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Paper No.: 309	Paper Code TP5-37	Abstract ID 258	Author name Rosenberg, Henrik	Company Balslev Consult-ing Engineers A/S	Country DENMARK

Title

Electric power, HVDC from land to off-shore structures utilizing sea-electrodes for return cur-rent, concerns and precautions with regard to environment and corrosion.

Abstract

There is an environmental and commercial interest in supplying electric power from land to off-shore oil and gas platforms. Cable connections can transmit power over a longer distance provided the transmission system is based on direct current (DC) in a so called High Voltage Direct Current (HVDC) connection. Reduced energy losses and increased redundancy are obtainable utilizing the sea and electric conductive strata below the sea floor as one of the two conductors in the electric circuit. Planning of a HVDC connection requires knowledge of electric conductivity in the sea water, sea bottom and coast/land in order to analyze the elec-tric footprint which will be produced by the DC-current. Potential influence on pipelines off-shore as well as on-land must be thoroughly analyzed and prober mitigation of stray current impact, as for example increased sacrificial anode depletion rates must be managed as a part of the planning/pre-design. HVDC electrodes located on the sea floor can be trapped by fishing gear, trawls for example, and must be designed to withstand such impact. Other im-portant and manageable environmental requirements for the HVDC electrodes are limits to electric field strength and development of chlorine. These issues and actual measures will be discussed in this paper.

1. Introduction

There is an electric power demand in the off-shore gas industry which must be met. Today power generation off-shore is the common solution; it is however likely that power from land will take over a part of the supply. Production cost and environmental concerns are in favor for such a development. Increased fuel efficiency and redundancy are also positive out-comes.

We have therefore looked into possibilities and constrains for the concept. Solutions based on proven technology have been used for the different parts of the required setup. Installa-tion, operation and maintenance as well as derived effects have been thoroughly analyzed.

2. Principle, power link

All electric cables do have a power capacity limit. The capacity becomes significantly less in long high voltage ac cables compared with dc cables (ac: alternating current, dc: direct current). It is hence often necessary to supply off-shore installations with electric land power via a HVDC link (High Voltage Direct Current). In a HVDC link it is possible to use a subsea cable to transport the current in one direction and to return the current via ground.

The HVDC link is then denoted "Monopolar with ground return". The ground return is obtained with two sea electrodes, an anode and a cathode, in the sea with connection to a converter station off-shore respectively on land. It is possible to double the capacity by means of a parallel HVDC link that will utilize the same sea electrodes. The configuration is then denoted "Bi-polar with ground return", see figure 1 below.

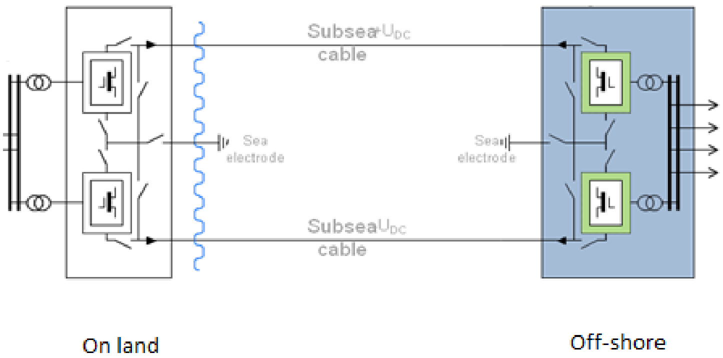

Figure 1 Bi-polar HVDC link with ground return

3. Environmental concerns

3.1 Electric fields

An electric field exists where there is a potential difference between two points. In a homogeneous electric field the field strength is the voltage divided by the distance between the points.

When current is injected and collected by two electrodes in the sea, there is a voltage drop caused by the resistance of the water. The field strength is higher the closer we are to the electrodes.

3.1.1 Electric chock

If the field is too high it can cause electric chock. In the design of the electrodes this must be considered and it must be made sure that the voltages never reach dangerous levels.

3.1.2 Prey search

All animals produce small electrical fields. Some fish species have sensors that can detect the fields and in this way they can detect prey. Electric fields from sea electrodes can also be detected by these fish. Research studies have been done to investigate how the additional electrical fields affect the fish.

3.1.3 Effect on other structures

If a structure, e.g. a submersed pipeline, extends parallel with an electric field, the voltage drop over the structure corresponds to the difference between the highest and lowest potential. A stray current will then go through the structure, and corrosion will occur where it exits. Depending on the size and direction of the structure, this is an affect that may require mitigation on pipelines several kilometers away from the electrode (-s).

3.2 Magnetic fields

Magnetic fields are produced by the flow of current.

3.2.1 Occurrence

Magnetic fields will occur around the electrode cables. The magnitude of the natural magnetic field is about 50µT. The field enclosing the electrode cable is directly proportional to the current and inversely proportional to the distance from the cable(-s).

3.2.2 Effect on marine life

Some fish and marine animals use the earth's magnetic field for navigation. Close to the electrode and cables they can be affected by the additional field.

3.2.3 Effect on compass navigation

Conventional compasses can be disturbed by the additional magnetic field from the electrode cables. The effect is inversely proportional with the distance to the cable, so the affect is very limited.

3.3 Chemical by-products

3.3.1 Chlorine

A small amount of chlorine will be developed at the anode - the electrode where the current is injected to the sea. On the cathode, no harmful chemical products are produced.

Chlorine is toxic and can be lethal to some organisms.

3.3.2 Faraday's law of electrolysis - maximum chlorine production

Chlorine is developed as current is injected into the sea at the anode. At the surface of the anode, negative chloride ions are oxidized and the electrons flow into the anode. The amount of chlorine produced is related to how much current that goes through the circuit, and can be calculated using Faraday's law of electrolysis:

$$m = \frac{Q * M}{n * F} = \frac{I * t * M}{n * F}$$

where *m* is the amount of chlorine (Cl_2) liberated at the electrode during the time *t*. *Q* is the charge passed through the water, expressed as the current multiplied by the time in the second expression. M is the molar mass, *n* is the number of electrons transferred per ion and *F* is the Faraday constant.

3.3.3 Chlorine selectivity

The chlorine selectivity of a specific electrode determines what percentage of the current that forms chlorine.

The chlorine selectivity depends on which material the electrode is made of and on other variables, and it increases with:

- Higher salinity
- Lower water temperature
- Higher potential and current density
- Lower pH, resulting from the formation of hydrogen ions that bond with anions in the water and produce acids.

Water circulation (currents) combined with an open electrode structure dilutes the acids and increases the pH.

A titanium MMO-coated mesh electrode with a large surface area leads to a chlorine selectivity of around 10%, cf. laboratory measurements performed by electrode manufactures.

3.3.4 Halocarbons

Halocarbons can be formed when halogens (chlorine, bromine, iodine) bond with organic material in the sea. The possible formation of halocarbons that bioaccumulate in the vicinity of the electrode must be limited to ensure that it does not pose a threat to the environment.

4. MMO Electrode material

Electrodes made of platinum covered titanium mesh are used in a number of HVDC links today. They are durable and further advantages are reduced environmental impact (less chlorine production) and handling of the material due to flexibility and low weight.

5. Electrode subsea structure

It is advisable that subsea structures are designed for example in accordance with the principles for general design of structures as described in NORSOK N-003, N-004 and NORSOK U-001.

5.1 Optimizing electrode element design

MMO sea electrodes in existing HVDC links have been used with success for 20 years. They have been installed in shallow waters element by element for example with 20 m^2sub-electrodes on concrete frames. The total required electrode area is in the range 800 m^2 – 1600 m^2. For optimal handling off-shore a revised design is being investigated, using fewer sub-electrodes at each sea electrode location. Homogeneous current density on the electrode is however an important requirement. This limits the electrode size and so do capacity of installation vessels. Up to 15x25 m^2 is regarded possible.

5.2 Materials

The sub-electrode support can be made of a proven material in the off-shore industry. Use of metals that can corrode is obviously not an option.
Reversible electrodes are required for Bi-polar operation. MMO mesh with low current density has been used for anode and cathode operation in existing HVDC links.

5.3 Protection

Mechanical protection of the electrode is required where fishing and dropped items can damage the installation.

5.3.1 Fishing gear

Protection against trawls can be designed in accordance with NORSOK U-002.

5.3.2 Dropped objects

Protection should comply with NORSOK U-002.

5.4 Installation

All parts of the electrodes that can be pre-assembled shall be assembled on land, leaving only sea-launch of the subsea structure and finale cable connections as off-shore tasks.

6. Electric impact on pipelines

The current that flows between the sea electrodes will use not only the sea but also the conductive parts of the earth crust. Current flow through the sea and the conductive earth strata is predictable. The voltage drop between the two electrodes is a stray current source when for example pipelines intersect areas with different electric potential. It is important to analyze the possible influence on pipelines off-shore as well as in land. The appropriate tools are FEM models in two and three dimensions.

6.1 FEM modeling

Geology and bathymetric data are used for modeling the large volume of water and earth crust through which the return current will pass. A large sea volume provides a better conductivity compared with high resistivity bed rock. An example of a 3D "box" with conductive sea and less conductive bed rock is shown in figure 2 below (Height profile).

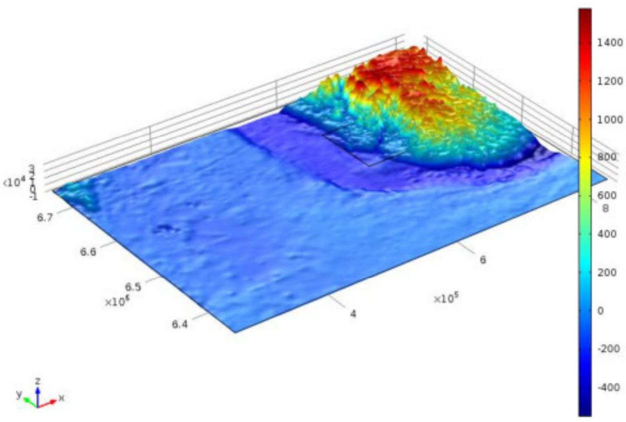

Figure 2 Height profile in a 3D "box" (740kmx400kmx5km)

6.2 Electric potential distribution

As a next step, with the conductivities given, a diagram, indicating the potential distribution between to electrodes in the 3D "box", can be produced. The figure 3 below provides a good impression of a voltage profile. The scale is indicating V/kA. Electrode locations are near the coast and off-shore. It is evident that the overall conductivity is limited near the coast compared with the location far from the coast.

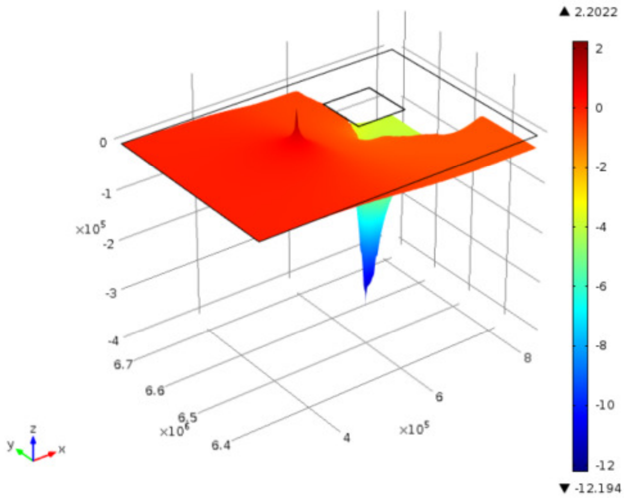

Figure 3 Potential distribution between electrodes

6.3 Stray current

A subsea pipeline equipped with bracelet anodes will electrically behave as a long conductor with a connection to the surrounding sea at each anode point. A potential difference between two bracelet anode points will in principle enable a stray current entry at one point and an exit at the other point, which can result in an uneven anode depletion rate, as long as the potential difference between such two points does not exceed the driving potential of the sacrificial bracelet anode vs. the pipe. An excessive potential difference may cause over protection on the pipeline and an accelerated anode depletion rate. Analyzing these effects is therefore most relevant as a part of the design of a HVDC link with ground return.

Subsea pipelines interconnecting off-shore platforms and pipelines that transport gas to shore can be influenced by stray currents in a way where current entry/exit is restricted to a part of the pipeline. Stray current will only enter and exit where the potential along the pipeline changes.

Relation between current entry/exit and accelerated anode depletion rate, for a large diameter pipeline extending more than 250 km out of the influenced area (near an electrode), is indicated in below Figure 4.

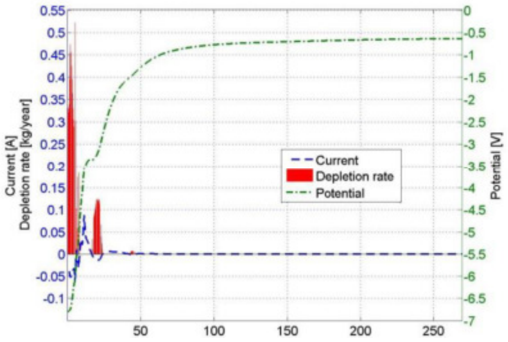

Figure 4 Stray current interaction on a subsea pipeline > 250 km

The influence on a specific pipeline is depending on the actual pipeline route, diameter, wall thickness, anode spacing and coating.

7. Conclusion

The HVDC power supply concept is a solution with a proven technology. Earth return requires that influence on metallic structures is thoroughly analyzed prior to and as part of the detailed design. It is clearly important to maintain compliance with corrosion protection of pipelines, cables, platforms and other off-shore installations. Different constrains can be handled as a part of the design and other important concerns such as impact on the environment is also manageable.