



Safety signals illuminate obstacles in maritime and aviation transport

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Offshore wind farms are often noticed first by their flashing obstruction lights, not the turbines themselves. These signals are safety critical for aviation and shipping and must be explicit in even the harshest of conditions. TÜV SÜD supports manufacturers and operators with independent testing and technical assessment of signal and turbine alike. It also provides certifiable documentation across the wind turbine generator (WTG) lifecycle.

When it comes to offshore wind farms, flashing lights might appear to some as decorative signals or optional accessories. In fact, they are much more than that: they are a controlled safety function designed to prevent accidents by making objects conspicuous to both aircraft and vessels. In practice, this places obstruction lighting at the intersection of regulation, photometric engineering, offshore operations and increasingly, digital security.

The risks rise offshore because distances are larger, weather is harsher and the number of moving actors, like service vessels, commercial traffic, helicopters and aircraft, creates a dense risk environment. As turbines become larger in hub height and rotor diameter and as new maritime sites are developed, the visual and navigational field of offshore wind farms expands. That growth makes marking systems more important and, simultaneously, more complex to implement consistently across different jurisdictions and permitting regimes.

Why 'one size fits all' rarely works

Obstacle marking for wind turbines is mandatory both under aviation rules and under maritime safety regimes. For offshore projects, this means operators typically have to fulfil a combination of national requirements and international guidance.

In Germany, for example, the Federal Waterways and Shipping Administration (WSV) defines key framework expectations for marine marking and international Aids to

Navigation (AtoN) guidance is shaped by the International Organization for Marine Aids to Navigation (IALA). At the same time, aviation authorities impose their own requirements for aircraft warning.

This multi-layered regulatory landscape creates a practical challenge: a wind farm designed with a uniform marking concept across borders quickly runs into differences in interpretation, local permitting conditions and project-specific constraints.

As a result, developers and original equipment manufacturers (OEMs) often end up implementing site-specific solutions and integrating marking requirements into turbine and balance-of-plant design choices rather than treating lights as interchangeable off-the-shelf parts.

The implication is important: compliance cannot be demonstrated by checking a single parameter or presenting a catalogue specification. Authorities and stakeholders expect evidence that the full marking solution is fit for purpose in the real environment in which it operates.

Photometric performance

Luminous intensity is one of the most straightforward requirements because it can be defined in clear numeric ranges. Examples of typical ranges include lower intensity lights intended for shorter visible distances and much higher intensities for long-range marine recognition.

But intensity alone does not determine whether a light actually functions as a navigational cue. Detectability depends on a bundle of parameters, including:

- Luminous intensity distribution (photometric distribution): Not only does it matter how bright the source is, but also how the light is distributed across horizontal and vertical planes. Marine marking commonly requires 360° horizontal visibility, along with minimum intensity requirements across defined vertical angles, ensuring the signal can be reliably seen from both ships and aircraft.
- Luminance of illuminated surfaces: Offshore marking often includes illuminated surfaces such as tower sections, markings, or reflective elements. Their luminance, measured in candela per square metre, can determine whether the structure remains detectable in twilight, haze or fog.
- Chromaticity: In both aviation and marine contexts, colour is not a styling choice. It communicates meaning. A colour point outside the prescribed region can lead to misinterpretation, especially in mixed environments where multiple installations or navigation marks may be visible simultaneously. Chromaticity assessments are typically performed against CIE chromaticity diagram criteria.
- Uniformity and glare control: Even distribution across an illuminated area helps prevent hot spots, excessive contrast and glare that can distract or impair perception, particularly at night or in reduced visibility.



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Together, these factors define whether a light creates a reliable, recognisable and distinct signal under operational conditions.

Preventing confusion in crowded visual environments

The presence of many identical lights in close proximity across a wind farm presents a specific offshore challenge. If these lights flash out of phase, the site can appear visually chaotic, especially to a vessel or aircraft crew scanning the horizon. The risk is not only annoyance; asynchronous flashing can hinder distance estimation, cause confusion about turbine positions, or mask individual lights intermittently.

Therefore, synchronisation is often treated as a functional requirement. In many real-world specifications, allowable timing deviation between identical lights is extremely tight, sometimes even under a tenth of a second. Achieving that level of coherence is not purely a hardware task. It also depends on the control logic, communication networks and time reference stability that coordinate the flash pattern across the site.

This is where a systemic view becomes essential. A light that meets the photometric requirements in isolation may still fail the operational requirement if the farm-level control system cannot maintain synchronisation during network latency, component ageing, maintenance swaps or partial outages.

Environmental resistance as a design requirement

Offshore conditions are unforgiving. Marking lights must withstand high wind loads, salt-laden air, continuous UV exposure, vibration from turbine operation and repeated temperature cycling. Over time, these stressors can degrade optical performance and reliability in ways that are not obvious during basic commissioning checks.

Typical degradation mechanisms include optical ageing, such as UV-driven yellowing or



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clouding of diffusers and lenses, which reduces transmitted intensity or shifts chromaticity. Corrosion of reflectors and metallic components can also occur, altering beam distribution and lowering effective output.

Seal and enclosure degradation may introduce moisture ingress, leading to intermittent electrical faults. Mechanical loosening caused by vibration can affect alignment and, in extreme cases, compromise the stability of mounting points. Additionally, deposits from salty environmental conditions can accumulate on lenses, resulting in an imbalance in light distribution.

From an engineering standpoint, these are not 'maintenance inconveniences'. They influence whether the marking function remains reliable throughout the WTG lifecycle. That is why manufacturers benefit from incorporating requirements early in product development and qualification rather than trying to prove robustness retrospectively once the turbine is in the field.

Verification in practice

A credible verification concept typically combines different layers of testing. This includes on site visual inspection and functional testing to confirm operation, flash behaviour and any obvious defects.

It also involves system-level checks to validate control behaviour, such as synchronisation, redundancy switching, alarms and monitoring signals. In addition, photometric measurements under defined conditions, often carried out in laboratories, are used to document the full light distribution, intensity, chromaticity and uniformity characteristics within a controlled setup.

Laboratory photometry matters because it answers a more demanding question than 'does it switch on?' It determines whether the light meets its intended performance envelope and whether the signal maintains its intended function under the relevant viewing geometry. It also provides a baseline used as a reference point to help identify wear and tear.

These comparative measurements can help reveal gradual drift over time. That supports predictive maintenance planning and helps operators avoid unexpected non-compliances that may trigger corrective actions, operational restrictions or increased risk exposure.

An integrated installation

Regulatory expectations are expanding beyond traditional 'always on' night lighting. One prominent topic is demand-controlled night marking (DCNM), in which lights operate at night only when aircraft are detected, reducing unnecessary light emissions while maintaining safety. This concept introduces functional dependencies on sensors, detection logic, system availability and fail-safe behaviour.

Additionally, redundancy is increasingly central. Offshore operators cannot always reach a failed unit quickly due to weather and access constraints. Redundant architectures, whether at the component, circuit or system level, reduce the probability that the marking function is lost between maintenance windows.

Electromagnetic compatibility (EMC) must also be considered. Wind turbine systems are electrically complex and obstruction lighting must coexist with power electronics, communication equipment and monitoring systems without creating interference or being disrupted by it. EMC is not merely a lab tick-box; it affects reliable operation, fault rates and the integrity of control signals, especially on IP-based networks.

All of these dimensions reinforce a key message: obstruction marking must be evaluated as an integrated installation. A component-only view can miss systemic failure modes such as communication timing issues, common-cause faults or control logic misbehaviour under partial degradation.

Digitalisation and cybersecurity

Modern offshore wind farms rely heavily on digital connectivity. Lighting systems are increasingly integrated into IP-based control and monitoring architectures to enable central supervision, diagnostics and coordination. This improves operational visibility and can reduce downtime, but it also expands the attack surface.

Because offshore wind farms can fall under critical infrastructure regulations, cybersecurity frameworks such as ISO/IEC 27001 become relevant for operators seeking robust information security management. For obstruction marking, this is not an abstract IT concern. If a malicious actor can disrupt communication, manipulate flash timing, disable alarms or falsify monitoring data, the safety function can be compromised without obvious physical damage.



A practical approach, therefore, links three domains: the photometric hardware, the control and communication layer and the cybersecurity controls that protect availability and integrity. Access management, secure configuration, logging and continuous monitoring help ensure that the marking function remains trustworthy, especially when maintenance is performed remotely or by multiple parties.

Permits and documentation

Authorities and stakeholders need more than assurances; they need evidence that the marking solution meets the applicable rules and site conditions. For OEMs and operators, that translates into documentation that is technically complete, traceable and aligned with the relevant standards and permit conditions.

This often includes photometric test reports demonstrating compliance with intensity, distribution, chromaticity and uniformity requirements, as well as system descriptions that outline synchronisation methods, redundancy behaviour and fail-safe states.

It also covers maintenance and inspection concepts that are aligned with lifecycle risk,

offshore access constraints and expected ageing, along with records that support audits and demonstrate ongoing conformity over time.

Independent third-party assessment can strengthen confidence in these materials, particularly when projects involve cross-border stakeholders, lenders, insurers or complex permitting interfaces.

Offshore growth raises the bar for marking systems

In the North and Baltic Seas, offshore capacity expansion plans point toward rapid scaling over the coming decades. More turbines, larger structures and denser maritime operating environments will increase the importance of marking solutions that remain stable, serviceable and compliant over long operating lives.

Technology is moving in the same direction. New generations of obstruction lights are expected to incorporate richer diagnostics, automated self-tests and electronics designed for longevity in harsh conditions. These capabilities can improve reliability and maintenance efficiency, provided they are validated properly and integrated into a secure, well-documented system architecture.

Safety where regulation, technology and operations align

Obstruction lighting on offshore wind turbines is a classic example of safety-critical infrastructure that looks simple from afar but is complex in execution. Compliance requires understanding multiple regulatory regimes, while safety requires robust photometric performance and unambiguous signalling.

Offshore operations demand durability, redundancy and maintainability; and digital integration introduces cybersecurity as a necessary layer of protection.

The most resilient approach treats obstruction marking as a system across the WTG lifecycle, from early design integration and qualification through commissioning, monitoring, periodic verification and planned replacement. When these elements are aligned, the result is not merely regulatory conformity, but a marking solution that consistently protects aircraft and vessels, exactly when conditions make visibility and reliability most important.

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