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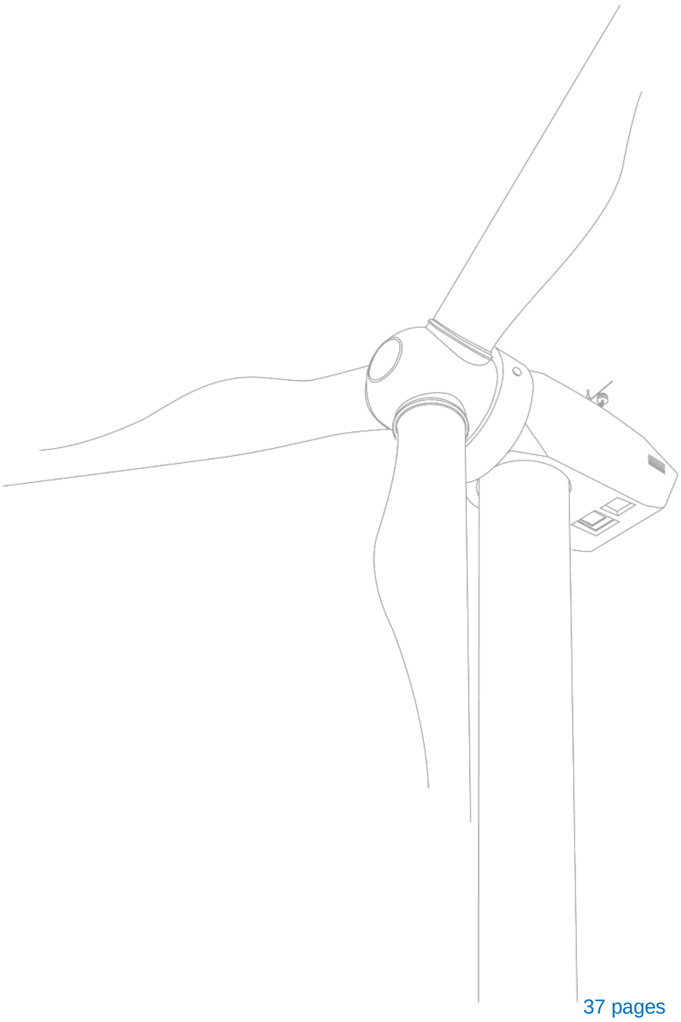
Goldwind V15 Platform

Overall Design Scheme for Lightning Protection and Earth-Termination Subsystem



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FOREWORD

The document is drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The document is under the jurisdiction of Xinjiang Goldwind Science & Technology Co., Ltd. (hereinafter referred to as Goldwind) and applies to Goldwind and its subsidiaries.

The document is prepared by the Electromechanical and DFX Department of R&D Center.

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This is the first edition.

The technology content of this document is identical to GW-26FA.0024 Edition A.

Goldwind V15 Platform

Overall design scheme for lightning protection and earth-termination subsystem

1 Scope

This document specifies the design requirements and overall design scheme for lightning protection and earth-termination subsystem of Goldwind V15 Platform.

This document is applicable to the lightning protection and earth-termination subsystem of Goldwind V15 Platform.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

GB 17467-2010, *High-voltage/low-voltage prefabricated substation*

GB/T 19666-2019, *Flame retardant and fire resistant wires and cables*

GB/T 36490-2018, *Wind turbines – Technical specification of lightning protection system inspection*

GB 50057-2010, *Code for design protection of structures against lightning*

GB/T 50065-2011, *Code for design of AC electrical installations earthing*

GB 50343-2012, *Technical code for protection of building electronic information system against lightning*

IEC 60099-4-2014, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for A.C. systems*

IEC 60364-5-54-2011, *Low-voltage electrical installations – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements and protective conductors*

IEC 61400-24-2019, *Wind energy generation systems – Part 24: Lightning protection*

IEC 61643-12-2020, *Low-voltage surge protective devices – Part 12: Surge protective devices connected to low-voltage power distribution systems – Selection and application principles*

IEC 61643-22-2015, *Low-voltage surge protective devices – Part 22: Surge protective devices connected to telecommunications and signaling networks – Selection and application principles*

IEC 62305-1-2010, *Protection against lightning – Part 1: General principles*

IEC 62305-3-2010, *Protection against lightning – Part 3: Physical damage to structures and life hazard*

IEC 62305-4-2010, *Protection against lightning – Part 4: Electrical and electronic systems within structures*

GW-06CG.0136, *Goldwind MW-class wind turbines - Technical specifications for ordering blade lightning protection system*

GW-00CG.0504, *Goldwind MW-class wind turbine – Technical specifications for ordering online lightning monitoring system*

3 Overall design requirements for lightning protection and earth-termination system

3.1 Integrated lightning protection system

Goldwind V15 Platform employs an integrated lightning protection system which consists of internal and external lightning protection systems. In different lightning protection zones, different protection measures are provided, including lightning interception and conductor system, shielding, equipotential bonding, and surge protection. These measures are designed by fully considering the properties of lightning and have proven simple and effective. See Figure 1 for the composition of the integrated lightning protection system.

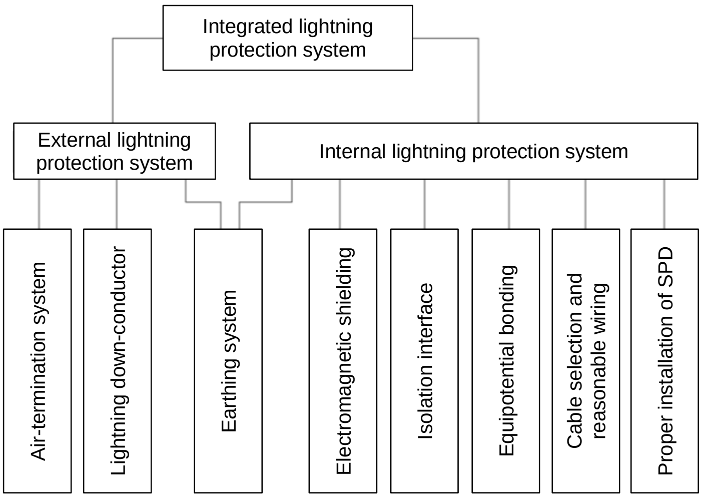


Figure 1 – Integrated lightning protection system

3.2 Lightning protection level of wind turbine

Considering the structural characteristics of the wind turbine, its value, and the potential direct and indirect losses caused by lightning strikes, and in combination with the classification of lightning protection levels for wind turbines abroad, the strictest lightning protection level (LPL) is applied. With reference to Chapter 8 of IEC 61400-24-2019, LPL I is adopted. The lightning current parameters are as shown in Table 1. The maximum values of lightning current parameters for LPL I are used to design lightning protection components (such as cross-section of conductors, thickness of metal sheets, current capability of surge protective devices, and minimum separation distance against dangerous sparking) and to define test parameters simulating the effects of lightning current on such components.

Table 1 – Lightning current parameters of different LPLs

First short positive stroke			LPL			
Current parameters	Symbol	Unit	I	II	III	IV
Peak current	I	kA	200	150	100	
Short stroke charge	Q_{short}	C	100	75	50	
Specific energy	W/R	MJ/Ω	10	5.6	2.5	
Time parameter	T_1/T_2	μs/μs	10/350			
First short negative stroke[a]			LPL			
Current parameters	Symbol	Unit	I	II	III	IV
Peak current	I	kA	100	75	50	
Average steepness	d_i/d_t	kA/μs	100	75	50	
Time parameter	T_1/T_2	μs/μs	1/200			
Subsequent short stroke			LPL			
Current parameters	Symbol	Unit	I	II	III	IV
Peak current	I	kA	50	37.5	25	
Average steepness	d_i/d_t	kA/μs	200	150	100	
Time parameter	T_1/T_2	μs/μs	0.25/100			
Long stroke			LPL			
Current parameters	Symbol	Unit	I	II	III	IV
Long stroke charge	Q_{long}	C	200	150	100	
Time parameter	T_{long}	s	0.5			
Lightning flash			LPL			
Current parameters	Symbol	Unit	I	II	III	IV
Flash charge	Q_{flash}	C	300	225	150	
a The use of this wave shape concerns only calculations and not testing.						

3.3 Lightning protection zones

Lightning protection measures (for example, lightning interception and conductor systems, and shielding protection) are taken to protect the wind turbines as per IEC 61400-24-2019. These measures determine the lightning protection zones (LPZs) of the wind turbines, as shown in Figure 2 The rolling sphere radius used is 20 m.

LPZ 0_A: In this zone, the objects are likely to be struck directly by lightning and conduct all the lightning current. The electromagnetic field is not attenuated. This zone is outside the wind turbine and beyond the protection area calculated by using the rolling sphere method. It covers the blades, part of the outside of nacelle, and most of the outside of tower.

LPZ 0_B: In this zone, the objects are not likely to be struck directly by lightning current larger than that calculated based on the rolling sphere radius. The electromagnetic field is not attenuated. This zone is outside the wind turbine but within the protection area calculated by using the rolling sphere method. It covers the wind measurement system, part of the outside of nacelle (the inside of unshielded nacelle), the part below 80% of the height of the tower, and part of the tower base.

LPZ 1: In this zone, the objects are not likely to be struck directly by lightning and the current flowing through conductors is less than that in LPZ 0_B. The electromagnetic field can be attenuated depending upon the shielding measures. It covers the inside of shielded nacelle, hub, tower, and electrical cabinets outside the tower.

LPZ 2-n: It refers to the area that can shield lightning electromagnetic impulses to a certain degree inside LPZ 1. It covers the inside of hub, electrical cabinets in the nacelle, and electrical cabinets at the tower base.

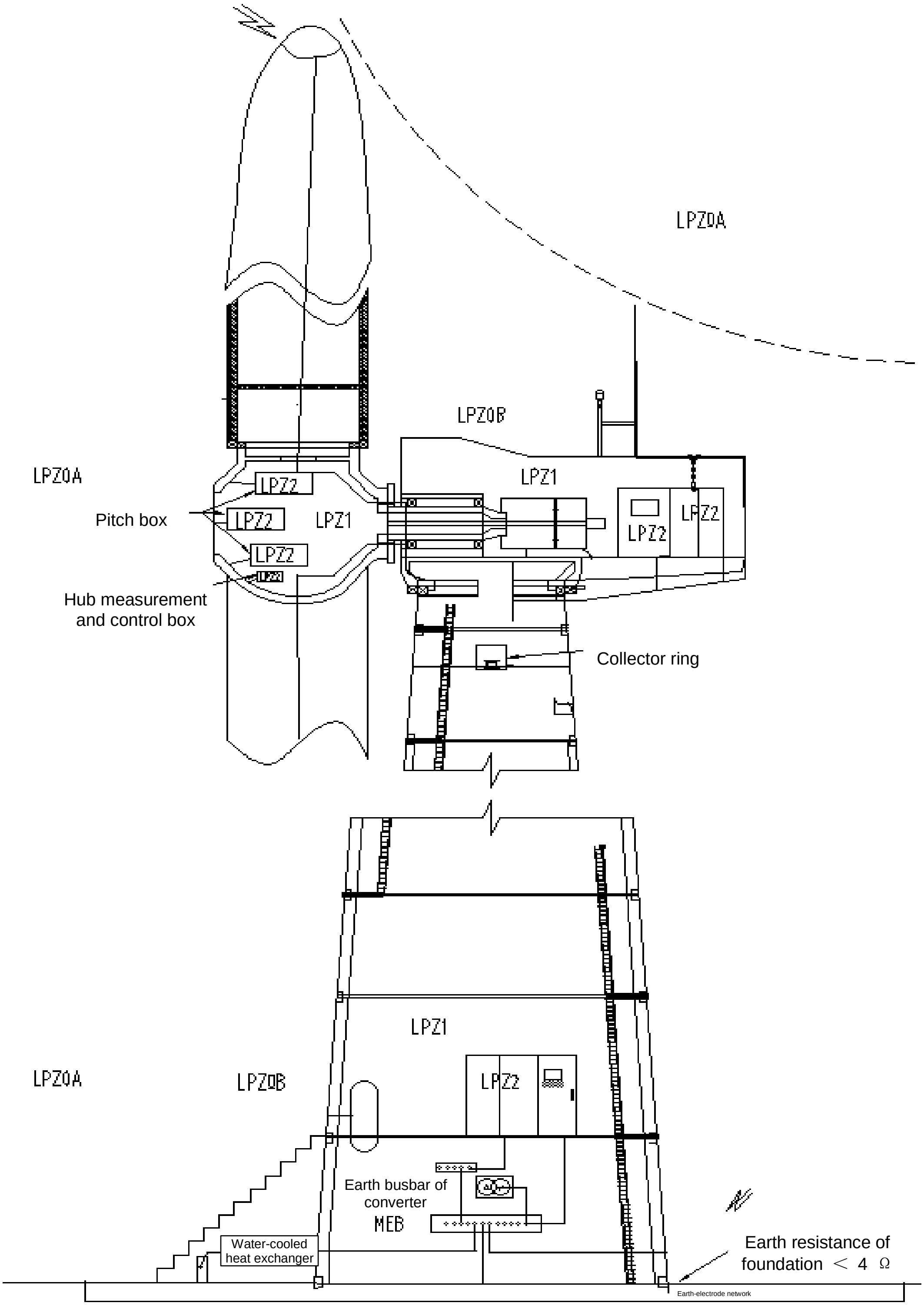


Figure 2 – Lightning protection zones

3.4 Design requirements for lightning protection and equipotential components

The minimum values of parameters of lightning protection components comply with 5.6 of IEC 62305-3-2010, as shown in Table 2.

Table 2 – Material, configuration, and minimum cross-section of air-termination conductors, air-termination rods, and down-conductors

Material[a)]	Configuration	Minimum cross-sectional area mm^2
Copper Tin plated copper	Solid tape Solid round[b)] Stranded[b)] Solid round[c)]	50 50 50 176
Aluminum	Solid tape Solid round Stranded	70 50 50
Aluminum alloy	Solid tape Solid round Stranded Solid round[c)]	50 50 50 176
Copper-coated aluminum alloy	Solid round	50
Hot dip galvanized steel	Solid tape Solid round Stranded Solid round[c)]	50 50 50 176
Copper-coated steel	Solid round Solid tape	50 50
Stainless steel	Solid tape [d)] Solid round[d)] Stranded Solid round[c)]	50 50 70 176

The bonding bar and earth cable shall be copper braid and yellow-green copper cable, and the copper braid shall be sheathed with yellow-green heat shrink tube. Table 3 shows the minimum cross-section of the bonding conductor connecting different equipotential bonding points or connecting the bonding point to the earth-termination system. Table 4 shows the minimum cross-section of the bonding conductor connecting the internal metal equipment to the equipotential bonding point.

Table 3 – Minimum size of conductor connecting different equipotential bonding points or connecting bonding point to earth-termination system

LPS category	Material	Cross-section (mm^2)
I, II, III, and IV	Copper	14
	Aluminum	22
	Steel	50

Table 4 – Minimum size of conductor connecting internal metal equipment to equipotential bonding point

LPS category	Material	Cross-section (mm^2)
I, II, III, and IV	Copper	5
	Aluminum	8
	Steel	16

4 External lightning protection system

4.1 Direct lightning current path

The lightning current path bypasses the bearings or the bearings themselves are capable of withstanding lightning current, as recommended in IEC 61400-24:2019. A bearing lightning protection scheme is designed for Goldwind V15 Platform. The independent down-conductors establish a low-resistance channel at three types of bearings. The lightning current does not pass through the pitch bearing, main bearing, and yaw bearing. The direct lightning current path is as shown in Figure 3.

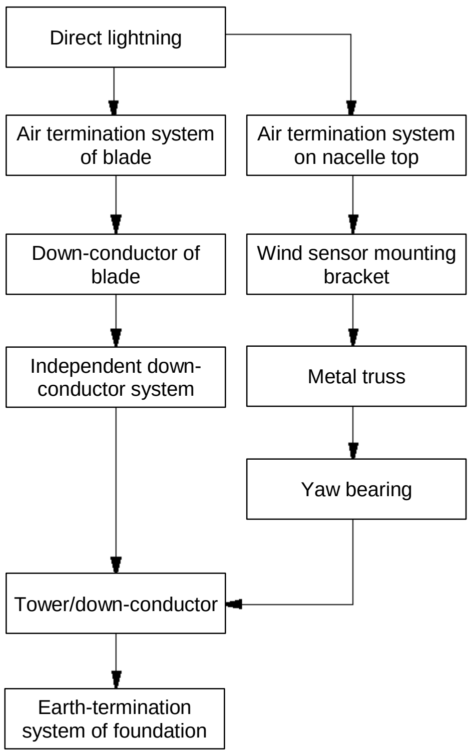


Figure 3 – Lightning current path when using independent down-conductor lightning conductor system

4.2 Lightning protection of blade

4.2.1 Overall design of lightning protection system of blade

The lightning protection system of blade consists of blade tip receptor, blade body receptor, down-conductor inside the blade, and connection accessories. The lightning protection system of blade is designed to withstand the lightning current of LPL I stipulated in IEC 61400-24-2019 and IEC 62305-1-2010, without structural damage to the blade.

4.2.2 Air termination system of blade

The air termination system, including blade tip receptor (or metal blade tip) and blade body receptor, is made of metal or metal alloy with good corrosion resistance and electrical conductivity and complies with the design drawing. Stainless steel, aluminum alloy, copper alloy, and tungsten alloy are recommended. Studs of the blade body receptor are columnar, with thickness not less than 9mm and diameter not less than 18 mm. The air termination system of blade shall be designed and manufactured in such a manner that its mechanical installation and electrical connection are reliable, and the edges are smooth and free of sharp corners. The air termination system shall replaceable, and its surface shall not applied with paint, gel coat or other non-conductive anti-corrosion coatings.

The quantity of the air termination system of blade shall meet the requirements in 8.2.4 of IEC 61400-24-2019. At least two sets of air termination systems shall be arranged at 3 m from the blade tip. Table 5 shows the arrangement rules.

Table 5 – Requirements on positions of air termination system of blade

Position	0 m - 0.5 m from blade tip	0.5 m - 3 m from blade tip
Quantity	One set of blade tip receptor or one metal blade tip	One set of blade body receptor

4.2.3 Down-conductor of blade

The minimum values of parameters of cables used as blade down-conductors are determined according to 5.6 of IEC 62305-3-2010. The blade down-conductor is a single-core stranded copper cable with a cross-section not less than 50 mm^2 or single-core stranded aluminum cable with a cross-section not less than 70 mm^2. The down conductor for the same blade shall be made of the same material. If aluminum alloy cable and copper cable are used together, copper-aluminum connector shall be used.

The flame retardancy of down-conductors shall comply with Class C defined in GB/T 19666-2019.

The design of the main down-conductor of the blade shall meet one of the following conditions:

a) The main down-conductor of the blade is a MV cable of voltage class of 8.7/15 kV (17.5 kV) or a cable for which other measures are taken to guarantee a voltage class not lower than 8.7/15 kV (17.5 kV).

b) When the main down-conductor is connected by using MV and LV cables, or when reinforced insulation is made for part of the cables, the voltage class of the cable at 10 m in front of blade tip shall be 8.7/15 kV (17.5 kV), and the data about the current conduction test on the cable section parts and the dielectric withstand test on the reinforced insulation parts shall be provided as evidence.

4.2.4 Interface at blade root

In the blade root platform, the down-conductor is connected to the L-shaped metal block on the blade root platform along the inner surface of the blade, as shown in Figure 4. The L-shaped metal block is installed near the center of the blade root platform. Its exposed part has Φ11 mm holes for connecting cable terminals. An M10 stainless steel bolt is installed at the center of the blade root platform. The bolt has an exposed length of 20 mm after being inserted into the blade root platform. It is used to fix the cable fixture. The distance between the bolt and the L-shaped metal block shall not be less than 100 mm.

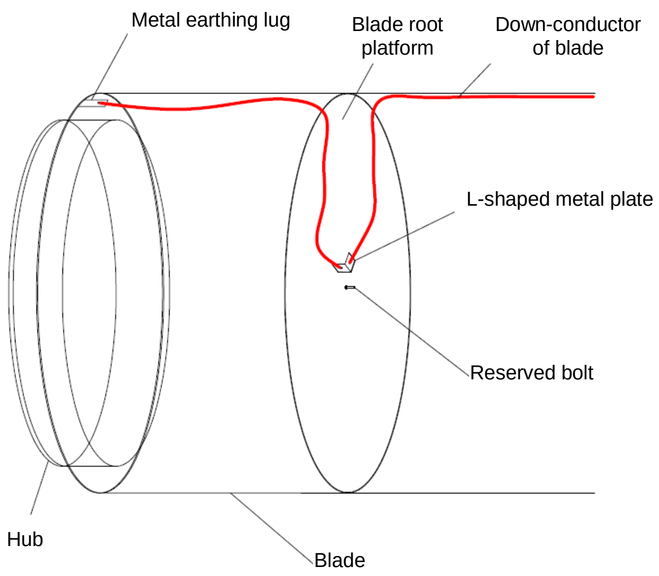


Figure 4 – Reservation of interface for lightning protection down-conductor at blade root

4.2.5 Test and inspection

The lightning protection system of blade shall pass the high-voltage test and high-current test as specified in IEC 61400-24-2019. If the lightning surge test is not conducted as required, it is required to demonstrate the similarity of the blade lightning protection system with the one previously verified by testing and make an assessment. The lightning protection system of blade is subjected to stress and fatigue tests together with the blade.

For fiberglass blades, make sure that the DC resistance from the blade tip receptor and the blade body receptor to the down-conductor connection at the blade root does not exceed 0.05 Ω. For carbon fiber blades, make sure that the DC resistance from any point on the metal mesh and the blade air termination system to the down-conductor connection at the blade root does not exceed 0.05 Ω. The resistance change of the lightning protection system of the blade before and after the dynamic load test shall not exceed ±20%.

4.2.6 Other requirements

A peak current sensor card (provided by the blade manufacturer) with a measuring range not less than 200 kA shall be installed for each blade on the main down-conductor for lightning protection of the blade.

For other detailed technical requirements, see GW-06CG.0136.

4.3 Lightning protection for hub

The hub of V15 Platform is of a large hollow cast iron structure, and the metal material is thick enough to prevent the hub structure itself from being affected by lightning stroke. The electric circuit of the electrical system, mechanical control system, and actuator in the hub leads to the outside of hub, the blade, and the nacelle. Therefore, magnetic shield shall be established for the hub. The equipotential bonding can be achieved by using control cabinet bracket on the hub opening facing the blades, front, and nacelle. Transient protection measures, such as shielding and installation of SPD, shall be considered for the electrical control system inside the hub connected to the external circuit of the hub.

4.4 Lightning protection for nacelle

4.4.1 Structural members of nacelle

The structure of the nacelle is an important part of the lightning protection system. Its lightning protection design can make sure that the lightning current is intercepted by the air termination system on the nacelle and conducted to the designed lightning current path. The electrical connection performance and anti-corrosion form shall be reasonably determined according to the installation position and purpose of the structural members. The specific requirements are as follows:

a) The electrical connection performance shall be considered for the structural members along the lightning current path. The contact surface at the connection shall be hot zinc sprayed or hot dip galvanized for anti-corrosion, and the contact area shall at least 90 mm^2.

b) Equipotential bonding is required for electrical equipment and their brackets, and the transition resistance shall be no more than 0.2 Ω. In the nacelle, the base is used as the reference point for equipotentiality. The hub is equipped with equipotential bonding points for the equipotential bonding of electrical equipment and metal structural members. The aluminum and stainless steel structural members need no additional anti-corrosion treatment. The contact surface at equipotential bonding of carbon steel structural members shall be zinc sprayed or dip galvanized for anti-corrosion. When other anti-corrosion measures are taken, it is required to verify the conductivity or use connecting wire for bridging. The equipotential bonding of plate-type structural members is realized by crimping with bolts and sclaw washers.

The metal truss structure inside the nacelle forms a large-scale grid in the space and a cage structure around the nacelle. The lightning protection system outside the nacelle is connected to this cage structure, and can withstand the expected lightning current.

4.4.2 Lightning rod of nacelle

The air termination system is in the form of lightning rods, and double rods with equal height are used for protection (see Figure 5 for the reach of protection of nacelle lightning rod). The reach of protection of the air termination system is calculated based on the rolling sphere of 20 m specified in IEC 61400-24. The air termination system can protect the wind detection system, aviation obstruction light, other devices, and the rear of the nacelle. The air termination system shall be made of hot dip galvanized round steel. The top of the lightning rod shall be a hemisphere with a bending radius of 4.8 m to 12.7 m. The diameter of the lightning rod shall meet the following requirements:

a) When the air termination system is less than 1 m in length, the round steel shall be no less than 12 mm.

b) When the air termination system is 1 m to 2 m in length, the round steel shall be no less than 16 mm.

The lightning rod is mounted on the wind sensor mounting bracket at the inner side of the aviation obstruction light, and is more than 100 mm from the aviation obstruction light and other equipment. It is connected to the wind sensor mounting bracket as a whole with bolts. The front guardrail of the nacelle is connected to the metal truss of the nacelle with copper braid, whose cross-section shall be no less than 50 mm^2. The wind sensor mounting bracket and the air termination system are integrally hot dip galvanized. The contact surface at the connection between the wind sensor mounting bracket and the nacelle, and the metal parts in the lightning current path shall be hot dip galvanized (or zinc sprayed) for anti-corrosion. Among the metal structures embedded in the nacelle cover, those connected to the metal truss of the nacelle shall be zinc sprayed on the surface to guarantee good electrical connection.

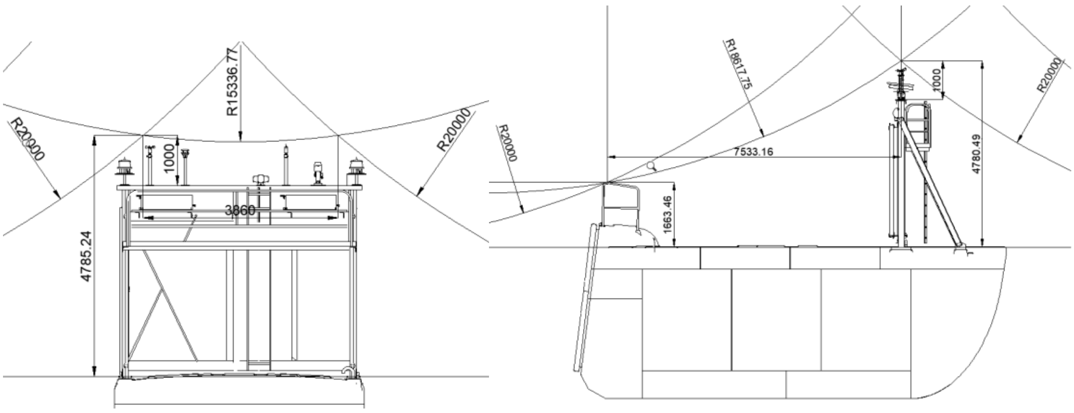


Figure 5 – Reach of protection of lightning rod of nacelle

4.5 Lightning protection and earthing design of bearing

4.5.1 General design idea

The lightning current path bypasses the bearings, or the bearings themselves are capable of withstanding lightning current. An independent down-conductor lightning conductor system is designed for Goldwind V15 Platform, establishing a low-resistance channel at three types of bearings (pitch bearing, main bearing, and yaw bearing) and protecting the bearings from being damaged by lightning current. Sliding contact or cable twist is used to establish the independent down-conductor system.

4.5.2 Lightning protection for pitch bearing

The lightning protection for pitch bearing is achieved through the bracket which is installed on the shear web of hub and points to the center of the blade root maintenance platform, and the copper braid mounted at the end of the bracket. The down-conductor of the blade extends to the stator shaft of main bearing for lightning protection of the pitch bearing. The design is as shown in Figure 6.

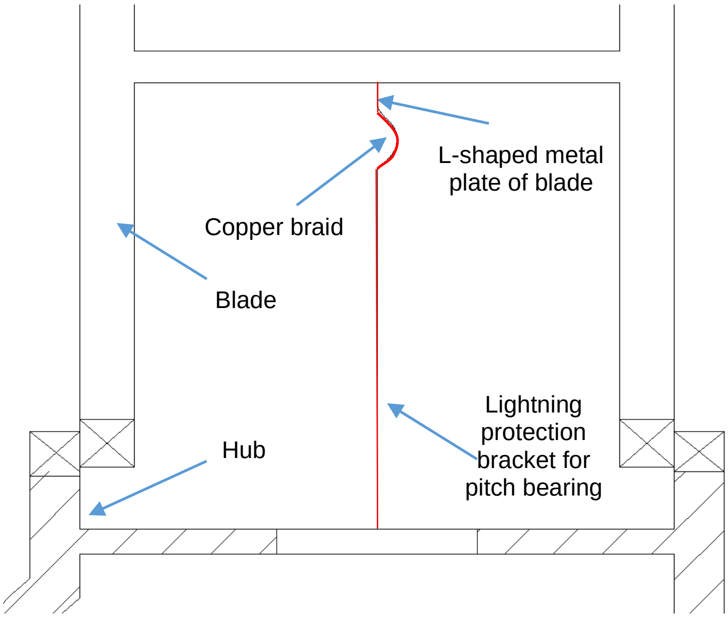


Figure 6 – Design of independent down-conductor for pitch bearing

4.5.3 Lightning protection for main bearing

A set of electric brushes are used for lightning protection of main bearing. The brush support is fixed on the bearing housing of main bearing and contacts the conductive slide rail at the end of the stator shaft to connect the rotor shaft and the stator shaft. The down-conductor of blade is arranged along the inner wall of the hub, and connected to the brush for lightning protection through the L-shaped metal block of the blade. The lightning protection of main bearing is as shown in Figure 7.

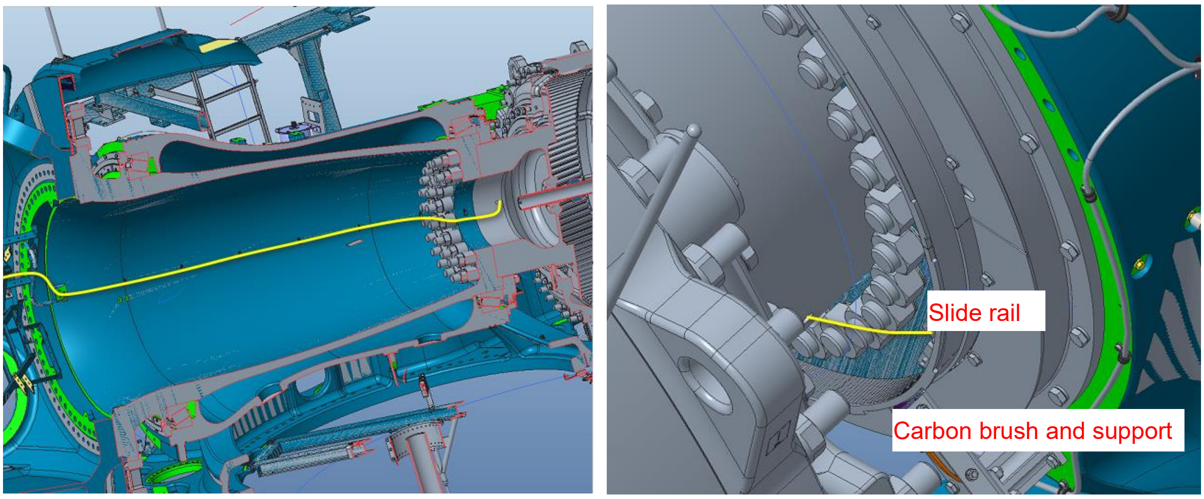


Figure 7 – Lightning protection for main bearing

4.5.4 Lightning protection system for yaw bearing

The gasket on the yaw bearing is designed with four copper rods with a diameter of Φ20 mm. The copper rod is connected to the base at one end, and is connected to the yaw gear ring at the other end. Furthermore, a set of lightning protection brushes are used to connect both ends of the yaw bearing. One end of the brush is connected to the nacelle base, and the other end is in sliding contact with the tower brake disc,as shown in Figure 8.

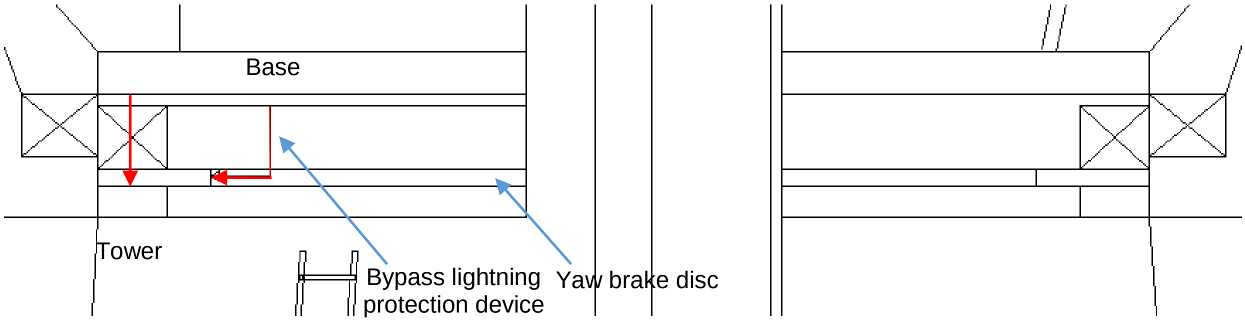


Figure 8 – Design of bypass device for yaw bearing

Independent down-conductor design is considered. Meanwhile, another set of lightning protection brushes are provided for connecting the down-conductors at the main bearing. One end of the brush is the lead for the conductive slide rail of the main bearing, and the other end is in sliding contact with the tower brake disc.

4.6 Lightning protection for tower

When a tubular steel tower is used for V15 Platform, it can be considered as a nearly perfect Faraday cage for electromagnetic shielding. Three or four copper cables of not less than 50 mm^2 are installed evenly across each flange connection between tower sections to achieve equipotential bonding of the tower. The cables used depend on the tower diameter: When it is less than 6 m, three copper cables shall be installed at an interval of 120°; when it is greater than 6 m, four copper cables shall be installed at an interval of 90°.

Special down-conductors in circular and vertical directions are used for prestressed concrete towers, and 40 × 4 mm galvanized steel straps are used for circular and vertical earthing. The vertical distance between the steel straps for circular earthing of the concrete tower section shall be no more than 20 m. The steel straps for vertical earthing installed in each concrete tower section are distributed in three groups with an angle of 120° between each other. The steel straps for circular and vertical earthing are connected by welding or clamping, as shown in Figure 9. The lightning protection down-conductors shall be kept away from the prestressed wire ropes when designing the concrete tower tube. Furthermore, the rebar in the concrete shall be provided with equipotential bonding and connected to the down-conductor system of the wind turbine for discharging lightning current on the one hand, and for good shielding on the other hand. The prestressed elements shall not be used for earthing or lightning protection.

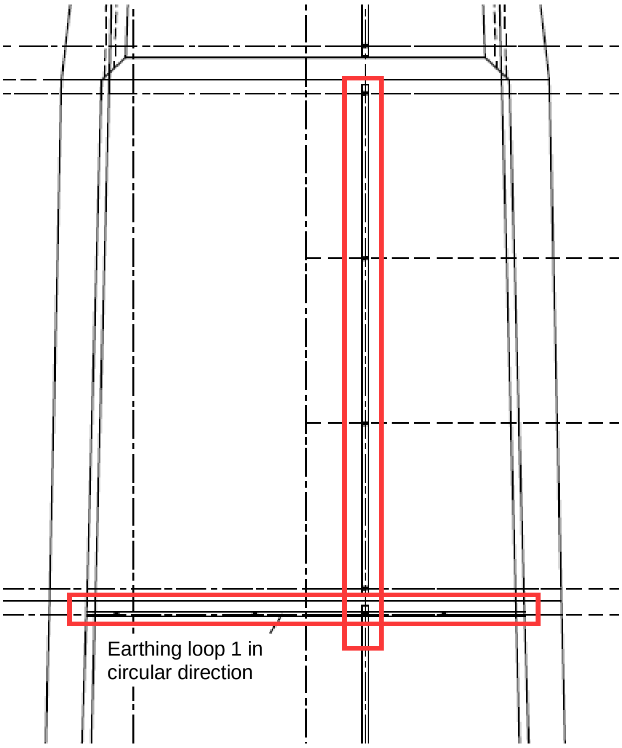


Figure 9 – Section of earthing down-conductor between concrete tower sections

5 Internal lightning protection system

5.1 Equipotential bonding

5.1.1 Design requirements for equipotential bonding

To minimize the potential difference between metal devices, equipotential bonding shall be made for all exposed metal parts of a wind turbine if natural connection cannot guarantee the continuation of electrical conductivity. Key locations requiring equipotential bonding include the following parts:

a) Large metal structures of a wind turbine, such as hub, generator, nacelle base, and flange connection of each tower.

b) Metal devices of a wind turbine, such as various metal brackets, cable trays, cable slots, and ladders inside and outside the tower.

c) The shielding layer, armor layer, and intensified metal core of power cables and control cables of a wind turbine.

d) Electrical and electronic systems of a wind turbine; electrical equipment inside the nacelle, hub, and tower; equipment outside the tower.

5.1.2 Equipotential bonding of rotor

Each electrical cabinet inside the rotor is earthed locally. The hub serves as the equipotential body and metal parts with Φ12 earthing holes are reserved at four positions of the shock absorber for pitch box support. M10 bolts are used to secure the earth wires which are 1 × 16 mm^2 flexible copper wires. The wiring is shown in Figure 10 and the cables are listed in Table 6.

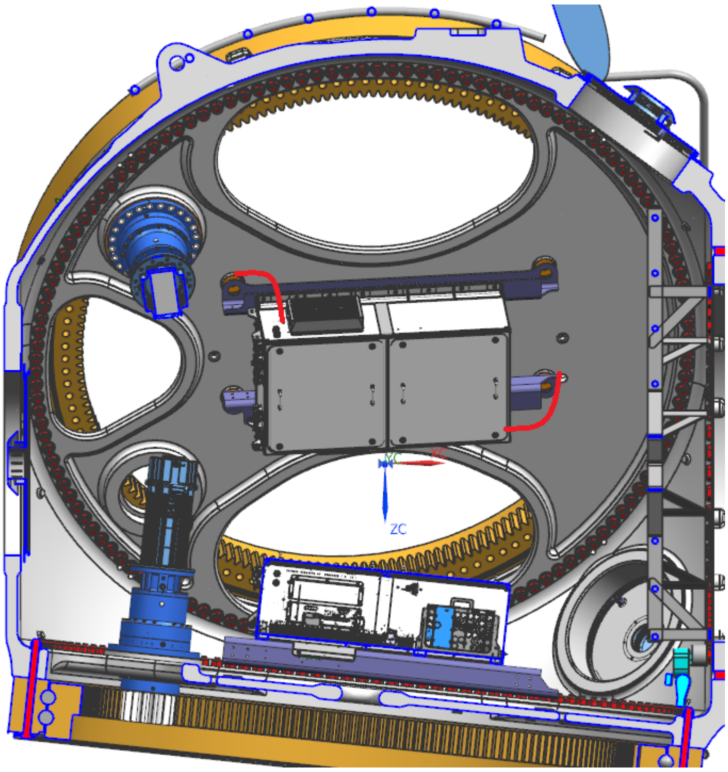


Figure 10 – Earthing connection of rotor

Table 6 – Equipotential bonding cables of rotor

No.	**Name of cable**	**Start and end positions**		**Cross-section of cable** mm^2	**Outer diameter (D)** mm	**Weight** kg/m	**Bending radius** mm	**Quantity**	**Specifications of terminal**	**Specifications of fixture**	**Size of hole**
		Start	End								
1	Earth wire of pitch box	Pitch box	Hub earthing point	1 × 16	8	0.28	6D	6	OT16-Φ10	M10 × 30	Φ12
2	Earth cable of test box	Hub measurement and control cabinet	Hub earthing point	1 × 16	8	0.28	6D	1	OT16-Φ10	M10 × 30	Φ12
3	Earth cable for blade monitoring cabinet	Blade monitoring cabinet	Hub earthing point	1 × 16	8	0.28	6D	1	OT16-Φ10	M10 × 30	Φ12

NOTE 1 The length of earth wires is determined according to the reserved earthing points, and the earth wires shall be as straight and short as possible.

NOTE 2: All cables are bound and fixed with nylon cable ties.

5.1.3 Equipotential bonding of generator

Two M10 threaded holes are reserved on the generator body (as shown in the red boxes in Figure 11), and two earth connection points are reserved at the corresponding positions on the nacelle platform. The generator and the nacelle platform are connected with two 1 × 70 mm² cables for equipotential bonding. The rotor shaft of generator is connected to the enclosure of generator with four brushes (as shown in the red circles in Figure 11).

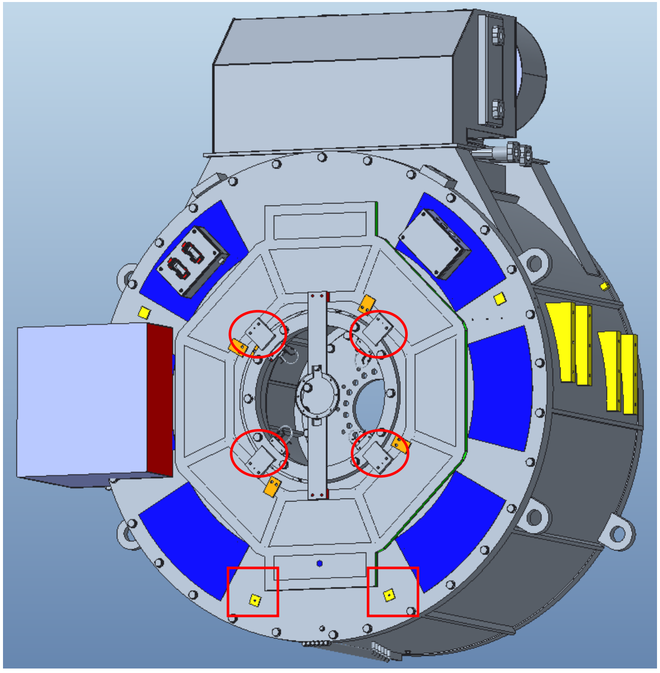


Figure 11 – Earthing connection of generator

5.1.4 Equipotential bonding of nacelle

The metal frame and base of the nacelle are used as the equipotential body. The wind sensor mounting bracket, guardrail, and large embedded metal parts on the nacelle cover are locally connected to the metal truss. The base and frame of the nacelle have reliable electrical connection. The connections between the nacelle platform and the nacelle base, connections on the nacelle frame, and connections between the nacelle base and the nacelle frame are hot dip galvanized or cold zinc sprayed. An earth busbar is reserved on the support of nacelle platform. The nacelle power cabinet, nacelle cabinet, nacelle drive cabinet, gearbox, and generator are respectively earthed locally to the reserved earth busbars. The list of equipotential bonding cables is as shown in Table 7.

Table 7 – List of equipotential bonding cables of nacelle

No.	Name of cable	Start and end positions		Cross-section of cable mm²	Outer diameter (D) mm	Weight kg/m	Bending radius mm	Quantity	Specifications of terminal	Specifications of fixture	Size of hole
		Start	End								
1	Earth cable of nacelle control cabinet	Earth rod of nacelle control cabinet	Main platform	1 × 35	12	0.28	6D	1	OT35-Φ10	M10 × 30	Φ12
2	Earth cable of power distribution cabinet of nacelle	Earth rod of power distribution cabinet of nacelle	Main platform	1 × 35	12	0.28	6D	1	OT35-Φ10	M10 × 30	Φ12
3	Earth cables of generator	Earthing point of generator	Earth busbar of nacelle	1 × 70	23	0.6	6D	2	OT70-Φ10	M10 × 30	Φ12
4	Earth cable of gearbox	Earthing point of gearbox	Earth busbar of nacelle	1 ×70	23	0.6	6D	2	OT70-Φ10	M10 × 30	Φ12
5	Equipotential bonding cables of gearbox and generator	Earthing point of gearbox	Earthing point of generator	1 ×70	23	0.6	6D	2	OT70-Φ10	M10 × 30	Φ12
6	Equipotential bonding cables of nacelle cover handrail	Nacelle cover handrail	Truss	1 ×70	23	0.6	6D	2	OT70-Φ10	M10 × 30	Φ12
NOTE 1 The length of earth wires is determined according to the reserved earthing points, and the earth wires shall be as straight and short as possible. NOTE 2: All cables are bound and fixed with nylon cable ties.											

5.1.5 Equipotential bonding of tower

5.1.5.1 General design

According to GB 17467-2010, a main earthing conductor system is provided for earthing all metallic parts of the prefabricated substation not belonging to the main circuit and/or auxiliary circuit of the equipment. It consists in a main earthing conductor on which each component is connected through a single circuit. If the framework of the enclosure is made of metallic bolted or welded material, it may serve as the main earthing conductor system. The main earthing conductor system is capable of carrying the rated short time and peak withstand currents under the neutral earthing condition of the system. See Figure 12 for the general design of equipotential bonding of tower

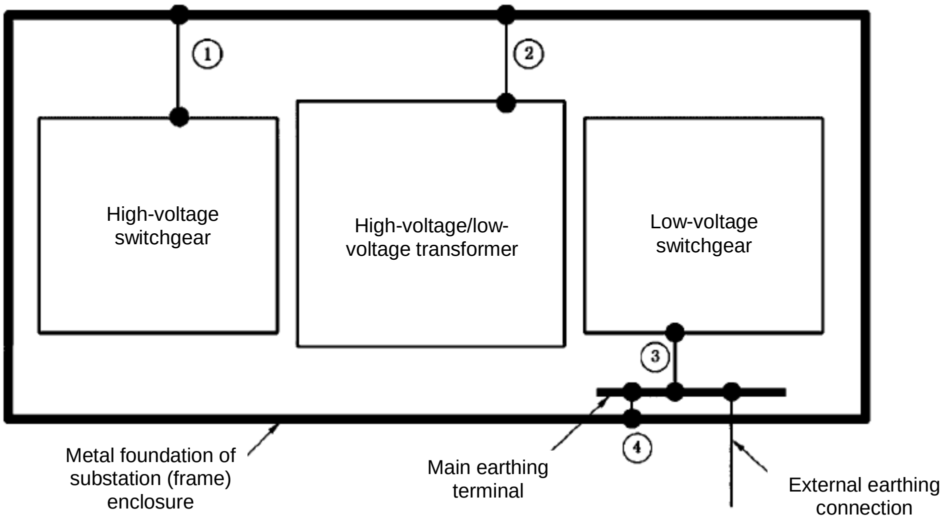


Figure 12 – Principle of equipotential bonding of tower

5.1.5.2 Equipotential bonding between tower sections

Sliding contact (copper rod and brush) is used for nacelle and tower for equipotential bonding.

M10 earth studs are designed according to 4.6 and specifically for connection locations of upper and lower flanges of tower. The contact surface of stud is smooth, galvanized, and free of burr. See Figure 13 for stud positions for the tower with a diameter of less than 6 m. Equipotential bonding is made between tower sections with 1 × 50 mm^2 earth cables, and the cable length is determined according to the layout and wiring drawing.

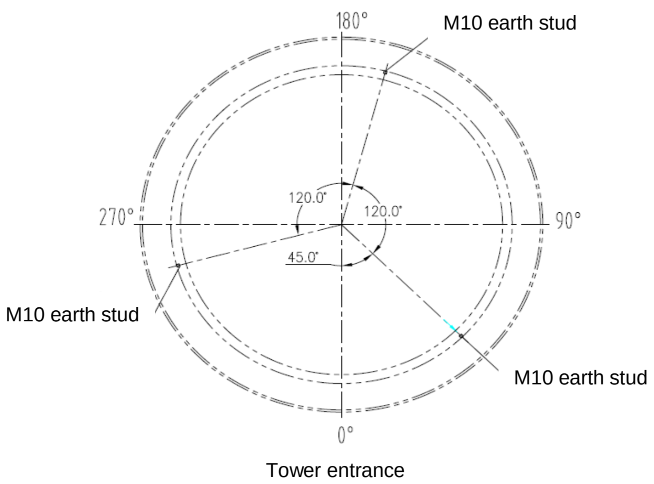


Figure 13 – Positions of studs for equipotential bonding between steel tower sections

5.1.5.3 Equipotential bonding of metal structural members

Main equipotential earth busbar and local equipotential earth busbar are respectively arranged on the tower and at the tower base. They are used to earth the collector ring, tower base equipment, cable tray, ladder, cable slot, armor layer of grid-side buried cable, PE cable, etc.

M10 earth studs are reserved on the tower door and adjacent tower wall as shown in Figure 14, and 1 × 16 mm^2 earth cable is used for equipotential bonding of tower door.

Figure 14 – Earthing of tower door

5.1.5.4 Earthing design of tower base

The recommended working earthing system at the tower base when external transformer and single-cabinet converter are used is as shown in Figure 15.

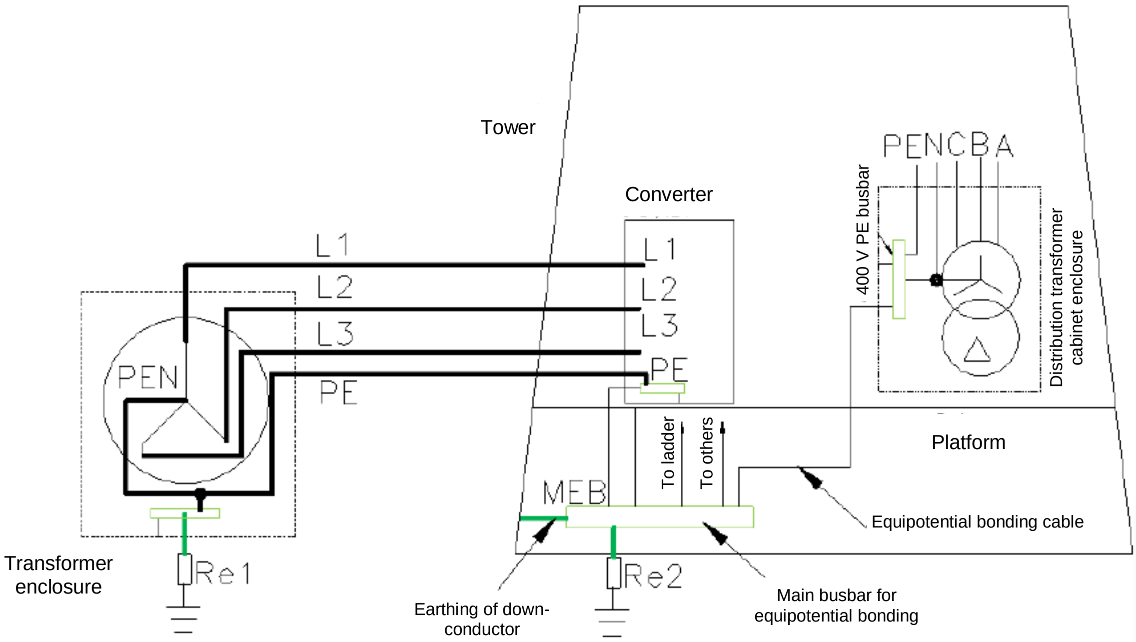


Figure 15 – Working earthing method in the case of external transformer and single-cabinet converter

Main equipotential busbar and local equipotential busbar are respectively arranged at the tower base. The local equipotential busbar is used to earth all platform equipment. The 1 × 185 mm^2 earth cable of converter and the PEN cable from the gird side are connected to the same local equipotential busbar. The main equipotential busbar is for the earth cables of other electrical control cabinets at the tower base. They mainly include: three 1 × 50 mm2 tower equipotential bonding cables at tower base, shielding cable on the armor layer of grid-side cable, tower base equipment, and metal structural members at tower base.

According to the specifications for design and construction of onshore wind turbine foundation, a grading ring is provided at the tower base, as shown in Figure 16. At the horizontal angles of +45°, +165°, and +285° on the grading ring, earthing holes are reserved at each angle, with a hole pitch of 50 mm.

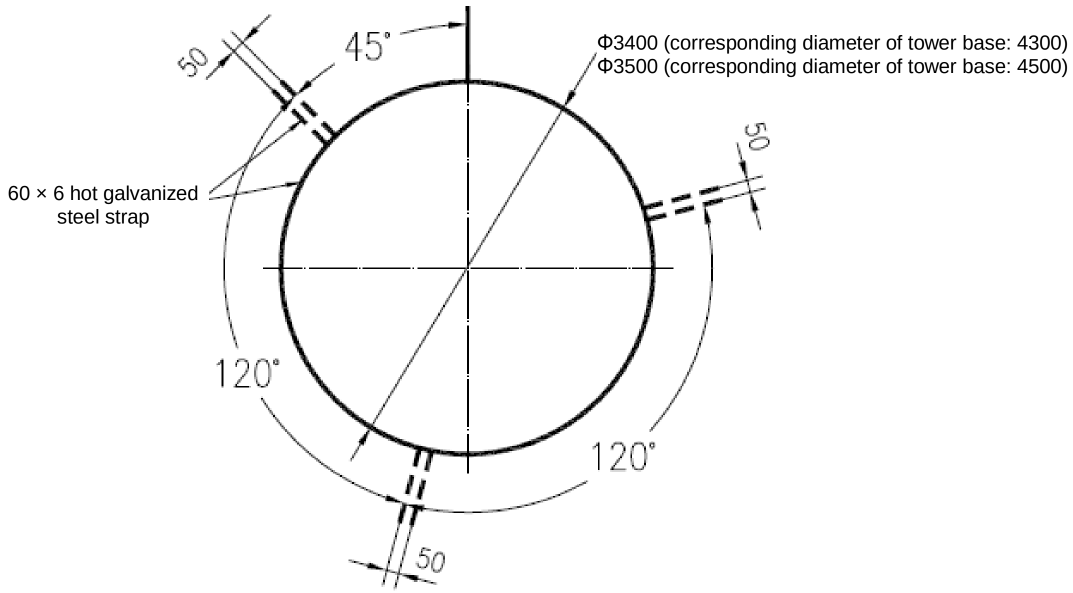


Figure 16 – Earthing of grading ring

5.1.5.5 Design of earth busbar outside the tower

A hot dip galvanized steel strap is led out from the foundation outside the tower, and two Φ13 earthing holes are reserved on it, as shown in Figure 17. Two 1 × 16 mm^2 cables are used to connect the casing of the water-cooled heat exchangers reliably. As there is no reliable equipotential bonding between the tower access ladder and the tower, a 1 × 16 mm^2 cable is used to connect the foot of the ladder to the hot dip galvanized steel strap led out from the foundation earthing.

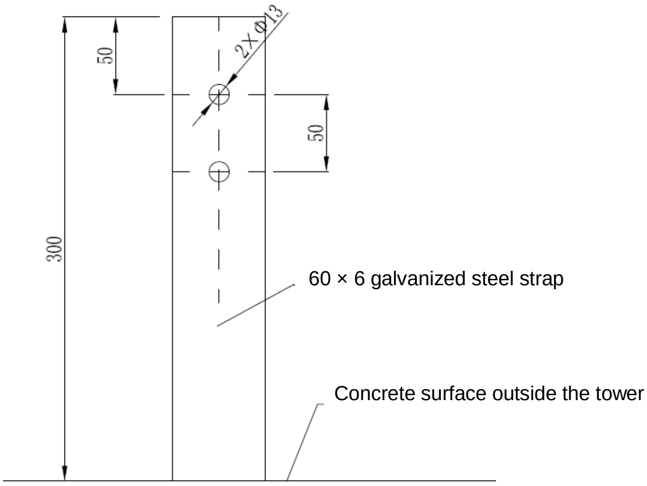


Figure 17 – Earth busbar outside the tower

5.1.5.6 Configuration list of earth cables and copper braids

The equipotential bonding system of the tower comprises steel tower, grading ring, earthing lug, busbar, earth stud, cables, and copper braids. Table 8 shows the configuration of cables and copper braids.

Table 8 – Equipotential bonding cables of tower

No.	Name of cable	Start and end positions		Cross section of cable mm²	Quantity /pc	Terminal Specification	Size of hole
		Start	End				
1	Collector ring	Earthing point of collector ring	Earthing point of nacelle/tower	1 × 35	2	OT35-Φ10	Φ12
2	Earth wire of saddle	Saddle support	Earthing lug at the saddle	1 × 16	1	OT16-Φ10	M10
3	Earth wire of converter	Earth busbar of converter	Busbar at tower base	1 × 185	2	DT185-Φ16	Φ18
4	Earth wire of main control cabinet	Earth busbar of main control cabinet	Grading ring	1 × 35	1	OT35-Φ10	Φ12
5	Earth cable of auxiliary transformer	Earth busbar of auxiliary transformer	Grading ring	1 × 35	1	OT35-Φ10	Φ12
6	Earth wire of automatic fire control cabinet	Support of automatic fire control cabinet	Grading ring	1 × 35	1	OT35-Φ10	Φ12
7	Earth wire of dehumidifier	Earthing point of dehumidifier	Grading ring	1 × 16	1	OT16-Φ10	Φ12
8	Tower entrance	Earthing point of tower door	Earthing point of tower door frame	1 × 16	1	OT16-Φ10	M10
9	Earth wire of tower access stairs	Mounting hole on the side of tower access stairs	Reserved metal earthing lug outside the tower	1 × 16	1	OT16-Φ10	Φ12

No.	Name of cable	Start and end positions		Cross section of cable mm²	Quantity /pc	Terminal Specification	Size of hole
		Start	End				
10	Earth wire of water-cooled heat exchanger	Support of water-cooled heat exchanger	Reserved metal earthing lug outside the tower	1 × 16	2	OT16-Φ10	Φ12
11	Earth cable harness of tower	Earth rod on the flange of the lower section of tower (or grading ring)	Earth rod on the flange of the upper section of tower	1 × 50	-	DT50-Φ10	M10
12	Earth wire of neutral line of step-up transformer inside the tower	Neutral point of step-up transformer	Busbar at tower base	1 × 185	2	DT185-Φ16	Φ18

No.	Name of cable	Start and end positions		Cross section of cable mm²	Quantity /pc	Terminal Specification	Size of hole
		Start	End				
13	Earth cable of enclosure of step-up transformer (step-up transformer inside the tower)	Earthing point of enclosure of step-up transformer	Grading ring	1 × 16	1	OT16-Φ10	Φ12
14	Earth wire of ring main unit (step-up transformer inside the tower)	Earth busbar of ring main unit	Grading ring	1 × 70	1	DT70-Φ10	Φ12
NOTE 1 The length of earth wires is determined according to the reserved earthing points, and the earth wires shall be as straight and short as possible. NOTE 2: All cables are bound and fixed with nylon cable ties.							

5.2 Shielding

Casting metals such as the hub and base of the wind turbine shall be regarded as a shielding protective layer. The metal tubular tower is a good shielding protective layer. The metal enclosures of the electrical cabinets inside and outside the wind turbine (such as the main control cabinet, step-up transformer, etc.) are regarded as shielding protective layers.

All the power cables and signal cables leading from the outside to the inside of nacelle shall be shielded cables, and shield earthing shall be made at one end or both ends depending on the signal features. Examples are the cables for wind sensor, aviation obstruction light, bird repeller, and laser equipment.

All the power cables and signal cables leading from the outside to the inside of the tower shall be shielded cables, and shield earthing shall be made at one end or both ends depending on the signal features, such as the armor layer of grid-side armored cable.

All signal cables connected across the electrical cabinet in the nacelle, hub, and tower shall be shielded cables, and shielded earthing shall be made at one end or both ends depending on the signal features. Examples are bearing temperature sensor, pitch communication cable, etc.

5.3 Surge protective device (SPD)

5.3.1 Design principles

According to the classification of LPZs, suitable SPDs are installed at the boundary of LPZs. Class I SPDs are installed at the boundary between LPZ 0B and LPZ 1, Class II/III SPDs are installed at the boundary between LPZ 1 and LPZ 2, and at the boundary between LPZ 2 and LPZ 3.

According to IEC 62305-4-2010, when the step-up transformer is outside the tower, low-voltage cables entering the wind turbine are provided with SPDs for protection. When the step-up transformer is inside the tower, protection is achieved by extending LPZ 0 to LPZ 1 and SPD is still installed on the low-voltage side, as shown in Figure 18.

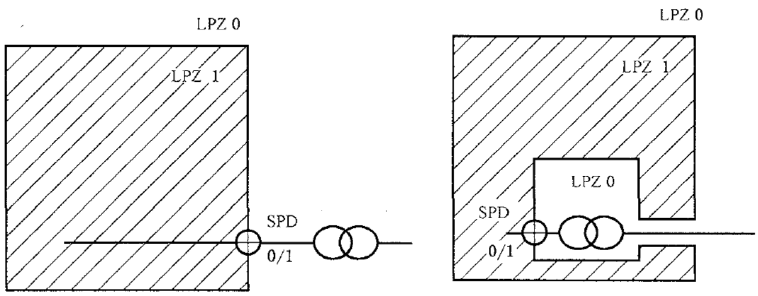


Figure 18 – Extended lightning protection zone

5.3.2 Configuration scheme

According to IEC 61643-12-2020, appropriate Class I and Class II power supply SPDs and signal SPDs are provided at the boundary of LPZs of Goldwind V15 Platform platform, Class I SPDs are provided from LPZ 0 to LPZ 1, and Class II SPDs are provided from LPZ 1 to LPZ 2, as shown in Figure 19.

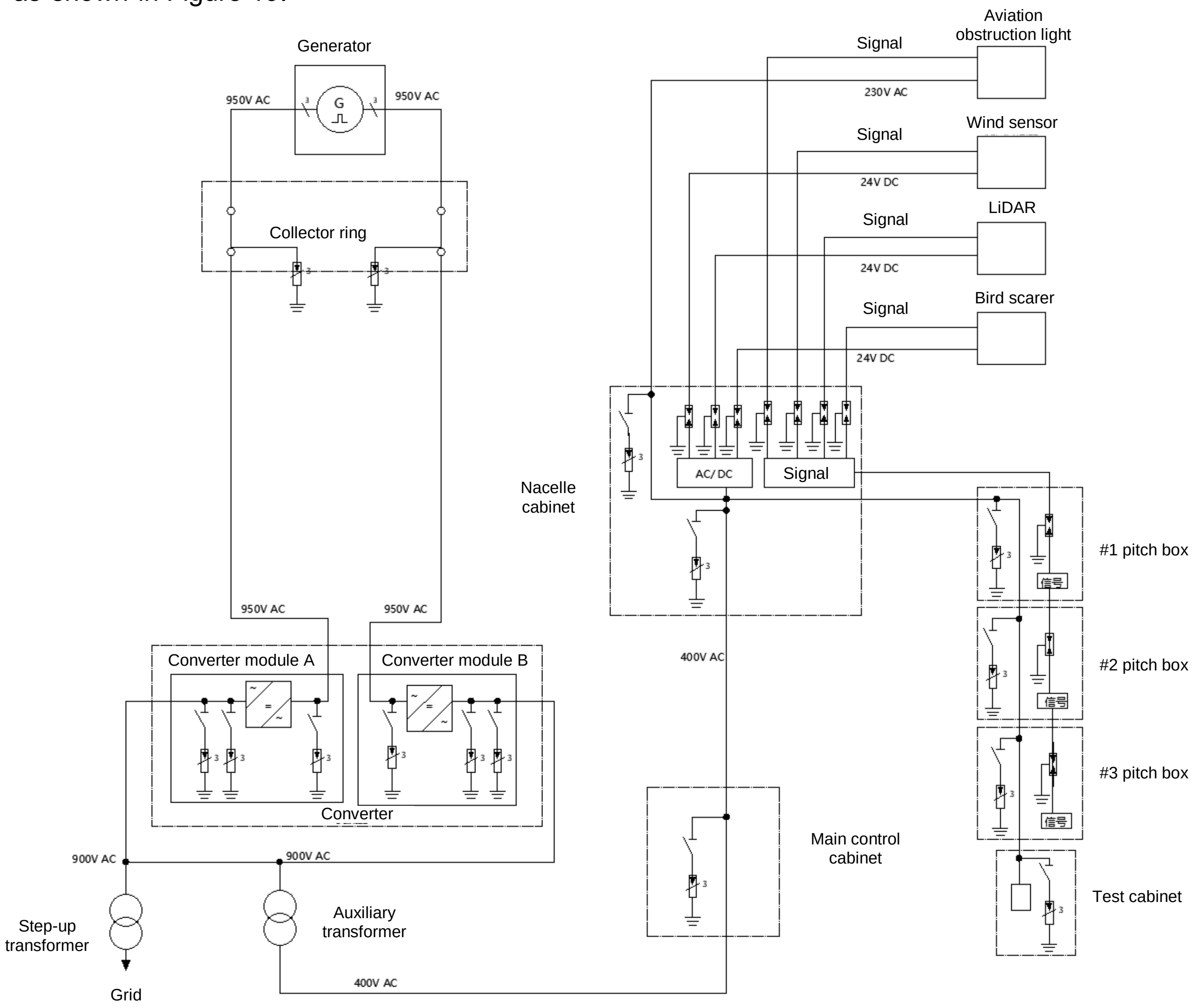


Figure 19 – Design layout of SPDs

The parameters of power supply SPDs are as shown in Table 9, and the power supply SPDs shall comply with the requirements of IEC 61643-12-2020.

Table 9 – Parameters of power supply SPDs

SPD class	Class I	Class II			Class I/II	
Installation position	Grid side of converter	Grid side of converter, primary side of control transformer	Generator side of converter, generator-side transfer box	Incoming power supply cable of main control cabinet, pitch box, nacelle cabinet	Aviation obstruction light and lidar	Anemometer and wind vane
Nominal operating voltage U_n	660/1140 V AC	660/1140 V AC	1380 V AC	230/400V AC	230/400V AC	24V DC
Maximum continuous operating voltage U_C	≥ 1.1 U_n	≥ 1.1 U_n	≥ 1.1 U_n	≥ 1.1 U_n	≥ 1.1 U_n	≥ 27 V DC
Voltage protection level U_p	≥ 6.4 kV	≥ 4.8kV	≥ 4.8kV	≥ 3.2kV	≥ 2.0kV	≥ 180V
Nominal discharge current (8/20μs) I_n	–	15kA	15kA	20kA	20kA	1kA
Maximum discharge current (8/20 μs) I_{max}	–	≥ 25kA	≥ 25kA	≥ 40kA	≥ 40kA	≥ 2kA
Impulse current (10/350 μs) I_{imp}	≥ 12.5kA	–	–	–	–	–

All signal cables led out of the nacelle are installed with SPDs. They are installed at positions such as signal cable inlets of wind vane, anemometer, lidar, and aviation light as well as where DP signal cables are led into the pitch box. The parameters of signal SPDs shall be as shown in Table 10, and comply with the requirements of IEC 61643-22-2015.

Table 10 – Parameters of signal SPDs

Signal SPD	Voltage class 24 V DC SPD	Voltage class 5V DC SPD
Nominal operating voltage U_n	24VDC	5VDC
Maximum continuous operating voltage U_C	≥ 28 V DC	≥6VDC
Voltage protection level U_p	Phase to phase voltage: ≤ 60 V	Phase to phase voltage: ≤ 32V
Nominal discharge current (8/20μs) I_n	10kA	10kA
Maximum discharge current (8/20 μs) I_{max}	≥ 20kA	≥ 20kA

5.3.3 Energy coordination of SPDs

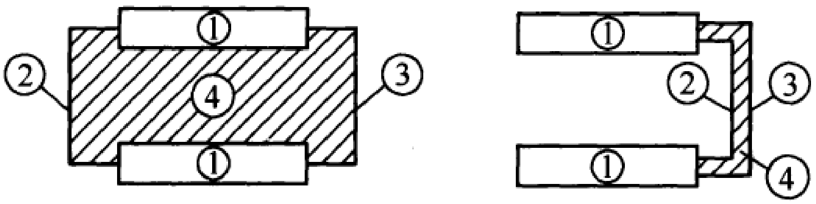
Normally, where SPDs are installed at multiple positions of the line, the line length between a voltage switching type SPD and a voltage limiting type SPD shall not be less than 10 m and that between voltage limiting type SPDs shall not be less than 5 m. If the line length between SPDs does not meet the above requirement, different SPDs, such as Class I and Class II SPDs on the grid side of converter, shall be able to coordinate with each other.

5.4 Cable selection and reasonable wiring

When installing the lightning protective down-conductors together with other cables, the spacing requirements shall be met, or shielded cables shall be used with shield earthing made properly.

The bending angle of the earth cable and the SPD connecting wire shall be greater than 90°, and the bending radius shall meet the bending radius requirements of the corresponding earth cable.

The communication cables shall be installed in metal slots or metal pipes, close to the metal parts of the equipotential bonding network. The communication cable route shall be arranged in a manner to minimize the area of the electromagnetic induction loop formed by the cable itself, as shown in Figure 20.



(a) Inappropriate wiring system

(b) Appropriate wiring system

1 – Equipment; 2 – Cable a (power cable); 3 – Cable b (signal cable); 4 – Area of induction loop

Figure 20 – Wiring system

The diameter of connecting wire of power supply SPD shall meet the requirements in Table 11. The connecting wires of various classes of SPDs shall be short and straight, and the sum of the lengths of the wires at both ends shall not exceed 0.5 m. If the length does not meet the requirement, it is required to adopt the wiring method shown in Figure 21 (Kevin wiring method).

Table 11 – Wiring of power supply SPDs

Degree of protection	Type of SPD	Cross-section of conductor mm²	
		Copper conductor for connecting phase cable	Copper conductor for earthing
Class I	Voltage switching type or voltage limiting type	6	16
Class I	Voltage limiting type	5	6
Class I	Voltage limiting type	2.5	4
Class I	Voltage limiting type	2.5	4
NOTE: For combination type SPDs, refer to the cross-sectional areas at corresponding protection levels.			

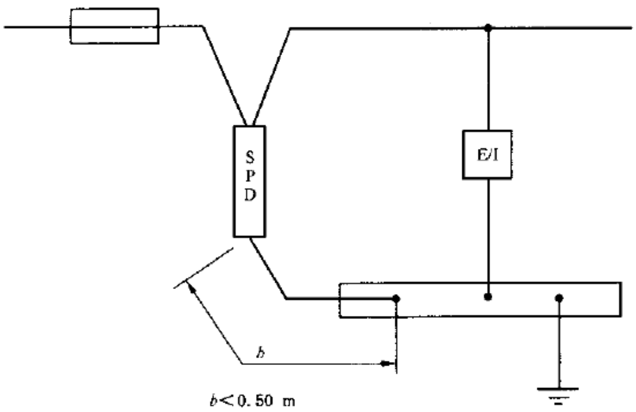


Figure 21 – Kevin wiring

The earthing end of SPD for the signal system shall be connected to the local equipotential earthing terminal board with a copper cable of a cross-section of not less than 1.5 mm².

5.5 Surge arrester

The wind turbine is connected through the transformer to a HV cable system which connects the wind turbine to the grid. A lightning arrester is used to protect the transformer and HV system to avoid them from being affected by the rise of earth potential caused by the lightning current passing through the earthing system of the wind turbine, and to protect against the transient current entering the wind turbine from the HV cable system outside the wind turbine.

The surge arrester shall be metal oxide surge arrester without gaps, as specified in IEC 60099-4. The surge arrester shall be selected according to the actual voltage class. The recommended parameters for 40.5 kV transformer are as shown in Table 12. The protection scheme can also be provided by the manufacturer.

Table 12 – Configuration of HV surge arrester

No.	Indicator	Parameter requirement
1	Rated voltage	51kV
2	Continuous operating voltage	40.8kV
3	Nominal discharge current	≥ 5kA
4	Steep current impulse residual voltage (1/3 μs, 5 kA)	≤ 154 kV (peak)
5	Lightning impulse residual voltage (8/20 μs, 5 kA)	≤ 134kV (peak)
6	Switching impulse residual voltage (30/60 μs, 100 A)	≤ 124kV (peak)

5.6 Isolation interface

The isolation interface refers to the devices capable of reducing or isolating the conducted surge on the line entering the LPZ, including the isolation transformer earthed by the shielding layer between the windings, the metal-free optical fiber cable and the optical isolator. These devices are capable of withstanding corresponding surge impact due to their own insulation withstanding properties, or through being provided with SPDs.

6 Earthing system

6.1 General requirement

According to GB/T 50065-2011, the earth-termination system of the wind turbine can be classified into working earthing, protective earthing, lightning protective earthing, and static protective earthing, in terms of purposes. The electrical equipment and facilities of the wind turbine which have different purposes and voltage classes share a single and integrated earth-termination system that is suitable for the whole electrical system of the wind turbine, that is, the common earth-termination system. The components of earthing system shall be capable of withstanding lightning current and power system fault current.

6.2 Onshore wind turbine

6.2.1 Type of earth-termination system

The common earth-termination system of onshore wind turbine is composed of earth electrodes and earth cables. The earth electrodes include horizontal and vertical earth electrodes. Type B earth-termination system specified in IEC 61400-24-2019 shall be used, which is composed of foundation earth electrodes and annular earth electrodes at the peripheral region. The annular earth electrode shall be inserted into the soil for at least 80% of the electrode length. The annular earth electrode shall be reliably connected to the foundation earth electrode at multiple points, and also connected to the tower.

The foundation of a wind turbine is one part of LPS, and shall be reliably connected to the earth-electrode network. The earth-termination systems of the step-up transformer and the wind turbine shall be reliably connected at no less than two positions. The final design scheme of the earth-electrode network is subject to the drawings of the design institute. At least three cables shall be led out from the earth-electrode network, and then reliably connected to the earth busbar or foundation ring inside the wind turbine, as shown in Figure 22.

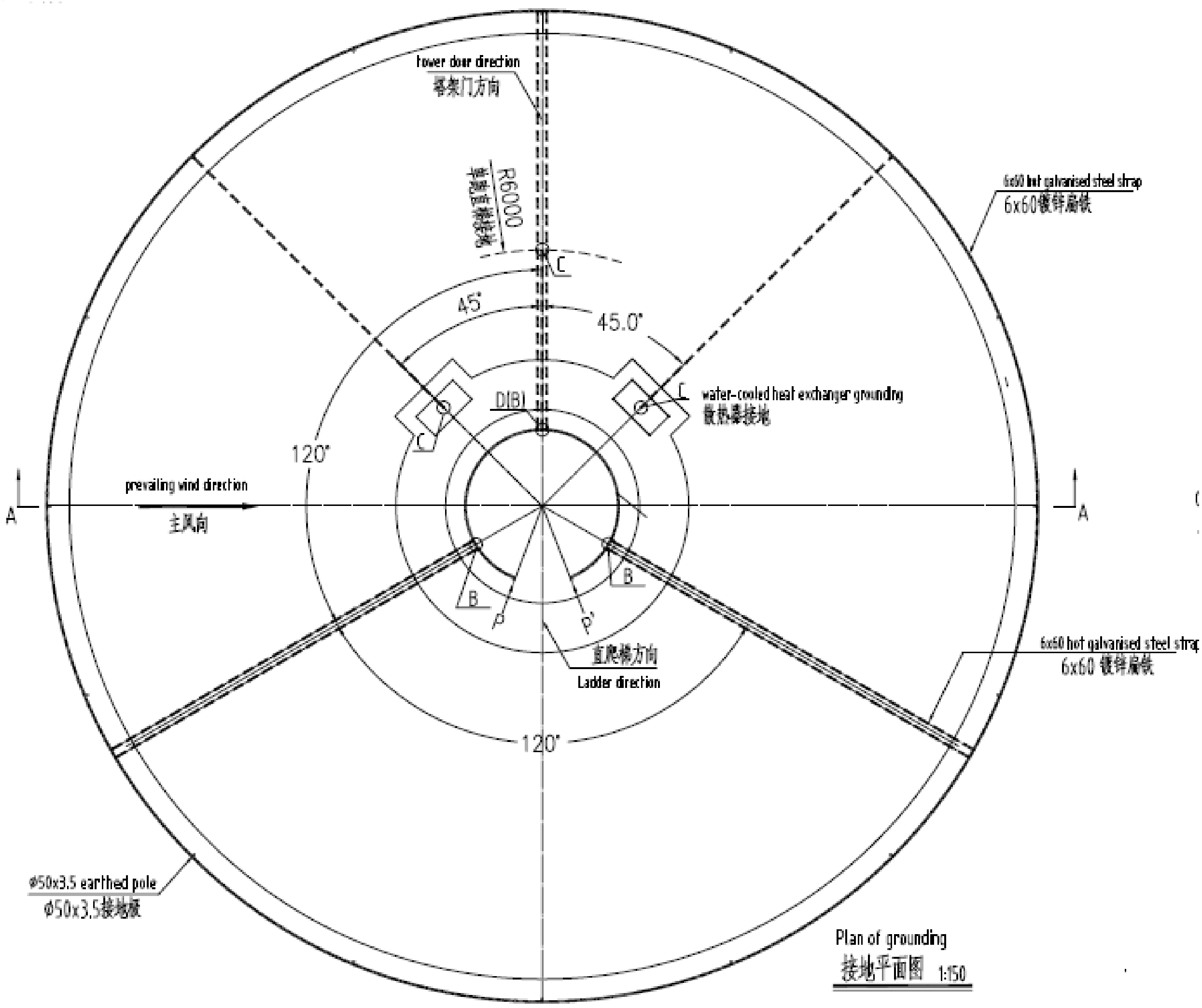


Figure 22 – Earth-electrode network design for reference

6.2.2 Specifications and materials of earth-termination system

The material of the earth-electrode network shall be mainly hot dip galvanized steel, and the service lifetime of the earth-electrode network shall be at least 20 years. Normally, it is recommended to use 50 mm × 5 mm hot dip galvanized steel strap. Under salt-alkali and high corrosion conditions, it is recommended to use 60 mm × 6 mm (or steel of higher specifications) hot dip galvanized flat strap. Copper material is also acceptable, but the minimum cross-section shall meet the requirements of thermal stability verification, and the electrochemical corrosion factor shall be fully considered.

The embedded depth and type of the earth electrode shall be determined as appropriate for minimizing the effects of corrosion, soil dryness, and freezing, so that the earthing resistance can be stable.

6.2.3 Earthing impedance

The agreed earthing impedance of the earthing system shall not affect the efficiency of the air-termination system and the down-conducting system. The designed pulse impedance of the earthing system shall be as low as possible to reduce the total voltage drop, the lightning current passing the service line of the wind turbine, and the risk of sparks from other service lines near the earthing system.

Considering the large differences in the actual installation conditions of wind turbines, the earth resistance of the wind turbine shall meet the following requirements:

a) In the local areas with soil resistivity less than 3000 Ω m, the power frequency earth resistance R for each wind turbine shall be equal to or less than 4 Ω.

b) If the power frequency earth resistance for each wind turbine cannot be equal to or less than 4 Ω due to the geological conditions on site, it is allowed to be equal to or less than 10 Ω. In this case, joint earthing for multiple wind turbines shall be adopted to increase the discharge area.

c) In the installation areas, if the lightning protection competent authority or the owner has special requirements for the earth resistance of the wind turbine, the earth resistance shall meet such requirements.

The seasonal variation of the earth resistance of the wind turbine shall not exceed 50% of the specified earth resistance. Within two years after the earth-electrode network passes the acceptance, the earth resistance shall be tested during brief rain period. If the tested resistance exceeds the designed resistance, the earthing shall be rectified in time. Normally, the earth resistance is to be tested once every 2 years.

6.2.4 Measures to reduce resistance in areas with high soil resistivity

In the areas with high soil resistivity (soil resistivity $\rho > 3000$ Ω·m), if the earth resistance of earth-termination system of a wind turbine does not meet the requirements, the following measures shall be adopted to reduce the earth resistance:

a) Adopt multi-branch external lead earth-termination system. The length of external lead does not exceed the effective length, and the effective length complies with the regulations in Annex C of GB 50057-2010.

b) Bury the earth electrode in deep soil with low resistivity.

c) Use physical resistance-reducing agents.

d) Conduct soil removal and replacement.

7 Lightning monitoring system

7.1 Lightning monitoring configuration principle

Each blade is equipped with a standard peak current sensor (PCS) card (configured by the blade manufacturer) with a measuring range not less than 200 kA.

When the wind turbine is installed in high frequency thunderstorm or offshore area, or when the owner has customized requirements, the wind turbine can be equipped with an optional online lightning monitoring program.

7.2 Online lightning monitoring (optional)

7.2.1 Introduction

When the wind turbine suffers lightning stroke, the OLMS accurately receives real-time signals through the lightning current sensors and transmits such signals to the lightning monitor. The lightning monitor stores the collected and calculated "lightning stroke occurrence time, current peak value, and polarity" in the internal memory. Then the lightning monitor performs corresponding communication protocols (to be confirmed) through the communication interface, and transmits the data to the main control system of the wind turbine. The data then, together with other data in the main control system, are sent to the monitoring center for data display, management, statistics and report through the centralized monitoring system of wind farm. The lightning online monitoring system mainly includes lightning analyzer, lightning sensor and corresponding power cable, communication cable, and installation bolts. See Figure 23 for the structure and principle of the system.

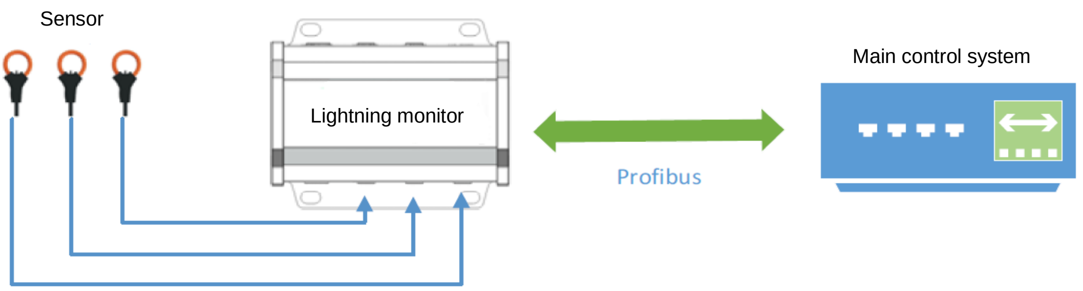


Figure 23 – Working principle of online lightning monitoring system

7.2.2 Design and installation scheme

The online lightning monitoring system is installed inside the rotor. The lightning analyzer is installed in the blade monitoring box. The box supplies 24 V power to the system. The communication cable is connected to the communication network in the box. The three sensors are respectively fixed on the main down-conductors for lightning protection of the blades. The cables of the sensors enter the box from the main down-conductors through the cable gland of the box, and are connected to the lightning analyzer. See Figure 24 for the installation method.

In case of a lightning stroke, the lightning online monitoring system records the time, scale, and polarity of the lightning. When the amplitude of the lightning current exceeds the warning threshold, it uploads it to the main control system which then generates an early warning file and uploads it to SCADA to realize warning function for large current.

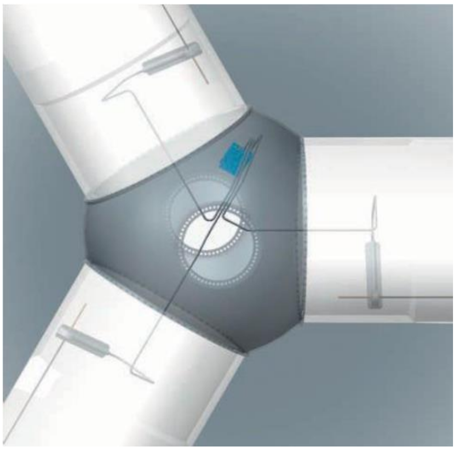


Figure 24 – Installation of online lightning monitoring system

8 Maintenance and inspection of lightning protection and earthing system

The entire lightning protection and earth-termination system shall be inspected by an independent professional agency according to GB/T 36490-2018 and IEC 61400-24-2019 every year, and a complete inspection shall be performed at least once every 2 years.