NOTE The value of frequency of damage F obtained by adding the two risk components F_2 and F_4 is overestimated. A more correct assessment of frequency could be made taking into account that a flash to ground simultaneously has influence on internal systems by direct inductive coupling and by the overvoltage induced on the connected lines, and so that their effects (component F_2 and component F_4) can be overlapped.

Each partial frequency of damage F_1, F_2, F_3, F_4, may be expressed by the following general equation:

$$F_X = N_X \cdot P_X \tag{B.16}$$

where

N_X is the number of dangerous events per annum (see also Annex A);

P_X is the probability of damage.

For evaluation of the frequency of damage related to lightning flashes to the wind turbine (S1) structure, the following relationship applies:

$$F_1 = N_D \cdot P_C \tag{B.17}$$

For evaluation of the frequency of damage related to lightning flashes near the wind turbine (S2), the following relationship applies:

$$F_2 = N_M \cdot P_M \tag{B.18}$$

For evaluation of the frequency of damage related to lightning flashes to an incoming line (S3), the following relationship applies:

$$F_3 = (N_L + N_{DJ}) \cdot P_W \tag{B.19}$$

For evaluation of the frequency of damage related to lightning flashes near a line connected to the wind turbine, the following relationship applies:

$$F_4 = N_I \cdot P_Z \tag{B.20}$$

According to IEC 62305-1 the frequency of damages F should be considered in the evaluation of the need of protection against lightning.

The following steps should be taken:

- calculation of the partial frequency of damage F_X
- calculation of the total frequency of damage F;
- identification of the tolerable frequency of damage F_T;
- comparison of the frequency of damage F with the tolerable value F_T.

B.3.5 Assessment of probability, P_X, of damage

The probabilities given in this Annex B, which is based on IEC 62305-2, are valid if protection measures conform to:

- IEC 62305-3 for protection measures to reduce injury to human beings and for protection measures to reduce physical damage;
- IEC 62305-4 for protection measures to reduce failure of internal systems.

Other values may be chosen, if justified.

B.4 Assessing the probability of damage to the wind turbine

B.4.1 Probability, P_{AT}, that a lightning flash to a wind turbine will cause dangerous touch and step voltage

The values of probability P_{AT} that a damage due to touch and step voltage by a lightning flash to the wind turbine appear, depend on the protection measures provided:

$$P_{AT} = P_{TWS} \cdot P_{am} \cdot r_t \tag{B.21}$$

where:

P_{TWS} is the probability with which a thunderstorm warning system (TWS) does not detect a lightning related event in the target area.

P_{am} is the probability that a flash to a structure will cause damage owing to touch and step voltages according to different protection measures. Values of P_{am} are given in Table B.3.

r_t is the reduction factor as a function of the type of surface of soil or floor. Values of r_t are given in Table B.4.

NOTE P_{AT} = 0 may be assumed when the structure:

– has an extensive metal framework (see IEC 62305-3:2010, 8.1 and 8.2);

– is made of reinforced concrete cast on site, with the reinforcing rods perfectly done of building; (see IEC 62305-3:2010, E.4.3);

– is protected by an LPS complying with this document;

– is provided with a meshed earth termination system and there is no metal installation that can become a part of the path of the lightning current.

Table B.3 – Values of probability, P_A, that a lightning flash to a wind turbine will cause shock to human beings owing to dangerous touch and step voltages (corresponds to IEC 62305-2)

Protection measure	P_{am}	Comments
No protection measures	1	
Warning notices	10^{-1}	
Electrical insulation of exposed down-conductor (e.g. at least 3 mm cross-linked polyethylene)	10^{-2}	Not relevant for wind turbines using the tower structure as down conductor
Effective soil equipotentialization	10^{-2}	Mandatory for wind turbines holding HV equipment according to typical electrical codes

If more than one provision has been taken, the value of P_{am} is the product of the corresponding values.

Table B.4 – Values of reduction factor r_t as a function of the type of surface of soil or floor (corresponds to IEC 62305-2)

Type of surface	Contact resistance kΩ [a]	r_t
Agricultural, concrete	≤ 1	10^{-2}
Marble, ceramic	1 to 10	10^{-3}
Gravel	10 to 100	10^{-4}
Asphalt, wood	≥ 100	10^{-5}

[a] Values measured between a 400 cm^2 electrode compressed with force of 500 N at a point of infinity.

B.4.2 Probability, P_{AD}, that a lightning flash to the wind turbine will cause injury to an exposed person on the structure

The values of probability, P_{AD}, that a lightning flash will strike a human being depend on the position of people in the exposed area, on the lightning protection (LPL) of adopted measures to protect the exposed areas of the wind turbine against direct lightning flash and on additional protection measures provided:

$$P_{AD} = P_{TWS} \cdot P_o \cdot P_{LPS} \tag{B.22}$$

where:

P_{TWS} is the probability with which a thunderstorm warning system (TWS) does not detect a lightning related event in the target area.

P_{LPS} is the probability depending on LPL of measures to protect the exposed areas of the structure against direct lightning flashes. Values of P_{LPS} are given in Table B.6.

If a TWS creates a warning message, immediate and complete evacuation of the exposed area shall be ensured. If this evacuation is not ensured or a TWS is not provided, $P_{TWS} = 1$ should be assumed. P_o is the probability factor according to the position of the person in the exposed area. Values of P_o are given in Table B.5.

Table B.5 – Values of factor P_o according to the position of a person in the exposed area (corresponds to IEC 62305-2)

Position of person	P_o
Close to the border of exposed area [a]	0,9
Far away from the border of the exposed area	0,1
[a] Within 3 m from the border of the exposed area	

Table B.6 – Values of probability, P_{LPS}, depending on the protection measures to protect the exposed areas of the wind turbine against direst lightning flash and to reduce physical damage (corresponds to IEC 62305-2)

Characteristics of wind turbine	Class of LPS	P_{LPS}
Wind turbine not protected by LPS	-	1
Wind turbine protected by LPS	IV	0,2
	III	0,1
	II	0,05
	I	0,02
Wind turbine with lightning protection of blades and nacelle conforming to LPS I with complete protection of any nacelle roof installations against direct lightning attachment and the tower acting as a continuous natural down conductor.		0,01

NOTE Values of P_{LPS} other than those in Table B.6 are possible if based on a detailed investigation – refer to IEC 62305-2:2010, Clause B.2.

B.4.3 Probability, P_B, that a lightning flash to the wind turbine will cause physical damage

The probability P_B that a flash to a wind turbine will cause physical damage is given by:

$$P_B = P_S \cdot P_{LPS} \cdot r_f \cdot r_P \tag{B.22}$$

where:

P_S is the probability that a flash to a structure will cause dangerous sparking. Values of P_S are given in Table B.7.

P_{LPS} is the probability depending on the protection measures to reduce physical damage. Values of P_{LPS} are given in Table B.4.

r_P is the reduction factor as function of provisions taken to reduce the consequences of fire. Values of r_p are given in Table B.8.

r_f is the reduction factor as function of risk of fire or explosion of the wind turbine. Values of r_f are given in Table B.9.

Table B.7 – Values of probability P_S that a flash to a wind turbine will cause dangerous sparking (corresponds to IEC 62305-2)

Type of structure	P_S
Composite materials	1
Reinforced concrete or interconnected metalwork	0,5

Table B.8 – Values of reduction factor r_p as a function of provisions taken to reduce the consequences of fire (corresponds to IEC 62305-2)

Provisions	r_p
No provisions	1
One of the following provisions: extinguishers; fixed manually operated extinguishing installations[a]; manual alarm installations; hydrants; fire proof compartments; protected escape routes	0,5
One of the following provisions: fixed automatically operated extinguishing installations; automatic alarm installations[b].	0,2
[a] Provisons are effective only if operated by persons trained for this purpose.	
[b] Only if protected against overvoltages and other damage and if firemen can arrive within 10 min.	

If more than one provision has been taken, the value of r_p should be taken as the lowest of the relevant values.

NOTE 1 Risk of explosion is not considered relevant for wind turbines.

Table B.9 – Values of reduction factor r_f as a function of risk of fire of the wind turbine (corresponds to IEC 62305-2)

Risk of fire	r_f
High	10^{-1}
Ordinary	10^{-2}
Low	10^{-3}
None	0

NOTE 2 Structures considered as having a high risk of fire can be assumed to be structures with surface materials (blades and nacelle roofs) made of combustible materials with a specific fire load larger than 800 MJ/m^2.

NOTE 3 Structures considered as having an ordinary risk of fire can be assumed to be structures with surface materials (blades and nacelle roofs) made of combustible materials with a specific fire load between 800 MJ/m^2 and 400 MJ/m^2.

NOTE 4 Structures considered as having a low risk of fire can be assumed to be structures with surface materials (blades and nacelle roofs) made of combustible materials with a specific fire load less than 400 MJ/m^2.

NOTE 5 Specific fire load is the ratio of the energy of the total amount of the combustible material in a structure and the overall surface of the structure.

B.4.4 Probability, P_C, that a lightning flash to the wind turbine will cause failure of internal systems

A coordinated SPD system is suitable as a protection measure to reduce P_C.

The probability, P_C, that a lightning flash to the wind turbine will cause failure of internal systems is given by:

$$P_C = P_e \cdot P_{SPD} \cdot C_{LD} \quad \text{(B.23)}$$

P_{SPD} depends on the coordinated SPD system conforming to IEC 62305-4 and on internal system characteristics. Refer to IEC 62305-2:2010, Annex B for values of P_{SPD}. For low-voltage systems and telecommunication systems.

P_e is the probability that equipment is exposed to damaging event,

C_{LD} is a factor depending on shielding, grounding and isolation conditions of the line to which the internal system is connected. Values of C_{LD} are given in IEC 62305-2 Annex B.

Values of P_{SPD} depend on the lightning protection level (LPL) for which the SPDs are designed.

NOTE 1 Only "coordinated SPD protection" is suitable as a protection measure to reduce P_C. Coordinated SPD protection is effective to reduce P_C only if the wind turbine hub, nacelle and tower are protected with an LPS, or if the structures with continuous metal or reinforced concrete framework act as a natural LPS where bonding and earthing requirements of IEC 62305-3 are satisfied.

NOTE 2 Shielding internal systems connected to external lines consisting of lightning protective cable or systems with wiring in lightning protective cable ducts, metallic conduit or metallic tubes; may not require the use of coordinated protection.

B.4.5 Probability, P_M, that a lightning flash near the wind turbine will cause failure of internal systems

Due to the height of the wind turbines, most lightning flashes will strike the turbines directly and not in the area near the wind turbine. Furthermore, the large metal structures will shield the internal systems. Hence the probability that a lightning flash near the wind turbine will cause failure of internal systems can be considered negligible when the wind turbine hub, nacelle and tower are protected with an LPS or when the structures with continuous metal or reinforced concrete framework act as a natural LPS where bonding and earthing requirements of IEC 62305-3 are satisfied.

NOTE R_M can be neglected for wind turbines with a total height of more than 100 m. In this case, the conventional distance of 350 m is usually covered by direct strikes

B.4.6 Probability, P_U, that a lightning flash to a service line will cause injury to human beings owing to touch voltage

The values of probability, P_U, of injury to human beings owing to touch voltage caused by lightning flashes to a service line (power cable or communication cable) entering the wind turbine depends on the characteristics of the service line shield, the impulse withstand voltage of internal systems connected to the service line, the typical protection measures (physical restrictions, warning notices, etc. [see Table B.8]) and the SPDs provided at the entrance of the service line in accordance with IEC 62305-3.

NOTE A coordinated SPD protection in accordance with IEC 62305-4 is not necessary to reduce P_U in this case. SPD(s) in accordance with IEC 62305-3 are sufficient.

The value of P_U is given by:

$$P_U = P_{am} \cdot P_{EB} \cdot P_{LD} \cdot P_{TWS} \cdot C_{LD} \cdot r_t \quad (B.24)$$

where:

P_{am} depends on protection measures against touch voltages, such as physical restrictions or warning notices. Values of P_{am} are given in IEC 62305-2:2010, Annex B.

P_{TWS} is the probability with which a thunderstorm warning system (TWS) does not detect a lightning related event in the target area.

P_{LD} is the probability of failure of internal systems due to a flash to the connected line depending on the line characteristics. Values of P_{LD} are given in IEC 62305-2:2010, Annex B.

P_{EB} depends on the equipotential bonding conforming to IEC 62305-3. Values of P_{EB} are given in IEC 62305-2:2010, Annex B.

C_{LD} is a factor depending on shielding, grounding and isolation conditions of the line. Values of C_{LD} are given in IEC 62305-2:2010, Annex B.

r_t is the reduction factor as a function of the type of surface of soil or floor. Values of r_t are given in IEC 62305-2:2010, Annex B.

B.4.7 Probability, P_V, that a lightning flash to a service line will cause physical damage

The values of probability, P_V, of physical damage caused by a lightning flash to a service line entering the wind turbine depend on the characteristics of the service line shield, the impulse withstand voltage of internal systems connected to the service line and the SPDs provided for equipotential bonding at the entrance of the line in accordance with IEC 62305-3.

NOTE A coordinated SPD protection in accordance with IEC 62305-4 is not necessary to reduce P_V in this case. SPDs in accordance with IEC 62305-3 are sufficient.

The value of P_V is given by:

$$P_V = P_{EB} \cdot P_{LD} \cdot P_{TWS} \cdot C_{LD} \cdot r_f \cdot r_p \quad (B.25)$$

where:

P_{EB} depends on the equipotential bonding conforming to IEC 62305-3. Values of P_{EB} are given in IEC 62305-2:2010, Annex B;

P_{LD} is the probability of failure of internal systems due to a flash to the connected line depending on the line characteristics. Values of P_{LD} are given in IEC 62305-2:2010, Annex B;

P_{TWS} is the probability of a thunderstorm warning system (TWS) not detecting a lightning-related event in the target area;

C_{LD} is a factor depending on shielding, grounding and isolation conditions of the line. Values of C_{LD} are given in IEC 62305-2:2010, Annex B;

r_f is the reduction factor as a of provisions taken to reduce the consequences of fire. Values of r_f are given in Table B.9;

r_p is the reduction factor as a function of provisions taken to reduce the consequences of fire. Values of r_p are given in Table B.8.

B.4.8 Probability, P_W, that a lightning flash to a service line will cause failure of internal systems

The values of probability, P_W, of failure of internal systems caused by lightning flash to a service line entering the wind turbine depend on the characteristics of the service line shielding, the impulse withstand voltage of internal systems connected to the service line and the coordinated SPD system provided.

The value of P_W is given by:

$$P_W = P_e \cdot P_{SPD} \cdot P_{TWS} \cdot P_{LD} \cdot C_{LD} \tag{B.26}$$

where:

P_e is the probability that equipment is exposed to damaging event;

P_{SPD} depends on the coordinated SPD system conforming to IEC 62305-4 and on internal system characteristics. Refer to IEC 62305-2:2010, Annex B for values of P_{SPD} for low-voltage systems and telecommunication systems;

P_{TWS} is the probability of a thunderstorm warning system (TWS) not detecting a lightning-related event in the target area;

P_{LD} is the probability of failure of internal systems due to a flash to the connected line depending on the line characteristics. Values of P_{LD} are given in IEC 62305-2:2010, Annex B.

C_{LD} is a factor depending on shielding, grounding and isolation conditions of the line to which the internal system is connected. Values of C_{LD} are given in IEC 62305-2:2010, Annex B.

B.4.9 Probability, P_Z, that a lightning flash near an incoming service line will cause failure of internal systems

The values of probability, P_Z, that a lightning flash near to a service line entering the structure will cause a failure of internal systems depend on the characteristics of the service line shield, the impulse withstand voltage of the system connected to the service line and protection measures provided.

The value of P_Z is given by:

$$P_Z = P_e \cdot P_{SPD} \cdot P_{TWS} \cdot P_{LI} \cdot C_{LI} \tag{B.27}$$

where:

P_e is the probability that equipment is exposed to damaging event;

P_{SPD} depends on the coordinated SPD system conforming to IEC 62305-4 and on internal system characteristics. Refer to IEC 62305-2, Annex B for values of P_{SPD} for low-voltage systems and telecommunication systems;

P_{TWS} is the probability of a thunderstorm warning system (TWS) not detecting a lightning-related event in the target area;

P_{LI} is the probability of failure of internal systems due to a flash near the connected line depending on the line and equipment characteristics. Values of P_{LD} are given in Table B.12 and IEC 62305-2:2010, Annex B;

C_{LI} is a factor depending on shielding, grounding and isolation conditions of the line. Values of C_{LI} are given in IEC 62305-2:2010, Annex B.

Table B.10 – Values of probability P_{LI} depending on the line type and the impulse withstand voltage U_W of the equipment (corresponds to IEC 62305-2)

Line type	Voltage U_W in kV				
	1	1,5	2,5	4	6
	P_{LI}				
Power lines	1	0,6	0,3	0,16	0,1
TLC lines	1	0,5	0,2	0,08	0,04

B.4.10 Probability P_P that a person will be in a dangerous place

The probability P_P that a person will be in a dangerous place depends on the time t_z in hours per year for which the persons are present in the dangerous place:

$$P_P = t_z / 8\,760 \tag{B.28}$$

NOTE Where the value of t_z is not known, the ratio t_z / 8 760 should equate to the value of 1.

B.4.11 Probability P_e that equipment will be exposed to damaging event

The probability P_e that undamaged equipment is exposed to a damaging event depends on the time t_e in hours per year of exposure of equipment to the damaging event:

$$P_e = t_e / 8\,760 \tag{B.29}$$

NOTE Where the value of t_e is not known, the ratio t_e / 8 760 should equate to the value of 1.

B.5 Assessing the amount of loss L_X in a wind turbine

B.5.1 General

L_X represents the mean amount of loss consequent to a specified type of damage owing to a dangerous event, expressed in relative way related to the maximum amount of loss in the wind turbine to be protected.

The values of loss L_X should be evaluated and fixed by the lightning protection designer (or the owner of the wind turbine). The mean values of loss L_X in a wind turbine given here are considered typical values. Different values may be assigned by each national committee (or agreed between the manufacturer and the customer).

B.5.2 Mean relative loss per dangerous event

The loss L_X refers to the mean relative amount of a specified type of damage for one dangerous event caused by a lightning flash considering both its extent and effects.

The loss L_X varies with the cause of damage (D_{1D}, D_{1T}, D_2 and D_3).

The loss L_X should be determined for each zone of the wind turbine into which it is divided.

The loss L_X for each zone can be determined in accordance with Tables B.11 and B.12.

Table B.11 – Loss values for each zone (corresponds to IEC 62305-2)

Typical loss
$L_{AT} = L_{UT} = L_T$
$L_{AD} = L_D$
$L_B = L_V = L_F = L_{F1} = L_{F2}$

where

L_T is the typical mean ratio of persons injured by touch and step voltages related to the total number of persons in the zone, owing to one dangerous event (see Table B.12);

L_D is the typical mean ratio of persons injured by direct lightning stroke related to the total number of persons exposed in the zone, owing to one dangerous event (see Table B.12);

L_{F1} is the typical mean ratio of persons injured by fire or explosion in relation to the total number of persons in the zone, owing to one dangerous event (see Table B.12);

L_{F2} is the typical mean ratio of physical damage of social relevance by fire or explosion related to the maximum amount of damage of social relevance in the zone, owing to one dangerous event (see Table C.2);

L_O is the typical mean ratio of persons injured by failure of internal systems in relation to the total number of persons in the zone, owing to one dangerous event (see Table B.12).

NOTE 1 Risk of explosion is not considered relevant for wind turbines.

NOTE 2 According to IEC 62305-2, a loss of social relevance is a loss which involves injury to human beings, unavailability of service to the public, damage of cultural heritage and in general costs that the society is forced to pay.

Table B.12 – Typical mean values of L_T, L_D, L_F and L_O (corresponds to IEC 62305-2)

Type of zones	L_T	L_D	L_{F1}	L_{F2}	L_O
Critical zones [a)]	0,01	0,1	0,01	0,1	0,0001
Normal zones [b)]	0,01	0,1	0,01	0,05	0,00001

[a)] Zones with essential equipment for carrying out processes (control, communication)

[b)] Zones open to the public

NOTE 3 Values of Table B.12 refer to continuous attendance of people in the structure.

Annex C
(informative)

Protection methods for blades

C.1 General

C.1.1 Types of blades and types of protection methods for blades

Wind turbine blades are large hollow structures manufactured of composite materials, such as glass fibre reinforced plastic (GFRP), wood, wood laminate and carbon fibre reinforced plastic (CFRP). CFRP is typically used for reinforcement of the blade structure or for special components, such as the tip shaft for blades with tip brakes (tip-stall braking mechanism). Some parts and discrete components such as mounting flanges, balancing weights, hinges, assembly brackets for split blades, bearings, wires, electrical wiring, springs and fixtures are made of metal. Lightning strikes will attach to blades even without metallic components, and whenever a lightning arc is formed inside the blade, damage is severe.

The two sides or surface skins of a blade are normally manufactured as separate sheets of glass fibre, or other composite materials, glued together along the leading and trailing edges and to an internal load-carrying structure also made of glass fibre. Inside the blade, there are large air-filled cavities formed by the surface skin and the internal structure commonly stretching the entire length of the blade. Alternatively, the blade skins can supply the mechanical strength of the blade without a load-carrying spar. Finally, blades may be fabricated in one piece using advanced resin casting techniques without the above-mentioned glued interfaces.

There are several types of blades depending on the control and braking mechanism employed, and the use of insulating and conductive composites. Five main types are shown in Figure C.1.

Type A blades use a flap (aileron) in the outer part of the leading edge for braking. On type A blades, lightning attachment points are often found on the flap steel hinges, and severe damage is often seen since the cross-section of the steel wires used for operating the flap is usually insufficient for conducting the lightning current.

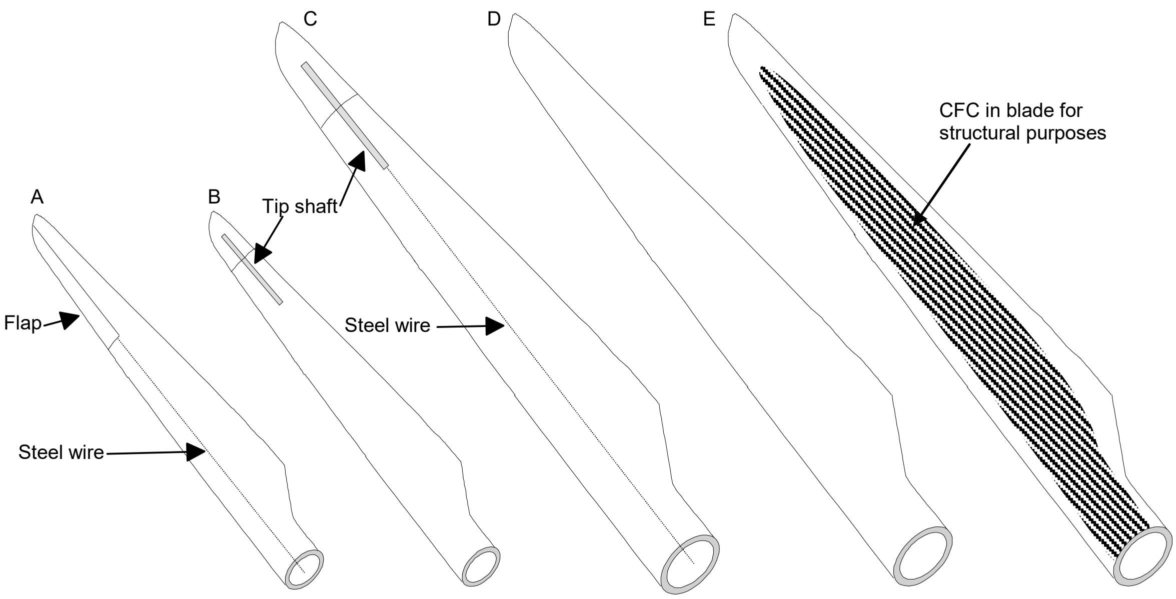

Figure C.1 – Types of wind turbine blades

Type B blades use a tip brake which is retained by a spring and released at excessive rotational speed by centrifugal force. With type B blades, lightning attachment points are predominantly seen within a few tens of centimetres from the outermost tip, or on the sides of the tip at the position of the outermost end of the tip shaft. From the attachment point, a lightning arc is formed inside the tip section to the outermost end of the tip shaft, and from the other end of the shaft, an arc is formed inside the main blade down to the steel mounting flange at the blade root. Such internal arcs invariably cause catastrophic destruction to the blade. Blades of types A and B were commonly used with older wind turbines as large as 100 kW.

Type C is a blade with a tip brake controlled by a steel wire. With type C blades, lightning attachment points are predominantly found within a few tens of centimetres from the outermost tip of the blade, or on the sides of the tip at the position of the outermost end of the tip shaft. With type C as with type B blades, a lightning arc formed inside the tip section between the attachment point and the outermost end of the shaft causes severe damage. On type C blades, damage to the main blade is mostly seen when the steel wire has been unable to carry the lightning current. Steel wires used for this purpose are of a minimum diameter of 10 mm or 12 mm for 17-m-long blades. Such wires are capable of conducting most lightning currents, and thereby protecting the main blade from damage (see Clause C.6 for further discussion on dimensioning of protection systems).

Type D is a blade constructed entirely from non-conducting materials. Experiences with non-conducting blades are that, as with the other types of blades, lightning attachment points are mostly found close to the tip. Compared to the other types of blades, attachment points can also be found randomly distributed at other positions along the length of the blade.

Type E is a blade where some of the structural components are made with carbon fibre reinforced plastics (CFRP), since it has high stiffness for a given weight. Depending on the specific design, CFRP can be used as reinforcement of the blade skin, as well as for load carrying structural components, such as the internal spar. Owing to its electrical properties, CFRP should be coordinated carefully with the lightning protection system to ensure the necessary separation distance, electrical insulation and/or current carrying capability. The issues of lightning protection of wind turbine blades containing CFRP are treated in Clause C.3.

Lightning flashes attaching to non-conducting blades or to insulating parts of blades containing conducting parts may at least partly be explained by the fact that pollution and water make such blades more conductive over time. High-voltage laboratory experiments have shown that arc attachments occur to a non-conducting blade sprayed with saline water practically as if the blade was metallic. Another part of the explanation is that the blades are simply in the way of lightning striking the wind turbine. In addition, it is known that discharges develop along a surface more easily than through air, and especially if the surface is contaminated with saline pollution and water. In any case, practical experience shows that severe lightning damage to both non-conducting blades (type D) and blades containing CFRP (type E) is quite common and hence lightning protection is needed.

C.1.2 Blade damage mechanism

Typical types of damage at the lightning attachment points are delamination and incineration of the surface composite material, and heating or melting of metallic components serving as the attachment point.

The most severe damage to wind turbine blades occur, however, when lightning forms high energy arcs inside the blade due to attachment to an unprotected part of the blade skin. The arcs may form in the air volume inside the blade or along the internal surfaces. Another type of damage occurs when the lightning current or part of it is conducted in or between layers of composite materials or in glue cracks in connection with the down conductor system, presumably because such layers and cracks hold some moisture. The pressure shock wave caused by such internal arcs may literally explode the blade, ripping the blade surface skins apart along the edges and from the internal carrying spar. All grades of damage are seen