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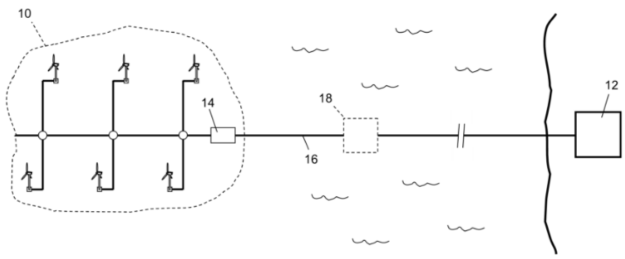
(54) Title **Delivering power to offshore vessels**

(57) Abstract

During installation of an offshore facility, a vessel is connected to a supply line at a location offshore. Energy is supplied to the vessel from the supply line, and that supplied energy is used in electrical form to perform installation operations on the facility without producing harmful emissions. The vessel can perform those operations itself or can provide energy to a separate work vessel or rig that performs those operations instead. When the facility is installed and in operation, the supply line is used to convey energy to, from or within the facility.



Delivering power to offshore vessels

This invention relates to local delivery of power to vessels for the purpose of reducing or avoiding harmful emissions during their operation. The invention has particular benefits for work vessels used in offshore construction or installation projects.

For decades, most offshore work vessels have been powered by diesel engines. Some current vessels employ diesel-electric propulsion whereas others are powered by gas turbines. In recent years, efforts to improve fuel efficiency and to reduce emissions have led to the adoption of hybrid propulsion in offshore work vessels such as the applicant's vessel *Seven Viking*.

Hybrid propulsion is characterised by storing energy in large onboard batteries and using that stored energy to propel the vessel to some extent. In this respect, the batteries are not capacious enough to serve as the sole source of propulsive energy. Consequently, traditional combustion engines remain the main source of motive power and the stored energy powers only auxiliary electric motors. However, some of the energy stored in batteries can be used to power other systems aboard a vessel. For example, the stored energy can provide an immediately accessible power reserve for critical equipment such as dynamic positioning systems, cranes and winches.

Typically, the combustion engines of a hybrid vessel drive generators that charge the batteries from time to time. Charging cycles take place between discharge cycles in which the batteries provide energy to the electric motors to propel the vessel alone or in conjunction with the combustion engines. Specifically, the vessel can be propelled entirely electrically for short zero-emission periods, for example when moored or when manoeuvring in harbour, or the electric motors can contribute to propulsion of the vessel over longer periods, for example while in transit to a work site or when performing tasks at that site. In that case, the stored energy can enable load-smoothing to allow the combustion engines to operate more efficiently.

All sectors of commerce are striving to minimise emissions that can damage health or the environment, notably carbon dioxide, oxides of nitrogen and particulates. In the marine sector, those efforts have led to recent proposals for fully electric vessels that need not consume any fossil fuels or generate any harmful emissions at all. However, fully electric propulsion requires a huge battery capacity that is often impractical due to constraints of cost, weight, space, range and operating duration.

Recognising that limited battery capacity is a barrier to the adoption of fully electric vessels, the invention is concerned with making energy available locally offshore to provide power to such vessels near to where they are used and where energy is therefore consumed. However, the invention has benefit not only with fully electric vessels but also with hybrid vessels whose batteries can be recharged from external sources of electrical energy.

As will be explained, aspects of the invention also have benefit in hydrogen-powered vessels in which hydrogen is used to power fuel cells that generate electricity or to fuel combustion engines. In principle, consumption of hydrogen fuel emits only water, and ‘green hydrogen’ can be produced without harmful emissions by using energy from renewable sources to power electrolysers.

The prior art includes various proposals to reduce restrictions on long-distance or long-duration operation of electric vessels. KR 20210044091, for example, proposes that surface vessels could be charged remotely by wireless power transfer from cables laid on the seabed. However, the capital cost of such system would be prohibitive and power losses would be excessive, especially in deeper water.

GB 2584284 discloses a subsea network for charging small underwater vehicles such as autonomous underwater vehicles (AUVs), which can dock to a node of the network to receive power and data periodically. Such a network is not suitable for charging surface vessels, in particular vessels that have large enough batteries to be useful for surface operations.

WO 2020/044601 describes how an electric vessel can charge its batteries by navigating to and connecting to an offshore power source, such as a generator driven by a turbine that may be powered, in turn, by a liquefied gas such as liquefied natural gas or LNG. The object of that disclosure is to charge the batteries without requiring the vessel to be moored beside a quay. It also teaches organising charge cycles of multiple vessels using the same power source.

In WO 2021/032259, a buoy suspends a power cable that preferably extends to the buoy from a source of electrical power onshore. A vessel or a drilling rig can connect to a cable terminal on the buoy, providing an alternative to diesel- or gas-powered generators to maintain a power supply for the vessel or rig. Similarly, WO 2021/104588 discloses a mooring buoy supporting a power cable to provide electrical power to a vessel, and a field comprising a plurality of such buoys for powering multiple vessels simultaneously. These documents recognise that a vessel will consume energy even when moored, for example for crew accommodation and for deck operations. Thus, the external power supply avoids running a primary or auxiliary genset, which would otherwise consume fuel inefficiently and generate undesirable emissions.

Installing and maintaining a dedicated power-supply buoy and its associated cabling as taught by the prior art is costly and can be technically challenging, especially in locations far offshore. Also, the power supply must be used often enough, and over a long enough period of operation, to justify its high cost. There remains a need for a power supply system for offshore vessels that can be installed and operated economically in a wide range of offshore locations, even if it is to be used only transiently during a construction project or in other circumstances where the requirement to power vessels may be short-lived.

Against this background, the invention resides in a method of installing an offshore facility, that method comprising: connecting an offshore vessel to a supply line; supplying energy from the supply line to the vessel; performing installation operations on the facility using the supplied energy in electrical form; and when the facility is installed and in operation, using the supply line to convey energy to, from or within the facility, for example between power-generating elements of the facility. The supplied electrical energy can be used to operate onboard equipment and propulsion systems without producing harmful emissions during the installation operations.

Energy can be supplied from the supply line to the vessel as electrical energy. That electrical energy could be derived from an onshore power grid or could be generated offshore from wind, wave, tidal or solar generation.

Energy can instead be supplied from the supply line to the vessel as chemical energy, for example in the form of hydrogen produced by electrolysis of water offshore, preferably using electrical energy generated offshore. The chemical energy can then be converted to electrical energy aboard the vessel, for example in a fuel cell.

The installation operations may be performed using the vessel that is, or was, connected to the supply line to receive energy. For example, the installation operations could be performed while the vessel remains connected to the supply line. Alternatively, electrical energy can be conveyed from the vessel to a separate work vessel, jack-up or rig that performs the installation operations. In that case, energy supplied by the supply line can be stored aboard the vessel before disconnecting the vessel from the supply line and moving the vessel, for example under remote or autonomous control, to a position beside the work vessel, jack-up or rig before transferring the stored energy in electrical form.

The supply line can be supplied with energy from a pre-existing installation serving as a power source. Such a pre-existing installation could also provide power to other consumers before the vessel is connected to the supply line and/or after the facility is installed and in operation. Alternatively, a power source can be installed temporarily offshore to provide the supply line with energy, and can then cease to provide energy to the supply line when the facility is installed and in operation.

To facilitate stepwise emission-free movement of a vessel around a facility from one element of that facility to another, the method may comprise: connecting the vessel to a first supply line connection; supplying energy to the vessel via the first supply line connection; performing a first installation operation on the facility using the energy supplied via the first supply line connection; connecting the vessel to a second supply line connection; supplying energy to the vessel via the second supply line connection; and performing a second installation operation on the facility using the energy supplied via the second supply line connection.

The first and second supply line connections can communicate with different respective supply lines or with the same supply line. The vessel can be connected to the second supply line connection while the vessel is connected to the first supply line connection.

The installation operations can be performed at mutually-spaced worksites between which the vessel travels after performing the first installation operation. Those operations may, for example, be performed on respective offshore wind turbines or other offshore electricity generators.

Conveniently, the vessel can be connected to the supply line via an umbilical extending from the supply line at a subsea location toward the surface. Optionally, the vessel may be connected to the supply line via a link that extends from the vessel to an intermediate buoyant support at an upper end of the umbilical.

To facilitate transfer between supply line connections, the vessel can be connected to one or more supply lines via first and second links extending from the vessel to respective intermediate buoyant supports, each located at an upper end of a respective umbilical. The or each intermediate buoyant support could be launched from the vessel and could be manoeuvred relative to the vessel.

Two or more offshore vessels can be connected to the supply line to receive energy, preferably at the surface. For example, the vessels can be connected to a common connection that communicates with the supply line directly or via an umbilical.

Correspondingly, the inventive concept embraces a system for performing installation operations on an offshore facility, that system comprising: an energy supply line; a connection by which a vessel can be connected to the supply line to receive energy from the supply line; and at least one vessel arranged to receive energy from the supply line via the connection and to use or transfer that energy in electrical form for the installation operations to be performed. In accordance with the invention, the supply line is a permanent installation for transferring energy to, from or within the facility when the facility is operational.

The supply line may be connected to an onshore power grid or to an offshore power source that employs wind, wave, tidal or solar generation. The power source can be permanently installed to support long-term operations other than installation or temporarily installed to support only short-term operations including installation. The supply line can also be a pipeline or downline that conveys energy to the vessel as chemical energy, in which case the vessel can include at least one fuel cell powered by the chemical energy to generate electricity.

The system may further comprise a power transfer connection between the vessel and a separate work vessel, jack-up or rig that is configured to perform the installation operations.

The invention can be embodied in various forms. In some aspects, the invention enables offshore electrification to provide an alternative energy source for work vessels operating in offshore facilities such as subsea oil and gas fields or wind farms, especially when using those vessels during installation of such facilities. Such a vessel could be propelled entirely electrically or could be a barge or rig that is towed to a work site to perform installation tasks or to provide local electrical power to other vessels or rigs engaged in installation operations.

The invention envisages an alternative use of a transfer or supply line, exemplified by a power cable or a group of such cables, leading to or placed in an offshore facility to export power from, or to provide power to, that facility as a whole or from or to one or more power-generating or power-consuming elements of that facility. For example, cables or other elements may extend across the seabed or hang in the water column to effect a power export connection to the shore from an offshore facility or from one offshore facility to another. Similarly, such cables or other elements may define a power grid or network within a facility to export power from, or to provide power to, generating or consuming elements of that facility, those elements being nodes of that network.

More specifically, the invention envisages pre-use of a supply line such as a cable to deliver electrical power to a work vessel during installation of the facility. Thus, the supply line could be installed as the first item of the facility, hence before the facility itself is installed, or while installation of the facility is ongoing. Put another way, the supply line may be installed before installation of at least some elements of the facility that will, subsequently, export power along or receive power from that supply line themselves. Meanwhile, and potentially also after installation, the supply line is available to provide electrical energy to vessels that connect to it via a link cable.

Thus, the supply line may include one or more connection points at an end or along its length, located underwater or at the surface, to which vessels can connect from time to time to receive electrical energy. A connecting link extending from the vessel could be coupled temporarily to a connection point, or a connecting link extending from a connection point could be coupled temporarily to the vessel. In either case, the coupling could involve wet-mating or contactless inductive coupling. Alternatively, vessels could connect directly to an end of the supply line.

A vessel connected to the supply line can receive and store electrical energy, thus enabling the vessel to disconnect from the supply line and to perform installation tasks over a relatively large area while its propulsion systems and/or other equipment are driven electrically. Alternatively, a vessel can remain connected to the supply line via a connecting link to perform installation tasks within a smaller radius about the connection point defined by the length of the connecting link, again while its propulsion systems and/or other equipment are driven electrically. As just two examples of installation tasks, a vessel could install rock ballast or foundations for a wind turbine, being an element of a wind farm facility.

If the vessel needs to work further from a subsea connection point to which it is to remain connected to receive electrical energy from a subsea supply line, the vessel can launch a surface relay such as a remotely operated vessel or a float or buoy above the connection point, interposed between the vessel and the connection point. Then, a long link cable extending from the vessel can be connected to the surface relay, and another cable or umbilical can extend from the surface relay to the connection point. A floating structure with a different primary purpose, such as a floating wind turbine, or another structure not launched by the vessel can also be used as a surface relay interposed between the vessel and the connection point.

The link cable serving as a connecting link to the vessel is likely to be subject to fatigue due to surface dynamics and so may advantageously be a replaceable product.

A vessel could operate two remotely operated vessels that can each connect to the next connection point independently. This allows the vessel to move from one location to the next using electric propulsion alone, even if the distance between those locations exceeds the working radius allowed by a single connecting link.

In principle, as noted above, this aspect of the invention could also be implemented in a permanent, installed facility, allowing a power grid of that facility to deliver power to a vessel while the facility is in operation.

In an example of dynamic energy management, the vessel could communicate with an onshore power supply or other power source while connected to the supply line, so that power levels delivered from the source to the vessel can be increased or decreased at the appropriate time in accordance with demand.

The invention also contemplates an autonomous, independent or dedicated energy storage vessel whose internal volume is largely devoted to batteries and, if the vessel if self-propelled, to propulsion motors. The battery storage could be dedicated to the energy requirements of that vessel or, in a power supply vessel, the stored energy could be shared with another, temporarily connected, vessel. Advantageously, an autonomous vessel or an independent power supply vessel could be designed from the outset to have autonomous or remote-control capability or to be dedicated primarily to onboard energy storage rather than requiring modification of existing vessels. Alternatively, the vessel could be a hybrid vessel with, for example, a diesel engine in conjunction with an onboard battery to receive power from a remote power supply.

Work vessels may include transportable, reusable rigs, such as jack-up rigs or jack-up barges, otherwise known as jack-ups. Again, a jack-up could receive power from an autonomous or independent vessel whose internal volume is primarily devoted to batteries.

The invention also extends to the use of an autonomous, independent or remote-controlled power generation vessel that is supplied with hydrogen to produce and deliver electrical power to other vessels or rigs. The power generation vessel can be filled with hydrogen at an energy island or at shore or can be supplied with hydrogen via a pipeline serving as a supply line. The power generation vessel may, for example, use fuel cells to generate electrical energy from the hydrogen without harmful emissions.

Again, the power generation vessel can be designed from the outset for its specialised duties rather than requiring existing vessels to be modified, for example by finding space for bulky fuel cells among the other equipment of existing vessels. Also, the use of a dedicated power generation vessel keeps flammable hydrogen a safe distance away from vessels that have personnel on board.

Embodiments of the invention provide a method to deliver power to at least one offshore construction vessel located offshore at a wind farm or at an oil and gas field, the method comprising: installing at least one transfer element or supply line serving as a permanent power transport means on the offshore field, preferably connected to a pre-existing power source; connecting a terminal to the supply line; and plugging in or otherwise connecting the vessel to the terminal.

The supply line may be installed to connect two or more permanent offshore installations before at least one of those installations is installed. In that case, the construction vessel may support or participate in installing the or each installation that remained to be installed.

The power could be delivered by a flow of electrical energy, in which case the supply line may be a cable or an umbilical. Alternatively, the power could be delivered by a flow of energy in chemical or elemental form such as hydrogen, in which case the supply line may be a rigid or flexible pipeline.

In the case of brownfield construction, a pre-existing source of the delivered power may be located offshore. For example, the power source could be a wind turbine, a substation of a wind farm, or an oil or gas production facility.

In the case of greenfield construction, the method may further comprise pre-installing a temporary power source offshore. Such a temporary power source could, for example, be a battery rack or array, a wave energy converter, a floating solar plant or other producer of renewable energy such as a wind turbine or a tidal turbine. Any of those sources could be used in conjunction with an electrolyser for producing hydrogen.

The terminal can be located subsea, preferably on the seabed, or can be located on a surface buoy, or can be located in the water column between the surface and the seabed. The terminal may be installed permanently or temporarily, for example only for the duration of an offshore construction project requiring delivery of electrical power to work vessels involved in that project. The vessel can connect to the terminal by deploying a connection cable or a flexible pipe through water. The terminal may, for example, comprise a wet-mate connector or a contactless inductive connector. The terminal could also comprise a transformer.

The emission-free range of the construction vessel may be extended by installing at least one additional cable or umbilical, permanently or temporarily, from the power source or from the terminal. Such an additional cable or umbilical may also comprise a terminal of its own.

The vessel can perform work on a field or other work site while linked to the power source via the terminal to receive power. Alternatively, the vessel can store energy onboard to perform work independently on the work site without having to maintain a physical link with the power source via the terminal.

In summary, a vessel is connected to a supply line at a location offshore during installation of an offshore facility. Energy is supplied to the vessel from the supply line, and that supplied energy is used in electrical form to perform installation operations on the facility, hence without producing harmful emissions. The vessel can perform those operations itself or can provide energy to a separate work vessel or rig that performs those operations instead. When the facility is installed and in operation, the supply line is reused to convey energy to, from or within the facility.

In order that the invention may be more readily understood, reference will now be made, by way of example, to the accompanying drawings, in which:

Figure 1 is a schematic plan view of an offshore facility exemplified by a wind farm, also showing its connection to an onshore power grid;

Figures 2a to 2c are a sequence of schematic plan views showing an export cable of the facility installed before the remainder of the facility is installed, also showing a work vessel receiving electrical power from that cable to install an element of the facility connected to that cable;

Figures 3a to 3d are a sequence of schematic plan views of a work vessel receiving electrical power from another cable of the facility when installing another element of the facility that is to be connected to that cable;

Figure 4 is a flowchart showing an exemplary method of the invention;

Figure 5 is a schematic side view of a work vessel connected by an umbilical and a connection point to a subsea cable serving as an electricity supply line;

Figure 6 corresponds to Figure 5 but shows a jack-up as another example of a vessel connected to the supply line;

Figure 7 corresponds to Figure 5 but shows a connecting link and a remotely operated vessel interposed between the work vessel and the umbilical;

Figure 8 corresponds to Figure 5 but shows the work vessel connected directly to an end of the supply line;

Figure 9 is a schematic side view of a power supply vessel connected by an umbilical and a connection point to a subsea cable serving as an electricity supply line;

Figure 10 is a schematic side view of a jack-up receiving power from the power supply vessel of Figure 9;

Figure 11 is a schematic side view of a power generating vessel connected to a subsea pipeline serving as a hydrogen supply line;

Figure 12 is a schematic side view of a jack-up receiving power from the power generating vessel of Figure 11;

Figure 13 is a schematic side view of a work vessel using two remotely operated vessels to transfer its power supply from one connection point to another;

Figure 14 is a schematic side view of a mooring arrangement for two or more vessels receiving power from a subsea cable serving as an electricity supply line; and

Figure 15 is a schematic plan view corresponding to Figure 3d but showing the wind turbines of an offshore facility daisy-chained with successive cable legs between them.

Figure 1 shows part of an offshore facility 10, here in the form of a wind farm. The facility 10 is connected to an onshore power grid 12 by a subsea export cable extending onshore from a substation 14 of the facility 10. During installation of the facility 10, in accordance with the invention, the export cable can be used preliminarily as a supply line 16 to convey electrical energy to vessels performing installation tasks offshore. Conveniently, therefore, the grid 12 or another onshore power source can be used to provide energy to vessels via the supply line 16 defined by the export cable.

For simplicity, the description that follows will refer to the export cable as a supply line 16, it being understood that the supply line 16 can serve as an export cable after installation of the facility, when the facility is operational.

In this example, Figure 1 also shows an optional dedicated offshore power source 18 that can also, or instead, provide energy to vessels via the supply line 16. The offshore power source 18 could be a pre-existing permanent installation, potentially one installed for other purposes, such as a wind turbine, a substation or an oil or gas production installation. Alternatively, the offshore power source 18 could be pre-installed specifically to provide power to the facility 10 being installed. In that case, the offshore power source 18 could be installed temporarily, in the sense of being operational only for as long as its power is required to perform installation tasks.

A permanent or temporary power source 18 could, for example, be a battery rack or array, a wave energy converter, a floating solar plant, or another producer of renewable energy such as a tidal turbine.

Figures 2a to 2c show some initial stages of installing the facility 10. In this example, the supply line 16 has been laid on the seabed first as shown in Figure 2a, extending offshore from the grid 12.

Next, Figure 2b shows a work vessel 20, which could be a fully electric vessel or a hybrid vessel that is arranged to receive and store electrical energy from an external source. The work vessel 20 connects to the supply line 16 either directly by recovering a free end of the supply line 16 from the seabed or, as in this example, via an umbilical link 22 extending to the supply line 16 at the seabed. The work vessel 20 can thereby receive electrical energy from the supply line 16 to perform installation operations, using onboard electric motors to manoeuvre, to remain on station and to perform construction operations, all without producing harmful emissions.

As an example of an installation operation, Figure 2c shows the work vessel 20 installing the substation 14 of the facility 10 in readiness to connect the supply line 16 to the substation 14 so that the supply line 16 can serve as export cable when the facility 10 becomes operational. The work vessel 20 can remain connected to the supply line 16, as shown here, to continue drawing electrical energy during the installation operation. Alternatively, the work vessel 20 can disconnect from the supply line 16 during the installation operation if onboard batteries of the work vessel 20 hold enough energy to complete the installation operation without requiring recharging.

A similar principle can be employed at any stage of an installation process, when installing any element of an offshore facility 10. To illustrate this, Figures 3a to 3d show later stages of installation of the wind turbine facility 10 involving assembly of an individual turbine *in situ*. Here, it will be apparent that the facility 10 comprises an array of wind turbines 24 each connected to the substation 14, and hence to the supply line 16 that will serve as the export cable, via a respective spur cable 26. In this example, the spur cables 26 are used as additional supply lines to provide electrical energy to work vessels 20 that then complete installation operations at work sites corresponding to each wind turbine 24.

In Figure 3a, a spur cable 26 has been laid on the seabed in readiness to connect to a wind turbine 24 that is about to be installed as part of the array. In this example, the spur cable 26 terminates at its free end in a terminal or connection point 28 via which a work vessel 20 can connect to the spur cable 26 to receive electrical energy. The connection point 28 may be underwater, for example on the seabed where a connection can be made via an umbilical 22 that is suspended from the work vessel 20 or recovered to the surface by the work vessel 20. Alternatively, the connection point 28 may be at the surface, for example on a buoy or other docking structure, to which the work vessel 20 can connect via a link cable. Connections can be made at the connection point 28 and/or at the work vessel 20 by plug-in connectors such as wet-mate connectors, or contactlessly by inductive couplings.

Figure 3b shows a work vessel 20 connected to the spur cable 26 via an umbilical link 22 extending to the connection point 28. The work vessel 20 can thereby receive electrical energy to perform installation operations without producing harmful emissions. Figures 3c and 3d exemplify such operations in which the work vessel 20 uses its crane to overboard loads, the operation shown in Figure 3c being installation of a subsea foundation 30 for a wind turbine 24 and the operation shown in Figure 3d being assembly of the mast or tower 32 of the wind turbine 24 atop the foundation 30. Different work vessels 20 could be used for each operation if appropriate, those work vessels 20 connecting to the connection point 28 either simultaneously or in succession.

The steps exemplified with reference to Figures 3a to 3d can be repeated as often as necessary to install a facility 10, with work vessels 20 moving from one work site to another as required while being propelled and operated electrically. This principle is illustrated by the flowchart in Figure 4, which shows a first step 34 of installing a first supply line, such as an export cable or a spur cable, extending to a location where an offshore facility 10, or a future element of such a facility 10 such as a wind turbine 24, will be installed. In a second step 36, at least one work vessel connects to the first supply line, or to a first connection point of a supply line. This enables the work vessel to execute the third step 38 of performing an installation operation, without harmful emissions, on equipment that is to be connected to that supply line or connection.

In a fourth step 40, the work vessel connects to a second supply line, or to a second connection point of the first supply line, to perform another installation operation in the fifth step 42, again without harmful emissions, on equipment that is to be connected to that supply line or connection. The work vessel can move between different locations on disconnecting from the first supply line or from the first connection point and reconnecting to the second supply line or to the second connection point. To the extent that the lengths of link cables or umbilicals permit, the work vessel can also move between different locations while maintaining one of those connections or both connections simultaneously.

The second supply line is installed in installation step 44. That step 44 is shown in Figure 4 as taking place after installation of the first supply line at step 34 but it could take place at any time before the work vessel connects to the second supply line at step 40, for example at the same time as installation of the first supply line at step 34 or even before.

Figures 5 and 6 show manned electrically powered or hybrid vessels in the form of, respectively, a work vessel 20 and a jack-up rig or jack-up barge, also known simply as a jack-up 46, at the surface 48, each connected to a subsea supply line 16 via a connection point 28 on the seabed 50. Electrical energy supplied from the supply line 16 is stored in batteries 52 aboard the work vessel 20 or jack-up 46, in an amount sufficient to support emission-free installation operations. As noted above, the work vessel 20 or jack-up 46 can remain connected to the connection point 28 to continue drawing electrical energy from the supply line 16 during an installation operation. Alternatively, the work vessel 20 or jack-up 46 can be disconnected from the connection point 28 during an installation operation if the onboard batteries 52 hold enough energy to complete the installation operation without requiring recharging.

In these examples, the umbilical 22 hangs from the work vessel 20 or jack-up 46 as a catenary to connect the onboard batteries 52 to the connection point 28. An ROV or a diver can assist to make a subsea connection between the lower end of the umbilical 22 and the connection point 28. Alternatively, the umbilical 22 can be pre-connected to the connection point 28 and laid on the seabed 50, in which case the free upper end of the umbilical 22 can be lifted from the seabed 50 to the surface 48 to be connected to the work vessel 20 or the jack-up 46 topside.

A vessel such as a work vessel 20 or jack-up 46 can connect to the supply line 16 in other ways, for example as shown in Figures 7 and 8. In Figure 7, the upper end of the umbilical 22 is supported by an intermediate support floating at the surface 48, such as a buoy or a remotely operated vessel 54 controlled by the work vessel 20. A link cable 56 extends laterally from the work vessel 20 to the remotely operated vessel 54 to convey electrical energy from the umbilical 22 to the onboard batteries 52 of the work vessel 20. This increases the working radius of the work vessel 20 while remaining connected to the supply line 16. It would also be possible for an end of the supply line 16 to extend upwardly from the seabed 50 for direct connection to the intermediate support, hence omitting the umbilical 22 and the connection point 28. Similarly, in Figure 8, the end of the supply line 16 extends upwardly from the seabed 50 directly to the work vessel 20, hence omitting the link cable 56 and the remotely operated vessel 54 or other intermediate support.

Figures 9 and 10 show a power supply vessel 58 connected to the supply line 16 to charge its onboard batteries 52. In this example, the connection between the power supply vessel 58 and the supply line 16 is effected via an umbilical 22 and a connection point 28 like the arrangement shown in Figure 5. However, other connection arrangements like those shown in Figures 7 and 8 are possible.

The power supply vessel 58 is shown in Figure 10 moved adjacent to a jack-up 46. A link cable 56 connects the power supply vessel 58 to the jack-up 46 to provide electrical energy from the onboard batteries 52 of the power supply vessel 58 to onboard batteries 52 or other power consumers of the jack-up 46. The power supply vessel 58 is shown here disconnected from the supply line 16 so as to service a jack-up 46 that is remote from the supply line 16. The power supply vessel 58 therefore shuttles between the supply line 16 and the jack-up 46, or other vessels or surface installations that require supplementary electrical power from time to time. In principle, however, the power supply vessel 58 could remain connected to the supply line 16 when servicing the jack-up 46, if the jack-up 46 is close enough to the supply line 16.

The power supply vessel 58 can be dedicated to that function and therefore, in the absence of equipment to perform other functions, can contain large onboard batteries 52. In principle, those batteries 52 could fill most of the internal volume of the hull or account for most of the payload of the vessel. The power supply vessel 58 could be capable of unmanned operation either under remote control or autonomously, thus further increasing its capacity for energy storage.

In Figures 11 and 12, the supply line 16 is not an electrical cable but is instead a pipeline conveying a gas such as hydrogen from a source such as an onshore or offshore electrolyser, which is preferably powered by a source of renewable energy such as a wind turbine so as to produce green hydrogen. In this example, therefore, the power supply vessel 58 of Figures 9 and 10 is replaced by a dedicated power generating vessel 60 that generates electrical energy from hydrogen.

Specifically, the power generating vessel 60 receives and stores hydrogen from the supply line 16 in onboard tanks 62 and uses that hydrogen to generate electricity when required, for example using onboard fuel cells 64. Electrical energy generated in this way could be stored in onboard batteries, omitted here for simplicity, or could be generated on demand from a consumer such as a jack-up 46 external to the power generating vessel 60. Other than being filled from the supply line 16, the power generating vessel 60 could be filled with hydrogen at an energy island or at the shore.

The power generating vessel 60 is shown in Figure 12 moved beside a jack-up 46, with a link cable 56 conveying electrical energy from the power generating vessel 60 to the jack-up 46. Again, the power generating vessel 60 is represented here as a shuttle that is disconnected from the supply line 16 periodically so as to service a jack-up 46 that is remote from the supply line 16. Similarly, though, the power generating vessel 60 could remain connected to the supply line 16 when servicing the jack-up 46, if the jack-up 46 is close enough to the supply line 16.

As the power generating vessel 60 is dedicated to that function, its capacity to store hydrogen in its tanks 62 is maximised. Again, the power generating vessel 60 may be capable of unmanned operation either under remote control or autonomously. In this case, separating personnel and other vessels or installations from stored hydrogen could be advantageous to minimise safety risks.

Having conveyed hydrogen to the power generating vessel 60 to produce emission-free energy for use in installation operations, the pipeline serving as the supply line 16 can remain *in situ* and can then be used for various purposes to support the offshore facility 10 in operation. For example, hydrogen could continue to be supplied along the pipeline to the facility 10 to generate electricity for powering the facility 10, or could be exported along the pipeline if produced at the facility 10. Alternatively, the pipeline could be repurposed to convey another fluid to or from the facility in support of its operations.

Figure 13 shows an evolution of the arrangement shown in Figure 7, in which umbilicals 22 connected to one or more supply lines 16 at respective subsea connection points 28 are supported by intermediate supports floating at the surface 48, such as remotely operated vessels 54. Link cables 56 extend laterally from a work vessel 20 to the remotely operated vessels 54 to convey electrical energy from the or each supply line 16 via the umbilicals 22 to the onboard batteries 52 of the work vessel 20.

This arrangement allows the work vessel 20 to move from one connection point 28 to another without producing harmful emissions, remaining connected to one connection point 28 to receive electrical energy continuously while making a connection to the other connection point 28. In this respect, the umbilical 22 shown to the left in Figure 13 is shown hanging from the associated remotely operated vessel 54 ready to be connected to the corresponding connection point 28, for example with the assistance of an ROV or a diver. Once the umbilical 22 shown to the left is connected to its connection point 28, the umbilical 22 shown to the right can be disconnected from its connection point 28. Then, the work vessel 20 is free to travel, without harmful emissions, within an area centred on the newly-made connection.

Figure 14 shows an arrangement in which two or more vessels, be they work vessels 20, power supply vessels 58 or power generating vessels 60, can connect simultaneously to a supply line 16. For this purpose, the vessels can connect to a shared buoy 66 at the surface 48 to receive energy from the supply line 16 via the buoy 66. Thus, the buoy 66 serves as a junction box. Optionally, the vessels can also moor to the buoy 66.

In this example, the buoy 66 is connected to the supply line 16 by a temporary umbilical 22 that extends to a subsea connection point 28 on the supply line 16. However, an end of the supply line 16 could instead be lifted up to the buoy 66 so that the supply line 16 is connected directly to the buoy 66. In either case, the umbilical 22 or the suspended part of the supply line 16 can be supported and located by lines 68 connected to a subsea foundation 70 as shown, especially to resist lateral loads if vessels are moored to the buoy 66.

In the example shown in Figure 14, the supply line 16 is a cable that conveys electrical energy to work vessels 20 or power supply vessels 58 but it could instead be a pipeline that conveys a flow of hydrogen to power generating vessels 60.

Finally, Figure 15 shows a wind turbine facility 10 that comprises an array of wind turbines 24 and a substation 14 connected in series with each other and with a supply line 16. This daisy-chain arrangement comprises cable legs 72 between successive wind turbines 24 in the series. As in Figure 3d, a work vessel 20 is shown using its crane to assemble a mast or tower 32 of one of the wind turbines atop a foundation. The invention finds particular benefit in such an arrangement, where the work vessel 20 can move from one work site to another in succession, travelling along and around the paths of the cable legs 72 without producing harmful emissions.

Many other variations are possible within the inventive concept. For example, at least some of the electricity produced by an offshore or onshore power source could be used to power an electrolyser to produce hydrogen from water. Production of hydrogen can take place at the power source that produces the electricity, or elsewhere.

A connection point need not be situated only at an end of a cable but could alternatively, or additionally, be situated at one or more intermediate locations along the length of a cable.

Aspects of the method of the invention, and infrastructure used in that method, can also be employed in a permanent facility whose power grid can still be used to deliver power to vessels when the facility has been installed and is in operation.

Claims

1. A method of installing an offshore facility, the method comprising:

connecting an offshore vessel to a supply line;

supplying energy from the supply line to the vessel;

performing installation operations on the facility using the supplied energy in electrical form; and

when the facility is installed and in operation, using the supply line to convey energy to, from or within the facility.

2. The method of Claim 1, comprising supplying energy from the supply line to the vessel as electrical energy.

3. The method of Claim 2, wherein the electrical energy supplied from the supply line is derived from an onshore grid.

4. The method of Claim 1 or Claim 2, wherein the electrical energy supplied from the supply line is generated offshore from wind, wave, tidal or solar generation.

5. The method of Claim 1, comprising supplying energy from the supply line to the vessel as chemical energy, and converting the chemical energy to electrical energy aboard the vessel.

6. The method of Claim 5, wherein the chemical energy is in the form of hydrogen.

7. The method of Claim 6, wherein the hydrogen is produced by electrolysis of water offshore using electrical energy generated offshore.

8. The method of any preceding claim, comprising performing the installation operations using the vessel connected to the supply line.

9. The method of Claim 8, comprising performing the installation operations while the vessel remains connected to the supply line.

10. The method of any of Claims 1 to 7, comprising conveying the electrical energy from the vessel to a separate work vessel, jack-up or rig that performs the installation operations.

11. The method of Claim 10, comprising: storing aboard the vessel the energy supplied by the supply line; disconnecting the vessel from the supply line; and moving the vessel beside the work vessel, jack-up or rig before conveying the stored energy in electrical form from the vessel to the work vessel, jack-up or rig.

12. The method of Claim 11, comprising controlling the movement of the vessel remotely or autonomously.

13. The method of any preceding claim, comprising providing the supply line with energy from a power source being a pre-existing installation.

14. The method of Claim 13, wherein the pre-existing installation also provides power to other consumers before the vessel is connected to the supply line and after the facility is installed and in operation.

15. The method of any of Claims 1 to 12, comprising: installing a power source temporarily offshore; providing the supply line with energy from the temporarily-installed power source; and ceasing to provide the supply line with energy from that power source when the facility is installed and in operation.

16. The method of any preceding claim, comprising:

connecting the vessel to a first supply line connection;

supplying energy to the vessel via the first supply line connection;

performing a first installation operation on the facility using the energy supplied via the first supply line connection;

connecting the vessel to a second supply line connection;

supplying energy to the vessel via the second supply line connection; and

performing a second installation operation on the facility using the energy supplied via the second supply line connection.

17. The method of Claim 16, wherein the first and second supply line connections communicate with different respective supply lines.

18. The method of Claim 16, wherein the first and second supply line connections communicate with the same supply line.

19. The method of any of Claims 16 to 18, comprising connecting the vessel to the second supply line connection while the vessel is connected to the first supply line connection.

20. The method of any of Claims 16 to 19, wherein the first and second installation operations are performed at mutually-spaced worksites between which the vessel travels after performing the first installation operation.

21. The method of any of Claims 16 to 20, wherein the first and second installation operations are performed on respective offshore wind turbines or other offshore electricity generators.

22. The method of any preceding claim, comprising connecting the vessel to the supply line via an umbilical extending from the supply line at a subsea location toward the surface.

23. The method of Claim 22, comprising connecting the vessel to the supply line via a link extending from the vessel to an intermediate buoyant support at an upper end of the umbilical.

24. The method of Claim 23, comprising connecting the vessel to one or more supply lines via first and second links extending from the vessel to respective intermediate buoyant supports each located at an upper end of a respective umbilical.

25. The method of Claim 23 or Claim 24, comprising launching the or each intermediate buoyant support from the vessel.

26. The method of Claim 25, comprising manoeuvring the intermediate buoyant support relative to the vessel.

27. The method of any preceding claim, comprising connecting two or more offshore vessels to the supply line.

28. The method of Claim 27, comprising connecting the vessels to a common connection that communicates with the supply line directly or via an umbilical.

29. The method of Claim 28, comprising connecting the vessels to the common connection at the surface.

30. The method of any preceding claim, comprising using the supplied electrical energy to operate vessel equipment and vessel propulsion systems without producing harmful emissions.

31. A system for performing installation operations on an offshore facility, the system comprising:

an energy supply line;

a connection by which a vessel can be connected to the supply line to receive energy from the supply line; and

at least one vessel arranged to receive energy from the supply line via the connection and to use or transfer that energy in electrical form to perform the installation operations;

wherein the supply line is a permanent installation for transferring energy to, from or within the facility when the facility is operational.

32. The system of Claim 31, wherein the supply line is connected to an onshore power grid.

33. The system of Claim 31 or Claim 32, wherein the supply line is connected to an offshore power source that employs wind, wave, tidal or solar generation.

34. The system of Claim 31, wherein the supply line is a pipeline or downline that conveys energy to the vessel as chemical energy, and the vessel includes at least one fuel cell powered by the chemical energy to generate electricity.

35. The system of any of Claims 31 to 35, further comprising a power transfer connection between the vessel and a separate work vessel, jack-up or rig configured to perform the installation operations.

36. The system of any of Claims 31 to 35, further comprising a temporarily installed power source that provides the supply line with energy.

37. The system of any of Claims 31 to 36, comprising first and second supply line connections that communicate with respective different supply lines or the same supply line.

38. The system of any of Claims 31 to 37, wherein the facility comprises offshore wind turbines or other offshore electricity generators.

39. The system of any of Claims 31 to 38, wherein the connection comprises an umbilical extending from the supply line at a subsea location toward the surface.

40. The system of Claim 39, wherein the connection further comprises a link extending from the vessel to an intermediate buoyant support at an upper end of the umbilical.

41. The system of Claim 40, comprising first and second links extending from the vessel to respective intermediate buoyant supports each located at an upper end of a respective umbilical.

42. The system of any of Claims 31 to 41, comprising a common connection at which two or more vessels can communicate simultaneously with the supply line.

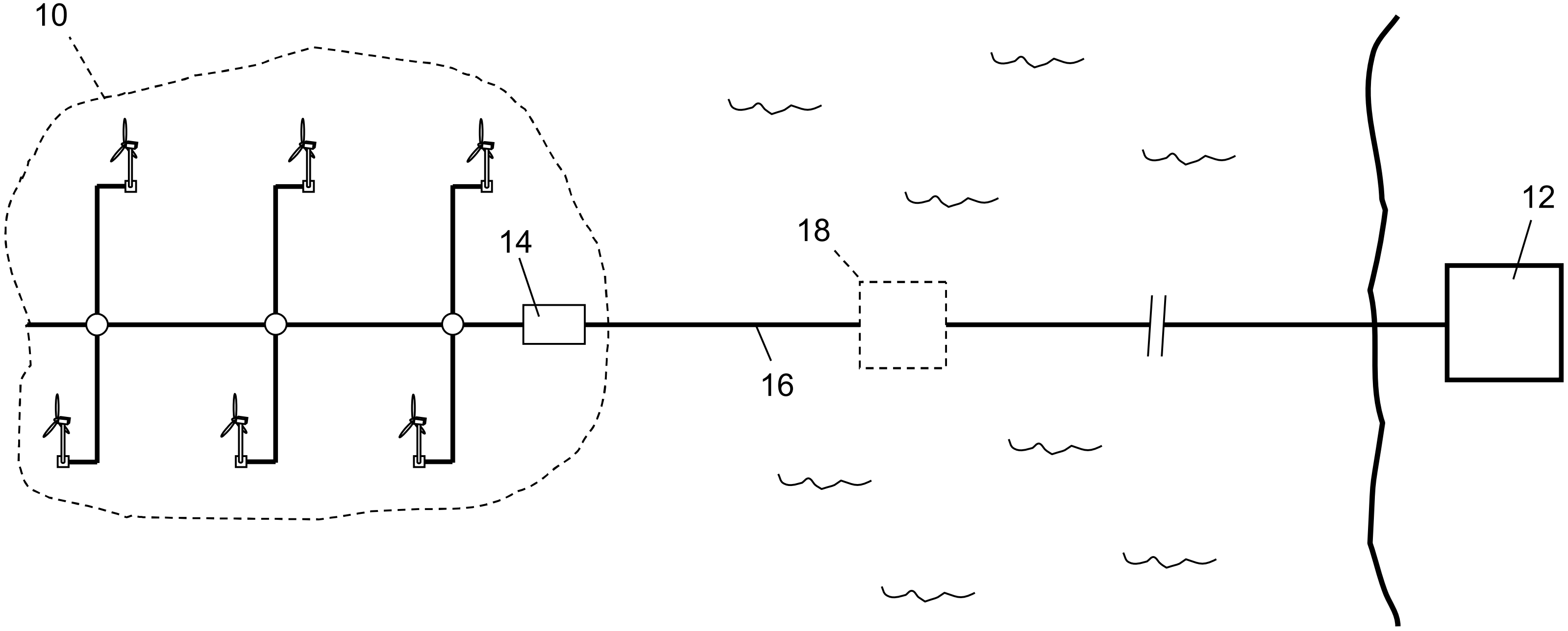


Figure 1

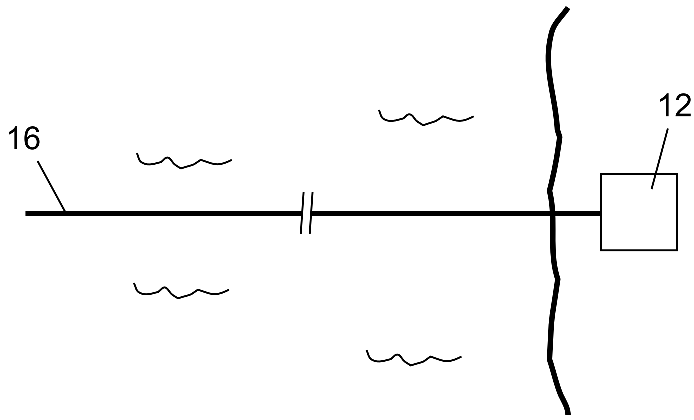


Figure 2a

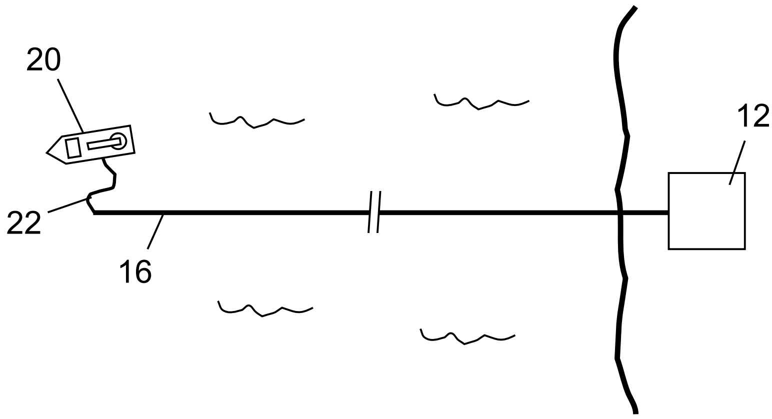


Figure 2b

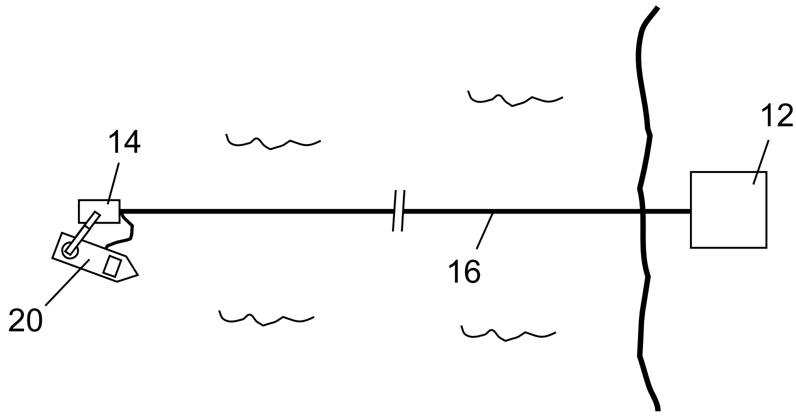


Figure 2c

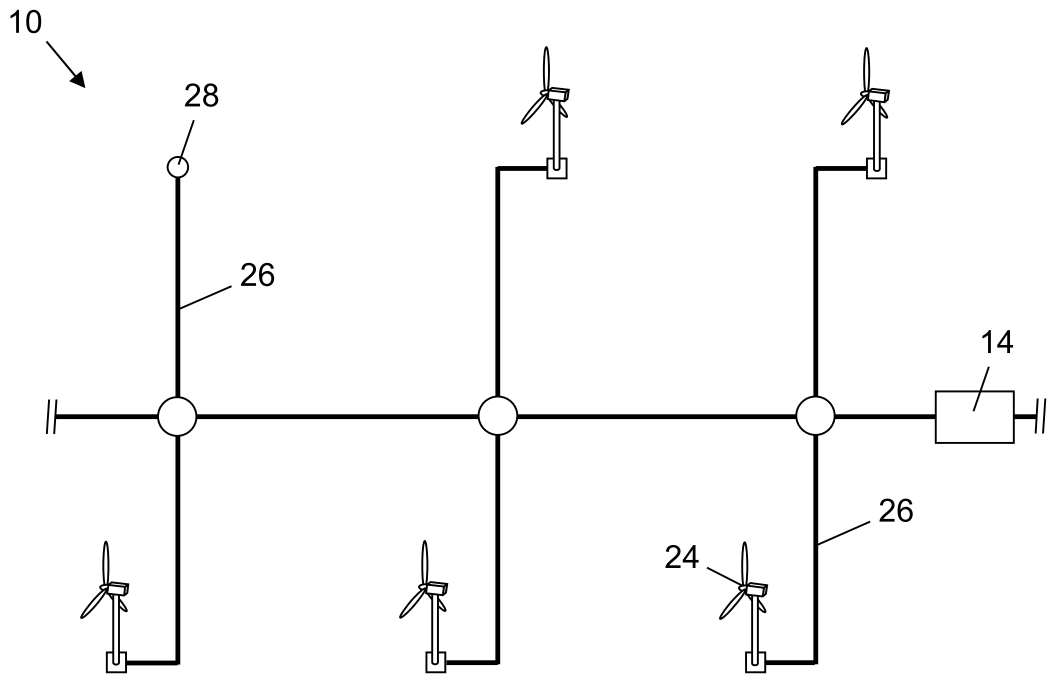


Figure 3a

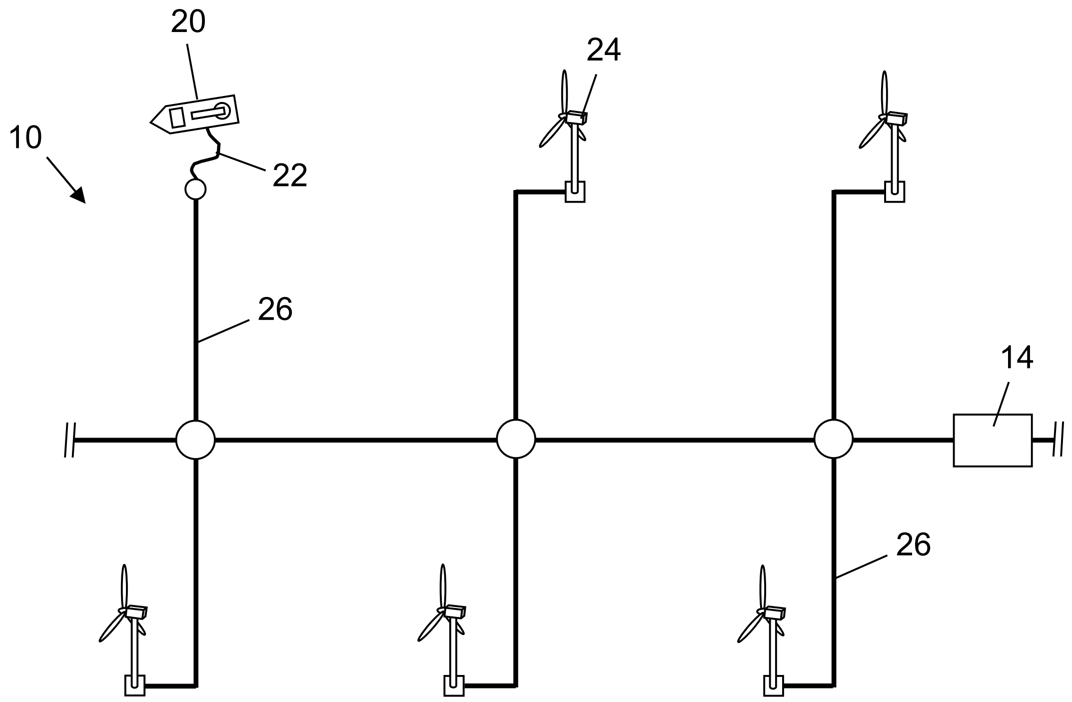


Figure 3b

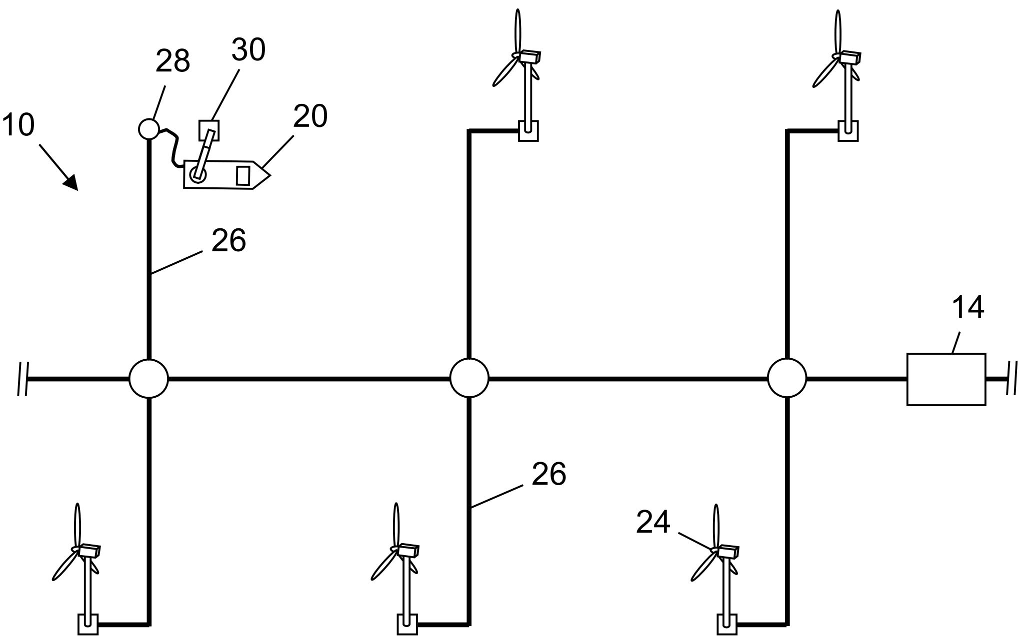


Figure 3c

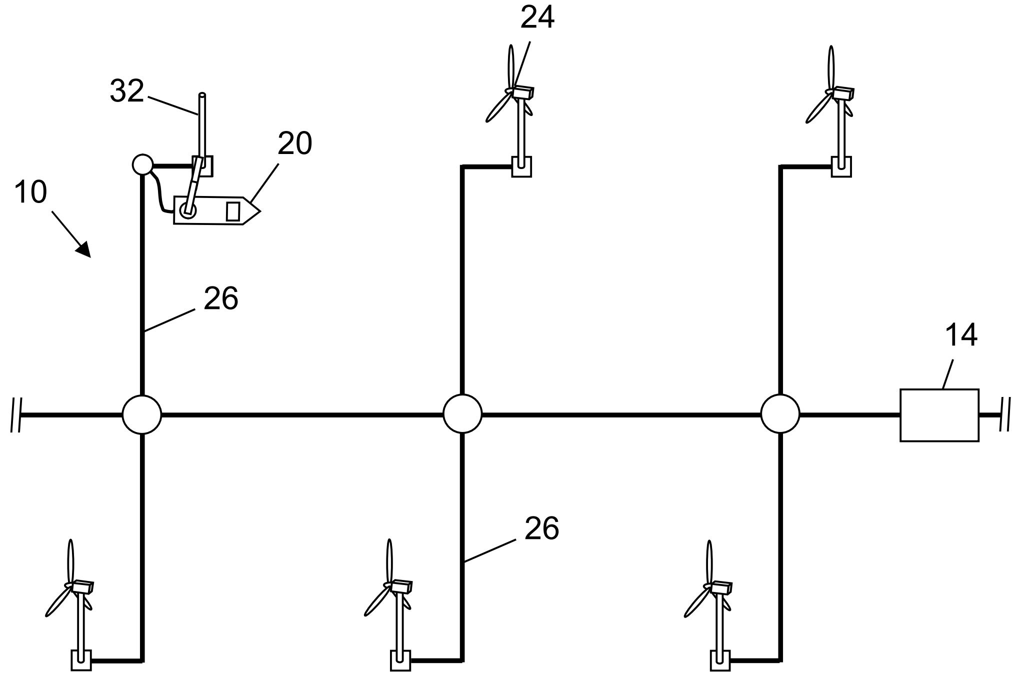


Figure 3d

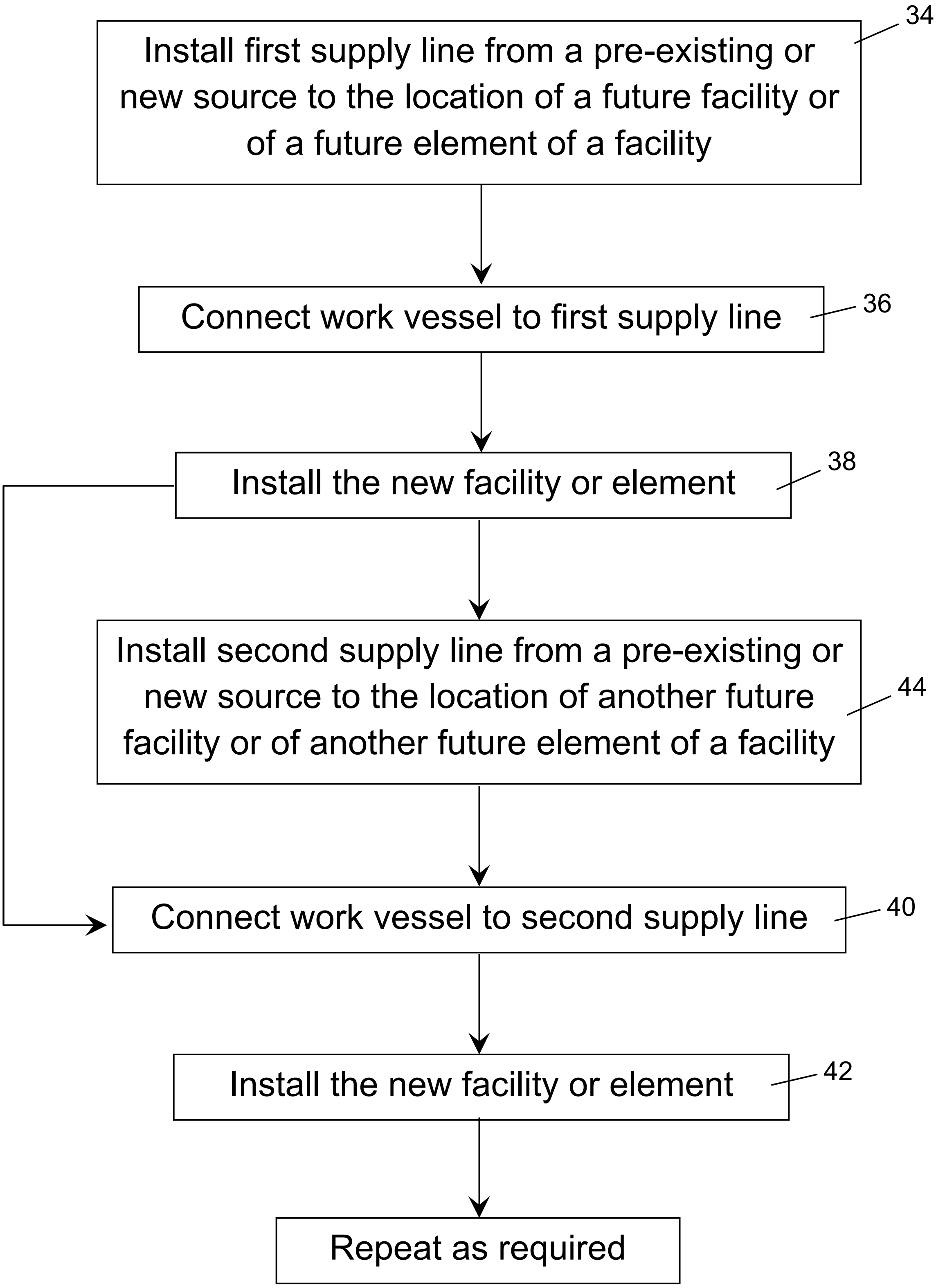

Install first supply line from a pre-existing or new source to the location of a future facility or of a future element of a facility
34
Connect work vessel to first supply line
36
Install the new facility or element
38
Install second supply line from a pre-existing or new source to the location of another future facility or of another future element of a facility
44
Connect work vessel to second supply line
40
Install the new facility or element
42
Repeat as required

Figure 4

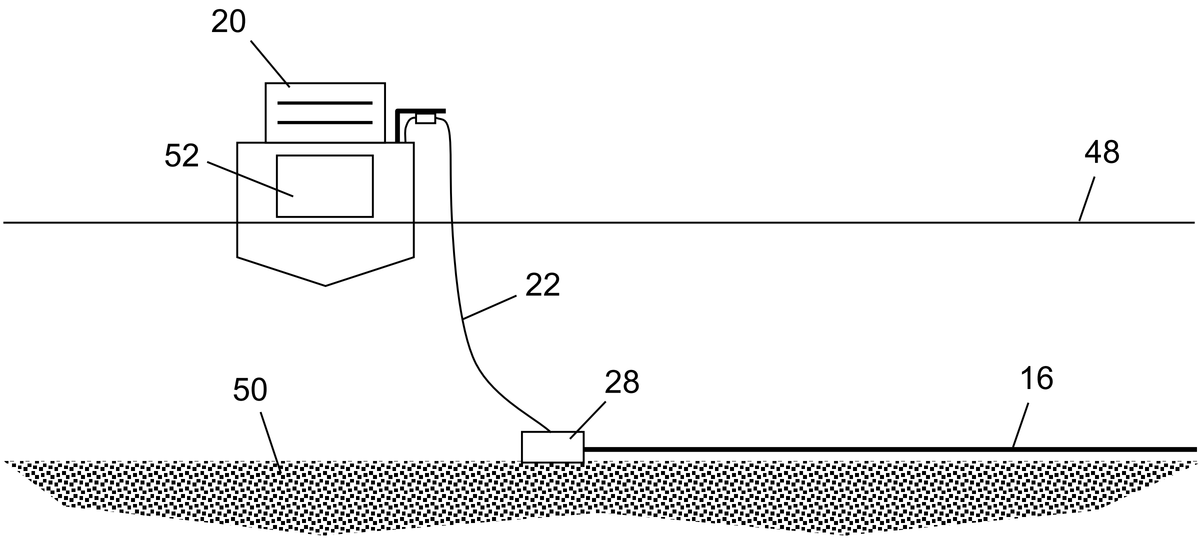


Figure 5

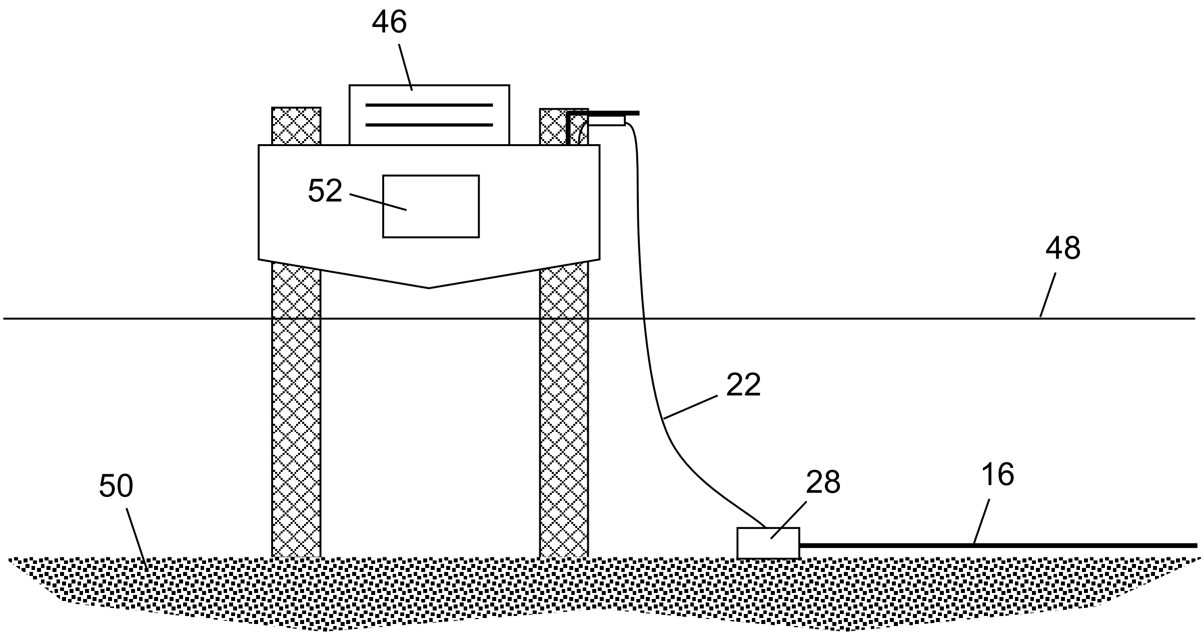


Figure 6

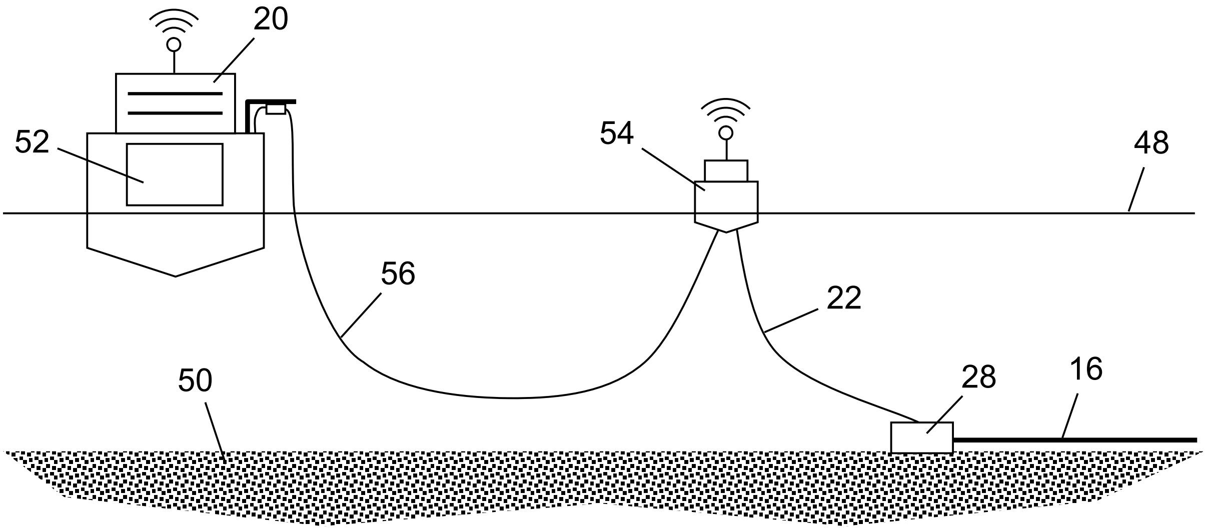


Figure 7

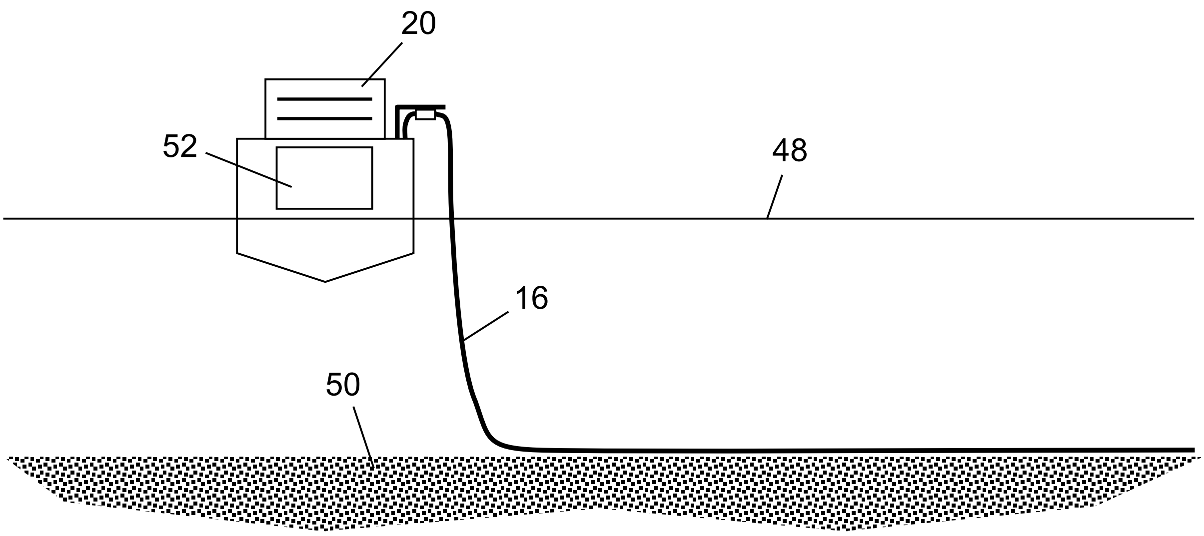


Figure 8

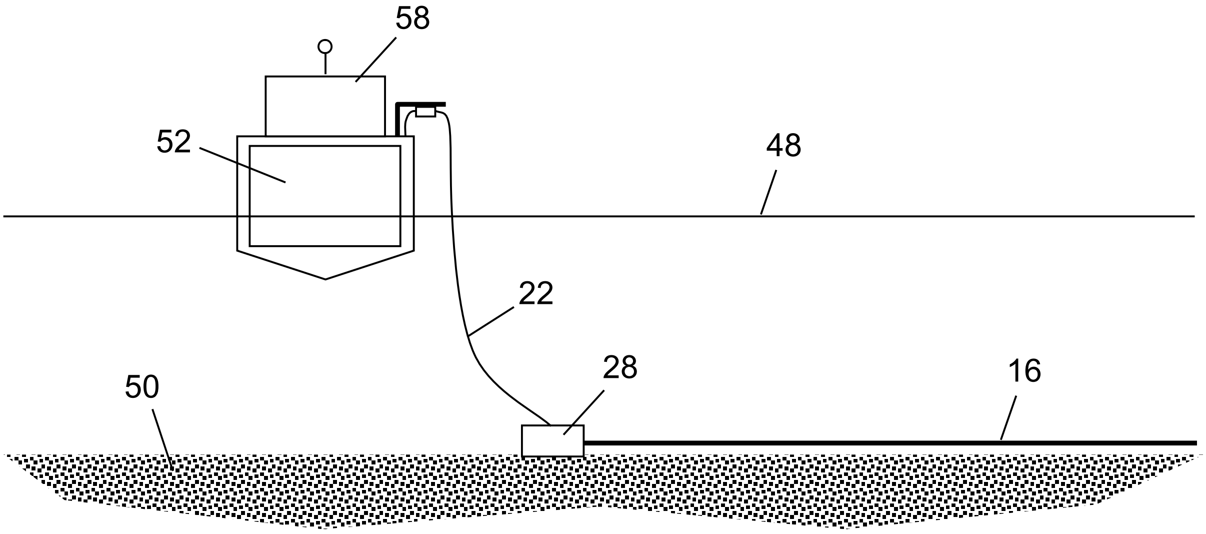


Figure 9

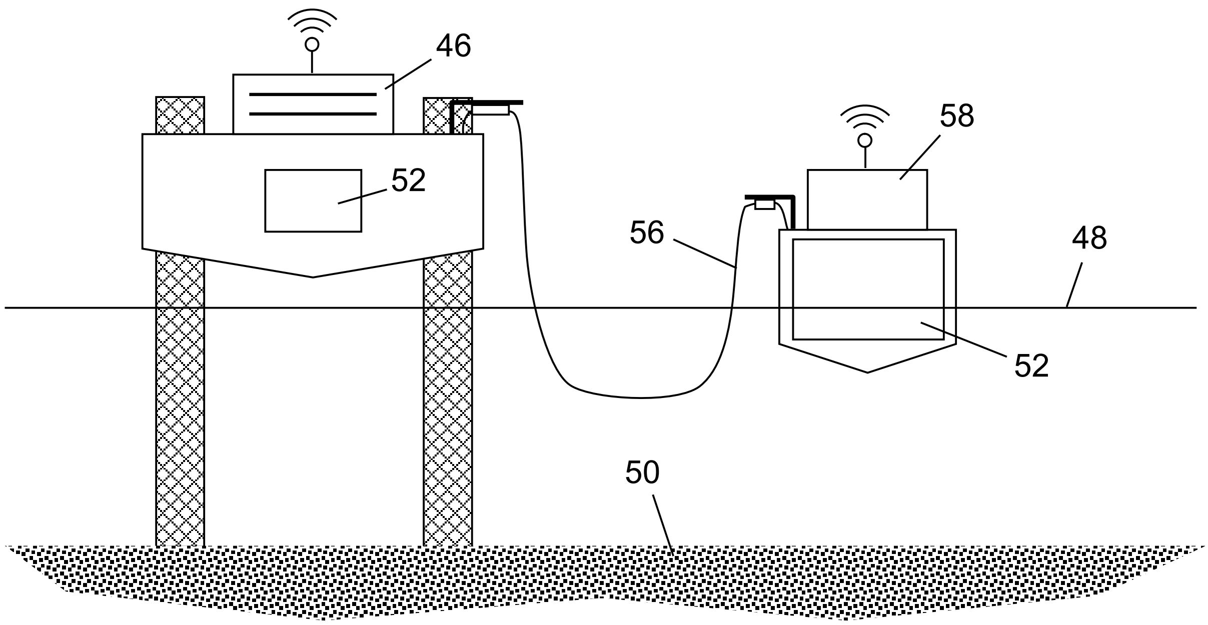


Figure 10

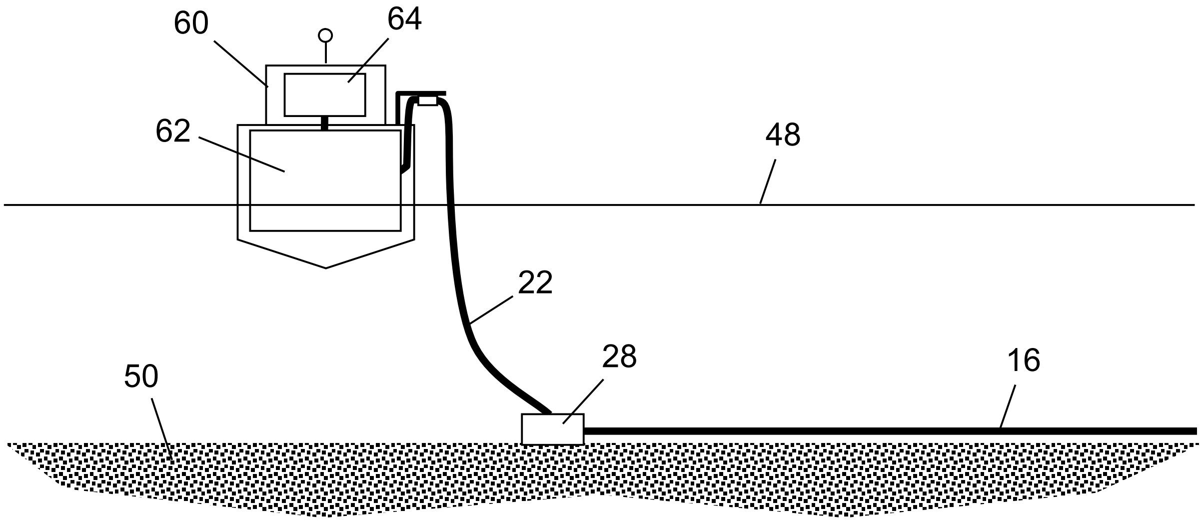


Figure 11

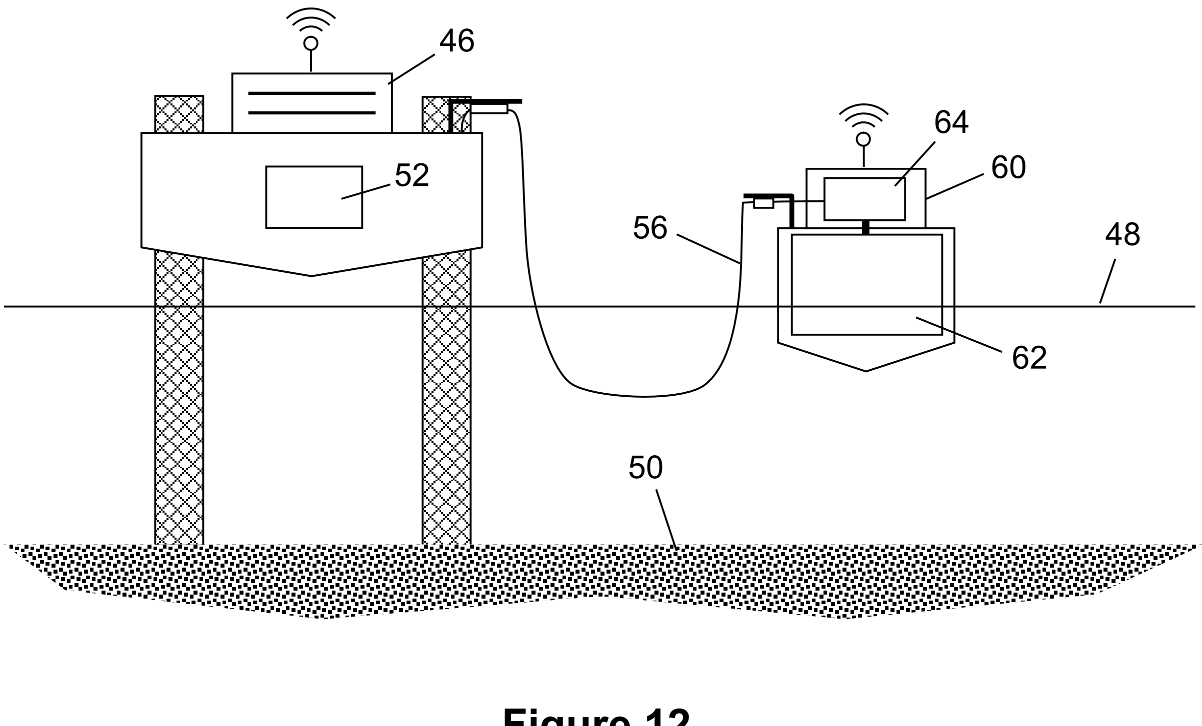


Figure 12

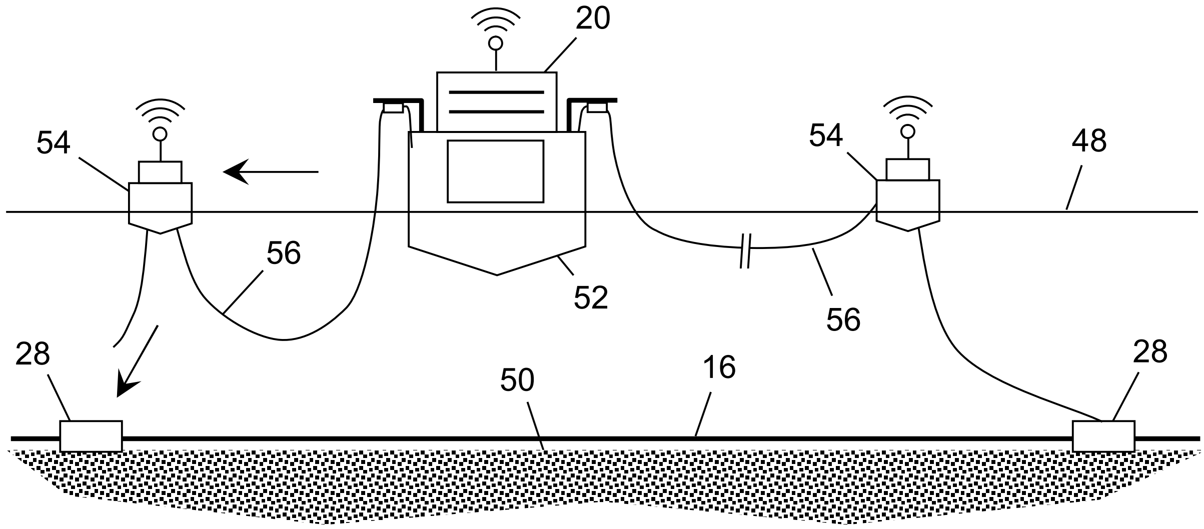


Figure 13

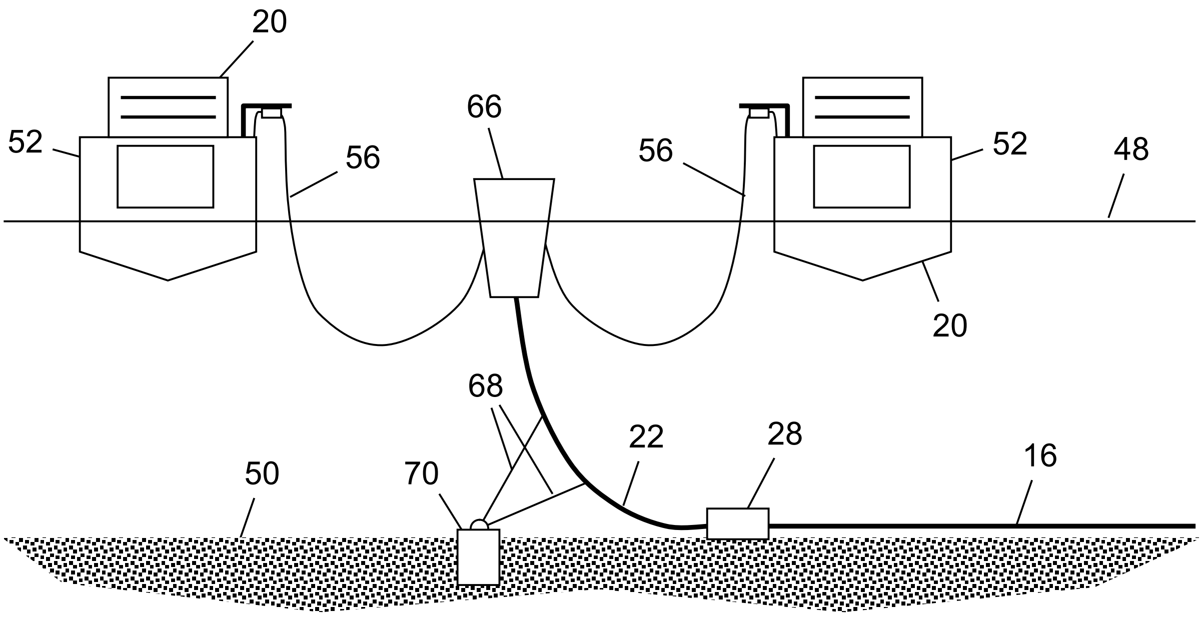


Figure 14

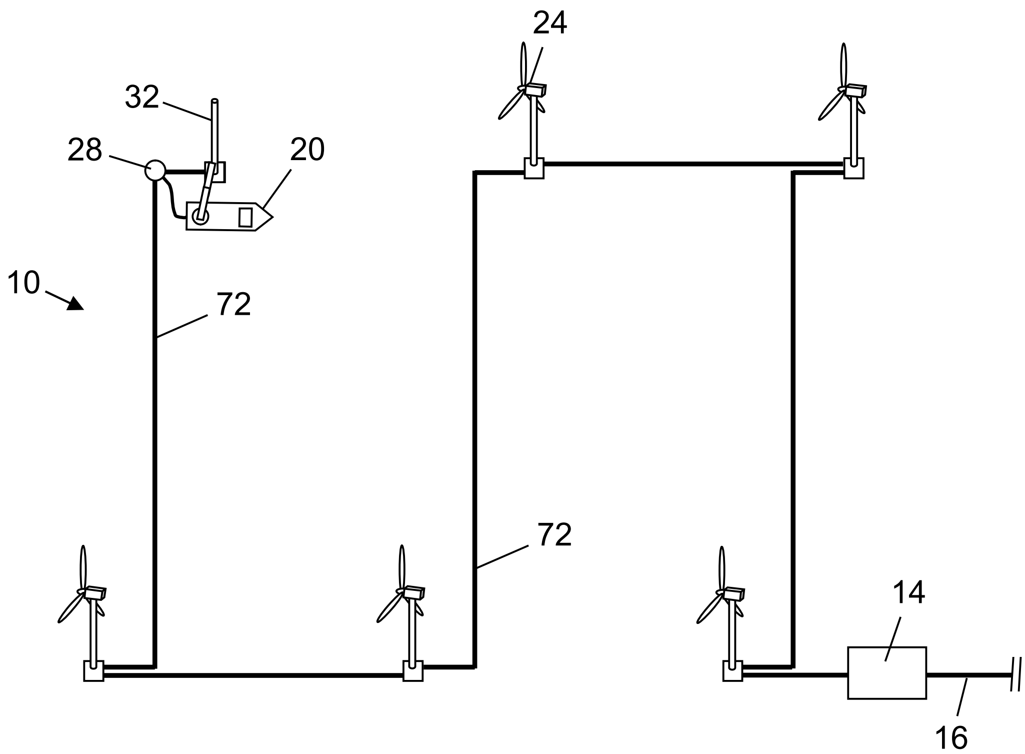


Figure 15