(51) International Patent Classification:
E21B 33/035 (2006.01)

(21) International Application Number:
PCT/GB2012/052766

(22) International Filing Date:
6 November 2012 (06.11.2012)

(25) Filing Language:
English

(26) Publication Language:
English

(30) Priority Data:
1119136.8 7 November 2011 (07.11.2011) GB

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Published: without international search report and to be republished upon receipt of that report (Rule 48.2(g))

(54) Title: IMPROVED MONITORING OF SUBSEA INSTALLATIONS

(57) Abstract: A system for monitoring a subsea installation comprising one or more sensors located upon the installation; each sensor including a rechargeable power supply and a first wireless transceiver; a mobile underwater apparatus including a second wireless transceiver; the mobile underwater vehicle being operable to move to within a first range of at least one sensor and the first wireless transceiver being operable to transmit data to the second wireless transceiver; the mobile underwater vehicle being operable to move to within a second range of the at least one sensor and the second wireless transceiver being operable to transmit power to the first wireless transceiver; and the first range being greater than the second range.
IMPROVED MONITORING OF SUBSEA INSTALLATIONS

The present invention relates to monitoring of subsea installations and in particular, though not exclusively, to a wireless monitoring system for data harvesting and recharging of sensors monitoring a subsea installation.

As energy requirements increase, technology is being developed to find and exploit new energy sources in our oceans. Offshore wind farms are being constructed and tidal power generators are seeing a resurgence in interest. Oil and gas exploration and production is also venturing further into deeper waters. As a result large numbers of subsea installations are being constructed. In many instances control modules are located upon the installations together with process sensors, to control and operate the facilities. Electrical power needs to be delivered to the control modules and sensors. Additionally, control and monitoring data needs to be relayed to and from the control modules and sensors.

GB 2 458 944 to Vetco Gray Controls Limited have considered this for a hydrocarbon extraction plant. Communication between a topside facility of a hydrocarbon extraction plant and Subsea Control Modules (SCMs) at an underwater hydrocarbon extraction installation of the plant, for example at a "Christmas tree" associated with a hydrocarbon extraction well, is currently effected by the use of copper or fibre-optic cables within an umbilical line, which connects the topside communications equipment to the subsea field. Likewise, Subsea Production Control System process sensors, mounted on a subsea Christmas tree, manifold or other structure, are currently connected by copper wires to the Subsea Control Module (SCM). Both these types of connection require Electrical Flying Leads (EFLs). The capital, topside and subsea installation costs of EFLs forms a significant portion, approximately 15%, of the overall cost of a Subsea Production Control System suite of equipment. Due to the electro-mechanical nature of the connectors, combined with the need to be wet-mateable for recovery, for example, of SCMs and / or sensors, the reliability of EFLs has historically been poor. EFLs can also cause problems during Remote Operation Vehicle (ROV) operations such as the recovery of a failed SCM or the updating of software. The topside to SCM umbilical line typically carries control and monitoring signals via a modem, whereas an SCM
provides DC power and Fieldbus serial communications (e.g. Profibus, Modbus, ANBus, etc) to the sensors and relays the sensor data to the topside equipment via the umbilical.

GB 2 458 944 removes the need for most of the EFLs and their associated expensive electrical connectors for communication in a hydrocarbon extraction plant by providing a method of enabling communication between components of a hydrocarbon extraction plant or Christmas tree, the plant having an underwater hydrocarbon extraction installation including at least one hydrocarbon extraction well, and comprises providing a plurality of Radio Frequency (RF) communication means at components of the installation. The method may comprise a subsea control module, a sensor, a remotely operated vehicle (ROV), a repeater or a battery. Unfortunately, while the RF communication means can transfer control, monitoring and sensor data, the system uses a power line connection to surface or batteries as the electrical power source. The power line is a major disadvantage as this is a similar connection to the umbilical to surface. The use of batteries limits the operating life of sensors and control modules. Additionally, power is required by each of the RF communication means.

Due to the harsh environments of subsea and the operating depths from surface, there is a limit to the amount of electrical power which can be transferred down a power line. Where batteries are used, there limited lifespan makes them unsuitable for use on long term installations. Accordingly, only essential control modules and sensors are located on the installations. This prevents the use of integrity sensors being used on the installation for monitoring structural parameters such as stress and corrosion monitoring.

It is an object of the present invention to provide a system for monitoring a subsea installation which obviates or mitigates at least some of the disadvantages in the prior art.

According to a first aspect of the present invention there is provided a system for monitoring a subsea installation comprising; one or more sensors located upon the installation; each sensor including a rechargeable power supply and a first wireless
transceiver; a mobile underwater apparatus including a second wireless transceiver; the mobile underwater vehicle being moved to within a first range of at least one sensor and the first wireless transceiver transmitting data to the second wireless transceiver; the mobile underwater vehicle being moved to within a second range of the at least one sensor and the second wireless transceiver transmitting power to the first wireless transceiver; and the first range being greater than the second range.

In this way, data is harvested from the sensors and the sensors are recharged wirelessly removing the requirement for a power line or batteries. The sensors can then be considered as ‘sealed for life’.

Preferably, each transceiver has an electrically insulated magnetic coupled antenna. Alternatively, each transceiver has an electric field coupled antenna. The antenna may be a wire loop, coil or similar arrangement. Such antenna create both magnetic and electromagnetic fields. The magnetic or magneto-inductive field is generally considered to comprise two components of different magnitude that, along with other factors, attenuate with distance (r), at rates proportional to $1/r^2$ and $1/r^3$ respectively. Together they are often termed the near field components. The electromagnetic field has a still different magnitude and, along with other factors, attenuates with distance at a rate proportional to $1/r$. It is often termed the far field or propagating component.

Preferably, the data is transmitted as an electromagnetic and/or magneto-inductive signal. Signals based on electrical and electromagnetic fields are rapidly attenuated in water due to its partially electrically conductive nature. Propagating radio or electromagnetic waves are a result of an interaction between the electric and magnetic fields. The high conductivity of seawater attenuates the electric field. Water has a magnetic permeability close to that of free space so that a purely magnetic field is relatively unaffected by this medium. However, for propagating electromagnetic waves the energy is continually cycling between magnetic and electric field and this results in attenuation of propagating waves due to conduction losses. The seawater provides attenuation losses in a workable bandwidth which still provide for data transmission over practical distances.
Preferably, the power is transmitted by magnetic coupling between the first and second transceivers. In this way, there is no need for direct electrical conductive contact. More preferably, each transceiver includes a circular coil structure surrounded by a flux guiding enclosure that inductively couples energy from a primary coil in the second transceiver to a secondary coil in the first transceiver. Preferably, the transferred energy is used to power the sensor and the first transceiver. In this way, there is no limit to the lifespan of the sensor.

As the power transfer is achieved by magnetic coupling while the data transfer is by electromagnetic or magneto-inductive signals, the data can be transferred with the mobile apparatus at a greater distance from the sensor than that required for power transfer. The first and the second range may be approximately equal. In this embodiment, data and power transfer can be simultaneous.

The data may be compressed prior to transmission. In this way the occupied transmission bandwidth can be reduced. This allows use of a lower carrier frequency which leads to lower attenuation. This in turn allows data transfer through fluids over greater transmission distances. In this way, the first range can be increased by lowering the carrier frequency.

Preferably, the data transmission is bi-directional. In this way, command and control signals can be transferred to the sensors.

Preferably, the system includes at least one control module located on the subsea installation; the control module including a rechargeable power supply and a third wireless transceiver; the underwater mobile vehicle being moved to within the first range of the control module to facilitate signal transfer between the third wireless transceiver and the second wireless transceiver; and the underwater mobile vehicle being moved to within the second range of the control module and the second wireless transceiver transmitting power to the third wireless transceiver. In this way, wireless control can also be achieved without requiring power lines or batteries at the control module. This allows the system to be used in SCADA architectures.
Preferably the underwater mobile vehicle is an autonomous underwater vehicle (AUV). More preferably, the underwater mobile vehicle is a remotely operated vehicle (ROV). Such vehicles are already used in a subsea environment and can be guided to the subsea installation.

The subsea installation may be one of a group comprising: a rig, a blow-out preventor, a lower stack, a wellhead, a Christmas tree, a wind power generator support, a wave power generator, a separator, a pump, a manifold and a compressor.

Preferably the one or more sensors include an integrity monitoring sensor. More preferably, the one or more sensors include a sensor for monitoring cathodic protection. Alternatively, the one or more sensors are measurement devices and may be selected from gauges, sensors, valves, sampling devices, a device used in intelligent or smart well completion, temperature sensors, pressure sensors, flow-control devices, flow rate measurement devices, oil/water/gas ratio measurement devices, scale detectors, actuators, locks, release mechanisms, equipment sensors (e.g., vibration sensors), sand detection sensors, water detection sensors, data recorders, viscosity sensors, density sensors, bubble point sensors, composition sensors, resistivity array devices and sensors, acoustic devices and sensors, other telemetry devices, near infrared sensors, gamma ray detectors, H₂S detectors, CO₂ detectors, downhole memory units, downhole controllers, and locators.

In an embodiment, the subsea installation may include an umbilical to transfer data and/or power to sensors and/or a control module. The use of the system would then provide a back-up for real-time control in the event of failure in the umbilical.

In an embodiment, at least one sensor and/or at least one control module includes a wet-mate connector for signal, data or power transfer. The use of the system would then provide a back-up for failure of the wet-mate connector.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings of which:
Figure 1 is a schematic illustration of a subsea installation including a system for monitoring the subsea installation according to an embodiment of the present invention;

Figure 2 is a block diagram of a transceiver for use in a system of the present invention;

Figure 3 is a block diagram of an antenna for use in the transmitter or receiver of the transceiver of Figure 2; and

Figure 4 is a schematic illustration of a subsea installation including a system for monitoring the subsea installation according to a further embodiment of the present invention.

Reference is initially made to Figure 1 of the drawings which illustrates a system, generally indicated by reference numeral 10, at a subsea installation 12, the system 10 being used to monitor the subsea installation 12 according to an embodiment of the present invention.

In Figure 1, the subsea installation 12 is the support structure 14 of an offshore wind turbine 18. The support structure 14 is located on the seabed 16 and secured thereto by use of piles 20. As the structure 14 is underwater within the harsh environment of the sea, it is liable to corrosion and tidal movement can cause stress and strain to the structure 14. In order to monitor the integrity of the structure 14, sensors 24, 26 are located on the structure 14. Sensor 24, located on a splayed support 28, monitors stress on the structure by measuring temperature, pressure and strain at the support 18. A second sensor 26, located on the upright 30, records potential and current density to monitor the performance of a cathodic protection system for corrosion monitoring.

Sensor 24 includes a first transceiver 32 and sensor 26 includes a second transceiver 34. There is also a third transceiver 36 mounted on an ROV 38. Reference is now made to Figure 2 of the drawings which illustrates parts of each transceiver 32,34,36. In transceivers 32,34 the sensor interface 56 receives data
from the measurement systems in the sensors 32,34 which is forwarded to data processor 58. Data is then passed to signal processor 60 which generates a modulated signal which is modulated onto a carrier signal by modulator 62. Transmit amplifier 64 then generates the desired signal amplitude required by transmit transducer 66. In the transceiver 36, there is a control interface 68 which sends command signals to the data processor 58 which are transmitted by the above described path. These command signals can be used to detect the location of a wireless transceiver 32,34 to determine if the transceivers 32,34,36 are within proximity or range to transmit data and/or power.

The transceivers 32,34,36 also have a receive transducer 70 which receives a modulated signal which is amplified by receive amplifier 72. De-modulator 74 mixes the received signal to base band and detects symbol transitions. The signal is then passed to signal processor 76 which processes the received signal to extract data. Data is then passed to data processor 58 which in turn forwards the data to control interface 68. For the transceiver 36, there is also a memory 78 which can store data for onward transfer.

Figure 3 shows an example of an antenna that can be used in the transmitter and receiver of Figure 2. This has a high permeability ferrite core 80. Wound round the core are multiple loops 82 of an insulated wire. The number of turns of the wire and length to diameter ratio of the core 80 can be selected depending on the application. However, for operation at 125 kHz, one thousand turns and a 10:1 length to diameter ratio is suitable. The antenna is connected to the relevant transmitter/receiver assembly parts described in Figure 2 and is included in a sealed housing 84. Within the housing the antenna may be surrounded by air or some other suitable insulator 86, for example, low conductivity medium such as distilled water that is impedance matched to the propagating medium 22. The antenna can also be used to magnetically couple energy between the transceivers 32,34,36. In this regard the housing acts as a magnetic flux guide and the multiple loops 82 with the ferrite core 80 provide a transformer when a pair of transceivers are brought together. In order for successful energy transfer the two transceivers must be arranged close together, there being an acceptable gap of only 1-2cm. Thus the range for power transfer is much smaller than the range for data communication. Coupling efficiency reduces as
frequency increases because of leakage inductance effects. Eddy current losses increase with frequency so also act to reduce the bandwidth available for data transmission. Data and power transmission can be separated in frequency to allow simultaneous operation of the two functions. Transfer efficiency is more critical for power transfer than for data communication applications so a higher frequency will usually be assigned to the data communication signals. While a transceiver 32,34,36 is described with a common antenna for transmit and receive, separate antennas may be used. Additionally, a separate transmitter coil arrangement can be provided solely for power transfer.

In use, sensors 24,26 are installed on the wind turbine 18. They may be fitted during the construction phase or alternatively they may be retrofitted to take measurements when required. The sensors 24,26 can be programmed to make measurements at predetermined intervals and save the data in an on board memory. When the data requires to be retrieved an ROV 38 including a transceiver 36 travels underwater to the location. At or near the location transceivers 32,34 will identify themselves to the transceiver 36 when in range. Data can then be transferred by the process described with reference to Figure 2. The ROV 38 can be separately positioned relative to each sensor 24,26 or, if within range, the transceiver 36 can simultaneously collect data from each sensor 24,26 at a single position. The ROV 38 can then be repositioned with the transceiver 36 close to a transceiver 32,34 on either sensor 24,26. At this much smaller range, magnetic coupling for power transfer can occur and batteries within the sensors can be recharged in turn. In this way the sensors 24,26 are sealed for life sensors as the data is harvested wirelessly and recharging is also achieved wirelessly. The collected data can then be downloaded from the ROV 38. Advantageously, an ROV 38 can harvest all the data from all the sensors located on the subsea installation 12 in a single trip. On the same trip each sensor can also be recharged to ensure sufficient power is available to record measurements until the next trip is due. Alternatively, the ROV can be selective in which sensors it collects data from and/or which sensors it transfers power for recharging. If power transfer is taking place, then the transceivers can be positioned close together, and in this position data can also be transferred. However, as the positioning for power transfer is more critical than for data transfer,
the ROV can be moved off and away from the subsea installation 12 for data transfer.

Reference is now made to Figure 4 of the drawings which illustrates further features which may be incorporated into embodiments of the present invention. The system 40 is located upon a subsea installation 42 which in this embodiment is a hydrocarbon production facility 44. Facility 44 comprises wells 46a,b drilled into a formation 48. Each well 46 reaches the seabed 48 at a wellhead 50a,b. The subsea installation 42 comprises equipment such as a BOP 90, lower stack 92, pipeline 94, compressor 96, manifold 98 and pump 100. A riser 102 takes the produced fluids to a rig 104. A variety of sensors 106,108 which are measurement devices are located across the facility 44. In such a production facility the measurement devices may be selected from gauges, sensors, valves, sampling devices, a device used in intelligent or smart well completion, temperature sensors, pressure sensors, flow-control devices, flow rate measurement devices, oil/water/gas ratio measurement devices, scale detectors, actuators, locks, release mechanisms, equipment sensors (e.g., vibration sensors), sand detection sensors, water detection sensors, data recorders, viscosity sensors, density sensors, bubble point sensors, composition sensors, resistivity array devices and sensors, acoustic devices and sensors, other telemetry devices, near infrared sensors, gamma ray detectors, H₂S detectors, CO₂ detectors, downhole memory units, downhole controllers, and locators. Additionally, control modules 110,112 are positioned over the facility 44 to provide operational capability. As is typical the sensor 106 and the control modules 110 are hardwired to the rig 104 via an umbilical 130 tethered to the riser 102. In this way, power transfer, control signals and data collection occur via the umbilical to equipment at the first wellhead 50a. The sensor 108 and control module 112 located on equipment at the second wellhead 50b is remote from the umbilical 130. They are separated by a pipeline 94, which is not to scale in the Figure. An ROV 122 is required to travel through the sea 126, and the power transfer, control signals and data collection is achieved by wet-mate connection between the ROV and the sensor 108 and control module 112.

In this embodiment, each sensor 106,108 and control module 110,112 is equipped with a transceiver 114,116,118,120 respectively. Each transceiver 114,116,118,120 operates as described herein before with reference to Figures 2 and 3. The ROV 122
which travels through the sea 126, has a transceiver 124 attached thereto. In the event that there is a failure of the umbilical 130 the ROV 122 comes within range of the sensor 106 and control module 110 to transfer data and control signals. The ROV 122 can also move to a closer range to transfer power as described herein before. In this way, the present invention can provide back-up for real time control in the event of umbilical failure. Additionally, when the ROV 122 is making a wet-mate connection to the sensor 108 or control module 112, the transceivers 116,120, 124 can transfer data and control signals between each other as a back-up to the wet-mate connection which are known to be unreliable.

The principle advantage of the present invention is that it provides a system for monitoring a subsea installation which can use sealed for life sensors as the data can be harvested and the sensors recharged wirelessly. These sealed for life sensors offer the opportunity to mount any number of sensors on a subsea installation and thus provide improved integrity management of the installation.

A further advantage of at least one embodiment of the present invention is that it provides a system for monitoring a subsea installation which can provide back-up for real time control in the event of failure of the umbilical.

A yet further advantage of at least one embodiment of the present invention is that it provides a system for monitoring a subsea installation which can provide back-up to wet-mate connectors currently used.

It will be appreciated by those skilled in the art that various modifications may be made to the invention herein described without departing from the scope thereof. For example, the mobile underwater vehicle may be a manned submarine. The mobile underwater vehicle may be used to transfer data and control signals between sensors located on the subsea installation or between subsea installations.
Claims

1. A system for monitoring a subsea installation comprising:
   one or more sensors located upon the installation; each sensor including
   a rechargeable power supply and a first wireless transceiver;
   a mobile underwater apparatus including a second wireless transceiver;
   the mobile underwater vehicle being operable to move to within a first range
   of at least one sensor and the first wireless transceiver being operable to
   transmit data to the second wireless transceiver;
   the mobile underwater vehicle being operable to move to within a second
   range of the at least one sensor and the second wireless transceiver being
   operable to transmit power to the first wireless transceiver; and the first range
   being greater than the second range.

2. A system for monitoring a subsea installation as claimed in claim 1 wherein
   each transceiver has an electrically insulated magnetic coupled antenna.

3. A system for monitoring a subsea installation as claimed in claim 1 wherein
   each transceiver has an electric field coupled antenna.

4. A system for monitoring a subsea installation as claimed in any preceding
   claim wherein the antenna is a wire loop, coil or similar arrangement.

5. A system for monitoring a subsea installation as claimed in any preceding
   claim wherein the data is transmitted as an electromagnetic and/or magneto-
   inductive signal.

6. A system for monitoring a subsea installation as claimed in any preceding
   claim wherein the power is transmitted by magnetic coupling between the first
   and second transceivers.
7. A system for monitoring a subsea installation as claimed in any preceding claim wherein each transceiver includes a circular coil structure surrounded by a flux guiding enclosure that inductively couples energy from a primary coil in the second transceiver to a secondary coil in the first transceiver.

8. A system for monitoring a subsea installation as claimed in any preceding claim wherein the transmitted energy is used to power the sensor and the first transceiver.

9. A system for monitoring a subsea installation as claimed in any preceding claim wherein the first and the second range may be approximately equal.

10. A system for monitoring a subsea installation as claimed in any preceding claim wherein data and power transfer is simultaneous.

11. A system for monitoring a subsea installation as claimed in any preceding claim wherein data is compressed prior to transmission.

12. A system for monitoring a subsea installation as claimed in any preceding claim wherein data transmission is bi-directional.

13. A system for monitoring a subsea installation as claimed in any preceding claim wherein the system includes at least one control module located on the subsea installation; the control module including a rechargeable power supply and a third wireless transceiver; the underwater mobile vehicle being moved to within the first range of the control module to facilitate signal transfer between the third wireless transceiver and the second wireless transceiver; and the underwater mobile vehicle being moved to within the second range of the control module and the second wireless transceiver transmitting power to the third wireless transceiver.
14. A system for monitoring a subsea installation as claimed in any preceding claim wherein the underwater mobile vehicle is an autonomous underwater vehicle (AUV).

15. A system for monitoring a subsea installation as claimed in any one of claims 1 to 13 wherein the underwater mobile vehicle is a remotely operated vehicle (ROV).

16. A system for monitoring a subsea installation as claimed in any preceding claim wherein the subsea installation may be one of a group comprising: a rig, a blow-out preventer, a lower stack, a wellhead, a Christmas tree, a wind power generator support, a wave power generator, a separator, a pump, a manifold and a compressor.

17. A system for monitoring a subsea installation as claimed in any preceding claim wherein the one or more sensors includes an integrity monitoring sensor.

18. A system for monitoring a subsea installation as claimed in any preceding claim wherein the one or more sensors includes a sensor for monitoring cathodic protection.

19. A system for monitoring a subsea installation as claimed in any preceding claim wherein the subsea installation may include an umbilical to transfer data and/or power to sensors and/or a control module.
20. A system for monitoring a subsea installation as claimed in any preceding claim wherein at least one sensor and/or at least one control module includes a wet-mate connector for signal, data or power transfer.
Figure 2.
Figure 3.

E.g. 1000 turns, 10:1 length-to-diameter ratio for operation at 125 kHz.

80 High permeability ferrite core

82 Insulated wire turns

84 Waterproof housing

86 Enclosed air or alternative insulator

transceiver and communicating system