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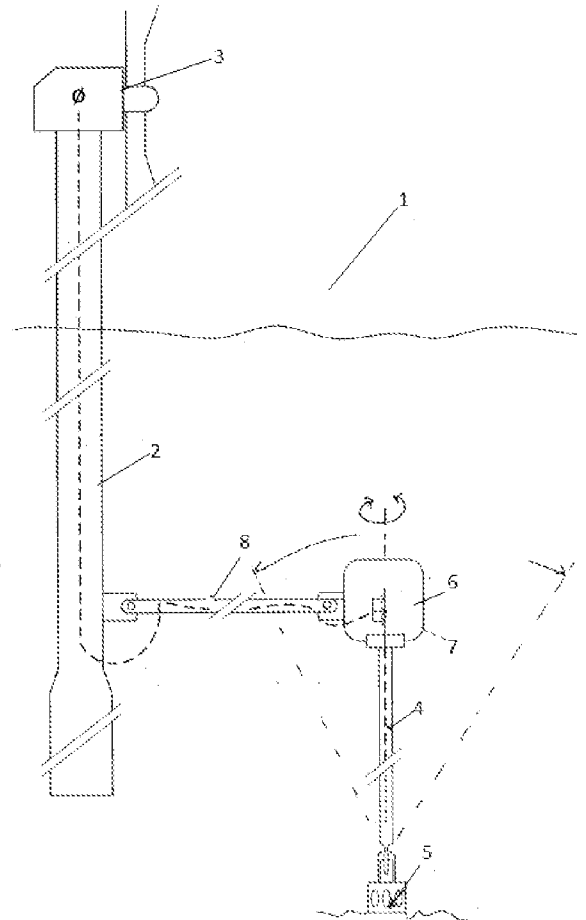
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(57)	Abstract			

The invention provides a floating windmill, comprising a floating element and a wind turbine. The floating windmill is distinguished in that it further comprises: a tension leg, an anchoring, a buoyancy element, a swivel and a cross bar, wherein the swivel is arranged in the buoyancy element. In operation, the floating windmill is configured with the wind turbine in an upper end of the floating element extending up above the sea level, with a lower end or part of the floating element submerged in the sea, with the cross bar connected in one end to the lower part or end of the floating element and the opposite end connected to the buoyancy element, with the buoyancy element fully submerged, with the tension leg arranged between the buoyancy element and the anchoring on the seabed. The floating element with the wind turbine in the upper end can weathervane freely around the buoyancy element, wherein in a low force condition when the forces by ocean current, wind and waves are low the floating element, the buoyancy element and the tension leg is oriented in substance in vertical direction and the cross bar is oriented in substance in horizontal direction, wherein in a high force condition when the forces by ocean current, wind and waves are high the shape of the floating element, cross bar, buoyancy element and tension leg is stretched by the forces to provide a shape like a lazy-s configuration, which change in shape contributes in damping extreme forces.



## **FLOATING WINDMILL**

### **Technical Field**

The present invention relates to floating windmills, also termed floating wind turbines. More specifically, the invention relates to a floating windmill with  
5 reduced cost compared to produced electric energy, if fabrication, transport, installation and maintenance is included in the cost and leveled out over the estimated lifespan of at least 20 – 30 years.

### **Background Art**

10 The shift towards greener energy will be facilitated if the cost for floating wind energy can be reduced. Enormous areas offshore can thereby be available for electric energy produced by floating windmills.

The state-of-the-art with respect to floating windmills are presumably Hywind,  
15 WindFloat and Sway. However, cost is a limiting factor for the utilization of floating wind, and economic subsidizing is still required for the concepts to be economic viable.

Patent publication US 2016/0075413 A1 has been identified as the nearest art.  
20 A tension leg is not described or illustrated in said publication.

If possible, new windmills leading to reduced cost would benefit the shift towards greener energy. The objective of the present invention is to provide one such new windmill.

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### **Summary of invention**

The invention provides a floating windmill, comprising a floating element and a wind turbine. The floating windmill is distinguished in that it further comprises:  
a tension leg, an anchoring, a buoyancy element, a swivel and a cross  
30 bar, wherein the swivel is arranged in the buoyancy element,

wherein the floating windmill in operation is configured with the wind turbine in an upper end of the floating element extending up above the sea level, with a lower end or part of the floating element submerged in the sea, with the cross bar connected in one end to the lower part or end of the floating element and the opposite end connected to the buoyancy element, with the  
5 buoyancy element fully submerged, with the tension leg arranged between the buoyancy element and the anchoring on the seabed,

wherein the floating element with the wind turbine in the upper end can weathervane freely around the buoyancy element, wherein in a low force  
10 condition when the forces by ocean current, wind and waves are low the floating element, the buoyancy element and the tension leg is oriented in substance in vertical direction and the cross bar is oriented in substance in horizontal direction, wherein in a high force condition when the forces by ocean current, wind and waves are high the shape of the floating element, cross bar,  
15 buoyancy element and tension leg is stretched by the forces to provide a shape like a lazy-s configuration, which change in shape contributes in damping extreme forces.

In one preferable embodiment, the floating element is a spar buoy.  
20

In other preferable embodiments, the floating element is a rectangular or triangular, polygonal, elliptic or circular floating or semi-submersible structure. In a further preferable embodiment, the floating element is a triangular, rectangular or square floating structure with one, two three or four windmill towers.  
25

The submerged part of the floating element can extend far below the point where the cross bar is connected, which is preferable for reducing or eliminating tilting of the floating element in downwind direction by the load of the wind on the turbine blades. Retaining an angle of the turbine blade plane in substance  
30 perpendicular to the wind direction increases efficiency.

The terms “vertical direction” of the floating element and “the cross bar is oriented in substance in horizontal direction between the buoyancy element and the floating element” are relative terms, not necessarily meaning literally vertical

within a small margin or horizontal within a small margin. With a spar buoy as the floating element, and low force condition, the terminology will typically be literally as described, with other floating elements the terminology is relative, but the “stretching out” more or less to a lazy-s like shape by the forces at higher  
5 force condition is retained as an essential feature. This is correct also for embodiments with floating element retaining a vertical orientation even far into high force condition, since the orientation change of the cross bar opens up the angle above the cross bar towards the floating element.

10 The axial movements by said stretching, combined with lateral movements by orientation change and position change, contributes in reducing the extreme stress in the structural elements.

Preferably, the floating windmill comprises a releasable coupling between the  
15 cross bar and the buoyancy element. Preferably, the floating windmill also comprises a releasable coupling between the cross bar and the floating element. Releasable coupling in this respect means a coupling that can be coupled and decoupled/released at the windmill site offshore. Releasable couplings can preferably comprise guide funnels or guide structures and/or  
20 guidelines, for facilitates coupling and decoupling/release with or without assistance by an ROV (Remotely Operated Vehicle).

Preferably, the floating windmill includes no gear rim in the wind turbine/nacelle of the floating element. The swivel in the buoyancy element is sufficient to take  
25 up the rotation when weathervaning.

The invention also provides a method of transport, installation or maintenance of the floating windmill, comprising to transport, install or maintain the windmill in components.

30

In one preferable embodiment, the method comprises that installation takes place by transporting the floating element and the wind turbine to the windmill site, where said components are coupled to the buoyancy element that has been preinstalled with an anchor on the seabed, preferably the buoyancy

element and/or the vessel used for the operation includes a buoyancy system allowing to bring the buoyancy element up and down between a surface position and a submerged position, whereby the coupling can take place near or at the surface position. A variable, or no-rigid tension leg can be preferable, as  
5 will be described below.

In another preferable embodiment, the method comprises that maintenance takes place by replacing components on the windmill field, by installing a new component and transporting away the part that is damaged or need  
10 maintenance or repair, as one combined operation, preferably with by a single trip with a single vessel.

Some advantages of the floating windmill of the invention are:  
Lower weight in the wind turbine/nacelle, due to no gear rim, which saves at  
15 least 3-5 times the corresponding floating element structure weight subsea.  
Only one anchoring point is required, reducing safe zone area.  
Self- directing orientation by weathervaning.  
Self-dampening effect by shape variation, reducing extreme tensions.  
Simplified cable routing, no swivel required in wind turbine/nacelle.  
20 Simplified logistics, by fabrication into parts, transport into parts or partly preassembled structure, facilitating fabrication, transport and installation, allowing fewer and/or smaller vessels at lower rate than for larger structures.  
Simplified maintenance, by replacing/maintenance of only the element requiring maintenance, on the field site, reducing windmill downtime and vessel  
25 operations time.

The total cost savings are roughly estimated to be more than 30%, 40% or even 50% per MWh produced, if fabrication, transport, installation and maintenance are included in the cost and leveled out over a lifespan of at least 20-30 years.

30

### **Brief description of drawings**

Figure 1 illustrates an embodiment of a floating windmill of the invention.

### Detailed description of the invention

Reference is made to Figure 1, illustrating an embodiment of a floating windmill 1 of the invention, comprising a floating element 2 and a wind turbine 3. The floating windmill further comprises: a tension leg 4, an anchoring 5, a buoyancy element 6, a swivel 7 and a cross bar 8, wherein the swivel is arranged in the buoyancy element.

The illustrated floating windmill comprises a spar buoy as the floating element 2, with the wind turbine 3 in the upper end above the sea level. The lower end of the floating element is submerged in the sea and is connected to one end of the cross bar 8 and the opposite end of the cross bar is connected to the buoyancy element 6. The buoyancy element 6 is fully submerged and in a lower end is connected to the tension leg 4, which tension leg is connected to the anchoring 5.

The anchoring preferably is a weight anchor or a suction anchor or a combination of a weight anchor and a suction anchor. Other anchors, such as pile anchors, can be used.

The floating element 2 can weathervane freely around the buoyancy element 6, as indicated by a rotation symbol above the buoyancy element.

The operation state as illustrated is a low force condition, meaning that the forces by ocean current, wind and waves are low, not forcing the components/elements significantly out of an equilibrium condition or orientation taken when no current, wind or waves are present. Not significantly out of an equilibrium condition or orientation means less than 5° out of orientation for elements oriented vertical or horizontal, as defined.

As the skilled person will understand, the equilibrium condition is deviated from by more than 5° in a high force condition, drawing out the shape of the configuration of the elements towards a lazy s shape. This is illustrated by a

turning angle of the tensioning leg and buoyancy element by dashed line, exceeding 5°. For clarity, such dashed line deviation is indicated only for the buoyancy element as being pulled out of vertical orientation by high forces. The skilled person will understand that also the angular orientation of the cross bar and for many embodiments also the angular orientation of the floating element will change when stretched towards a lazy s shape.

Preferably, the anchor, the tension leg and the buoyancy element are preinstalled, whilst the floating element with the cross bar is coupled to the buoyancy element on the windmill site, wherein the cables are preinstalled out from the swivel, arranged on the cross bar and is pulled into the inner part of the floating element, with or without a coupling in dry location inside the floating element. Preassembling can be in alternative configurations, preferably involving coupling at least two preassembled groups of components with the cross bar in one or both ends.

The tension leg can be a flexible wire or a number of flexible wires, preferably combined with a buoyancy system in the buoyancy element or connectable from a vessel, such as a pump and required piping and valves for adjusting a ballast water level in the buoyancy element, for moving the buoyancy element up to or near the surface when coupling to the cross bar and down to operation position.

Preferably, also the buoyancy element comprises a releasable coupling, towards the tension leg.

Preferably, also the floating element comprises a buoyancy system or facilities for connecting to a buoyancy system on a vessel. The buoyancy system can be a pump and required piping and valves for adjusting a ballast water level in the floating element. Thereby, installation, replacement or maintenance of the wind turbine, nacelle or parts thereof can be simplified by submersing more of the floating element. Preferably, the submerging can be down to a level where the nacelle is reachable with a ship crane on the ship used for installation.

As the skilled person will know, the anchor can be a single anchor vertically below the buoyancy element in equilibrium position. However, also several anchors, such as suction anchors are possible embodiments within the term

5 one anchor, arranged in substance close together as one unit below the buoyancy element but positioned apart as the soil conditions dictate for sufficient strength. One big weight anchor that can be weighted on site to sufficient weight/strength is a preferable embodiment in many shallow areas with relatively rigid bottom.

10

## Claims

1.

Floating windmill (1), comprising a floating element (2) and a wind turbine (3),  
c h a r a c t e r i s e d i n that the floating windmill further comprises:

5 a tension leg (4), an anchoring (5), a buoyancy element (6), a swivel (7)  
and a cross bar (8), wherein the swivel (7) is arranged in the buoyancy element  
(6),

wherein the floating windmill (1) in operation is configured with the wind  
turbine (3) in an upper end of the floating element extending up above the sea  
10 level, with a lower end or part of the floating element submerged in the sea, with  
the cross bar (8) connected in one end to the lower part or end of the floating  
element (2) and the opposite end connected to the buoyancy element (6), with  
the buoyancy element fully submerged, with the tension leg (4) arranged  
between the buoyancy element (6) and the anchoring (5) on the seabed,

15 wherein the floating element (2) with the wind turbine (3) in the upper end  
can weathervane freely around the buoyancy element (6), wherein in a low  
force condition when the forces by ocean current, wind and waves are low the  
floating element (2), the buoyancy element (6) and the tension leg (4) is  
oriented in substance in vertical direction and the cross bar (8) is oriented in  
20 substance in horizontal direction, wherein in a high force condition when the  
forces by ocean current, wind and waves are high the shape of the floating  
element (2), cross bar (8), buoyancy element (6) and tension leg (4) is stretched  
by the forces to provide a shape like a lazy-s configuration, which change in  
shape contributes in damping extreme forces.

25

2.

Floating windmill according to claim 1, comprising a releasable coupling  
between the cross bar (8) and the buoyancy element (6).

30 3.

Floating windmill according to claim 1 or 2, comprising a releasable coupling  
between the cross bar (8) and the floating element (2).

4.

Floating windmill according to claim 1, 2 or 3, including no gear rim in the upper end of the floating element, in the nacelle and/or wind turbine.

5 5.

Method of transport, installation or maintenance of the floating windmill (1) of any one of claim 1 - 4, comprising to transport, install or maintain the windmill in components.

10 6.

Method according to claim 5, whereby installation takes place by transporting the floating element (2) and the wind turbine (3) to the windmill site, where said components are coupled to the buoyancy element (6) that has been preinstalled with an anchor (5) on the seabed, preferably the buoyancy element includes a buoyancy system allowing to bring the buoyancy element up and down between a surface position and a submerged position, whereby the coupling can take place near or at the surface position.

7.

20 Method according to claim 5, whereby maintenance takes place by replacing components on the windmill field, by installing a new component and transporting away the part that is damaged or need maintenance or repair, as one combined operation, preferably by a single trip with a single vessel.

25 8.

Method according to claim 5 or 6, whereby the anchor (5), the tension leg (4) and the buoyancy element (6) are preinstalled, whilst the floating element (2) with the cross bar (8) is coupled to the buoyancy element (6) on the windmill site, wherein the cables are preinstalled out from the swivel, arranged on the cross bar (8) and is pulled into the inner part of the floating element, with or without a coupling in dry location inside the floating element.

## Patentkrav

1.

Flytende vindmølle (1), omfattende et flyteelement (2) og en vindturbin (3),

5 k a r a k t e r i s e r t v e d at den flytende vindmølle videre omfatter:

et strekkstag (4), et anker (5), et oppdriftselement (6), en svivel (7) og en tverrstang (8), idet svivelen (7) er anordnet i oppdriftselementet (6),

10 idet den flytende vindmølle (1) i drift er konfigurert med vindturbinen (3) i en øvre ende av flyteelementet som strekker seg over sjøflaten, med en nedre ende eller del av flyteelementet nedsenket i sjøen, med tverrstangen (8) koblet i en ende til den nedre del eller ende av flyteelementet (6) og motsatt ende koblet til oppdriftselementet (6), med oppdriftselementet helt nedsenket, med strekkstaget (4) anordnet mellom oppdriftselementet (6) og ankeret (5) på  
15 sjøbunnen,

idet flyteelementet (2) med vindturbinen (3) i øvre ende kan dreie fritt etter været rundt oppdriftselementet (6), hvorved flyteelementet (2), oppdriftselementet (6) og strekkstaget (4) er orientert i hovedsak vertikalt og tverrstangen (8) er orientert i hovedsak horisontalt i en lav kraft tilstand når  
20 kreftene fra havstrøm, vind og bølger er lave, og hvorved flyteelementet (2), tverrstangen (8), oppdriftselementet (6) og strekkstaget (4) er strukket ut av kreftene til å gi en lang s-lignende form i en høy kraft tilstand når kreftene fra havstrøm, vind og bølger er høye, hvilken endring i form bidrar til demping av ekstreme krefter.

25

2.

Flytende vindmølle ifølge krav 1, omfattende en løsbar kobling mellom tverrstangen (8) og oppdriftselementet (6).

30 3.

Flytende vindmølle ifølge krav 1 eller 2, omfattende en løsbar kobling mellom tverrstangen (8) og flyteelementet (2).

4.

Flytende vindmølle ifølge krav 1, 2 eller 3, idet den er uten tannkrans i nacellen og/eller turbinen i øvre ende av flyteelementet.

5 5.

Fremgangsmåte for transport, installasjon eller vedlikehold av den flytende vindmølle (1) ifølge et hvilket som helst av krav 1 – 4, omfattende å transportere, installere eller vedlikeholde vindmøllen i komponenter.

10 6.

Fremgangsmåte ifølge krav 5, hvorved installasjonen finner sted ved transport av flyteelementet (2) og vindturbinen (3) til vindmøllens lokasjon, idet nevnte komponenter kobles til oppdriftselementet (6) som er blitt forinstallert med et anker (5) på sjøbunnen, fortrinnsvis inkluderer oppdriftselementet et oppdriftssystem som gjør det mulig å bringe oppdriftselementet opp og ned mellom en overflateposisjon og en nedsenket posisjon, hvorved koblingen kan finne sted i eller nær overflateposisjonen.

7.

20 Fremgangsmåte ifølge krav 5, hvorved vedlikehold finner sted ved å erstatte komponenter på vindmøllefeltet, ved å installere en ny komponent og transportere bort delen som er skadet eller behøver vedlikehold eller reparasjon, som en kombinert operasjon, fortrinnsvis ved en enkelt tur med ett enkelt skip.

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8.

Fremgangsmåte ifølge krav 5 eller 6, hvorved ankeret (5), strekkstaget (4) og oppdriftselementet (6) er forinstallert, mens flyteelementet (2) med tverrstangen (8) kobles til oppdriftselementet (6) på vindmøllens lokasjon, idet kabler er forinstallert ut fra svivelen, anordnes på tverrstangen (8) og trekkes inn i indre del av flyteelementet, med eller uten en kobling tørt inne i flyteelementet.

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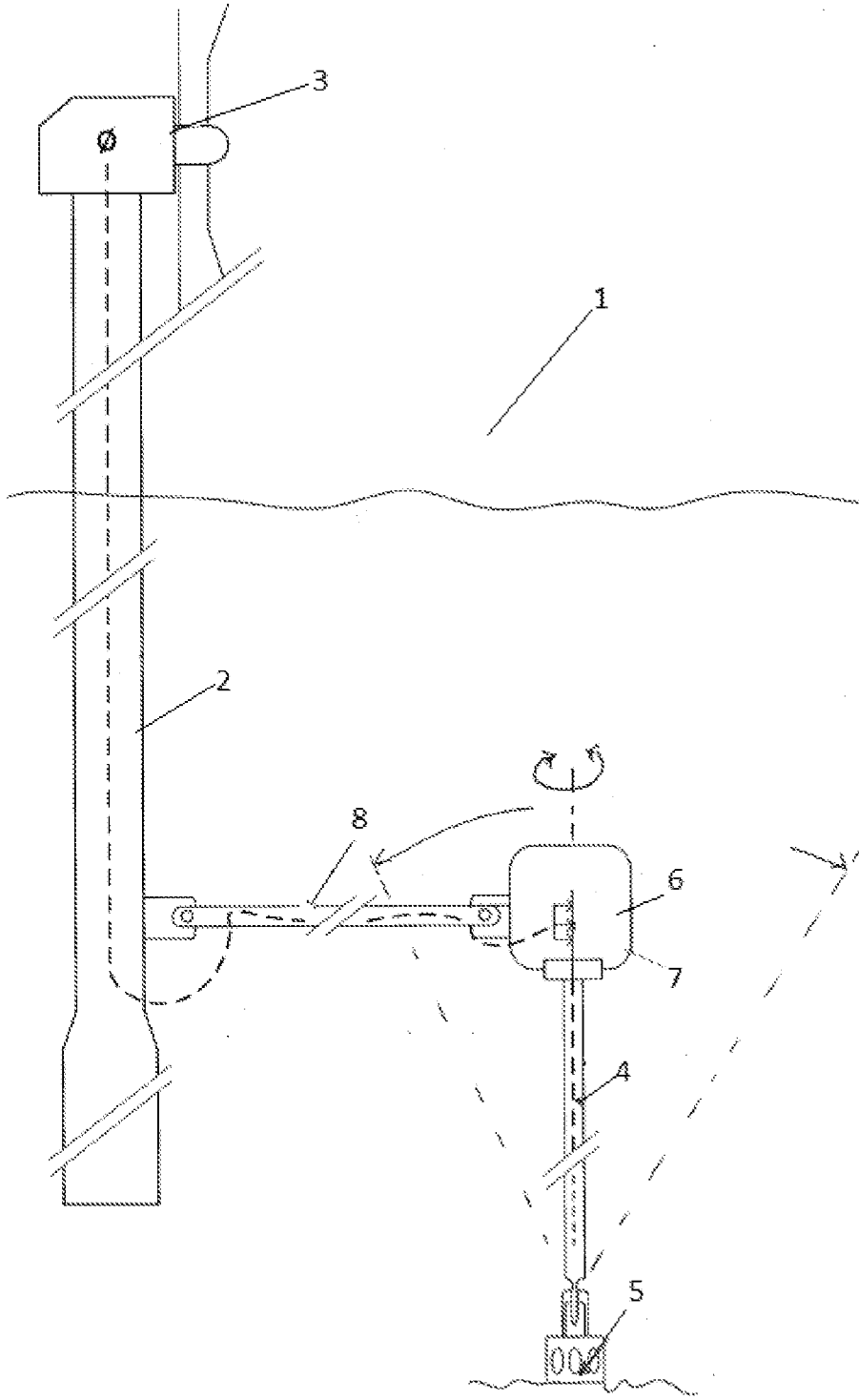


Fig. 1