   c. time of filing/furnishing:
      - [ ] contained in the application as filed.
      - [ ] filed together with the application in electronic form.
      - [ ] furnished subsequently for the purposes of search.

3. [ ] In addition, in the case that more than one version or copy of a sequence listing and/or table relating thereto has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

4. Additional comments:

Box No. V  Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

   Novelty
   - Yes: Claims 5, 6, 8-11, 13-15, 17-19, 21-24, 26, 27
   - No: Claims 1-4, 7, 12, 16, 20, 25

   Inventive step
   - Yes: Claims 5, 6, 14, 23
   - No: Claims 1-4, 7-13, 15-22, 24-27

   Industrial applicability
   - Yes: Claims 1-27
   - No: Claims

2. Citations and explanations
   see separate sheet
Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1 Reference is made to the following documents:


D2 US 2010/133385 A1 (OLSON GAYLORD G [US]) 3 juni 2010

D3 GB 2 469 740 A (KITETECH ENERGY SYSTEMS LTD [GB]) 27 oktober 2010


D5 NL 1 015 028 C2 (WUBBO JOHANNES OCKELS [NL]) 30 oktober 2001

2 INDEPENDENT CLAIMS 1 AND 25

2.1 Lack of Novelty

The present application does not meet the criteria of patentability, because the subject-matter of independent claims 1 and 25 is not new.

2.2 D1 discloses (references in brackets refer to D1, see e.g. paragraphs [0122] - [0124]; figures 10,11): an airborne wind energy system comprising a wind-engaging member (150) with a bridle system connected to a tether (160), a tether storage device (158) connected with an energy converting device (154); a steering device (152) to generate a steered movement of the wind engaging member (150) and/or to steer the relative angle of the wind engaging member with respect to the tether; one or more control units are provided for steering the wind-engaging member and/or winding and unwinding the tether, wherein the bridle system comprises power lines (162a-d) and steering lines (164L, 164R) and wherein the power lines (162a-d) are connected to the tether (160) (via the steering device), the steering lines (164L, 164R) are connected to the steering device (152) and the steering device (152) is-connected to the tether (160).

2.3 D1 also discloses a method for operating an airborne wind energy system comprising one or more of the following steps (see e.g. [0022], [0122]):

Form NL237-3 (separate sheet) (July 2006)-(sheet 1)
• alternately winding and unwinding the tether
• when the length of the unwound tether has reached a maximum, the wind-engaging member is at least partly de-powered and if as a result thereof the tether force is sufficiently reduced, winding of the tether will start
• when the length of the unwound tether has reached a minimum, the wind-engaging member is powered and if as a result thereof the tether force has sufficiently increased, unwinding of the tether will start.

2.4 D3 also discloses (references in brackets refer to D3, see e.g. page 12, line 21 - page 13, line 18; figures 3 and 4): an airborne wind energy system comprising a wind-engaging member (15) with a bridle system connected to a tether (17), a tether storage device (19) connected with an energy converting device (47); a steering device (30) to generate a steered movement of the wind engaging member (15) and/or to steer the relative angle of the wind engaging member with respect to the tether; one or more control units (40) are provided for steering the wind-engaging member and/or winding and unwinding the tether, wherein the bridle system comprises power lines (31-34) and steering lines (26-29) and wherein the power lines (31-34) are connected to the tether (17), the steering lines (26-29) are connected to the steering device (30) and the steering device (30) is connected to the tether (17) via the power lines.

2.5 D3 also discloses a method for operating an airborne wind energy system (see e.g. page 11, line 6 - page 12, line 5), comprising steps of alternately winding and unwinding the tether.

2.6 Lack of inventive step
The present application does not meet the criteria of patentability, because the subject-matter of independent claims 1 and 13 is also not inventive over documents D4 or D5:

Both D4 (see e.g. paragraphs [0001], [0002], [0027]-[0029], [0044]-[0052], [0058]-[0062]; figures 1-5) and D5 (see e.g. page 2, lines 10-30; page 5, line 25 - page 7, line 2; figures 1, 2) disclose an airborne wind energy system with a bridle and steering device comprising power lines and steering lines. However neither document discloses any details about a tether storage device or the energy converting device. These features however are known to be used in such wind energy systems and therefore it is obvious for the skilled person to also include them into the devices disclosed by D4 or D5.
3 DEPENDENT CLAIMS

3.1 Novelty

3.2 Dependent claims 2-4, 7, 12, 16, 20 do not contain any features which, in combination with the features of any claim to which they refer, meet the requirements of novelty: D1 discloses the technical features of claims 2-4, 7, 12, 16 and 20 and D3 discloses the technical features of claim 7 (see the passages and figures cited in the search report).

3.3 Inventive Step

3.4 Dependent claims 8-11, 13, 15, 17-19, 21, 22, 24, 26 and 17 do not contain any features which, in combination with the features of any claim to which they refer, meet the requirements of inventive step:

3.4.1 The features of claims 8, 9, 15, 17 and 19 refer to slight constructional changes in the airborne wind energy system as disclosed by D1 which comes within the scope of the customary practice followed by persons skilled in the art, especially as the advantages thus achieved can readily be foreseen. The method steps disclosed in claims 26 and 27 are such that the skilled person would use them in a control scheme of an airborne energy system such as mentioned in D1, paragraphs [0122] and [0123], without the use of inventive step. A combination of D1 with D2, would lead to an airborne energy system with a launch and retrieve installation as claimed in claims 21, 22 and 24.

3.4.2 The features of claims 2, 4, 8-11 and 18 refer to slight constructional changes in the airborne wind energy system as disclosed by D3 which comes within the scope of the customary practice followed by persons skilled in the art, especially as the advantages thus achieved can readily be foreseen.

3.4.3 The features of claims 2, 4, 10, 12, 13 and 16 are also disclosed by D4. The features of claim 17 is a slight constructional change whose addition to the system of D1 is not inventive.

3.4.4 The features of claims 7, 8 and 16 are also disclosed by D5. The features of claim 17 is a slight constructional change whose addition to the system of D1 is not inventive.

3.5 The combination of the features of dependent claims 5, 6, 14 and 23 is neither known from, nor rendered obvious by, the available prior art.