

TECHNICAL SPECIFICATION



**Wind energy generation systems –
Part 29: Marking and lighting of wind turbines**

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TECHNICAL SPECIFICATION



**Wind energy generation systems –
Part 29: Marking and lighting of wind turbines**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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WIND ENERGY GENERATION SYSTEMS –

Part 29: Marking and lighting of wind turbines

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IEC TS 61400-29 has been prepared by IEC technical committee 88: Wind energy generation systems. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
88/894/DTS	88/913/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 61400 series, published under the general title *Wind energy generation systems*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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INTRODUCTION

As the Wind Industry grows, airspace users (military, civil and emergency aircraft) need to continue to operate safely in an environment that includes wind turbines, and the two industries need to exist harmoniously.

To assist in creating a safe environment, some wind turbines are required to have aeronautical lights so they can be seen by airspace users. Unfortunately, some of these lights can have an adverse visual impact, which produces lighting pollution for nearby communities.

Annex 14 to the Convention on International Civil Aviation published by the International Civil Aviation Organization (ICAO) contains Standards and Recommended Practices (specifications) that prescribe the marking and lighting of wind turbines. However, many countries have interpreted these specifications differently and issued their own guidelines and conditions to suit their local requirements. Therefore, there is little homogeneity and wind turbine manufacturers are obliged to produce bespoke designs to suit specific markets.

There are currently approximately 20 different marking and lighting specifications for countries such as Belgium, Brazil, Canada, Finland, France, Germany and Japan. In many cases, those requirements are very similar. However, they often differ in terms of light intensity, positioning and markings, which could lead to confusion and reduction in air safety.

In some cases wind farms that are separated by only a few kilometers are marked and illuminated in accordance with different guidelines. This includes the transition from the onshore to the offshore wind environment, and vice versa.

This document reflects the need to allow the coexistence of wind turbines and aviation, ensuring that the ICAO Standards and Recommended Practices are followed but also balances with the environmental impact on nearby residents.

References to national regulations are important in this document, given the regional specific circumstances required in many cases. Users should be aware that national and/or "local" regulations can apply. The aim is to encourage safe airspace but with minimum light pollution.

NOTE Throughout the drafting process for this document, the National Guidelines, related to lighting and marking wind turbines, of many ICAO Member States have been used as a resource. However, the guidance documents are too numerous to list and, therefore, reference to any non-normative documents has been omitted.

WIND ENERGY GENERATION SYSTEMS –

Part 29: Marking and lighting of wind turbines

1 Scope

This part of IEC 61400, which is a Technical Specification, instils good practice for aviation lighting and marking of wind turbines in both onshore and offshore domains. Consideration is given to visible lighting and infrared (IR) lighting, which is necessary to maintain conspicuity to users of night vision goggles (NVGs).

ICAO Annex 14 Standards and Recommended Practices have been used as the basis to develop supplementary harmonised specifications to assist with implementation.

This document provides a set of technical requirements for marking and lighting of wind turbines with a tip height from/at 150 meters and below 315 meters Above Ground Level (AGL), or Above Mean Sea Level (AMSL) for offshore sites. This will improve situational awareness for airspace users, maintain safety of aircraft flying in the vicinity of wind turbines, and provide additional tools to assist with the reduction in environmental impacts consistent with aviation safety objectives. In the event that the wind turbine development exceeds 315 m tip height and the regulatory frameworks is updated to cater for these heights, this document will be reviewed and amended as necessary. In the absence of an update to the regulatory framework, the guidance in this document is to be followed as a minimum.

In some cases, lighting may be required for wind turbines at or below 150 meters tip height. However, this is not in the scope of this document and in these situations, the developer should contact the relevant National Aviation Authority or Planning Authority for further guidance.

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.

IEC 61400-3-1:2019, *Wind energy generation systems - Part 3-1: Design requirements for fixed offshore wind turbines*

IEC 62443-4-2:2019, *Security for industrial automation and control systems - Part 4-2: Technical security requirements for IACS components*

International Civil Aviation Organization, Annex 14, *Aerodromes – Volume I – Aerodromes Design and Operations*. 8th Edition, July 2018

International Civil Aviation Organization, *Aerodrome Design Manual – Part 4 – Visual Aids* (Doc 9157 – Part 4). 5th Edition. 2021

European Union Aviation Safety Agency (EASA), *Certification Specifications and Guidance Material for Aerodromes Design CS-ADR-DSN*, Issue 5, June 2021

Federal Aviation Administration. Advisory Circular 150/5345-43J – *Specification for Obstruction Lighting Equipment*, 11 March 2019

Federal Aviation Administration. 70/7460-1M – *Obstruction Marking and Lighting*, 16 November 2020

IALA Recommendation R0139 (O-139) , *The Marking of Man-Made Offshore Structures*, Edition 3.0, December 2021

NOTE Although too many to list explicitly, in drafting this document the national guidelines of many ICAO Member States, for lighting and marking wind turbines, have been given due consideration. In some cases, specific examples have been provided from national guidelines to enhance the international guidance in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1

aerodrome

defined area (including any buildings, installations and equipment) intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft

3.2

aviation Obstacle Lights

warning lights (visual and infrared) used to reduce hazards to aircraft by indicating the presence of the obstacles

3.3

aviation Obstacle Markings

warning markings used to reduce hazards to aircraft by indicating the presence of the obstacles

3.4

candela

International System of Units (SI) base unit of luminous intensity that denotes the luminous power per unit solid angle emitted by a point light source in a particular direction

3.5

cluster configuration wind farm

wind turbines arranged in a non-linear configuration (see 3.10)

3.6

daytime light

period(s) of the day when the background luminance is above 500 cd/m²

3.7

effective luminous intensity

effective luminous intensity of a flashing light is equal to the intensity of a steady-burning (fixed) light of the same colour which produces the same visual range under identical conditions of observation

3.8

grid configuration wind farm

wind turbines arranged in a geographical shape such as a square or a rectangle, with each turbine placed a consistent distance apart in rows

3.9

LED technology

light emitting diode (LED) is a semiconductor light source that emits light if electrical current flows through it

Note 1 to entry: It can emit visible, IR or ultraviolet radiation depending on the semiconductor material and the doping wavelength. LEDs are energy efficient and have a long lifespan.

3.10

linear configuration wind farm

wind turbines arranged in linear configuration are placed in a row along a ridgeline, the face of a mountain, or along the borders of a hill or field

Note 1 to entry: The line may be ragged in shape or be periodically broken.

3.11

luminance

luminous intensity per unit emitting area. It is a photometric quantity which may be applied to light sources but also to light which is reflected or passes through a particular area

Note 1 to entry: Its unit is 'Candela per Square Meter' (cd/m^2).

3.12

nanometer

unit of length in the metric system, equal to one billionth of a meter

Note 1 to entry: The international unit for nanometer, nm is $10^{(-9)}$ m.

3.13

nautical mile

unit of measurement used in both air and marine navigation

Note 1 to entry: The international nautical mile is exactly 1 852 meters.

3.14

night-time light

period(s) of the day when the background luminance is below 50 cd/m^2

3.15

night vision goggles

helmet mounted night vision enhancement aid that utilises image intensifier technology and is sensitive to light wavelengths between 660 and 920 nanometers

3.16

obstacle

fixed (whether temporary or permanent) and mobile objects, or parts thereof, that:

- a) are located on an area intended for the surface movement of aircraft; or
- b) extend above a defined surface intended to protect aircraft in flight; or
- c) stand outside those defined surfaces assessed as being a hazard to air navigation

3.17

offshore wind turbine

wind turbine that converts kinetic energy in the wind into electrical energy and has a sub-structure that is subject to hydrodynamic loading and is founded on the seabed, including floating structures

3.18

onshore wind turbine

wind turbine that converts kinetic energy in the wind into electrical energy located on a land mass

3.19

tip height of a wind turbine

maximum height AGL (onshore) and AMSL (offshore), of the tip of the turbine blades at their highest point

3.20

twilight-time light

light during the period(s) of the day when the background luminance is between 50 and 500 cd/m²

3.21

visibility

aeronautical visibility is the greater of:

- a) the greatest distance at which a black object of suitable dimensions, situated near the ground, can be seen and recognised when observed against a bright background, represented by the meteorological optical range (MOR)
- b) the greatest distance at which lights in the vicinity of 1000 candelas (cd) can be seen and identified against an unlit background, which varies with the background illumination

3.22

wind farm

group of two or more wind turbines in the same geographical area, used to produce electricity

3.23

wind turbine

structure intended for the production of electrical power; comprising a support tower, a nacelle, a generator unit, and rotor blades that are caused to rotate by the wind

4 Symbols and abbreviated terms

4.1 Abbreviations

ADS	aircraft detection system
AGL	above ground level
AIP	Aeronautical Information Publication
AMSL	above mean sea level
cd	candela
CIE	International Commission on Illumination
EASA	European Union Aviation Safety Agency
FAA	Federal Aviation Administration
fpm	flashes per minute
IALA	International Association of Lighthouse Authorities
ICAO	International Civil Aviation Organization
IEC	International Electrotechnical Commission
IR	infrared
ISO	International Organization for Standardization
JORF	Journal officiel de la République française (Official Journal of the French Republic)
LED	light emitting diode
MOR	meteorological optical range
NM	nautical mile
NOTAM	notice to airmen

NVG	night vision goggles
PAS	Publicly Available Specifications
RAL	Reichs-Ausschuß für Lieferbedingungen und Gütesicherung (Imperial Commission for Delivery Terms and Quality Assurance)
SARPs	Standards and Recommended Practices
SI	International System of Units
TS	Technical Specification
UK	United Kingdom
USA	United States of America
UTC	coordinated universal time
VFR	visual flight rules

5 Marking of a wind turbine and wind farms

5.1 General

ICAO recommends rotor blades, nacelle and upper 2/3 of the supporting tower of all wind turbines be painted white. Due to a number of factors, including gaining planning permission, grey is the generally accepted colour choice for onshore turbines, to enhance conspicuity. Colours are based on colorimetric quantities and luminance factor.

This document only recommends the use of colour bands in geographic areas that have lengthy periods of snow cover, such as Alaska or Nordic countries, and where it is deemed necessary, the rotor blades and the tower of the turbine may have a band of Traffic Red as given in Annex A to provide additional contrast against the snow in accordance with national requirements.

In the offshore environment, if there are railings on the nacelle for a helicopter winch area, it is recommended that the railings are painted a conspicuous colour, preferably red, in accordance with IEC 61400-30, *Safety of Wind Turbine Generator Systems – General principles for design*. Should railings be installed, the 360° visibility of the light must be maintained.

5.2 Reflectance or luminance factor

The luminance factor of grey colours shall be greater than or equal to 0,4. The luminance factor of white colours is to be greater than or equal to 0,6.

Table 1 shows a list of the most commonly white and grey colours used on wind turbines. Any other colour may be used as long as it complies with the above mentioned requirements of luminance factor.

Table 1 – Wind turbines paint colours

Name	RAL	Luminance Factor (β)
Grey white	9002	0,68
Signal white	9003	0,84
Pure white	9010	0,85
Traffic white	9016	0,85
Papyrus white	9018	0,61
Light grey	7035	0,56
Agate grey	7038	0,43
Telegrey 4	7047	0,57

The specifications of surface colours given above are described in Annex B.

6 Lighting of a wind turbine and wind farms

6.1 International Civil Aviation Organization requirements

There are over 190 countries that are signatories to the Chicago Convention of 1947, which established the International Civil Aviation Organization. Article 12 of the Convention requires Member States to keep their own regulations uniform “to the greatest possible extent” with the Standards and Recommended Practices (SARPs) promulgated by ICAO. Under Article 37, States are obliged to “collaborate in securing the highest practicable degree of uniformity” in their domestic law, regulations and procedures with their domestic law, regulations and procedures with SARPs.

ICAO Annex 14, paragraph 6.2.4.1, which is a standard, states that:

- “A wind turbine shall be marked and/or lighted if it is determined to be an obstacle.”

This is supported by a reference to paragraph 4.3.2, which notes that:

- “in areas beyond the limits of the obstacle limitation surfaces [of aerodromes], at least those objects which extend to a height of 150 m or more above ground elevation should be regarded as obstacles, unless a special aeronautical study indicates that they do not constitute a hazard to aeroplanes.”

The application of lighting requirements specified in this document is to ensure that an obstacle to air navigation remains visible and supporting standardisation in accordance with ICAO SARPs.

6.2 Planning considerations

Prior to submitting an application to the local planning authority to request approval to construct a wind turbine or wind farm, the applicant shall inform the local civil aviation authorities of their intention to develop or build a wind turbine or wind farm.

To achieve this, aviation obstacle lights might be installed on the top of the nacelle. Additionally, it may also have a level of obstacle lights around the tower, depending on the total height of the wind turbine.

It is a requirement that a 360° lighting coverage in the horizontal plane is accomplished, as viewed from an aircrew perspective when approaching from all directions. To achieve this requirement the number of physical light sources shall be minimised. By employing the lowest number of light sources the environmental impact is reduced in all situations. Consideration to maximising each lighting unit's beam angle should be given to achieve this 360° view, whilst keeping the number of light units as low as possible.

In considering the 360° lighting requirement, it is acknowledged that each individual turbine will not be able to meet this continuously when viewed from any direction. This is due to obscuration caused by its own blades and adjacent turbines. It is not possible to specify a minimum number of lights but it is essential that any proposed lighting scheme ensures the windfarm is lit contiguously so that it can be seen from any angle.

Wind turbines can create hazards for a number of reasons, however, only the specific physical impact on aviation that requires aviation lighting is dealt with in this document. Other risks and hazards associated with wind turbines are addressed in IEC TS 61400-31, *Wind energy generation systems – Part 31: Siting Risk Assessment*.

6.3 Wind turbines with a tip height less than 150 m

Wind turbines with a total height of less than 150 m are not considered an obstacle in this document. Therefore, they do not need to be equipped with aviation obstacle lights, either on the top of the nacelle or on the tower, unless otherwise indicated by an aeronautical study or requested by an aviation authority.

If night lighting is installed, wind turbines should be equipped with medium-intensity Type B or C lights on the top of the nacelle as described in 6.7.

If two lights are installed, the lights should be mounted on the top of the nacelle and arranged horizontally with enough separation to ensure an unobstructed view of at least one light by an aircraft approaching from any direction.

6.4 Wind turbines with a tip height of 150 m or more

Wind turbines from/at 150 m to 315 m in overall height shall be equipped as described below. However, the aviation lights on one or more wind turbines within a wind farm can be omitted as described in 6.5.

- At night, red medium-intensity Type B or C lights according to 6.7 shall be mounted on the top of the nacelle and arranged horizontally with enough separation to ensure an unobstructed view of at least one light by an aircraft approaching from any direction.
- If daytime lighting is installed, white medium-intensity Type A lights according to 6.7 shall be mounted on the top of the nacelle and arranged horizontally with enough separation to ensure an unobstructed view of at least one light by an aircraft approaching from any direction. Alternately, high-intensity Type A or B lights might be required by aviation authorities under certain circumstances.
- If tower lights are installed, one level of low-intensity Type B lights according to 6.7 shall be placed at a point midway between the top of the nacelle and ground level. The location shall have a vertical tolerance of ± 20 m subject to national authority approval. Consideration should be given to locating the lights to be below the lowest pass point of the rotor blades to minimise flicker effects but remaining within the ± 20 m tolerance. The lights shall be arranged horizontally with enough separation to ensure a 360° unobstructed view of at least one light by an aircraft approaching from any direction. Due to factors such as effectiveness and acceptance, flashing lights are not recommended.

The lighting requirement configurations are illustrated in Figure 1.

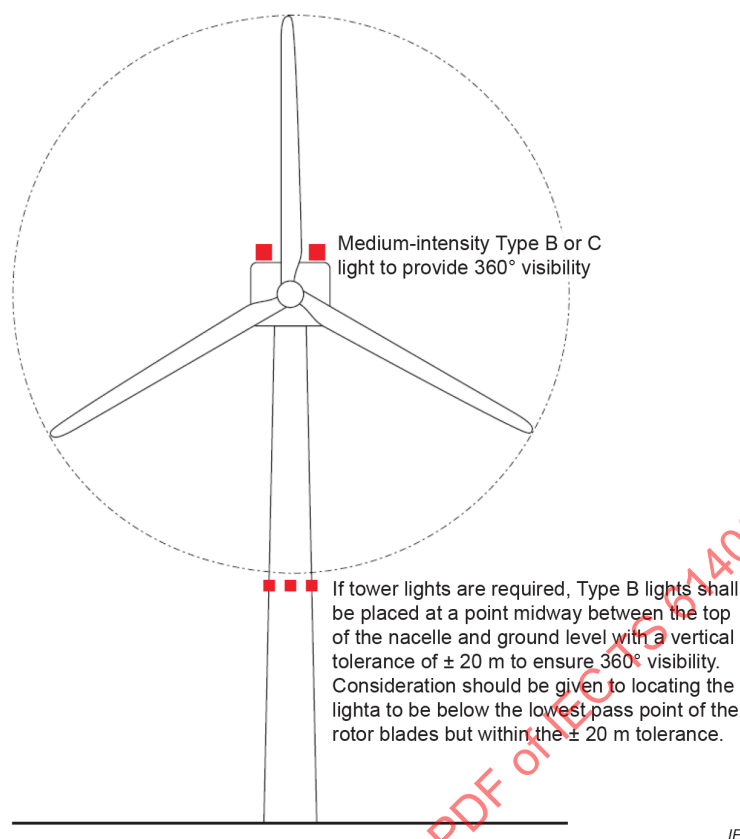


Figure 1 – Lighting configurations for wind turbines exceeding 150 m

6.5 Lighting of wind farms

6.5.1 General

The aviation lights on one or more wind turbines within a wind farm can be omitted, depending on the terrain features, geographic location and the overall layout of the wind farm.

As a general rule, the maximum distance between lit turbines shall be no more than 900 m for onshore wind turbines and no more than 1 800 m (1 nautical mile (NM)) for offshore wind turbines. This is in accordance with ICAO Annex 14 for onshore but it is noted that as wind turbine sizes increase with a subsequent impact on spacing between individual turbines, the need to balance aviation safety requirements with environmental lighting impact will become more challenging. Consequently, there may be a need for wind farm developers to engage with national authorities to develop a safety case to support greater spacing. In addition, national authorities may be requested to refer this to the appropriate ICAO working group for further consideration.

As shown in Figure 2, the wind turbines at each end of the line as well as any breakage or change of direction should be fitted with aviation lights.

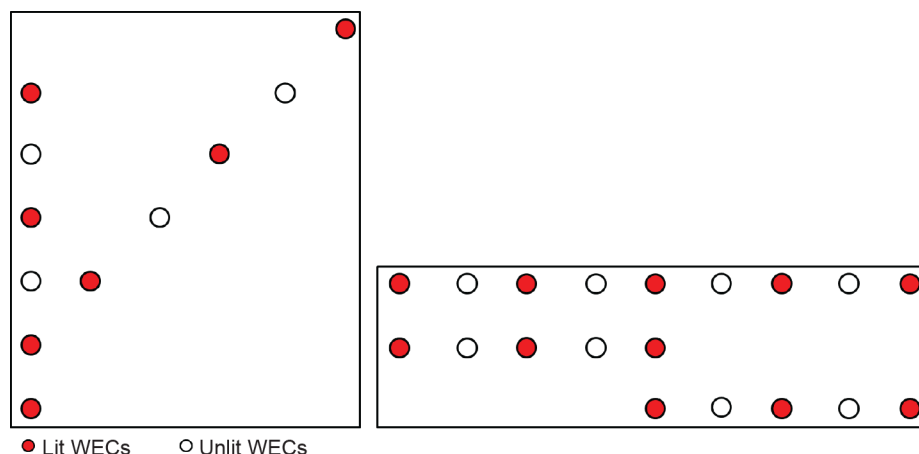


Figure 2 – Linear configuration wind farm

To determine the periphery of a wind farm, three successive wind turbines are considered to be aligned if the intermediate wind turbine is located at a distance equal or less than 200 m from the line segment connecting the two outer wind turbines. Due to a number of variables, e.g. topography, it may not be possible to apply this rule absolutely in all cases and some variation to this calculation may be required. Further discussion with the aviation and planning authorities may be needed.

A basic layout of linear alignment of wind turbines is shown in Figure 3. It applies for both onshore and offshore. The values for an offshore alignment are in brackets and written in blue.

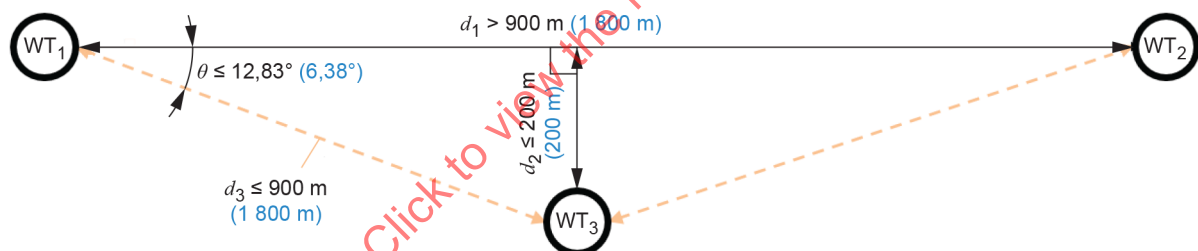


Figure 3 – Basic layout of a linear alignment

ICAO Annex 14 specifies lighting at longitudinal intervals not exceeding 900 m. However, it is stated in respect of wind turbines that the maximum spacing between the lights along the perimeter should be respected unless a dedicated assessment shows that a greater spacing can be used. While the 900 m requirement is particularly relevant to onshore wind turbines, especially given the turbine size at the time the text was drafted, offshore turbines have significantly increased in height. Consequently the spacing between turbines has increased to ensure efficient operation. This, in conjunction with increased spacing to allow for helicopter access, means that individual turbine spacing generally exceeds 900 m by a significant margin. Consequently, there has been a realistic approach by some administrations to consider an increased spacing of 1 800 m in the offshore environment as long as it does not present an increased safety risk. As this approach is not inconsistent with ICAO Annex 14, developers are advised to consult with the relevant National Aviation Authority to gain approval for their lighting proposals.

Methods for minimizing the visual impact of offshore and onshore wind farm are described in Clause 8.

For grid configuration: Wind turbines on the corners should be fitted with aviation lights, and then use the same concept described in 6.5.2 to ensure there is no gap exceeding 900 m without unlit turbines.

For cluster configuration: A turbine from the outer perimeter of the farm needs to be lit and selected as starting point, the next wind turbine along the outer perimeter is lighted assuring that there is no space of more than 900 m without unlit turbines. This pattern should be continued until the starting point is reached. In the event that the gap between the lights on the last segment of turbines is significantly short, it may be appropriate to move the lights along the perimeter of the cluster back toward the starting point to present a well-balanced perimeter of lights. If the across distance of the wind farm is greater than 1 800 m, the most central wind turbines should be fitted with aviation lights as described in 6.5.2 and 6.5.3.

6.5.2 Onshore wind farms

If the farm layout is configured in a non-linear arrangement, like a grid or a cluster configuration, the following steps should be applied in the order as shown in 1) to 4). The lighting configuration should apply to both night and day lighting:

- 1) The corners and the periphery of the wind turbine farm are to be lit, the maximum distance between lit turbines shall be no more than 900 m in order that the outline of the windfarm can be clearly delineated by aviators;
- 2) If the tip height of any wind turbine that is significantly higher in elevation than other wind turbines in close proximity, that turbine should be lit independently of its position. In making the assessment to identify which turbines need to be lit in this scenario, the topography and lateral separation of the individual turbines will need to be assessed on a specific site basis. However, as guidance, if the height of other turbine nacelle(s) in the wind farm exceed the height of a plane extending at an elevation of 10° above the horizontal from the nacelle of a turbine that is required to be lit, then obstacle lighting must be fitted and operated on the identified wind turbine. The 10° value is based on a practical assessment and may need to be adjusted to meet local circumstances based on the advice of regulatory authorities. It should also be noted that this approach may not meet the requirements in every terrain circumstance and an alternative approach of setting a criteria of lighting any additional turbine which has a significant height difference, e.g. > 20 m agl, from those that are lit could be used as an alternative means of assessment;
- 3) Any wind turbine that is located at a distance greater than 900 m from the nearest marked wind turbine should be also lit;
- 4) To avoid any potential light pollution, a distinction can be made, if agreed with the national regulatory authorities. An example of this is to tilt the aviation light beam angle upwards between 0° and 3° to the horizontal plane, dependant on turbine height;
- 5) Any wind turbine inside the cluster of wind turbines located at a distance greater than 1 800 m (1 NM) from the nearest marked wind turbine must be also lit unless there are significant discrepancies in elevations referred to in 2) above.

Additionally, if some turbines are located apart from the main group, i.e. if one or more turbines protrude from the general limits of the wind farm, they should also be lit.

Figure 4 shows the night-time lighting configuration of an onshore wind farm. However, the steps mentioned in 1) to 4) should apply to daytime lighting as well.

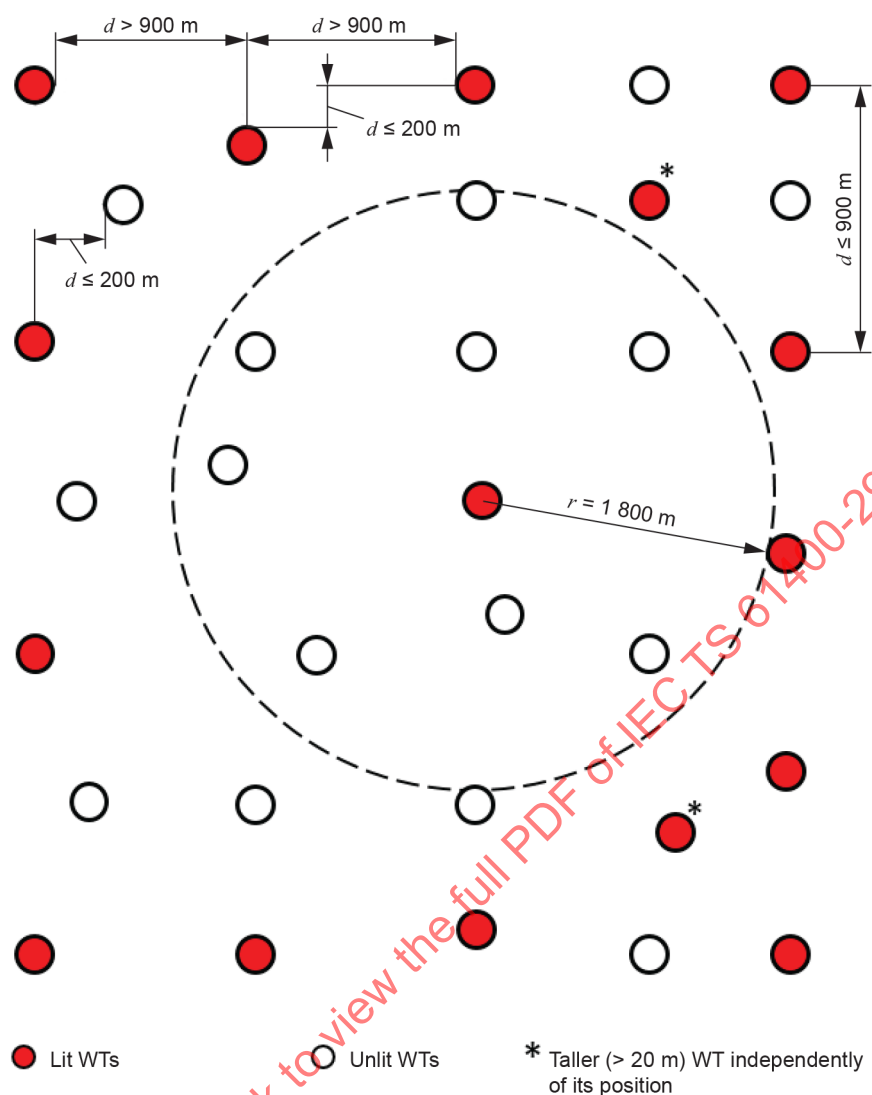


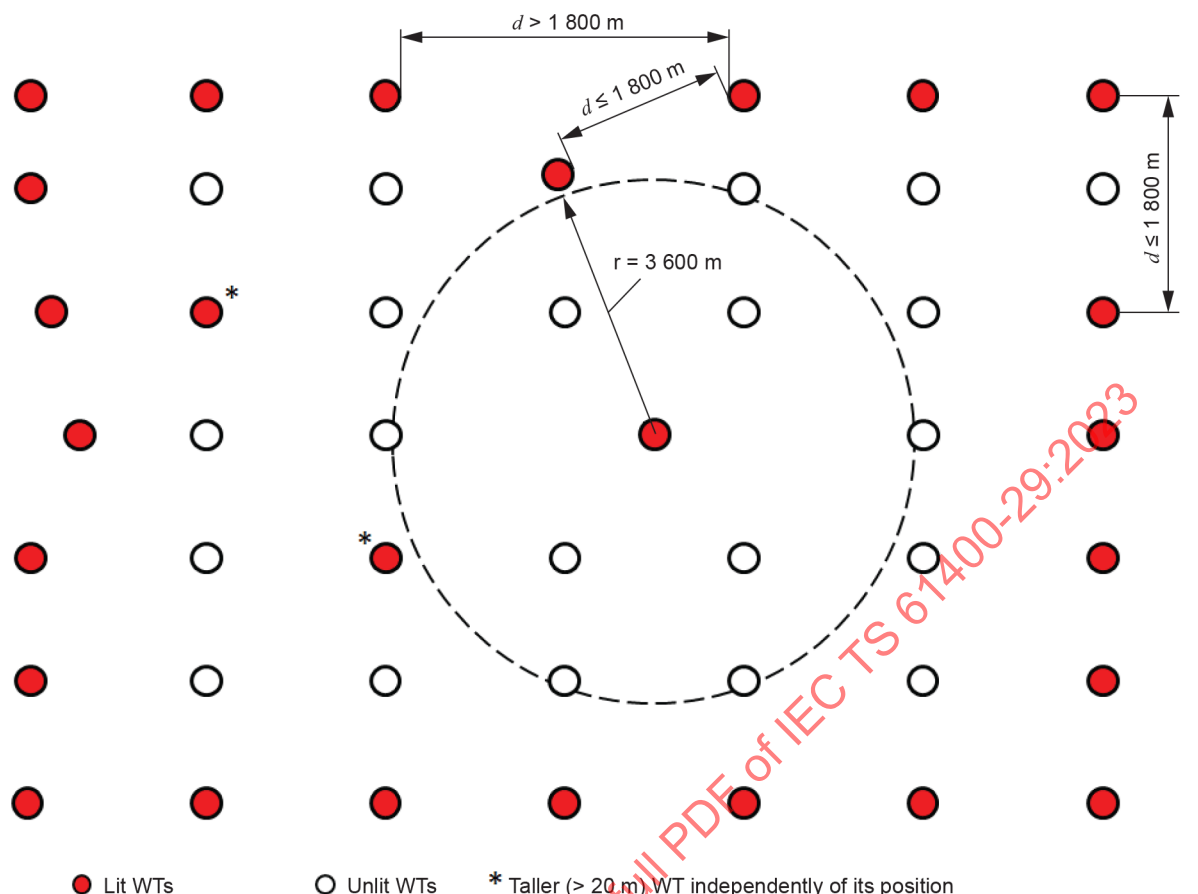
Figure 4 – Lighting configuration of an onshore wind farm

6.5.3 Offshore wind farms

The following steps should be applied in the order as shown below for the lighting configuration of offshore wind farms on the basis that the turbines are of equal height:

- 1) The periphery (corners) of the wind turbine farm is to be lit, the maximum distance between lit turbines shall be no more than 1 800 m (1 NM). However, in accordance with the note in 6.5, this may need to be updated as wind turbine sizes increase.
- 2) Any wind turbine inside the cluster of wind turbines located at a distance greater than 3 600 m (2 NM) from the nearest marked wind turbine must be also lit.

Figure 5 shows a night-time lighting configuration of an offshore wind farm. However, the steps mentioned in 1) and 2) should apply to day lighting as well.



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Figure 5 – Lighting configuration of an offshore wind farm

6.5.4 Deconfliction with marine lighting

To avoid any potential confusion between maritime and aeronautical lighting of objects, there are a number of distinctions that can be made, if agreed with the national regulatory authorities. Two examples of this are:

- Tilting the aviation light beam angle upwards between 0° and 3° to the horizontal plane, to avoid confusion with marine lights and reduce light pollution
- Using a flashing Morse Code 'W' light on the turbine hub as used in United Kingdom (UK) waters

The scope of this document only covers lighting of wind farms in the aeronautical domain. However, it is important to be aware of the International Association of Lighthouse Authorities (IALA) document, 'The Marking of Man-made Offshore Structures', which follows a similar approach to lighting obstacles to this document in the marine domain.

6.6 Wind farms near aerodromes

All wind turbines in the vicinity of any aerodrome might be considered as potential obstacles to flight operations. Those wind turbines can be marked and lit according to previous chapters of this document. However, those requirements could be varied by local authorities if they determine additional lighting and/or marking requirements.

A developer applying to build a wind farm in the vicinity of any aerodromes should provide an aeronautical risk assessment. This risk assessment should be conducted by a suitably qualified person/organisation and it should examine the effect of the proposed wind turbines on the operation of aircraft at or near the aerodrome.

The resulting assessment should be made available to local authorities to assist in the assessment of any potential risk to aviation operation.

6.7 Lights specifications

6.7.1 General

Wind turbines that are required to be lit shall be equipped with low, medium or high intensity aviation obstacle lights. It is recommended that these lights shall be in accordance with the specification in Table 2 and the definition of light colours described in Annex C.

Table 2 – Characteristics of obstacle lights¹

Light Type	Colour	Signal Type/ (flash rate)	Minimum average luminous intensity (cd) at a vertical elevation angle of 0° at given Background Luminance		
			Day (Above 500 cd/m ²)	Twilight (50 to 500 cd/m ²)	Night (Below 50 cd/m ²)
Low-intensity, Type B	Red	Fixed	N/A	N/A	32
Low-intensity, Type E	Red	Flashing (20 flashes per minute (fpm))	N/A	N/A	32
Medium-intensity, Type A	White	Flashing (20 fpm)	20 000	20 000	2 000
Medium-intensity, Type B	Red	Flashing (20 fpm)	N/A	N/A	2 000
Medium-intensity, Type C	Red	Fixed	N/A	N/A	2 000
High-intensity, Type A	White	Flashing (40 fpm)	200 000	20 000	2 000
High-intensity, Type B	White	Flashing (40 fpm)	100 000	20 000	2 000

Light distribution for low, medium or high intensity aviation obstacle lights are described in Annex D.

Additionally, it is recommended that the aviation obstacle lights of a wind turbine or wind turbines within a wind farm are configured as follows:

- Have a back-up power supply in case of power loss and comply with 6.7.2
- Have a fault feedback signal which detects malfunction for any lights
- Have a flash period for night-time of ½ on, ½ off for table 2 Low-intensity type E, medium-intensity B and high intensity type A and B lights types

¹ Table 2 is an extract from ICAO Annex 14. An aim of this document is to reduce the number of lighting configurations available to Member States to standardise the options as much as is practicable, therefore, the number of light types is reduced and specific values are provided for flash rates rather than a range of values.

- Have a flash duration for day-time of 100 ms +/- 10 ms² for table 2 medium intensity lights type A and high intensity type A and B lights types
- The aviation obstacle lights shall begin their flashing sequence at 00.00.00 Coordinated Universal Time (UTC) with an admissible tolerance of ±1/20 second (0,05 second)

The photometrical and colorimetric performances shall be type tested by an independent laboratory which is accredited according to ISO/IEC 17025 for photometrical and colorimetric measurements.

6.7.2 Battery back-up time

If battery back-ups are installed, the lights on a wind turbine or wind farm shall be continuous and are designed so that the power supply is backed up by an automatic device which triggers within 15 seconds in case of a failure and/or the wind turbine ceases operation. The power source for the lighting back-up supply shall have an independent operating capacity of six hours to support the landing of already airborne Visual Flight Rules (VFR) flights and the process of publishing a Notice to Airmen (NOTAM) through the authorities. The times stated should be used unless a different duration is instructed by the national regulatory authorities.

Although the operators are responsible for the correct operation of the aviation obstacle lights, this time is not meant to repair the power loss of the wind turbines but to notify the relevant local authorities of the situation.

When the power loss has been solved, the operator must also report this to the local authorities.

6.7.3 Night vision goggle compatibility

6.7.3.1 General

NVGs are used by military and civilian organisations to allow flight at night, at flight levels potentially lower than the maximum height of wind turbines. Hence, lighting specifically appropriate for NVG users may be necessary in certain countries or regions where NVG use is prevalent. In providing guidance, attempts have been made to identify common standards which may have relevance on a global basis. This has not been successful and, as a consequence, only general guidance is given. To resolve IR lighting and NVG issues, developers are advised to engage directly with the relevant national civil and military authorities to determine the specific requirements.

NVGs utilise image intensifier technology sensitive over the visual and near IR wavebands, however, when used in cockpits it is necessary to filter the response of the NVG and cockpit lighting in a complementary manner to minimise interference from the cockpit lighting to the NVG.

There are two issues applicable to compatibility with NVGs:

- The intended effect of cockpit compatibility filtering in the NVG is to severely limit sensitivity of the image intensifier to emissions from the cockpit instruments in the visible region, from instruments emitting blue, green, red and white lighting. By careful design of optical filters fitted to the instruments any emission in the IR is mostly eliminated. An unintended consequence occurs where visible LED lighting, which due to the technology does not emit IR, is fitted to a wind turbine. The visibility of this lighting, when viewed through the NVG, may be significantly lower than as viewed directly with the naked eye, depending on factors such as range and atmospheric conditions. In this case it is necessary to provide IR content in addition to the visible lighting, to enhance visibility to NVG users.

² In the absence of any standard Flash Pattern in ICAO Annex 14, the value of 100 ms has been adopted from Federal Aviation Administration (FAA) guidance document AC 150/5345-43. The +/- 10 ms provides some additional flexibility for national regulation variation.

- ii) There may be regions where visible lighting of wind turbines is not required by civil regulations or is undesirable due to adverse impact on local populations at night but where flight by NVG users is still necessary. In this case it would be beneficial, and may be necessary, to provide IR lighting specifically, to provide visibility only to NVG users.

6.7.3.2 Flashing

As the NVG scene is monochrome to the viewer (white or green) there is no colour discrimination between aviation obstacle lighting and the general scene, which may include other lighting. Therefore flashing is essential. Flash rates should be as per visible lighting (defined elsewhere in this document), and synchronous with the visible lighting where this is present.

6.7.3.3 Intensity

Intensity within the IR region must be sufficient to provide visibility at a significant range but not high enough to cause large halos within the NVG image to be seen around the light source, which can significantly degrade the visibility of the adjacent region.

6.7.4 Monitoring and control

To ensure availability and sufficient time to react to an outage i.e. issue a NOTAM, aviation obstacle lights shall be monitored remotely, in accordance with the appropriate regulatory authority. The following parameters of aviation obstacle lights shall be monitored as a minimum:

- On/Off status of each light
- Fault status of the light
- Set and current mode³
- Power supply and battery back-up status
- Synchronisation status (if applicable)
- Fault status of the visibility meter (if applicable)

The aviation obstacle lights shall be able to be switched on and adjusted to 100 % intensity remotely thereby overriding the local control by photocell, visibility meter or other dimming technique. Remote switching and intensity adjustments shall be possible for individual as well as groups of aviation obstacle lights. Switching off aviation obstacle lights remotely or reducing their intensity remotely shall only be performed by a competent person through a password protected system with trace logging of such activity. The password shall meet the standard set out in IEC 62443-4-2.

All on/off status changes and changes to the intensity of each light shall be logged for a period of at least 12 months. Additionally, all outages shall be logged and used to calculate the annual availability of each light.

7 Considerations during construction

For a higher level of safety, all wind turbines or wind farms should be marked on the aviation charts before their construction, in accordance with national aviation authority requirements.

If required and to ensure conspicuity of a wind turbine or wind farm at night or poor visibility during construction, all turbines are lit with a single temporary light at the highest point (excluding the rotor blades) once they reach a height of 150 m or more, until the final lighting is turned on.

³ Potential modes: day/night; dimmed to xx %; no aircraft (aircraft detection system in use).

If required, during the construction period, notification of lighting arrangements should be in accordance with national regulatory requirements.

As the height of the structure continues to increase, the temporary lights are relocated to the uppermost part of the structure (excluding the rotor blades) and they may be removed for periods when they would interfere with construction and/or personnel. The lights should be seen by pilots from any direction (360°).

It is understood that the wind farm site will not be connected to the national grid, until it becomes operational. Therefore, solar or battery powered systems would be adequate for the purpose, and for the optimization of the battery power consumption, it is recommended to use a low-Intensity Type E light without IR component. It is assumed that the visual inspection of the lights is ensured by the personnel on site.

The final lighting configuration is described in Clause 6 and it shall be applied as soon as the wind turbine is connected to the national grid and operational.

8 Reduction of light pollution

8.1 General

National and local planning authorities, based on input from local residents and some environmental organisations, have sought options to minimize additional lighting, particularly in dark skies areas. Clause 8 describes methods that seek to provide a suitable warning to flight crew of vertical obstacles and maintain compliance with the spirit of ICAO obstacle lighting requirements.

8.2 Dimming

8.2.1 Scope

The luminous intensity of the medium and high Intensity lights is designed to be within the visible range of aircraft in poor visibility conditions. When the visibility conditions are good enough, the luminous intensity of the lights may be reduced.

The visible range of the lights can be calculated according to ICAO Doc 9157 Aerodrome Design Manual Part 4, Table 15-1.

8.2.2 Operation

If dimming is required, wind farms shall be equipped with visibility range sensors that measure the meteorological visibility. The distribution of sensors and their operation are to be in accordance with the following:

- The distribution of the sensors should be related to the size of the wind farm and its related topography to provide adequate visibility coverage;
- The lowest meteorological visibility measured by all installed sensors determines the visibility of the whole wind farm;
- In the case of a failure of a sensor, the luminous intensity of the whole wind farm shall be set to the default intensity stipulated by the applicable regulation;
- Activity data of all sensors shall be logged for at least 30 days and include time, visible range, luminous intensity reduction and system status.

8.2.3 Visible ranges

If the meteorological visibility is good enough, the luminous intensity of obstacle lights may be dimmed. The dimmed luminous intensity shall be no lower than that needed to support minimum visible detection according to local VFR regulation, often set at 5 km/3 NM.

8.3 Aircraft detection systems

8.3.1 General

Where there is a need to minimize obstacle light exposure to meet environmental concerns, an aircraft detection system (ADS) may be installed as possible mitigation so that obstacle lighting is operated only when required by an approaching aircraft. Such systems have already been installed in some countries and are based either on active/passive radar detection or by using the signals transmitted by aircraft transponders through the application of cooperative surveillance techniques. The selection of the appropriate technology will depend on the scenario and national policy. Whatever approach is chosen, the system will need to activate the lighting when an aircraft is within a defined area in the vicinity of the wind farm and subsequently turn the lighting off when the aircraft leaves the area. However, the principle requirements as detailed below will need to be taken into consideration.

8.3.2 Operation and boundaries

There are currently no internationally agreed standards for ADS for lighting activation but the issue is under consideration within ICAO. The following identifies the performance principles but the specific operating parameters will need to be agreed with the appropriate national authority:

- a) The ADS should be designed to cover the complete area of the monitored airspace above the wind farm and out to lateral limits to ensure the safe detection and tracking of aircraft entering the designated area. The system performance must be capable of detecting aircraft at a range of speeds and directional tracks to meet the aviation obstacle lighting safety requirements. The horizontal range of activation could be based on aircraft speed (to allow a minimum transit time to reach the obstacle), or an absolute range to ensure timely activation of the lights.
- b) The vertical detection coverage must be sufficient to ensure activation is appropriate to the topography surrounding the wind farm and taking into account the airspace structure. A coverage of 300 m/1 000 ft above the highest point above the obstacle is considered an appropriate minimum. In determining the vertical coverage and taking into account the system performance, consideration must be given to ensuring that an excessive false alarm rate does not result in unnecessary and inappropriate light activation.
- c) National policy, airspace requirements, topography or local requirements will determine the optimum set of parameters together with the most suitable means of activation. However, to ensure the system meets the specifics of each wind farm consistent with national requirements, determination of whether the detection should use active or cooperative surveillance technology must be discussed with the relevant national authorities.
- d) The ADS performance in activating the lighting will be determined by the relevant national policy and regulatory requirements. This may require a safety case in relation to a specific wind farm and detection system characteristics or may be covered in a generic safety case.
- e) The light shall remain on until the aircraft leaves the coverage volume. Should the signal of the aircraft be lost the light shall stay switched on for a period of time agreed with the national regulatory authority.
- f) The ADS must be able to detect an aircraft with a cross-sectional area of 1 m² or more within the area of operational interest, which is consistent with accepted aviation performance criteria. If the detection system is based on cooperative surveillance, it must provide comparable performance integrity.
- g) The performance and characteristics of the ADS must be consistent with the standards required by the relevant aviation authorities to ensure the integrity and sustainability of the surveillance environment and its supporting elements are maintained. The details of the system employed in relation to a specific wind farm will need to be promulgated by the appropriate means, e.g. Aeronautical Information Publication (AIP), VFR charts, etc, to ensure pilots are aware of the specific characteristics.

8.3.3 Integrity monitoring

The ADS shall have continuous monitoring to detect any degradation in detection probability. In the event of performance loss or failure of the detection system, a reversionary capability is required to ensure the regulatory requirements for obstacle lighting are met.

Data on sensor performance, detected flight activity, cooperative surveillance data (if applicable) and lighting activation/deactivation shall be logged for at least 30 days and include time and system status.

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Annex A (informative)

Wind turbines located in areas with lengthy periods of snow

Wind turbines of more than 150 m AGL, which are located in geographic areas where there is snow most of the year, an alternative marking as described in Clause 5 may be applied. This is determined by an aeronautical study or by the local authorities.

It is recommended that the rotor blades are painted with a 6 m red stipe and the supporting tower with a 3 m red ring starting at $45\text{ m} \pm 5\text{ m}$ AGL as shown in Figure A.1. The marking can be arranged offset for technical reasons or due to local characteristics, e.g. due to the height of the surrounding vegetation.

RAL 3020 is considered to be the most suitable option for a day marking. RAL 3024 is also permitted as an alternative colour.

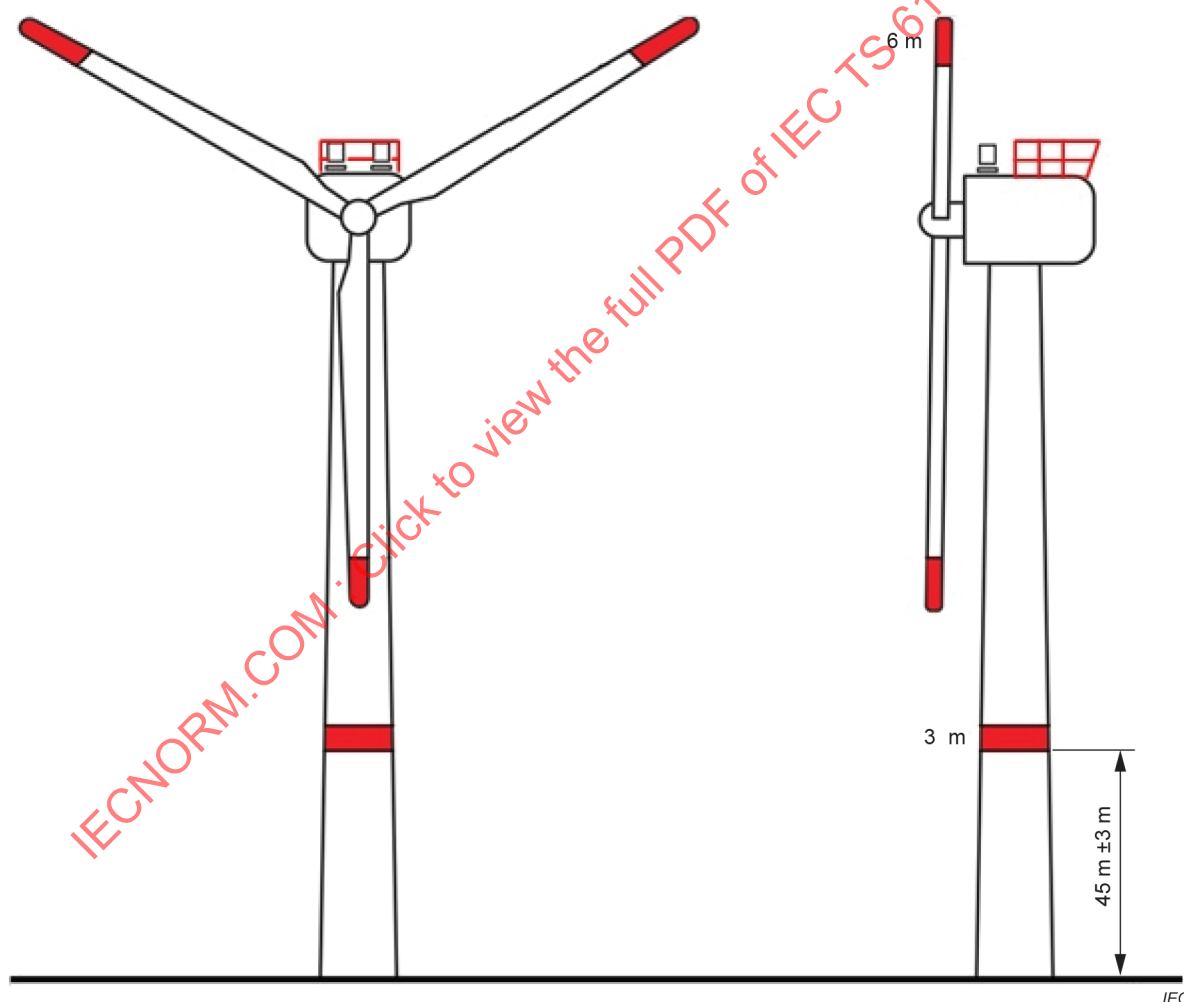


Figure A.1 – Wind turbines in areas with lengthy periods of snow