Protection against wind-turbine fires

Wind power has grown unstoppably in recent years. Installed power is increasing year after year and the wind turbines themselves are getting bigger and bigger. The wind-turbine fire problem is now becoming a growing concern for the various stakeholders, especially the wind-farm operator, not only due to the direct fire loss but also the production shutdown and, in large measure, image damage. But to come up with an efficient and viable wind-turbine fire protection system is a sterling challenge, due to the idiosyncrasies of the wind-turbine itself and its siting. An account is given below of a wind-turbine protection system taking all these circumstances into account.

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Worldwide technological development has made energy a top priority. At the same time fossil fuels are becoming scarcer while our dependence on them becomes heavier. A growing sense of the need to look after the environment also needs to be factored into this picture. The world has therefore had to come up with a brand new energy strategy. This is where renewable energy sources come into their own as a real solution to all the abovementioned problems.

Fires in wind farms and wind turbines are a fairly rare event but they can cause irreparable damage, with a high cost in terms of capital-goods losses and long production shutdowns. Wind farm facilities therefore need to be designed in such a way as to guarantee maximum fire protection, reducing any losses if fires do break out and ensuring the shortest possible downtime afterwards.

Wind-turbine fire protection is a growing concern, especially for the operator and the insurance company and it cannot be tackled from a conventional viewpoint. Any system has to meet the following objectives:

The first objective has to be the safe shutdown of the wind turbine at the first sign of any fire, understanding «safe shutdown» to be not only a progressive closure without jeopardising wind-turbine stability but also the certainty that this will be done in a trustworthy and dependable way only when strictly necessary.

The second objective is to ensure efficient protection of the wind turbine if any fire breaks out in the nacelle. “Efficient” in this sense means:
• Pre-empting false triggering of the protection system.
• Reliability of the fire-suppression system used.

Finally, a third objective of the fire protection system is that it must be viable, both when initially installed and in the medium and long term. This means:

• That system installation does not interfere with the maintenance or repair of other nacelle components.
• That the system is robust, i.e., that it suffers no manifest deterioration due to the working circumstances of the wind turbine.
• That the fire-suppression system itself is low maintenance.
• That the system-installation and -maintenance cost is affordable.

It is really difficult to come up with a protection system that is 100% capable of meeting all the abovementioned objectives, but the right study might at least provide a compromise solution. The first step is to ascertain the workings of the wind turbine, its critical fire-generating points and also inherent construction factors and its siting, whether onshore or offshore. All these factors will impinge on the chosen solution.

**Characteristics of the wind turbine and main risks**

The wind turbine’s main function is to turn kinetic energy into electricity. It has three main parts: the tower, nacelle and rotor.
The rotor is the item most prone to lightning strike (cause of most wind-turbine fires) and therefore has to be properly safeguarded against this particular circumstance. This apart, it is the nacelle that poses the biggest fire-protection problem, since it houses all the abovementioned electricity and mechanical systems.

The common elements contained in a wind-turbine nacelle are the following:

**Step-up gear.** Its function is to gear up the rotor turning speed of only a few revs per minute (17-48 rpm) to the high turning speed of the generator (1000-1500 rpm). This produces friction between the gear bearings, heating up the whole gearbox and neighbouring items. It should also be borne in mind here that this item needs force lubrication with oil at all times, since it is a heat focus (friction) with a flammable element (oil); this therefore needs to be factored into its fire protection.

The step-up gear is usually mounted on shock-absorbing elements to minimise transmission of noise and vibration to the structure.

**Generator.** This is the main component of the wind-turbine electricity system. Its role is to transform the rotor’s mechanical energy into electricity.

The high installed power of modern wind turbines means the electricity generator works at very high temperatures; there is:
therefore a need for a cooling system. This is generally by way of air cooling though liquid cooling is used in some models.

Generator fires occur as a result of overheating in the winding, either due to a prolonged surge or a failure in the cooling system. The oil heats up, increasing its internal pressure to evaporation point, sparking off a generator fire or explosion. This situation is exacerbated if poor maintenance leads to a build-up of carbon deposits in the winding; any sudden temperature rise or even the normal working temperature might then lead to combustion.

As well as the winding problems another fire focus is the friction points of the rotary elements.

Figure 2. Main air turbine components
Mechanical brake. This system carries out a twofold function. On the one hand it has to bring the rotor to a complete halt and keep it in parking position whenever workers are carrying out maintenance tasks. On the other, the brake has to be capable of carrying out emergency stops whenever the wind turbine is in peril.

This leads to a high level of friction between the brake shoe and disc with consequent heating and possible breakage of the disc. The shoe might then give off incandescent material that comes into contact with the flammable nacelle casing sparking off a fire.

The brake might be fitted on the slow-speed shaft (joining the rotor to the step-up gear) or the high-speed shaft (leading out from the generator).
Control cabinets. The nacelle is fitted with electricity control cabinets that govern the workings of the various pieces of equipment (yaw of the nacelle, rotation of the blades, speed regulation, grid-connection and -disconnection manoeuvres, component ventilation, etc.).

The fire danger of control cabinets is often the result of human error or poor maintenance, due to slack joints, false contacts, dirt, rust on the surface of the items or insufficient heat dissipation. The commonest risks are circuit overheating and electric arcing.
Figure 6. Schematic representation of a wind turbine substation.
Figure 7. Installed wind power at the end of 2011 in the ten most highly developed wind-power countries.
Figure 8. Share of installed wind power in the Spanish electricity sector, broken down by origin.
Figure 9. Installed wind power in 2011 broken down by regions, number of farms and variation on 2010.
Wind-turbine fire protection is a growing concern, especially for the operator and the insurance company, and it cannot be tackled from a conventional viewpoint.

Transformer. This component does not belong to the wind turbine strictly speaking. In the first wind turbines it was included in the nacelle but in the most modern versions it is usually fitted in the base. This remit of this component is to raise voltage up to about 20-30 KV before injection into the grid, thus reducing ohmic losses.

The main cause of a transformer fire is the formation of an electric arc due to a system defect (perforation of the insulation). Internal faults could occur in these elements, causing overheating or local arcing. An electric arc breaks down the oil, producing combustible gases. This fact, together with the high temperature of the oil and the mixture with oxygen after oil leaks through the perforation, could produce a fire.

The problem posed by these potential ignition points is exacerbated by the fact that the nacelle casing is made from material like glass fibre and carbon fibres, i.e., combustible material with an appreciable fireload.

These possible ignition points are not unique per se to wind turbines. They may also crop up in many industrial activities and there are tried-and-tested fire detection and suppression systems. In wind turbines, however, the problem stems from the idiosyncrasies of the item to be protected.
**Idiosyncrasies of off-shore wind turbines**

Wind turbines have to be adapted for installation in an offshore wind farm. Manufacturers therefore opt to create specific turbines for sea installation. Protection measures also have to be taken, raising costs for the promoter.

Above all structures need to be safeguarded against corrosion and the entry of salt-laden air, which might affect the electrical equipment and system control. This calls for an additional initial outlay in the following equipment:

- **Airtight towers and nacelle.** Onshore turbines usually have nacelle casing vents for cooling purposes; neither is the connection between hub and nacelle airtight. Offshore turbines, on the other hand, need absolute airtightness against the aggressiveness of the marine environment.

- **Dehumidification systems.** For obvious reasons ambient humidity is much higher for wind turbines of this type, compared to onshore turbines. This calls for the fitting of specific dehumidification systems to minimise any oxidation damage to equipment and systems.

- **Surfaces with a special corrosion-proof finish.** The salty environment is highly aggressive. Material therefore needs to be specially treated to minimise its rust degradation.

- **Transformer and computing equipment fitted inside the tower.** Onshore wind turbines always offer the possibility of housing certain equipment in auxiliary casings. This is not possible with offshore wind turbines, so all the equipment has to be fitted in the tower.

- **Including this equipment calls for knock-on modifications such as fitting a heat exchanger for the cooling air and a platform at the base of the tower to house the transformer.**
Figure 12. Typical layout of an analog fire-detection system.

Figure 13. Principle of detection by darkening.
Wind-turbine fire-protection constraints

Wind turbines pose several fire-protection constraints. These can be broken down into two types: constructive and working constraints.

Constructive constraints

Limited nacelle accessibility
Wind-turbine accessibility is very limited, especially in an offshore wind farm. This balks firefighter intervention and makes system maintenance tasks much more expensive.

Nacelle height
The height of the nacelle from the ground may be up to 100 metres, depending on the wind-turbine output. This implies a huge constraint for many fire-protection systems, either due to intrinsic technological impossibility of the system themselves or oversizing of the system’s working elements.

The nacelle height creates many difficulties for in situ assembly and conveyance.
Limited nacelle space
Space is cramped inside the nacelle, taken up almost entirely by mechanical and electrical items that are essential for wind-turbine operation. There is therefore little space left over for fitting a fire-protection system.

Load Distribution
When the wind turbine comes on stream it produces electricity from the wind-driven circular movement of its blades. The rotor tends to pass on its inertia to the whole structure, so load distribution is crucial to forestall unnecessary vibration that may jeopardise stability.

![Conductor cable - Protective covering - Outer jacket - Heat-sensitive coverin](image)

Figure 16. Linear fixed temperature heat detector.

Materials and Structure
The nacelle is made up by a resistant frame, normally made from some steel alloy, capable of withstanding torsion and flexion loads under working conditions. The fibre panels are dismountable and serve simply to lighten the weight of the whole set and provide some weatherproofing.

From all the above it follows that there are very limited possibilities for siting and supporting the components of a fire protection system. The metal structure does offer good anchoring capacity but no materials or heavy elements can be fixed to the fibre panels.
Nil accessibility to the rotor
Rotor design and structure rule out installation of any autonomous fire-protection system whether in the rotor hub or inside the blades.

Wind-turbine working constraints
Humidity and Temperature
Temperatures inside the nacelle swing appreciably from day to night and from season to season. The working equipment also raises the temperature. Humidity conditions also vary inside the nacelle, especially in non-airtight onshore wind turbines.

Lack of Airtightness
Onshore wind turbines have air inlets and outlets in the hollow part of the rotor hub and small vents in the nacelle casing bringing the inside of the nacelle into contact with the outside environment. This means dirt from outside can reach the interior.

This is not the case for offshore wind turbines because the nacelle casing is hermetic to safeguard it from the corrosion of the marine environment.

Dirt
As well as dust, another factor has to be taken into account here. Internal and external friction between working parts or between different pieces of equipment coming into contact with each other means that all these components have to be lubricated. The main lubricating agents are oil and grease. Wear and tear tends to produce slack between the working parts, through which oil may ooze and drip onto the floor or other components. If this oil leaks towards the shafts, whether slow or fast, it may then be sprayed off centrifugally onto nearby zones.
Figure 18. Thermovolocimetric point thermal detector.
Figure 19. Fibre optic thermal detector cable.

Figure 20. Selection of detection technology in terms of the magnitude to be measured.
It is really difficult to come up

Figure 21. Typical network with two water supply arrangements.

Vibration
Under normal working conditions the wind turbine comes under considerable strain, producing constant vibration affecting the whole ensemble. This ends up weakening the fastening of systems, pipeline joints, etc, creating slack between parts or contact or breaking elements due to material fatigue.

Nacelle yawing
To harness the wind properly the nacelle turns as the wind changes, doing so with the aid of a yaw motor.

This yawing of the nacelle with respect to the base complicates the design of any fire-protection system that aims to protect components of both tower and nacelle.

Movement of the rotor with respect to the nacelle
The constant turning of the rotor with respect to the nacelle rules out the fitting of any fire-protection system physically linked to both parts.

Assessment of automatic fire-detection systems
An assessment is now given of smoke detectors, heat detectors and flame detectors that might be installed on wind turbines.

Smoke Detectors
Optical point smoke detectors
The detectors are very sensitive to dust and dirt. This poses a problem in onshore turbines, when internal air currents can lead to a build-up of dust in the sensor chamber. These same currents, moreover, in the event of a fire, would tend to dissipate the smoke reducing its detectability and delaying tripping of the alarm.

They could, on the contrary, be a good option for offshore wind turbines, which are airtight and therefore do not suffer from this problem (plus the fact that dust levels are much lower at sea than on land).

Installation of these detectors inside equipment with a certain level of airtightness (for local detection) could give a good result.
The sensors have to be connected up to a central detection unit, which could be housed in the base of the tower. Onshore wind turbines, however, due to the abovementioned maintenance and cleaning problems, would need to house the detection unit in the nacelle.

**Optical beam smoke detectors**
These might be prone to false alarms due to the differential dilation and vibration of the nacelle. In an onshore wind turbine they would also suffer from the same fire-detection problem as point detectors: the delay in building up a sufficiently dense smoke layer to detect the fire.

**Aspirating smoke detectors**
This technology involves a sort of point detector with a constant sample of air driven to the sensor. In comparison to a simple point detector, however, it does offer certain advantages for wind-turbine use:

- Since an air sample is driven to the detector, it acts quicker and detects the fire earlier.
- Like point detectors it can discriminate between different degrees of darkening. This means a pre-alarm threshold can be set (shutdown of wind turbine) together with an alarm threshold (tripping the suppression system), depending on the degree of darkening in both cases.
- To combat the problem of airborne dust and dirt, the system is fitted with a filter along the pipeline. Some aspirating detectors offer dual-source optical smoke detection, using two light sources (infrared laser and blue LED) to discriminate dust particles from smoke.
- Air intake points are located in the nacelle, while the detector itself can be housed in the tower base, the two connected to each other by up to 120 metres of aspiration tubing. Housing the detector in the base of the wind turbine would also facilitate maintenance tasks.
Heat Detection
An assessment is now made of the possibility of fitting heat detectors in wind turbines:

Static Heat Detectors
These low-maintenance detectors are robust against dust and dirt. Their working principle, however, makes them incapable of early fire detection. They are therefore a good option from the dependability point of view but less apt than smoke detectors for early fire detection.

Thermovelocimetric Detectors
These are just as robust as the former, detecting the fire earlier as temperature increases over time.

Continuous Heat Detectors
These range from the simple technology of a cable short-circuiting at a given temperature to more complex fibre optic detection but the working principle is always the same, with the alarm tripped by a temperature threshold or a particular temperature rise.

Flame Detection
The main drawback of flame detection for wind-turbine application is the need of direct visual flame contact for their activation. This means a great number of detectors need to be fitted in a very small space to cover all the angles and blind points. By their very working principle they are not tripped until flames have developed; this is usually at an advanced state of the fire.
Wind turbines pose several fire-protection constraints. These can be broken down into two types: constructive and working constraints.

Assessment of automatic fire-suppression systems

An assessment is now made of fire-suppression systems based on water, gas, chemical agents and aerosols.

Water-based fire suppression
Sprinklers, water mist, foam water

Water-based fire suppression systems have a fundamental drawback for wind turbine use: the need for a water supply. This calls in turn for some sort of tank and pumping system. Prima facie, given the cramped space inside the nacelle there is no room for installing such equipment. The same goes for the base. The equipment would therefore need to be housed in a specific construction at some point of the wind farm, pumping the water from there to the nacelle, with all the difficulty this entails. Height differences alone could produce pressure losses of from 6 to 10 bar, depending on the model to be protected in each case. The yawing of the nacelle with respect to the base poses another problem. This might be solved by means of a knuckle joint, but this would be a weak point of the system in the medium term. These systems are maintenance-intensive, more so in terms of the water-supply than discharge components.
Water mist
These systems pose fewer water-supply problems than the abovementioned systems. Less water needs to be stored but it does need to be kept at a higher pressure. This can be solved by way of reserve cylinders or a volumetric pump. These items are small enough to be housed in the nacelle after an appropriate study of the matter. The drawback is that system maintenance has to be carried out in the nacelle itself, including testing of the pumping systems and pressure supply and checking the reserve water level.

Water mist is a fairly efficient fire suppression system while the fire is still in its early stages. Any false triggering would also cause less damage than with other water systems.

This technology calls for very small pipe diameters so there should be few fastening problems. This facilitates protection of the elements of greatest risk, since nozzles can actually be fitted inside them.

Gas-based fire suppression
Gas-based fire-suppression systems are similar to water mist in terms of components. Space needs might vary considerably depending on whether the suppression system works with fluorinated agents, inert gases or CO$_2$.

But their biggest drawback is the need for nacelle airtightness. These gases need to remain in situ with at least the fire suppression concentration to forestall any re-ignition. In this respect inert gases and CO$_2$ are less sensitive than fluorinated agents. Another factor that needs to be borne in mind here is that not all nacelles pose the same airtightness problem. Offshore nacelles have a much higher degree of airtightness than onshore nacelles.

Unlike water-based fire suppression systems, gases achieve the suppression objective only a few seconds after discharge while fire damage is still incipient. Furthermore, the gas spreads unhindered throughout the whole protected site whatever obstacles might exist between the nozzle and the fire; it can even penetrate inside equipment. Pipe diameters are so small that nozzles could even, if necessary, be fitted inside equipment of greatest risk for specific protection.

Gases are clean agents, leaving no residue and not affecting electrical components. Gases therefore produce less collateral damage during actual fire-suppression tasks and also in the event of false triggering.

These systems have to be linked up to an automatic fire-detection system. They pose no great maintenance problems apart from control of the amount of suppression agent discharged to avoid leaks; this can be monitored electrically.

Fire-suppression by chemical agents
Chemical-agent fire-suppression systems are in general fairly easy to set up in the nacelle, since they call for little storage space and the diffusion network is fairly light too. This distribution flexibility means they can be added on as complementary protection for elements of greatest risk. These systems call for little maintenance, except for control of agent storage pressure, which can be monitored electrically.

This type of agent, however, could cause corrosion damage to the protected equipment, especially the most sensitive items like the switchboard.

As with gases these systems call for a suppression control system; unlike the former, however, they are not sensitive to lack of airtightness. These systems, especially wet chemical agents, can be balked from reaching the target area by intervening obstacles.

At the time in which it activates a detector (1), the main valve system (3) opens due to the loss of pressure chamber Priming control valve Halar coated foam (4) allowing simultaneous opening making the foam is introduced into the system sprinklers. Meanwhile, in the tank diaphragm (5) is pressurized vacy between the inner wall tank and the membrane, which force the foam to come out to the proportioning (6). The passage of water Nearby venturi proportioner causing a pressure drop Extracting controlled foaming and mixing with the water in the set proportion. Starting then, the foam solution the system being discharged by passing open sprinklers or nozzles (7).
When a detector is activated (1), the system’s main valve (3) opens due to the loss of pressure in the feed chamber of the halar-coated foam control valve (4), allowing its simultaneous opening and feeding the foam into the sprinkler system. At the same time, in the diaphragm tank (5), the void is pressurised between the inner tank wall and the membrane. This forces the foam towards the dispenser (6). Passage of the water through the venturi zone of the dispenser produces a controlled pressure fall that extracts the foam and mixes it with the water in the right proportion. From that moment the foam solution passes through the nozzle discharge system or open sprinklers (7).

Aerosol-based fire suppression
Aerosol fire suppression is a valid option for wind-turbine protection. These systems take up little space; they need no agent distribution network or pressurisation to work; they can provide local or total flooding protection; they leave no post-discharge residue; they can even dispense with automatic fire-detector activation and can be activated instead by a temperature-sensitive pyrotechnic fuse (although this option has to be carefully weighed up, since a high nacelle temperature is needed, by which time there will be a bigger fire to work on). They require almost no maintenance and have a guaranteed useful life of 15 years.

Their main drawback is that they have been less tried and tested than aforementioned systems. In many cases, moreover the system, due to the pyrotechnic fuse or the exothermic reaction, does more damage than the fire itself. When choosing systems of this type it is crucial to opt for one of the latest versions, issued with certifications vouching for the low reaction temperature reached and the lack of any pyrotechnic fuses.
Protection Approach

Protection approaches have been broken down for onshore and offshore wind turbines, with protection ranging from the most basic (level 0) to the most complete (level 2).

Protection of onshore wind turbines
Onshore wind turbines pose added protection problems due to their lack of airtightness. They are cheaper than offshore facilities and offer better maintenance accessibility. For this reason they are less critical, and protection measures can therefore afford to strike the right balance between reliability and cost.

Level 0
A traditional thermal cable detection system is fitted, shutting down the wind turbine and tripping the aerosol fire suppression system. The cable’s melting temperature should be as low as possible, bearing in mind the normal environmental and working circumstances inside the nacelle. Two separate cable lines are installed, constituting two detection zones.

A conventional control unit is fitted in the wind turbine, tripping a pre-alarm upon receiving a signal from one cable and ordering wind-turbine shutdown; upon receiving a signal from the second cable it trips a full alarm and orders aerosol discharge. The aerosol system is installed for ambient nacelle protection. Several units can be installed, adding up between them to the necessary product amount. Triggering of all units is simultaneous when generated electrically. If the detection signal fails, the system could be triggered automatically by means of the temperature-sensitive fuse.

It is a cheap, low-maintenance and dependable but late-triggered system. Nacelle equipment will be lost but it forestalls any important damage to the image of the wind-turbine operator and prevents flames from spreading into a forest or bush fire.
Level 1
A laser aspiration system is fitted, with intake points inside the closed equipment posing the greatest risk. This detector shuts down the wind turbine. Should the detection level rise to alarm threshold, this trips the fluorinated fire-suppresser agent inside the closed equipment posing the greatest fire risk (if this equipment is not very airtight, CO2 should be installed in preference to inert gas).

It would not be effective against fires originating in other equipment or risks outside protected ones. Shutdown would be for days, since the fire is detected early inside the equipment. Suppression, if triggered, would usually cause minimum damage but could lead to total nacelle loss if the fire starts in zones other than the protected ones.

The aspiration detector is fitted in the base of the tower, together with the fire-suppression control unit, to facilitate their maintenance. The aspiration ducts run up the tower to penetrate inside the nacelle, with a suitable device to allow for nacelle-tower yawing. The intake points are spread around the various pieces of equipment as indicated, the result being backed up with a hydraulic calculation.

A single cylinder can be installed in the nacelle, with a product distribution network entering each piece of protected equipment, or, space permitting, several cylinders adding up to the necessary amount of gas, all being triggered simultaneously.

The aspiration detector relay outlets can be connected up to the inputs of the fire-suppression control unit, which gives out the fire-suppression triggering order.

Level 2
A laser aspiration detection system is fitted, capable of discriminating between dust and smoke, with outside intake points and also inside the closed equipment posing the biggest fire risk. This detection system shuts down the wind turbine. If the detection level then rises to the alarm threshold, the ambient water-mist fire-suppression system is tripped. Dependability of this system is high and the shutdown could last several weeks, since it would usually call for replacement of the affected equipment.

System distribution is the same as for level 1, with the aspiration detector fitted at the base of the tower and the fire suppression system in the nacelle. High-pressure water mist will be used, stored in one or several pressurised cylinders loaded up with the amount necessary for total flooding and always being triggered simultaneously.
All these proposals should be adapted and fleshed out by testing all these systems under circumstances as similar to actual operating conditions as possible.

Figure 27. Comparison of the extinguishing sprinkler and gaseous agents.

Protection of offshore wind turbines
Offshore wind farms call for a higher reliability and response capacity, since the equipment involved is high cost both in terms of purchase price and maintenance thereafter. Any undue shutdown of the high-output wind turbines would cause heavy losses. In the protection of this equipment, performance overrides cost.

Level 0
Ambient point smoke detectors are fitted, set at a pre-alarm threshold to shut down the wind turbine and an alarm threshold to trigger an aerosol fire-suppression system.

It is a cheap, very low-maintenance and dependable but late-triggered system. Nacelle equipment will be lost but i forestalls any important damage to the image of the operator of the burning wind turbine.

The point smoke detection system requires installation of a ceiling-mounted detector over each piece of fire-prone equipment. The detectors are interfaced with an analogue control unit, which, in normal operating mode, gives information on the protected zone. This facilitates planning of maintenance manoeuvres, and it can be set for simple detection to shut down the wind turbine and for coincident detection to trigger the fire-suppression agent through the appropriate outlets.

The control units of the wind farm will be connected up to a graphic terminal that will supervise and monitor the information coming from the units.

Level 1
A laser aspiration detection system is fitted, interfaced with a fire-suppression control unit.

The type of aspiration detector chosen must allow for supervision thereof by web server. This gives a real time view of the situation in the protection zone. The detector is connected up to a fire-suppression control unit by means of its relay outputs. These items are housed in the base of the tower for ease o
maintenance. It must be possible to monitor and control the fire-suppression control unit remotely by IP connection to a management terminal, to which all control units of the same wind farm are connected, making it possible to send out a fire-suppression order remotely.

The fire-suppression control unit will give out an automatic triggering order upon receiving an alarm from the aspiration detector. The fire-suppression system will be ambient water mist. The storage cylinders will be stored in the nacelle. One or, space permitting, two cylinders will be fitted, both firing simultaneously.

Level 2
The same as for protection level 1, but the laser detector will be dual-source, and as well as the ambient water-mist fire suppression system, a fluorinated agent fire-suppression system is also fitted inside the closed equipment (airtightness permitting, otherwise CO₂ or inert gas is used instead).

Conclusions
Wind-turbine fire protection poses such idiosyncratic constraints that it is hard to come up with any one-size-fits-all solution. The proposals made herein should always go hand in hand with an analysis of the specific wind-turbine mode involved in each case. It is above all necessary to establish clearly beforehand the objectives in view, since 100% achievement of all the objectives of system dependability, early detection and minimum maintenance are unlikely to be met at once. All these proposals should therefore be adapted and fleshed out by testing all these systems under circumstances as similar to actual operating conditions as possible.