Offshore Windfarm Monopile Cathodic Protection: Deficiencies in Standards and Specifications

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Summary

Monopiles are the most common foundation for offshore windfarms in the developments to date. They are normally uncoated internally and many are uncoated externally. Externally, corrosion protection has most commonly been provided to the monopiles (MPs) by galvanic (sacrificial) anode cathodic protection (CP) with anodes installed onto the lower elevation of transition pieces (TPs). Some developments have utilised impressed current CP, again with anodes secured to the TPs and power supplies at higher elevation, normally within the TPs.

Many of these designs have been undertaken in accordance with Contract requirements as brief as ‘Provide cathodic protection in accordance with DNV-RP-B401’. Developers and their advisors have assumed that this is an adequate definition; their financial backers and insurers have assumed that the developers and their advisors know that they will be supplied with a CP system that will prevent external corrosion, and importantly corrosion fatigue, for the full life of the foundation. The contractors and their designers have reasonably assumed that their contractual obligation is to deliver precisely what is requested in the Contract requirements.

There are no CP performance requirements, no inspection and no performance verification requirements in DNV-RP-B401; its scope makes it clear that it is applicable to offshore oil and gas structures. Very few of these are monopiles and the document is severely lacking in relevant content for the design of CP systems for monopiles.

Many offshore wind foundations are designed in accordance with DNV-OS-J101 and subject to the requirements for Classification by DNV (now DNV GL). DNV-OS-J101 originally required CP designs for monopile foundations to be in accordance with DNV-RP-B401 but recent revisions have both inserted significant overriding changes to the RP-B401 requirements and have made its use optional. Despite this, recent Contract requirements for new developments continue to read ‘Provide cathodic protection in accordance with DNV-RP-B401’.

For the internals of monopile foundations, DNV-OS-J101 has undergone repeated changes but has been widely interpreted to allow or encourage control of internal corrosion by oxygen depletion, assuming that there will be no ingress/egress of sea water into the monopile via cable seals, MP/TP interfaces and via the sea bed and no ingress of oxygen via ‘air tight decks’ above the MP at the base of the TP. This has not proved to be a robust approach in many developments; this is now reflected in the latest revision of J101.

This paper details the deficiencies of RP-B401 and with earlier and present revisions of J-101. It describes the resultant deficiencies in corrosion protection. It proposes more secure methods of specifying effective and reliable CP. It argues that more immediate improvements to CP systems for windfarm monopile foundations can be
achieved by cooperating with DNV GL in improving their requirements rather than producing new EN or ISO Standards in competition with them.

1 Introduction

Cathodic Protection Design Process

Cathodic protection for marine structures is a relatively simple process but it requires a detailed understanding of the fundamentals of cathodic protection, the polarisation processes that occur and, most importantly, a thorough understanding of the input data into the design process and how the environmental conditions will vary these.

The process is well presented in BS EN ISO 13174: 2012 Cathodic Protection of Harbour Installations, in the Germanischer Lloyd Rules for Classification and Construction IV Industrial Services, Section 6 Offshore Technology, Section 6 Corrosion Protection (which actually gives worked examples) and DNV-RP-B401.

Of these documents only BS EN ISO 13174 (and its associated documents BS EN ISO 12473, BS EN 13173 and BS EN 12495, respectively the Offshore General Principles, CP of Floating Structures and CP of Fixed Offshore Structures), make it clear that the personnel undertaking design, supervision of installation, commissioning, supervision of operation, measurements, monitoring and maintenance of CP systems shall have the appropriate level of competence for the tasks undertaken. They require that the Competence should be independently assessed and documented; there is an established scheme BS EN 15257 “Cathodic Protection – Competence Levels and Certification of CP Personnel”, which the Institute of Corrosion operates in the UK and elsewhere. The scheme operates throughout Europe with schemes well organised in France, Italy, Germany and other countries. This scheme delivers Training and Certification for CP Personnel.
Personnel Certificated to Level 3 in the Marine sector of CP should be those responsible for CP designs for offshore wind farms.

The design process is summarised as the following, with the particular pitfalls that have been seen in real projects:

i. Assessment of the specific location for water conditions, in particular tidal, current, wave height and storm frequency, salinity, temperature, dissolved oxygen, suspended solids, marine growth, bed conditions. ALL of these affect the cathode current density, some affect the protection criterion due to MIC threat, salinity and temperature affect the resistance and thus current output of anodes. Most of these are simplified to “default values” in DNV-RP-B401; these default values are often not correct for windfarm projects.

ii. Determination of the appropriate protection criterion. Is it -800mV wrt Ag/AgCl/sea water as is appropriate in open sea water with no MIC threat? Or is it -900mV as is essential if ALWC or other manifestations of MIC are certain or possible during the life of the asset? DNV-RP-B401 strangely persists in a design process that targets -800mV even if -900mV is a requisite, on the basis that, due to other hidden elements of conservatism in their design process and default parameters, most designs will deliver -900mV most of the time. This
may be adequate for offshore oil and gas assets in deep water where the assets are installed with their CP systems working from day one; it is not appropriate for windfarm turbine foundations where the monopiles may be installed months before the transition piece, which often carries the anodes of the CP system, is placed and connected and where the MIC threat may be greater. Further, the ‘hidden elements of conservatism’ proven for larger deepwater jacket structures largely do not apply for inshore monopiles.

iii. Calculation of surface areas of steel immersed, driven or buried, in the tidal zone. Some projects “estimate” these from their drawing packages; I have seen errors of 25% in an early large gas jacket. DNV-RP-B401 is not clear as to whether the CP design should include steel to MWL or MHWS; this can be extremely significant for shallow coastal wind farms; the CP system should have sufficient current capacity to deliver full current demand at MHWS.

iv. Calculation/estimates of coating breakdown factors for any coatings applied. All transition pieces (TPs) of offshore wind turbines are coated, but only some monopile foundation MPs are coated. DNV (and most other standards) give reasonably competent advice on the likely coating damage and subsequent breakdown factors for coatings; however as much of the coating performance is determined by the cleanliness and surface profile of the steel substrate and the competence of the application, a competent CP design will take these quality issues into account in estimating the likely in service coating performance for particular assets. The number of known coating failures on offshore wind projects proves that simply specifying coatings to NORSOK M501 and allowing the coating supplier and coating contractor to be responsible for ‘independent coating inspection’ will not always deliver quality.

v. Estimates of Initial, Maintenance and Final cathode current densities for bare steel to achieve and maintain the selected protection potential. As noted in i. above, environmental conditions, notably the sea current and wave effects which determine the velocity of water past the steel/water interface, significantly affect the current density.

It is well known within the “expert” community that the Code and Standard current density guidance, including that in DNV-RP-401, is “broad brush”, proven to be adequate to deliver secure designs for deep water oil and gas assets (which is the declared scope of this DNV Recommended Practice) but that the Maintenance or Mean current density figures are overstated for normal ocean locations (intentionally, to deliver extra life for facilities which are extremely expensive to retrofit with additional CP as and when, as it often happens, the original design life of the asset is extended). These factors are generally NOT true for inshore windfarm locations.

It is equally well known that the Initial current density significantly underestimates the early days and weeks of real current demand for polarisation but that, with larger offshore facilities installed with CP systems from day one and many structures being partly coated, the ability of the CP system to deliver current in the early months normally exceeds the design Initial figure. This may not be true for windfarm monopile structures with clusters of anodes only fitted to transition pieces.
vi. The CP current demand is then calculated as a product of bare surface area \( x \) cathode current density. This assumes uniform delivery of current; this is reasonably true of a large oil and gas jacket structure with multiple legs and bracings all of which are fitted with anodes each delivering a very small proportion of the total current. It is not true of a monopile of say 60m length, half in water and half driven into the sea bed, with anodes clustered on the transition piece at the extreme top of the pile.

vii. The anodes (impressed current or galvanic) are then selected, typically by an iterative trial and error process to optimise current output and life and to best match to the current demand and in “normal” CP system designs, current distribution.

The design process detailed above is mathematically simple; any competent 16 year student can handle the maths. The DESIGN process in in the selection of the appropriate input parameters and in the selection of optimal solutions; there is no guidance or scope for these in DNV-RP-B401 or OS-J101.

2 Particular Issues for Offshore Wind Farms

The typical transformer or substation jacket, to which a series of turbines are connected, are normally very similar to the shallow water oil and gas drilling/production jackets for which there is huge experience in the design, construction and maintenance in Northern Europe.

This is true also in respect of the design of the corrosion protection systems, both CP and coatings. The jacket CP design would be relatively simple and secure based on proven offshore jacket practice. The most likely, lowest full life cost, most reliable and lowest maintenance CP systems will be cast galvanic anodes. These would likely be of an aluminium alloy, of proven capacity by long term testing in accordance with DNV-RP-B401 Annex C, cast onto 4 inch Schedule 80 tubes, welded to the jacket typically with a 300mm standoff. These anodes might typically weigh 200 to 400Kg each and be 2-3m long.

The only slightly difficult issues with any such design of CP for these jackets would be the best anode distribution to ensure uniform protection on relatively small, shallow jackets and, if the jacket is coated below MSL, estimating the coating breakdown rate. In addition, the CP design would need to account for:

- the particular sea conditions on the site
- the typical water flow rates
- the tidal range as a proportion of the fully immersed areas (dependent upon location)
- the presence of any suspended abrasive solids in the water

All of these factors could lead to peak CP current demands higher than those identified in DNV-RP-B401, which is primarily for larger and deeper structures.
The external CP of foundations for the turbines might seem even simpler, as the structures are typically monopiles of simple geometry. However, for economic reasons a typical shallow water wind farm foundations will comprise a driven tubular monopile (MP), generally driven to just around or below MSL. The transition piece (TP) will be “slotted”, like a spigot and socket arrangement, onto the MP after the piling vessel has moved on, using a crane vessel. In order to minimise cost the CP system will ideally comprise galvanic anodes welded to the TP.

In order for such an arrangement to deliver effective CP to the entire MP and immersed TP external surfaces, the criterion of -0.900V to silver/silver chloride sea water needs to be achieved for the full area subjected to MIC/ALWC risk. This will be difficult if anodes are only placed on the TP, if the MP is not coated and if the water level is much more than approximately 15m. The TP will need to be electrically bonded to the MP for CP current to flow in the circuit anode/sea/steel/return; bonds are normally made for electrical storm discharges, so adequately low resistance and long life connections for CP should not be a problem if properly specified.

The distribution of sufficient current from anodes on the TP to the full length of the MP is not a matter that is covered adequately by the ENs, ISOs or DNV-RP-B401 referenced above. Monopiles were not widely used when these documents were conceived; the then normal applications were either to jackets which were quite dense with members and had little intrinsic distribution difficulties, or to driven piles onto which anodes would be welded directly at perhaps 3-5m spacings if uncoated. Further, whilst the DNV-RP-B401 acknowledges MIC risk and that -0.900V is needed to control corrosion in anaerobic conditions, where MIC will occur, it does not address ALWC (MIC under decaying marine growth) and it actually requires designs to be undertaken for a protection criterion of -0.800V, even if the desired protection potential is -0.900V. This may be adequate for large jacket structures in reasonably deep water, due to undeclared safety margins in the overall design process in this RP. It is not adequate for uncoated monopiles in shallow, tidal, relatively high flow rate near coastal waters.

It may be necessary to coat the MPs in order to make these simple, optimum, galvanic anode CP systems, with anodes only on the TPs, robust for all environmental conditions. The designs can be further optimised by rigorous mathematical modelling, but the correct protection criteria are needed (for ALWC) and the correct polarisation/performance characteristics for inshore, high flow rate, significantly tidal and possibly abrasive conditions need to be used in the mathematical model input data. These designs and models can then be further optimised by the collection of detailed CP performance data from the assets (or similar existing assets in similar environments) in a full range of weather/wave/water movement conditions.

3. Are Present Standards Adequate?

In the UK Sector (and the Scandinavian Sectors) many of the offshore windfarms are the subject of Classification by Det Norske Veritas, now DNV GL. Compliance with DNV Standards and Recommended Practice is often a requirement on the Design and Construction Contractors, imposed by the Developers.
The Round 2 UK developments, now in construction or in operation, were often awarded for design and construction with a Specification requirement in respect of corrosion control that can be characterised as:

- Brief functional requirements relying heavily on DNV Recommended Practices and Standards
- Cathodic protection to DNV-RP-B401
- Coatings often only to external topside facilities in jackets and the TPs and superstructures on monopiles generator foundations
- Allowances for section loss

Although not defined within most Developer Specifications, it became established practice amongst many designers that the internally flooded monopiles could be adequately protected against internal corrosion, in the water column (and above and below the water column), simply by constructing an “air tight” deck in the TP, a few meters above the mean sea level, and assuming that oxygen would be depleted and corrosion would be stopped.

At the time of the UK Round 2 designs the then current DNV-RP-B401 was the 2005 version (now 2010 Amended April 2011). At the time of most Developer Specifications for Round 2, DNV had not yet published their DNV-OS-J101: 2010 or the significantly more competent May 2014 revision, so designers were being required/encouraged by Developers to use a CP design Recommended Practice conceived for use on what are generally large, relatively deep water, fixed offshore oil and gas jacket structures for what are generally small, relatively shallow water monopile turbine foundation structures.

I would argue (and was arguing with and for various UK and other sector Developers and their technical advisors and contractors in 2009 onwards) that DNV-RP-B401: 2005 was inadequate for monopile wind farm foundations in respect of:

- Cathode current density provisions that did not take account of local tidal flows and suspended solids in some of the coastal development areas
- Inadequate treatment of attenuation of protection current/potential from anodes located on the TPs down often uncoated MPs
- Inadequate treatment of the effects of anodes being juxtaposed one to another and to the structure and the resultant “Tension Hill” effects reducing the current output of anodes
- Inadequate treatment of the corrosion threats of SRBs, ALWC and other MIC phenomena to the external and internal immersed and buried steel
- Inadequate in respect of its galvanic anode design process in ensuring, where necessary to protect against MIC, meeting the criteria of protection of -900mV
- Inadequate in respect of lack of warnings that the complexities and sometime fragility of poorly designed impressed current systems could deliver incompetent and unreliable CP systems
- Inadequate in respect of lack of guidance regarding proof of system performance at “commissioning” and ongoing fixed monitoring and mobile surveying during service
- Throughout it offers “default” guidance for design parameters that are perfectly appropriate for most oil and gas developments, in well established
environments where these have been proven to be adequate, but which may not be adequate in typical wind farm sectors.

- Throughout it contains undeclared safety factors that result in CP designs providing very considerable over-provision of galvanic anodes weight (and thus life) which I consider are absolutely appropriate for the oil and gas sector where jacket and manifold structures are often extended in life beyond their original design life concept, but which may not be appropriate for inshore wind farm monopile foundations where the life is likely to be limited by fatigue, or changing generator design, and would be low cost and easy to retrofit for any life extension.

During 2009 and 2010 I was involved in many discussions with offshore wind farm designers and contractors who generally appeared to take the view that their contractual responsibility in respect of cathodic protection was to deliver systems that complied perfectly with the written words of DNV-RP-B401, but that they had no responsibility for the performance of the CP system. More often than not the personnel tasked with the “design” were not corrosion or cathodic protection specialists and had no comprehension of the deficiencies of the RP-B401 or the need to diverge from the default parameters therein. However, they were perfectly able to populate an MS Excel sheet generated by a long gone colleague who once attended a one week corrosion course and could read RP-B401.

In October 2010 DNV produced their Standard (as opposed to the RP-B401 Recommended Practice), DNV-OS-J101 “Design of Offshore Wind Turbine Structures”. This was a minor step forward in respect of the internals of monopile foundations:

Section 11 Corrosion Protection

B401: Closed flooded compartments should be protected with CP, coating near and above the water line and a corrosion allowance should be made.

However, it made no progress in respect of cathodic protection. It stated:

C101: CP as DNV RP 401
Guidance (in B301) that “CP may not sufficiently effective" in the zone near the sea bed “can be disregarded where a good electrical connection is established for the CP system.”

For those not expert in cathodic protection, with a CP system comprising anodes welded to a TP, intended to protect the MP over which the TP is grouted at its top, no CP will be provided if there is not an effective electrical connection between the TP and the MP. CP may not be sufficiently effective in the zone near the sea bed with a well bonded TP to MP if the design has not properly addressed attenuation down the MP, something ignored by DNV at this time.

Section 13 Periodical Inspection of Structures below Water

E101: Inspections at maximum intervals of 5 years.

E201: Inspection should cover (inter alia) “corrosion protection systems (anodes, coatings etc)"

E203 “The anode potential shall be measured and fulfil minimum requirements.”

For those not expert in cathodic protection it is necessary to make clear that visually inspecting anodes and measuring their potentials is not in any way a competent
method of assessing the performance of a CP system; this is particularly true of a CP system with anodes fitted only to a TP intended to protect an MP over a depth of say 15-25m to the sea bed and beyond. What should have been required are steel/sea water potential measurements to determine the efficacy of the CP system at the sea bed; the “minimum requirements” should be potential values of -900mV or more negative with respect to a standard Ag/AgCl/sea water reference electrode.

So, in late 2010, DNV were still advising that RP-B401 was suitable for windfarm monopile turbine foundations and were giving ill conceived advice on performance assessment of such schemes.

In September 2011 DNV significantly revised OS-J101. This was a belated but significant improvement and was received with some wry amusement by those of us (I was not alone) who had been arguing that RP-B401 and the first J101 were inadequate, but to be told that DNV defended RP-B401 absolutely and, if the contractors met its simplistic design procedures, all would be well.

An extract from a DNV web press release in 2011 advised that the September 2011 Revision of DNV OS J101 was focussed on reducing costs and increasing safety and the changes were highlighted as specifically addressing, inter alia:

- **Section 11 for corrosion protection is restructured and expanded.** It is first stating requirements for which types of corrosion protection shall be applied in the different corrosion zones, and subsequently stating requirements for corrosion allowance, cathodic protection and coating. Further, DNV replaced the definition of splash zone with the definition used in IEC61400-3.

- **Section 13 for inspection is rewritten.** It is bringing the standard in alignment with current practice for the necessary level of inspection in large wind farms and giving the owner a choice between periodic inspections and inspections according to a risk-based inspection plan.

The September 2011 revision of J101 made considerable improvements, but some backward steps, particularly in A102:

**Section 11**

A102: Re-introduces “control of humidity or depletion of oxygen” as corrosion mitigation methods in closed internal compartments.

B303: Protection of internal immersed surfaces should be protected by either CP or by provision of corrosion allowance, both can be with or without coatings.

Guidance note does declare experience of difficulty in sealing compartments. Guidance suggests sea water filled pipes can be protected for 5 diameters from open end by external CP. There is no guidance in respect of possible MIC in closed compartments or the effect of water flow on attenuation inside pipes.

D101: Galvanic anode CP declared as well established but declared impressed current for wind turbine structures to be "largely unproven and there is no design standard available giving detailed requirements and advice".

D201: The use of DNV-RP-B401 is inferred as optional: “DNV-RP-B401 gives requirements and guidelines for CP design....In case DNV RP B401 has been specified for a galvanic
anode CP system, all design parameters...shall apply, unless otherwise specified or accepted by the owner in writing. It then contradicts this and states: The initial current densities in DNV-RP-B401 shall be increased by 50% for bare steel to take account of higher seawater current in shallow water.

D203: “The anodes shall be distributed to avoid interference reducing their current output in accordance with the applicable CP design Standard. RP-B401 does NOT give adequate requirements in this respect. It then goes in to state: if there are reasons to assume “significant interaction between anodes, an analysis by a computer model should be carried out to determine a reduction factor for the anode current output.” Guidance then is given: For monopiles in water with depths approx. >15m it may be difficult to protect to the seabed with anodes only on the TP. Complete or partial coating may reduce current demand.

D204: A CP survey is required between 30 and 180 days. This sound requirement is then diminished by there being no definition of the survey requirements and the incorrect guidance that: “It is sufficient to establish an adequate global protection level extending from the uppermost part of the submerged zone to the seabed”; diver or ROV deployment is not strictly necessary. It then partially remedies this by: “If marginal protection is indicated (less negative than -850mV wrt Ag/AgCl/sea water) the survey should be extended to include close potential recordings at anodes and remote locations. The planning, execution and interpretation of the survey does not require involvement of the CP system designer. It does not require anyone competent to specify it and interpret the data.

D205: Requires proper documentation of the galvanic anode CP design including recommendations for the initial survey.
D301-307: Impressed current systems are permitted. There are significant warnings and good advice covering: mechanical integrity, replaceability, design justification, contingency (taken as redundancy) and a current contingency of a minimum of 150% of calculated current output, dielectric shields. Requires a most negative potential of -1150mV wrt Ag/AgCl/sea water and confirmation of distribution by mathematical modelling to include adequacy of fixed reference electrode locations. Requires “remote control of current output based on fixed potential data; it is unclear if this really means the normal local (not remote) closed loop control or if it really means systems must have remote data links to shore and remote alarms. In guidance it recommends the CP mathematical model is validated with field data. It does require the CP system designer’s involvement in the planning, execution and interpretation of the 30-180 day CP performance survey.

D308: Requires proper documentation of the impressed current CP design including recommendations for the initial survey. Requires CP model data at 10, 100 and 1000 Hrs particularly with potentials at edges of dielectric shield, at reference electrodes and at locations remote from anodes. Requires data on monitoring and control, commissioning and survey, operations including replacement of anodes, electrodes, data loggers and periodic inspection and maintenance of power supplies.

Section 13
A103: Recommends Risk Based Inspection of representative turbine structures and their foundations.
B301: Advises the “entire wind farm should be inspected at least once during a 5 year period.”
C601: Requires the intervals between inspections below water should not exceed 5 years. The guidance note recommends more frequent inspections during early years.
C701: Requires inspection of (inter alia) the “corrosion protection systems (anodes, coating, etc)”
C703: “The anode potential shall be measured and fulfil minimum requirements”

This remains incompetent advice; measuring anode potentials informs us inadequately of the CP system performance. The advice in Section 11 D204 (whilst deficient as noted above) is much better and in conflict with Section 13 C703. This requires change.

This document is a very significant improvement on RP-B401 and the previous J101. It has some relatively limited deficiencies which could result in very poor outcomes in the protection of windfarm turbine foundations; the most serious is that there are no requirements for Competency of Designers or those specifying or interpreting the data from performance surveys. It does not define the requisite criterion of protection; in the light of significant MIC threats this should be -0.900V wrt Ag/AgCl/sea water and not the -0.800V inferred (but not defined) in RP 401 or the -0.850V that could be inferred from the guidance note following D204.

The DNV-OS-J101 was again revised in January and February 2013. There were no changes to the September 2011 text in respect of cathodic protection. It was significantly revised in May 2014.

The May 2014 OS-J101 makes particular improvements:

- Internal surfaces, both atmospherically exposed and in the ‘splash zone’ shall be protected by a corrosion control system; this may be a coating system or a corrosion allowance as a minimum of 0.10mm/yr unless experience or other considerations indicate otherwise.
- Internal surfaces of the submerged zone shall have CP or corrosion allowance as above. It warns of MIC in the upper sediment zone producing higher corrosion rates but gives no guidance on these rates.
- It warns of ineffectiveness of the previously encouraged oxygen depletion strategy.
- As in 2011 it warns of lower reliability of impressed current CP systems compared with galvanic anode systems and infers the greater design complexity for the former. It requires the Owner to evaluate any decision to use impressed current......’buyer beware’.
- As in 2011 it allows the use of RP-B401 but as default design parameters increases the initial cathode current densities by 50%; it allows the Owner to modify the anode characteristics (see below for anode capacity).
- As in 2011 it requires anodes to be distributed to avoid interference affecting their current output, OR requires computer modelling to determine reduced current output from anodes.
- As in 2011 it requires survey within 365 days (presumably of the CP system being installed) of representative structures (possibly 1 in 20) but does NOT require proximate reference electrode placement unless ‘marginal protection is indicated’ (defined as less negative than -0.90V Ag/AgCl/sea water, measured with what may be a quite remote reference electrode). Note that this is the only indication in either J-101 or RP-B401 that the protection criterion should be -0.90V or more negative. It does NOT require any involvement of the CP Designer…..or any CP Specialist….. in defining or evaluating the survey or data from it.
For impressed current systems the survey requirements are more onerous, requiring the reference electrodes to be placed by ROV and the CP Designer to be involved in defining the survey and evaluating the data from it.

It requires appropriate documentation for the design of the system. These are more rigorous for impressed current systems and there are more subtle warnings of likely poor performance with inadequately designed impressed current systems.

During this period of changes to its J-101 Standard DNV have also been revising its main cathodic protection document RP-B401. The 2005 document was marginally revised in April 2006 and in April 2008. The document was significantly revised in October 2010 and an apparently small but actually significant change was made in April 2011. Most importantly for offshore windfarms, this document remains competent primarily for its main scope; fixed oil and gas production structures. It remains inadequate for windfarm turbine foundations due to inadequate advice in respect of input data particular to inshore coastal locations, attenuation and anode/anode and anode/cathode interactions. DNV-RP-B401 in its latest revision in the guidance note to clause 6.5.2 gives “strong recommendation that the inherent conservatism of using the default values in Table 10-6 shall be utilised for design, also (sic even) if an anode manufacturer claims that his product is capable to achieve a higher performance.” Table 10-6 is the recommended maximum anode capacity to be used in designs. It continues to give secure advice on the caution needed in interpreting short term and long term anode capacity data and on the importance of precise anode composition and casting conditions on actual anode performance.

This guidance is possibly appropriate for large, deepwater fixed oil and gas jackets; its result is to increase the weight (and thus life and cost) of galvanic anodes in a CP scheme by 25%. This is in addition to the existing additional undisclosed weight/life cost safety margin hidden in Table 10-2 where the mean current density figures are known to be between 30 and 50% in excess of published and company confidential measured data which already result in the weight (and thus life and cost) of galvanic anodes in a CP scheme being 30-50% greater than optimum.

I would argue that it not appropriate for inshore windfarm turbine foundations to be penalised by these undisclosed “inherent conservatism” margins of safety which collectively could add unnecessary cost and weight to their CP systems.

So, are existing Standards adequate? I would argue:

- Recent changes by DNV in their OS-J101 document have significantly improved matters, but not to a position where secure and reliable designs are assured
- The use of default parameters from DNV-RP-B401 can on one hand lead to designs that are inadequate as the current densities for polarisation may not be appropriate for many coastal windfarm locations (corrected in an imprecise manner by OS-J101) but conversely can lead to excessive weight and cost of anodes due to excessively conservative guidance on anode capacity
- The lack of clarity as to design protection criterion is unacceptable
- The need for competent CP specialists to select appropriate input data for the design, to ensure that these requirements are consistent in anode purchase specifications (ensuring design capacities and utilisation factors are met) and
in the specification, execution supervision and interpretation of performance surveys is missing

- DNV-OS-J101 infers but is insufficiently robust in requiring adequate attention to attenuation of protection down monopiles and to anode/anode and anode/cathode “Tension Hill” related interactions.

- Recent work on cathodic protection of monopile internal surfaces indicate that, expectedly, the design current densities in DNV-RP-B401 for external surfaces are grossly excessive for internal surfaces with minimal water flow, that, perhaps less obviously, the use of aluminium anodes can be detrimental unless there is considerable exchange of water into the monopile each tide and, of course, that there are safety issues of possibly incendive gas collection in closed spaces. Some of this work is being presented in Eurocorr 2015.

So my answer is no; they could do better.

4. Suggested Improvements to DNV-OS-J101

It is suggested that the following, relatively minor changes to DNV-OS-J101 would render it competent in respect of cathodic protection for offshore windfarms and would remove any need for Standards activity in Europe or Internationally on this subject. Alternatively Developers and Owners could use the following as an Addendum to the CP requirements of DNV-OS-J101

1. Cathodic protection of offshore wind turbine structures shall be designed and the designs documented by a professionally qualified corrosion and cathodic protection Specialist with a minimum of 5 years senior, responsible, experience in the design of offshore cathodic protection systems and who shall have Certification of Competence in this field. One such Certification scheme is that in EN 15257.

2. The design and documentation shall be checked/verified by a similarly qualified, experienced and Certificated as competent, independent corrosion and cathodic protection Specialist.

3. The performance requirement for the CP system shall be that all immersed surfaces below mean sea level (MSL) shall be protected to between -0.900V and -1.100V Ag/AgCl/sea water. If any materials liable to HISC are used on the structure, less negative values may be proposed and agreed in writing by the Owner/Developer. This protection criterion shall be applicable to all immersed external surfaces and to internal immersed surfaces if cathodic protection is selected as the corrosion control method for internal immersed surfaces.

4. The preferred method of cathodic protection shall be by galvanic anodes. If impressed current systems are proposed, their advantages and disadvantages shall be detailed by the designer, taking account of a rigorous reliability assessment of anodes, reference electrodes, power supplies (ac and dc), monitoring and control systems, cabling and cable management systems. The full life costs shall be calculated, taking into account reasonable predictions of offshore inspection, performance verification, maintenance, replacement and remedial works and their costs. The Owner or Developer shall assess these details and agree in writing to any use of impressed current. Impressed current systems shall not be employed for internal surfaces due to the hazardous nature of the anodic reaction products.
5. Internal CP designs shall reflect the much lower water flow rates within the monopile and thus lower current densities. Caution shall be exercised in using aluminium anodes for internal protection as their use can result in significant acidification of the water column and ineffective CP. Zinc anodes or significant water exchange during the tidal cycle can mitigate this effect. Designs involving anodes on 'strings' shall take account of the string resistance on individual anode current outputs. Aluminium anodes shall not be cast onto galvanised steel ropes.

6. The CP design shall take account of the quality regime at the applicator of any coatings applied to surfaces to receive CP. The designer shall assess if the coating breakdown default figures in DNV-RP-B401 are applicable.

7. The requirements of DNV-OS-J101 shall apply.

8. The CP design process shall be as detailed in EN 13174 or DNV-RP-B401 but the input parameters shall be selected by the designer to reflect the metocean characteristics of the wind farm location and if applicable the conditions within the monopile. In particular the steel (cathode) current density figures used for the design shall reflect the local conditions of tidal flow, tidal rise and fall and suspended solids in the water. The designer shall take account of published cathode current density data including those of Strommen and of Hack and Guanti. If the designer determines to use current density default values in DNV-RP-B401 then the initial external cathode current density shall be increased by 50% as in DNV-OS-J101; such a design will likely be excessively conservative (in weight and cost) particularly if the anode capacity figures in RP-B401 are used.

9. The CP design process shall include the design of electrical continuity bonds between monopile (MP) and transition piece (TP) if all or some anodes are installed on the TP. The volt drop in these bonds shall be used in the design process.

10. All CP designs for multiple foundation wind farm developments shall be subject to mathematical modelling of the CP design in respect of anode/anode and anode/cathode mutual interaction (reducing anticipated anode current output) and to attenuation of current and potential for the full depth of the MP, including the driven depth below bed. For single foundations, such as 'met masts', where the costs of modelling cannot be amortised over multiple foundations, past modelling of similar systems may be used to estimate anode current outputs and attenuation.

11. All modelling shall be undertaken by specialist modelling companies working under the direction and detailed challenge of the CP designer. The modelling companies shall not be the designers; the designers shall not themselves use commercially available modelling software to undertake the modelling. The CP designer shall be held responsible for the accuracy of the modelling.

12. The design documentation shall include a specification for commissioning testing the CP systems. This shall include, as a minimum, confirmation by current and potential measurement that all continuity bonds between TPs and MPs for all foundations are functional and a ‘dipping’ electrode measurement of each MP/water potential with the electrode remote from anodes for all foundations. Detailed potential surveys with reference electrodes within 0.5m of the steel surface shall be completed on representative foundations (a minimum of 1 in 20 for galvanic anode systems and 1 in 5 for impressed current systems) with potential measurements at 12, 3, 6 and 9 o’clock at sea bed level and at maximum 2m intervals to MSL. For impressed current
systems, additional measurements shall be taken within 0.5m of the impressed current anodes and at the edge of any dielectric shield applied to the TP/MP in order to demonstrate that the -1.100V Ag/AgCl/sea water potential limit is not exceeded at the shield limit.

13. The commissioning testing shall be supervised by similarly qualified, experienced and Certificated as competent, independent corrosion and cathodic protection Specialist as the CP system designer. The Owner/Developer may use the designer for this task or may require the use of an independent Specialist. The survey data shall be assessed by the Specialist as a design verification. The survey data shall be provided to the CP designer and the mathematical modelling company in order that the model can be calibrated with real field data.

14. The field data and calibrated models shall be used in future CP performance verification assessments of representative foundations (minimum 1 in 20 for galvanic anode systems and minimum 1 in 5 for impressed current systems) every 5 years for galvanic anode systems and every 1-2 years dependent upon reliability for impressed current systems. These performance verifications shall, as a minimum, repeat the commissioning surveys as item 12. above. Every 5 years any bonds between TPs and MPs shall be visually inspected for integrity and potentials and currents measured at all bonds on all foundations.

15. The calibrated models shall be used to demonstrate if full protection will be maintained in typical winter conditions (lower temperatures, thus higher water resistivity and different polarisation characteristics) and worst case storm conditions (higher water flow rates).

16. It is recommended that the field data and calibrated model data are exchanged in Joint Industry Programmes in order that lessons may be quickly learned and designs improved.

17. For impressed current systems monthly CP raw data logs of anode currents and steel/sea water potentials from all foundations shall be subject to independent (not the CP system provider) specialist review and comment.

It is considered that the above requirements will immediately minimise the risks of deficient CP system designs and the need for excessively expensive offshore retrofits. None of the requirements are considered to be excessively onerous or expensive; most have been in place in the offshore oil and gas industry for the past 30 years, following early design failures and retrofits. The offshore renewables industry should benefit from this practice.

Whilst there may be benefits in having EN or ISO Standards defining these, or better requirements, the reality is that the offshore renewables industry is committed to the use of Classification Society rules. Far quicker results in lower cost and improved safety can be delivered by helping Societies like DNV GL to improve their rules.

Cathodic protection is well proven and there is excellent design experience and proven performance in the offshore oil and gas sector. This expertise is directly applicable to the offshore wind farm industry. Subject to adequate design and in service inspection & monitoring, the immersed externals and internals of offshore wind farm assets can be expected to be free of serious corrosion damage for their full and possible extended design lives by using CP. However, their unique locations and
geometries do present some issues that require particular care in the design of their CP systems.

References:
1) DNV-RP-B-401: 2010 Amended April 2011. Recommended Practice: Cathodic Protection Design, DNV Hovik, Norway
5) BS EN 15257: 2006. Cathodic Protection – Competence Levels and Certification of CP Personnel
8) H P Hack and R J Guanti, Research Report DTRC/SME-87/82, 'Effect of high flow rate on calcareous deposits and cathodic protection current density', David Taylor Research Center, Bethesda, MD, USA, April 1988