A wind farm owned by Paulding Wind Farm LLC, Paulding Wind Farm II LLC, and Paulding Wind Farm III LLC

TIMBER ROAD
WIND FARM

Operations & Maintenance Office
9630 State Route 49
Payne, OH 45880

419.263.0137 phone
419.263.0151 fax

April 1, 2021

Ohio Power Siting Board
180 E. Broad St.
Columbus, OH 43215
Case No. 18-91-EL-BGN

To Whom It May Concern:

This letter continues the communication between your office, the Ohio Power Sitting Board ("OPSB") and EDP Renewables North America ("EDPR NA") on behalf of its subsidiary, Paulding Wind Farm IV LLC ("Timber Road IV"), regarding the September 3, 2020 failure of one blade on one Vestas V150-4.2MW wind turbine at the Timber Road IV project in Paulding County, Ohio ("Incident"). As follow up to the previous correspondence delivered to OPSB this letter provides details on the event investigation, actions taken since the event, and the final incident report.

Timber Road IV has worked closely with the turbine manufacturer (Vestas) on the investigation, risk assessment and restoring the turbine into operations. Through its engineering investigation and analysis, Vestas has concluded the primary factor contributing to the blade failure was weakened fiberglass due to a manufacturing anomaly. As a precautionary measure, containment actions were promptly initiated, including the visual inspections of all V150 blades at the project site, and the review of manufacturing records and data for the V150 blades in operation at Timber Road IV. Vestas has cleared all V150 blades at the project for operation.

The impacted turbine was brought back into operations on December 14, 2020. Additional details can be found in the included Vestas Incident Report.

DS
CJ

A wind farm owned by Paulding Wind Farm LLC, Paulding Wind Farm II LLC, and Paulding Wind Farm III LLC

TIMBER ROAD
WIND FARM

Operations & Maintenance Office
9630 State Route 49
Payne, OH 45880

419.263.0137 phone
419.263.0151 fax

We appreciate OPSB's collaboration as we work to ensure Timber Road IV continues operating in a safe and responsible manner.

Sincerely,

Paulding Wind Farm IV LLC

DS

DocuSigned by:

1AA6B44331BC410...

Brian Hayes
Executive Vice President, Asset Operations
EDP Renewables North America

Vestas

Incident report

Timber Road IV, Ohio, USA
Blade Incident on September 3, 2020
V150-4.2 MW Mk 3E

Date of report:	February 5, 2021
Vestas ref.:	4995
Document no.:	0104-6124 V00

Important notice

Preface

Part of Vestas's strategy is a constant and on-going desire to improve the quality, operational reliability, and safety of our products. Major incidents of damage and malfunction of wind turbines are therefore investigated very thoroughly.

Scope

Vestas has prepared this report as part of its investigation of a blade incident which occurred on September 3, 2020 to a V150 turbine at a wind farm in Ohio, USA.

Glossary

TERM OR ABBREVIATION	DEFINITION
DSC	Differential Scanning Calorimetry
FVF	Fiber Volume Fraction
Leading edge (LE)	The leading edge of the blade, i.e. the 'nose' that is heading into the wind during operation.
Leeward (LW)	The leeward side is also known as the suction side. It is the side of the blade facing the tower during turbine operation.
Trailing edge (TE)	The trailing edge of the blade is the thin edge where the airflow leaves the blade during operation.
Web	Wall inside the structural shell blade that supports the inner structure of the blade.
Windward (WW)	The windward side faces the wind and is also known as the pressure side.

Measures

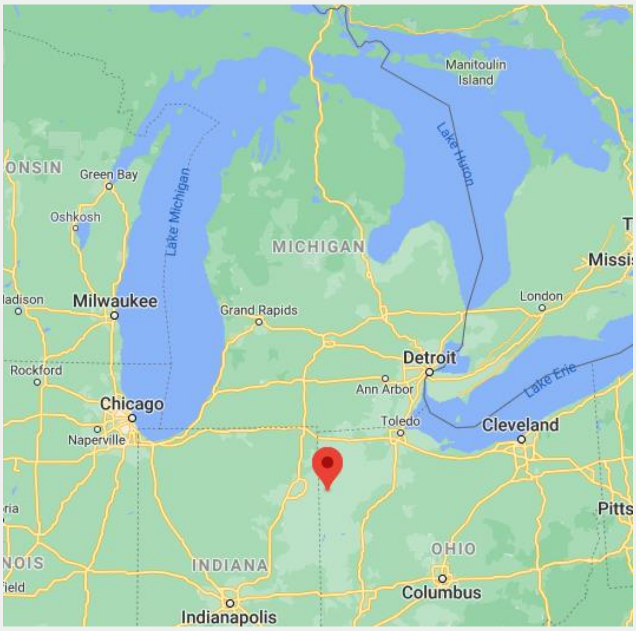
ABBREVIATION	UNIT OF MEASURE
ID	Identification
MW	megawatt (1,000 kilowatt)
kNm	Kilonewton meter (1,000 newton meter)
m/s	meters per seconds
rpm	revolutions per minute

Table of contents

1 Description of incident

1.1 Wind farm

Owner	Paulding Wind Farm IV LLC
Name of wind farm	Timber Road IV
Country	Ohio, USA
Site location	



1.2 Turbine information

Local wind turbine no.	TMR428
Time of installation	2020-03-07

1.3 Investigation timeline

Date of event	September 3, 2020
Drone inspection	September 8, 2020
Blade on ground	October 9, 2020
Second on-site inspection	October 13, 2020
Final report released	February 5, 2021

1.4 Event

On September 3, 2020 at 22:36 local time, one of the blades of turbine TMR428 experienced a structural failure while the turbine was in operation at a wind speed of 9-11 m/s.

The vibration shock sensor alarm was triggered by the rotor imbalance caused by the blade break and the turbine was brought to a safe stop as intended by the turbine safety system.

The site lead was notified at 6:28 on September 4, 2020 and arrived at the tower at 6:45 to find severe blade damage and debris on the pad.

The broken blade caused damage to a second blade, the nacelle, cooler top and spinner.

No one was near the turbine at the time of the incident.

2 Immediate containment actions

The area was cordoned off. There are 24 V150 turbines at the site. Blade inspections were performed on the remaining 23 turbines with no issues found.

3 Root cause analysis

3.1 Drone inspection and up-tower inspection

A drone inspection performed after the incident provided an immediate overview of the damage incurred. A piece of the broken blade was resting on top of the nacelle and the rest of the broken part had fallen to the ground. In the up-tower inspection, the failed blade was confirmed to be blade C. The debris map in Figure 1 shows the location and estimated weights of all significant debris around the turbine after the incident.

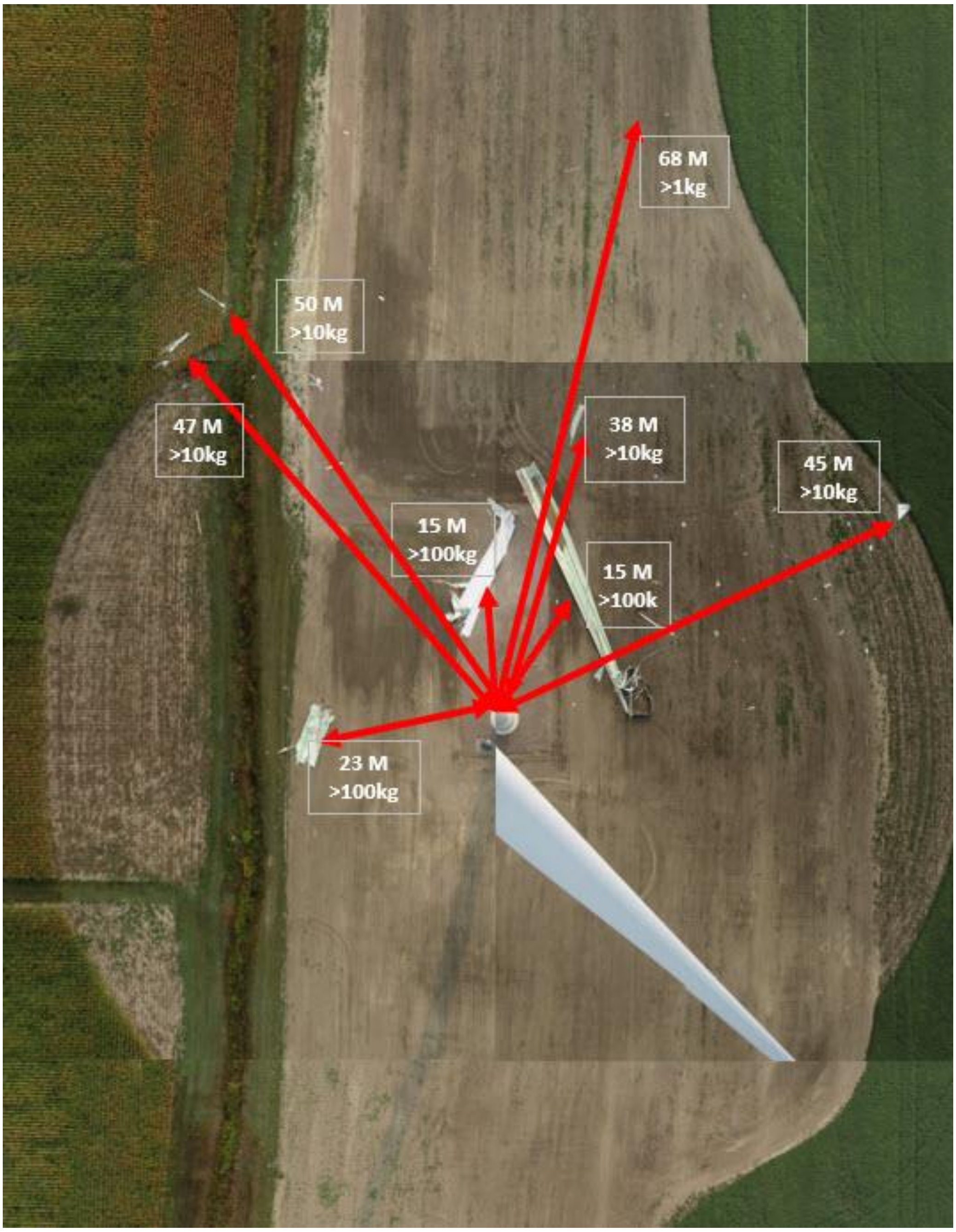


Figure 1 Debris map

3.2 Environmental data

At the time of the incident, the turbine was producing approximately 3 MW and wind speeds were in the range of 9-11 m/s. No unusual wind conditions were recorded.

No lightning activity had been recorded in the vicinity of the turbine.

3.2.1 Turbine controller data

The event log retrieved from the turbine controller for a period leading up to the incident was analysed. From the recorded vibration, tower acceleration, and blade load data it can be confirmed that the incident occurred at 22:36 local time on September 3, 2020.

In the event log, the wind speed was recorded at 9-11 m/s in the hour leading up to the incident. The remaining data in the 30-minute log for generator rpm, pitch angle, and power production did not deviate from normal. Hence, the turbine was operating as expected in the period leading up to the incident. The blade broke with no prior warnings or early indications.

3.3 Blade data

The blade manufacturing records were reviewed, and it was confirmed that the blade satisfied all quality requirements. All non-conformities identified during the blade manufacturing process were reviewed and confirmed to have been resolved prior to blade delivery. The blade was visually inspected upon delivery to the project site and no anomalies were detected.

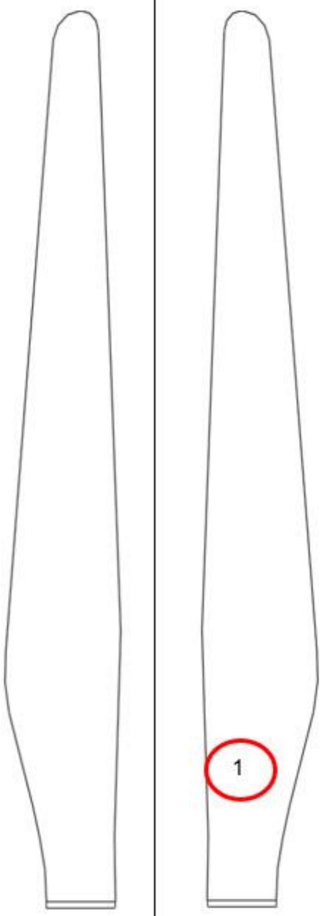
3.4 On-site inspection

After the root section of the damaged blade had been lowered safely and secured below the turbine, an on-site inspection was carried out on October 13-14, 2020 by Vestas specialists. The blade had broken into three sections. The leeward and windward shells of the broken tip section had separated.

Dry laminates were observed in the structural shell interlayer laminate sections in the shell laminate section of the trailing edge panel, and in the laminate panel adjacent to the main web in the leeward shell.

Selected shell samples were cut and sent for laboratory examination along with samples of bond line and glass laminate, see section 3.5 Laboratory analysis. Adhesive samples from the bond lines and the resin in the shell laminates were confirmed by DSC sampling to have cured properly.

Bond lines of web, trailing edge and leading edge were inspected, and no anomalies were found. Bond widths at various locations were measured and found to be within specification.
No evidence of lightning damage was observed.



Blade inspection sketch			
		Project no./name:	Timber Road IV
		Pad no.:	TMR428
		Comments to the damage shown in the drawing:	1) R7-8 – Break location Dry laminates found Large folded ply/wrinkle found
Windward	Leeward		

Figure 2 Summary of inspection

3.5 Laboratory analysis

The leeward laminate panel around the main web and the trailing edge web close to the blade break line were subjected to laboratory analysis at Vestas's blade factory. The results of the laboratory analysis are detailed below.

3.5.1 Visual and invasive inspection of samples at laboratory

In a detailed visual inspection of laminate panels performed at the laboratory, the following observations were identified:

- Dry laminates were observed throughout the thickness of the shell laminate.
- Under-core laminates exhibited poor bonding with the core and the carbon pultrusion indicating poor interlaminar bonding as shown in Figure 3.
- A hole saw cut was made in the laminate section of the leeward shell exposing the dry laminate between the over and under core laminate as shown in Figure 5.

Figure 3 Individual fibers can be pulled from the laminate showing poor consolidation

Figure 4 Dry fibers

Figure 5 Hole cut through shell - dry laminate layer in the middle of the shell

3.5.2 Destructive testing of samples

Samples from the on-site investigation were subjected to the following laboratory analyses:

1. Differential Scanning Calorimetry, or DSC, is a thermal analysis technique that looks at how a material's heat capacity is changed by temperature.
2. Multiple Fiber Volume Fraction (FVF); measures the percentage of fiber volume to the volume of resin in a fiberglass laminate section.
3. Pull-off tests measuring the interlaminar bonding strength.

The DSC analysis shows that the resin in the sample shell panel had cured completely.

The Fiber Volume Fraction was found to be higher than the production specification in most inspection locations, indicating lower resin content than required in the laminate area around the blade break line.

The pull-off test results never reached the specification limit, indicating poor interlaminar bonding in the laminate section around the blade break line.

The most plausible cause of poor laminate quality is an inadequate consolidation of glass layers caused by a vacuum leak during the blade manufacture. In a review of the vacuum consolidation blade manufacture record, an anomaly was identified in the vacuum chart during the curing of the leeward shell of the blade, which is further explained below in section 3.6 Vacuum failure mechanism.

3.6 Vacuum failure mechanism

The poor laminate quality of the blade is a result of a measured leak during the shell infusion process at a critical time when the resin was still liquid, which allowed air to enter into the laminate. The vacuum failure mechanism is outlined below.

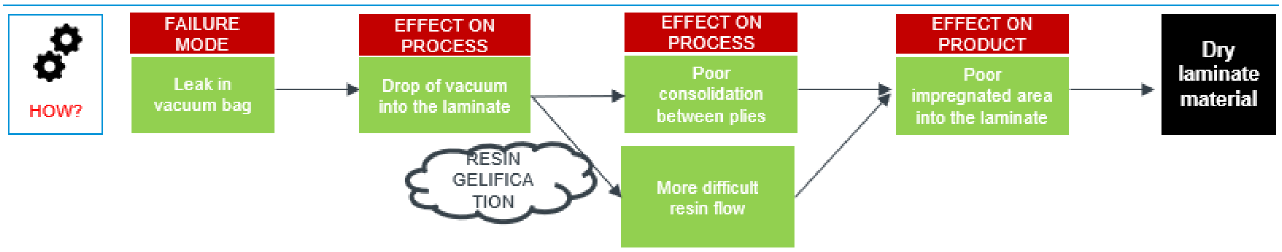


Figure 6 Vacuum failure mechanism

3.7 Corrective actions

3.7.1 Production Improvements

The actions listed below are taken at the production facilities of the V150 blade as a result of this blade failure. The actions outlined will provide additional controls to mitigate the introduction of leaks and to improve detection of leaks during the vacuum consolidation and infusion-curing process.

Allowed vacuum level during curing

At the time when the blade was produced, the vacuum level during the production of this blade rose to approx. 15 mbar, which was below the vacuum alarm limit at the time.

The vacuum alarm limit has since been reduced to ensure detection of any similar leaks in the future.

Resin consumption

The blade had recorded less resin consumption than other blades produced in the same month.

Due to this finding, a control limit has been introduced to ensure a certain resin consumption during blade production. A reaction plan has been defined so any consumption outside these limits is investigated and addressed accordingly.

Waiting to install insulation covers

Since the blade failure, the factory has implemented a delay in the installation of the insulation covers from the start of the cure to provide additional time to inspect for air leaks and confirm vacuum seals. In case of a leak detected by a change in the vacuum level, this delay makes it easier to locate the leak and act upon it.

This period allows the resin to slowly increase its viscosity from liquid to gel, at which point it is no longer possible for air in a potential leak to penetrate the gel and form an air bubble inside the resin. If a leak occurs after the gel phase, it will cause damage to the outside of the shell, which can easily be detected and repaired.

This change also minimizes the effect of a potential leak introduced while installing the insulation cover because the resin will have already solidified by that time in the process.

Tighter limits on vacuum when starting drop test

The factory has also implemented a change to the vacuum level limit that triggers the start of the leak test. The limit has been decreased. This lower vacuum level limit makes it easier to detect any leaks during the drop (leak) test.

4 Failure mechanism

From the on-site and laboratory investigations as well as load simulation, Vestas has determined that the blade break was the result of a low-cycle fatigue mode. This failure mode was likely due to high spanwise strains caused by a poor laminate quality from the blade manufacturer that gradually weakened the blade over a period. The blade broke once the laminate strength was sufficiently reduced.

5 Conclusion

This report presents the findings of the root cause investigation of the blade incident that occurred on September 3, 2020.

Blade C broke at R8 under normal turbine operating conditions. At the time of the break, the blade was in the 3 o'clock position with its leading edge downwards.

A review of the turbine's operational data, alarm logs, and environmental data (including lightning) at the time of the incident did not reveal external environmental contributors to the failure of the blade.

An on-site investigation identified dry laminate in the interlayers of the leeward shell in the area of the failure.

The panels with dry laminate were sampled and sent for examination at Vestas' laboratory. Low interlaminar strength was measured in the panels due to insufficient resin in the laminate.

The root cause of the blade break was weakened dry laminate caused by a leak in the vacuum bag during the infusion process. This introduced air into the resin when the blade was manufactured and produced the observed dry fiber material.

The failure mechanism is found to be high strains due to poor laminate quality causing a fatigue damage that grew gradually and weakened the blade laminate structure. The blade broke once the laminate strength was sufficiently reduced.

6 Containment Actions

Immediately following the incident, internal visual inspections were completed on all V150 blades at the project site focusing on identification of shell laminate conditions (stressed or dry laminate). No anomalies were identified.

Manufacturing data of all V150 blades at the project site were reviewed and identified no blades showing a similar production signature as the broken blade. However, to confirm the absence of another dry laminate blade in operation, five blades at the project site were identified for further inspection based on one or more of the following criteria: (a) unresolved vacuum drop during curing stage, (b) dry spots observed in the post moulding stage, and (c) low resin consumption compared to other blades.

The five blades were recommended for field inspection using air blow test procedure to check for presence of dry laminate or void in the subsurface laminate of the shell. All five blades successfully cleared the air blow test, showing no evidence of dry laminate or voids in the subsurface laminate which would have allowed air to pass through. All V150 blades at the project site have been cleared for operation.

Air blow test

Two adjacent holes were drilled in several locations of the shells, each reaching the subsurface laminate in these blades. Air was introduced to the subsurface laminate through one of the holes while checking for escaping air in the adjacent hole.