

WAVE ENERGY CONVERSION SYSTEM

Technical Field

[0001] The present disclosure relates to a wave energy conversion system for converting wave movements to electrical energy.

Background

[0002] Offshore structure such as jackup rigs and offshore jackets consume significant amounts of fuel to meet their electrical energy needs. Due to growing concerns about the depletion of non-renewable energy resources, it is desirable to reduce the fuel consumption of such offshore structures. A sustainable energy source that has not yet been fully tapped is that of wave energy. To capture wave energy, a variety of wave energy conversion devices have been created, including point absorbers, oscillating water columns, and buoys. However, these have faced drawbacks including poor performance, high costs, and susceptibility to severe maritime environments.

[0003] It is therefore desirable to provide a wave energy conversion system for supplementing the electrical energy demands of offshore structures that addresses the drawbacks of existing wave energy conversion devices.

Summary

[0004] According to a first aspect, there is provided a wave energy conversion system for use on an offshore structure to convert wave movements to electrical energy, the wave energy conversion system comprising: a frame adjustably attachable to the offshore structure, the frame having a number of upright linear guides; a buoy provided in slidable engagement with the linear guides, wherein the buoy is configured to float on a surface of a body of water where the offshore structure is deployed and to rise and fall with wave movements on the surface when the frame is attached to the offshore structure in a working position; a rack and pinion arrangement, wherein the rack is attached to the buoy in an upright arrangement such that the rack moves up and down as the buoy rises and falls respectively and wherein the pinion is

provided in rotatable engagement with the rack and configured to be attached to one of: the frame and the offshore structure, wherein in use, the pinion is rotated in a first direction by upward movement of the rack when the buoy rises with wave movement and the pinion is rotated in a second direction by downward movement of the rack when the buoy falls with wave movement; a bi-rotational hydraulic pump driven by rotation of the pinion in both the first and second directions to draw fluid from a fluid tank and to output pressurized fluid; and a hydraulic motor coupled to an electrical generator, wherein the electrical generator is driven by the hydraulic motor to generate electrical energy when the hydraulic motor is driven by the pressurized fluid that is output by the bi-rotational hydraulic pump.

[0005] The rack may be pivotably attached to the buoy, and the wave energy conversion system may further comprise a roller guide configured to be attached to one of: the frame and the offshore structure and provided in rotatable engagement with the rack such that the rack is movably gripped between the pinion and the roller guide.

[0006] The wave energy conversion system may further comprise at least one resilient member provided to bias at least one of the pinion and the roller guide against the rack.

[0007] The frame may include at least one structural ring configured to be removably attachable to the offshore structure, wherein the upright linear guides are disposed on and around the at least one structural ring, and wherein the upright linear guides pass through through holes provided around a periphery of the buoy.

[0008] The wave energy conversion system may further comprise a hydraulic accumulator in connection with the hydraulic motor, the hydraulic accumulator configured to store excess output fluid of the bi-rotational hydraulic pump and further configured to release the stored output fluid for continued driving of the hydraulic motor to drive the electrical generator to generate electrical power when amplitude of the waves is reduced.

[0009] The wave energy conversion system may further comprise an inverter provided to export generated electrical power to an electrical grid of the offshore structure.

[0010] Length of portions of the upright linear guides provided for slidable engagement with the buoy may be at least twice the mean amplitude of the waves.

[0011] The buoy may be ballastable and wherein the wave energy conversion system further comprises a ballasting system for ballasting and deballasting the buoy to be as close to resonance of the wave movements as possible, wherein the ballasting system comprises: a water tank with a valve for supplying water as ballast to the buoy, a pump for pumping water from the water tank through the valve into the buoy, a motion reference unit provided on the buoy to measure frequency of movement of the buoy, and a synchronized controller provided to receive the measured frequency and wave frequency and to control activation of the pump for ballasting or deballasting the buoy according to a predetermined function involving the measured frequency and the wave frequency.

[0012] A shape of the buoy may be optimizable for maximum heave motion and minimum sway motion of the buoy in response to wave movements.

[0013] The wave energy conversions system may further comprise clamps provided on at least one of: the upright linear guides and the at least one structural ring for immovably securing the frame to the offshore structure during use of the wave energy conversions system.

[0014] The wave energy conversions system may further comprise a plurality of extension arms provided to immovably secure the frame to the offshore structure during use of the wave energy conversions system, wherein each extension arm has a clamp provided at each of two ends of the extension arm, wherein in use, one end of each extension arm is clamped to the frame and the other end of the extension arm is clamped to the offshore structure.

Brief Description of the Drawings

[0015] In order that the invention may be fully understood and readily put into practical effect there shall now be described by way of non-limitative example only exemplary embodiments of the present invention, the description being with reference to the accompanying illustrative drawings.

Fig. 1 is an elevation view of a schematic illustration of an exemplary wave energy conversion system attached to a leg of a jackup rig.

Fig. 2 is a close-up view of the wave energy conversion system and the leg of the jackup rig of Fig. 1.

Fig. 3 is a top view of the wave energy conversion system and the leg of the jackup rig of Fig. 1.

Fig. 4 is an elevation view of a schematic illustration of an exemplary wave energy conversion system attached to an offshore jacket.

Fig. 5 is a top view of the wave energy conversion system and the offshore jacket of Fig. 4.

Fig. 6 is a schematic exemplary circuit diagram of wave energy conversion to electrical energy using the wave energy conversion system.

Fig. 7 is a schematic circuit diagram of wave energy conversion to electrical energy including an inverter.

Fig. 8 is a schematic exemplary circuit diagram of a ballasting system.

Fig. 9 is a schematic illustration of the wave energy convertor of Fig. 1 being installed for use on the leg of a jackup rig.

Detailed Description

[0016] Exemplary embodiments of the wave energy conversion system 100 will be described with reference to Figs. 1 to 9 in which the same reference numerals are used across the figures to refer to the same or similar parts.

[0017] In general, referring to Figs. 1 to 5, the wave energy conversion system 100 comprises a frame 101 that is releasably attachable to an offshore structure 200 for supporting the other components of the system 100. The offshore structure 200 to which the wave energy conversion system 100 is attached during use is preferably one that does not significantly obstruct wave movements. Examples of the offshore structure 200 include structures such as a trussed leg 5 of a jackup rig 200 as shown in Figs. 1 to 3, an offshore jacket 200 as shown in Fig. 4 and 5, or a floater of an offshore wind turbine (not shown).

[0018] The frame 101 has a number of upright linear guides 7 for slideably engaging a buoy 1 of the system 100. The upright linear guides 7 preferably engage a periphery of the buoy 1, for example by passing through through holes provided in the periphery of the buoy 1 or by engaging slots provided around the periphery of the buoy 1. The frame 101 may include at least one structural ring 102 for supporting the upright linear guides 7 as can be seen in Figs. 3 and 5, wherein the upright linear guides 7 are disposed on and around the structural ring 102. In

use, the frame 101 is immovably secured to the offshore structure 200. In some embodiments, as shown in Fig. 3, this may be achieved by providing clamps 103 (for example G-clamps or C-clamps) on the structural ring 102 and/or on the upright linear guides 7 of the frame 101. In use, jaws of the clamps 103 may be tightened (e.g., using bolts) around the horizontal braces 501 of a leg 5 of a jackup rig 200 or an offshore jacket 200 in order to immovably secure the frame 101 to the offshore structure 200. In alternative embodiments where the frame 101 may be located at a greater distance away from the horizontal braces 501 such that clamps 103 provided on the structural ring 102 and/or on the upright linear guides 7 are unable to reach the horizontal braces 501, extension arms (not shown) each having a clamp provided at each of two ends of the extension arm may be used to immovably secure the frame 101 to the offshore structure 200 during use. This may be achieved by clamping one end of the extension arm to the frame 101 and clamping the other end of the extension arm to the offshore structure 200. Notably, where the clamps 103 are provided on the upright linear guides 7, the clamps 103 should be provided at or near the ends of the upright linear guides 7 in order not to interfere with sliding engagement of the buoy 1 with the upright linear guides 7.

[0019] The buoy 1 is configured to float on the surface 60 of a body of water in which the offshore structure 200 is installed. In use, when the frame 101 is immovably secured to the offshore structure 200 in its working position, the buoy 1 rises and falls with wave movements on the water surface 60, in sliding engagement with the upright linear guides 7 of the frame 101. In order to allow for maximum heave movement of the buoy 1 in response to wave movements, a length of the portions of the upright linear guides 7 that the buoy 1 can slidably engage is preferably at least twice the mean amplitude of the waves, in order to allow the buoy 1 to move fully from crest to trough of each wave without obstruction from any part of the frame 101. Appreciably, the wave energy conversions system 100 should be attached to the offshore structure 200 at a height on the offshore structure 200 such that the midpoint of the portions of the upright linear guides 7 that the buoy 1 can slidably engage is midway between crests and troughs of the waves. This working position of the system 100 on the offshore structure 200 will allow movement of the buoy 1 to cover the full amplitude of both the crests and troughs of the wave movements in order to maximise generation of electrical energy from movement of the buoy 1.

[0020] The wave energy conversion system 100 includes a rack and pinion system in engagement with the frame 101 and the buoy 1. The rack 2 of the rack and pinion system is attached to the buoy 1 in an upright arrangement as can be seen in Figs. 1, 2, 4 and 6, so that the rack 2 moves up and down as the buoy 1 rises and falls respectively in response to wave movements. The pinion 3 of the rack and pinion system 30 is provided in rotatable engagement with the rack 2. In the exemplary embodiments shown in Figs. 1 to 5, the pinion 3 is attached to the frame 101 by being mounted on a platform 105 provided within the frame 101, as shown in Figs. 1 to 5 and 9. In alternative embodiments (not shown), the pinion 3 may be attached to a part of the offshore structure 200, such as a horizontal brace 501 of a trussed leg 5 of a jackup rig 200 or of an offshore jacket 200 using an adjustable pinion arm.

[0021] Preferably, the rack 2 is pivotably attached to the buoy 1 via a pivot connection 201 in order to prevent the buoy 1 jamming against the upright linear guides 7 as the buoy 1 rises and falls in slidable engagement with the upright linear guides 7. The wave energy conversion system 100 may further include a roller guide 4 attached to the frame 101 using an adjustable roller guide arm 401 provided on the platform 105 as shown in FIGS 1 to 5. In alternative embodiments (not shown), the roller guide 4 may be attached to another stationary part of the offshore structure 200 such as another horizontal brace 501 of the leg 5 of the jackup rig 200 or of the offshore jacket 200.

[0022] The roller guide 4 is provided in rotatable engagement with the rack 2 such that the rack 2 is movably gripped between the pinion 3 and the roller guide 4. Optionally, a resilient member such as a compression spring 402 may be provided to bias the roller guide 4 against the rack 2 as shown in Figs. 1 to 5. Alternatively (not shown), the resilient member may be provided to bias the pinion 3 against the rack 2. Further alternatively, both the pinion 3 and the roller guide 4 may be individually biased against the rack 2 (not shown). Providing at least one resilient member 402 to bias at least one of the pinion 3 and the roller guide 4 against the rack 2 keeps the pinion 3 in continuous contact with the rack 2, so as to optimize efficiency of conversion of linear movement of the rack 2 to rotational movement of the pinion 3.

In use, the pinion 3 is rotated in a first direction by upward movement of the rack 2 when the buoy 1 rises with wave movement, and the pinion 3 is rotated in a second direction by downward movement of the rack 2 when the buoy 1 falls with wave movement. Rotational

movement of the pinion 3 is transmitted to drive a bi-rotational hydraulic pump 601 of the wave energy conversion system 100. In some embodiments, the pinion 3 and the bi-rotational hydraulic pump 601 may both be supported by the platform 105 within the frame 101, as shown in Figs. 3 and 5. The bi-rotational hydraulic pump 601 is connected to a fluid tank 21 containing a fluid, as shown in Figs. 6 and 7, and outputs the pressurized fluid (preferably through a valve 20) to a hydraulic motor 8a of the wave energy conversion system 100 to drive the hydraulic motor 8a whenever there is rotation of the pinion 3 in any direction. The hydraulic motor 8a is coupled to an electrical generator 8 of the wave energy conversion system 100. The electrical generator 8 is driven by the hydraulic motor 8a to generate electrical energy when the hydraulic motor 8a is driven by the pressurized fluid that is output by the bi-rotational hydraulic pump 601. In Fig. 6, it can be seen that the output of three hydraulic pumps 601 can be combined to drive a single hydraulic motor 8a for driving the electrical generator 8 in order to generate sufficient electrical energy. The hydraulic motor 8a and electrical generator 8 are preferably provided on a platform 10 of the offshore structure 200 away from the water surface 60.

[0023] Notably, rotation of the pinion 3 in the first direction causes the bi-rotational hydraulic pump 601 to output the pressurized fluid to the hydraulic motor 8a by drawing the fluid from the fluid tank 21, and rotation of the pinion 3 in the second direction also causes the bi-rotational hydraulic pump 601 to output the pressurized fluid to the hydraulic motor 8a by drawing the fluid from the fluid tank 21, due to the bi-rotational nature of the hydraulic pump 601. In this way, whether the buoy 1 and the rack 2 move up or down, and whether the pinion 3 consequently rotates in the first or second directions, electrical energy continues to be generated by the bi-rotational hydraulic pump 601 outputting the pressurized fluid to the hydraulic motor 8a that in turn drives the electrical generator 8 to generate electrical energy.

[0024] In the event that the pressurized fluid that is output by the bi-rotational hydraulic pump 601 exceeds that required to drive the hydraulic motor 8a, a hydraulic accumulator 22 is optionally provided to store the excess pressurized fluid, as can be seen in Figs. 6 and 7. The hydraulic accumulator 22 is configured to release the stored fluid to continue driving the hydraulic motor 8a for driving the electrical generator 8 to generate electrical power when amplitude of the waves is reduced and output of the fluid from the bi-rotational hydraulic pump 601 is consequently lowered, thereby smoothening the output of the electrical generator 8. Where the offshore structure 200 is an offshore jacket 200 as shown in Fig. 7, an inverter 11

may also be provided to export the generated electrical power to the electrical grid 12 of the jacket 200.

[0025] Optionally, the buoy 1 may be ballastable to change its mass so that it can be tuned to be as close to resonance of the wave movements as possible. To that end, the wave energy conversion system 100 may further include a ballasting system 80 for the buoy 1 as shown in Fig. 8. The ballasting system 80 includes a water tank 33 with a valve 34 for supplying water as ballast 38 to the buoy 1, and a pump 32 for pumping water from the water tank 33 through the valve 34 into the buoy 1. The buoy 1 may be provided with internal compartments to reduce movement of the ballasting water within the buoy 1. The ballasting system 80 also includes a motion reference unit 37 provided on the buoy 1 to measure frequency of movement of the buoy 1. The ballasting system further includes a synchronized controller 35 provided to receive the measured frequency 31 and wave frequency 36 that can be obtained using a wave measurement buoy or a wave recorder, and to control activation of the pump 32 for ballasting or deballasting the buoy 1 according to a predetermined function involving the measured frequency 31 and the wave frequency 36.

[0026] To maximize heave motion and minimize sway motion of the buoy 1 in response to wave movements, shape of the buoy 1 is optionally optimizable by providing retractable flaps (not shown) on the buoy 1 to adjust and enlarge the shape of the buoy 1.

[0027] Preferably, the wave energy conversion system 100 is configured to be readily installed for use on existing appropriate offshore structures 200 such as the trussed leg 5 of a jackup rig 200 as shown in Fig. 9, and also uninstalled when the offshore structure 200 is being moved. In this way, the system 100 will not require new infrastructure to be provided for supporting the system 100 during use, and the system 100 can be readily retrofitted to existing offshore structures 200 to supplement their electrical power supply. Ready deployment of the system 100 on an offshore structure 200 may be achieved by providing a lifting pad eye 109 at a top of the frame 101 and providing a hoist 9 on the offshore structure 200 with its lifting rope passed through the lifting pad eye 9 for raising and lowering the wave energy conversion system 100 between a storage location of the wave energy conversion system 100 on the offshore structure 200 and a working position on the offshore structure 200. The storage location may be on the platform 10 of the offshore structure 200 or may be under the platform 10 but at a higher

position on the offshore structure 200 (i.e., higher up on a leg 5 of the jackup rig 200) that is away from the water surface 60.

[0028] In an exemplary deployment of the system 100, such as during installation of the jackup rig 200, as shown in Fig. 9, when a spudcan 502 provided at a bottom of a leg 5 of the jackup rig 200 has been established on the seabed 50, with the exception of the hydraulic pump 8a and the electrical generator 8 that remain on the platform 10, other components of the wave energy conversion system 100 including the frame 101, the buoy 1, the rack2, the pinion 3 and the bi-rotational hydraulic pump 601 are lowered using the hoist 9 until the working position of the frame 101 on the jackup rig 200 is reached. As discussed above, the working position may be one wherein the buoy 1 floats on the water surface and wherein the midpoint of the portions of the upright linear guides 7 that the buoy 1 can slidably engage is midway between crests and troughs of the waves, as discussed above. The frame 101 is then attached to horizontal braces 501 of the jackup rig 200 to secure the wave energy conversion system 100 in its working position on the jackup rig 200, for example using the clamps 103 described above. To prevent the buoy 1 from falling off the frame 101 when the upright linear guides 7 are raised above the water surface 60 (such as when the wave energy conversion system 100 is being moved to its storage location), stoppers 701 as shown in Fig. 1 may be provided at bottom ends of the upright linear guides 7 on which the buoy 1 can rest when the frame 101 and the buoy 1 are out of the water.

The presently disclosed wave energy conversion system 100 thus provides a means for harvesting offshore renewable wave energy by using existing offshore structures 200 as a base on which to generate electrical power from wave movements. The generated electrical power can be stored for future use, and/or integrated into the electric grid 12 of the offshore structure 200 to reduce its fuel requirements and energy costs.

[0029] While there has been described in the foregoing description exemplary embodiments of the present invention, it will be understood by those skilled in the technology concerned that many variations in details of design, construction and/or operation may be made without departing from the present invention. It will be appreciated that many further alterations, modifications and permutations of various aspects of the described embodiments are possible that fall within the spirit and scope of the appended claims.

Claims

1. A wave energy conversion system for use on an offshore structure to convert wave movements to electrical energy, the wave energy conversion system comprising:
 - a frame adjustably attachable to the offshore structure, the frame having a number of upright linear guides;
 - a buoy provided in slidable engagement with the linear guides, wherein the buoy is configured to float on a surface of a body of water where the offshore structure is deployed and to rise and fall with wave movements on the surface when the frame is attached to the offshore structure in a working position;
 - a rack and pinion arrangement, wherein the rack is attached to the buoy in an upright arrangement such that the rack moves up and down as the buoy rises and falls respectively and wherein the pinion is provided in rotatable engagement with the rack and configured to be attached to one of: the frame and the offshore structure, wherein in use, the pinion is rotated in a first direction by upward movement of the rack when the buoy rises with wave movement and the pinion is rotated in a second direction by downward movement of the rack when the buoy falls with wave movement;
 - a bi-rotational hydraulic pump driven by rotation of the pinion in both the first and second directions to draw fluid from a fluid tank and to output pressurized fluid; and
 - a hydraulic motor coupled to an electrical generator, wherein the electrical generator is driven by the hydraulic motor to generate electrical energy when the hydraulic motor is driven by the pressurized fluid that is output by the bi-rotational hydraulic pump.
2. The wave energy conversion system according to claim 1, wherein the rack is pivotably attached to the buoy, and wherein the wave energy conversion system further comprises a roller guide configured to be attached to one of: the frame and the offshore structure and provided in rotatable engagement with the rack such that the rack is movably gripped between the pinion and the roller guide.
3. The wave energy conversion system according to claim 2, further comprising at least one resilient member provided to bias at least one of the pinion and the roller guide against the rack.

4. The wave energy conversion system according to any one of claims 1 to 3, wherein the frame includes at least one structural ring configured to be removably attachable to the offshore structure, wherein the upright linear guides are disposed on and around the at least one structural ring, and wherein the upright linear guides pass through through holes provided around a periphery of the buoy.
5. The wave energy conversion system according to any one of claims 1 to 4, further comprising a hydraulic accumulator in connection with the hydraulic motor, the hydraulic accumulator configured to store excess output fluid of the bi-rotational hydraulic pump and further configured to release the stored output fluid for continued driving of the hydraulic motor to drive the electrical generator to generate electrical power when amplitude of the waves is reduced.
6. The wave energy conversion system according to any one of claims 1 to 5, further comprising an inverter provided to export generated electrical power to an electrical grid of the offshore structure.
7. The wave energy conversion system according to any one of claims 1 to 6 wherein length of portions of the upright linear guides provided for slidable engagement with the buoy is at least twice the mean amplitude of the waves.
8. The wave energy conversion system according to any one of claims 1 to 7, wherein the buoy is ballastable and wherein the wave energy conversion system further comprises a ballasting system for ballasting and deballasting the buoy to be as close to resonance of the wave movements as possible, wherein the ballasting system comprises: a water tank with a valve for supplying water as ballast to the buoy, a pump for pumping water from the water tank through the valve into the buoy, a motion reference unit provided on the buoy to measure frequency of movement of the buoy, and a synchronized controller provided to receive the measured frequency and wave frequency and to control activation of the pump for ballasting or deballasting the buoy according to a predetermined function involving the measured frequency and the wave frequency.

9. The wave energy conversion system according to any one of claims 1 to 8, wherein a shape of the buoy is optimizable for maximum heave motion and minimum sway motion of the buoy in response to wave movements.
10. The wave energy conversions system according to any one of claims 1 to 9, further comprising clamps provided on at least one of: the upright linear guides and the at least one structural ring for immovably securing the frame to the offshore structure during use of the wave energy conversions system.
11. The wave energy conversions system according to any one of claims 1 to 9, further comprising a plurality of extension arms provided to immovably secure the frame to the offshore structure during use of the wave energy conversions system, wherein each extension arm has a clamp provided at each of two ends of the extension arm, wherein in use, one end of each extension arm is clamped to the frame and the other end of the extension arm is clamped to the offshore structure.