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EMC Considerations and Planning for an Offshore HVDC

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SUMMARY

This paper describes the EMC considerations and planning for the High Voltage Direct Current (HVDC) platform DolWin β. For this purpose subjects are described that require special attention, compared to onshore substations. At the Dolwin β platform a complete voltage source converter station is installed. To support the HVDC system also secondary systems, such as sea water treatment systems, safety systems, fire detecting and fighting systems, marine and satellite communication are installed. This paper makes clear that in this new environment with a complex HVDC system and large HV switchgears housed in a metal platform at sea, assessing EMC issues is required. Special focus areas, from vulnerability point of view and of criticality, are safety systems, firefighting /detection systems, aeronautical systems and naval communications systems. The overall EMC philosophy of any HVDC installation, whether it is offshore or onshore, is that the basic disturbance level shall be similar to industrial environment whereas some areas might need to be declared as protected areas. The platform, as a massive metallic structure, effectively tends to equalize the potential in all location on the platform. However, steel is a magnetic material with high permeability and relatively high resistivity. Therefore, to minimize the magnetic coupling, a complementary earth grid of copper and/or aluminium conductors is installed.

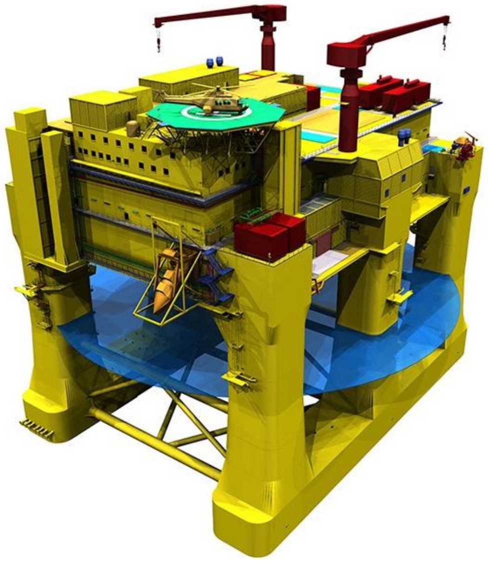

Figure 1; Dolwin β HVDC platform

Exposure of people to EM fields requires attention. The EM-fields generated by the HVDC converters are considerable with frequencies ranging from DC to several MHz. Exposure of workers to higher levels (allowed for workers, higher than for the general public) is only permitted during a restricted time. As workers stay on the platform for a longer time, it should be assured that living areas have low enough exposure levels.

The Dolwin β platform is located outside the 12 mile zone, the EMC-directive is formally not applicable to platform equipment and installations. However, German authorities indicate that for the German sector of the North Sea the European standards and EMC directive also apply to the Dolwin β platform. For other situations it is important that the owner of a platform shall, together with authorities, specify which standards shall be complied with. Maritime standards give general guidance regarding considerations and design of an offshore substation. However, they do not consider the special conditions for very high power switchyards with voltages above 36 kV level. Standards related to very High Voltage switchyard are adapted to outdoor onshore substations with a buried earth grid with buildings of conventional design.

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The authors of this paper would therefore recommend that the current applicable DNV and IEC standards should be modified and/or extended with this new offshore application. Until international or industry standards are available owners of new offshore HVDC substations should clearly indicate how this lack of standardisations should be handled in the project.

KEYWORDS
Offshore wind – HVDC offshore platform - EMC requirements – Design – DNV standards – EMF-human exposure – Dolwin β - 12 mile zone – safety systems – fire fighting and detection systems

INTRODUCTION
German politics has decided to support large scale development of offshore wind. In the German sector of the North Sea outside the 12 miles zone special areas are reserved for the development of offshore wind production. TenneT TSO (Transmission System Operator) has the regulatory task to connect offshore wind parks to the onshore grid. The so-called grid connection point is for offshore wind parks defined at the high voltage terminals situated at the AC offshore substation. Depending on the situation two to four offshore wind parks are connected to a single high voltage collector substation. In the German sector of the North Sea is due to distance between the offshore collector station and the onshore grid station, the connection between them mostly realized by means of a HVDC system. At this moment HVDC offshore station Borwin α is in operation, seven other HVDC projects are in different phases of development. This paper describes considerations for the HVDC platform DolWin β. This HVDC offshore substation is designed for a transport capacity of 900 MW with an expected lifetime of 30 years. At the platform a complete voltage source converter station is installed. To support the HVDC system, also other systems such as sea water treatment systems, safety systems, fire detecting and fighting, marine and satellite communication are installed.

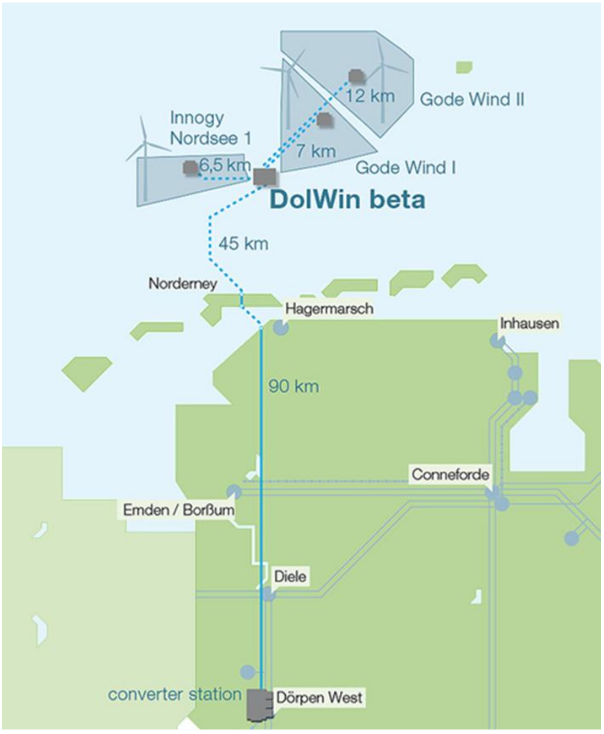

Figure 2: DolWin beta

The platform is designed for un-manned and manned modes of operation. The platform itself and all equipment thereon are designed for a high availability and reliability. The project has shown that it is necessary to assess several EMC issues in this new environment, consisting of a complex HVDC system and large HV switchgears located on a metal platform at sea. This paper describes special challenges, applicable guidelines and special requirements for the design of the earthing system and classification of the EMC zones for the Dolwin β project.

EMC ZONE AND CONSIDERATIONS FOR PLATFORMS WITH HVDC INSTALLATION
From the EMC point of view, on an offshore substation he following electromagnetic environments zones have to be taken into account;

- Zone 1: A protected environment for vulnerable systems that can easily be victim of EM interference.
- Zone 2: An industrial environment. In this environment industrial systems are located like motors, frequency drives and power supplies (including converters).
- Zone 3: The substation environment inside the platform. This environment consists of high voltage power installations and is a well-known environment onshore.

- Zone 4: A harsh EM-environment, going beyond the substation environment. Some parts of the HVDC installation have to be considered as a special EM-environment, offshore as well as onshore.
- Zone 5: The typical marine environment, at the outside of the platform. The EM-environment consists of lightning, ship- and airborne radar and strong radio transmitters.

Sources for interference

Most of the environments mentioned above are also present on onshore substations and measures to mitigate possible interference are well known and laid down in standards for most cases. However, a voltage source HVDC converter cannot be defined yet as a common well known source of EM-fields. Even for the onshore situation no standards are available yet to define test levels for equipment and to propose mitigation measures. While converters in general belong to an industrial environment because of their high frequency EM-disturbances, some parts of the HVDC installation only fit into a dedicated EM-environment. The AC side reactors of the HVDC installation emit strong magnetic fields and the commutation process of the HVDC valves generates considerable electromagnetic fields of high frequencies, up to several MHz. Special measures are required in such an environment.

Also the combination of a great number of high power converters in the power supply of the installations might give unexpected electromagnetic issues in this offshore installation. Electric faults in the high voltage area may be a source of disturbance as these will cause high currents flowing in earthing systems and/or through the platform structure. The high voltage system of Dolwin β is designed for a maximum fault current of 31,5 kA at the 170 kV busbar. This designed maximum fault current, although relatively small for onshore installations, is a new phenomenon for offshore installations. In case of a short circuit also very high transient currents can be induced in earthing conductors and in metallic structures. In addition, in the vicinity of power cables and transformers the magnetic field may increase.

Victims of interference

On the side of possible victims, special attention shall be given to control and protection systems as well as security and safety systems (including communication and navigation systems). As these systems depend for their function on low energy signals they can be sensitive to electromagnetic phenomena. Disturbance of these systems in high emission level environments is likely when no precautions are taken. Especially the cables between these (sub)systems can pick up currents and voltages that might be able to disturb equipment.

Disturbance of the systems mentioned above may most likely lead to availability issues but dangerous situations could also be possible. Defect controllers or failing protection results in power systems that cannot be controlled or protected and transport of wind power energy to onshore may be interrupted. Wrong control commands or missing protection actions in case of a short circuit may give extended damage and severe accidents. Disturbance of security and safety systems like fire detection and fire extinguishing may lead to decreased availability that can result in safety issues; not detecting a fire in time or not being able to extinguish a fire, may give extended damage and severe accidents.

Aeronautical and naval communications systems form a special group because of their increased vulnerability to EM interference. For these communication systems a continuous and undisturbed availability and a high reliability is essential as they are required for a safe helicopter approach and to contact support vessels. Special attention shall be given to protected frequencies these systems apply. Special attention shall also be given to protected frequencies for airborne navigation. The AIS (Automatic Identification System) of the platform is not allowed to be disturbed. The same goes for the NDB (Non Directional Beacon) and aeronautical communication. Also some international distress frequencies shall not be disturbed as these radio frequencies are designated for emergency communication by international agreement.

Human exposure

Exposure of people to EM fields requires attention and in some case special precautions. The EM-fields generated by the HVDC converters are high with frequencies ranging from DC to several MHz. All areas with hazardous voltages or EM field levels are closed during operation, but EM-fields will extend outside these areas. Also, field strengths very close to high power cables or near transformers needs to be considered.

CLASSIFICATION OF EMC ENVIRONMENT

Platforms with HVDC converter stations can be divided into the five EMC zones as mentioned before. These zones are categorized based on the severity of the electromagnetic environment present within each zone. The overall EMC philosophy of any HVDC installation, whether it is offshore or onshore, is that the basic disturbance level shall be similar to industrial environment. Substation equipment has its own environment whereas the HVDC environment has been defined as harsh and nonstandard. Non HVDC equipment and conducting cables shall not be located in this environment unless special precautions are taken.

Between different zones, EMC protective measures shall be taken at the zone border. The difference in EM disturbance levels between two Zones determines the required mitigation measures. Some areas might need to be declared as protected areas where extra interference-sensitive equipment can be installed and where disturbance levels should allow for the use of equipment classified for domestic and/or commercial EM environment. An EMC management plan can be helpful and shall, as a kind of construction file and as a quality document, be kept up to date during the project. At the end the final document shall prove that EMC requirements are met.

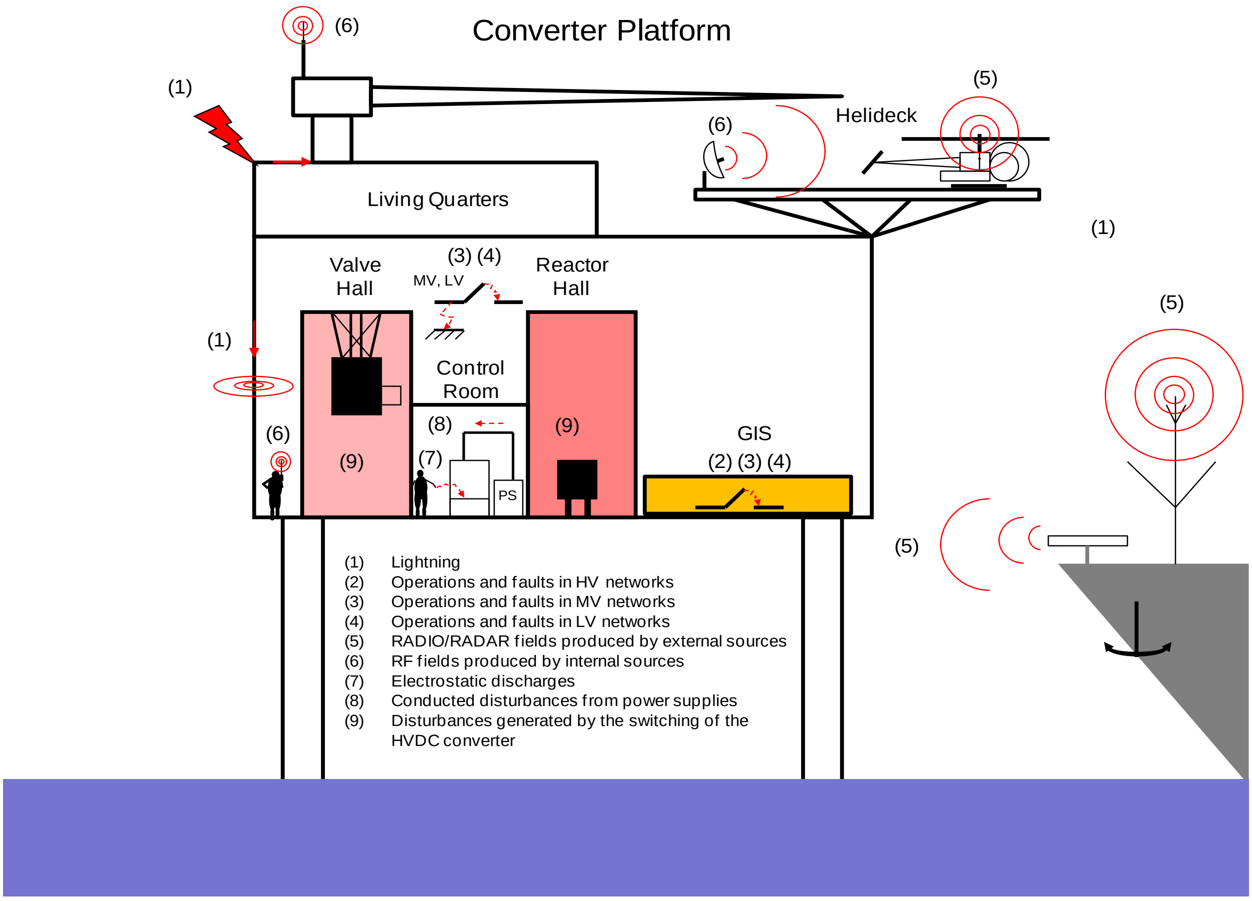

Figure 3: layout converter platform - EMC sources

The figure above exemplifies the electromagnetic environment encountered on the Dolwin β platform. Strong power frequency magnetic fields origin from the HVDC AC-reactors and the HVDC valves generate strong EM-fields in the frequency range up to several MHz. In some areas of the platform, such as Valve Hall and Reactor Hall, an extremely harsh electromagnetic environment prevails, e.g. E-fields can be in one order of magnitude higher than for industrial EMC environment. This means that no standardized EMC immunity tests for auxiliary equipment applies that can replicate the stresses on

equipment here. These areas both belong to the harshest EMC zone, Zone 4. For areas with high voltage equipment, e.g. GIS rooms, the classification is similar to a high voltage switchyard (Zone 3). In the internal of the platform, e.g. pump rooms or similar, common industrial electromagnetic disturbance levels prevails, so this zone can be designed as Zone 2. The protected areas, such as control rooms and living quarters, are assigned Zone 1. The outside of the platform has an environment similar to any other offshore installation with regard to disturbance levels, therefore all outdoor parts should be assigned as Zone 5, maritime zone. Ship- and airborne radar, strong radio transmitters and lightning makes this zone different from industrial zone.
As an example of the attenuation required between two zones with regard to field emission at power frequency, the field generated by the converter reactors measured at the wall of the reactor hall needs to be attenuated from a value in the range of 10 mT (Tesla) to values around 1000 µT (according to exposure regulations). At certain locations within zone 2 and 3, magnetic field levels are actually much higher than at the zone border due to currents in high voltage cables and transformers. This might require restrictions of access to parts of the installation outside zone 4.

EARTHING GRID ON THE PLATFORM

In current standards for offshore equipment [1] - [3] the voltage of High Voltage equipment covered by the standard is up to 36 kV. However, for an HVDC platform the voltage for the 400 kV equipment is an order of ten times higher and these systems are capable of having a maximum fault current of 31,5 kA. As the driving voltages for the fault current is more than 100 kV, the fault current can induce very significant voltage and/or current in other circuits and metallic structures by inductive or resistive coupling. In addition, faults but also switching actions in the 170 kV or the 420 kV GIS switchyards can generate very fast high voltage transients with a steepness in the nano second range. The effective counter measure to prohibit interference is a properly designed complementary earthing grid, the use of signal cables with screens earthed at both ends and a correct layout of cables.
From another point of view the platform is a massive metallic structure that effectively tends to equalize the potential in all location on the platform. This is true for DC current. However, the platform is made of steel and steel is a magnetic material with high permeability and relatively high resistivity. The penetration depth in steel for 50 Hz current is less than one mm. Furthermore, if AC or transient current circumscribe a closed metallic structure, the metallic structure will be magnetically excited and the flux in the energized steel structure will induce voltage or current in any other conductor or metallic structure that circumscribe the energized steel structure, including cable screens. In addition, the steel structure will be exposed for excitation losses.

Complementary earth grid

The objective of the complementary earth grid of copper and/or aluminium is:
1) Minimize the magnetic coupling from fault and load current to other structures, especially cables.
2) Preventing excitation of steel structures by load and fault current to prevent significant loading of the hull by electric currents.
3) Preventing dangerous step and touch voltages.

The complementary earth grid of copper or aluminium conductors is installed in the same route in the platform as the high power high voltage conductors and cables for providing a low impedance return path for return fault current and as a path for mirror currents. The complementary earth grid is a combination of earth bars, earth wires and screen/sheath of the high power cables. For preventing harmful voltage differences between the platform steel structure and the complementary earth grid, the complementary earth grid has to be repeatedly bonded to the steel structure. By interconnecting various parts of the complementary earth grid at crossing points and by bonding it to the steel structure, an effective meshed earth system is obtained. Although the currents in the steel structure are low, they will not be zero. Especially, high currents in the earthing system in case of a fault will result in small differences in the potential of the steel structure. As a consequence, there is no global point that can be used as reference point for all instrument earthing (IE). For sensitive signals the reference point for IE has to be local, preferably in the main cubicle for each system.

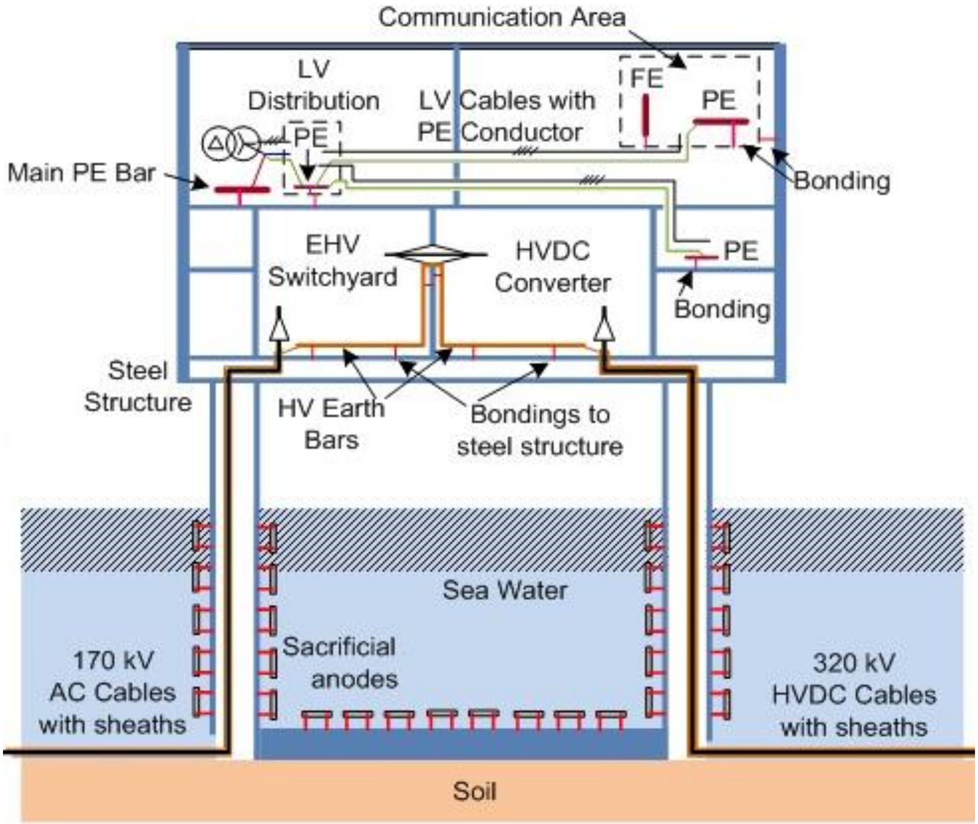

Figure 4: complementary earth grid

Outside the switchyard area

With a properly designed earthing system for the EHV and high power areas, no additional requirements exist for the earthing system of the LV power supply or the auxiliary power supply up to 36 kV. However, when auxiliary power is supplied from a tertiary winding of the main HVDC transformer, the high short circuit current and the risk for capacitively induced surge voltage has to be considered. Fault and zero sequence current of 50 Hz and above, fed from an external source via sea cables are to about 90 % returned via the cable sheaths. The remaining current will be returned via the sea water close to the cable. The penetration depth for 50 Hz current in sea water is about 45 m. Consequently, the potential of the main body of the platform in relation to the sea water is not impacted.

From EMC point of view, the most important aspect regarding cable layout is that cable routing in areas with harsh EMC environment such as the valve halls and the converter reactor hall or near the high power cables shall be avoided as far as possible. Also cables shall be routed as close as possible to steel structures as this minimizes coupling of disturbing EM-fields. For preventing induced voltage, signal cables entering areas with high voltage high power cables or equipment, has to be provided with screens earthed in both ends. Overload of the cable screen is prevented by earth wires following the cable routes.

Furthermore, structures of control rooms or enclosures with control equipment shall not be exposed to heavy lightning current during possible lightning strokes as this may induce disturbances in the signal and control cables. In addition to normal consideration this has to be considered at the design of the lightning protection system for an HVDC platform.

SPECIAL EMC CONSIDERATIONS

The concentration of strong EM-fields and vulnerable systems in a relative small area gives some challenges. Also the presence of people on a 24/7 basis causes some extra issues in relation with the EM environment caused by the HVDC-installation.

Radio communication
The allowed risk that a system will disturb radio communication equipment is restricted to a certain level. International standards have been developed which, when applicable and when applied correctly, will decrease the possibility that radio communications are disturbed. Standards are also applied to specify required immunity and permitted emission levels for other systems. For the offshore substation the required immunity and permitted emission levels shall be assessed for this special situation. Applying standards is a good way to reach EMC but as this is a special situation, application of standards might not be sufficient and an assessment of this situation is required. For instance, in case the HVDC installations emit strong harmonics in a protected frequency band, extra mitigation measures might be required. For the substation a dedicated EMC-plan for all (essential) frequencies is therefore required.

Human exposure
ICNIRP, as the International Commission on Non-Ionizing Radiation Protection, advices international governments and the World Health Organization (WHO) about exposure of people to electric and magnetic fields. National (European) governments are advised by the European Council to apply ICNIRP limits in their legislation. Based on the advice of ICNIRP, the European Council has made available a guideline for workers (latest version second half of 2013). The limits mentioned in this guideline are based on the ICNIRP advice and shall protect workers to be exposed to too high electric or magnetic fields. This guideline is mandatory for every employer in Europe. So the requirements of this guideline shall also be met at the platform. For German employers these requirements are laid down in the German standard BGV B11. To prevent people from being exposed to high voltages or high field strengths, these areas are closed and not accessible during operation.
Permitted exposure levels for workers are higher than those for the general public. However, this higher exposure is only allowed during a restricted time. At onshore substations this time related requirement is almost automatically fulfilled as workers are not all the time at the substation. In this way the environment of the platform is different; people can be 24/7 at the platform. This means that during a substantial part of the day workers shall not be exposed to field strengths higher than those allowed for the general public, although they are at their work location. This item is not covered in the European Council guideline. As people may only be exposed to high EM-fields during a restricted period of time, areas where people stay when they don't work shall have low EM-field levels. Special attention in this respect shall be given to the living quarters on the platform. For workers an exposure level of 1000 µT is permitted without any action needed. When field levels are higher (until 6000 µT), the employer shall perform actions like informing employees and restrict exposure levels where reasonably possible. However, workers are only allowed to be exposed to these levels during a restricted time. When they have to be considered as 'general public' when not working, their maximum allowed exposure level is 100 µT. Depending on the field strengths people can be exposed to, special attention shall also be given to workers with medical implants like pacemakers, Implantable Cardioverter Defibrillator (ICD's) and cochlear implants (IC). The European Guideline states that adequate precautionary measures shall be taken to prevent interference of pacemakers.

The skin effect
Steel has a high permeability resulting in significant skin effect for ac currents, especially for higher frequencies. Although the steel structure is an excellent equipotential plane and it defines the local reference potential everywhere within the platform, the high permeability results in a substantial high impedance for AC. Due to the skin effect high local concentration of AC current may be possible, resulting in local heating. This is the reason to apply a complementary earth grid of conductor material to take care of AC currents and transient currents.

Steel in the vicinity of strong magnetic fields
AC magnetic fields will cause eddy currents (or Foucault currents) in conductors. The strong fields of the reactors are able to give heating effects in steel constructions nearby. Special precautions are required to prevent local hotspots. The same goes for high, single phase currents through a hole in the steel structure. This can also lead to local heating of the steel structure. Wall bushings always penetrate a wall or roof/floor in a hole in the steel structure. The magnetic excitation of steel in the

neighbourhood of installations with high currents can be prevented by a proper design of the earthing system for these areas.

Short circuit currents to and from the platform

A short circuit on the platform or on neighbouring platforms causes currents to flow from or to the platform. Due to inductive coupling this current flow through cable sheets and only a small fraction loads the steel structure, the seawater and the earth. The sacrificial anodes bars for electrolytic cathodic corrosion protection gives a very low impedance between the platform steel structure and the sea water, thus the potential difference between the platform and the sea water is negligible.

Corrosion protection of the platform

For a platform installed in sea far from land, corrosion is an important factor to be considered. For avoiding corrosion due to electrolytic potential difference between steel and sea water the platform is protected by sacrificial aluminium anodes. For a platform with a High Voltage HVDC power station it has to be evaluated if the AC and DC power lines will induce return current in the platform that will impact the lifetime of sacrificial protective anodes. As there is no galvanic connection of the DC circuit to the platform there will be no DC return current loading the platform. The only DC currents terminated in the platform is resistive DC voltage dividers for voltage measuring and the resistors for capacitor grading. As the HVDC scheme is a balanced monopole the current from the positive and the negative pole is balanced resulting in a worst case unbalance of a few mA DC that is negligible. The unbalanced AC side currents is to about 90 % returned via the sheaths of the feeding submarine cables and the unbalanced AC current that may load the platform is estimated to be a few ampere with negligible impact on the life time of the sacrificial anode. The other corrosion phenomenon of concern is the possible electrolytic corrosion between the conductor material in the earthing grid and the steel structure of the platform. For electrical and safety reasons it must be a good electric contact where the earth wires and earth bars are bonded to the steel structure. However, in the humid atmosphere of the platform, electric contact between materials of different material implies a risk for galvanic corrosion. For aluminium bars in contact with steel there is a risk for corrosion of the aluminum. When copper is used, metallic contact between copper and steel implies a corrosion risk for the steel. However, by use of a special design and suitable selection of material these corrosion risks are eliminated.

APPLICABLE STANDARDS`

For the German sector of the North Sea, German authorities indicated that the German standards are also applicable for the Dolwin β platform. In this case the essential requirements of the EMC directive are mandatory; all systems and installations have to comply with the directive and shall meet the essential requirements of it. In case such legislation is not applicable, it is important that the owner of the platform together with authorities shall specify which standards are to be complied with.

- Zone 1: the generic immunity standard IEC 61000-6-1 [12] for residential, commercial, and light industrial environments shall be applied.
- Zone 2: for the immunity of equipment in Zone 2 generic standard IEC 61000-6-2 [4] should be applied, and for emission generic standard IEC 61000-6-4 [5].
- Zone 3: contains high voltage apparatus, applicable emission standard should be EN 62271-1 [9]. For immunity of the auxiliary equipment present in zone 3 generic standard IEC TS 61000-6-5 [6] should be applied.
- Zone 4: with the HVDC equipment, no standards are available yet and requirements and measures shall be specified according to the situation.
- Zone 5: for immunity and emission for equipment in Zone 5 there are two applicable international standards, IEC 60533 [7] and IEC 60945 [8], that should be applied as they deal with maritime equipment. These standards have been referred to in the DNV offshore standards, [1]-[3].

Maritime standards [1], [2], [3] give general guidance regarding considerations and design of an offshore substation. However, they do not consider the special conditions for very high power switchyards with voltages above 36 kV level. Standards related to very High Voltage switchyard are adapted to outdoor onshore substations with a buried earth grid and with buildings of conventional design. The conditions for an outdoor very HV switchyard are very different from the conditions for a corresponding switchyard located indoor inside a steel platform. Thus, even if the overall design objectives are the same, the design must be different. Regarding specific EMC standards the generic EMC standards [4], [5], [6] and [9] are applicable both for onshore and offshore installations. However, some parts of the standards do not fully adapt to the offshore installation environment. For the offshore platform also the marine standards [7] and [8] are applicable.

CONCLUSION

The necessity to examine the EMC topic in this new environment with a complex HVDC system and large HV switchgears housed in a metal platform at sea is evident. Special focus areas are safety systems, firefighting and detection systems and aeronautical and naval communications systems. Permitted exposure levels for workers are higher than those for the general public. For an offshore substation people can be 24/7 at the platform. This aspect is not covered in the European Council guideline.

The overall EMC philosophy of any HVDC installation, whether it is offshore or onshore, should be that the basic disturbance level is similar to an industrial environment. Special measures may be required to decrease the emission level of the HVDC systems to this industrial level. Where vulnerable equipment is located, these protected areas require even a lower emission level.

A complementary earth grid of copper and/or aluminium for minimize the magnetic coupling is required to prevent the steel from being loaded with high AC currents.

Maritime standards give general guidance regarding considerations and design of an offshore substation. However, they do not consider the special conditions for very high power switchyards with voltages above 36 kV level. Standards related to very High Voltage switchyard are adapted to outdoor onshore substations with a buried earth grid with buildings of conventional design. It is important that the owner of a platform shall together with authorities specify which standards shall be complied with.

The authors of this paper would recommend that the current applicable DNV and IEC standards should be modified and/or extended with this new offshore application. Until international or industry standards are available owners of new offshore HVDC substations should clearly indicate how this lack of standardisations should be handled in the project.

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