DNV·GL

RECOMMENDED PRACTICE

DNVGL-RP-0416 Edition March 2016

Corrosion protection for wind turbines

DNV GL AS

FOREWORD

DNV GL recommended practices contain sound engineering practice and guidance.

Any comments may be sent by e-mail to *rules@dnvgl.com*

CHANGES – CURRENT

General

This is a new document.

CONTENTS

SECTION 1 GENERAL

1.1 Introduction

This recommended practice (RP) provides principles, technical recommendations and guidance for design and construction and in-service inspection of corrosion protection systems for wind turbines.

The emphasis is put on the protection of support structures of offshore wind farms. The recommended practice can also be used for design of corrosion protection for other structures in an offshore wind farm, such as offshore substations or meteorological masts.

The recommended practice does not cover design of wind turbine components such as nacelle, rotor, generator and gearbox. For structural design of support structures DNVGL-ST-0126 applies.

Recommendations regarding the corrosion protection of the machinery parts are given in DNVGL-ST-0361 *Machinery for wind turbines*.

The recommended practice has been written for worldwide application. National and governmental regulations may include requirements in excess of the provisions given by this recommended practice depending on the size, type, location and intended service of the wind turbine support structure.

1.2 Objectives

The objectives of this recommended practice are to:

— provide an internationally acceptable level of safety by defining minimum requirements for corrosion protection systems (in combination with referenced standards, recommended practices, guidelines, etc.)
— serve as a reference document between suppliers and purchasers related to design, construction, installation and in-service inspection
— serve as a guideline for designers, suppliers, purchasers and regulators
— specify procedures and requirements for corrosion protection systems
— serve as a basis for verification of corrosion protection systems scope and application.

The recommended practice is applicable to all types of wind turbines.

The recommended practice is applicable to the design of complete structures, including towers, substructures and foundations, but excluding wind turbine components such as nacelles and rotors.

This recommended practice gives recommendations for the following:

Corrosion control including

— corrosion allowance,
— cathodic protection (CP),
— corrosion protective coatings and
— use of corrosion resistant materials.

1.3 Certification

Certification principles and procedures related to certification services for corrosion protection of wind farm structures are specified in relevant DNV GL service specifications.

SECTION 2 REFERENCES

2.1 Normative references

2.1.1 General

The standards in Table 2-1 include provisions, which through reference in this text constitute provisions of this recommended practice. Current editions / revisions of the documents shall apply.

Table 2-1 Normative standards and guidelines.

Reference	*Title*
DNV-RP-B401	Cathodic Protection Design
DNVGL-SE-0073	Project certification of wind farms according to IEC 61400-22
DNVGL-SE-0074	Type and component certification of wind turbines according to IEC 61400-22
DNVGL-SE-0190	Project certification of wind power plants
DNVGL-SE-0420	Certification of meteorological masts
DNVGL-SE-0441	Type and component certification of wind turbines (planned published 2016)
DNVGL-ST-0126	Design of support structures for wind turbines
DNVGL-ST-0145	Offshore substations (planned published 2016)
DNVGL-ST-0361	Machinery for wind turbines
EN 1090-1	Execution of steel structures and aluminium structures – Part 1: Requirements for conformity assessment of structural components
EN 1090-2	Execution of steel structures and aluminium structures - Part 2: Technical requirements for steel structures
EN 10025	Hot rolled products of structural steels
EN 10204	Metallic products – types of inspection documents
EN 10225	Weldable structural steels for fixed offshore structures – technical delivery conditions
EN 12473	General principles of cathodic protection in sea water
EN 12495	Corrosion Protection of Fixed Offshore Structures
EN ISO 12944	Paints and varnishes – Corrosion protection of steel structures by protective paint systems
EN ISO 14713	Zinc coatings –Guidelines and recommendations for the protection against corrosion of iron and steel in structures – Part 1: General principles of design and corrosion resistance
ISO 8501	Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness
ISO 8502	Preparation of steel substrates before application of paints and related products — Tests for the assessment of surface cleanliness
ISO 8503	Preparation of steel substrates before application of paints and related products - Surface roughness characteristics of blast-cleaned steel substrates
ISO 20340	Paints and varnishes — Performance requirements for protective paint systems for offshore and related structures
NACE SP 0176	Corrosion Control of Steel Offshore Platforms Associated with Petroleum Production
NACE SP 0108	Corrosion Control of Offshore Structures by Protective Coatings
NORSOK M-501	Surface preparation and protective coating

2.2 Informative references

2.2.1 General

The documents in Table 2-2 include acceptable methods for fulfilling the requirements in the standards. See also current DNV GL list of publications on the internet. Other recognised codes or standards may be applied provided it is shown that they meet or exceed the level of safety of the actual standard.

Table 2-2 Informative standards and guidelines

Reference	*Title*
EN 10088	Stainless steels
EN 50308	Wind Turbines – Protective measures – Requirements for design, operation and maintenance
IEC61400-1	Wind Turbines – Part 1: Design Requirements
IEC61400-3	Wind Turbines – Part 3: Design requirements for offshore wind turbines
IEC61400-22	Wind Turbines – Part 22: Conformity testing and certification of wind turbines

SECTION 3 DEFINITIONS AND TERMINOLOGY

3.1 Definitions

3.1.1 Verbal forms

Table 3-1 Verbal forms

Term	*Definition*
shall	verbal form used to indicate requirements strictly to be followed in order to conform to the document
should	verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required
may	verbal form used to indicate a course of action permissible within the limits of the document

3.1.2 Terms

Table 3-2 Terms

Term	*Definition*
accidental limit states (ALS)	ensure that the structure resists accidental loads and maintain integrity and performance of the structure due to local damage or flooding
atmospheric zone	the external region exposed to atmospheric conditions
basic design standard	the standard(s) from Table 2-1 selected as a basis for the design in combination with this standard
cathodic protection	a technique to prevent corrosion of a steel surface by making the surface to be the cathode of an electrochemical cell
characteristic resistance	the reference value of a structural strength to be used in the determination of the design resistance The characteristic resistance is normally based upon a 5% quantile in the lower tail of the distribution function for resistance.
characteristic value	a representative value of a load variable or a resistance variable For a load variable, it is a high but measurable value with a prescribed probability of not being unfavourably exceeded during some reference period. For a resistance variable it is a low but measurable value with a prescribed probability of being favourably exceeded.
classification notes	the classification notes cover proven technology and solutions which are found to represent good practice by DNV GL, and which represent one alternative for satisfying the requirements stipulated in the DNV GL Rules or other codes and standards cited by DNV GL The classification notes will in the same manner be applicable for fulfilling the requirements in the DNV GL offshore standards.
coating	metallic, inorganic or organic material applied to steel surfaces for prevention of corrosion
construction	this term is used for building and installing the support structure Also the terms fabrication and/or manufacturing is used for building a support structure.
contractor	a party contractually appointed by the purchaser to fulfil all, or any of, the activities associated with fabrication and testing
corrosion allowance	extra wall thickness added during design to compensate for any reduction in wall thickness by corrosion (externally and internally) during design life
current (electric)	a flow of electric charge
current (water)	a flow of water past a fixed point and usually represented by a velocity and a direction
design basis	a document defining owner's requirements and conditions to be taken into account for design and in which any requirements in excess of this standard should be given

Table 3-2 Terms (Continued)

Term	*Definition*
design life	the period of time over which the structure in question is designed to provide an acceptable minimum level of safety, i.e. the period of time over which the structure is designed to meet the requirements set forth in this standard
design temperature	the lowest daily mean temperature that the structure may be exposed to during installation and operation
design value	the value to be used in the deterministic design procedure, i.e. characteristic value modified by the resistance factor or the load factor, whichever is applicable
expected value	the mean value, e.g. the mean value of a load during a specified time period
fatigue	degradation of the material caused by cyclic loading
fatigue critical	structure with predicted fatigue life near the design fatigue life
fatigue limit states (FLS)	related to the possibility of failure due to the cumulative damage effect of cyclic loading
foundation	the foundation of a support structure for a wind turbine is in this document reckoned as a structural or geotechnical component, or both, extending from the seabed downwards
guidance note	information in the standards in order to increase the understanding of the requirements
highest astronomical tide (HAT)	level of high tide when all harmonic components causing the tide are in phase
inspection	activities such as measuring, examination, testing, gauging one or more characteristics of an object or service and comparing the results with specified requirements to determine conformity
limit state	a state beyond which the structure no longer satisfies the requirements The following categories of limit states are of relevance for structures; ULS = ultimate limit state; FLS = fatigue limit state; ALS = accidental limit state; SLS = serviceability limit state.
lowest astronomical tide (LAT)	level of low tide when all harmonic components causing the tide are in phase
lowest waterline	typical light ballast waterline for ships, transit waterline or inspection waterline for other types of units
mean	statistical mean over observation period
mean water level (MWL)	mean still water level, defined as mean level between highest astronomical tide and lowest astronomical tide
metocean	abbreviation of meteorological and oceanographic
non-destructive testing (NDT)	structural tests and inspection of welds by visual inspection, radiographic testing, ultrasonic testing, magnetic particle testing, penetrant testing and other non-destructive methods for revealing defects and irregularities
offshore standard	the DNV offshore standards are documents which presents the principles and technical requirements for design of offshore structures The standards are offered as DNV’s interpretation of engineering practice for general use by the offshore industry for achieving safe structures.
offshore wind turbine structure	a structural system consisting of a support structure for an offshore wind turbine and a foundation for the support structure
partial safety factor method	method for design where uncertainties in loads are represented by a load factor and uncertainties in strengths are represented by a material factor
pile head	the position along a foundation pile in level with the seabed This definition applies regardless of whether the pile extends above the seabed.
potential	the voltage between a submerged metal surface and a reference electrode
primary steel	structural parts where failure will have substantial consequences (e.g. tower, monopole, flanges)
purchaser	the owner or another party acting on his behalf, who is responsible for procuring materials, components or services intended for the design, construction or modification of a structure
recommended practice (RP)	the recommended practice publications cover proven technology and solutions which have been found by DNV to represent good practice, and which represent one alternative for satisfying the requirements stipulated in the DNV offshore standards or other codes and standards cited by DNV

Table 3-2 Terms (Continued)

Term	*Definition*
redundancy	the ability of a component or system to maintain or restore its function when a failure of a member or connection has occurred Redundancy can be achieved for instance by strengthening or introducing alternative load paths.
reference electrode	electrode with stable open-circuit potential used as reference for potential measurements
reliability	the ability of a component or a system to perform its required function without failure during a specified time interval
risk	the qualitative or quantitative likelihood of an accidental or unplanned event occurring considered in conjunction with the potential consequences of such a failure In quantitative terms, risk is the quantified probability of a defined failure mode times its quantified consequence.
rotor-nacelle assembly	part of wind turbine carried by the support structure
scour zone	the external region of the unit which is located at the seabed and which is exposed to scour
secondary steel	structural parts where failure will be without significant consequence (e.g. ladders, platforms, railings, boat landings and J-tubes)
serviceability limit states (SLS)	imply deformations in excess of tolerance without exceeding the load-carrying capacity, i.e., they correspond to tolerance criteria applicable to normal use
slamming	impact load on an approximately horizontal member from a rising water surface as a wave passes The direction of the impact load is mainly vertical.
specified value	minimum or maximum value during the period considered This value may take into account operational requirements, limitations and measures taken such that the required safety level is obtained.
splash zone	external or internal surfaces of a structure which are intermittently wetted by tide or waves or both
submerged zone	the part of the installation which is below the splash zone, including the scour zone and permanently buried parts
support structure	the support structure of a wind turbine is defined as the structure below the yaw system of the rotor-nacelle-assembly and includes tower structure, sub-structure and foundation See also Figure 3-1.
target safety level	a nominal acceptable probability of structural failure
tidal range	distance between highest and lowest astronomical tide
tide	regular and predictable movements of the sea generated by astronomical forces
tower	structural component, which forms a part of the support structure for a wind turbine, usually extending from somewhere above the still water level to just below the nacelle of the wind turbine
ultimate limit states (ULS)	correspond to the limit of the load-carrying capacity, i.e., to the maximum load-carrying resistance
utilisation factor	the fraction of anode material that can be utilised for design purposes
verification	examination to confirm that an activity, a product or a service is in accordance with specified requirements

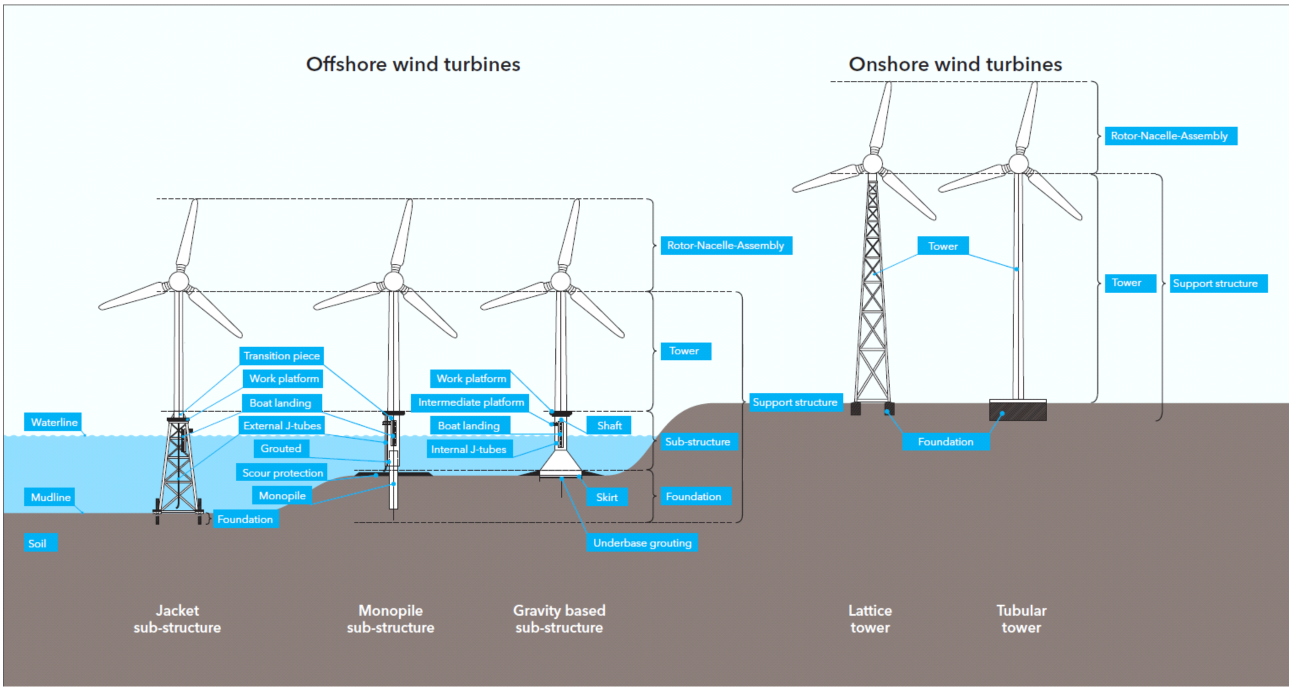

Figure 3-1 Definition of wind turbine components

3.2 Acronyms, abbreviations and symbols

3.2.1 Acronyms and abbreviations

Table 3-3 Abbreviations

Short form	*In full*
AISI	American Iron and Steel Institute
ALARP	as low as reasonably practicable
ALS	accidental limit state
API	American Petroleum Institute
BSH	Bundesamt für Seeschifffahrt und Hydrographie
CA	corrosion allowance
CP	cathodic protection
DFT	dry film thickness
DNV GL	DNV GL
FLS	fatigue limit state
GACP	galvanic anode cathodic protection
GRP	glass reinforced plastic
HAT	highest astronomical tide
HISC	hydrogen induced stress cracking
ICCP	impressed current cathodic protection
IEC	International Electrotechnical Commission
IOB	iron-oxidicing bacteria
IR	I × R = Current × Resistance = Voltage
IRB	iron-reducing bacteria
ISO	International Organization for Standardization

Table 3-3 Abbreviations (Continued)

Short form	*In full*
LAT	lowest astronomical tide
MIC	microbiologically influenced corrosion
MP	monopile
MWL	mean water level
NACE	National Association of Corrosion Engineers
NDT	non-destructive testing
ROV	remotely operated vehicle
RP	recommended practice
SCF	stress concentration factor
SLS	serviceability limit state
SRB	sulphate reducing bacteria
SWL	still water level
T_C	design useful life of the coating
T_D	design life of the structure
TP	transition piece
ULS	ultimate limit state
YR	YEAR

3.2.2 Symbols

3.2.2.1 Latin characters

F	force, load
F_d	design load
F_k	characteristic load
F_{pd}	design preloading force in bolt
G	permanent load
H	height
H_{max}	maximum wave height
H_0	wave height in deep waters
H_S	significant wave height
M	moment
M_p	plastic moment resistance
M_T	torque
M_y	elastic moment resistance
N	fatigue life, i.e. number of cycles to failure
N	number of shear keys
N_p	number of supported stiffeners on the girder span
Ns	number of stiffeners between considered section and nearest support
P	load
P	axial force
P_{pd}	average design point load from stiffeners
Q	variable functional load
R	radius
R	resistance
R_d	design resistance

R_k	characteristic resistance
R_p	outer radius of pile
R_s	outer radius of sleeve
R_{TP}	outer radius of transition piece
SZ_l	lower limit of the splash zone
SZ_u	upper limit of the splash zone
T_C	design useful life of coating
T_D	design life of structure
V	wind speed
V_{corr}	expected maximum corrosion rate
f_y	specified minimum yield stress
g	acceleration of gravity
h	height
h	water depth
n	number
p_d	design pressure
t_{JL}	thickness of jacket leg
t_k	corrosion addition
t_p	wall thickness of pile
t_s	wall thickness of sleeve
A_W	wave amplitude
D_{JL}	diameter of jacket leg
D_P	diameter of pile
D_S	diameter of sleeve
E	modulus of elasticity
E	environmental load
F	force, load
F_d	design load
F_k	characteristic load
F_{pd}	design preloading force in bolt
G	permanent load
H	height
H_{max}	maximum wave height
H_S	significant wave height
M	moment
M_T	torque
M_y	elastic moment resistance
P	load
P	axial force
R	radius
R	resistance
R_d	design resistance
R_k	characteristic resistance
R_p	outer radius of pile
R_s	outer radius of sleeve
R_{TP}	outer radius of transition piece
SZ_l	lower limit of the splash zone

SZ_u upper limit of the splash zone
T wave period
T plate thickness
T_C design useful life of coating

3.2.2.2 Greek characters

$\Delta\sigma$ stress range
ϕ friction angle
ϕ resistance factor
γ_m material factor
γ_M material factor
μ friction coefficient
ρ density
σ_d design stress

3.2.2.3 Subscripts

c characteristic value
d design value
k characteristic value
p plastic
y yield

SECTION 4 CORROSION PROTECTION

4.1 Introduction

In this recommended practise the requirements and guidance for corrosion control of wind turbine support structures are given. Additionally the requirements and guidance of the DNV-RP-B401 *Cathodic Protection Design* apply.

Methods for corrosion control include corrosion allowance, cathodic protection, corrosion protective coatings and use of corrosion resistant materials. In closed internal compartments, corrosion may also be mitigated by control of humidity or depletion of oxygen. The term corrosion control further includes the inspection and maintenance of corrosion protection systems during operation.

Guidance note:

Corrosion control by exclusion of oxygen is primarily an option for structural compartments which are only externally exposed to seawater. Compartments potentially exposed to air will need to be kept permanently sealed by welding or by maintenance of overpressure by nitrogen to prevent any air ingress. The inside of monopile structures cannot be considered as oxygen free due to volume of the enclosed water and entrapped air and various possibilities of water exchange or need for inspection.

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When corrosion allowance is part of the required corrosion protection, the corrosion allowance shall be considered in the structural design for all limit state analyses by appropriate reduction of nominal thicknesses, see DNVGL-ST-0126 Sec.4. In this case special consideration shall also be paid to selection of applicable S-N curves for fatigue design.

Galvanic corrosion can occur when metallic materials with different electrochemical characteristics are combined. The designer must always take this effect into consideration. Mitigation actions can be e.g. electrical insulation or cathodic protection.

4.2 Atmospheric zone

External and internal surfaces of steel structures exposed in the atmospheric zone, which is the zone extending above the splash zone as defined in [4.3], shall be protected by coating.

Corrosion resistant materials are applicable for certain critical components, for example stainless steel for bolting and other fastening devices, and GRP for grating. (See also Sec.7.)

4.3 Splash zone

4.3.1

The splash zone is the part of a support structure which is intermittently exposed to seawater due to the action of tide or waves or both. As a consequence of this action, the corrosive environment is severe, maintenance of corrosion protection is not practical and cathodic protection is not effective for parts of this zone. Special requirements for fatigue design of structural components exposed to the splash zone apply, DNVGL-ST-0126 Sec.4.

4.3.2

The upper limit of the splash zone is the high still water level with a recurrence period of 1 year increased by the crest height of a reference wave whose height is equal to the significant wave height with a return period of 1 year. The lower limit of the splash zone is the low still water level with a recurrence period of 1 year reduced by the through depth of a reference wave whose height is equal to the significant wave height with a return period of 1 year.

Guidance note:

The definition of the splash zone in [4.3.2] is in accordance with the definition given in IEC 61400-3 and GL 2012.

The crest height and the trough depth of the reference wave used in the definition of the splash zone are location-specific and depend on the applied wave theory.

The definition of the splash zone in [4.3.2] deviates from the definition used in EN 12495.

The definition of the splash zone also deviates from the definition used in other DNV GL offshore codes, such as DNV-OS-C101.

For the calculation of the internal splash zone the reference waves heights may omitted.

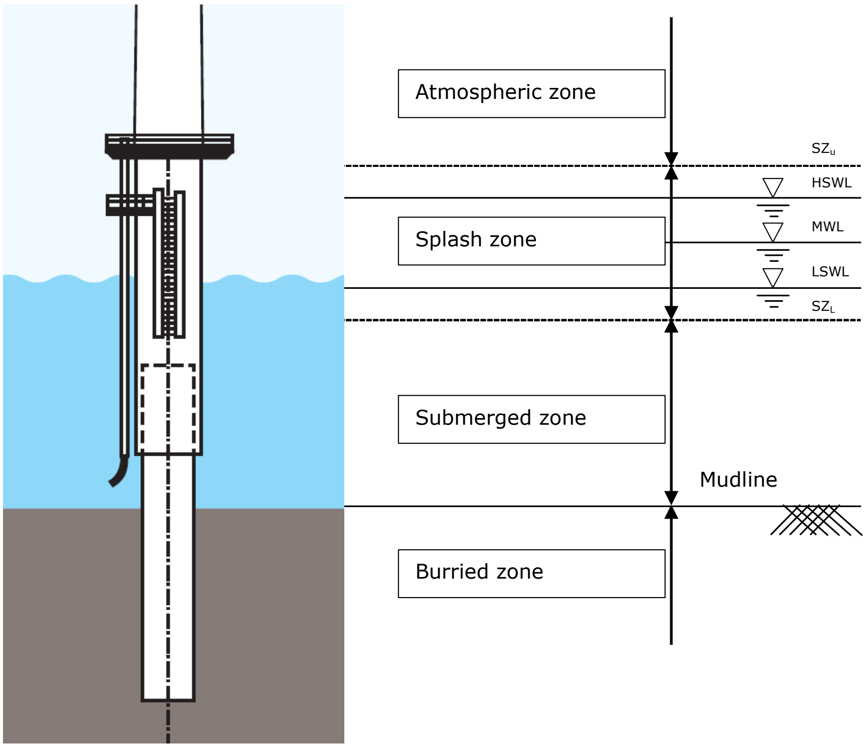
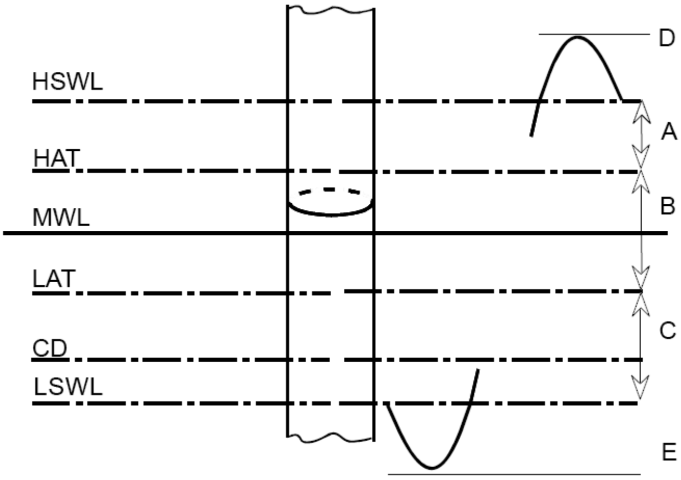


Figure 4-1 Schematic representation of levels and zones in sea water environment



HSWL highest still water level
HAT highest astronomical tide
MWL mean water level
LAT lowest astronomical tide
CD chart datum (often equal to LAT)
LSWL lowest still water level
A positive storm surge
B tidal range
C negative storm surge
D maximum crest elevation
E minimum trough elevation

Figure 4-2 Schematic representation of levels acc. to IEC 61400-3

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4.3.3

External and internal surfaces of steel structures in the splash zone shall be protected by a corrosion control system. The corrosion control system shall be suitable for resisting the aggressive environment in the splash zone which in certain areas may include drifting ice. Use of coating is mandatory for external surfaces of primary structures. Coating systems to be applied in the splash zone shall be based on manufacturer specific materials that have been qualified for the actual coating system by proven experience or relevant testing, (e.g. according to NORSOK M-501, EN ISO 12944). Maintenance of coating systems in the splash zone is not practical and coating of primary structures shall therefore be combined with a corrosion allowance.

For internal surfaces of primary structures, use of coating is optional. The necessary corrosion allowance for internal surfaces shall be calculated according to [4.5.2], assuming $T_C = 0$ when no coating is used.

For parts of the splash zone located below MWL, cathodic protection may be assumed for design purposes to be fully protective and no corrosion allowance is required. Coatings for corrosion control in the splash zone shall as a minimum extend to MWL–1.0 m, taking into account the uncertainties in controlling this level during installation.

Guidance note:
It is considered best practice to apply coating to the entire vertical extension of the splash zone, down to S_{ZL} as a minimum.

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4.3.4

For coating systems based on epoxy and meeting the requirements for coating materials and quality control of surface preparation and coating application in NORSOK M-501 Coating System No. 7A (min. DFT 600 μm) with a useful life of up to 15 years may be assumed in the splash zone. For an equivalent system based on glass-flake reinforced epoxy or polyester (min. DFT 700 μm), the useful life may be assumed to be up to 20 years in the splash zone. Pre-qualification of these coating systems in accordance with a recognized standard (i.e. NORSOK M-501, ISO 12944, ISO 20340) is mandatory in order to design for the proposed design useful life T_c.

Guidance note:
For pre-qualification of the coating acc. to NOSROK M-501 and ISO 20340 the use of primers other than Zn is mainly applicable to repair and maintenance. Please consider ISO 20340, Table 3 — Minimum requirements for protective paint systems and their initial performance, clause c.

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4.3.5

In cases where a coating system is applied to surfaces where no or very limited wear and tear and UV exposure is expected, the useful coating life relied on in the design may be extended compared to the design lifetime of the coating (see [4.5.2]). This may be the case for e.g. monopile internals. However it must be evaluated in each case if such extended coating useful lifetime can be relied on.

4.3.6

For secondary structural parts in the splash zone, the needs for corrosion allowance may be assessed on an individual basis. The needs for corrosion allowance for such parts may depend on risk to human life, economical risk, possibility for inspection, maintenance and repair, and possibility for replacement. Provisions for replacement of corroded components may be considered as an alternative to a corrosion control designed for the service life of the support structure.

4.3.7

For boat landings and access ladders, coating shall be applied in order to minimize nuisance, caused by corrosion, for service personnel. Combination with a corrosion allowance is recommended. As an alternative, corrosion resistant alloys may be considered for certain applications.

4.3.8

Bolts and other critical components in the splash zone for which corrosion allowance is not adequate shall be manufactured from corrosion resistant materials, see Sec.7. Special attention shall be paid to deviating pre-tension behaviour of bolts made of these materials compared to C-steel bolts e.g. in terms of E-modulus and skin friction.

4.3.9

The potential susceptibility of HISC to materials exposed to CP shall be considered in design. Guidance on limitations are given in [5.5] in DNV-RP-B401. For fasteners for structural purposes the hardness and strength class in the atmospheric zone shall not exceed ISO 898 class 10.9. For splash zone and submerged zone, the fasteners shall not exceed ISO 898 hardness and strength class 9.8.

4.3.10

It is mandatory that external surfaces in the splash zone below MWL shall have cathodic protection. See also the guidance note to [4.3.3].

4.4 Submerged zone

4.4.1

The submerged zone consists of the region below the lower limit of the splash zone, including the scour zone and the zone of permanently buried structural parts.

4.4.2

It is mandatory that external surfaces of the submerged zone shall have cathodic protection. Use of coating is optional and is then primarily intended to reduce the required CP capacity. Use of coating may also be advised to reduce the danger of microbiologically influenced corrosion (MIC) in absence of CP. Manufacturer specific materials to be used for a coating system shall have documented compatibility with CP. The design of CP shall take into account possible scouring causing free exposure to seawater of surfaces initially buried in sediments. The design of CP shall also take into account current drain to all external surfaces to be buried in sediments. Steel surfaces buried in deep sediments need no corrosion protection, but will still drain current from a CP system due to the electrochemical reduction of water to hydrogen molecules on such surfaces. Internal surfaces of skirts and piles are not required to be included in current drain calculations for the external CP system.

4.4.3

In the uppermost buried zone anaerobic bacteria may cause corrosion which will be prevented by functional CP.

Guidance note:

Coating of the seawater exposed surfaces and the first 1-2 m to be buried in sediments is recommended as it reduces the required CP capacity and makes the structural system more robust and tolerant to potential deviation between environmental conditions designed for, and actual environmental conditions on site, e.g. higher tidal velocities, appearance of sources leading to MIC, collisions or increased duration of installation.

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4.4.4

Cathodic protection systems can prevent MIC to cause relevant problems. The use of coatings with high resistance in the presence of bacteria can provide additional protection if site conditions indicate so.

Guidance note:

MIC is a site specific problem depending on the environmental conditions and is hard to predict or even detect.

MIC could be detected using coupons as test samples in the suspected areas to monitor the corrosion processes and examining these during the inspection program. Changes in the pH value of the internal water column can also indicate relevant bacteria growth. Objective evidence on the impact of the corrosion processes and the integrity of the structure will only be attained by local inspection and wall thickness measurements by Remotely Operated Vehicle (ROV) or diver.

In the uppermost buried zone anaerobic bacteria may cause corrosion which will be prevented by functional CP.

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4.4.5

Internal surfaces of the submerged zone shall be protected by either CP or corrosion allowance, with or without coating in combination. When CP is to be used it shall take into account current drain to any buried internal surfaces, such as internal surfaces of skirts, piles and J-tubes. Any corrosion allowance for primary structural parts with replenishment of seawater, or of air above the seawater surface, shall be determined based on a corrosion rate of minimum 0.10 mm/yr, unless practical experience or other considerations indicates otherwise. In the upper sediment zone, bacteria may cause a mean corrosion rate in excess of 0.10 mm/yr, and the application of a coating should be considered for this zone. With coating of seawater or sediment exposed internal surfaces, CP is applicable as a backup for coating damage. In the internal splash zone, coating to be provided in combination with corrosion allowance may be accounted for as described in [4.5.2]. The requirement for a corrosion allowance on internal surfaces when no CP is used does not apply for permanently buried structural parts located deeper than 1 m below the seabed.

Guidance note 1:
Corrosion rates lower than 0.10 mm/yr may, in principle, apply in the atmospheric seawater-exposed zones of closed compartments compared to the corresponding zones of open compartments. However, experience shows that, in practice, it is difficult to obtain compartments that will be completely sealed and airtight. Some compartments such as the interiors of monopiles are periodically accessed for inspection and repair and can therefore not be considered completely sealed. Also, large differences in tide may result in variations of the internal water level. In addition, even in virtual absence of oxygen in the seawater, corrosion induced by anaerobic bacteria can occur. It is recommended that these issues be taken into consideration when evaluating options for corrosion control for internal compartments. Coating of internal surfaces in the submerged zone should be considered if the compartments are not welded airtight.

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Guidance note 2:
If CP is used for internal protection inside the monopoles, the replenishment rate of seawater should be considered. In case the replenishment rate is low, zinc anodes should be used since acidification of the internal seawater will take place with aluminium anodes. Possibly reduced pH level in the internal areas can prevent sacrificial CP systems from working properly. The current output of galvanic anodes can be significantly reduced at low pH levels. ICCP systems are flexible and controllable in protective current output and can be designed to supply optimum protection levels at low pH levels.

In case of galvanic anode strings are used the resistance within the string and a possible corrosion of this suspension system above the water line should be considered with special care. Polymeric wire ropes are recommended for the suspension.

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Guidance note 3:
Inside flooded jacket brace members below S_{ZL} and without CP or coating, corrosion allowance should be determined based on a corrosion rate of minimum 0.10 mm/yr. In such cases the fatigue design inside the member may be based on the “in seawater” SN-curve (instead of the “free corrosion” variety) due to expected limited exchange of water. Flooded members in the splash zone are not recommended.

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4.5 Corrosion allowance

4.5.1

The extension of the corrosion zones defined in [4.2] - [4.4] and any corrosion allowances to apply in these zones for a specific project shall be specified in a dedicated section of a relevant project document, preferably the design basis. The specification of the corrosion zones shall take into account all uncertainties, (e.g. the final seabed level) likely to be identified at the time of the installation. The specification of corrosion allowance shall take into account the criticality of the structural part in question.

4.5.2

For surfaces of primary structural parts exposed in the splash zone and for internal surfaces of the submerged zone, which are without CP, the corrosion allowance (CA) for surfaces with and without coating shall be calculated as

$$CA = V_{corr} * (T_D - T_C)$$

where V_{corr} is the expected maximum corrosion rate, T_C is the design useful life of the coating and T_D is the design life of the structure. For V_{corr}, see also Table 4-1 below. To properly reflect the actual exposure time, T_D shall include the time between the installation of the structure and the installation of the wind turbine, typically 1 to 2 years, as well as the design life of the wind turbine. To use a design useful life of the coating,

T_C, the coating systems shall be based on manufacturer specific materials that have been qualified for the actual coating system by proven experience or relevant testing, (e.g. according to NORSOK M-501, EN ISO 12944) for this lifetime.

Guidance note:
Corrosion allowance applied for primary structural parts will affect all fatigue calculations to be performed, because the corrosion rate used to specify the corrosion allowance must comply with the assumed corrosion conditions which govern the S-N curve to be used for the fatigue calculations. In particular, this implies that if metal loss and roughening of the steel surface is expected, free corrosion conditions must in general be assumed, and the "free corrosion" S-N curve is then required. For further details, see DNVGL-ST-0126 Sec.4.

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Table 4-1 Minimum values for design corrosion rate (V_{corr}) on primary structural parts in splash zone

Region	V_{corr} *External Surface*	V_{corr} *Internal Surface*
Temperate climate (annual mean surface temperature of seawater ≤ 12ºC)	0.30 mm/yr	0.10 mm/yr
Subtropicial and tropical climate	0.40 mm/yr	0.20 mm/yr

4.5.3

For secondary structural parts, the needs for corrosion allowance may be assessed on an individual basis, e.g. considering a possible exchange of components.

SECTION 5 CATHODIC PROTECTION

5.1 General

Cathodic protection of offshore structures by galvanic anodes (GACP) is well established and is generally preferred for such structures. Use of impressed current cathodic protection (ICCP) for offshore structures may offer certain advantages but there is no generally acknowledged design standard available giving detailed requirements and advice as for galvanic anode systems. Even with adequate design, ICCP systems are more vulnerable to environmental damage and third-party damage than GACP systems, in particular cables to anodes and reference electrodes are vulnerable. Requirements for documentation of GACP or ICCP design are given in [5.4.2] or [5.5.7].

Guidance note 1:
Use of ICCP in lieu of GACP should be evaluated in a conceptual CP design report to be duly assessed by the owner prior to the implementation of ICCP for external corrosion control.

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Guidance note 2:
The execution and verification of CP design, installation of CP, monitoring and maintenance of CP systems should be performed by personnel with adequate competence. Certification schemes according to e.g. EN 15257 and NACE are adequate for documentation of such competence.

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Use of GACP or ICCP and the applicable design standard and applied rules for this use shall be specified in the project design basis.

For the issues of manufacturing, testing, inspection and installation of anodes DNV-RP-B401 or NACE RP 0387 applies.

5.2 Galvanic anode cathodic protection

5.2.1

DNV-RP-B401 gives requirements and guidelines for cathodic protection design, anode manufacturing and installation of galvanic anodes. Alternative standards using the CP calculation procedure of DNV-RP-B401 may be used. However, the documentation of the design shall fully comply with the requirements in [5.5.3], which contains amendments to the requirements given in DNV-RP-B401 [7.13]. In case DNV-RP-B401 has been specified for a GACP system, all design parameters affecting the CP current demand and the performance of anodes specified in DNV-RP-B401 shall apply, unless otherwise specified or accepted by the owner in writing.

5.2.2

When DNV-RP-B401 is specified for CP design for structures located in waters with high seawater currents, such as in shallow waters with large differences between HAT and LAT, the initial GACP design current densities for all initially bare steel surfaces should be considered increased in order to account for the effect of high seawater currents. Initial GACP design current densities are preferably to be specified in the design basis.

Guidance note:
The terminology for CP-related terms used in this section complies with that used in DNV-RP-B401.

In case reference is made to DNV-RP-B401 for CP design and no project-specific initial GACP design current densities are specified in the design basis, the initial design current densities in Table 10-1 in DNV-RP-B401 are recommended to be increased by 50% for all initially bare steel surfaces in order to account for the effect of high seawater currents. Great variety has been seen in various projects for this value. Site specific considerations are advised.
The mean and final GACP design current densities recommended in DNV-RP-B401 may be reduced to reflect provisions made for retrofitting of anodes as well as other factors reducing the need for inherent conservatism in the CP design.

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5.2.3

Cathodic protection by galvanic anodes shall utilise Al or Zn based materials with a composition in compliance with the applicable CP design standard or a specification issued or approved by the owner.

Unless otherwise specified or accepted by the owner, the CP system shall have a design life which as a minimum shall be equal to the design life of the structure, including the period from installation to start of operation as well as the planned duration of operation. Anodes to be used on a structure shall preferably be of identical or similar size (externally or internally anodes respectively). Reference is made to DNV-RP-B401 [7.8.6].

Guidance note:
The ratio between design current output and net anode mass for anodes of different type or size should not differ by more than 50% unless early consumption of certain anodes is intentional.

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5.2.4

All anodes shall be located minimum 1.0 m below LAT and minimum 1.0 m above the seabed with due consideration of possible variation in the seabed level owing to migrating sand dunes. For calculation of initial current demand in areas with large tidal zones, the surface area up to HAT shall be considered for CP design.

5.2.5

The design of anode supports and their fastening to the structures shall take into account the forces applied during installation and operation of the structure. For structural design, reference is made to DNVGL-ST-0126 Sec.4. A reference to structural design calculations for anode fastening shall be included in the CP design report. In case replacement of anodes is foreseen, provisions for subsea fastening of new anodes shall be described in the design documentation.

5.2.6

The anodes shall be distributed to avoid interference reducing their current output in accordance with the applicable CP design standard. In case there are reasons to assume a significant interaction between anodes, an analysis by a computer model should be carried out to determine a reduction factor for the anode current output, see [5.5.3]. The reduction factor is to be applied as a factor on anode current output as calculated by anode resistance formulas for anodes with such interaction.

Guidance note:
For largely uncoated monopiles in waters with depths larger than approximately 20 to 25 m, it may be difficult to achieve sufficient external cathodic protection from anodes located solely at the transition piece between tower and pile due to a large number of anodes required and a limited surface area available for distribution of anodes. Complete or partial coating of the external seawater-exposed pile surface may then be applied to reduce the current demand for the initial exposure period. even "Category I" coating according to DNV-RP-B401 can be considered.

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5.2.7

For structures for which a GACP design is applied, a GACP system shall be in place and operating as soon as possible after the installation of the structure. After maximum 365 days, a CP survey shall be performed to confirm that the structures for which the GACP design was applied are adequately protected. This survey shall be documented in detail. In wind farms with many series manufactured structures with identical CP systems, it suffices to carry out the CP survey on a few representative structures only.

Guidance note:
It is strongly recommended that the structure be protected by the GACP system as soon as possible after installation of the structure, preferably instantaneously, if no other corrosion protection such as coating is applied to the fatigue critical parts of the structure (see also guidance note to paragraph [4.5.2]). For the CP survey of a few representative structures, it is recommended as a minimum to survey one structure for every 20 installed structures. However, the actual number of structures to be surveyed should reflect what in each case is deemed necessary in order to obtain the required representativeness of the survey. All potential sources for variation from structure to structure should be considered, for instance the duration of the installation period which in large wind farms may span more than one year.

For the CP survey, it is sufficient to establish an adequate global protection level extending from the uppermost part of the submerged zone to the seabed. Positioning of a reference electrode by means of a diver or an ROV is then not strictly necessary, provided the weather and sea current conditions allow the positioning of the reference electrode within a few metres of the steel surface. On the other hand, if marginal protection is indicated (protection potentials less negative than −0.90 V rel Ag/AgCl/seawater), the survey should be extended to include close potential recordings, less than 0.5 m from the steel surface, and focus on locations as far as possible from the anodes, including locations at the seabed. For steady-state conditions, which may require more than 180 days for largely uncoated structures, a protection potential lower than −0.90 V (corrected for any IR drop) is an indication of adequate functioning of a GACP system. DNV GL is not aware of any documentation that a potential (IR free) in the range −0.80 to −0.90 V has ever led to any corrosion damage (including corrosion damage by bacteria), but a potential in this range will cause enhanced current output and increased consumption rate of anodes. The enhanced current output and consumption of anodes may not match the mean current density which is used for design and which is lowest in the potential range −0.90 to −1.00 V (as aimed for in DNV-RP-B401).

Recordings of anode potential in the immediate vicinity of the anode surface should also be included in a close potential survey. For CP monitoring of monopiles with anodes located on the transition piece and with the reference electrode connected to the transition piece, corrections should be made for any significant voltage (IR) drop through continuity cables from the transition piece to the pile.

The detailed planning and execution of initial potential survey and the evaluation of the results will not require the involvement of the designer of the GACP system. However, a method statement should be prepared.

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5.3 Location of anodes

5.3.1

Based on the calculated number of anodes required for different zones of the structure, EN 12495 and DNV-RP-B401 and the following aspects shall be considered for the distribution of anodes:

— Anodes shall be uniformly distributed, where reasonable practicable.
— Anodes for the splash zone shall be located on the upper level of immersed zone.
— Anodes shall be located close to complex and critical points such as node areas, but not closer than 600 mm to nodes.
— Anodes protecting conductor pipes shall be uniformly distributed at the different levels in their immediate proximity on the conductor guide frames.
— On legs, the anodes shall face the centre of the structure.
— On diagonals, the anodes shall be alternately placed on the upper and lower surface if more than one anode is required.
— On horizontal bracings at different levels, the anodes shall be installed alternately facing up and down with the exception of the uppermost level where they shall be mounted facing downwards.
— The location of anodes shall take into account restrictions imposed by fabrication, installation and operation. For large and/or complicated objects, early liaison with other engineering disciplines, as well as with fabrication and installation contractors is advised.

Additional aspects for monopile structures:

— Anode clustering shall be minimized interference effect of anode clustering must be considered in the design.
— The adequacy of the current distribution can be improved using a greater number of anodes, which have a lower individual electrical current output.

5.4 Anodes' inserts and attachments design

5.4.1

The method of attachment of the anodes to the structure shall be in accordance with EN 12495 and DNV-RP-B401.

5.4.2

The GACP design shall be documented in a dedicated report containing the following items:

— Design premises (with reference to the project design basis and other relevant project specifications, codes and standards), specified or approved by the owner, including design life and all modifications of CP design parameters specified or recommended in the applicable CP design standard.
— Calculations of surface areas and current demands (initial/final and mean), including current drain to sediment buried surfaces.
— Calculations of anode resistance and current output (initial/final) of the anode(s) to be used

- Assessment of all anode interactions for external CP according to [5.2.4] to [5.2.6] and modelling of protection potential distribution for any internal CP
- Anode drawing(s) and drawing(s) showing dimensions and locations of anode cores and any provisions for electrical continuity by other means than welding (if applicable)
- Calculations of required net anode mass and anode current output to meet the calculated current demands, and the required number of anodes to meet both requirements.
- Calculations and assessment of voltage drop across electrical continuity cables (if applicable)
- Drawings showing distribution of anodes and locations of all electrical continuity cables
- Requirements for manufacturing of anodes (e.g. by reference to a standard or a project specification)
- Requirements for installation of anodes (e.g. by reference to a standard and project specific procedures) and assessment of structural integrity.
- Recommendations, requirements and draftmethod statement for the initial potential survey, including reporting requirements.

Calculation spread sheets for CP design may be contained in an appendix to the report; however, the design parameters and the results of all calculations referred to above shall be compiled in the report.

5.5 Impressed current cathodic protection

5.5.1

In addition to adequate CP potential and current distribution, the detailed design of an impressed current CP (ICCP) system shall focus on the long term mechanical integrity of the equipment, including impressed current anodes, reference electrodes, cables and connectors, with due consideration of environmental parameters, primarily wave forces and sea currents.

Guidance note:
The detailed design of an ICCP system should be preceded by a conceptual design activity for the owner to conclude that an ICCP system is preferred for the specific project and is to be included in the project design basis. This can be done by taking costs for installation and operation into account, and by including other relevant considerations, in particular aspects of operational reliability. Considerations for the selection of GACP or ICCP may include effects of weight and drag forces of GACP systems, availability of a continuous current source for ICCP, mechanical integrity of anodes, reference electrodes and cables of ICCP systems, and environmental effects (release of Zn from galvanic anodes and of active chlorine from impressed current anodes). Guidance for the design of ICCP systems for offshore structures is given in NACE SP0176 and EN 12495.

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5.5.2

Unless otherwise specified or agreed by owner, ICCP anodes and reference electrodes shall be designed to be replaceable if damaged or degraded by environmental effects or by other effects. In any case, long-term reliability of anodes, reference electrodes, subsea electrical couplings and cables shall be documented by the designer of the ICCP system making reference to a standard or documented performance of manufacturer specific equipment. The ICCP design shall duly consider needs for contingency due to damage or malfunction of individual anodes or reference electrodes. Based on design current demands (initial and final) applicable to GACP systems, a contingency corresponding to a minimum of 150% anode current capacity shall be included. A minimum of two reference electrodes shall be provided to control current output of each rectifier.

5.5.3

The ICCP design shall demonstrate that the capacity of the current source(s) and the anodes are adequate to achieve and maintain cathodic protection of all submerged parts of the structure, including current drain to sediment buried areas. The design shall aim for adequate protection to be effected within 30 days from commissioning of the ICCP system. This shall be achieved without exposing steel surfaces to more negative potentials than −1.10 V rel. Ag/AgCl/seawater which may otherwise lead to damage of any paint coating and possibly also to hydrogen induced damage to the steel structure. Adequate potential distribution shall be confirmed by computer based modelling of cathodic protection and utilising some empirical time-dependent relation between the cathodic current density and the protection potential. The CP modelling shall further demonstrate that the number and location of fixed reference electrodes is adequate to confirm that the structure is protected as required by the design.

Guidance note:

There are no standards defining the time dependent relation between potential and cathodic current density; hence, such relations are chosen at the discretion of the provider of the CP modelling tool. The provider of CP modelling tools should validate the reliability of the tools, e.g. by a potential survey of a real structure that has been subject to such modelling.

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5.5.4

Impressed current anodes should be located as far as practical from any structure member (usually a minimum distance of 1.5 m, but proportional to current magnitude). Dielectric shields are used to avoid overprotection close to ICCP anodes and to facilitate adequate current distribution. In the immediate vicinity of anodes, a prefabricated polymeric sheet is normally applied whilst a relatively thick layer of a special paint coating is applied as an outer shield, extending to the range of overprotection, i.e. protection potentials more negative than −1.15 V rel. Ag/AgCl/seawater according to the computer CP modelling. The selection of the particular coating shall then be justified by long term testing of resistance to cathodic disbondment at the most negative potential that (according to the CP modelling) may apply at the edge of the innermost shield of polymeric sheeting.

Guidance note:

Whilst the innermost dielectric shield (homogeneous polymeric sheet or polymer-lined steel sheet) is supplied by ICCP anode manufacturer, the outer shield (special paint coating) is normally applied by the fabrication contractor for the support structure. Quality control of surface preparation and coating application is then essential and should preferably be supervised by the manufacturer of the coating material or a third-party specialist.

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5.5.5

ICCP systems shall be designed for remote control of anode current output based on recordings from fixed reference electrodes. In addition to potential data, rectifier current output and voltage shall be recorded remotely, e.g. with a frequency of one or a few hours, and stored for easy retrieval and display. The rectified current output may be set to a fixed value based on an evaluation of recordings from fixed reference electrodes (minimum two per rectifier). As an option, the rectifier current output may be controlled automatically based on recordings from one or more reference electrodes. Minimum two reference electrodes per rectifier shall be provided for both options and with alarm functions for minimum/maximum potentials recorded by the reference electrodes.

5.5.6

ICCP systems shall be commissioned according to a project specific procedure. It is strongly recommended that the structure be protected by the ICCP system as soon as possible after installation of the structure, if no other corrosion protection such as coating is applied. After minimum 30 days and maximum 365 days, a detailed CP survey shall be performed to confirm that the structures for which the ICCP design has been applied are adequately protected. In wind farms with many series manufactured structures with identical CP systems, it suffices to carry out the CP survey on a few representative structures only, but rectifier parameters shall be checked for all structures and a potential survey shall be carried out if any inconsistency is established.

For the CP survey of a few representative structures, it is recommended as a minimum to survey one structure for every 20 installed structures. However, the actual number of structures to be surveyed should reflect what in each case is deemed necessary in order to obtain the required representativeness of the survey. In this respect all potential sources for variation from structure to structure shall be considered. One issue to consider in this respect is the relative positioning and distances between the structures in a wind farm together with differences in environmental conditions. Another issue is the duration of the installation period which in large wind farms may span more than one year.

For the CP survey, the reference electrode will need to be positioned by an ROV at locations close to and remote from the ICCP anodes. Use of divers is restricted by safety hazards when approaching ICCP anodes.Mitigation measures shall be included in the ICCP design (e.g. use of protection caps or sleeves) on the anodes for reducing these risks. For a large number of similar units in the same area, it is only necessary to carry out a survey of a number of structures which are considered to be representative.

5.5.7

The designer of the ICCP system shall be involved in the planning and execution of the initial potential survey and in the evaluation of the results.

Guidance note:
The involvement of the ICCP designer in the execution of the initial potential survey should be specified in the agreed scope of work for the design of the ICCP.

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5.5.8

The ICCP design shall be documented in a dedicated report containing the following items:

— Design premises (with reference to the project design basis and other relevant project specifications, codes and standards), specified or approved by the owner, including design life and all modifications of CP design parameters specified or recommended in the applicable CP design standard.
— Calculations of surface areas and current demands (initial/final and mean), including current drain to sediment buried surfaces and including needs of contingency of current output capacity (due to e.g. damage/malfunction of one or more anodes).
— Calculations of anode current output based on rectifier voltage, voltage drops in cables and anode resistance.
— Results from CP modelling with coloured graphs showing the development of the protection potential (e.g. after 10, 100 and 1000 hours) with emphasis on potentials at the edges of the inner and outer dielectric shields, at reference electrodes and at remote locations from the anodes).
— Justification of design life for anodes, fixed reference electrodes, cables, electrical connectors and other items with restricted access for maintenance and repairs.
— Specification and drawings for rectifier unit or other current sources.
— Specifications and detailed drawings of anodes, dielectric shields, fixed reference electrodes and outline of electric circuiting.
— Material Data Sheets for cables, electrical connectors, dielectric shield materials, fastening devices and other equipment.
— Drawings showing distribution of anodes, reference electrodes and tracing of cables, including cable conduits.
— Requirements for installation of anodes, reference electrodes and cables by welding to primary and secondary structural components (e.g. by reference to a standard and project specific procedures).
— Description of system for monitoring of protection potential and control of anode current output and logging of potential recordings and rectifier current and voltage.
— Procedures for commissioning and recommendations (method statement) for the initial potential survey.
— General description of operational procedures, including replacement of anodes and reference electrodes, logging of data and periodic inspection and maintenance of current sources.

SECTION 6 COATING

6.1 General

6.1.1

Requirements for corrosion protective coatings shall be specified in a dedicated document or in a section of some other relevant design document. At least for primary structural parts, generic types of coating systems and requirements to the qualification of manufacturer specific materials (as defined in the data sheets by the coating supplier of the intended protections systems) to be used for such systems shall be specified in the project design basis. Pre-qualification of these coating systems in accordance with a recognized standard (i.e. NORSOK M-501, ISO 12944, ISO 20340) with the designated use and environment is mandatory.

Guidance note:

Documentation of requirements for type of corrosion protective coating systems and for qualification of manufacturer specific coating materials is required in order to allow for subsequent verification of the overall corrosion control system.

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6.1.2

For structural parts in each corrosion zone, the selection of coating systems as defined in, for example, NORSOK M-501 or ISO 12944 shall be specified, as well as requirements for the qualification of manufacturer specific coating materials and of personnel to carry out coating work. The specification shall further contain general requirements for the quality control of coating work and for the coating applicator's documentation to be provided prior to, during and after completion of the work.

6.1.3

The most suitable form of coating depends on the type of structure and its environment. In the selection of a coating, the aim should be to achieve overall economy in the combined cost of the protected structure and of the initial and operating costs of the protection schemes. Due regard should be paid to the design life of the structure and the economics of repairing the coating should this become necessary (and be realistic). More information is given in the respective Standards, see NACE SP0108, ISO 12944, ISO 20340 and NORSOK M-501.

6.1.4

Organic coatings are semi-permeable membranes. They act as a barrier to water and oxygen and delay corrosion if applied correctly, but water will be transported through them. The bulk of the corrosion on a painted surface does not occur beneath the intact coating but at the base of holidays bare patches and pin holes. If cathodic protection is applied to a painted surface, the coating acts as a substantial resistive barrier to current flow and where the current does flow, it is to the bare patches and pin holes. In terms of cathodic protection the presence of a coating improves current distribution and reduces current demand and interference effects.

6.1.5

Organic coatings promote the formation of a dense calcareous deposit at bare patches between coating because the initial current density may be relatively high at such locations. However, the solubility of potential film-forming calcareous deposits normally increases with decreasing temperature such that colder waters may prevent the formation of such protective calcareous deposits or can require higher initial current density in order to achieve polarization.

6.1.6

The application of coatings are generally not suitable for parts of submerged structures requiring frequent inspection for fatigue cracks, e.g. critical welded nodes of jacket structures.

6.1.7

For components of materials sensitive to HISC by CP, an organic coating should always be considered as a protective measure againstadsorption of hydrogen (ions). This will not be sufficient as a durable protection in many cases.

6.1.8

For the topics of application, testing and repair of paint reference is made to NACE SP0108, ISO 12944, ISO 20340 and NORSOK M-501.

6.1.9

A coating procedure specification that includes inspection and test plan shall be prepared for the coating work and the coating procedures shall be qualified under realistic conditions likely to be present during coating application.

6.2 Surface preparation

6.2.1

Requirements for surface preparation following the guidance given in ISO 8501-3 shall be clearly defined for all parts of the structure to be coated. Every item in table 1 of ISO 8501-3 shall be addressed.

Guidance note:

The minimum requirements stated in Table 6-1 should be met for the surface preperation of offshore steel structure foundations for wind turbines, justified deviations should be agreed upon with DNV GL:

Table 6-1 Minimum requirements for preparations of surfaces of offshore steel structure foundations acc. to ISO 8501-3 Table 1

Type of imperfection	*Preparation grade*
1.1 Welding spatter	P3
1.2 Weld ripple/profile	P2
1.3 Welding slag	P2
1.4 Undercut	P3
1.5 Weld porosity	P3
1.6 End craters	P3
2.1 Rolled edges	P3
2.2 Edges made by punching, shearing, sawing or drilling	P3
2.3 Thermally cut edges	P3
3.1 Pits and craters	P3
3.2 Shelling	P2
3.3 Roll overs/roll laminations/cut laminations	P2
3.4 Rolled-in extraneous matter	P2
3.5 Grooves and gouges formed by mechanical action	P2
3.6 Indentations and roll marks	P2

Surfaces grit blasted to Sa 2½ according to ISO 8501-1, roughness 50-85 µm according to ISO 8503, conductivity measured according to ISO 8502-9 corresponding to NaCl of 20 mg/m² (or higher, if owner and coating manufacturer accept), dust rating 2 according to ISO 8502-3.

The coating should be applied with steel surface temperature of 3°C or more above dew point and a relative humidity < 85% in order to prevent condensation of moisture on the surface.

The coating supplies data sheets should be followed.

The application of the coating system should be supervised by qualified personal, e.g. FROSIO-, NACE-, DIN-certified paint inspectors (or equivalent).

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6.2.2

Coating systems and manufacturer specific coating materials for the splash zone shall be selected with due consideration of the conditions that may apply for the specific project, including any exposure to floating ice and procedures for periodic removal of marine growth.

6.2.3

Hot dip zinc coating is applicable to certain secondary structural parts in the atmospheric zone and in the splash zone. With a specified minimum thickness of 50 μm and compliance with ISO 1461, the useful life of zinc coating exposed externally may be assumed to be minimum 5 years in the splash zone and minimum 10 years in the external atmospheric zone. Higher thicknesses extend this expected lifetime. Further guidance is provided in EN ISO 14713-1:2009, Table 2. Any polymeric coatings to be used for fasteners exposed externally in the atmospheric and splash zones should have an inner layer of electrolytic zinc and defined requirements to surface preparation prior to coating.

6.3 Coating breakdown factors

Coating breakdown factor is the anticipated reduction in cathodic current density due to the application of an electrically insulating coating when compared to that of bare steel. If the Coating breakdown factor is zero, the coating is 100% electrically insulating, thus decreasing the cathodic current density to zero. Coating breakdown factor of 1 means that the coating has no current reducing properties.

Guidance note:

The coating breakdown factor should not be confused with coating degradation as apparent by visual examination. A coating showing extensive blistering may still retain good electrically insulating properties. Conversely, an apparently perfect coated surface may allow a significant passage of current.

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6.3.1

An initial coating breakdown factor (fci) related mainly to mechanical damage occurring during the installation of the structure should be considered and a coating deterioration rate for subsequent stages shall be evaluated in order to take into account the coating ageing and possible small mechanical damage occurring to the coating during the structure life.

6.3.2

Due to possible interactions between the cathodic protection and the coating, all coatings to be used in combination with cathodic protection shall be tested in advance so as to establish that they have adequate resistance to cathodic disbondment. Alkali is generated on the cathodically protected surface and this may result in cathodic disbondment of the coating likely to develop into coating defects. The conventional coatings of the oleo-resinous or alkyd types are attacked by alkali, i.e. they are subject to saponification and are not recommended for use in association with cathodic protection. The use of polyvinyl butyral shop primers has also caused loss of adhesion when combined with cathodic protection.

6.3.3

Owner should preferably specify constants a and b for calculation of coating breakdown factors based on his own practical experience of specific coating systems in a particular environment. When Owner has not specified any such data, the default values in Appendix of DNV-RP-401 shall be used.

For structures with geometry like jackets and monopiles, the intrinsic conservatism of the coating breakdown factors, as described in DNV-RP-401 is more pronounced allowing for some reduction of the default values recommended in this RP. Any intended reduction shall be agreed upon with DNV GL and the owner.

SECTION 7 CORROSION RESISTANT MATERIALS

All corrosion resistant materials to be used shall be specified by reference to a material standard (e.g. ASTM, EN) defining requirements to chemical composition, mechanical properties and quality control of manufacturing.

Guidance note:
Stainless steels to be used in the atmospheric zone or the splash zone should have a corrosion resistance equivalent or better than that of type AISI 316 (EN 10088, WNr. 1.4401 (X5CrNiMo17-12-2)). Bolts of this material exposed to sea spray but sheltered from direct rainfall have sometimes suffered corrosion attacks and higher alloyed materials, such as type 25Cr duplex, should be considered for critical applications.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---