2016-11-24

Wave energy capture device

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http://hdl.handle.net/10026.1/9402

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
24 November 2016 (24.11.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/185189 A1

(51) International Patent Classification:
F03D 9/00 (2016.01) ***F03B 13/14*** (2006.01)

(21) International Application Number:
PCT/GB2016/051403

(22) International Filing Date:
16 May 2016 (16.05.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1508748.9 21 May 2015 (21.05.2015) GB
1508749.7 21 May 2015 (21.05.2015) GB

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,

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(54) Title: WAVE ENERGY CAPTURE DEVICE

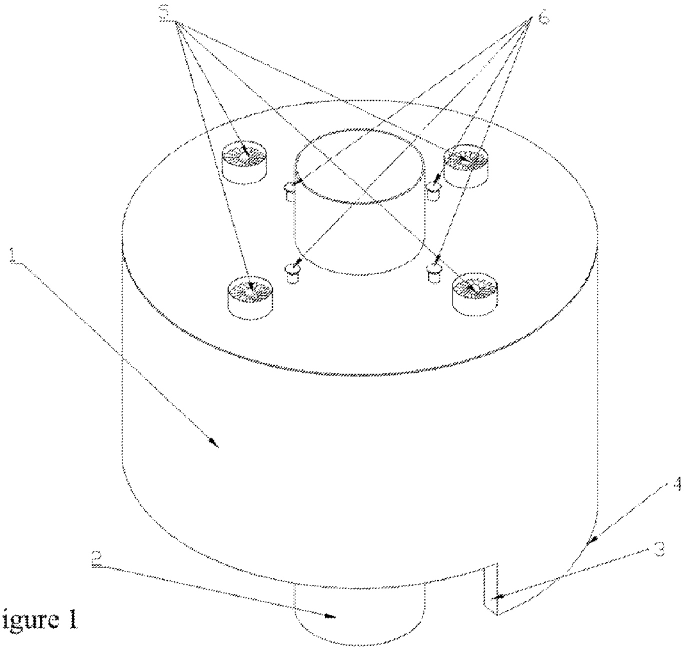

Figure 1

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DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(57) Abstract: A bottom-fixed wave energy capture device is provided and comprises a foundation and an oscillating water column energy collector device. The device comprises a collection chamber and the chamber includes means for changing a position of a surface of the chamber so there is an increased surface area against which waves coming from a generally opposite direction impact.

WAVE ENERGY CAPTURE DEVICE

The present invention relates generally to a wave energy capture device capable of converting wave energy into electricity and particularly to a device utilising an oscillating water column wave energy collector.

Background of the related art

Wave and offshore wind are amongst the renewables with the greatest potential, and both are part of marine renewable energies. Sharing the same hostile sea environment, wave and offshore wind energies face similar challenges. Whatever their level of technological development is not the same: while offshore wind is a mature and consolidated technology, wave energy is still at an early stage of development.

The sustainable development of the offshore wind and wave industries requires a proper use of the natural resources, and one that optimizes their exploitation. And it is in relation to this and to the shared challenge for both industries to reduce their costs that the option of integrating offshore wind and wave energy arises.

There are three main alternatives for combining wave and offshore wind energies, namely as: i) co-located systems, ii) hybrid systems and iii) island systems. Co-located systems combine an offshore wind farm with a Wave Energy Converter (WEC) array with independent foundation systems. Hybrid systems are part of a wider family of multipurpose platforms and they combine and offshore wind turbine and a WEC. Finally, Island systems combine wave and wind energy technologies in island systems (very large floating or fixed structures).

Bottom-fixed and floating are the two main types of wave-wind hybrid converters. The bottom-fixed ones are an evolution of current offshore wind foundation or substructure technologies to integrate a WEC. Alternatively, the floating hybrids are being developed as combined concepts where a floating structure designed to support a wind turbine combines also a WEC.

The foundation or substructure types of technologies developed so far by the offshore wind industry can be classified into three main groups: i) shallow water substructures, which can be subdivided in gravity-base structure (GBS), monopiles and suction bucket; ii) transition water substructures, composed by jacket frame, tri-pile and tripod; and iii) deep water or floating substructures, composed by spar floater, tensioned-leg platform (TLP) and semi-submersible platforms.

Monopiles and jacket frames are the most extended foundation technologies by the industry so far. Monopiles are vertical piles which are hinged deep into the seabed and connected to the wind turbine with a transition piece at the top (e.g. WO2013022338, US2008292408 and US2011142682). Jacket frames are complex tubular structures composed by different diameter tubular sections assembling a tower type structure which allows to reach deeper waters than monopiles (e.g. EP1867790, DE2644725 and US4102143).

There are three primary families of WEC technologies, according to the way in which the energy is extracted from the sea: i) Oscillating Water Columns (OWC), ii) Oscillating Bodies and iii) Overtopping. OWC are conversion devices with a semi-submerged chamber, keeping a trapped air pocket above a column of water. Waves cause the column to act like a piston creating an oscillatory movement of the air pocket which is channeled in and out the chamber to produce energy, generally through a turbine-generator group. Oscillating bodies are all those conversion devices that harnesses the wave energy through one or multiple bodies, usually a floater or a buoy, which is forced to maintain oscillatory movement i.e. a heave, roll or pitch motion. Finally, an overtopping device is usually a floating or fixed structure which has a water reservoir and a set of reflecting arms and a ramp. As waves arrive, they overtop the ramp and are restrained in the reservoir.

The Oscillating Water Column (OWC) is one of the most common WEC technologies, and many different so is among the most studied. These devices can be divided into two main parts: a chamber or collector (which extracts the wave energy by transferring the air contained inside the chamber) and an energy extraction system or 'Power Take Off (PTO)' (transforming pneumatic power into electricity or other use). The chamber generally consists of a static structure where the pressure inside is constantly changing. Thus, when the water level inside rises, the pressure increases, whereas when the water level inside falls, the pressure decreases. The PTO generally consists in an air turbine, usually of the self-rectifying type (a turbine which its turning direction keeps constant regardless the direction of the air flow). The most extended among this are the Wells (GB1595700) or the bi-directional impulse turbines (US3922739).

The first system of this type is known was 'the whistling buoy' (1885), which was used as navigation aid, as a warning buzzer. It was a century later when the first application as a WEC appears again in the field of navigation buoys, was MASUDA (1947), who designed and installed the first OWC moving a turbine to produce electricity to make a navigation buoy autonomous. It was between 1976 and 1979 when a team (working for the International Energy Agency) test this technology installing it on a barge in Japan, trying different turbine systems. During the decade of the eighties and nineties, were constructed and tested various devices of this type, usually on the waterfront. The largest of these was installed at the port of Sakata in Japan, had five cameras and was part of the structure of the port, in the form of a concrete box.

Most of these devices are terminators, integrated into the waterfront so that harness the energy of the terminal wave. This feature makes that most of these installation were built in cliffs, shorelines or docks. Examples of such devices are: Mutriku in Spain, the OWC do Pico in Portugal (e.g. PT1518052 and IE913641). These designs, as they are constrained to be settle at the shoreline, are limited by the shallow seafloor, which make that energy available to be extracted much lower than at other offshore locations. Recent designs have tried to move this well-known technology to deep waters. An example is solution proposed by Oceanlinx Ltd proposing floating solutions linked to the seafloor by conventional navigational mooring systems (AU717081). The greatest problem with this type of devices is that being floated, the movement generated in the structure reduces the sway of the water inside the chamber and consequently the energy efficiency.

In recent years there have been some attempts to propose a successful hybrid technology combining wave and offshore wind energy extraction under the same platform, however, none of these proposals has been successful so far. Some of them due to the large dimensions and so the construction costs of the proposed substructure or foundation as GB2365385 and GB2314124. Others fail due to the lack of development of a WEC technology which is not well known such as GB0900982 and GB0501553. More recently, WO2012/167015 presents an interesting low cost solution which integrates an OWC inside an offshore wind monopile foundation type, however, this solution has as main disadvantages: i) the reduced dimensions of the OWC chamber (limited to the inner part of the monopile) which limits considerably the energy production of the WEC; and ii) the proposed modification at the monopile (opening orifices at its submerged part) affects to the structural integrity of the foundation and to solve it will need to increase the cost of the whole structure. Even that the proposed alternative is a simple and economic one, due to these two points makes it difficult to implement.

Disclosure of the invention

The present invention seeks to provide improvements in or relating to wave energy collectors.

An aspect of the present invention provides a bottom-fixed wave energy capture device comprising a foundation and an oscillating water column energy collector device, in which the device comprises a collection chamber and the chamber includes means for changing a position of a surface of the chamber so there is an increased surface area against which waves coming from a generally opposite direction impact/collide/are constrained.

In some embodiments the present invention is therefore based on an increasing of the chamber volume length and extent at a “rear” side.

In some aspects and embodiments the surface is configured so there is an increased surface area against the incoming waves, resulting in an increase of the free surface oscillation at an inner oscillating water column chamber.

An aspect of the present invention provides a bottom-fixed wave energy capture device comprising a foundation and an oscillating water column energy collector device, in which the device comprises a collection chamber and the chamber includes means for changing a position of a surface of the chamber so there is an increased surface area against which waves, resulting in an increase of the free surface oscillation at the inner oscillating water column chamber.

The chamber (for example a skirt defining part of the chamber) therefore changes. As a consequence of this change the added mass on the OWC system (typically the volume of water around the chamber) varies, increasing the opposition to the wave to continue on the back.

The change in position of the surface may be an change in its shape, height or angle and the increased surface area results in an increased volume of water in the collection chamber due to an increased volume of water impacting on the means, with the result that there is an increased back force on the waves travelling towards the wave energy capture device

The means for increasing volume may comprise a skirt or a skirt extension.

The skirt may be movable. For example the skirt may be rotatable with respect to the chamber. In some embodiments the skirt is translatable with respect to the chamber to vary the depth thereof in use. By translatable what is meant is that the skirt can move in a generally vertical direction with respect to the axis of the device.

The angular extent of the skirt may be variable.

In some embodiments the skirt is fixed. In such embodiments the chamber may be movable with respect to the foundation whereby to adjust the position of the skirt.

The chamber may comprise an outer shell and the shell may comprise a skirt or skirt-like wall extension.

The device may be translatable with respect to the foundation, for example to vary the depth of the collector in use.

The device may further comprise a wind energy collector such as an offshore wind turbine.

The foundation may, for example, be suitable for shallow and/or intermediate deep waters, such as a jacket frame, a tubular truss, a tri-pile, or a tripod.

The device may comprise means for monitoring or establishing prevailing or predicted wave conditions, such as a buoy.

The skirt and/or chamber may be movable with respect to the foundation in response to the said wave conditions.

The chamber may comprise one or more internal oscillating water column compartments.

The chamber may comprises an outer shell

The chamber may comprise means for varying the weight thereof, such as one or more ballast tanks. The ballast tank/s may be formed as a double hull.

At least part of the foundation may be formed from a composite material and/or concrete and/or steel.

At least part of the converter may be formed from a composite material and/or concrete and/or steel.

At least part of the wind turbine may be formed from a composite material and/or concrete and/or steel.

The device may further comprise a power take off means.

The power take off means may comprise one or more air turbines.

The device may further comprise a relief system.

The relief system may comprise one or more pressure release valves.

The present invention also provides an array of two or more devices as described herein.

One objective of some embodiments of the present invention is to propose a hybrid device capable of convert wave energy into electricity by oscillating water column, which, for example, comprises:
a chamber or collector, comprising an external hull; some ballast tanks; one to five skirts; from one to ten separate inner compartments of the oscillating water column; a system consisting of a power generation unit and an air turbine situated in the upper part of the chamber; and a security system comprising overpressure valves;
a foundation, which acts as a clamping device for capturing wave energy to the seabed (the hybrid nature of the device makes that the foundation types commonly used in the offshore wind industry are considered, being the most widespread types the monopile and the jacket frame, however other types as the tripod, the tri-pile, the GBS and the suction bucket can also be considered);
a control system comprising: a control automaton; a guidance system, a control system of setting and an anchoring system of the camera to the foundation.

The present invention also provides a hybrid device capable of convert wave energy into electricity by oscillating water column, which is composed of: First, a chamber or collector, comprising an external hull; some ballast tanks; one to five skirts; from one to ten (for example) separate inner compartments of the oscillating water column; a system consisting of a power generation unit and an air turbine situated in the upper part of the chamber; and a security system comprising overpressure valves. Second, a foundation (which acts as a clamping device for capturing wave energy to the seabed). The hybrid nature of the device makes that the foundation types commonly used in the offshore wind industry are considered, being the most widespread types the monopile and the jacket frame, however other types as the tripod, the tri-pile, the GBS and the suction bucket can also be considered. Finally and thirdly, a control system comprising a control automaton; a guidance system, a control system of setting and an anchoring system of the camera to the foundation.

The present invention may be a hybrid with an offshore wind turbine, since both can share the same foundation system.

In one embodiment the invention comprises:

a) a chamber comprising an external hull; some ballast tanks; a system of (one or more) skirts; a set of inner compartments to separate the oscillating water column; a power generation system formed by wind turbines in the upper part of the chamber; and a security system comprising pressure relief valves.
b) a foundation, preferably opting for a monopile or jacket frame type systems, although other foundation systems are suitable to be considered such as those of tri-pile, tripod and suction buckets.
c) a control system comprising a control automaton; a guidance system; a regulatory system of setting and an anchoring system of the chamber to the foundation.

In some embodiments the device can be fitted into one of the following sectors:

- As a device or generator whose driving force is moving waves and an air turbine
- As an auxiliary device of a wind generator
- Within the marine energy converters, wave or current
- Within the offshore devices mounted on monopiles

In some aspects and embodiments an external chamber hull may have a streamlined shape, being the part under freeboard preferably cylindrical or conical, while the aerial part can take: either the same shape (cylindrical or conical), rather a warped way that reduces the waves loading on the whole structure. The chamber hull could be constructed on an entire cylindrical or conical body or adopt a section of these forms.

The ballast tanks may be arranged in a double hull in the chamber walls, have a system capable of regulating the volume of water inside, so as to modify the volume and consequently vary the chamber buoyancy allowing thus simple mechanism to control the chambers draft.

Skirts or an increased length at the bottom of the chamber, which can change their shape, height and angle, so that the device can increase its energy production and so be adapted to the site characteristics.

The internal compartments are delimited by a plurality of vertical bulkheads radially placed inside the chamber, with the purpose of separating oscillating water column into these compartments and so be able to optimize the energy extraction at each one individually.

The power take off system may comprise one or more wind turbines with their suction and discharge lines of air in the chamber, may be provided either an internal compartment for each turbine or a turbine to more than one.

A security system may comprise one or more pressure relief valves which allow the release of stored pressure within the chamber in extreme waves and to control the energy production by releasing part of the pressure at high waves.

The foundation can be used to ensure a fixed connection of the device to the seabed, preferably a mono pile or jacket frame type system will be used, although other foundation systems will not be discarded, such foundation systems also enables integration into the structure of other devices, as it can be an offshore wind turbine.

A guidance and control system of the device may be provided to permit varying both the draft and the orientation of the chamber to suit the sea conditions prevailing at the time, thus optimizing the device performance.

The guidance system may allow rotation of the camera around the foundation, so that the device can achieve the optimal orientation for the sea state existing in each moment.

The draft regulation system, allows to change the depth of the chamber acting on the volume of water contained in the ballast tanks, so that the device can be adapted to the conditions of swell and tide height existing at all times.

Therefore, there is the need for a system for harnessing offshore wave energy suitable to be assembled at the same substructure or foundation of an offshore wind turbine and at the same time. Such hybrid wave-wind energy converter should be: simple to manufacture, robust to survive extreme events, have a low maintenance and operation cost and have low cost of energy.

The present invention may provide a hybrid device for capturing wave energy by oscillating water column, comprising:

a. a chamber (figure 1), comprising an outer shell (1); a ballast tank (3); a fix or variable skirt (4); from one to ten separate inner compartments of the oscillating water column (8); a system power generating turbines consisting of air (5) located in the upper part of the chamber; and a security and control system comprising pressure relief valves (6).

b. a foundation (2) preferably opting for a monopile type system, although other systems do not rule foundation such as those of "jacket frame" or "tubular truss".

c. a control system comprising a control automaton; a guidance system, a control system of setting and an anchoring system of the camera to the foundation.

The outer shell (2) has hydro-dynamically, being the part that is under the line of preferably cylindrical float, whereas the aerial part can adopt: either a cylindrical shape, while a warped shape that reduces the efforts on the structure of the waves, or both parties can adopt the above methods section that defines the angle section (β).

The ballast tanks (3) may be arranged in a double hull in the walls of the chamber, have a system for regulating the volume of water inside, so that the change of this quantity, varies the chamber buoyancy thus allowing an adjustment of the draft of it.

The skirt or extension at the lower hull of the chamber, can vary in shape (Figures 9 to 12), height (a) and the angle (α) so that the device can be adapted to the characteristics of the site.

The internal compartments (9) may be defined by a series of vertical partitions radially arranged in the interior of the chamber (8), with the purpose of separating these compartments the oscillation of the column water.

The power generating system may comprise one or more self-rectifying air turbines (5) with its respective suction and discharge ducts of the air chamber may be arranged either a turbine by each inner compartment or a turbine to more than one.

The security system (6) may comprise one or more pressure relief valves which allow the release of pressure accumulated inside the chamber in extreme waves.

The foundation (2), ensures a fixed connection of the device to the seabed, for example a mono pile type system is used, although other foundation systems is not excluded such as the tubular lattice frame or jacket, the use of this type of foundation systems integration also allows the structure of other devices, such as an offshore wind turbine.

The orientation system and regulating draft device, allows to vary both the depth and the orientation of the camera to fit the existing conditions of the sea at all times, thus optimizing device operation.

The orientation system, allowing rotation of the camera around the foundation, so that the device can achieve the optimum orientation for the sea state existing in each moment.

The control system setting, to modify the depth of the chamber acting on the volume of water contained in the ballast tanks (3), so that the device it can adapt to the conditions of swell and tide height existing at all times.

The anchoring system of the camera to the foundation, well may be disposed in a closed position, thus maintaining a supportive connection between camera and foundation, thus ensuring the rigidity of the assembly either in the open position, allowing free movement of the camera around the foundation, can act now guidance systems and regulation draft.

The present invention also provides a bottom-fixed hybrid renewable energy capture device, comprising a substructure for anchoring the device to the seabed, a wind turbine being provided on or by the substructure, and an oscillating water column wave energy collector being provided on or by the substructure, the collector comprising a collection chamber, the chamber comprising a skirt, the skirt having a mobile skirt extension movable in response to prevailing wave conditions to position it generally opposite the side of the chamber incident waves enter.

The collector may be translatable with respect to the substructure to vary the depth thereof.

The collector may be rotatable with respect to the substructure, whereby to optimise energy collection.

In one aspect the present invention provides a bottom-fixed wave energy capture device comprising a foundation and an oscillating water column energy collector device, in which the device is movable with respect to the foundation.

The device may be translatable with respect to the foundation, for example to vary the depth thereof in use. The translation may, therefore, be “up and down” within, on or around a foundation.

The device may be rotatable with respect to the foundation, for example to optimise energy collection efficiency, for example by orientating the device in a most efficient position with respect to incident waves

The device may further comprise a wind energy collector, for example an offshore wind turbine.

The foundation may be, for example, a foundation suitable for shallow and intermediate deep water, such as a jacket frame, a tubular truss, a tri-pile, or a tripod.

There may be provided means for monitoring or establishing prevailing or predicted wave conditions. This may be, for example, a buoy. The converter may be movable with respect to the foundation in response to the said wave conditions.

The converter may comprise a chamber with one or more internal oscillating water column compartments.

The chamber may comprises an outer shell. The outer shell may be, for example, generally cylindrical. In some embodiments the shell is a complete cylinder, in other embodiments the shell is a segment of a cylinder.

The chamber may be movable using a ballast/buoyancy system. For example the chamber may comprises means for varying the weight thereof.

In some embodiments the chamber may comprise one or more ballast tanks. The ballast tank/s may be formed as a double hull (for example making up the chamber outer wall).

The chamber may include means for increasing volume at a rear side thereof which is generally opposite incident waves.

The means may comprise a skirt. The skirt may be movable so that its position and/or height and/or angular extent can be varied to position it in an optimal position depending on the incident waves.

The skirt may be rotatable with respect to the chamber.

The skirt may be translatable with respect to the chamber to vary the depth thereof in use.

The angular extent of the skirt may be variable.

In some embodiments the skirt may be fixed. In such embodiments the chamber itself may be movable with respect to the foundation whereby to adjust the position of the skirt.

The chamber may comprise an outer shell and the shell may comprise a skirt.

At least part of the foundation may be formed from a composite material and/or concrete and/or steel.

At least part of the converter may be formed from a composite material and/or concrete and/or steel.

At least part of the wind turbine may be formed from a composite material and/or concrete and/or steel.

The device may further comprise a power take off means, for example one or more air turbines.

The device may comprise a relief system, for example one or more pressure release valves.

The present invention also provides a bottom-fixed hybrid renewable energy capture device, comprising a jacket frame substructure, a wind turbine being provided on or by the substructure, and an oscillating water column wave energy collector being provided on or by the substructure, the collector being translatable within the jacket frame to vary the depth thereof.

The collector may be rotatable within the frame, whereby to optimise energy collection.

The present invention also provides an array of two or more devices as described herein.

One objective of some embodiments of the present invention is to propose a hybrid device capable of convert wave energy into electricity by oscillating water column, which is composed of: First, a chamber or collector, may comprise an external hull; some ballast tanks; one to five skirts; from one to ten separate inner compartments of the oscillating water column; a system consisting of a power generation unit and an air turbine situated in the upper part of the chamber; and a security system comprising overpressure valves. Second, a foundation, which acts as a clamping device for capturing wave energy to the seabed (the hybrid nature of the device makes that the foundation types commonly used in the offshore wind industry are considered, being the most widespread types the monopile and the jacket frame, however other types as the tripod, the tri-pile, the GBS and the suction bucket can also be considered). Finally, a control system comprising: a control automaton; a guidance system, a control system of setting and an anchoring system of the camera to the foundation.

The present invention also provides a hybrid device capable of convert wave energy into electricity by oscillating water column, which is composed of: First, a chamber or collector, comprising an external hull; some ballast tanks; for example one to five skirts; from one to ten separate inner compartments of the oscillating water column; a system consisting of a power generation unit and an air turbine situated in the upper part of the chamber; and a security system comprising overpressure valves. Second, a foundation (which acts as a clamping device for capturing wave energy to the seabed). The hybrid nature of the device makes that the foundation types commonly used in the offshore wind industry are considered, being the most widespread types the monopile and the jacket frame, however other types as the tripod, the tri-pile, the GBS and the suction bucket can also be considered. Finally and thirdly, a control system comprising a control automaton; a guidance system, a control system of setting and an anchoring system of the camera to the foundation.

The present invention may be a hybrid with an offshore wind turbine, since both can share the same foundation system.

In one embodiment the invention comprises:

d) a chamber comprising an external hull; some ballast tanks; a system of skirts; a set of inner compartments to separate the oscillating water column; a power generation system formed by wind turbines in the upper part of the chamber; and a security system comprising pressure relief valves.

e) a foundation, preferably opting for a monopile or jacket frame type systems, although other foundation systems are suitable to be considered such as those of tri-pile, tripod and suction buckets.

f) a control system comprising a control automaton; a guidance system; a regulatory system of setting and an anchoring system of the chamber to the foundation.

In some embodiments the device can be fitted into one of the following sectors:

- As a device or generator whose driving force is moving waves and an air turbine
- As an auxiliary device of a wind generator
- Within the marine energy converters, wave or current
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In some aspects and embodiments an external chamber hull may have a streamlined shape, being the part under freeboard preferably cylindrical or conical, while the aerial part can take: either the same shape (cylindrical or conical), rather a warped way that reduces the waves loading on the whole structure. The chamber hull could be constructed on an entire cylindrical or conical body or adopt a section of these forms.

The ballast tanks may be arranged in a double hull in the chamber walls, have a system capable of regulating the volume of water inside, so as to modify the volume and consequently vary the chamber buoyancy allowing thus simple mechanism to control the chambers draft.

Skirts or an increased length at the bottom of the chamber, which can change their shape, height and angle, so that the device can increase its energy production and so be adapted to the site characteristics.

The internal compartments are delimited by a plurality of vertical bulkheads radially placed inside the chamber, with the purpose of separating oscillating water column into these compartments and so be able to optimize the energy extraction at each one individually.

The power take off system may comprise one or more wind turbines with their suction and discharge lines of air in the chamber, may be provided either an internal compartment for each turbine or a turbine to more than one.

A security system may comprise one or more pressure relief valves which allow the release of stored pressure within the chamber in extreme waves and to control the energy production by releasing part of the pressure at high waves.

The foundation can be used to ensure a fixed connection of the device to the seabed, preferably a mono pile or jacket frame type system will be used, although other foundation systems will not be discarded, such foundation systems also enables integration into the structure of other devices, as it can be an offshore wind turbine.

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The guidance system may allow rotation of the camera around the foundation, so that the device can achieve the optimal orientation for the sea state existing in each moment.

The draft regulation system, allows to change the depth of the chamber acting on the volume of water contained in the ballast tanks, so that the device can be adapted to the conditions of swell and tide height existing at all times.

Therefore, there is the need for a system for harnessing offshore wave energy suitable to be assembled at the same substructure or foundation of an offshore wind turbine and at the same time. Such hybrid wave-wind energy converter should be: simple to manufacture, robust to survive extreme events, have a low maintenance and operation cost and have low cost of energy.

The present invention may provide a hybrid device for capturing wave energy by oscillating water column, comprising:

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The ballast tanks (3) may be arranged in a double hull in the walls of the chamber, have a system for regulating the volume of water inside, so that the change of this quantity, varies the chamber buoyancy thus allowing an adjustment of the draft of it.

The skirt or extension at the lower hull of the chamber, can vary in shape (Figure 9 to 12), height (a) and the angle (α) so that the device can be adapted to the characteristics of the site.

The internal compartments (9) may be defined by a series of vertical partitions radially arranged in the interior of the chamber (8), with the purpose of separating these compartments the oscillation of the column water.

The power generating system may comprise one or more self-rectifying air turbines (5) with its respective suction and discharge ducts of the air chamber may be arranged either a turbine by each inner compartment or a turbine to more than one.

The security system (6) may comprise one or more pressure relief valves which allow the release of pressure accumulated inside the chamber in extreme waves.

The foundation (2), ensures a fixed connection of the device to the seabed, for example a mono pile type system is used, although other foundation systems is not excluded such as the tubular lattice frame or jacket, the use of this type of foundation systems integration also allows the structure of other devices, such as an offshore wind turbine.

The orientation system and regulating draft device, allows to vary both the depth and the orientation of the camera to fit the existing conditions of the sea at all times, thus optimizing device operation.

The orientation system, allowing rotation of the camera around the foundation, so that the device can achieve the optimum orientation for the sea state existing in each moment.

The control system setting, to modify the depth of the chamber acting on the volume of water contained in the ballast tanks (3), so that the device it can adapt to the conditions of swell and tide height existing at all times.

The anchoring system of the camera to the foundation, well may be disposed in a closed position, thus maintaining a supportive connection between camera and foundation, thus ensuring the rigidity of the assembly either in the open position, allowing free movement of the camera around the foundation, can act now guidance systems and regulation draft.

Different aspects and embodiments of the invention may be used separately or together.

Further particular and preferred aspects of the present invention are set out in the accompanying independent and dependent claims. Features of the dependent claims may be combined with the features of the independent claims as appropriate, and in combination other than those explicitly set out in the claims.

Brief description of the drawings

The present invention will now be more particularly described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 represents a perspective view of the overall system of invention, formed by a chamber (1), which presents a preferably cylindrical hydrodynamic shape; an anchoring system (2) to enable a supportive binding device to the seabed; a ballast tank (3), which is arranged as a double hull in the outer wall of the chamber; a skirt (4) or extension at the bottom of the chamber; one or more turbines (5) with respective suction conduits, in the upper part and a security and control system comprising pressure relief valves (6).

Figure 2 shows a front elevation of the device, wherein the fastening system (2) integrally attached to the seabed is shown; Camera (1) which is semi-submerged line can be seen from the free surface; the skirt (4) or extension at the bottom of the chamber and the turbine (5).

Figure 3 shows a top plan view of the device, which can be seen: the ballast tank (3), which is arranged as a double outer hull and bulkheads separating the inner area (7).

Figure 4 is a rear elevation of the device, which can be seen the ballast tank (3); bulkheads separating the internal zones (7) and the security system (6).

Figure 5 is a representation of a cut made in the elevation of Fig its median plane AA, as shown in the diagram below. It can be seen: the ballast tank (3) and bulkheads separating the inner areas (7).

Figure 6 is a sectional plan view of the lip area, by the plane B, wherein the angle (8) defining the opening of the lip can be observed.

Figure 7 represents a top plan view of the device in which can be seen the angle (9).

Figure 8 shows a perspective view of an alternative configuration of the chamber (1), for an angle (9) of the lower chamber 180.

Figures 9, 10, 11 and 12 show four respective examples of possible alternative skirt and lip shapes.

Figures 13, 14 and 15 show three respective examples of possible alternative camera settings (1).

Figure 16 is a view of the device mounted on a wind turbine with a monopile foundation.

Figure 17 is a view of the device mounted on a wind turbine with a jacket frame foundation.

Figure 18 is a view of the device mounted on a monopile foundation without wind turbine.

Detailed description of preferred embodiments

The example embodiments are described in sufficient detail to enable those of ordinary skill in the art to embody and implement the systems and processes herein described. It is important to understand that embodiments can be provided in many alternate forms and should not be construed as limited to the examples set forth herein.

Accordingly, while embodiment can be modified in various ways and take on various alternative forms, specific embodiments thereof are shown in the drawings and described in detail below as examples. There is no intent to limit to the particular forms disclosed. On the contrary, all modifications, equivalents, and alternatives falling within the scope of the appended claims should be included. Elements of the example embodiments are consistently denoted by the same reference numerals throughout the drawings and detailed description where appropriate.

Unless otherwise defined, all terms (including technical and scientific terms) used herein are to be interpreted as is customary in the art. It will be further understood that terms in common usage should also be interpreted as is customary in the relevant art and not in an idealised or overly formal sense unless expressly so defined herein.

1. Physical Structure – First Embodiment

Referring now to the drawings, wherein like reference numbers are used to designate like elements throughout the various views, several embodiments of the present invention are further described. The figures are not necessary drawn to scale, and in some instances the drawings have been exaggerated or simplified for illustrative purposes only. One of ordinary skill in the art will appreciate the many possible applications and variations of the present invention based on the following examples of possible embodiments of the present invention.

With reference to Figure 1, a hybrid wave and wind energy converter in accordance with the preferred embodiment is shown and it is collectively referred to as a hybrid device. The hybrid device comprises a chamber, a foundation (2) and a control system. The hybrid device chamber comprises an outer shell (1), a ballast tank (3), a fix or variable skirt (4), one or more air turbines (5) and a security and control system composed by pressure relief valves (6). The outer shell (1), the ballast tank (3) and the inner shell (7) form the hull of the hybrid device; the hull fixes the geometry and gives structural integrity to the hybrid device, in particular the outer shell act as the main interface with the natural environment and protects the hybrid device from braking waves or possible impacts. The ballast tanks (3) are constructed as part of the inside part of the hull and have a system to regulate the volume of water contained on it (or ballast), so that the change of this quantity, varies the chamber buoyancy thus allowing an adjustment of the draft of it. The fixed or variable skirt (4) is an extension of the bottom of the chamber at the opposite side of the incident waves and has the purpose to increase the performance of the hybrid device by incrementing the added mass at the back side of the chamber, the length (a) and angle (α) of the skirt can be fixed after or variable. One or multiple air turbines (5) are the Power Take Off (PTO) system of the hybrid device and are positioned at the upper part of the chamber, each one of them is connected to each one of the internal compartments (9). A security and control pressure relief system (6) to reduce the internal pneumatic pressure produced by large waves, this is composed of one or a set of various pressure relief valves for each one of the internal compartments of the hybrid device.

With reference to Figure 2, a frontal view of the hybrid device mounted on a monopile type of foundation assembly is shown. In this frontal view, the following elements of the hybrid device can be appreciated: the foundation (2), the ballast tank (3), the chamber skirt (4), the air turbines (5), the inner shell (7), and the internal compartments (9). This section shows clearly the non-visible internal parts as the internal compartments (9), the hull and the skirt (4).

With reference to Figure 3, a top view of the hybrid device mounted on a monopile type of foundation assembly is shown. In this top view, the following elements of the hybrid device can be appreciated: the external shell (1), the ballast tank (3), the air turbines (5), the inner shell (7), and the bulkheads of the internal compartments (8). This section shows clearly the non-visible internal parts as the bulkheads of the internal compartments (8) and the hull.

With reference to Figure 4, a back view of the hybrid device mounted on a monopile type of foundation assembly is shown. In this back view, the following elements of the hybrid device can be appreciated: the ballast tank (3), security and control pressure relief system (6), and the bulkheads of the internal compartments (8). This section shows clearly the non-visible internal parts as the bulkheads of the internal compartments (8) and the hull.

With reference to Figure 5, a section AA view of the hybrid device mounted on a monopile type of foundation assembly is shown. In this section view, the following elements of the hybrid device can be appreciated: the ballast tank (3), the bulkhead of the internal compartments (8) and the variable height of the skirt of the chamber (a). This section shows clearly the possible variation in height of the skirt of the chamber.

With reference to Figure 6, a section BB view of the hybrid device mounted on a monopile type of foundation assembly is shown. In this section view, the following elements of the hybrid device can be appreciated: the foundation (2), the ballast tank (3) and the angle of aperture of the variable skirt of the chamber (α). This section has the main purpose of defining the variable angle for the skirt aperture (α).

With reference to Figure 7, a top view of the hybrid device with a partial chamber mounted on a monopile type of foundation assembly is shown. This top view of the representation shown in Figure 8 defines the angle of aperture of the hybrid device's chamber (β) for those device's configurations where the chamber has some aperture.

With reference to Figure 8, an isometric representation of the hybrid device with a partial chamber mounted on a monopile type of foundation assembly is shown. This representation shows an alternative embodiment where the chamber of the hybrid device is an angular section of the one defined on previous figures.

With reference to Figure 9, a section AA view of the hybrid device mounted on a monopile type foundation assembly is show. This section view represents a modified version of the one showed in Figure 5 where the external part of the skirt (the rear bottom part of the device, being the front the part facing the incident waves) geometry has been modified. The modified geometry has as objective to increase the volume of the hull.

With reference to Figure 10, a section AA view of the hybrid device mounted on a monopile type foundation assembly is show. This section view represents a modified version of the one showed in Figure 9 where the external part of the lip (the front bottom part of the device, being the one facing the incident waves) and the skirt (the rear bottom part of the device) geometry has been modified. The modified geometry has as objective to increase the volume of the hull.

With reference to Figure 11, a section AA view of the hybrid device mounted on a monopile type foundation assembly is show. This section view represents a modified version of the one showed in Figure 9 where the external and internal parts of the skirt (the rear bottom part of the device, being the front the part facing the incident waves) geometry has been modified. The modified geometry has as objective to increase the volume of the hull.

With reference to Figure 12, a section AA view of the hybrid device mounted on a monopile type foundation assembly is show. This section view represents a modified version of the one showed in Figure 10 where the external and internal parts of the lip (the front bottom part of the device, being the one facing the incident waves) and the skirt (the rear bottom part of the device) geometry has been modified. The modified geometry has as objective to increase the volume of the hull.

With reference to Figure 13, an isometric representation of the hybrid device with a warped aerial part chamber mounted on a monopile type of foundation assembly is shown. This representation shows an alternative embodiment where the upper part of the chamber of the hybrid device has a warped shape to reduce the eave loads over the whole structure.

With reference to Figure 14, an isometric representation of the hybrid device with a warped aerial part and partial chamber mounted on a monopile type of foundation assembly is shown. This representation shows an alternative embodiment where the chamber is a modified version of the one on Figure 9 by combining this with the one on Figure 8.

With reference to Figure 15, an isometric representation of the hybrid device with a warped aerial part and partial chamber mounted on a monopile type of foundation assembly is shown. This representation shows an alternative embodiment where the chamber is a modified version of the one on Figure 9 by positioning the air turbine at the back part of the chamber.

With reference to Figure 16, a frontal view of hybrid device mounted on an offshore wind turbine with a monopile foundation type is shown. This frontal view shows an operational representation of the first embodiment of the hybrid device is mounted on a wind turbine with a monopile foundation system.

With reference to Figure 17, a frontal view of hybrid device mounted on an offshore wind turbine with a jacket frame foundation type is shown. This frontal view shows an operational representation of an alternative embodiment where the hybrid device is mounted on a wind turbine with a jacket frame foundation system.
With reference to Figure 18, a frontal view of hybrid device mounted on a monopile foundation type without wind turbine is shown. This frontal view shows an operational representation of the alternative embodiment, represented in Figure 9 and 10, where the hybrid device is mounted on a monopile foundation system without wind turbine.

2. Operation

The embodiments depend where the hybrid device is sited and on what type of foundation system the offshore wind turbine has. The preferred embodiment is for a site where the cylindrical chamber Figure 1 is mounted on a wind turbine with a monopile foundation system Figure 12. The dimensions of the hybrid device chamber and internal compartments have been optimized for the most common wave lengths at the site. The shape and the range of for the height (a) and angle (α) of the skirt of the chamber has been optimized to cover the range of the most relevant wave heights and directions at the site. An optimum site would have (i) a water depth suitable for the installation of wind turbines with a monopile type of foundation, which usually ranges from 10 to 30 meters; and (ii) combined wave and wind resource which makes suitable a combined harness of both energies. The control system integrated into the hybrid device would be suitable to adapt the draft and orientation of the chamber to shelf adjust the chamber conditions to maximize its power output for the wave conditions existent at a certain moment. The power extraction of the hybrid device is obtained from the air turbines placed at the top of the chamber. The overpressure system positioned at the top of the chamber would relief the chamber pressure due to large waves in order to reduce the high pressure effects over the air turbine (e.g., reducing the stall during operation at higher ranges, or reduce high pressures during a storm event). The preferred embodiment operation will now be described when it is located at an optimum site.

With reference to Figure 1, the construction materials of the hybrid device will determine the general dimensions of the chamber of the hybrid device and the possible reinforcements for the combined foundation. On one hand, the design wavelength together with the material selection will be the design criteria to decide a total chamber diameter or external size. On the other hand, the design wave height together with the material choice will be the main factors to determine the total size of the chamber. The draft of the chamber together with the volume of air inside the chamber will be designed to maximize the power extraction and to minimize the risk of intrusion of sea water the inside the air turbine.

With reference to Figure 2, Figure 3 and Figure 4, a set of a bi-directional shelf rectifying air turbine and an electrical generator (5) per internal compartment (9) are located at the top of the OWC chamber of the hybrid device. The air turbines are connected in one side to the internal part of the chamber and on the other open to the atmosphere. The axis of the air turbine is connected to an electrical generator which is connected to the electrical grid to export the energy production. The ballast tanks (3) placed between the inner (7) and external shell (7) of the hybrid device have the structural strengthens to support the external actions of the wave loading under extreme events. The ballast tank has incorporated a system to pump in and out sea water in order to control the ballast inside the tanks and vary so the draft of the hybrid device. The sub-system that control s the volume of water inside the ballast tank is part of the global control system of the hybrid device, which has the purpose to maximize its energy production and protect it under extreme conditions. Finally, the construction materials for the bulkheads (8) that divide the chamber into the internal compartments (9) are the same ones that the ones used for the main chamber. Preferably composite materials such as fiber glass or carbon fiber will be used; however, steel or reinforced concrete can also be considered.

With reference to Figure 5 and Figure 6, the hybrid device has a skirt (4) or extension of the bottom rear part of the ballast tank which is variable in shape/geometry (Figures 9 to 12), height (a) and aperture angle (α). This skirt cam be either fix or mobile, however, in both configurations the fix or variable range of values of (a) and (α) have been optimized for the most common sea conditions existent at the selected deployment site. In the configuration with the variable skirt this will controlled by the global control system to maximize the performance of the hybrid device. In this preferred embodiment the skirt will adopt the variable configuration ranging from 0.5 and 3 metres in height and between 90 and 270 degrees in aperture.

With reference to Figure 12, the hybrid device is shown attached to an offshore wind turbine in the preferred embodiment. The hybrid device in this configuration is able to vary its relative position with the wind turbine in the vertical axis (height) and rotate around the turbine, in order to orient itself to face the direction of the incident waves and maximize its energy production.

3. Alternative Embodiments

One skilled in the art will recognize the many possible embodiments of the present invention. The hybrid device skirt (4) could be used as fixed or variable. The orientation and draft variation of the chamber can be neglected and just keep a fixed configuration where the chamber remain solidary linked to the foundation with no movement allowed. The chamber can be divided into various or just one internal compartments in order to increase the energy production and reduce the nominal power of the air turbines or just use a single one chamber one turbine configuration. The shape and angle of the chamber can vary in order to reduce weight or minimize the hydrodynamic loads over the foundation. Some examples of possible embodiments are described and can be seen in Figure 9, Figure 10, Figure 11, Figure 13 and Figure 14.

Although illustrative embodiments of the invention have been disclosed in detail herein, with reference to the accompanying drawings, it is understood that the invention is not limited to the precise embodiments shown and that various changes and modifications can be effected therein by one skilled in the art without departing from the scope of the invention.

CLAIMS

1. A bottom-fixed wave energy capture device comprising a foundation and an oscillating water column energy collector device, in which the device comprises a collection chamber and the chamber includes means for changing a position of a surface of the chamber so there is an increased surface area against which waves coming from a generally opposite direction impact.

2. A device as claimed in claim 1, in which the means for increasing volume comprises a skirt.

3. A device as claimed in claim 2, in which the skirt is movable.

4. A device as claimed in claim 3, in which the skirt is rotatable with respect to the chamber.

5. A device as claimed in any of claims 2 to4, in which the skirt is translatable with respect to the chamber to vary the depth thereof in use.

6. A device as claimed in any of claims 2 to 5, in which the angular extent of the skirt is variable.

7. A device as claimed in claim 2, in which the skirt is fixed.

8. A device as claimed in any preceding claim, in which the chamber is movable with respect to the foundation whereby to adjust the position of the skirt.

9. A device as claimed in any preceding claim, in which the chamber comprises an outer shell and the shell comprises a skirt.

10. A device as claimed in any preceding claim, in which the device is translatable with respect to the foundation.

11. A device as claimed in any preceding claim, further comprising a wind energy collector.

12. A device as claimed in claim 11, in which the wind energy collector is an offshore wind turbine.

13. A device as claimed in any preceding claim, in which the foundation is a jacket frame, a tubular truss, a tri-pile, or a tripod.

14. A device as claimed in any preceding claim, in which there is provided means for monitoring or establishing prevailing or predicted wave conditions.

15. A device as claimed in claim 14, in which the skirt and/or chamber is movable with respect to the foundation in response to the said wave conditions.

16. A device as claimed in any preceding claim, in which the chamber comprises one or more internal oscillating water column compartments.

17. A device as claimed in any preceding claim, in which the chamber comprises an outer shell

18. A device as claimed in any preceding claim, in which the chamber comprises means for varying the weight thereof.

19. A device as claimed in claim 18, in which the chamber comprises one or more ballast tanks.

20. A device as claimed in claim 19, in which the ballast tank/s are formed as a double hull.

21. A device as claimed in any preceding claim, in which at least part of the foundation is formed from a composite material and/or concrete and/or steel.

22. A device as claimed in any preceding claim, in which at least part of the converter is formed from a composite material and/or concrete and/or steel.

23. A device as claimed in any preceding claim, in which at least part of the wind turbine is formed from a composite material and/or concrete and/or steel.

24. A device as claimed in any preceding claim, further comprising a power take off means.

25. A device as claimed in claim 24, in which the power take off means comprise one or more air turbines.

26. A device as claimed in any preceding claim, further comprising a relief system.

27. A device as claimed in claim 26, in which the relief system comprises one or more pressure release valves.

28. A bottom-fixed hybrid renewable energy capture device, comprising a substructure for anchoring the device to the seabed, a wind turbine being provided on or by the substructure, and an oscillating water column wave energy collector being provided on or by the substructure, the collector comprising a collection chamber, the chamber comprising a skirt, the skirt having a mobile skirt extension movable in response to prevailing wave conditions to position it generally opposite the side of the chamber incident waves enter.

29. A device as claimed in claim 28, in which the collector is translatable with respect to the substructure to vary the depth thereof.

30. A device as claimed in claim 28 or claim 29, in which the collector is rotatable with respect to the substructure, whereby to optimise energy collection.

31. A device substantially as hereinbefore described with reference to, and as shown in, the accompanying drawings.

32. An array of two or more devices as claimed in any preceding claim.

33. A bottom-fixed wave energy capture system comprising a foundation and an oscillating water column energy collector device, in which the collector device is movable with respect to the foundation.

34. A system as claimed in claim 33, in which the device is translatable with respect to the foundation.

35. A system as claimed in claim 33 or claim34, in which the device is rotatable with respect to the foundation.

36. A system as claimed in any preceding claim, further comprising a wind energy collector.

37. A system as claimed in claim 36, in which the wind energy collector is an offshore wind turbine.

38. A system as claimed in any preceding claim, in which the foundation is a jacket frame, a tubular truss, a tri-pile, or a tripod.

39. A system as claimed in any preceding claim, in which there is provided means for monitoring or establishing prevailing or predicted wave conditions.

40. A system as claimed in claim 39, in which the converter is movable with respect to the foundation in response to the said wave conditions.

41. A system as claimed in any preceding claim, in which the converter comprises a chamber with one or more internal oscillating water column compartments.

42. A system as claimed in claim 41, in which the chamber comprises an outer shell

43. A system as claimed in claim 41, in which the chamber comprises means for varying the weight thereof.

44. A system as claimed in claim 41, in which the chamber comprises one or more ballast tanks.

45. A system as claimed in claim 44, in which the ballast tank/s are formed as a double hull.

46. A system as claimed in any of claims 41 to 45, in which the chamber includes means for increasing volume at a rear side thereof which is generally opposite incident waves.

47. A system as claimed in claim 46, in which the means comprise a skirt.

48. A system as claimed in claim 47, in which the skirt is movable.

49. A system as claimed in claim 48, in which the skirt is rotatable with respect to the chamber.

50. A system as claimed in any of claims 47 to 49, in which the skirt is translatable with respect to the chamber to vary the depth thereof in use.

51. A system as claimed in any of claims 47 to 50, in which the angular extent of the skirt is variable.

52. A system as claimed in claim 47, in which the skirt is fixed.

53. A system as claimed in any of claims 47 to 52, in which the chamber is movable with respect to the foundation whereby to adjust the position of the skirt.

54. A system as claimed in any of claims 47 to 53, in which the chamber comprises an outer shell and the shell comprises a skirt.

55. A system as claimed in any preceding claim, in which at least part of the foundation is formed from a composite material and/or concrete and/or steel.

56. A device as claimed in any preceding claim, in which at least part of the converter is formed from a composite material and/or concrete and/or steel.

57. A device as claimed in any preceding claim, in which at least part of the wind turbine is formed from a composite material and/or concrete and/or steel.

58. A system as claimed in any preceding claim, further comprising a power take off means.

59. A system as claimed in claim 58, in which the power take off means comprise one or more air turbines.

60. A system as claimed in any preceding claim, further comprising a relief system.

61. A system as claimed in claim 60, in which the relief system comprises one or more pressure release valves.

62. A bottom-fixed hybrid renewable energy capture device, comprising a jacket frame substructure, a wind turbine being provided on or by the substructure, and an oscillating water column wave energy collector being provided on or by the substructure, the collector being translatable within the jacket frame to vary the depth thereof.

63. A device as claimed in claim 62, in which the collector is rotatable within the frame, whereby to optimise energy collection.

64. A device substantially as hereinbefore described with reference to, and as shown in, the accompanying drawings.

65. An array of two or more systems or devices as claimed in any preceding claim.

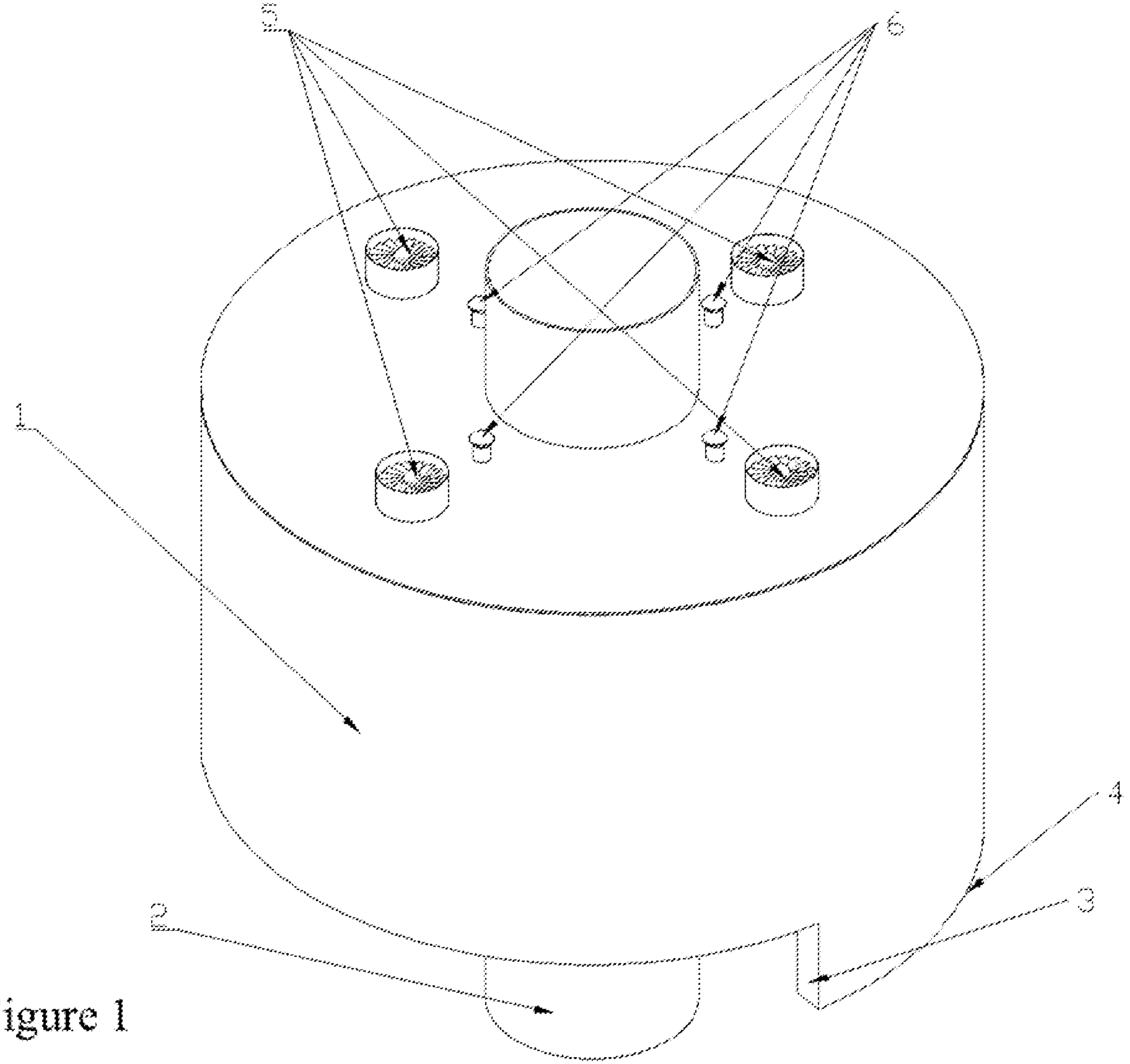


Figure 1

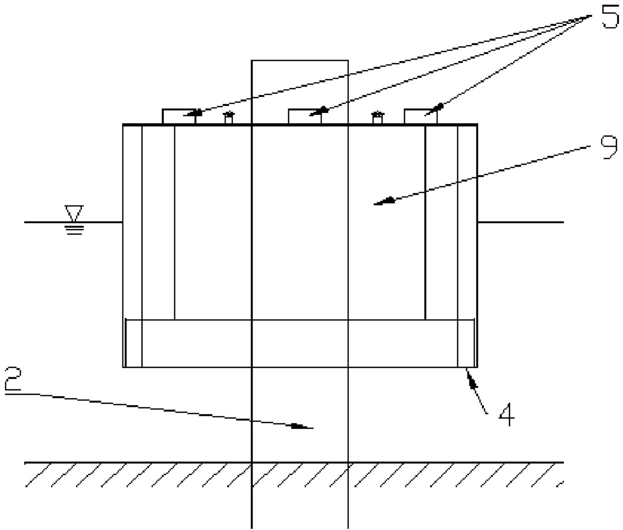


Figure 2

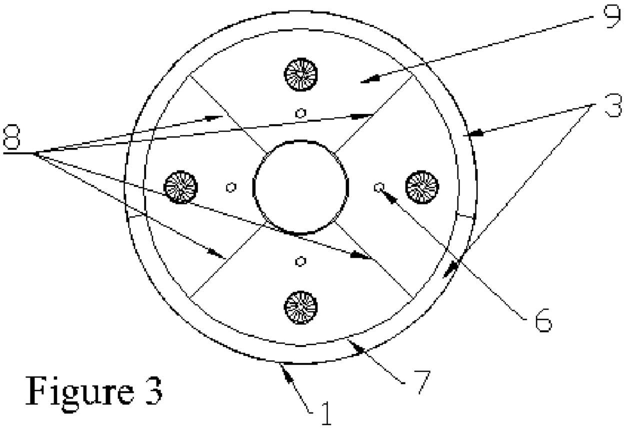


Figure 3

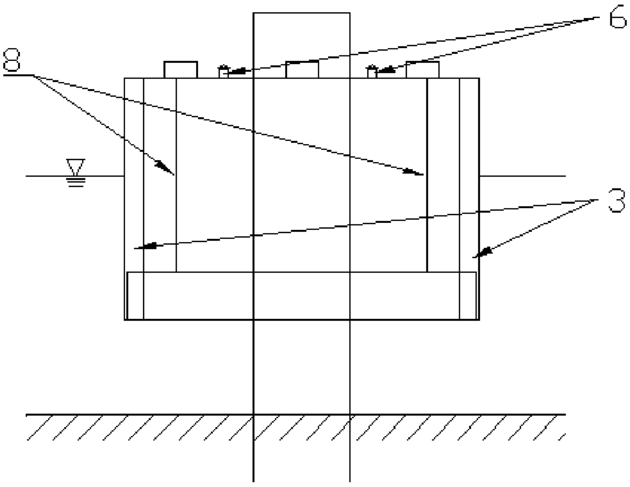
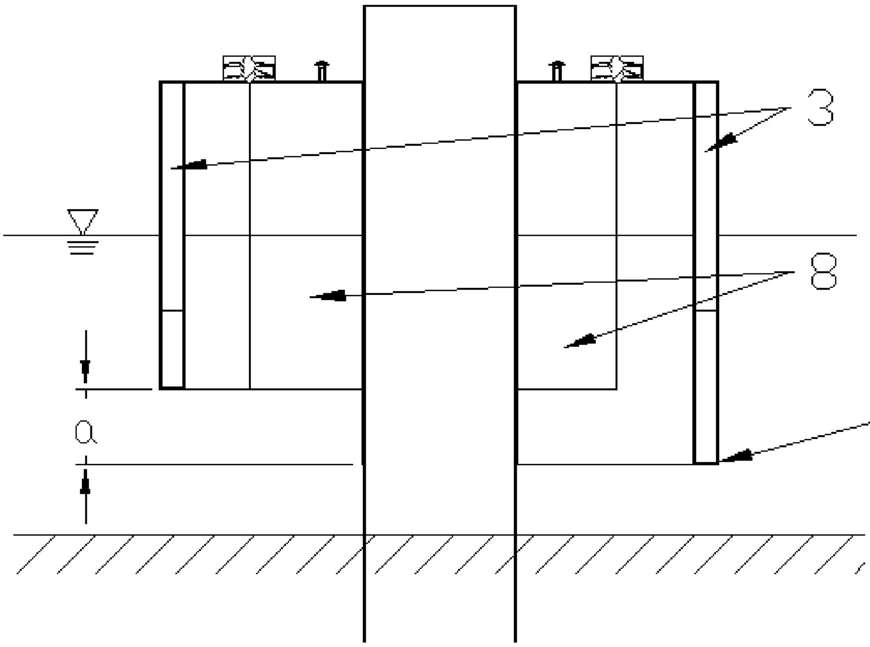


Figure 4



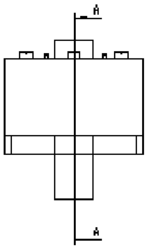
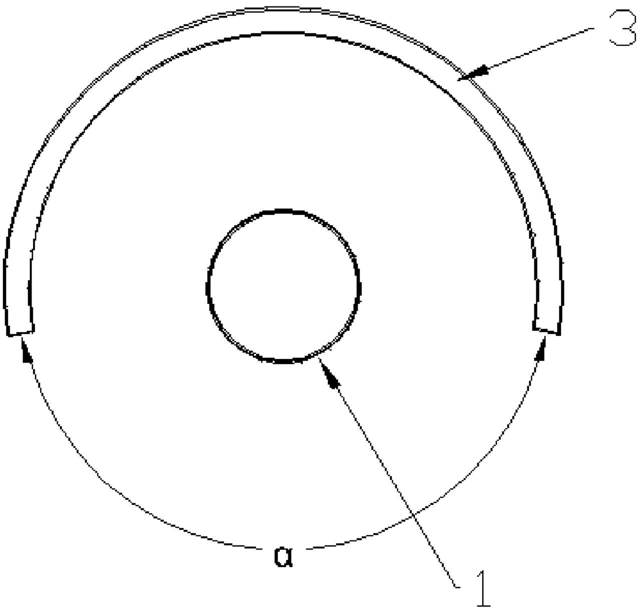


Figure 5



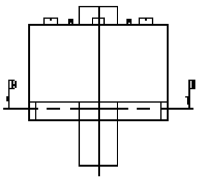


Figure 6

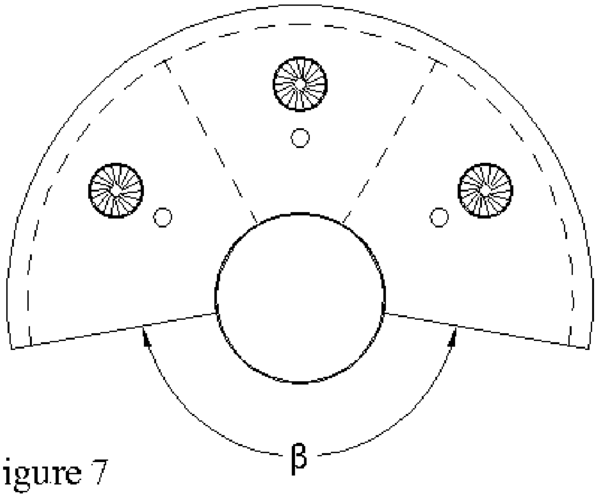


Figure 7

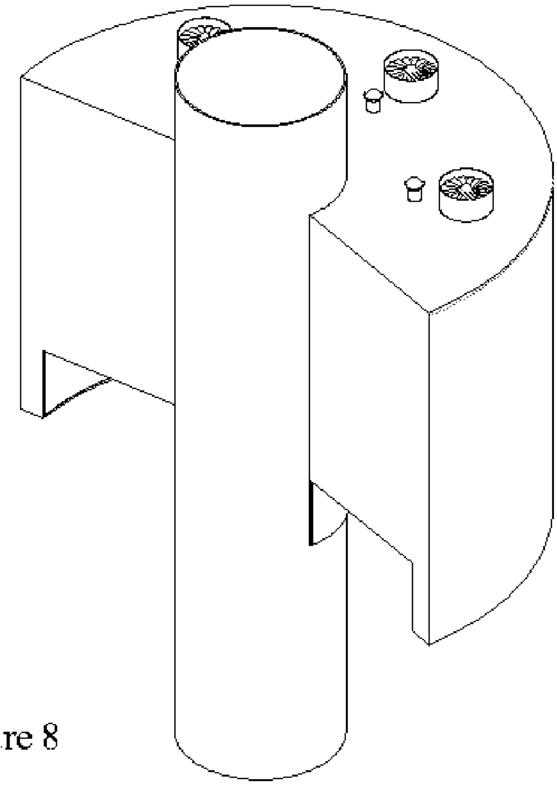


Figure 8

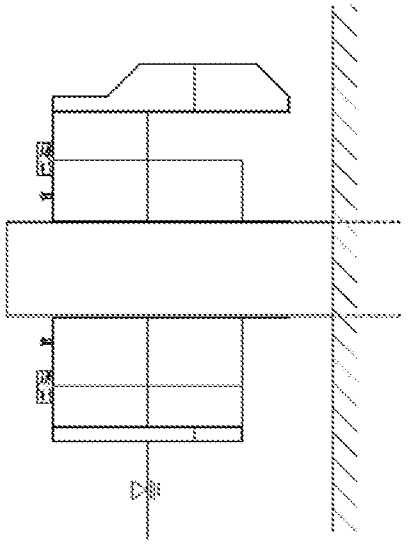


Figure 9

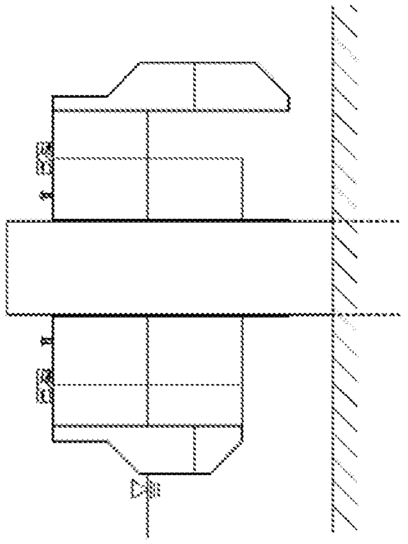


Figure 10

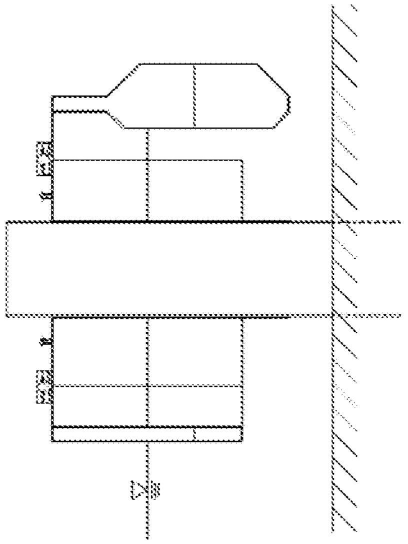


Figure 11

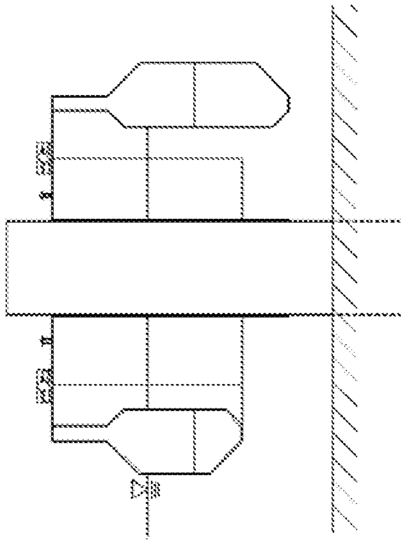


Figure 12

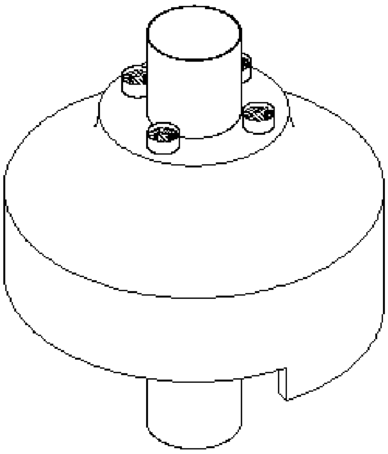


Figure 13

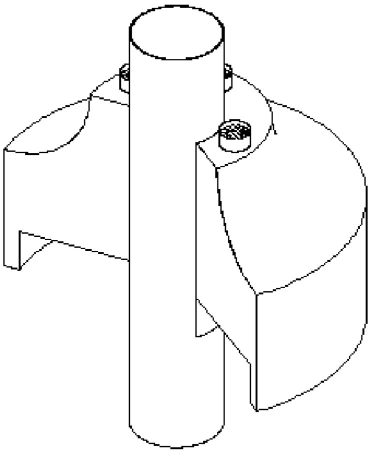


Figure 14

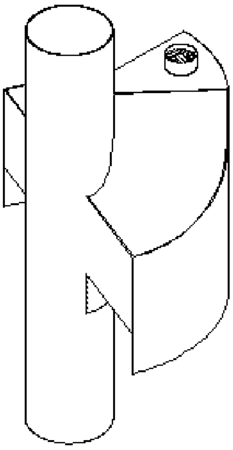


Figure 15

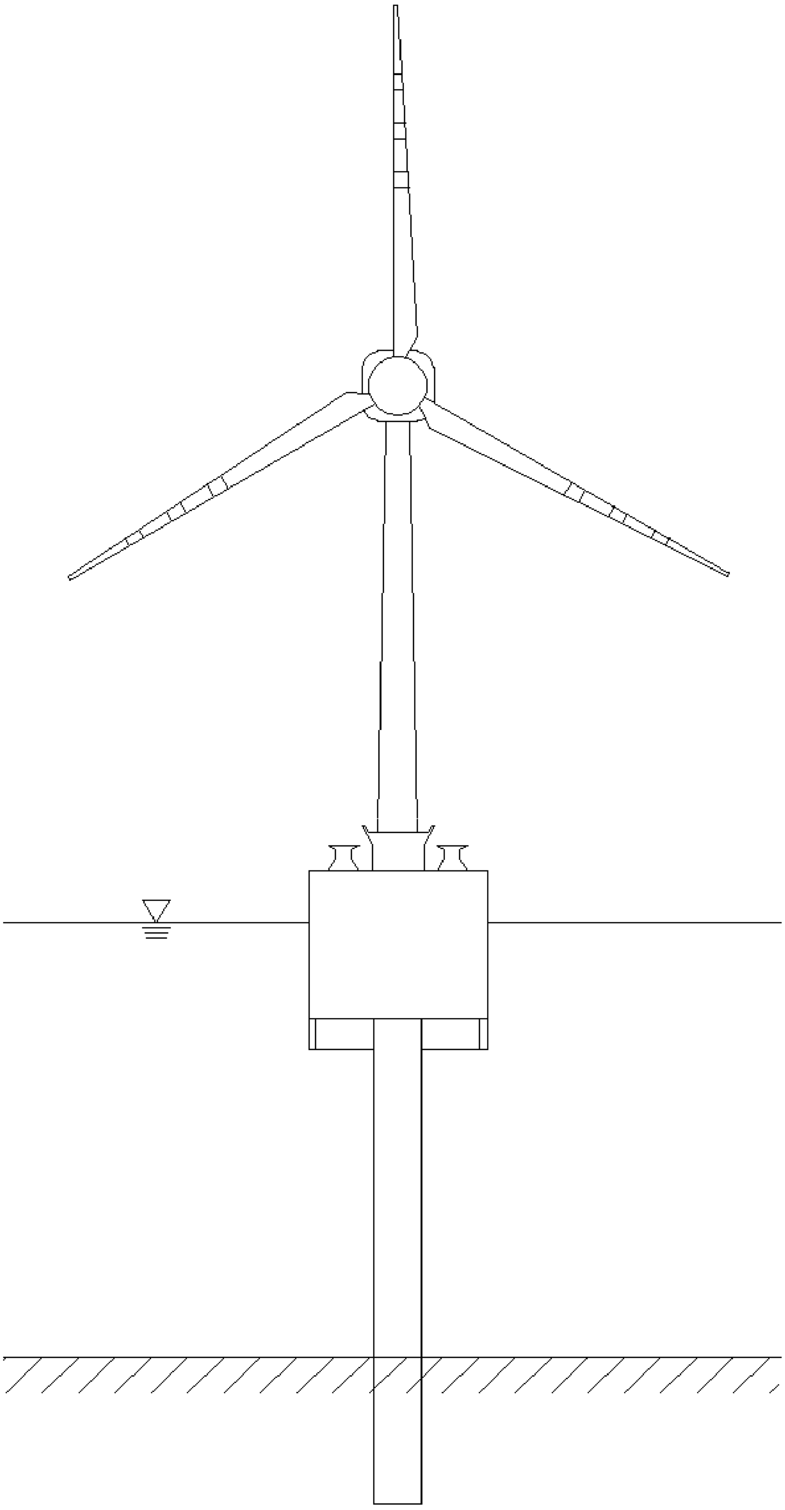


Figure 16

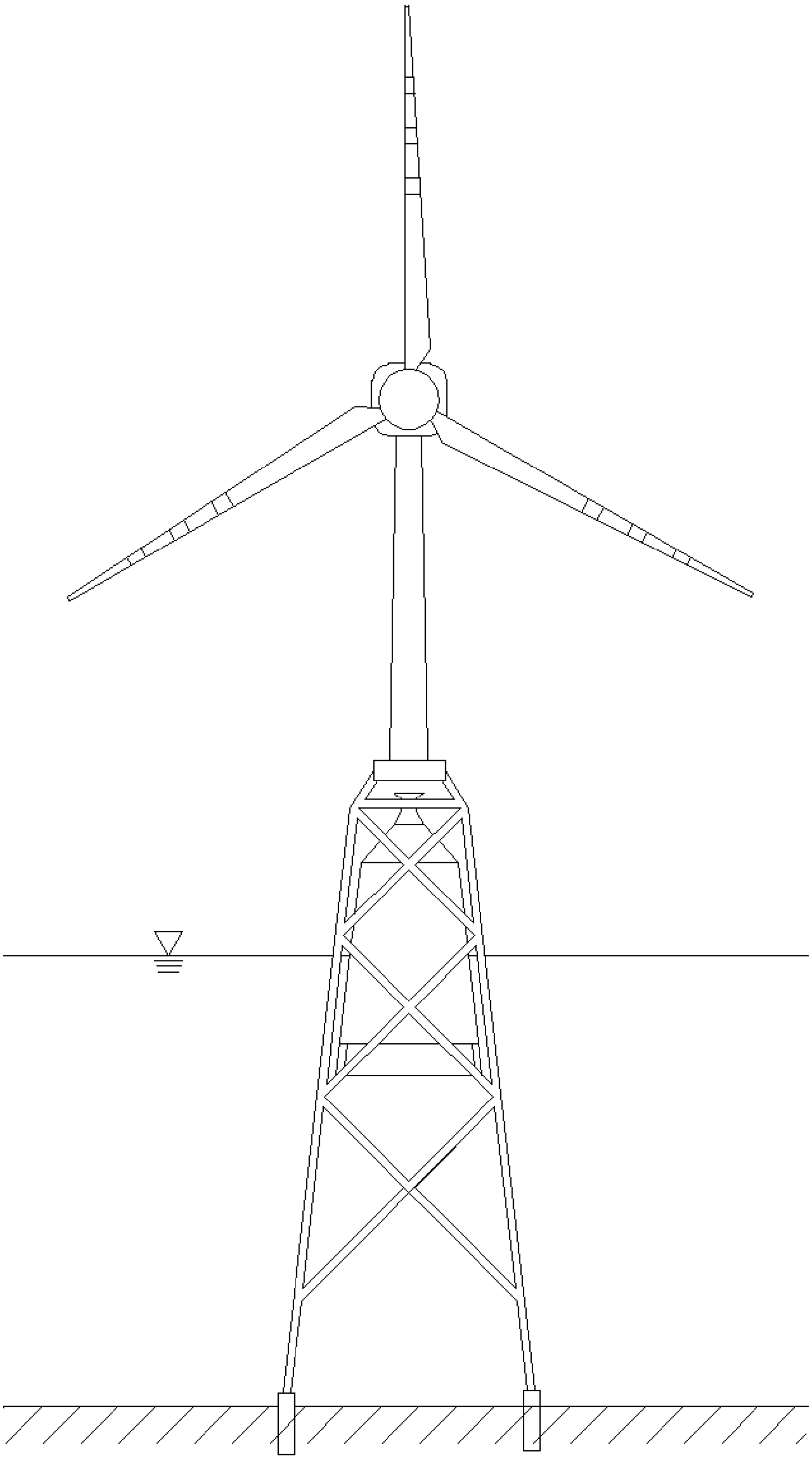


Figure 17

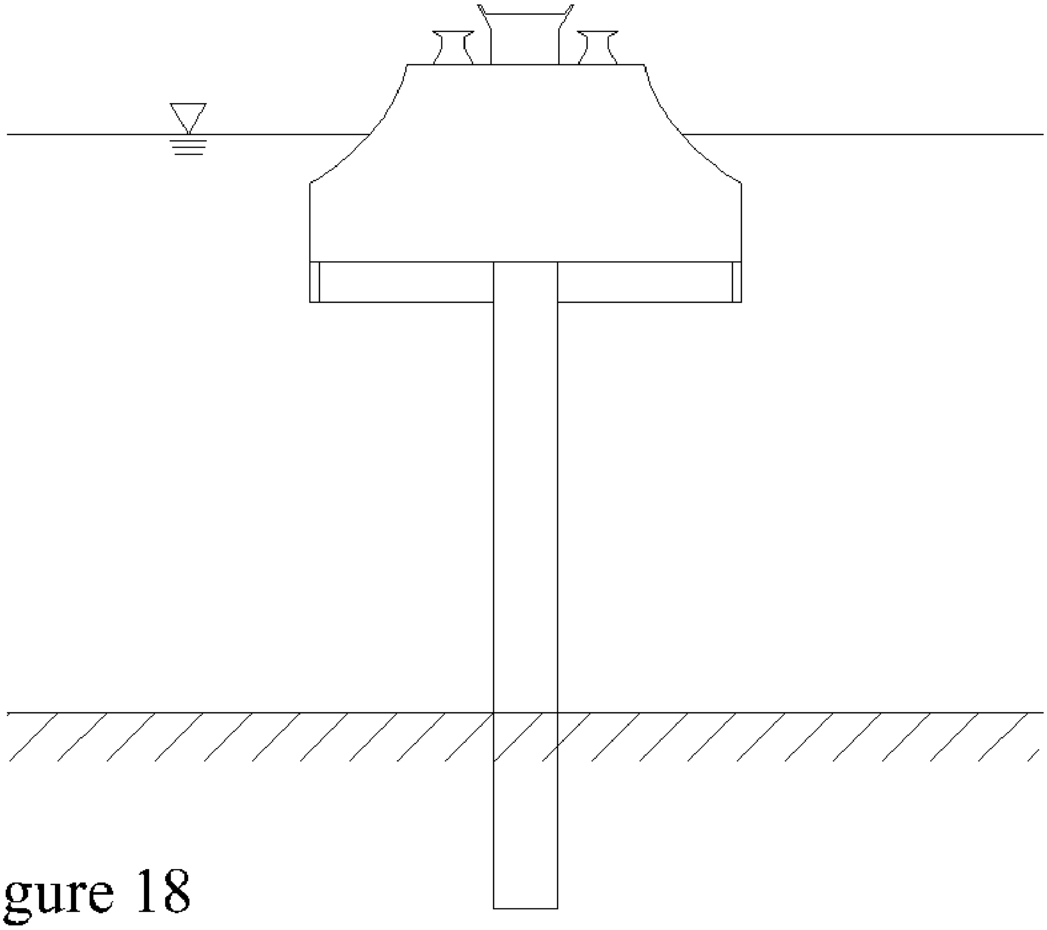


Figure 18

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2016/051403

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D9/00 F03B13/14
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F03D F03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 848 802 A1 (RICERCA SUL SIST ENERGETICO RSE S P A [IT]) 18 March 2015 (2015-03-18) paragraphs [0018], [0032] - [0036]; claims 1,2 ----- -/--	1-3, 6-10, 14-17, 21-24, 26-34, 39-42, 46-48, 52-56, 58,60-65

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

29 July 2016

Date of mailing of the international search report

05/08/2016

Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2016/051403

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	paragraphs [0014] - [0017], [0022] - [0024], [0041] - [0051], [0067], [0079], [0120] - [0129], [0134] - [0151]; figures -----	28-32, 47-54
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