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(54) Benevnelse **METHOD FOR CONTROLLING A FACILITY FOR GEOLOGICAL SEQUESTRATION OF CARBON DIOXIDE, ADAPTED TO A POWER SUPPLY BY RENEWABLE ENERGY**

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METHOD FOR CONTROLLING A FACILITY FOR GEOLOGICAL SEQUESTRATION OF CARBON DIOXIDE, ADAPTED TO A POWER SUPPLY BY RENEWABLE ENERGY

Description

The present invention relates to a method for regulating an installation for the geological sequestration of carbon dioxide, of the type comprising: a structure, preferentially a floating structure; a liquid carbon dioxide storage compartment, received in said structure; an injection device, able to inject carbon dioxide into a submarine geological reservoir, from said storage compartment; an energy production member, able to power said injection device; and an energy storage member, received in said structure, said storage member also being able to power the injection device.

The invention is particularly applicable to offshore installations, as disclosed in US2017/0283014. These installations are designed to inject carbon dioxide (CO_2) into underwater geological reservoirs for sequestration purposes.

Carbon dioxide sequestration aims to reduce greenhouse gas emissions into the atmosphere. It is therefore preferable to supply such installations with non-greenhouse-gas-emitting energy from renewable sources, such as wind, solar, tidal, ocean thermal or geothermal energy.

Renewable energy production has the disadvantage of being intermittent, based in particular on climatic conditions. However, depending on the implementation conditions, the use of a geological reservoir involves risks of hydrate formation in the diffusion channels of said reservoir, and/or the plugging of said channels. To reduce such risks and simplify the various operational aspects by avoiding frequent shutdowns and restarts, it is preferable to ensure continuous injection of carbon dioxide into the reservoir.

The purpose of the present invention is to propose an implementation of an installation for the geological sequestration of carbon dioxide, suitable for operation based on renewable energies while ensuring continuous injection with a flow rate that can potentially be modulated based on the available energy.

To this end, the invention has as its object a regulating method of the above-mentioned type, wherein: the energy production member supplies a time-variable power, said power supplied being associated with a first and a second defined power threshold, the second threshold being greater than or equal to the first threshold; the power supplied varying between a first low state, below the first threshold; a second intermediate state, between the first and second thresholds; and a third high state, greater than the second threshold; and when the power supplied is in the first low state, the injection device is powered by the energy storage member; and when said power supplied is in the third high state, the injection device is powered by the energy production member and said energy production member powers the energy storage member in parallel; so as to ensure a continuous injection of carbon dioxide into the submarine geological reservoir from the carbon dioxide storage compartment.

According to other advantageous aspects of the invention, the regulating method comprises one or more of the following features, taken individually or in any technically possible combination:

- when the injection device is powered by the energy storage member, the injection of carbon dioxide from the storage compartment is implemented at a first flow rate; and when the injection device is powered by the energy production member, said injection of carbon dioxide is implemented at a second flow rate, greater than the first flow rate;

- the installation comprises a tool for forecasting the power supplied by the renewable energy production member; and when said power supplied is in the second intermediate state, the injection of carbon dioxide from the storage compartment is implemented at a third flow rate which is variable over time between the first and second flow rates, depending on the forecasts of the tool.

The invention further relates to an installation for the geological sequestration of carbon dioxide, said installation comprising: a structure; a liquid carbon dioxide storage compartment, received in said structure; an injection device, able to inject carbon dioxide into a submarine geological reservoir, from said storage compartment; an energy production member, able to power said injection device;

and an energy storage member, received in said structure, said storage member also being able to power the injection device; the installation being provided with means of implementing a management method as disclosed hereinbefore, so as to ensure a continuous injection of carbon dioxide into the submarine geological reservoir from the storage compartment.

In other advantageous aspects of the invention, the installation comprises one or more of the following features, either individually or in any technically possible combination:

- the energy storage member comprises a hydraulic energy storage device;
- the energy storage member comprises a device for storing pressurized carbon dioxide;
- the energy storage member comprises an electrical storage battery;
- the energy production member is received on the structure;
- the energy production member is external to the structure;
- the energy production member is powered by a renewable energy source, preferentially chosen from wind, solar, ocean thermal, tidal, and geothermal energy.

The invention will be better understood upon reading the following disclosure, given solely by way of non-limiting example, and done with reference to the drawings, wherein:

[Fig. 1] [Fig. 2] [Fig. 3] Figures 1, 2 and 3 are schematic depictions of installations for the geological sequestration of carbon dioxide, according to a first, second and third embodiment of the invention, respectively.

Each of Figures 1, 2 and 3 shows an installation, 10, 110, 210 for the geological sequestration of carbon dioxide, according to a first, second and third embodiment of the invention, respectively.

More specifically, each of the installations 10, 110, 210 is able to inject carbon dioxide into a submarine geological reservoir 12, visible in Figure 1. “Submarine" means that the geological reservoir 12 is located in ground covered by the sea 14 or, alternatively, by a body of fresh water such as a lake.

The installations 10, 110 and 210 will be disclosed together below, with common elements designated by the same reference numbers.

The installation 10, 110, 210 comprises: a structure 20, floating on or submerged in a body of water; a compartment 22 for storing carbon dioxide; an injection device 24; an energy production member 26, 126, 226; an energy storage member 28, 128, 228; and a device 29 for connecting and discharging liquid CO_2.

The installation 10, 110, 210 comprises an electronic regulating module 30, shown in Figures 2 and 3.

In the embodiments shown, the structure 20 is in particular intended to be installed floating on the body of water, such as the sea 14, covering the geological reservoir 12. The structure 20 may be floating, such as a Single Point Anchor Reservoir (SPAR), or a semi-submersible platform or ship's hull. In a variant that is not shown, the floating structure 20 can be placed directly on the bottom of a body of water, such as a Gravity Base Structure (GBS) or a jack-up lattice structure. Alternatively, the floating structure 20 is a liquid CO_2 transporter.

The compartment 22 is received in the structure 20. The compartment 22 is able to store liquid carbon dioxide. In the embodiments shown, the installation 10, 110, 210 comprises several compartments 22 received in the structure 20.

The injection device 24 is received in the structure 20. The injection device 24 is able to inject carbon dioxide into the submarine geological reservoir 12, from the storage compartment(s) 22.

In particular, the injection device 24 is provided with means for: withdrawing liquid CO_2 from the storage compartment(s) 22; conditioning said CO_2, in particular its temperature and pressure, to a desired state; and sending said conditioned CO_2 into the geological reservoir 12.

As will be explained in greater detail below, the installation 10, 110, 210 is configured so that the injection device 24 continuously injects carbon dioxide into the geological reservoir 12 from the storage compartment 22. "Continuous injection" means that the injection flow rate from injection device 24 to the geological reservoir 12 is always strictly greater than zero.

The energy production member 26, 126, 226 is able to supply energy to the injection device 24.

In the first embodiment, the energy production member 26 of the installation 10 is located on the structure 20. In the second and third embodiments, the energy production member 126, 226 of the installation 110, 210 is located on an auxiliary structure 31, separate from the structure 20. As an alternative to the second and third embodiments, the energy production member of the installation is located on the structure.

Preferably, the energy production member 26, 126, 226 is powered by a renewable energy source. In the embodiments shown, the energy production member 26, 126, 226 is a wind turbine, able to generate energy from the wind. Alternatively, the renewable energy source is solar energy or tidal energy or ocean thermal energy or geothermal energy.

The energy storage member 28, 128, 228 is received in the floating structure 20.

The energy storage member 28, 128, 228 is able to supply energy to the injection device 24. In addition, the energy storage member 28, 128, 228 can be supplied with energy by the energy production member 26, 126, 226.

In the first embodiment, the energy storage member 28 is based on the energy accumulated by a difference in gravity between two reservoirs located at different heights. The transfer enables recovery by transformation of gravity potential energy and the production of hydraulic energy. More specifically, the member 28 comprises: a first 32 and a second 34 reservoir, a hydraulic turbine 36 and a pump 38.

The first reservoir 32 is vertically higher than the second reservoir 34 in the floating structure 20. The first 32 and second 34 reservoirs are in hydraulic communication via first 40 and second 42 circuits. The hydraulic turbine 36 and the pump 38 are located on the first 40 and second 42 circuits, respectively.

The first 32 and second 34 reservoirs and the first 40 and second 42 circuits are able to receive a fluid, preferably a liquid, such as water.

The hydraulic turbine 36 is able to supply energy to the injection device 24. The pump 38 is able to receive energy from the production member 26.

In the embodiment depicted in Figure 1, the member 28 comprises several sub-assemblies, each of said sub-assemblies comprising a first 32 and a second 34 reservoir, a hydraulic turbine 36 and a pump 38 as disclosed hereinbefore. The sub-assemblies are angularly distributed about a main vertical axis 44 of the floating structure 20, so that hydraulic transfers do not disturb a balance of said structure.

In the second embodiment, the energy storage member 128 is based on the energy of a fluid stored under high pressure. More specifically, the member 128 comprises: a third 132 and a fourth 134 reservoir including one or more storage units, a turbine system 136 and a compressor system 138.

The third reservoir 132 is suitable for storing carbon dioxide at high pressure. In one embodiment of the invention, the CO_2 is under temperature and pressure conditions that define a supercritical fluid state. The fourth reservoir 134 is suitable for storing liquid carbon dioxide at reduced pressure.

The third 132 and fourth 134 reservoirs are in fluid communication via a closed cycle. The turbine system 136 and the compressor system 138 are located on the closed cycle.

The turbine system 136 is able to supply energy to the injection device 24 by lowering the pressure of the CO2 taken from the reservoir 134, and delivering thermodynamic work with high efficiency. The compressor system 138 is able to receive energy from the production member 126 and store it in the reservoir 132. The compression and expansion of the CO_2 modify the temperature, and each cycle is equipped with heat exchange devices to maintain the temperature.

In the third embodiment, the energy storage member 228 is an electric battery 46 or a set of electric batteries 46. The battery or batteries 46 are able to supply energy to the injection device 24 and are able to receive energy from the production member 226.

Optionally, the energy storage member 28, 128, 228 further comprises a back-up element, such as a back-up battery 47 depicted in Figure 3. The back-up element is designed to store energy from a source other than the production member 26, 126, 226.

The coupling member 29 is able to connect to a CO_2-transporting vessel 48, depicted in Figures 2 and 3, to receive carbon dioxide on the floating structure 20.

In the embodiments depicted, the electronic regulating module 30 is received in the floating structure 20. In a variant that is not shown, the electronic module 30 is located in a control center external to the floating structure 20.

The electronic module 30 is provided with means, such as a computer program, for implementing a method for regulating the installation 10, 110, 210. Said method aims to maintain a continuous injection of carbon dioxide into the geological reservoir 12 from the storage compartment 22.

The regulating method takes into account the time-variable aspect of the power supplied by the energy production member 26, 126, 226, based on a renewable energy source. In particular, the electronic module 30 is able to measure, over time, the power P supplied by the energy production member 26, 126, 226.

According to the regulating method, the power P supplied is associated with a first P1 and a second P2 defined power threshold. The second threshold is greater than or equal to the first threshold.

Preferably, the second power threshold P2 is strictly greater than the first threshold P1. Alternatively, the first and second thresholds are equal, that is, there is only one defined power threshold. In the remainder of the disclosure, the second threshold P2 is considered to be strictly greater than the first threshold P1.

According to the regulating method, the power P supplied by the production member 26, 126, 226 varies over time between a first low state, below the first threshold P1; a second intermediate state, between the first P1 and second P2 thresholds; and a third high state, above the second threshold.

For example, in the case where the production member 26, 126, 226 is a wind turbine, the first low state corresponds to little or no wind; and the third high state corresponds to strong wind, enabling good performance of said wind turbine.

According to one embodiment, the first low state further corresponds to cases where the wind is too strong to allow safe operation of the wind turbine, in which case the wind turbine is stopped.

When the power P supplied by the production member 26, 126, 226 is in the first low state less than P1, the injection device 24 is powered by the energy storage member 28, 128, 228; and the injection of carbon dioxide from the storage compartment 22 is implemented with a non-zero first flow rate D1.

Preferably, D1 is chosen to be greater than a minimum value compatible with the injection equipment, while still meeting the objective of minimizing the number of installation shutdowns and restarts for a given energy storage size.

When the power P supplied by the power production member 26, 126, 226 is greater than P2 in the third high state, the injection device 24 is powered by said energy production member 26, 126, 226. Carbon dioxide is then injected from the storage compartment 22 at a second flow rate D2, greater than the first flow rate D1.

Said energy production member feeds the storage member 28, 128, 228 in parallel, until said storage member reaches a maximum stored energy capacity.

We will now consider the case where the power P supplied by the production member 26, 126, 226 is in the second intermediate state, between P1 and P2.

Preferably, the electronic module 30 is equipped with, or associated with, a tool 50 (Figure 2) for forecasting the variation in the power P supplied. For example, the tool 50 comprises a weather sensor or a set of weather sensors, as well as software for forecasting future weather conditions based on information obtained by said sensor(s). In the embodiments shown, the forecasting tool 50 is used to anticipate wind variations proximate to the wind turbine forming the production member 26, 126, 226.

Preferably, the forecasting tool 50 is also able to forecast an amount of CO_2 available for injection over a given period. For example, the tool 50 comprises software for calculating said amount based on information linked to an initial state of the CO_2 stock and quantities of deliveries planned on the structure 20. In particular, such a forecast makes it possible to reduce the injection rate before the stock of CO_2 to be injected is exhausted.

Preferably, the computer program of the electronic module 30 is defined so as to share the power P supplied by the production member 26, 126, 226 in the second intermediate state, based on the forecasting by the tool 50. For example, said program defines a flow rate D3, variable over time between D1 and D2, based on said forecasts by the tool 50. Said flow rate D3 mobilizes part of the power P, the remainder of said power being used for energy storage by the storage member 28, 128, 228.

Alternatively, in the second intermediate state, the computer program of the electronic module 30 sets the carbon dioxide injection flow rate to a constant value D3, between D1 and D2.

According to an embodiment, the computer program of the electronic module 30 provides several of the above possibilities for managing the second intermediate state, a choice between these possibilities being configurable by an operator at the electronic module 30.

Preferably, the computer program of the electronic module 30 reserves the use of the back-up battery 47 for the management of extreme situations, when energy storage proves insufficient or inoperative, always within the framework of the quest for injection continuity.

According to a variant that is not shown in the embodiments disclosed hereinbefore, the installation 10, 110, 210 further comprises at least one pressurization tank connected to the carbon dioxide storage compartment 22. According to this variant, when the power P supplied is in the second or third state, CO_2 is vaporized from said compartment 22 and pressurized in said at least one pressurization tank.

A case is then considered wherein the power P supplied is in the first low state and the installation 10, 110, 210 has insufficient stored energy to maintain the first flow rate D1.

In this case, according to a variant of the invention, the injection device 24 injects pressurized CO_2 into the geological reservoir 12 from said pressurization tank, using the "free-flow" principle. This variant enables a reduced, but not zero, injection rate to be maintained, despite the depletion of the energy available in the installation.

In this way, the installation 10, 110, 210 ensures continuous CO_2 injection, with a variable flow rate, preferably above a minimum value to ensure the objective of minimizing the number of shutdowns and restarts.

This kind of injection continuity maximizes the performance of the geological reservoir 12, while enabling the supply of renewable energy, thus optimizing the installation's carbon footprint.

PATENTKRAV

1. Fremgangsmåte for regulering av en installasjon (10, 110, 210) for den geologiske sekvestreringen av karbondioksid, installasjonen omfattende:

- en konstruksjon (20), fortrinnsvis en flytende konstruksjon;

- et flytende karbondioksidlagringsrom (22), mottatt i konstruksjonen;

- en injeksjonsanordning (24), i stand til å injisere karbondioksid inn i et undersjøisk geologisk reservoar (12), fra lagringsrommet;

- et energiproduksjonselement (26, 126, 226), i stand til å drive injeksjonsanordningen; og

- et energilagringselement (28, 128, 228), mottatt i konstruksjonen, lagringselementet er også i stand til å drive injeksjonsanordningen;

fremgangsmåten er **karakterisert ved at:**

- energiproduksjonselementet tilfører en tidsvariabel strøm (P), den tilførte strømmen assosieres med en første (P1) og en andre (P2) definert strømterskel, den andre terskelen er større enn eller lik den første terskelen; strømmen som tilføres varierer mellom en første svak tilstand, under den første terskelen (P1); en andre mellomtilstand, mellom den første og den andre terskelen; og en tredje høy tilstand, større enn den andre terskelen (P2);

- når den tilførte strømmen er i den første lave tilstanden, drives injeksjonsanordningen (24) av energilagringselementet (28, 128, 228); og når den tilførte strømmen er i den tredje høye tilstanden, drives injeksjonsanordningen av energiproduksjonselementet (26, 126, 226) og energiproduksjonsanordningen driver lagringselementet (28, 128, 228) parallelt;

for å sikre en kontinuerlig injeksjon av karbondioksid inn i det undersjøiske geologiske reservoaret fra lagringsrommet.

2. Reguleringsfremgangsmåten ifølge krav 1, hvori, når injeksjonsanordningen (24) drives av energilagringselementet (28, 128, 228), implementeres injeksjonen av

karbondioksid fra lagringsrommet ved en første strømningsrate (D1); og når injeksjonsanordningen drives av energiproduksjonselementet (26, 126, 226), implementeres injeksjonen av karbondioksid ved en andre strømningsrate (D2), større enn den første strømningsraten.

3. Reguleringsfremgangsmåten ifølge krav 2, hvori

- installasjonen omfatter et verktøy (50) for å forutsi strømmen (P) som tilføres; og

- når den tilførte strømmen (P) er i den andre mellomtilstanden, implementeres injeksjonen av karbondioksid fra lagringsrommet ved en tredje strømningsrate (D3) som er variabel over tid mellom den første og den andre strømningsraten, avhengig av prognosene for verktøyet (50).

4. Installasjon (10, 110, 210) for den geologiske sekvestreringen av karbondioksid, installasjonen omfattende:

- en konstruksjon (20);

- et flytende karbondioksidlagringsrom (22), mottatt i konstruksjonen;

- en injeksjonsanordning (24), i stand til å injisere karbondioksid inn i et undersjøisk geologisk reservoar, fra lagringsrommet;

- et energiproduksjonselement (26, 126, 226), i stand til å drive injeksjonsanordningen; og

- et energilagringselement (28, 128, 228), mottatt i konstruksjonen, lagringselementet er også i stand til å drive injeksjonsanordningen;

installasjonen tilveiebringes med middel for å implementere en styringsfremgangsmåte ifølge et hvilket som helst av de foregående kravene, for å sikre en kontinuerlig injeksjon av karbondioksid inn i det undersjøiske geologiske reservoaret fra lagringsrommet.

5. Installasjonen (10) ifølge krav 4, hvori energilagringselementet (28) omfatter en hydraulisk energilagringsanordning (30, 32).

6. Installasjonen (110) ifølge krav 4 eller krav 5, hvori energilagringselementet (128) omfatter en anordning (130) for lagring av trykksatt karbondioksid.

7. Installasjonen (210) ifølge ett av kravene 4 til 6, hvori energilagringselementet (228) omfatter et elektrisk lagringsbatteri (46).

8. Installasjonen (10) ifølge ett av kravene 4 til 7, hvori energiproduksjonselementet (26) mottas på konstruksjonen (20).

9. Installasjonen (110, 210) ifølge ett av kravene 4 til 7, hvori energiproduksjonselementet (126, 226) er utenfor konstruksjonen (20).

10. Installasjonen ifølge ett av kravene 4 til 7, hvori energiproduksjonselementet (26, 126, 226) drives av en fornybar energikilde, fortrinnsvis valgt fra vind-, sol-, havtermisk, tidevanns- og geotermisk energi.

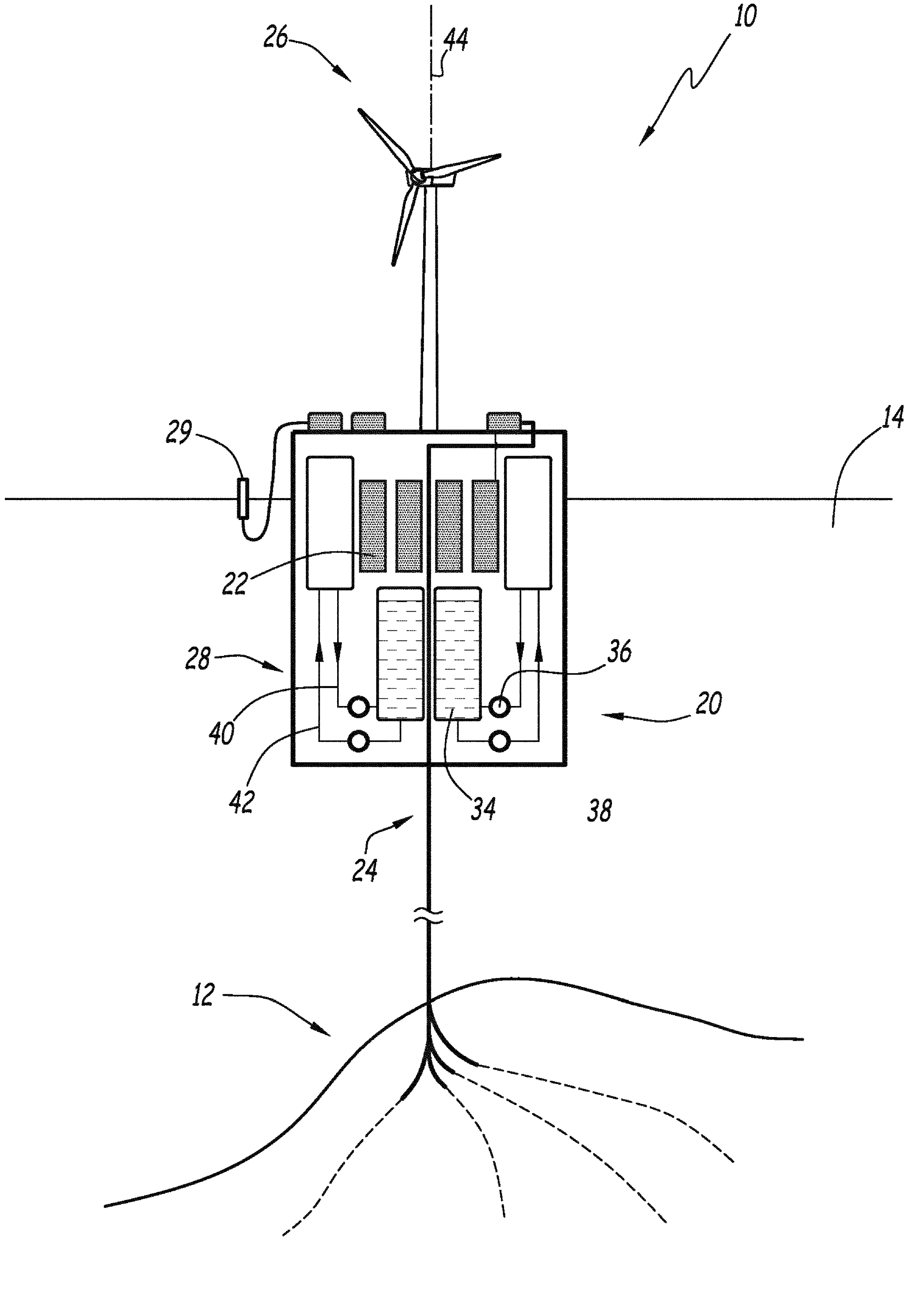

FIG.1

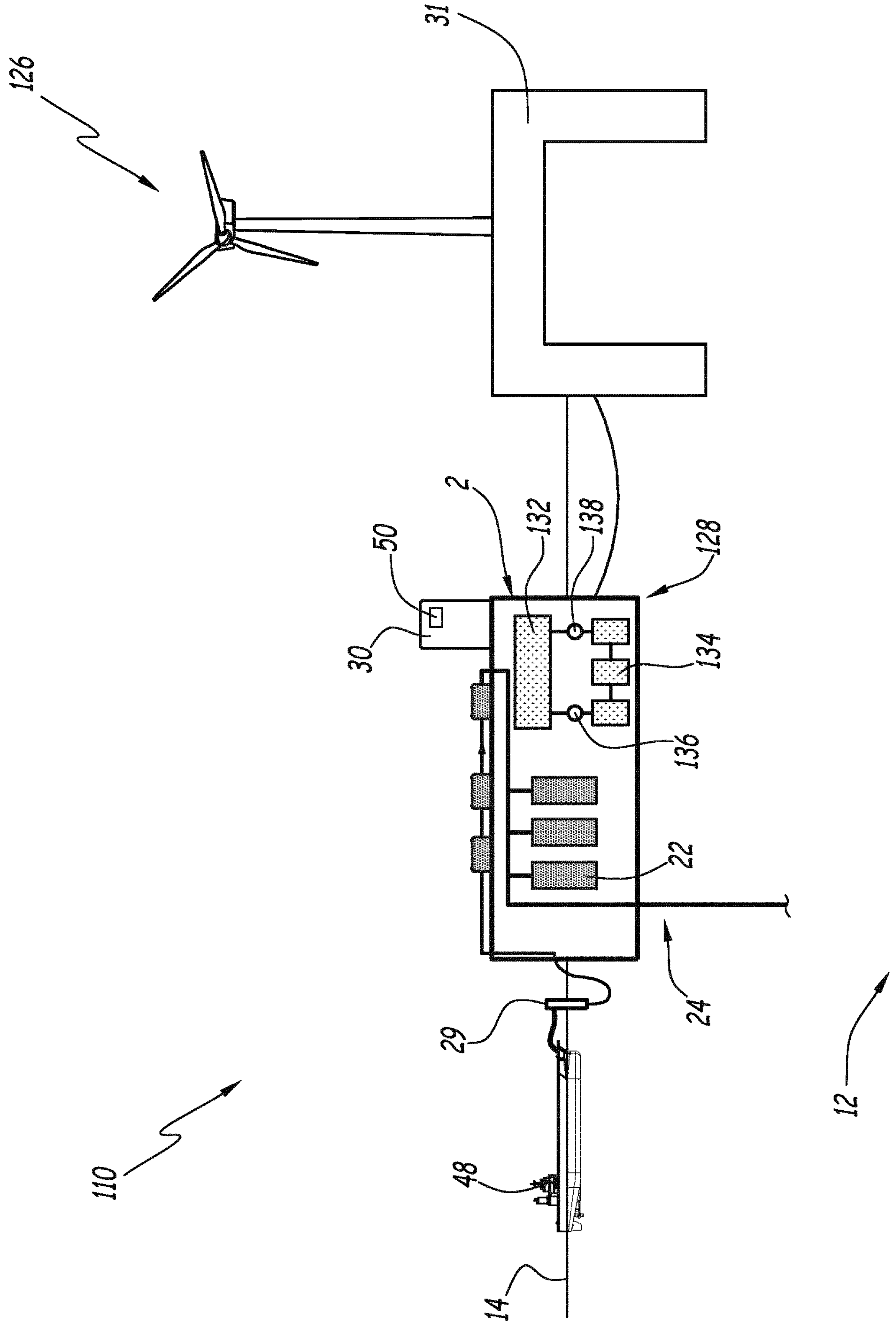

FIG.2

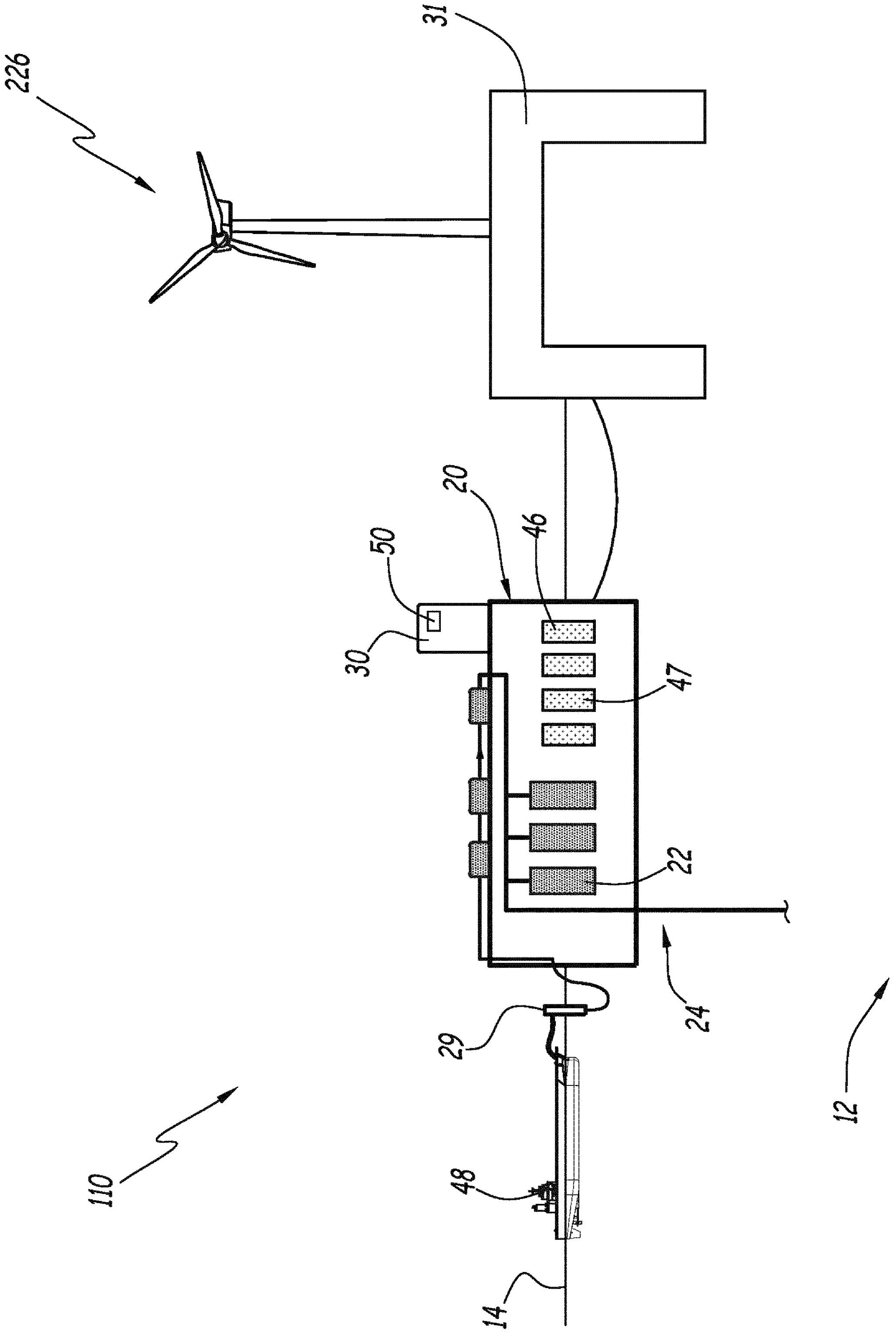

FIG.3