GUIDANCE DOCUMENT

Fire Safety in Wind Turbines

Selection of Protection Systems

EXTINGUISHING SECTION

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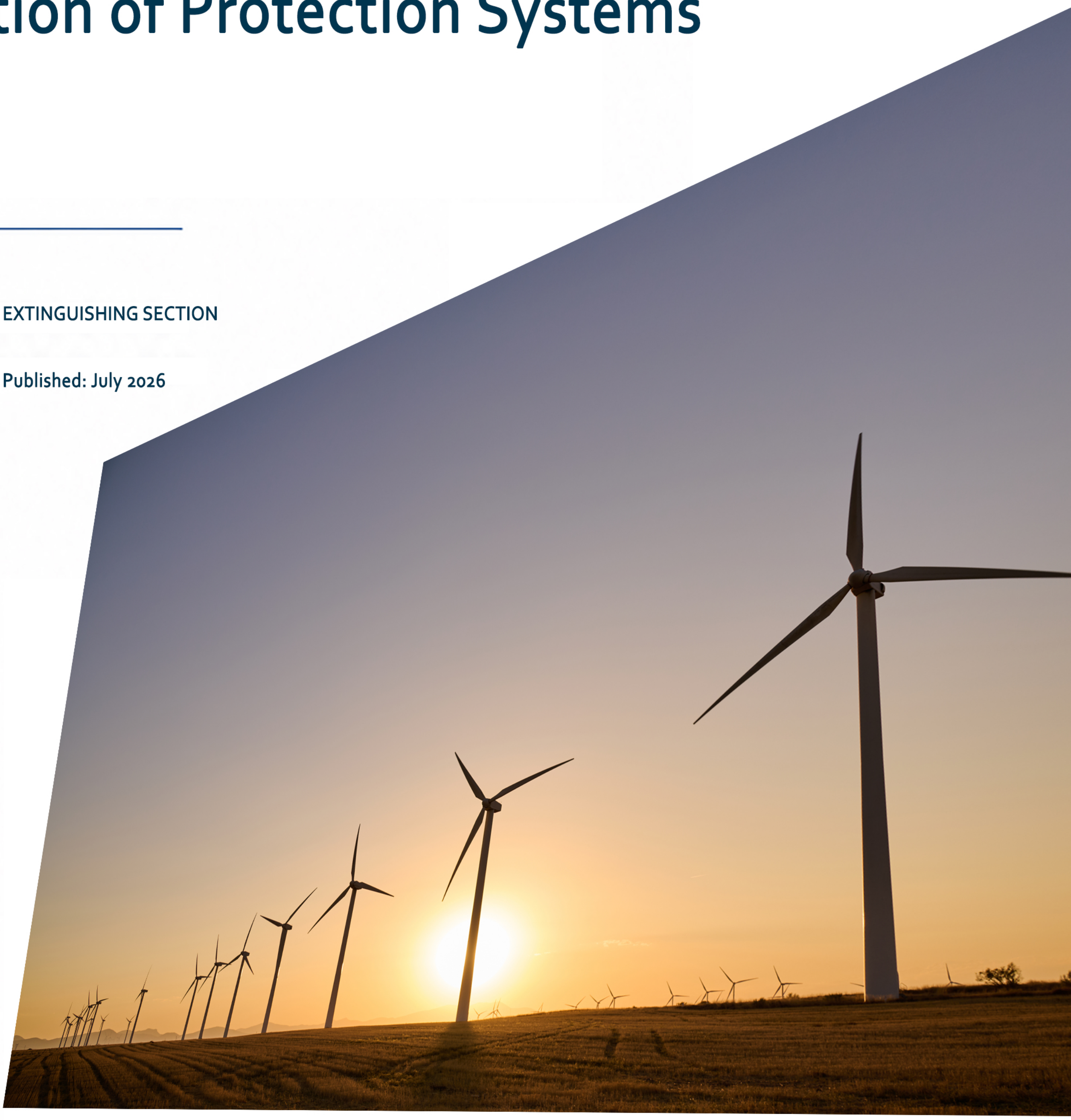

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Revision table

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FOREWORD

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Note: The English version of this document is the approved Euralarm reference document.

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1. Introduction

This document provides guidance on fire safety for wind turbine installations, covering both onshore and offshore applications across the operational lifecycle. It addresses the identification, assessment, and mitigation of fire risks associated with key turbine components and systems, including nacelles, hubs, towers, transformers, and associated electrical and hydraulic equipment.

The guidance supports a structured, risk-based approach to fire prevention, detection, containment, and protection (i.e. suppression and extinguishing), aligned with the IEC 61400 series and recognised international practice.

It applies to new installations, repowering projects, and existing turbines where modifications, ageing, or changes in operating conditions may influence fire risk, and is intended for designers, owners, operators, insurers, permitting authorities, and other stakeholders.

This document does not replace statutory obligations, OEM instructions, or jurisdiction-specific requirements, nor does it prescribe specific fire protection technologies. Responsibility for detailed design, system selection, and compliance remains with the relevant parties.

2. Summary and Key Conclusions

Fire safety in wind turbines is not governed by a single, harmonised international code. Instead, it is addressed through a combination of international design standards, national regulations, and insurer-driven guidance, most of which require a risk-based approach rather than prescribing specific protection measures.

Wind turbines contain multiple credible ignition sources and significant combustible materials, and while the probability of fire may be low, the consequences are frequently severe, often resulting in total asset loss and wider environmental and reputational impacts. The prevailing assumption that a turbine fire is inevitably catastrophic has shaped both design practice and insurance models, despite evidence that many fires originate in identifiable components and are therefore technically addressable.

This guidance sets out a structured fire protection strategy aligned with the IEC 61400 series, emphasising prevention, early detection, and proportionate intervention across the turbine lifecycle. It demonstrates that early identification of abnormal conditions and the considered application of automatic fire detection and automatic suppression/extinguishing - complementing passive protection and lightning mitigation - can materially reduce escalation, limit damage, and improve resilience. By moving beyond minimum compliance and treating fire protection as an integrated system rather than an isolated requirement, designers, operators, insurers, and regulators can reduce environmental harm, improve availability and insurability, and strengthen confidence in wind energy as a sustainable and responsible technology.

The traditional assumption that a turbine fire will inevitably lead to a total and catastrophic loss is increasingly being challenged and is neither technically necessary nor aligned with current expectations regarding safety and environmental responsibility.

3. Regulation and Standards

3.1. Introduction

Fire safety in wind turbines is not currently addressed by a single international code, but by a combination of international design standards, fire protection guidelines, insurance-driven requirements, and other national safety regulations. Collectively, these establish a risk-based framework within which fire hazards must be identified, assessed, and mitigated with or without the need for an onboard fire suppression system.

3.2. Fire Hazard Identification and Risk-Based Design Approach

Two internationally applicable standards are relevant to safety considerations for wind turbines. ISO 19353 "Safety of machinery — Fire prevention and fire protection" focuses on the general principles for identifying fire hazards in machinery and performing fire risk assessments, whilst IEC TS 61400 30 "Safety of wind turbine generators — General principles for design" is a Technical Specification that defines the essential health and safety requirements specific to the design of wind turbines. It also addresses requirements for safe operation, inspection, maintenance, installation, and decommissioning. Both standards emphasise the necessity of conducting a risk assessment, through which the risk of fire is to be reduced to acceptable levels by means of the machinery design and operational instructions without prescribing the potential for integrating a fire suppression system onboard.

In addition, for the US market, NFPA 850, "Fire Protection for Electric Generating Plants," addresses fire protection for power generation facilities in general, with specific reference to wind turbines in Chapter 13. In this chapter, the standard establishes the requirement for a Fire Protection Design Basis Document (FPDBD) to identify and address potential fire and explosion hazards. It also defines the framework of the overall safety strategy for the appropriate protection of this application, while referencing the applicable NFPA standards to be followed for the selected fire suppression systems.

3.3. Insurer-driven property loss prevention frameworks

On the other hand, publicly available guidelines addressing fire hazards associated with wind turbine operation are also available from insurance providers. For example, CFPA E Guideline No. 22 adopts and expands the principles of VdS 3523, focusing on the need for automatic fire detection and automatic stationary extinguishing systems. It also highlights other critical operational measures essential to the sequence of a fire protection strategy, such as early detection, automatic shutdown, and grid disconnection.

This differs from FM Global's approach to wind turbine fire protection, which is prevention-focused rather than suppression-driven. It identifies key fire hazards such as nacelle oils, hydraulic systems, electrical equipment, and transformers and states that the primary objective is "control of ignition sources and prevention of a fire within the nacelle". The FM strategy emphasizes non-combustible construction, automatic fire detection with turbine shutdown and oil system isolation, and emergency planning, without mandating automatic fire suppression systems.

3.4. Observable regulatory gaps

The available standards and guidance documents do not offer a harmonised fire code for wind turbines. The fire risk assessments mandated in some jurisdictions or the prescriptive design standard requirements regarding the use of automatic fire suppression technology are not universally deployed. As a result, the responsibility for determining appropriate protection systems frequently rests with the designer, operator, insurer and permitting authority acting collectively and in certain occasions.

4. Protection Considerations

Wind turbine technology continues to evolve at a rapid pace. Turbines are increasing in size, power output, and system complexity, driven by the need for greater efficiency and lower levelized cost of energy. While some original equipment manufacturers (OEMs) are actively working to reduce certain hazards - such as lowering volumes of lubricating oils or adopting alternative drivetrain concepts - the fundamental nature of a wind turbine remains unchanged: it is a large, elevated energy conversion system, often operating continuously and/or remotely, converting significant amounts of kinetic energy into electrical energy.

Their remote nature precludes prompt human intervention, in the event of a fire situation, in addition to physical impediments to access if and when a first responder can attend – such as the height of the turbine. In offshore installations in particular, turbines are frequently electrically interconnected ("daisy chained"), meaning that a single turbine may carry not only its own generated power but also the output of several neighbouring machines. This increases both the electrical energy present within the structure and the potential consequences of failures in shared components or systems.

In simple terms, wind turbines contain numerous combustible materials and multiple credible ignition sources. While the probability of fire may be low on a per turbine basis, the consequences of fire - when it does occur - are typically severe. Many presume any fire event will result in full and catastrophic loss. Protection considerations must therefore focus not only on likelihood, but also on consequence, resilience, and the ability to intervene early.

4.1. Protection Goals

The primary goals of fire protection in wind turbines should extend beyond the immediate preservation of life, essential though that is. Protection measures should aim to:

- Prevent fires where reasonably practicable;
- Detect and suppress fires at the earliest possible stage;
- Limit fire spread and escalation within the turbine;
- Reduce the likelihood of total and catastrophic loss of the asset;
- Minimise environmental harm, including secondary impacts beyond the turbine footprint (e.g. wildfire, crop contamination, marine life harm, etc);
- Support business continuity, availability, and insurability over the turbine's operational life.

While emergency response and evacuation procedures are critical - particularly given the challenges of escape from nacelles located more than 100 metres above ground or sea level - modern fire protection strategies should not assume that the only viable outcome of a turbine fire is complete burn out.

4.2. Key Risks

Fire risk within a wind turbine arises from the interaction of ignition sources, combustible materials, and operating conditions.

Most ignition risks are internal to the turbine and associated with normal operation or maintenance activities. These include electrical faults (such as failures in converters, transformers, switchgear, or cabling), mechanical friction or overheating (for example in brakes, bearings, gearboxes, or yaw systems), hydraulic system failures, and maintenance activities involving heat or electrical intervention. Also, braking procedures, can elevate fire risk since the brake will produce high temperature and can spark; in the presence of oil leaks and combustible materials this can result in a fire.

At the same time, turbines contain substantial quantities of combustible materials. These include hydraulic and transformer oils, lubricants, polymeric insulation, plastics, composite materials such as fiberglass reinforced plastics used in nacelles and blades, and extensive cabling and electronic components. The confined and elevated nature of the nacelle can exacerbate fire development once ignition occurs.

A further factor is asset age. As turbines mature, components, seals, wiring, and protective systems may degrade, increasing the probability of faults if inspection, monitoring, and refurbishment strategies are not rigorously applied.

Lightning strike represents a distinct and external ignition risk affecting the entire structure. While lightning protection systems are widely implemented and essential, lightning remains a credible cause of turbine fires and must be considered separately from internal component level risks.

Internal component level risks must be appraised – for new construction as well as potential retrofit needs.

4.3. Environmental Impact

The consequences of a wind turbine fire extend beyond the loss of the turbine itself. Full burn out events can result in the release of airborne pollutants, including combustion products from oils, polymers, and composite materials. In addition, falling debris - burning or otherwise - may be dispersed over a wide area by gravity and wind.

This debris can include fragments of blades, nacelle materials, and insulation, potentially introducing microplastics and other contaminants into surrounding environments. Offshore, this may affect marine ecosystems and water quality. Onshore, impacts may extend to farmland, crops, livestock, or nearby communities.

There is also a credible risk that burning debris or embers may act as an ignition source for secondary fires beyond the immediate turbine base. In an era of increasing climate volatility, prolonged droughts, and extreme weather, this risk cannot be dismissed. Although prosecutions and definitive causal links are today relatively rare, the reputational and environmental implications of even an alleged connection between a turbine fire and a wildland fire can be significant.

4.4. Business Risk Management

From a business perspective, the prevailing view among many wind energy professionals is that any fire within a turbine is likely to result in total and catastrophic loss of that turbine. This assumption has shaped both operational expectations and insurance models.

However, this outcome need not be inevitable in all cases. Many fires originate in specific, identifiable components or subsystems. Where these risks are known and technically addressable, targeted protection can materially alter the outcome - from a total loss to a limited incident resulting in token and temporary unavailability.

Reducing the severity of fire events can significantly shorten downtime, limit repair scope, stabilise insurance conditions, and protect long term asset value. Importantly, it also helps preserve the credibility of wind energy as a genuinely low impact and sustainable technology, rather than one whose risks are simply tolerated.

4.5. Cascading Impact

The cascading impacts of a wind turbine fire can be substantial. Beyond direct asset loss, there may be:

- Environmental consequences affecting land, sea, air quality, and biodiversity;
- Safety risks to emergency responders and maintenance personnel;
- Reputational damage to operators, developers, and the wider wind sector;
- Regulatory scrutiny or delays for future projects;
- Increased insurance premiums, deductibles, or coverage restrictions.

By contrast, early intervention - through detection, containment, and means of automatic suppression through full extinguishing - can prevent escalation. Many of the components from which fires originate can be practically and proportionately protected. Addressing fires in their incipient or early growth phase can transform an otherwise catastrophic event into a manageable maintenance issue.

In essence, while lightning risk must always be considered at the structural level, the majority of turbine fire risks are internal, component based, and therefore technically addressable. A protection strategy that recognises this reality can materially reduce environmental harm, protect personnel, improve turbine availability, and strengthen the long-term sustainability of wind energy.

5. Fire Protection Strategy

The fire protection strategy for wind turbines shall follow the risk-based framework established in the IEC 61400 series. Its overarching goal is to prevent fire initiation, detect abnormal conditions at the earliest possible stage, limit the spread of any fire that does occur, and protect personnel, equipment, and the environment. As wind turbines are difficult to access, especially during operation, the strategy must emphasize early detection and automatic protective measures. Relevant standards include IEC 61400-1 for design requirements, IEC 61400-24 for lightning protection, IEC TS 61400-23 and IEC TS 61400-4-1 for structural and drivetrain integrity, IEC 61400-25 for communication and monitoring, IEC 60204-1 and IEC 60364 for electrical safety, as well as the IEC 60695 series for fire hazard testing.

5.1. Fire Detection

In accordance with IEC 61400-1, fire detection systems shall be capable of identifying abnormal thermal or combustion related conditions before they escalate into a fully developed fire. These systems must be tailored to the operational and environmental challenges of wind turbines.

5.1.1. Nacelle

Within the nacelle, detection measures must target components that represent heightened ignition risk, such as the generator, gearbox, power converter, brake resistors, and hydraulic systems. Suitable detection technologies include heat and smoke detection systems designed for harsh, high vibration environments, and flame detection in areas where open equipment allows for visible flame signatures. Installed systems must be robust against dust, condensation, and operational heat loads, while providing reliable information to the turbine's control and SCADA systems according to IEC 61400-25.

Extra care in needed to avoid false / unwanted alarms. Due to the remote location, visual inspections and human verifications are unlikely to be viable and CCTV may not be appropriate. Normal wind turbine operation can produce a multitude of deceptive phenomena such as elevated temperature, sparks, and aerosols from braking, among others. Thermal, smoke and flame detectors should have appropriate programming and/or use of technology to mitigate the likelihood of unwanted and false alarms.

5.1.2. Hub

The rotor hub requires monitoring of the hydraulic or electric pitch systems, braking elements, and bearing assemblies. Temperature monitoring and linear heat detection are typically appropriate, especially near hydraulic components where leaks may create additional ignition potential.

5.1.3. Tower

Fire detection in the tower shall focus on risks associated with electrical cables, switchgear, and auxiliary power equipment. Smoke detection is generally most effective in the lower tower sections where smoke accumulates, complemented by heat monitoring along cable routes to identify overheating or insulation failures.

5.1.4. Transformer

Transformers shall be equipped with thermal monitoring of windings and, where applicable, oil systems. In enclosed transformer compartments, smoke or gas detection adds an essential layer of safety and helps ensure rapid response in case of internal faults.

5.2. Automatic Fire Suppression and Extinguishing Systems (Recommended)

Although IEC standards do not mandate a particular extinguishing agent, they emphasize that manual firefighting within a wind turbine is usually impractical. Therefore, automatic fire suppression systems should be considered wherever a risk assessment conducted under IEC 61400-1 identifies unacceptable risks.

There are numerous approaches to fire protection.

- Gaseous systems, for enclosed spaces as total flooding, able to penetrate equipment.
- Water mist in low and high pressure, provides wetting and cooling as well as oxygen displacement.
- Compressed air foam systems, generate a stable, small-bubbled and high momentum foam blanket.
- Condensed aerosols, for enclosed spaces as total flooding able to chemically interrupt the combustion process.
- Powder systems, use dry powder to put out fires interrupting the chemical reaction of fire.

These can provide prompt delivery of extinguishing agent directly to the asset and are viable with respect to the above. Readers are advised to consult a fire protection specialist for clarity in the pros and cons of the above technologies.

5.2.1. Nacelle Fire Suppression

Automatic suppression in the nacelle may protect critical equipment such as the generator, gearbox, and power electronics. Acceptable systems must be electrically non-conductive, suitable for enclosed and normally unoccupied spaces, and capable of operating reliably across the turbine's environmental range. Typical solutions include gas based and condensed aerosol systems, as well as localized extinguishing systems for object specific protection.

5.2.2. Hub Protection

If the risk assessment deems it necessary, compact automatic suppression units may also be installed in the hub. These systems must be designed to operate safely without interfering with pitch mechanisms or rotor dynamics.

5.2.3. Transformer Protection

Fire protection for transformers must be coordinated with electrical safety requirements and measures to prevent environmental contamination. Depending on the transformer type, fixed extinguishing systems and oil containment arrangements can significantly reduce both fire spread and secondary damage to the turbine structure.

5.3. Passive Fire Protection

Passive fire protection plays a crucial role in meeting IEC objectives for fault containment and damage limitation. It reinforces active systems by reducing the likelihood of fire spread and by protecting structural integrity.

5.3.1. Materials and Components

Materials used inside the turbine should meet flame retardant requirements under IEC 60695. Halogen free, low smoke cables and, where feasible, fire-resistant hydraulic fluids reduce both fire load and toxic hazards in the event of a fire.

5.3.2. Fire Separation and Compartmentation

Internal compartmentation should limit fire propagation between electrical, hydraulic, and mechanical systems. This includes the use of fire-resistant partitions, properly sealed cable penetrations, and design measures that prevent vertical spread through the tower shaft.

5.3.3. Structural Protection

The structural design must account for fire exposure of load bearing components. Passive measures shall ensure that local fires do not lead to structural instability or collapse, thereby safeguarding personnel and maintaining containment.

5.4. Lightning Protection

Lightning represents one of the most common ignition sources for wind turbines. Hence, lightning protection shall fully comply with IEC 61400-24.

5.4.1. External Lightning Protection

Blades shall incorporate receptors and down conductors that safely guide lightning currents through the nacelle and tower into the foundation's earthing network. The entire system must provide a continuous, low impedance path for the full duration of the lightning event.

5.4.2. Internal Lightning and Surge Protection

Inside the turbine, surge protective devices shall be installed to protect both power distribution and communication lines. All metallic components must be equipotential bonded, and sensitive systems—including detection and suppression equipment—must be shielded from transient over-voltage.

5.4.3. Fire Risk Mitigation

A properly designed lightning protection system shall minimize fire hazards by preventing arcing, controlling thermal effects on nearby materials, and minimizing the risk of ignition through electrical discharges.

5.5. Monitoring and Maintenance

Fire protection measures shall be integrated into the turbine's operational lifecycle and supported by systematic monitoring, inspection, and training activities. Remote monitoring of fire detection equipment allows collecting history of fire related events, faults, contamination and maintenance information on all peripherals connected to the fire panel, which can reduce overall cost of ownership as well as pre-empt any system impairment.

5.5.1. Condition Monitoring

Temperature monitoring of fire critical components, along with analysis of electrical load patterns and fault trends, shall form part of the turbine's SCADA based condition monitoring strategy in accordance with IEC 61400-25.

5.5.2. Inspection and Testing

Regular inspections and functional tests of both detection and suppression systems are essential to maintaining system reliability. Lightning protection systems must also be periodically verified to ensure continuity and compliance with design requirements.

5.5.3. Documentation and Training

All fire protection measures must be documented in the turbine's technical manuals. Maintenance personnel require training in fire risk awareness and proper response procedures, and all inspections, tests, and incidents shall be recorded to support continuous improvement.

6. Closing Statement

Fire in wind turbines should no longer be regarded as an unavoidable cause of total and catastrophic loss. As this guidance has demonstrated, most fire risks originate in identifiable components and can be addressed through a structured, risk-based combination of prevention, early detection, and appropriate protection measures.

By recognising fire as a technically manageable risk rather than an accepted outcome, the wind industry has a clear opportunity to improve resilience, reduce environmental impact, and enhance both asset performance and insurability. Achieving this requires a shift from minimum compliance towards integrated, lifecycle-based fire protection strategies that reflect the realities of modern turbine design and operation.

Adopting active fire suppression on board wind turbines is a viable approach that provides an immediate solution for mitigating the severity and consequences of fire events. Enhancing safety protection in this application will contribute to strengthening confidence in wind energy as a safe, reliable, and sustainable cornerstone of the global energy transition.

There are numerous approaches. For example, system types can include gaseous agents, low- and high-pressure water mist, compressed air foam, powder and aerosols. The general features of all these technologies are covered in published ISO, EN and NFPA standards. Additionally, ISO is currently drafting a new Standard for tube-based extinguishing systems and similar approaches. These can provide prompt delivery of extinguishing agent directly to the asset and are viable considerations.

Annex - Materials and Information referenced in this Document

CFPA-E Guideline No 22:2022. Wind turbines fire protection guideline.

FM Property Loss Prevention Data Sheets 13-10. April 2025. Land-based Wind Turbines and Farms.

IEC 60204-1:2016+AMD1:2021 CVS. Safety of machinery - Electrical equipment of machines - Part 1: General requirements.

IEC 60364 series. Low-voltage electrical installations.

IEC 60695 series. Fire hazard testing.

IEC 61400-1:2019+AMD1:2025 CVS. Wind energy generation systems – Part 1: Design requirements.

IEC TS 61400-4-1:2026. Wind energy generation systems - Part 4-1: Reliability assessment of drivetrain components in wind turbines.

IEC TS 61400-23:2014. Wind turbines - Part 23: Full-scale structural testing of rotor blades.

IEC 61400-24:2019+AMD1:2024 CSV. Wind energy generation systems - Part 24: Lightning protection.

IEC 61400-25 series. Communication for monitoring and control of wind power plants.

IEC TS 61400-30:2023. Wind energy generation systems - Part 30: Safety of wind turbine generators - General principles for design.

ISO 19353:2019. Safety of machinery — Fire prevention and fire protection

NFPA 850:2026. Standard for Fire Protection for Electric Generating Plants and High-Voltage Direct Current (HVDC) Converter Stations.

VdS 3523:2008-07. Wind turbines, Fire protection guideline.

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