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(54) **Title:** METHOD AND SYSTEMS OF MAINTAINING AN OFFSHORE POWER PLANT THAT USES AN AIRCRAFT ATTACHED TO A FLOATING STRUCTURE

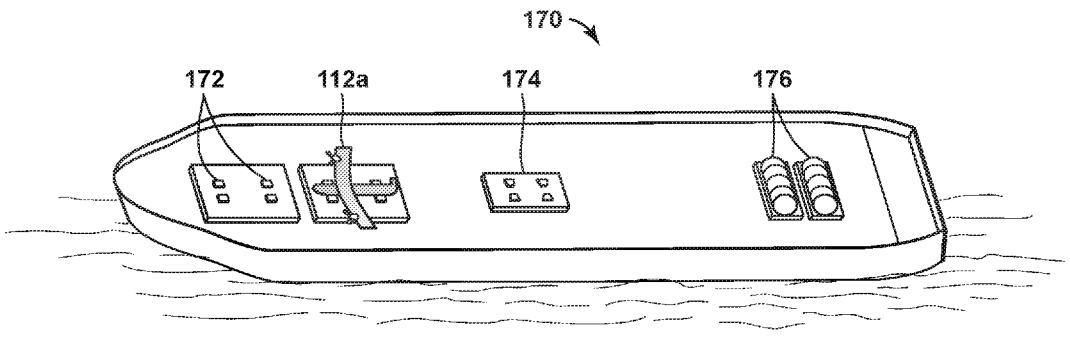


FIG. 10

(57) **Abstract:** A method of maintaining an offshore power plant. A plurality of airborne power generating craft are landed on or near a floating vessel. Each of the plurality of airborne power generating craft forms part of the offshore power plant.

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METHOD AND SYSTEMS OF MAINTAINING AN OFFSHORE POWER PLANT THAT USES AN AIRCRAFT ATTACHED TO A FLOATING STRUCTURE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit of United States Patent Application No. 62/351,547 filed June 17, 2016 entitled METHODS AND SYSTEMS OF MAINTAINING AN OFFSHORE POWER PLANT, the entirety of which is incorporated by reference herein.

[0002] This application is related to U.S. Provisional Patent Application No. 62/351,528, entitled "Systems and Methods for Offshore Power Generation Using Airborne Power Generating Craft"; U.S. Provisional Patent Application No. 62/351,541, entitled "Systems and Methods for Offshore Power Generation Using Airborne Power Generating Craft Tethered to a Floating Structure"; U.S. Provisional Patent Application No. 62/351,550, entitled "Methods and Systems for Electrical Isolation in an Offshore Power Generation Plant" and U.S. Provisional Patent Application No. 62/351,552, entitled "Method and Systems for Maintaining an Offshore Power Plant Having Airborne Power Generating Craft"; all of which are filed on an even date and have a common assignee herewith, the disclosures of which are incorporated by reference herein.

BACKGROUND

Field of Disclosure

[0003] The disclosure relates generally to offshore power generation, and more particularly, to tethered wind turbine systems.

Description of Related Art

[0004] This section is intended to introduce various aspects of the art, which may be associated with the present disclosure. This discussion is intended to provide a framework to facilitate a better understanding of particular aspects of the present disclosure. Accordingly, it should be understood that this section should be read in this light, and not necessarily as an admission of prior art.

[0005] A wind turbine converts the energy of moving air into electricity or other forms of energy. A common type of wind turbine system includes an electrical generator driven by rotor blades mounted in a rotatable manner near an upper end of a vertical support tower. The rotor may

be rotated relative to the tower as the wind direction changes such that the blades of the rotor are maintained perpendicular to the wind. These windmill-type wind turbine systems have become popular on land in regions that have open space and sufficient average wind velocities, and have also been adapted for use in offshore locations. Offshore locations offer the benefit of open space and potentially higher average sustained wind speeds.

[0006] Concepts for deeper water installations that are currently under development are mostly derived from configurations for offshore oil well rigs to include floating platforms. Accordingly, such concepts typically require large cranes for erection of the towers and turbines and are not optimal for wind turbines because of the large aerodynamic force in the direction of the wind as well as forces associated with dynamics from the angular momentum of the turbine blades. Furthermore, wind and wave forces cause coupled motions of the support tower and the rotor blades, resulting in greater structural dynamic loads, deflections and stresses upon the wind turbine system. The options of the prior art include large costly structures, with masses and/or dimensions often many times that of the wind turbine they are designed to support. For example, a typical offshore wind turbine system may have a height of approximately 100 meters from the sea surface with a weight of hundreds of tons.

[0007] One solution to the high cost of installation of wind turbines is an apparatus that is tethered to a fixed point. The apparatus generates electrical power by harnessing the wind in some manner. An example of a tethered wind turbine system is illustrated in Figure 1 and is indicated generally by reference number **10**. System **10** includes a wing or blade **12** fastened to a base **14** using a tether line **16**. The blade **12** is shaped to move generally perpendicular to the direction of the blowing wind W in a path, such as circular path **18**. The blades may be shaped to perform lift when wind W is passed over it. As the blade moves, propellers **20** mounted on the blade rotate and cause electrical power to be generated by motor/generators **22**, to which the propellers are rotatably mounted. The power so generated is transmitted through tether line **16**. Blade **12** may be raised and lowered by extending or retracting tether line **16**, and may be brought to rest on a mount or cradle **24**, which may be an integral part of base **14**. System **10** may be launched from its cradle using the motor/generators **22** in a motoring mode. Power transmitted to the motor/generators **22** is used to drive the propellers **20** in the motoring mode. Once at the desired altitude, and when wind velocities are sufficiently high and/or constant, system **10** may autonomously shift to a self-sustained state of flight using lift generated by blade **12**, and the

motor/generators **22** generate power as previously described. The motor/generators **22** preferably are operated in a motoring mode to control the descent of blade **12** as the blade is returned to rest on cradle **24**. System **10** as described has been developed by Makani Power, Inc. of Alameda, California.

[0008] Because system **10** requires no heavy vertical support tower, the mass of system **10** is significantly less than a similarly rated conventional wind turbine system – perhaps as much as 90% less. Additionally, system **10** may be employed at altitudes of 300 meters or more, potentially harnessing the stronger and more consistent winds there. Such altitudes simply are not commercially accessible by conventional systems using a vertical support tower. At these high altitudes, 85% of the United States can offer viable wind resources compared to the 15% of the United States accessible with conventional wind turbine technology. More importantly, because of the significant weight reductions and the potential for high altitude deployment, system **10** may be advantageously deployed in offshore waters, opening up a resource which is four times greater than the entire electrical generation capacity of the United States.

[0009] Current solutions for implementing system **10** offshore require placing base **14** on a semi-submersible structure that is secured to the seafloor with multiple anchoring cables. Such a solution still requires transporting and anchoring the semi-submersible structure, and these activities may reduce the commercial feasibility of system **10**. There is a need to reduce the cost of installation and to reduce the capital expenditures required to install wind power at sea, or over a body of water. There is also a need for solutions which enable installations in deeper water which are cost effective and suitable for the harsh deep water conditions. Therefore, it would be desirable to provide an offshore wind turbine system that can easily be installed in deep water locations and that minimizes or eliminates requirements for a foundational support structure at the water's surface.

SUMMARY

[0010] The present disclosure provides a method of maintaining an offshore power plant. A plurality of airborne power generating craft are landed on or near a floating vessel. Each of the plurality of airborne power generating craft forms part of the offshore power plant.

[0011] The present disclosure also provides a method of maintaining an offshore power plant having a first airborne power generating craft and a second airborne power generating craft. The

floating vessel is moved to a position adjacent the first airborne power generating craft. The first airborne power generating craft is landed on or near the floating vessel. The floating vessel is moved to a location adjacent the second airborne power generating craft. The second airborne power generating craft is landed on or near the floating vessel.

[0012] The present disclosure also provides a floating vessel for use with an offshore power generation system having a plurality of airborne power generating craft associated therewith. The vessel includes one or more mounts upon which any of the plurality of airborne power generating craft are landed and launched. The vessel also includes one or more storage racks upon which any of the airborne power generating craft may be transported.

[0013] The foregoing has broadly outlined the features of the present disclosure so that the detailed description that follows may be better understood. Additional features will also be described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] These and other features, aspects and advantages of the disclosure will become apparent from the following description, appending claims and the accompanying drawings, which are briefly described below.

[0015] Figure 1 is a side elevational view of a known tethered wind turbine system.

[0016] Figure 2 is a side elevational view of a tethered wind turbine system according to disclosed aspects.

[0017] Figure 3 is a perspective view of a portion of the tethered wind turbine system of Figure 2 according to disclosed aspects.

[0018] Figure 4 is a detail view of a portion of the tethered wind turbine system of Figures 2 and 3 according to disclosed aspects.

[0019] Figure 5 is a cross-section view of the tether taken along line 5--5 in Figure 2 according to disclosed aspects.

[0020] Figure 6 is a detail view of a portion of an anchor pile shown in Figure 2 according to disclosed aspects.

[0021] Figure 7 is a detail view of a portion of a tether shown in Figure 2 according to disclosed

aspects.

[0022] Figure 8 is a plan view of a wind farm according to disclosed aspects.

[0023] Figure 9 is a side elevational view of a tethered wind turbine system according to disclosed aspects.

[0024] Figure 10 is a perspective view of an offshore support vessel according to disclosed aspects.

[0025] Figure 11 is a side elevational view of a tethered wind turbine system according to disclosed aspects.

[0026] Figure 12 is a side elevational view of a tethered wind turbine system according to disclosed aspects.

[0027] Figure 13 is a schematic diagram of a control system according to disclosed aspects.

[0028] Figure 14 is a side elevational view of a buoy according to disclosed aspects.

[0029] Figure 15 is a side elevational view of a method of transporting a tethered wind turbine system according to disclosed aspects.

[0030] Figure 16 is a method according to aspects of the disclosure.

[0031] Figure 17 is a method according to aspects of the disclosure.

[0032] Figure 18 is a method according to aspects of the disclosure.

[0033] Figure 19 is a method according to aspects of the disclosure.

[0034] Figure 20 is a method according to aspects of the disclosure.

[0035] Figure 21 is a method according to aspects of the disclosure.

[0036] Figure 22 is a method according to aspects of the disclosure.

[0037] It should be noted that the figures are merely examples and no limitations on the scope of the present disclosure are intended thereby. Further, the figures are generally not drawn to scale, but are drafted for purposes of convenience and clarity in illustrating various aspects of the disclosure.

DETAILED DESCRIPTION

[0038] To promote an understanding of the principles of the disclosure, reference will now be made to the features illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the disclosure is thereby intended. Any alterations and further modifications, and any further applications of the principles of the disclosure as described herein are contemplated as would normally occur to one skilled in the art to which the disclosure relates. For the sake of clarity, some features not relevant to the present disclosure may not be shown in the drawings.

[0039] At the outset, for ease of reference, certain terms used in this application and their meanings as used in this context are set forth. To the extent a term used herein is not defined below, it should be given the broadest definition persons in the pertinent art have given that term as reflected in at least one printed publication or issued patent. Further, the present techniques are not limited by the usage of the terms shown below, as all equivalents, synonyms, new developments, and terms or techniques that serve the same or a similar purpose are considered to be within the scope of the present claims.

[0040] As one of ordinary skill would appreciate, different persons may refer to the same feature or component by different names. This document does not intend to distinguish between components or features that differ in name only. The figures are not necessarily to scale. Certain features and components herein may be shown exaggerated in scale or in schematic form and some details of conventional elements may not be shown in the interest of clarity and conciseness. When referring to the figures described herein, the same reference numerals may be referenced in multiple figures for the sake of simplicity. In the following description and in the claims, the terms “including” and "comprising" are used in an open-ended fashion, and thus, should be interpreted to mean "including, but not limited to.”

[0041] The articles “the,” “a” and “an” are not necessarily limited to mean only one, but rather are inclusive and open ended so as to include, optionally, multiple such elements.

[0042] As used herein, the terms “approximately,” “about,” “substantially,” and similar terms are intended to have a broad meaning in harmony with the common and accepted usage by those of ordinary skill in the art to which the subject matter of this disclosure pertains. It should be understood by those of skill in the art who review this disclosure that these terms are intended to

allow a description of certain features described and claimed without restricting the scope of these features to the precise numeral ranges provided. Accordingly, these terms should be interpreted as indicating that insubstantial or inconsequential modifications or alterations of the subject matter described and are considered to be within the scope of the disclosure.

[0043] As used herein, terms such as "offshore", "seafloor", "subsea", "underwater", and "water" are to be interpreted to refer to or describe any body of water, including oceans, lakes, reservoirs, seas, and rivers.

[0044] As used herein, the terms "electricity" and "power", when referring to the generation, transmission, and storage thereof, may be used interchangeably as is known in the art.

[0045] The disclosed aspects include a power generation plant having one or more tethered wind turbine systems, coupled with appropriate electrical infrastructure and energy storage technology, which may be configured to power new or existing developments. Such developments are described herein and may include offshore and/or onshore developments.

[0046] Figure 2 illustrates a power generation plant **100** according to aspects of the disclosure. Power generation plant **100** includes one or more airborne elements or airborne power generating craft, which in one aspect of the disclosure comprises wings, blades, or kites (collectively identified herein as kites **112**). Kites **112** may be similar to the stiff or substantially non-flexible blades disclosed in Figure 1, or may be at least partially comprised of a flexible material to provide a structure that is rigid, semi-rigid, or non-rigid. For example, kites **112** may flex under the forces of the wind and may be composed of one or more of a rigid material (for example, metal), a semi-rigid material (e.g., carbon fibers), and a non-rigid material (e.g., fabric). Figure 3 discloses an aspect in which each kite **112** may include an aircraft-like fuselage **102** to which a rear stabilizer **104** may be attached. A first end **116a** of each tether line **116** may be attached to a respective one of kites **112**. For example, as shown in Figure 4, first end **116a** may be attached to a gimbal **124** or other rotating structure on kite **112**. A quick disconnect mechanism **126** may be disposed at or near first end **116a** to facilitate rapid disconnection of tether line **116** from kite **112**. The quick disconnect mechanism **126** may be configured to be remotely triggered or operated and/or may be manually operated. Figure 5 shows a cross-section of a tether line **116**, which may include a tension element **128** that may be constructed of a material having a high strength-to-weight ratio such as carbon fiber, woven cable made of high-strength, corrosion-resistant steel, or the like. In

an aspect, tether line **116** is slightly buoyant or includes buoyant elements to prevent it from sinking to the seafloor when not connected to kite **112**. In an aspect, tension element **128** may be made of a material suitable for both subsea (i.e., underwater) and airborne application or deployment. In another aspect, tension element **128** has an underwater component suitable for continuous submersion in a body of water, and an airborne component suitable for use on or above the body of water. The lengths of the underwater and airborne components of tension element may be respectively determined by estimating the depth of the water in which the kite is to be used, and the intended height of kite **112** in operation. Tension element **128** may be designed to surround one or more electrical conduits, shown in Figure 5 as an inter-array transmission and communications umbilical cable **130**. Umbilical cable **130** may permit transmission of electrical current supplied to or generated by kite **112**. Umbilical cable **130** may also transmit control and/or diagnostic signals to and/or from the kite **112**, as will be described further herein. Additionally or alternatively, the tether line may include fiber optic or other control and communication elements in addition to the umbilical cable. One design for a tether line is described in PCT Patent Publication WO2012/012429, the disclosure of which is incorporated by reference herein. A layer of insulation **132** may surround and protect umbilical cable **130** from the surrounding water.

[0047] A second end **116b** of tether line **116** may be secured at an anchoring point at or on an underwater floor, such as a lake bed, a river bed, or a seafloor **134**, using an anchor pile **136** or similar means. For example, anchor pile **136** may be drilled and grouted, or as shown in Figure 6, may be a driven pile. Alternatively, a vertical load anchor may be used to secure second end **116b** of tether line **116**. The anchor pile **136** may be located entirely below the surface of the water **138**, as shown in the Figures, but in shallower water part of the anchor pile may be above the surface of the water. A rotating mechanism or element such as a combined gimbal and swivel **140** may be attached to or integrally formed as part of the top of the anchor pile. Second end **116b** of tether line **116** may then be attached to the gimbal **140**. Tether line **116**, so attached, is permitted to rotate about axes parallel and perpendicular to the seafloor **134**, to thereby enable kite **112** to freely move relative to the anchor pile **136**. A quick disconnect mechanism **142**, shown schematically in Figure 6, is employed at or near the point of connection between the tether line and gimbal to permit the tether to be disconnected and/or replaced if the tether, gimbal, and/or the anchor pile requires maintenance or replacement, or in the event of failure of operations of all or part of the power generation plant **100**. The quick disconnect mechanism **142** may be configured to be

remotely triggered or operated and/or may be manually operated. A spool or winch may be included at the anchor pile to permit the cable to be reeled in if the tether breaks or the kite crashes. The spool or winch may include a cable tensioner element that allows the tether line to be reeled in regardless of the amount of tension on the tether line.

[0048] Kite **112** is designed to move in a path **118**, shown as an elliptical or circular path in Figure 2, in response to the blowing wind W. As the kite moves along the path **118**, tether line **116** moves through the water in an oscillating or repeating pattern. Propellers **120** mounted on the kite rotate and cause electrical current to be generated using motor/generators **122**, to which the propellers are rotatably mounted. The electrical current so generated is transmitted through umbilical cable **130**. The length of each tether line **116** may be selected to enable kites **112** to capture wind energy at a desired altitude, which may exceed 100 meters, or 200 meters, or 300 meters. Each kite may have a nameplate power generation capacity of more than 20 kilowatts, or more than 100 kilowatts, or more than 500 kilowatts, or more than one megawatt, or more than five megawatts.

[0049] As illustrated in Figure 7, umbilical cable **130** and insulation **132** may diverge from the tension element **128** at a point of separation **142**, which may be at or close to second end **116b** of tether line **116**, or which may be at any point along the tether line. The umbilical cables associated with each of the tether lines shown in Figure 2 are electrically connected in a preferred configuration to an underwater electrical module **146** either directly or by connection to an array line **148**. The array line **148** transmits electrical current generated by the motor/generators to the underwater electrical module **146**, and transmits communications and control signals between each kite **112** and the underwater electrical module. The underwater electrical module **146** contains the infrastructure necessary for basic voltage transformation, power distribution, breaker switching, power isolation, connecting the umbilical cables **130** to the array line **148**, and/or increasing the size of the array line and/or umbilical cables as desired. The underwater electrical module **146** may also harmonize the voltage from the electrical modules and may interconnect the plurality of alternating current (AC) or direct current (DC) sources. The underwater electrical module 146 may perform a DC to DC conversion, an AC to AC conversion, a DC to AC conversion, or an AC to DC conversion, as required. A local electrical distribution cable **150** provides a path for the electrical current routed to underwater electrical module **146** to be sent to an electrical substation, which according to an aspect of the disclosure is an offshore substation **152**. Alternatively, the

umbilical cable **130** and/or the array line **148** may be connected directly to the offshore substation **152** without requiring an underwater electrical module **146**. The offshore substation **152** interconnects and directs the flow of electrical current from one or more underwater electrical modules **146**. The offshore substation **152** may harmonize the voltage from the electrical modules and may interconnect the plurality of alternating current (AC) or direct current (DC) sources. The offshore substation **152** may perform a DC to DC conversion, an AC to AC conversion, a DC to AC conversion, or an AC to DC conversion, as required. The offshore substation **152** may provide a location for or a connection to energy storage **154**, if desired. Such energy storage **154** may employ systems or technologies such as underwater pumped storage hydraulic technology, high-temperature thermal energy storage, a fly-wheel, one or more batteries such as a lithium-ion battery, compressed air storage, or other types of energy storage technologies. The offshore substation **152** may also include the capability for electrical isolation, as will be further described herein. The offshore substation **152** may send power to an onshore substation (not shown) through an export cable **156** for connection into a power grid **158** (Figure 8). Alternatively or additionally, the offshore substation **152** may send power to power machinery located offshore. Figure 8 is a top plan view of a representative layout of a power generation plant, according to disclosed aspects, in the form of a wind farm **160**. The wind farm **160** includes twenty-five kites (indicated by their respective paths **118**), five groups of umbilical lines **130** or array lines **148**, five underwater electrical modules **146**, five local electrical distribution cables **150**, one offshore substation **152**, and one export cable **156**. Wind farm **160** may have any number of kites as desired, and the electric current produced by kites **112** may be electrically connected to export cable **156** through any combination or arrangement of electrical modules, substations, umbilical cables, and electrical distribution cables.

[0050] Aspects of the disclosure described above anchor kite **112** to the seafloor, thereby eliminating the heavy and expensive offshore towers, semi-submersible structures, and other permanent structures used in known offshore wind farms. However, in some circumstances it may be desirable to limit the range of motion of the kite with respect to the seafloor. Figure 9 illustrates the use of a floating structure from which the kite **112** can rotate. The floating structure may be a tension leg platform, spar, semi-submersible structure, a ship-shaped floating structure, or as shown in Figure 9, a buoy **162**. The buoy **162** may be moored to the seafloor at a single point using tether line. Alternatively, multiple lines may be used to moor the buoy at multiple points on

the seafloor. In this aspect, tether line **116** may be divided into an underwater portion **116c** and an aloft portion **116d**. Each of the portions may then be optimally designed to meet the tension load requirements and to withstand the conditions of its respective environment. Other types of floating structures or foundational members may be used instead of buoy **162**, it being understood that such floating structures are anticipated to be much smaller than those used to support offshore windmill-type motor/generators. Additionally, buoy **162** may include basic electrical infrastructure in an electrical module **164** that results in further simplifying the structure and function of the underwater electrical module **146**. Buoy **162** may also include electrical isolation capability as part of or separate from the electrical module **164** as will be explained below. The electrical module **164** and/or the electrical isolation capability, if provided separately, may be provided in a modular form factor which allows easy removal, installation, repair, and replacement. The electrical module **164** may include any or all of the communications, electrical isolation, and power conversion means as desired.

[0051] All of the aspects disclosed herein include a kite **112** tethered to the seafloor, and as such there is no fixed point on which the kite can be landed for maintenance, replacement, or when winds are too low or too high for kite to be effectively operated. Known kite systems (Figure 1) employ a winch or spool to reduce the length of the tether line during such circumstances, but disclosed aspects use a tether line with a constant length between the kite and the anchor pile **136**. In an aspect, kite **112** may be designed to land on the surface of the water **138** and be serviced by a vessel. According to aspects of the disclosure, kites **112** can be landed and transported on a specially outfitted movable structure, barge or vessel, such as an offshore support vessel **170** as depicted in Figures 2 and 10. The offshore support vessel is designed to move or be moved temporarily to locations where kites **112** have been installed. The offshore support vessel **170** may be outfitted with padded racks or bridles **172** upon which kites **112** may be transported. The offshore support vessel may also include a mount or perch **174** for landing and/or launching kites **112** without spooling or winching in the tether line, or in other words, the deployed length of the tether line (i.e., the length of the tether line between the anchor pile and the kite) is constant during landing and/or launching operations. The offshore support vessel module may additionally include spare tether lines **116**, which may be wound around spools or drums **176** for storage in or on the offshore support vessel. Kites **112** may be controlled, through tether line **116** or via wireless communication/control systems onboard the offshore support vessel, to land on perch **174** for

maintenance, repair or replacement. In such a landing operation, propellers **120** powered by motor/generators **122** may provide the required lift to maneuver the kite to the perch or to a water surface. A spare kite **112a** could replace the landed kite if necessary. Offshore support vessel **170** could service and otherwise perform maintenance and repair on many kites in this manner, thereby eliminating the need for permanent offshore structures to land the kites for maintenance and repair, and eliminating the need to bring the kites onshore for much of the required maintenance and repair thereon. Such onsite installation, removal, service, maintenance, and repair may result in significant cost savings during commissioning, start-up, long-term operation, etc.

[0052] Another reason known tethered kites have relied upon permanent support structures is to protect the kite from potentially damaging high winds and from situations in which the wind speed is too low to either hold the kite aloft or to generate an acceptable level of power. According to disclosed aspects shown in Figure 11, kite **112** may be programmed to hover horizontally during times of high winds. Kite **112** is shown as having a significant wing shape, which should provide sufficient lift in a high wind situation to keep the kite airborne. Additionally, rear stabilizer **104** may provide lift as well as stability to kite **112** in this situation. On the other hand, kite **112** may be programmed or controlled to hover vertically during times of low winds, as shown in Figure 12. Propellers **120**, powered by motor/generators **122** (shown in Figure 3), may provide sufficient lift to maintain kite **112** aloft. Motor/generators **122** may be powered by an external power source or through stored power. Alternatively, kite **112** may be programmed or controlled to land on the surface of the water during periods of low winds, tether failure, or loss of grid power.

[0053] It is anticipated that the tether line **116** could carry electrical power in the range of thousands of volts AC or DC at energy levels of tens of kilowatts to tens of megawatts. Many scenarios exist where the kite **112** or its respective tether line **116** could come into unwanted electrical conduction with the surrounding water or other structures, craft and the like. Aspects disclosed herein include consideration of such electrical safety issues. For example, sensors may be used to detect parameters associated with the kite **112**, its surroundings, and its associated power system. Such parameters may include electrical parameters, such as voltage, lack of voltage, current, current loss, corona discharge, and current and/or voltage unbalance. Such electrical parameters may be measured at any location of the disclosed system. Other detected parameters may include signals indicating degradation of the tether line, altitude of the kite, tension of the tether line, wind speed, height and/or frequency of waves in the body of water in which the kite is

installed, the receiving or loss of a trip command from a remote device, the detection of craft or personnel in or approaching the kite, or the presence or absence of a remote signal. Sensors to detect such parameters may include one or more current sensors, voltage sensors, tension monitoring devices, strain gauges, wind meters, communication units, gyroscopes, altimeters, speed sensors, vibration sensors, camera systems, radar, and the like. The detected parameters may be used to determine whether the kite **112** and associated power systems should be switched to a failsafe operating mode or electrical safe state, which in an aspect may be termed a "safe park condition." The safe park condition may include an electrically safe state or condition. This safe park condition is one which may include de-energizing the tether line **116**. De-energizing the tether may include tripping electrical circuit breakers or activating electrical interrupting devices, and/or turning off the triggering to power electronics devices, which may include gated power electronics such as thyristors and the like. Transition to the safe park condition may include ending power transmission from the kite **112** into the tether line **116** by ending or interrupting electrical conduction to the tether line **116** from the generating source or sources located on the kite, and vice versa.

[0054] The safe park condition may include ending electrical conduction from the offshore power system by interrupting the electrical connection at any point between offshore substation **152** and kite **112**. The safe park condition may also include grounding the umbilical cable **130** associated with tether line **116**. To facilitate transfer to a safe park condition, electrical switching, interrupting or isolating means should be in electrical communication (preferably in series) with both the first end **116a** and the second end **116b** of the tether line **116**. The electrical switching, interrupting or isolating means may be in the form of circuit breakers, pyrotechnic interrupters, switches, power circuit electronics, fuses, grounding switches, and the like.

[0055] The decision to transition to an electrical safe state, such as the safe park condition, may be incorporated in to the normal operational steps of the kite **112**. For example, if a winged kite **112** were to execute a landing on an offshore support vessel **170**, a transition to the safe park condition may be included as one of the manual or automatically initiated steps of its control system. By way of example, a kite **112** using power from an offshore power system may be programmed or otherwise instructed to operate the motor/generators **122** in a motoring mode (used, e.g., to descend the kite to an offshore supply vessel **170** or to hover the kite during a low wind condition). In such a circumstance, the transition to a safe park condition may be initiated to

electrically isolate the tether line from electrical conduction from both the kite and the offshore power system.

[0056] According to disclosed aspects, electrical switching, interrupting or isolating means may be located at the buoy **162** (if used), in the underwater electrical module **146** as shown by reference number **146a**, at the offshore substation **152** (if used) as shown by reference number **152a**, on or in tether line **116** as shown by reference number **117**, or elsewhere in power generation system **100**. Transitioning to the safe park condition may include operating (e.g. opening) the electrical switching, interrupting or isolating means upon receipt of a command from a supervisory control system or via a manual command. Figure 13 is a schematic of a representative control system **200** that may be used to initiate a safe park condition or other failsafe mode. Control system **200** may reside on the kite **112**, but may advantageously reside on both the kite and a location not on the kite, such as the buoy **162**, underwater electrical module **146**, and/or offshore substation **152**. Control system **200** may be incorporated into the control system (not shown) used to control flight and autonomous operation of the kite, or alternatively may be independent from other functions. Control system **200** may include a programmable controller **202**, such as an electrically protective relay or a programmable logic controller, which receives input from various sensors **204** as have been previously described. Decision logic may be input at **206** into controller **202** according to known programming principles. Instructions to transition to an electrical safe state, such as the described safe park condition, are output at **208** to the buoy **162**, underwater electrical module **146**, and/or the offshore substation **152** as required. Such output instructions communicate the trigger to the safe park condition when the predetermined requirements for such trigger or transition are sensed, determined, or otherwise requested.

[0057] An example of a situation in which an electrical failsafe mode may be helpful is if the tether line **116** breaks while the kite **112** is generating power. Sensors **204**, such as current and voltage sensors on the kite, power monitor calculations in the control system of the kite **112**, and/or tension monitors associated with the tether **116** itself, may provide inputs to the programmable controller **202** of the control system **200**. The programmable controller **202** processes the input(s) using decision logic **206** to determine that an abnormal condition has occurred, and will then communicate through outputs **208** to initiating the safe park condition. The tether **116** can thus be safely electrically isolated.

[0058] In an aspect, conditions requiring electrical isolation are sensed, detected or calculated prior to when an abnormality is detected. It may be desirable for electrical isolation to occur before any abnormal current flow or voltage variation is detected. According to one aspect, the system may anticipate that current carrying conductors or components are approaching an increased risk of electrical fault (e.g., impact with the surface of a body of water). By way of example, sensing an undesirable condition may include sensing a position or calculating the trajectory of the kite or the tether line, and electrical isolation may be performed automatically in response to the anticipated trajectory or position of the kite, prior to an electrical anomaly being detected by sensors **204**.

[0059] The disclosed aspects have many advantages when compared with known wind energy solutions. Such advantages include significant weight reduction, manufacturing and installation cost, ability to harness wind energy at high altitudes, and the ability to harness wind energy inexpensively at extreme water depths. As such, aspects of the disclosure may be used to not only supply power to a power grid, but may also be used to power any type of offshore project, such as aquaculture or desalination. As another example, aspects of the disclosure may be used to access new oil and/or gas reservoirs adjacent existing an offshore oil and gas facility. If the most cost-effective way to develop the new reservoirs is to leverage the existing infrastructure, there will likely be additional power requirements for such development, especially if the development has significant subsea components. Since the original offshore oil and gas facility likely was not designed with the additional power requirements in mind, it may be expensive and time-consuming to meet the additional power requirements. The disclosed aspects enable additional power generating capacity to be added to the existing offshore facility at a reasonable cost.

[0060] Aspects of the disclosure may also advantageously be used with new offshore oil and gas projects that require power generation to operate. An offshore platform or facility may be economically powered at least in part by one or more kites as disclosed herein. Such kite-based power is especially attractive for subsea production that leverages existing processing, storage and/or transportation facilities that are a long way (>50 km) from existing subsea production and/or processing infrastructure.

[0061] Aspects described herein may have other advantageous applications. For example, the disclosed aspects may be used with other power sources, including other renewable sources such

as solar, tidal, thermal, geothermal, and the like, to power equipment used in subsea boosting or to be used when one of the renewable sources is not available because of low winds, low available solar energy, grid loss, etc.

[0062] The disclosed aspects have described a tether line secured at one end to a seafloor and at the other end to a kite. It is to be understood that such a tether line may actually be two separate lines – for example, an underwater portion and an aloft portion – that function together to secure the kite to the seafloor and transmit power generated by movement of the kite to the electrical transmission system. While the two separate lines may have different lengths, diameters, and compositions, for the purposes of this disclosure such separate tether lines or tether line portions may be considered to be a single tether line.

[0063] Figure 14 depicts another aspect of the disclosure in which a motor/generator **220** is located at the buoy **162** instead of at the kite. A spool **222** is rotatably connected to motor/generator **220**. Aloft portion **116d** of the tether line is configured to be wound and unwound around spool **222**. When motor/generator **220** acts as a motor, aloft portion **116d** of the tether line winds around spool **222**. When spool **222** is directed to unwind the aloft portion of the tether line, the motor/generator **220** generates power that is transmitted through umbilical cable **116b** to the electrical transmission system (not shown).

[0064] Because the kite **112** is light and capable of creating aerodynamic lift, it is much easier to transport and install. Figure 15 is a schematic illustration of how kite **112** may be transported to or from an installation site. As shown in Figure 15, kite **112** may be attached to a tow cable **230** that is at least partially wound around a spool **232**. In this disclosed aspect, the spool **232** is mounted on a small vessel or boat **234**. Using tow cable **230**, small boat **234** may tow the kite **112** from land or from an offshore support vessel to an installation site **236**, which is typically at a wind farm or other power generation site. Kite **112** may be maintained aloft using motor/generator **122** and the propellers **120**, principles of aerodynamic lift, or both. When the small boat **234** reaches the installation site **236**, tow cable **230** is reeled in until the kite is close enough to secure first end **116a** of tether line **116** to the kite. The kite may then ascend into the air to generate power as previously described. This procedure may be reversed if a kite is to be removed from an installation site to a land-based landing site, an offshore supply vessel, or other location. The method of transportation and installation/de-installation depicted in Figure 15 and described herein

is an alternative to using a much larger offshore supply vessel **170**. Alternatively, as described above, an offshore supply vessel may serve primarily to transport kites **112** to and from the general vicinity of their respective installation sites, and one or more small boats **234** may transport kites **112** to and from the offshore supply vessel to install the kites at their respective installation sites.

[0065] Figure 16 is a flowchart of a method **300** of generating power according to disclosed aspects. At block **302** an airborne power generating craft is connected to an anchor using a tether line. The anchor is secured to an underwater floor. At block **304** power is generated based on movement of the airborne power generating craft in response to a wind force. At block **306** a constant length of the tether line is maintained between the airborne power generating craft and the anchor as the airborne power generating craft moves in response to the wind force. At block **308** the airborne power generating craft is connected to an electrical transmission system through at least part of the tether line. At block **310** the generated power is transmitted to the electrical transmission system.

[0066] Figure 17 is a flowchart of a method **400** of generating power according to disclosed aspects. At block **402** an airborne power generating craft is connected to a floating structure, such as a buoy, using an aloft portion of a tether line. At block **404** the floating structure is connected to an anchor using an underwater portion of the tether line. The anchor is secured to an underwater floor. At block **406** power is generated based on movement of the airborne power generating craft in response to a wind force. At block **408** the floating structure is connected to an electrical transmission system through at least part of the tether line. At block **410** the generated power is transmitted to the electrical transmission system.

[0067] Figure 18 is a flowchart of a method **500** of maintaining an offshore power plant according to disclosed aspects. At block **502** a plurality of airborne power generating craft are landed on or near a floating vessel. Each of the plurality of airborne power generating craft forms part of the offshore power plant.

[0068] Figure 19 is a flowchart of a method **600** for maintaining an offshore power plant according to disclosed aspects. The offshore power plant has a first airborne power generating craft and a second airborne power generating craft. At block **602** the floating vessel is moved to a position adjacent the first airborne power generating craft. At block **604** the first airborne power generating craft is landed on or near the floating vessel. At block **606** the floating vessel is moved

to a location adjacent the second airborne power generating craft. At block **608** the second airborne power generating craft is landed on or near the floating vessel.

[0069] Figure 20 is a flowchart of a method **700** for generating power according to disclosed aspects. At block **702** an airborne power generating craft is connected to an anchor using a tether line. The anchor is secured to an underwater floor. At block **704** power is generated based on movement of the airborne power generating craft in response to a wind force. At block **706** a constant length of the tether line is maintained between the airborne power generating craft and the anchor as the airborne power generating craft moves in response to the wind force. At block **708** the airborne power generating craft is connected to an electrical transmission system through at least part of the tether line. At block **710** the generated power is transmitted to the electrical transmission system. At block **712** a condition is sensed in which transmitting power to the electrical transmission system is not desired. At block **714** the airborne power generating craft is electrically isolated to prevent power from being transmitted from the airborne power generating craft to the electrical transmission system.

[0070] Figure 21 is a flowchart of a method **800** of maintaining an offshore power plant according to disclosed aspects. At block **802** a power generating craft is attached to a tow cable on a floating vessel. At block **804** the floating vessel is moved to an offshore power generating site. At block **806** the power generating craft is maintained in an airborne state while the floating vessel is moving to the offshore power generating site. At block **808** the power generating craft is detached from the tow cable and attached to a first end of a tether line at the offshore power generating site. A second end of the tether line is anchored to an underwater floor. At block **810** operating the power generating craft is operated in an airborne state.

[0071] Figure 22 is a flowchart of a method **900** of maintaining an offshore power plant according to disclosed aspects. At block **902** detaching a power generating craft from a first end of a tether line at an offshore power generating site. A second end of the tether line is anchored to an underwater floor. At block **904** the power generating craft is attached to a tow cable on a floating vessel. At block **906** the floating vessel is moved away from the offshore power generating site. At block **908** the power generating craft is maintained in an airborne state while the floating vessel is moving away from the offshore power generating site.

[0072] Disclosed aspects may include any combinations of the methods and systems shown in

the following numbered paragraphs. This is not to be considered a complete listing of all possible aspects, as any number of variations can be envisioned from the description above.

C1. A method of maintaining an offshore power plant, comprising:

landing a plurality of airborne power generating craft on or near a floating vessel, each of the plurality of airborne power generating craft forming part of the offshore power plant.

C2. The method of paragraph C1, further comprising storing at least one of the plurality of airborne power generating craft on or in the floating vessel.

C3. The method of paragraph C1 or C2, further comprising moving the floating vessel from a location adjacent a first of the plurality of airborne power generating craft to a location adjacent a second of the plurality of airborne power generating craft.

C4. The method of any of paragraphs C1-C3, wherein landing the plurality of airborne power generating craft further comprises landing one of the plurality of airborne power generating craft on a water surface.

C5. The method of paragraph C4, further comprising:

retrieving the one of the plurality of airborne power generating craft from the water surface; and

placing the one of the plurality of airborne power generating craft on or in the floating vessel.

C6. The method of any of paragraphs C1-C5, further comprising:

after landing one of the plurality of airborne power generating craft, disconnecting the one of the plurality of airborne power generating craft from a tether line that connects the one of the plurality of airborne power generating craft to an anchoring point at or on an underwater floor.

C7. The method of paragraph C6, wherein the tether line is connected to a floating structure.

C8. The method of paragraph C7, wherein the floating structure is a buoy moored to anchoring point at or on an underwater floor.

C9. The method of any of paragraphs C6-C8, further comprising maintaining a length of the tether line at a constant deployed length while the airborne power generating craft is landing on or

near the floating vessel.

C10. The method of any of paragraphs C1-C9, further comprising:

attaching a spare airborne power generating craft to the tether line; and

launching the spare airborne power generating craft.

C11. A method of maintaining an offshore power plant having a first airborne power generating craft and a second airborne power generating craft, the method comprising:

moving the floating vessel to a position adjacent the first airborne power generating craft;

landing the first airborne power generating craft on or near the floating vessel;

moving the floating vessel to a location adjacent the second airborne power generating craft; and

landing the second airborne power generating craft on or near the floating vessel.

C12. The method of paragraph C11, wherein landing the first and second airborne power generating craft further comprises landing one of the first and second airborne power generating craft on a water surface.

C13. The method of paragraph C12, further comprising:

retrieving the one of the first and second airborne power generating craft from the water surface; and

placing the one of the first and second airborne power generating craft on or in the floating vessel.

C14. The method of any of paragraphs C11-C13, further comprising:

after landing one of the first and second airborne power generating craft, disconnecting the one of the first and second airborne power generating craft from a tether line that connects the one of the first and second airborne power generating craft to an anchoring point at or on an underwater floor.

C15. The method of paragraph C14, wherein the tether line is connected to a floating structure.

C16. The method of paragraph C15, wherein the floating structure is a buoy moored to anchoring point at or on an underwater floor.

C17. The method of any of paragraphs C14-C16, further comprising maintaining a length of the tether line at a constant deployed length while the one of the first and second airborne power generating craft is landing on or near the floating vessel.

C18. The method of any of paragraphs C11-C17, further comprising:

attaching a spare airborne power generating craft to the tether line; and

launching the spare airborne power generating craft.

C19. A floating vessel for use with an offshore power generation system having a plurality of airborne power generating craft associated therewith, the vessel comprising:

one or more mounts upon which any of the plurality of airborne power generating craft are landed and launched; and

one or more storage racks upon which any of the airborne power generating craft are transported.

[0073] It should be understood that the numerous changes, modifications, and alternatives to the preceding disclosure can be made without departing from the scope of the disclosure. The preceding description, therefore, is not meant to limit the scope of the disclosure. Rather, the scope of the disclosure is to be determined only by the appended claims and their equivalents. It is also contemplated that structures and features in the present examples can be altered, rearranged, substituted, deleted, duplicated, combined, or added to each other.

CLAIMS

What is claimed is:

1. A method of maintaining an offshore power plant, comprising:

landing a plurality of airborne power generating craft on or near a floating vessel, each of the plurality of airborne power generating craft forming part of the offshore power plant.

2. The method of claim 1, further comprising storing at least one of the plurality of airborne power generating craft on or in the floating vessel.

3. The method of claim 1 or 2, further comprising moving the floating vessel from a location adjacent a first of the plurality of airborne power generating craft to a location adjacent a second of the plurality of airborne power generating craft.

4. The method of any of claims 1-3, wherein landing the plurality of airborne power generating craft further comprises landing one of the plurality of airborne power generating craft on a water surface.

5. The method of claim 4, further comprising:

retrieving the one of the plurality of airborne power generating craft from the water surface; and

placing the one of the plurality of airborne power generating craft on or in the floating vessel.

6. The method of any of claims 1-5, further comprising:

after landing one of the plurality of airborne power generating craft, disconnecting the one of the plurality of airborne power generating craft from a tether line that connects the one of the plurality of airborne power generating craft to an anchoring point at or on an underwater floor.

7. The method of claim 6, wherein the tether line is connected to a floating structure.

8. The method of claim 7, wherein the floating structure is a buoy moored to anchoring point at or on an underwater floor.

9. The method of any of claims 6-8, further comprising maintaining a length of the tether line at a constant deployed length while the airborne power generating craft is landing on or near the

floating vessel.

10. The method of any of claims 1-9, further comprising:

attaching a spare airborne power generating craft to the tether line; and

launching the spare airborne power generating craft.

11. A method of maintaining an offshore power plant having a first airborne power generating craft and a second airborne power generating craft, the method comprising:

moving the floating vessel to a position adjacent the first airborne power generating craft;

landing the first airborne power generating craft on or near the floating vessel;

moving the floating vessel to a location adjacent the second airborne power generating craft; and

landing the second airborne power generating craft on or near the floating vessel.

12. The method of claim 11, wherein landing the first and second airborne power generating craft further comprises landing one of the first and second airborne power generating craft on a water surface.

13. The method of claim 12, further comprising:

retrieving the one of the first and second airborne power generating craft from the water surface; and

placing the one of the first and second airborne power generating craft on or in the floating vessel.

14. The method of any of claims 11-13, further comprising:

after landing one of the first and second airborne power generating craft, disconnecting the one of the first and second airborne power generating craft from a tether line that connects the one of the first and second airborne power generating craft to an anchoring point at or on an underwater floor.

15. The method of claim 14, wherein the tether line is connected to a floating structure.

16. The method of claim 15, wherein the floating structure is a buoy moored to anchoring point at or on an underwater floor.

17. The method of any of claims 14-16, further comprising maintaining a length of the tether line at a constant deployed length while the one of the first and second airborne power generating craft is landing on or near the floating vessel.

18. The method of any of claims 11-17, further comprising:

attaching a spare airborne power generating craft to the tether line; and

launching the spare airborne power generating craft.

19. A floating vessel for use with an offshore power generation system having a plurality of airborne power generating craft associated therewith, the vessel comprising:

one or more mounts upon which any of the plurality of airborne power generating craft are landed and launched; and

one or more storage racks upon which any of the airborne power generating craft are transported.

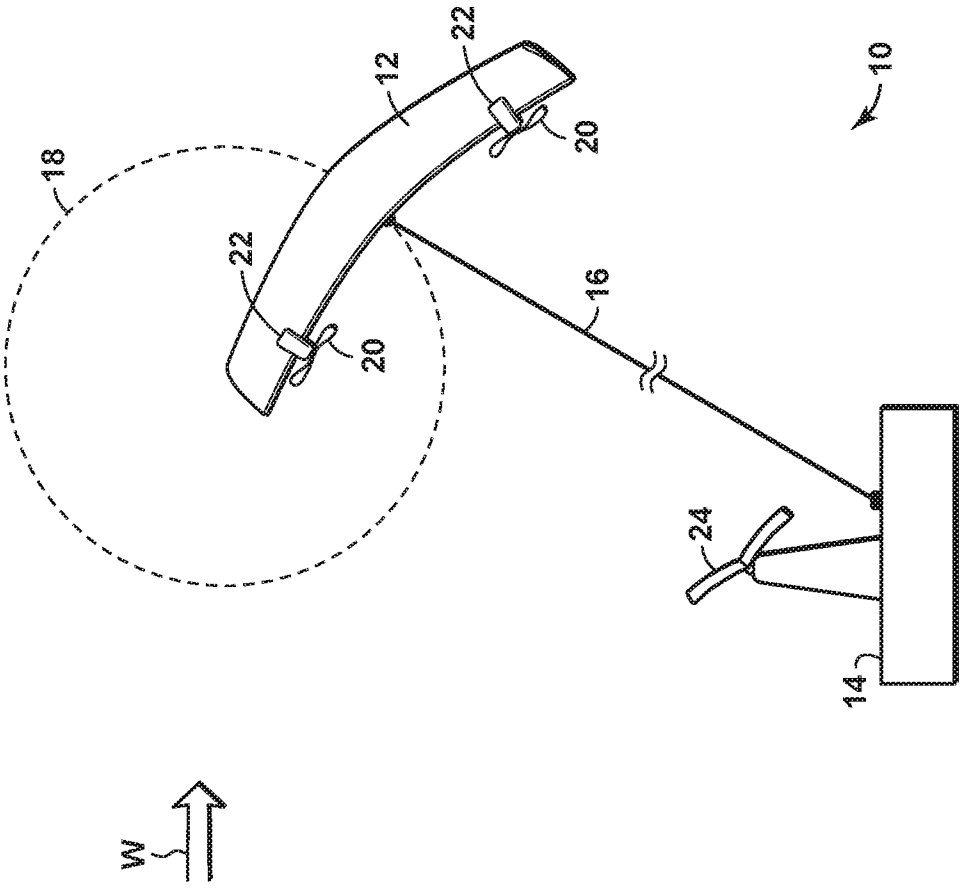


FIG. 1
(Prior Art)

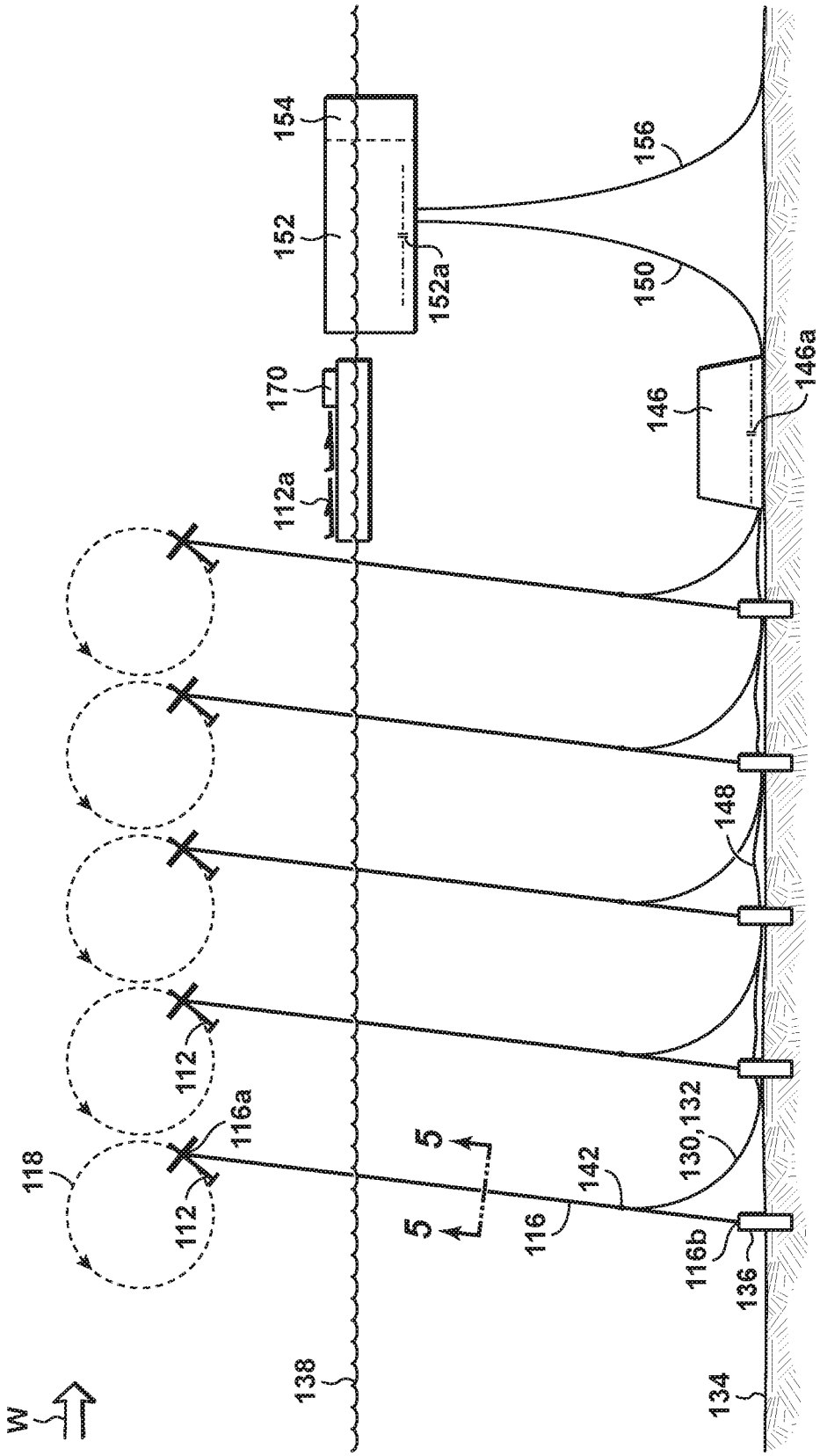

100
154
152
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170
112a
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116b
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138
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148

FIG. 2

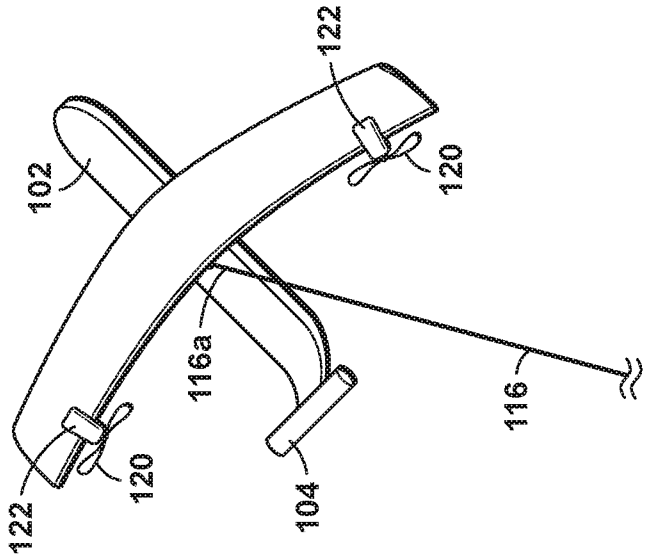


FIG. 3

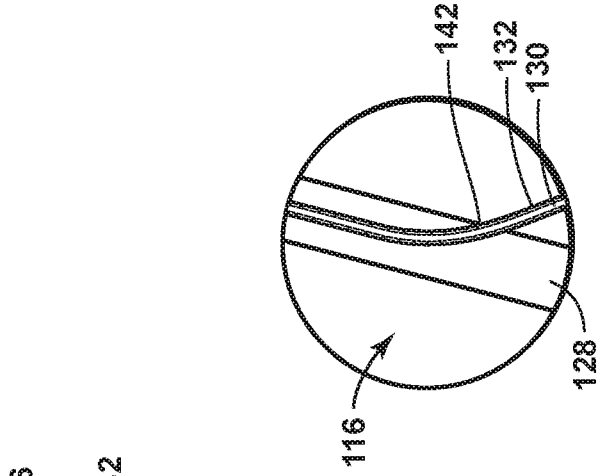


FIG. 7

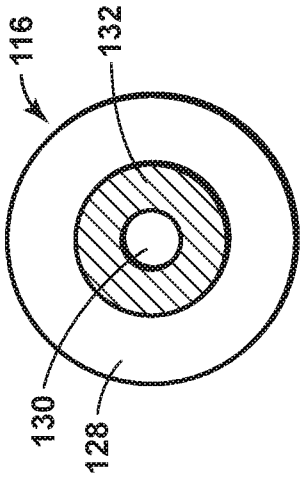


FIG. 5

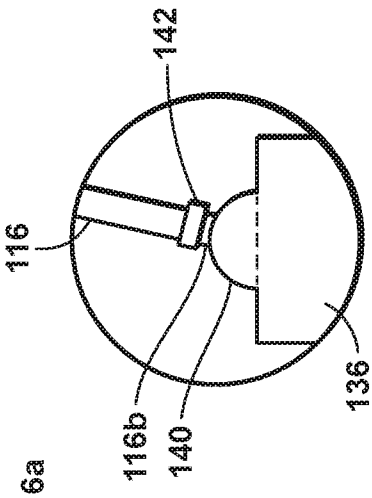


FIG. 6

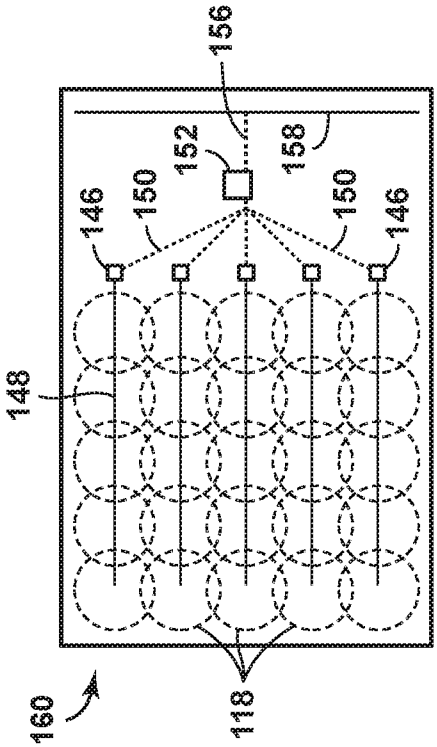


FIG. 8

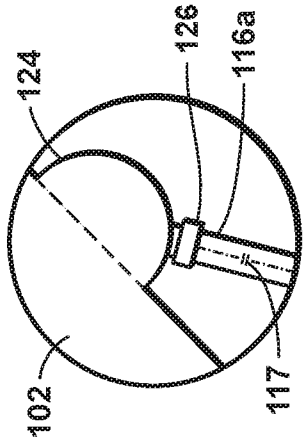


FIG. 4

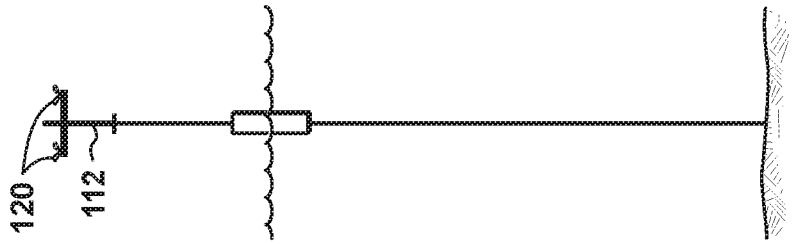


FIG. 12

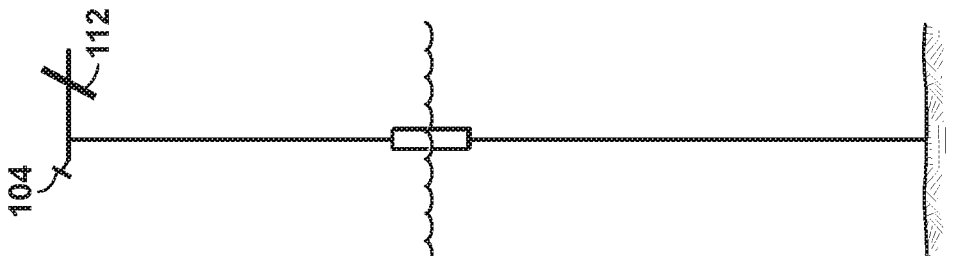


FIG. 11

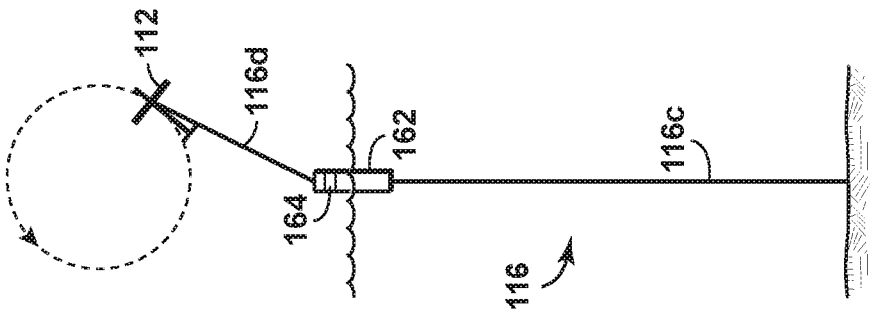


FIG. 9

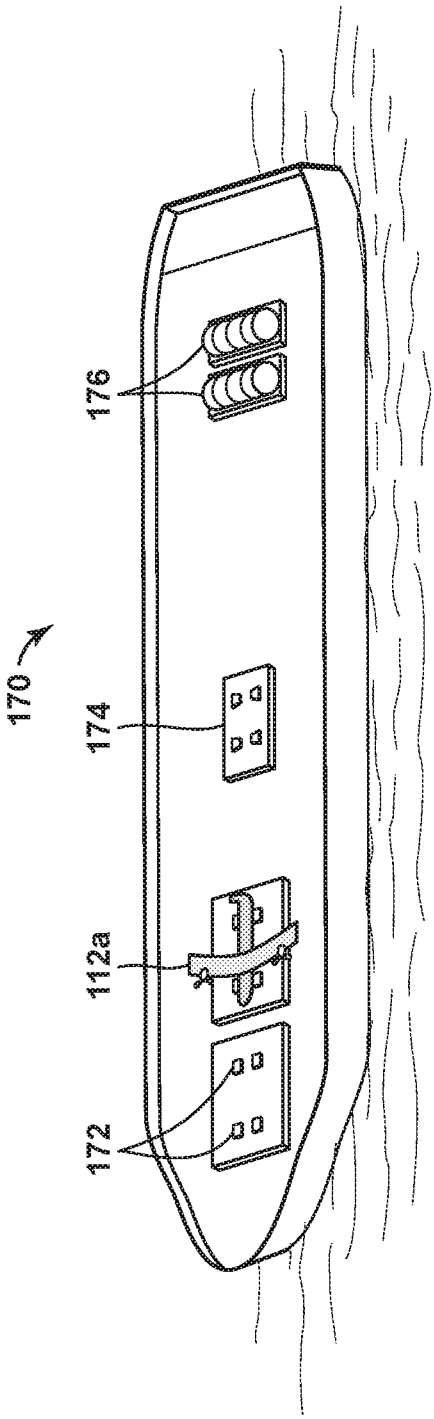


FIG. 10

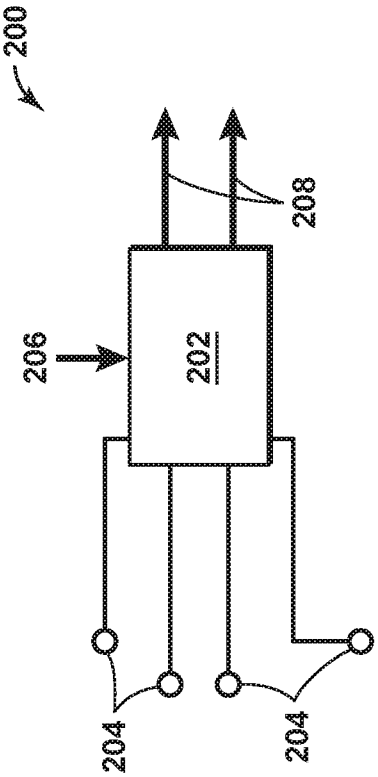


FIG. 13

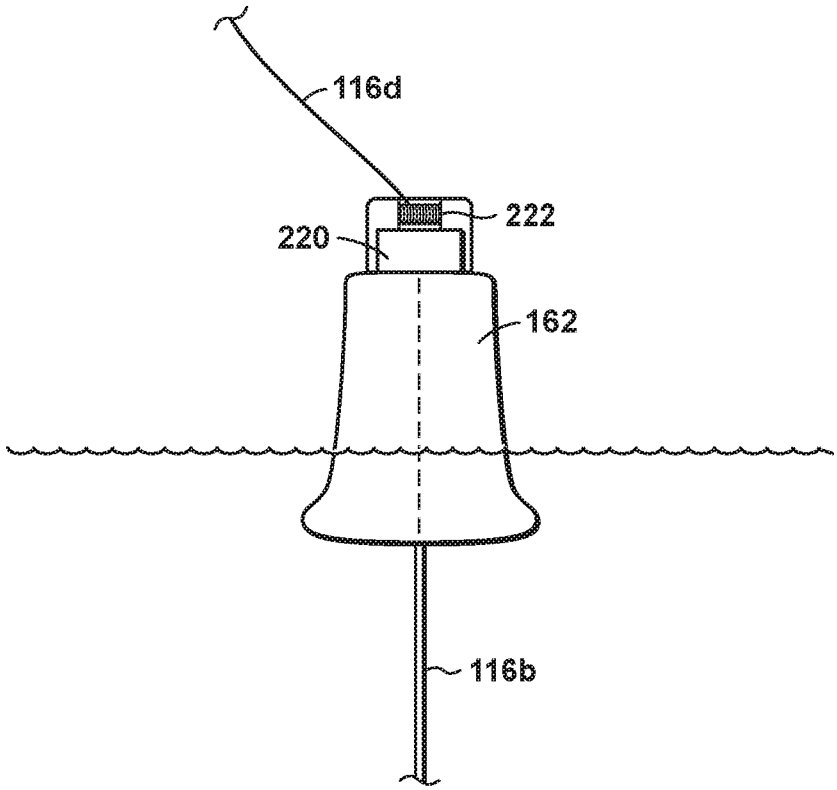


FIG. 14

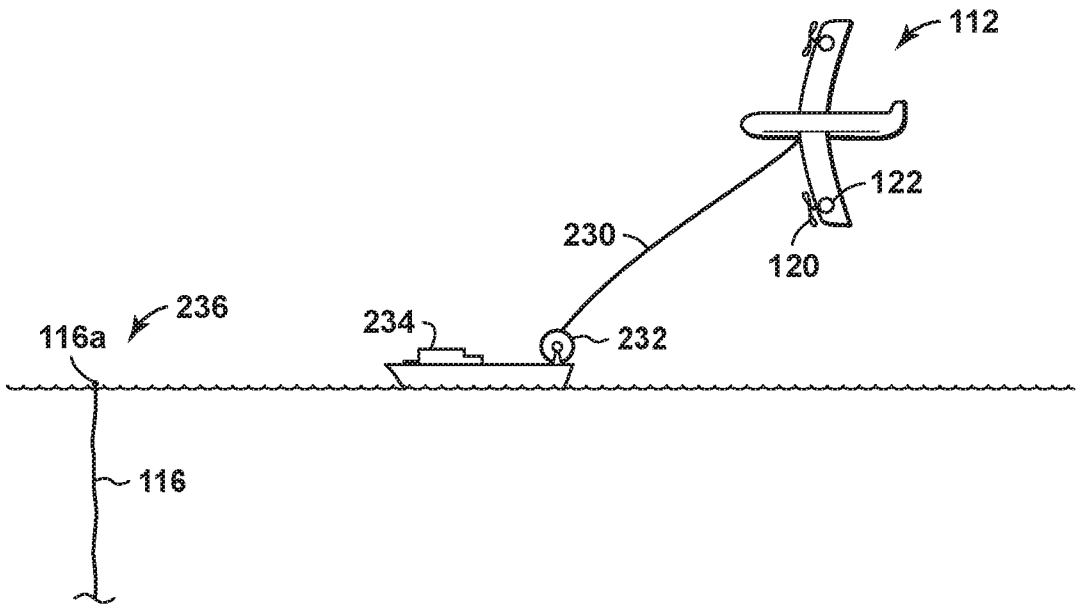


FIG. 15

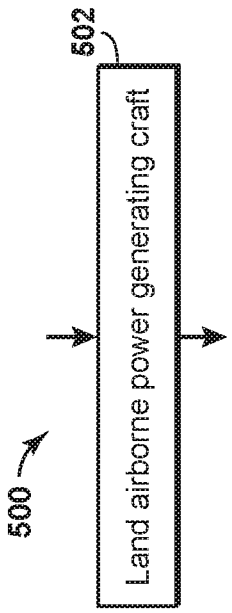


FIG. 18

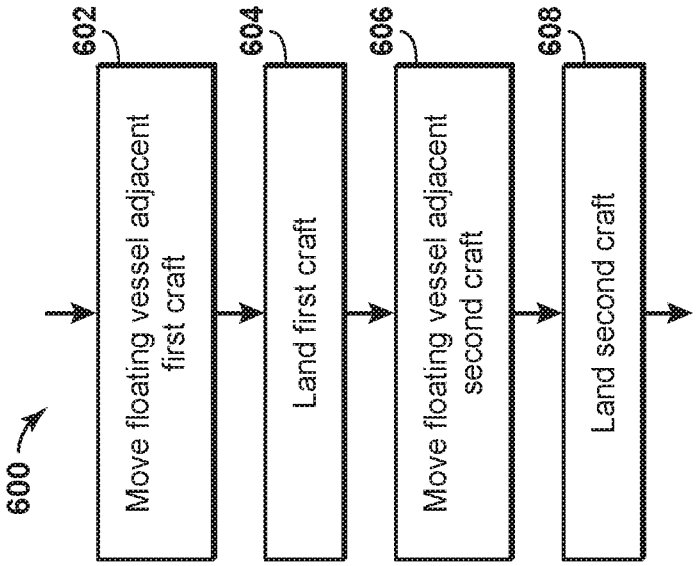


FIG. 19

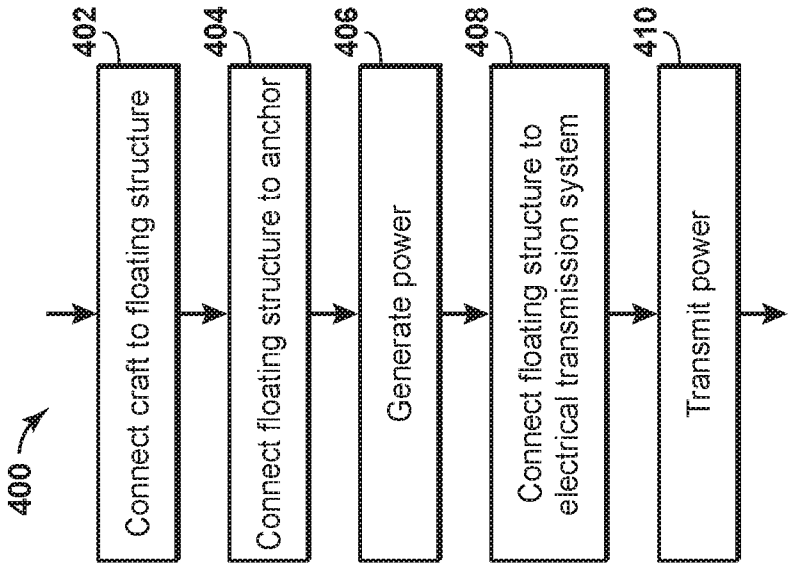


FIG. 17

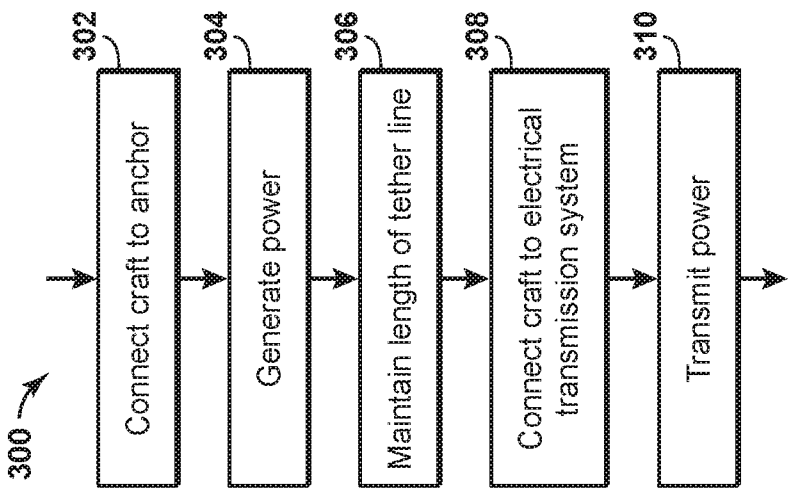


FIG. 16

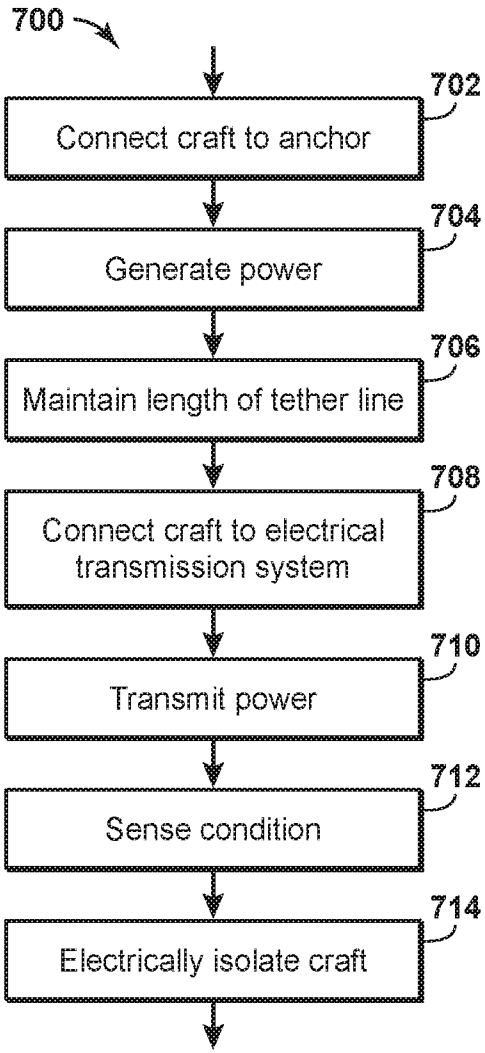


FIG. 20

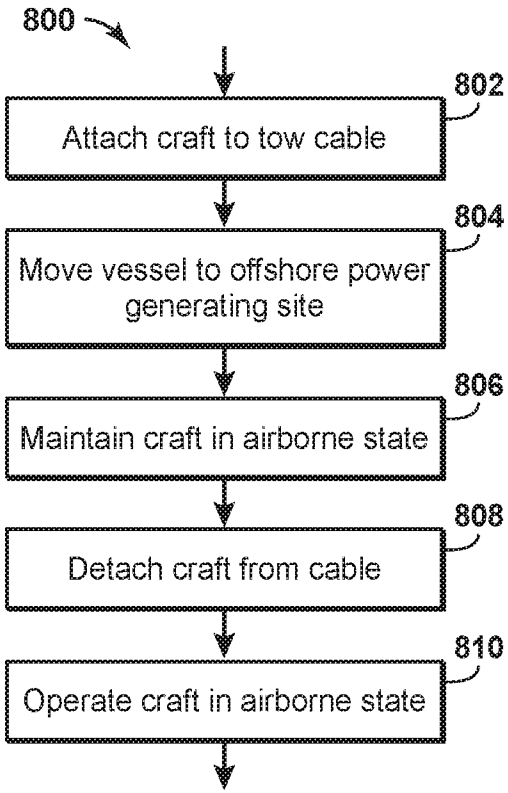


FIG. 21

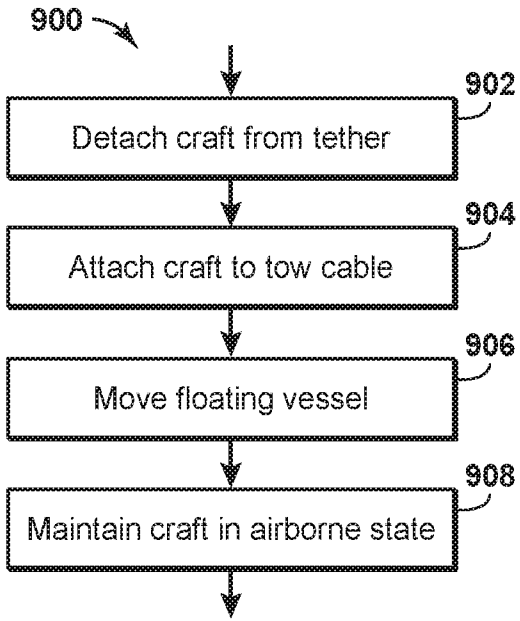


FIG. 22

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/032682

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D5/00
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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2012/146158 A1 (LUO CONGGUI [CN]; QIU HAOWEI [CN]) 1 November 2012 (2012-11-01) figures 45,46	1-19
X	US 2010/032948 A1 (BEVIRT JOEBEN [US]) 11 February 2010 (2010-02-11) paragraphs [0033], [0046], [0066]; figures 7(a),7(b)	1-19
X	US 2013/134261 A1 (GOLDSTEIN LEONID [US]) 30 May 2013 (2013-05-30) paragraph [0157] - paragraph [0159]; figures 13A,17A,19C,21A	1-19
X	US 2015/183516 A1 (VANDER LIND DAMON [US]) 2 July 2015 (2015-07-02) paragraph [0005]; figures 3-6C	1-19

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 July 2017	27/07/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Bradley, David

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INTERNATIONAL SEARCH REPORT

International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 2015/251763 A1 (VANDER LIND DAMON [US]) 10 September 2015 (2015-09-10) paragraph [0022]; figure 3	1-19
A	US 2015/375832 A1 (SU HSIN CHI [TW]) 31 December 2015 (2015-12-31) abstract; figure 3	1,11,19

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International application No
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		US 2015375832 A1	31-12-2015
		WO 2014116185 A1	31-07-2014