

Repairing Lightning Strike Damage

Executing rope-access blade repairs at a UK offshore wind farm

Conaill Soraghan and **Sally Shenton** | January 2018 | CS-0019

Summary

This case study explores how an incident of lightning strike damage was repaired at a UK offshore wind farm, after an End of Warranty (EoW) inspection found that three blades across the wind farm had been subject to lightning strike damage and required immediate attention. The Owner/Operator engaged with a service provider to execute the necessary rope-access repairs, despite harsh late autumn weather conditions.

To repair the damage, an industry standard technique was employed that involved exposing the affected area, then rebuilding fibreglass layers in-situ using rope-access technicians. The case study is based on experiences at an offshore wind farm in the UK that has been anonymised at the owner's request.

Lessons Learned

- The approach adopted for blade inspection and management during the first five years of the warranty contract resulted in lightning damage going unidentified and unrepaired for an unknown period.
- Lightning strike damage can expose the balsa wood core of a blade and any delays to repair will exacerbate the issue significantly.
- The damage was much larger than estimated from the inspection campaign. It is difficult to establish the extent of lightning strike damage from non-intrusive imaging techniques alone.
- In this particular repair campaign, lost production was the largest cost element and was a key driver. It is critical to repair lightning strike damage as early as is practically possible to minimise downtime and hence minimise cost.
- Application of the Owner/Operator’s in-house wind turbine safety rules avoided the need to request technician support from the turbine original equipment manufacturer (OEM).
- Ensure there is a strategy to manage weather risk. The Owner/Operator recommends removing the high-speed lock on brakes during maintenance downtime to avoid wear and tear on other components.
- Allow flexibility in working hours to optimise the suitable weather windows for priority maintenance tasks.
- Relationships with sub-contractors are extremely important when managing a weather-dependent repair of unknown scope.
- Blade damage is emerging as a considerable problem for offshore wind farms, and the Owner/Operator expects the services of wind turbine blade repair specialists to be in high demand.
- An increase in the number of authorised blade repair technicians will be required to meet the expected volume of work in the coming years.

Introduction

Modern offshore wind farms have hundreds of wind turbines, each with three blades spanning up to 80m. To generate lift, wind turbine blades have an aerofoil-style cross section. The centre of the blade is hollow, and the surrounding structure is made up of a “sandwich” of fibreglass and balsa wood, as shown in Figure 1. The blade’s balsa wood core layer is sandwiched between two layers of fibreglass, with a protective waterproof coating on the outside.

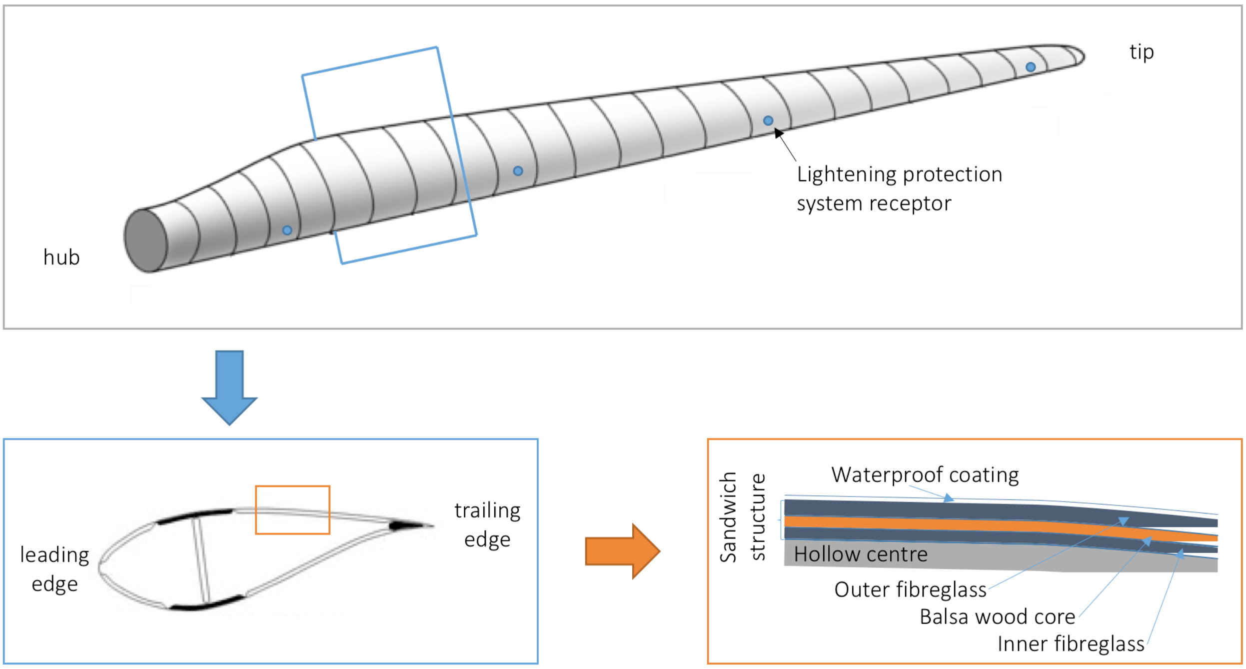

Figure 1: Offshore wind turbine blade cross-section

The primary function of the root of the blade is structural support and in this section the fibreglass can have up to 50 layers of laminate to give it strength. Towards the tip, the primary function of the blade is aerodynamic performance and consequently it is much lighter. The outer fibreglass typically has less than five layers of laminate in this section.

Typically, wind turbine blades are fitted with a lightning protection system (LPS) which uses conducting receptors on the blade surface (as shown in Figure 1) to attract any lightning strikes. The current is then grounded by routing it along an embedded conductor concealed within the sandwich blade structure. Subsequently, the current is routed to the blade bearing root, then to the hub, along the low speed shaft, to the main bearing, through the nacelle housing, down the tower, transition piece and foundation, and the current is ultimately dissipated into the seabed.

The LPS is necessary because the electric current in lightning has the potential to burn holes through the blade structure, significantly impacting its structural integrity and diminishing its aerodynamic performance.

The Challenge

As part of the scope of the End of Warranty (EoW) inspections at the offshore wind farm, every blade at the site was inspected using rope-access and high definition imaging techniques.

Across all the blades in the wind farm, the inspection identified a range of issues. This included damage such as marks on the top coat, leading edge erosion and cracks. Of all the blade maintenance that was recommended, the Owner/Operator originally identified three blades that required immediate attention, each of which had suffered lightning strike damage. One of the lightning strike damage images from the inspection is reproduced in Figure 2. It can be seen that lightening has burned a hole in the fibreglass structure. Such damage is a structural integrity concern that may require the turbine to be stopped. This introduced a risk of lost production for the approaching winter and hence, the owners were keen to carry out repairs quickly.

Figure 2: Lightning strike damage identified on a blade at the offshore wind farm

The only feasible solution available to the Owner/Operator for repairing the hole in the blade structure was to use a rope-access team to work at heights on the blade in-situ and expose the damaged section, before relaying the necessary fibreglass. In five years of operational experience at the offshore wind farm, neither the Owner/Operator nor the OEM had completed a rope-access blade repair.

Furthermore, the issue was identified in autumn. With winter approaching, the Owner/Operator was fully aware that they would be up against rough weather and sea states.

The Approach

Planning

The EoW inspection was carried out by the service provider, a specialist in turbine blade inspection and repair. The inspection identified three blades requiring immediate attention, each of which had been subject to lightning strike damage.

The inspection campaign was completed in August 2016 and in order to address these issues quickly to avoid worsening of the damage, the Owner/Operator awarded the repair contract for three blades to the service provider that carried out the EOW inspections. The work was scheduled to begin the month after EOW inspections had completed.

The service provider's Risk Assessments and Method Statements from the previous blade inspection campaign were used as a base for this repair project. These were adjusted to include Control of Substances Hazardous to Health (COSHH) and repair method information, allowing for quick approval.

Resources

The service provider team consisted of two technicians: one to access the blade and one to prepare material and cut fibreglass in the transition piece. The Owner/Operator provided an Authorised Technician to supervise the work. The application of in-house wind turbine safety rules at the offshore wind farm negated the need for an OEM representative to be present for this work.

The team were given priority use of a standard crew transfer vessel (CTV). This minimised downtime by allowing the team to keep their kit on board, and enabled the possibility of extending shifts to suit weather conditions.

Method

To repair the lightning strike damage, the service provider proposed an industry standard technique[1] for exposing the affected area, then rebuilding the fibreglass layers. From the EoW inspections, the service provider's engineers were aware that on at least one of the blades, a portion of the balsa wood core would have to be replaced, then coated with fibreglass layers that bond well with the original blade structure – a method illustrated overleaf in Figure 3.

The image shows the general approach for repairing a structure with eight layers of laminate – one line for each different layer. In the case of a wind turbine blade there can be much more than eight layers of laminate and they must be laid down in such a way that builds up this gradient at the interface with the original structure.

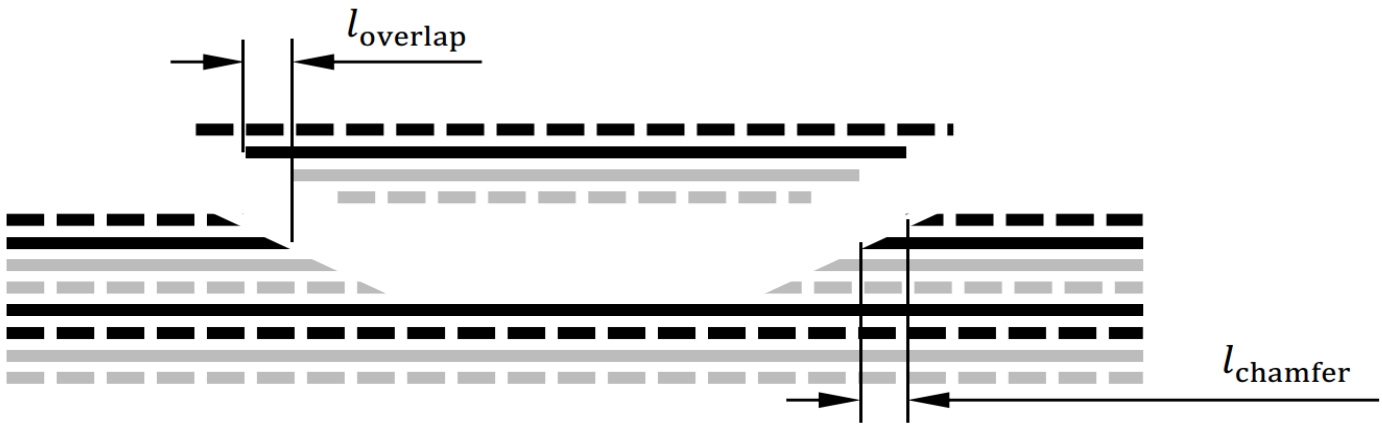

Figure 3: Laminate repair method as described in the DNV-GL guideline[1]. The solid and dotted lines represent different material types – in this case, balsa wood and laminate layers.

Firstly, the full extent of the damaged balsa would be replaced, then the layers of fibreglass in the outer section would be laid at a gradient to increase the surface area of the interface between the original and new fibreglass layers. This allows the new layers to bond effectively.

Execution

The individual blades requiring attention were identified as D10, E11 and F08. The repair work is summarised in Table 1.

Blade	D10	E11	F08
Repair Type	Permanent	Permanent	Temporary
Distance from hub	51m	39.5m	29m
Blade inspection finding	Laminate damage with width 150 mm	Laminate damage with area 100 x 50 mm	Laminate damage with area 180 x 200 mm
Full extent of damage after exposure	All outer and inner fibreglass layers burned. Wet balsa core material with saturated area larger than area of damaged laminate and a hole through all layers of the blade.	Outer fibreglass and core balsa material damaged by lightning. One layer of inner fibreglass damaged. Balsa core saturated to a much larger extent.	Outer and inner fibreglass layers burned. Core material damaged and wet.
Repair procedure	Damage area exposed. Wet core material removed. Burned inner fibreglass removed. Inner fibreglass layers rebuilt. Balsa core replaced. Outer fibreglass layers rebuilt. Re-profiling and waterproof coating applied.	Damage area exposed. One layer of inner fibreglass relaid. Wet core material replaced. Five phases of building 49 outer fibreglass layers. Re-profiling and waterproof coating applied.	Damage area exposed. Adhesive applied as sealant. Repaired area coated.
Repair time	Six working days One weather day	13 working days 22 weather days One CTV maintenance day	One working day

Table 1: Summary of lightning strike damage repairs at the offshore wind farm.

Blade D10

The first blade repaired was D10 and this work began on 5th September 2016. The damage as found on arrival is shown in Figure 4a. Once the damaged area was prepared for work, it was clear that many layers of the blade structure were affected, as seen in Figure 4b.

Figure 4a and 4b

The full extent of the damage became clear only after the technicians began removing the wet balsa wood core. Figure 5a shows the extent of the balsa that had to be removed and Figure 5b shows that the lightning had burned a hole all the way through the sandwich structure, exposing the hollow centre of the blade.

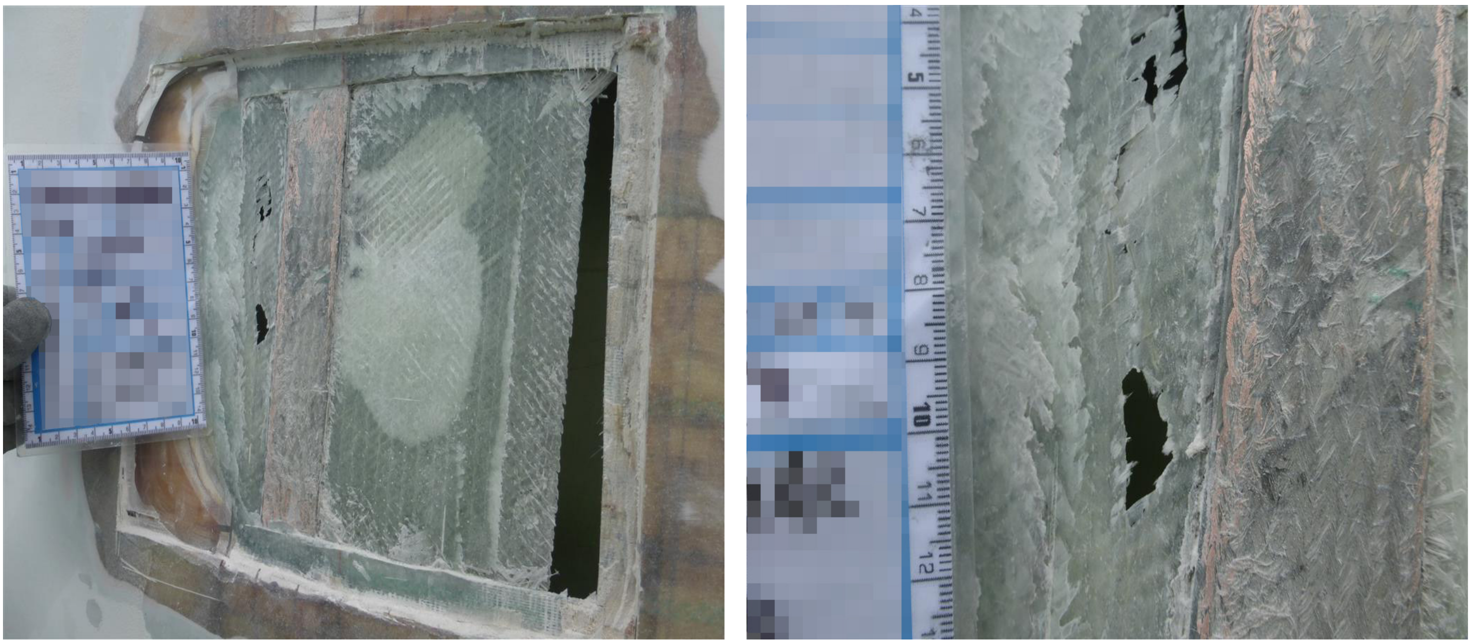

Figure 5a and 5b

Once the full extent of the damage was uncovered, work began on rebuilding the damaged layers. Figure 6a and Figure 6b show the repairs made to the inner laminate and the balsa core respectively.

Figure 6a and 6b

Subsequently, the outer fibreglass layers were built up as shown in Figure 7a. Finally, the damaged area was re-profiled and a waterproof coating was applied. The completed repair is shown in Figure 7b.

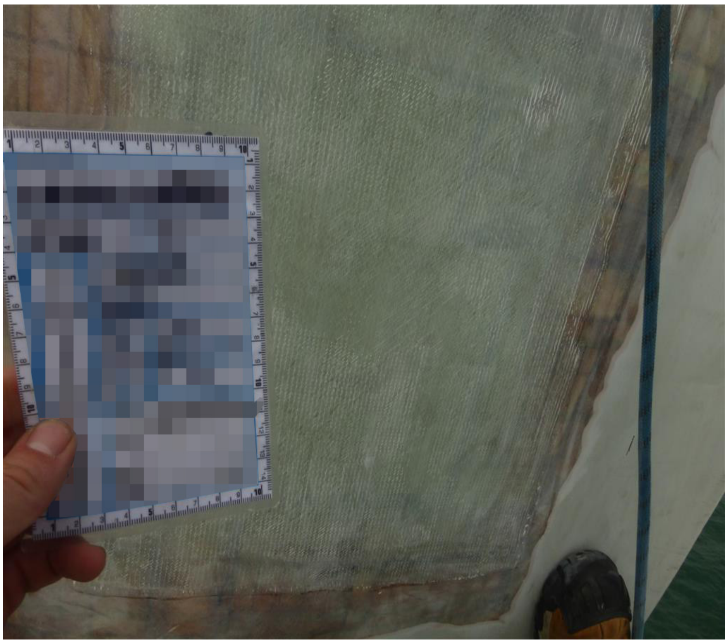

Figure 7a and 7b

Blade E11

Following completion of the D10 repair on 13th September, work started on blade E11 the next day. The damage as found on inspection was a relatively small burned hole as shown in Figure 8a. As the extent of the damage was exposed, it was clear that the balsa wood core was extremely wet and the engineer was able to pull away significant sections of rotten wood as shown in Figure 8b.

Figure 8a and 8b

The full extent of the area where wet balsa wood had to be removed is shown in Figure 9a. The depth of the incision into the blade is shown in Figure 9b.

Figure 9a and 9b

Once the balsa wood was replaced, the outer laminate layers were built up, as shown in Figure 10a. A heat blanket was used to cure the fibreglass layers. A maximum of three layers can be laid together, then the engineers have to wait for them to set. Given the location of the damage on the blade, this repair required 49 replacement layers of fibreglass in the outer region. This was a time-consuming process with several limiting factors including humidity, temperature, wind speed and precipitation. After nine successful days of work, weather conditions deteriorated causing 10 consecutive weather days. One day was also lost due to CTV maintenance, and the unfavourable weather conditions continued into October. Work was completed on 25th October, having suffered a total of 22 weather days. The completed repair is shown in Figure 10b.

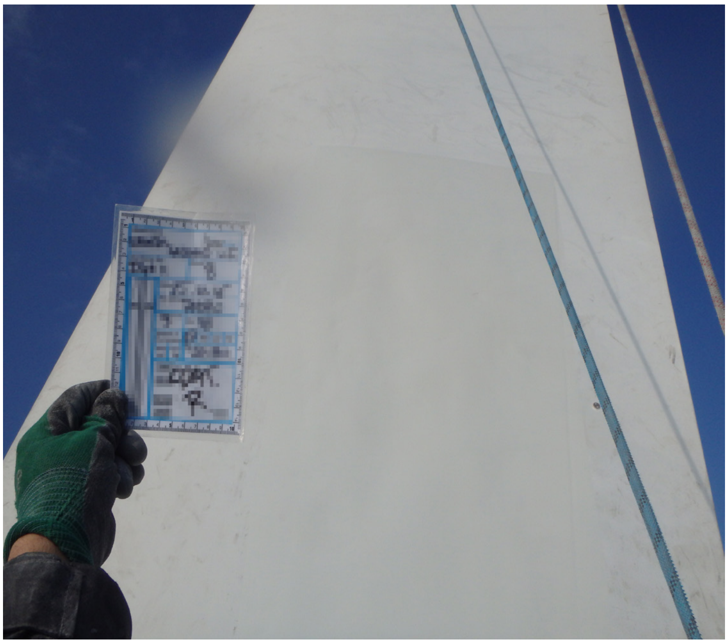

Figure 10a and 10b

Blade F08

Given the longer-than-expected time to repair the first two blades and the Owner/Operator prioritising the need to stem further degradation through the winter, it was decided to seal the blade on F08 using a temporary repair: a much simpler job than the repairs to blades D10 and E11. The damaged area is shown in Figure 11a. The repair involved applying 2C adhesive to seal the damaged area as shown in Figure 11b. Finally, the sealed area was coated as shown in Figure 11c, and the repair was completed in one day.

Figure 11a (top left), 11b (top right), and 11c (bottom)

The Results

The Owner/Operator considers the lightning strike damage repairs to be a success. In spite of the significant challenges imposed due to the unforeseen extent of the damage and the adverse weather, the work was executed to industry standards and without any health and safety issues. The three affected wind turbines are now back to full operation.

Quality assurance

An offshore wind engineer representing the Owner/Operator interviewed for this case study stressed the difficulty of performing quality checks on the repair given that important features such as the balsa core are enclosed by design, and there are no internal sensors recording data.

Therefore, it is crucial that a service provider provides excellent documentation of the damage and repair carried out. This should be in the form of photographs and technical reports. Progress should be monitored and regular de-briefing sessions with the team involved are useful.

Blade structure repairs involving laying sections of fibreglass carry the risk of layer separation. This failure mode can create small bubbles in the blade coating, but can be extremely difficult to spot. Therefore, the Owner/Operator plan to inspect the affected blades with an HD camera one year on from repair to provide assurance that the work has been effective.

Management of production losses throughout repair period

The shutting down of turbines for repair was overseen by the Owner/Operator's control room staff under their own wind turbine safety rules. During the initial stages of repair, the affected turbines remained shut down between repair visits. This was due to a reduction in the blade's structural strength caused by the layers of material being removed to expose the damaged area. As the repairs progressed, it was deemed safe to operate the turbine when the repair team was not working on the blade, allowing the turbine to be run overnight and on weather days. This approach was implemented successfully to minimise production losses.

Cost of Repair

The cost to repair the blades incorporates contracting a service provider, supervision, vessel costs and lost production. These cost elements are presented in Table 2.

Element	Cost Details
Contract with service provider	Fixed cost contract covering labour, equipment and materials. Weather risk included.
Owner/Operator authorised technician	20 days of Owner/Operator authorised technician for supervision of maintenance.
Making provisions for one CTV	The exclusive use of a CTV from the existing Owner/Operator fleet.
Lost production	27 turbine days of lost production estimated to be 933 MWh. Lost production estimation assumes the turbine operates with an average capacity factor of 40%.

Table 2: Cost of repair of three blades at the offshore wind farm.

The costs described during the interview revealed that even with a conservative estimate of the price paid per MWh for electricity generated, of the elements described in this table, lost production was the largest cost and hence the most significant cost driver.

Lessons Learned

The Owner/Operator and the service provider conducted a lessons learned workshop following the repair campaign, which led to the following conclusions:

- The approach adopted for blade inspection and management during the first five years of the warranty contract resulted in lightning damage going unidentified and unrepaired for an unknown period.
- Lightning strike damage can expose the balsa wood core of a blade and any delays to repair will exacerbate the issue significantly. Rain water will rot the core, resulting in an increasingly complex repair.
- The damage was much larger than estimated from the inspection campaign. It is difficult to establish the extent of lightning strike damage from non-intrusive imaging techniques alone, and therefore difficult to quote a price for the maintenance work. Going forwards, the Owner/Operator will introduce intrusive exploratory drilling and probing in the inspection phase in order to write a more representative work specification.
- In this particular repair campaign, lost production was the largest cost element and was a key driver. It is critical to repair lightning strike damage as early as is practically possible to minimise downtime and hence minimise cost.
- Application of the Owner/Operator's in-house wind turbine safety rules avoided the need to request technician support from the OEM. This reduces costs, increases flexibility and improves efficiency by reducing the number of people and organisations involved in planning and executing maintenance activity.
- The service provider is aiming to train its own staff to become authorised under the Owner/Operator's wind turbine safety rules. This initiative will negate the need for Owner/Operator staff to accompany them, and is currently being successfully used at some onshore wind farms.
- Ensure there is a strategy to manage weather risk. The Owner/Operator recommends removing the high-speed lock on brakes during maintenance downtime to avoid wear and tear on other components.
- Allow flexibility in working hours to optimise the suitable weather windows for priority maintenance tasks. In this job, the team started by working a fixed five-day shift pattern. But because poor weather caused significant delays of the repair of blade E11, the team started working on weekends. This facilitated increased access to the turbines and minimised mobilisation costs. The Owner/Operator stated that it would facilitate working on weekends for any similar repairs in the future.
- Relationships with sub-contractors are extremely important when managing a weather-dependent repair of unknown scope.
- Blade damage is emerging as a considerable problem for offshore wind farms, and the Owner/Operator expects a high demand on service providers capable of blade inspection and repair. Growth in installed capacity, coupled with a glut of wind farms coming out of warranty, has increased the volume of blade repair work required across the sector and only a limited number of companies can provide this service.
- More authorised blade repair technicians will be required for the expected volume of work in the coming years.

Appendices

References

[1] DNVGL-ST-0376, Rotor blades for wind turbines, December 2015.

Author profiles

Conaill Soraghan is a Renewable Technology Engineer at the Offshore Renewable Energy Catapult. He has a background in applied mathematics and completed a PhD in wind turbine design. Conaill's main area of interest is the management and optimisation of operational assets and he has extensive experience in the design and development of benchmarking systems and data/knowledge sharing for the offshore wind industry.

Sally Shenton is the Managing Director of the offshore wind O&M consultancy Generating Better. Prior to this, she held the position of Operations Manager for various offshore wind farms.

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This is one in a series of offshore wind O&M-focused case studies, supported by ORE Catapult's O&M forum and funded by The Crown Estate and the Offshore Wind Programme Board. These studies aim to highlight game-changing O&M projects, and promote the dissemination of knowledge among the offshore wind O&M community.

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ORE Catapult

Inovo

121 George Street
Glasgow
G1 1RD, UK
T: +44 (0)333 004 1400

National Renewable Energy Centre

Albert Street, Blyth
Northumberland
NE24 1LZ, UK
T: +44 (0)1670 359 555

Fife Renewables Innovation Centre

Ajax Way
Leven
KY8 3RS
T: +44 (0)1670 357 649

O&M Centre of Excellence

Room 241, 2nd Floor
Wilberforce Building
University of Hull
HU6 7RX

ore.catapult.org.uk

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info@ore.catapult.org.uk