Wind farm owner's view on rotor blades – from O&M to design requirements

BREMEN 25-27, February 2013

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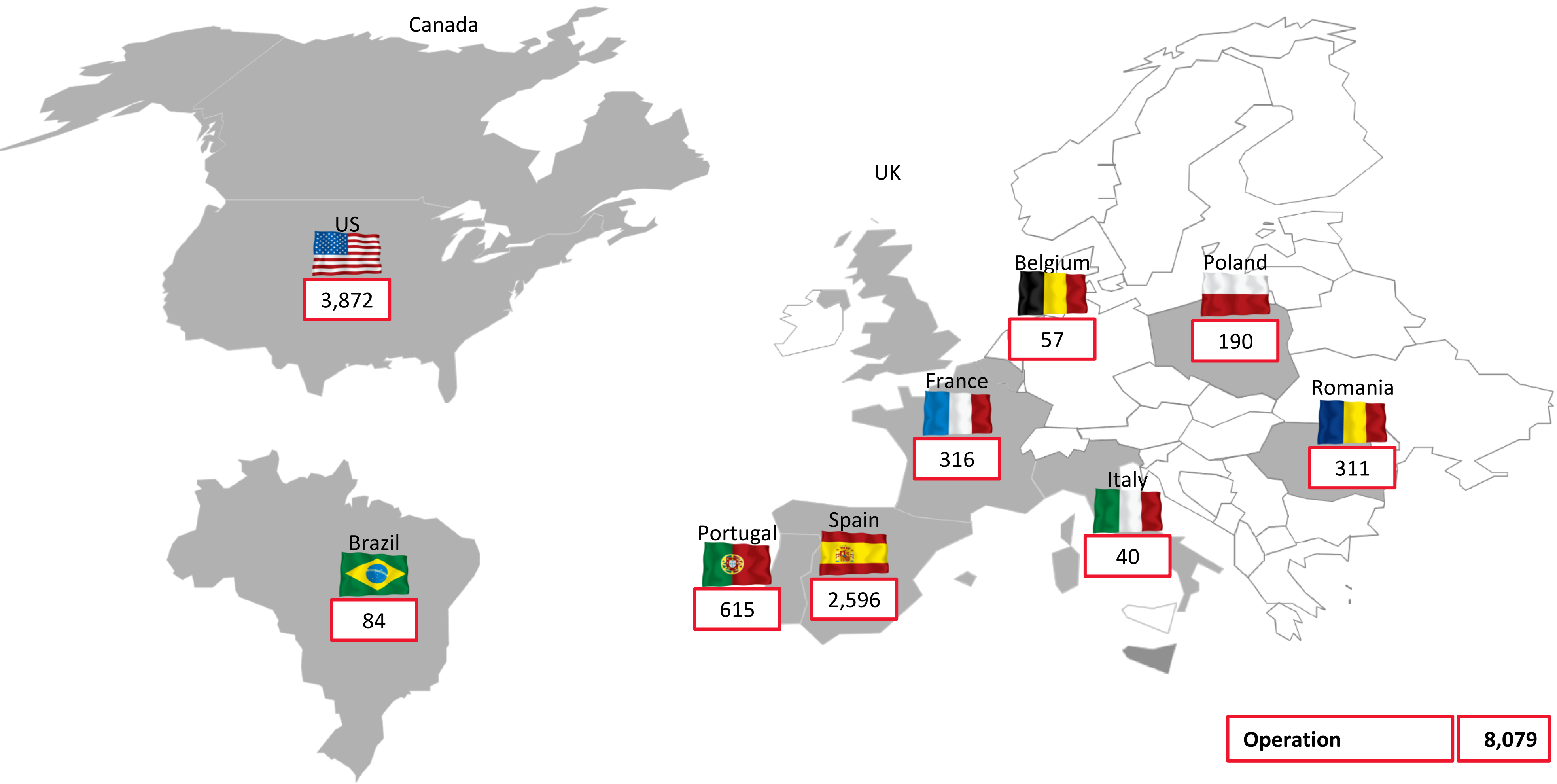
Wind farm owner's view on rotor blades – from O&M to design requirements

- Large and heterogeneous fleet of blades
- Typical failures in WTG blades
- Inspections
- How ser up a root cause analysis from owner perspective
- Interaction between WTG manufacturer and wind farm owner
- Repairs
- Main challenges and future scenarios

EDP Renewables



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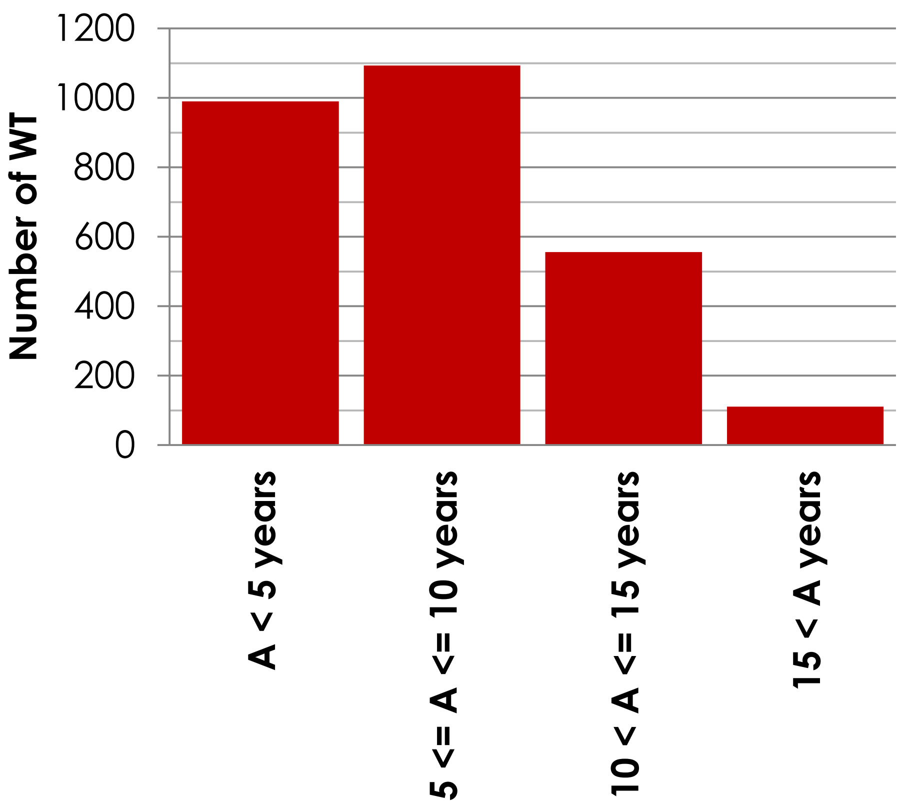
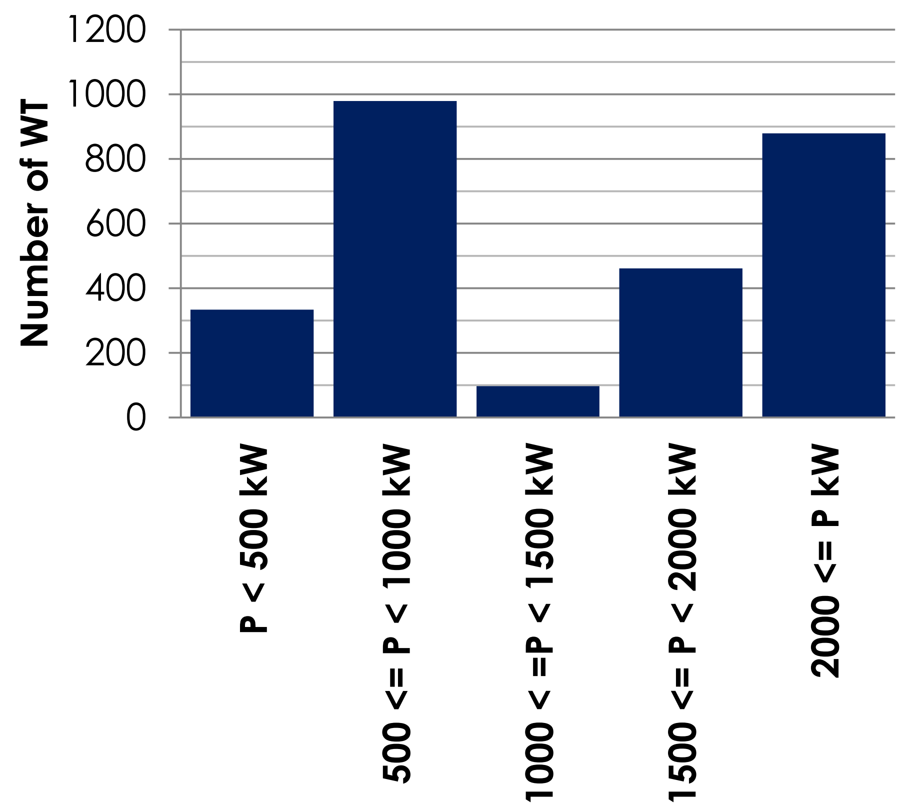
EDPR-EU fleet

Present fleet of EDPR in **Europe** has **3101 WT** with the following characteristics:





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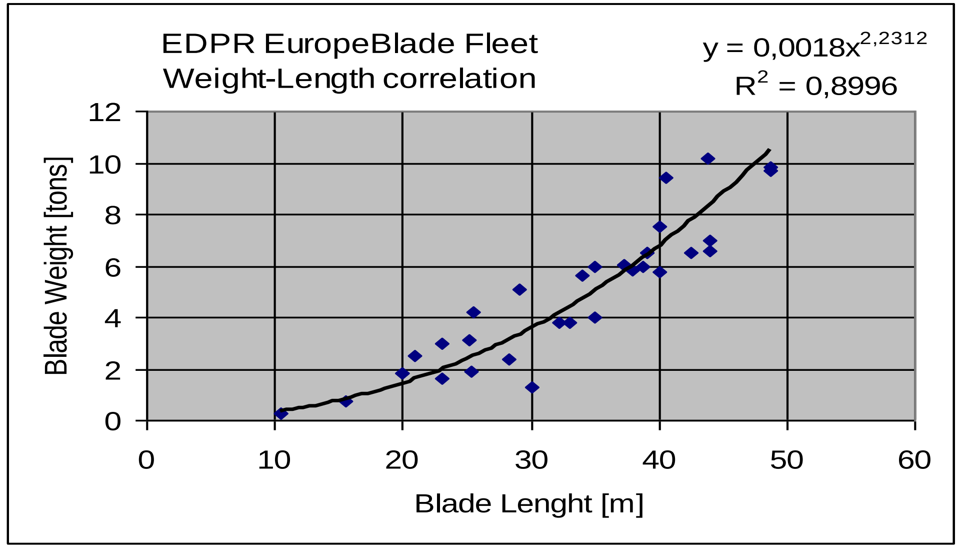
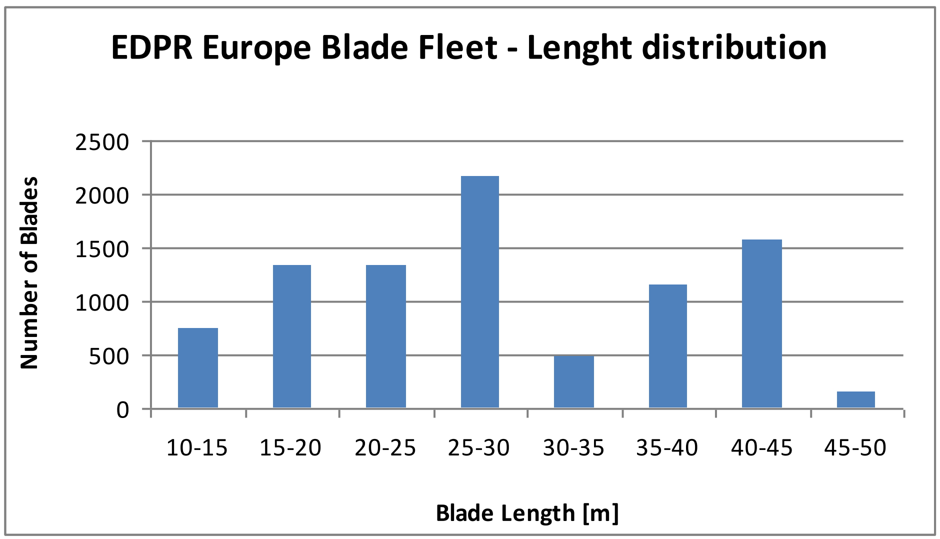
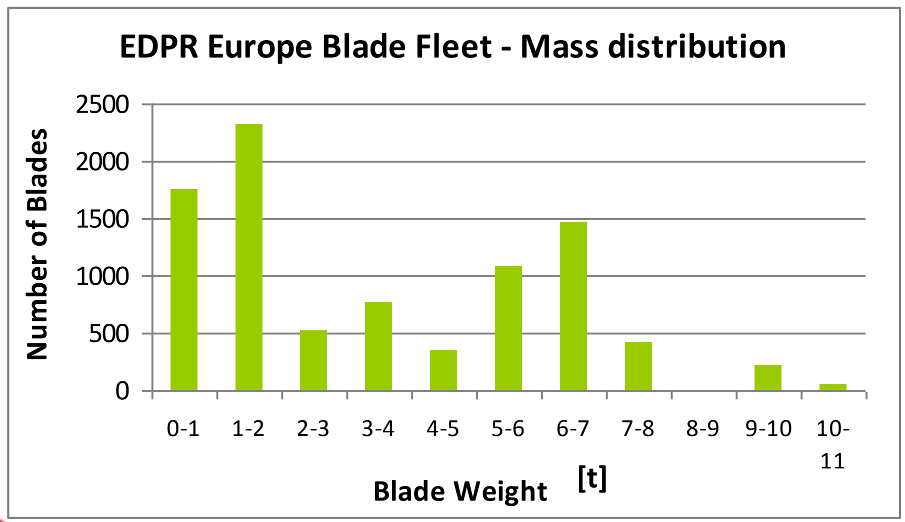
Blades on EDPR-EU fleet

- 4124 MW installed capacity (EU, December 2012)
- 3101 wind turbines
- 9303 blades
- Some 33.620 tons of composite material in total
- Lengths from 15 to 55 m
- Weights from 750 to 13752 kg
- Ages from 16 years to some months
- Materials: glass fiber, carbon fiber, polyester resin, vinyl ester resin, epoxy resin, balsa wood, birch wood







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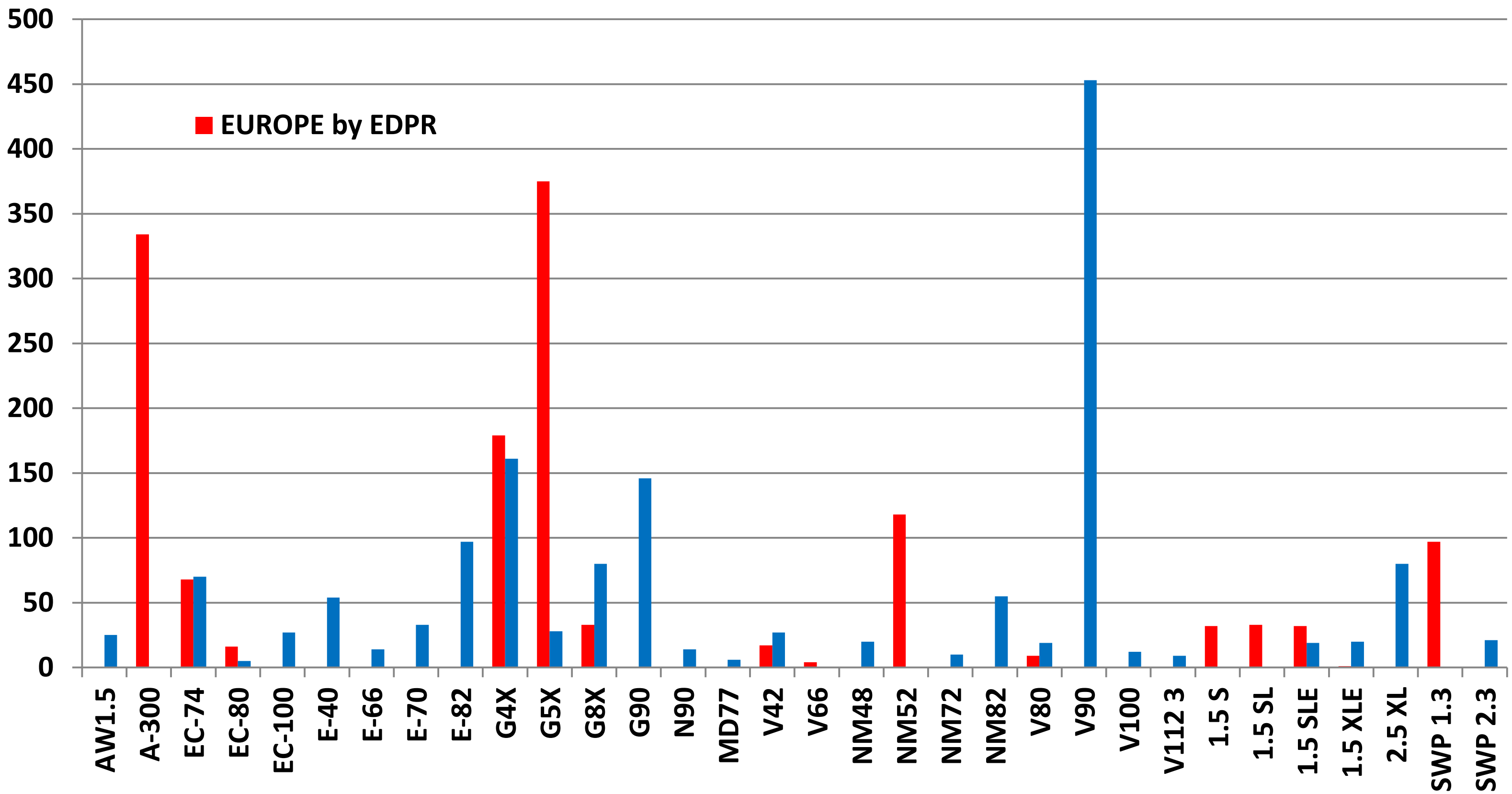
European fleet maintained directly by EDPR

EDPR in Europe has **3101 WT** :

- **1348 WT managed by EDPR (43%)**
- **1753WT managed by WT OEM (57%)**



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Covering the blade maintenance service

Framework agreement with 4 companies for inspections and repairs

•It is planned an inspection campaign for each wind farm 6 months before, adjusted 1 month before and confirmed 1 week before
• All blade technicians supply their CV
• Repairs are proposed base on inspections results and according to a procedure that must by approved by the owner
• Reports of inspections and repairs according to an standard and delivered 1 week after the works
• Teams of 2-3 technicians per wind turbine
• Prices closed for each work, calculated according to a unitary prices agreement:

→*Price of Inspection = f (number of blades ; longitude of blades ; modality of access ; distance to the ISP base)*
→ *Price of Repair = f (number of working hours ; hub height ; modality of access ; distance to the ISP base)*

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Inspections

•Visual inspection from the ground through powerful telescopes
→ 100% six months before the end of warranty
→ 33% - 50% each year after warranty

•Visual inspection at height by lifting platforms or rappelling techniques or crane with platform in cases where it is needed a more deep inspection

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Inspections

renováveis	Tipo documento:	Informe técnico
	Código Documento	
Categorización de daños en palas	Fecha:	2011-12-06
	Asunto:	00
	Página	16 of 18

Para categorizar los daños en el borde de ataque se sugiere la siguiente tabla e imágenes. Los daños en la tabla están referidos a las partes mostradas en la figura 1 de la página 8 del presente documento.

Categoría	Daños en cada parte de la pala
1	Sin daños
2	<10% de pérdida de pintura y agujeros puntuales de poca importancia
3	10-25% de pérdida de pintura y erosión leve del laminado
4	25-40% de pérdida de pintura, erosión moderada del laminado
5	>40% de pérdida de pintura, erosión grave del laminado

Tabla 2. Categorización de daños en el borde de ataque

Figura 16. Daños categoría 2 borde de ataque

Figura 17. Daños categoría 3 borde de ataque

Figura 18. Daños categoría 4 borde de ataque

Figura 19. Daños categoría 5 borde de ataque

Dpto. O&M

Looking for a common basis:

- Development of failure categorization criteria
- Development of decision making strategy depending on failure category
- Development of visual guidelines to be used by site managers and inspection service providers

Category	Repair Priority	Blade Inspection Description/Findings	Continue to Run / Take Offline?	Action
1	None	Blade is in good working condition typical for it's age with possible signs of minor wear	Continue to Run	No action necessary
2	None	Blade shows early signs of wear or damage	Continue to Run	Monitor & Repair within 1 year
3	Low	Blade shows significant signs of wear or damage	Continue to Run	Monitor & Repair within 6 months
4	Medium	Blade shows advanced signs of wear or damage and should be scheduled to be repaired before	Continue to Run	Monitor & Repair within 3 months
5	High	Blade has failed or must be taken out of service to prevent further damage	Take Offline	Repair or Replace Immediately

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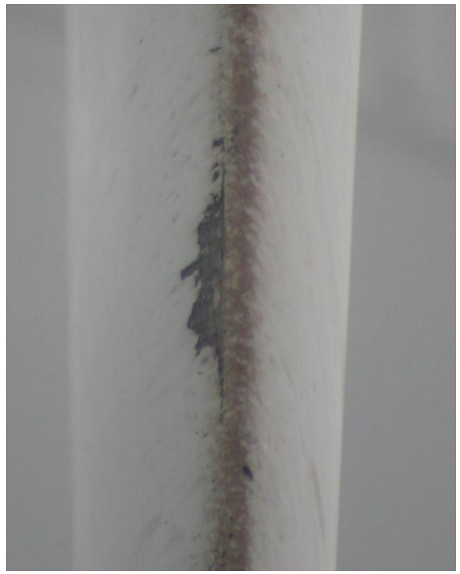
Inspections results

Example of a wind farm with 67 WT inspected after 14 years of operation:

	Nº of blades (total 201)	% afected blades
Leading Edge Erosion	174	87%
Severe leading edge erosion	100	50%
Dirtness, grease	197	98%
Gel coat debonding	54	27%
Transversal crack in pressure side	45	22%
Broken trailing edge	3	1%
Leading edge debonding	9	4%
Covered drain holes	6	3%

Typical defects due to aging and working hours



Inspections results

Example of a wind farm with 7 WT inspected after 5 years of operation:

		Damages to the coat					Damages to lamination							Damages to aerodynamic parts		Damages in LPS receptor		Dirt	
WTG	BLADE	Erosion of LE	Pitting on LE	Peeling of coat	Pitting	Crack in coat	Crack in bonded joint of LE	Crack in lamination or PVC of LE	Crack in TE	Fracture of fabrics of TE	Crack in bonded joint of TE	Damages to shell lamination	Crack in lamination of shell	Broken or damaged VG´s	Absence of Stall List Broken Stall List	Fusion of LPS screw	Absence of LPS screw	Presence of oil/grease	Dirt
1	1																	X	
	2								POS			X		X		X		X	
	3										POS					X		X	
2	1																		
	2												X						
	3														X				
3	1													X					
	2									X	X								
	3		X											X					
4	1								X							X		X	
	2																	X	
	3															X		X	
5	1																	X	
	2														X			X	
	3															X		X	
6	1				X														
	2																	X	
	3														X				
7	1				X											X			
	2																		
	3															X			
	Total	0	1	0	2	0	0	0	1	1	1	1	1	3	3	7	0	10	0
% Damages		0%	5%	0%	10%	0%	0%	0%	5%	5%	5%	5%	5%	14%	14%	33%	0%	48%	0%

The aging is not an issue in a wind farm with 5 years

Repairs

INSPECTION CAMPAING DESIGN → INSPECTIONS → INSPECTION REPORTING → REPORTING ANALYSIS → REPAIR CAMPAING DESIGN → REPAIRS → REPAIR REPORTING

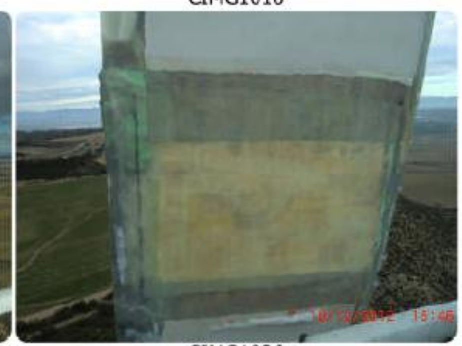

CIMG1014


CIMG1017


CIMG1018


CIMG1019


CIMG1020


CIMG1026

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Up-Tower Repairs

Example of a blade tip damaged by lightning.
Repaired Up-Tower

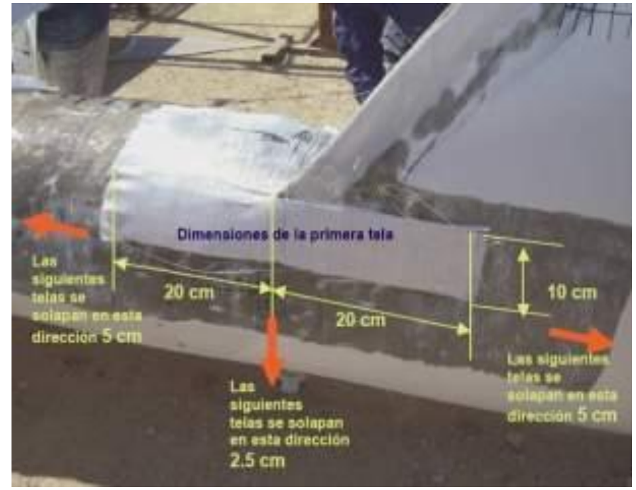






- It is used a crane with platform. Some companies have developed self-propelled platform lifts.
- Repairs that can be done:
  - Surface cleaning.
  - Leading edge wear.
  - Leading edge and trailing edge cracks and debondings.
  - Detachments of the external coats.
  - In some cases: important structural root cracks.
- Repairs are done by the blade manufacturer (usually if blades are under warranty) or by a ISP.

Down-Tower Repairs



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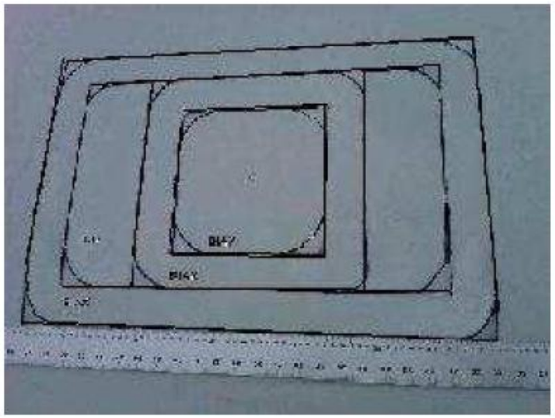
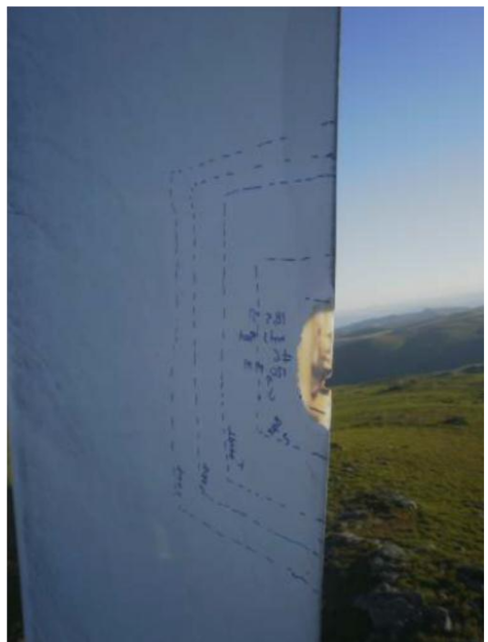
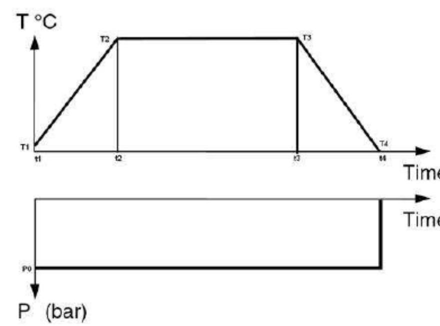
Repairs

LAMINATE SCHEDULE

Layer	Type of Material	Zstart	Zfinish	Length	Width
1 (Top Layer)	Biax 600 H.P	18150	18550	400	200
2	Biax 600 L.P	18150	18550	400	200
3	Triax 900 H.P	18075	18625	550	250
4	Triax 900 L.P	18075	18625	550	250
5	Biax 600 grapa	17975	18725	750	350
6	Biax 600 grapa	18025	18675	650	300



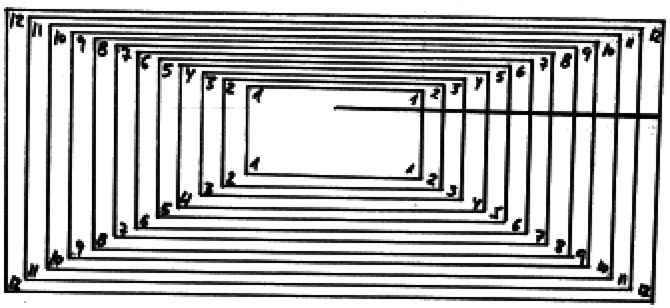


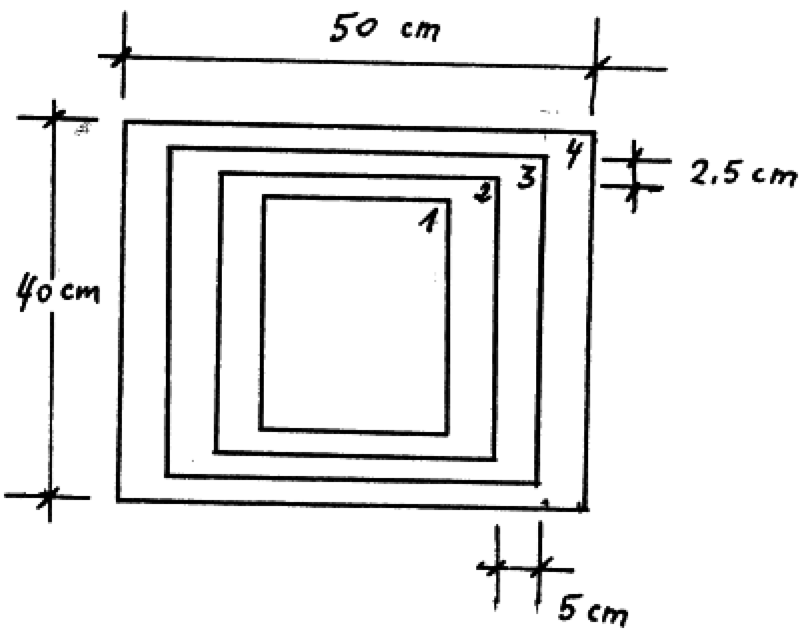


Vacuum and post-cured

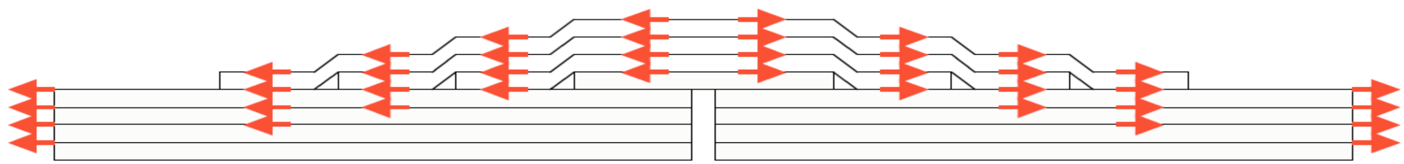
Repairs

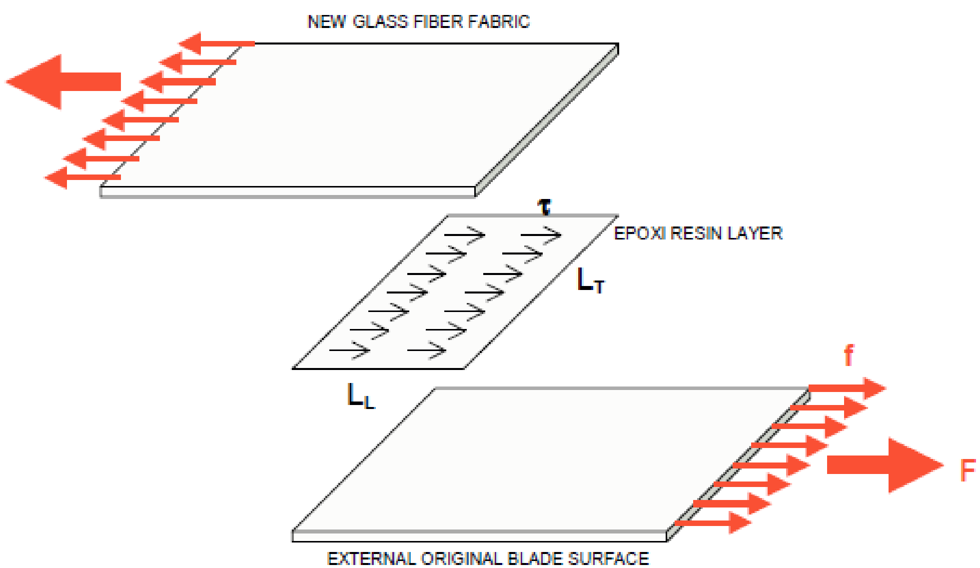
LAMINATE SCHEDULE





Repairs





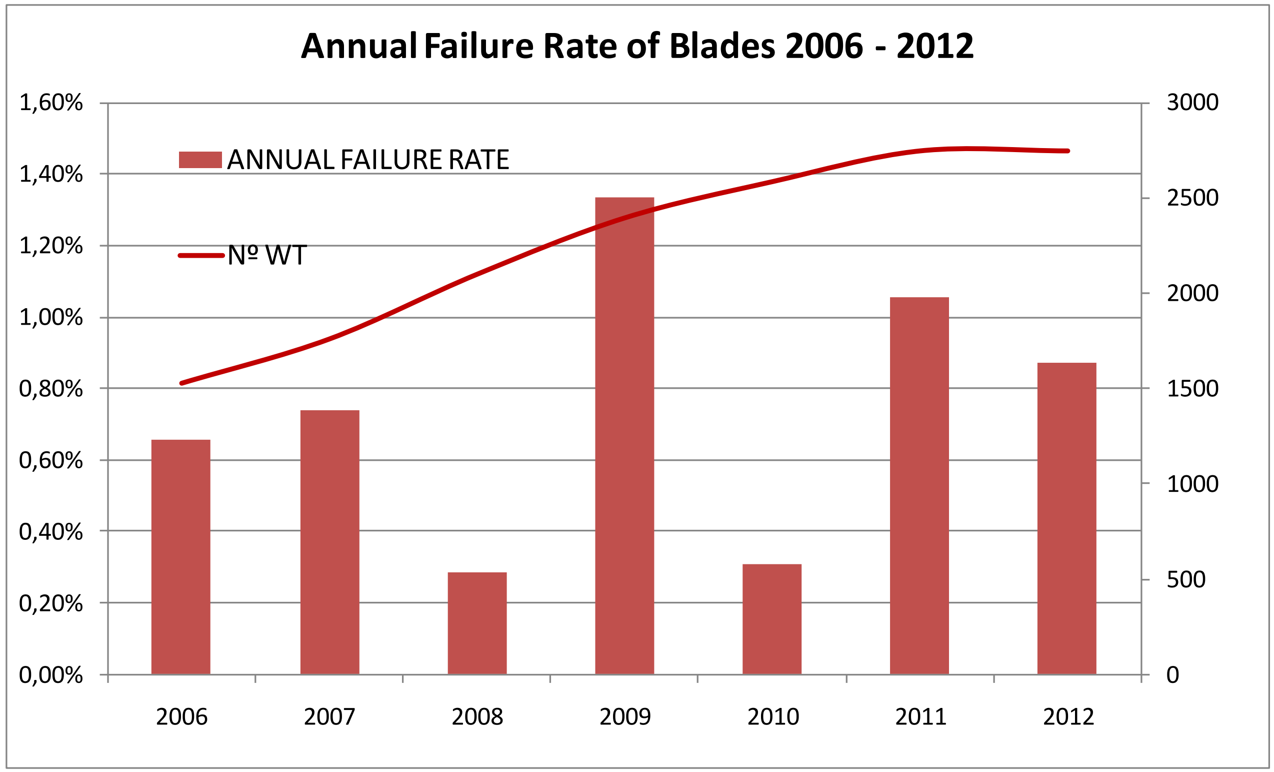
F	Total force [N] from a portion of the original blade that is going to be transferred to a portion of the new fabric.
L_L	Length [mm] of the portion in longitudinal direction, covered with adhesive, and where the original blade and the new fabric are overlapped.
L_T	Length [mm] of the portion in transversal direction, covered with adhesive, and where the original blade and the new fabric are overlapped.
f	Load per unit length [N/mm] (transversal direction) in the blade portion of in the new fabric.
τ	Shear stress [N/mm²] in the adhesive.

$$f = \frac{F}{L_T} \quad \therefore \quad \tau = \frac{F}{L_L \cdot L_T} = \frac{f}{L_L}$$

Major Correctives of blades

Some damages on blades require disassembly the blade to repair on the ground, or in a workshop or even require to replace the blade by another one

Average Annual Failure Rate below 1% (0.5 – 0.75%)
Some years there is a peak because of a massive blade failure (design or manufacturing error) or a particularly aggressive lightning storm season



Key points to manage Technical Issues in EDPR fleet

Technical Knowledge

Mechanical Engineers group
- Structural and Aerodynamic experience
- Composite structure manufacture skills
- Composite design

Blade Failure Data Base

EDPR data base with information of 7000 assets
- Breakdown by technology and wind farm
- Traceability from failure until applied solution

Work Methodology

Establish internal rules
- Feedback O&M site managers
- Inspection
- Operation information

WTG Manufacture & Owner Collaboration

Relationship & Close Collaboration
- Scheduled Technical Meetings

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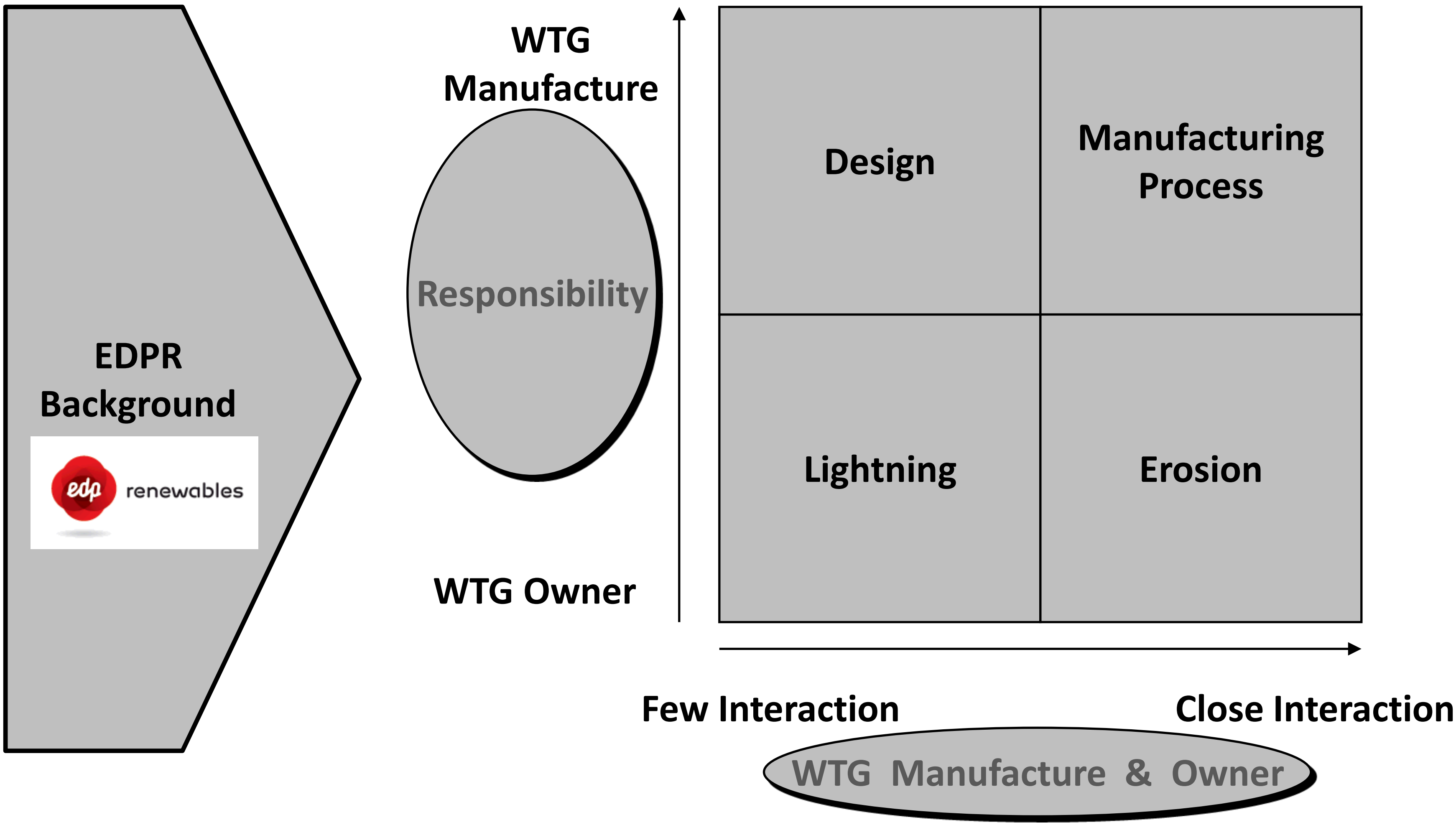
Root Cause of Blades Failures



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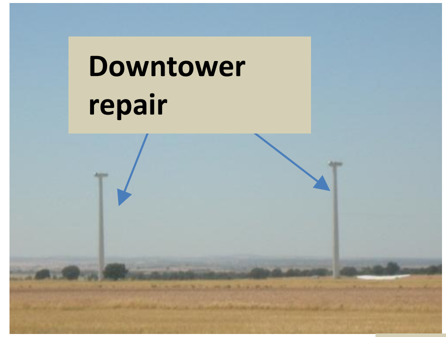
Topology failure (I)

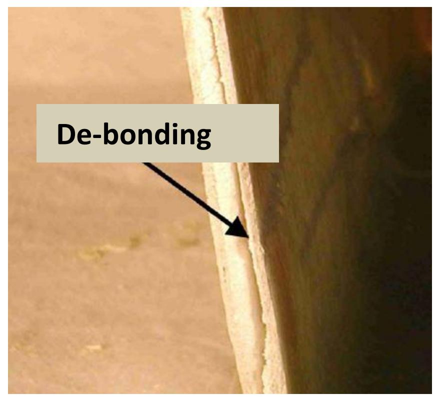
Design

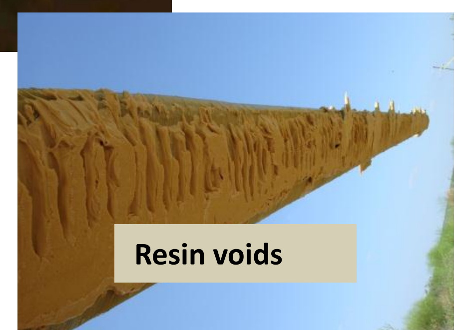
- Understrength laminates
- Wrong geometry
- Wrong subcomponent fatigue life



Manufacturing Process

- De-bonding
- Delamination
- Wrinkles
- Resin Voids





Topology failure (II)

Lightning

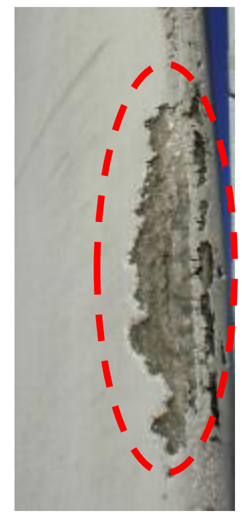
Insurance Damage

Bad behavior of the system

Erosion

Leading edge

Gel Coat



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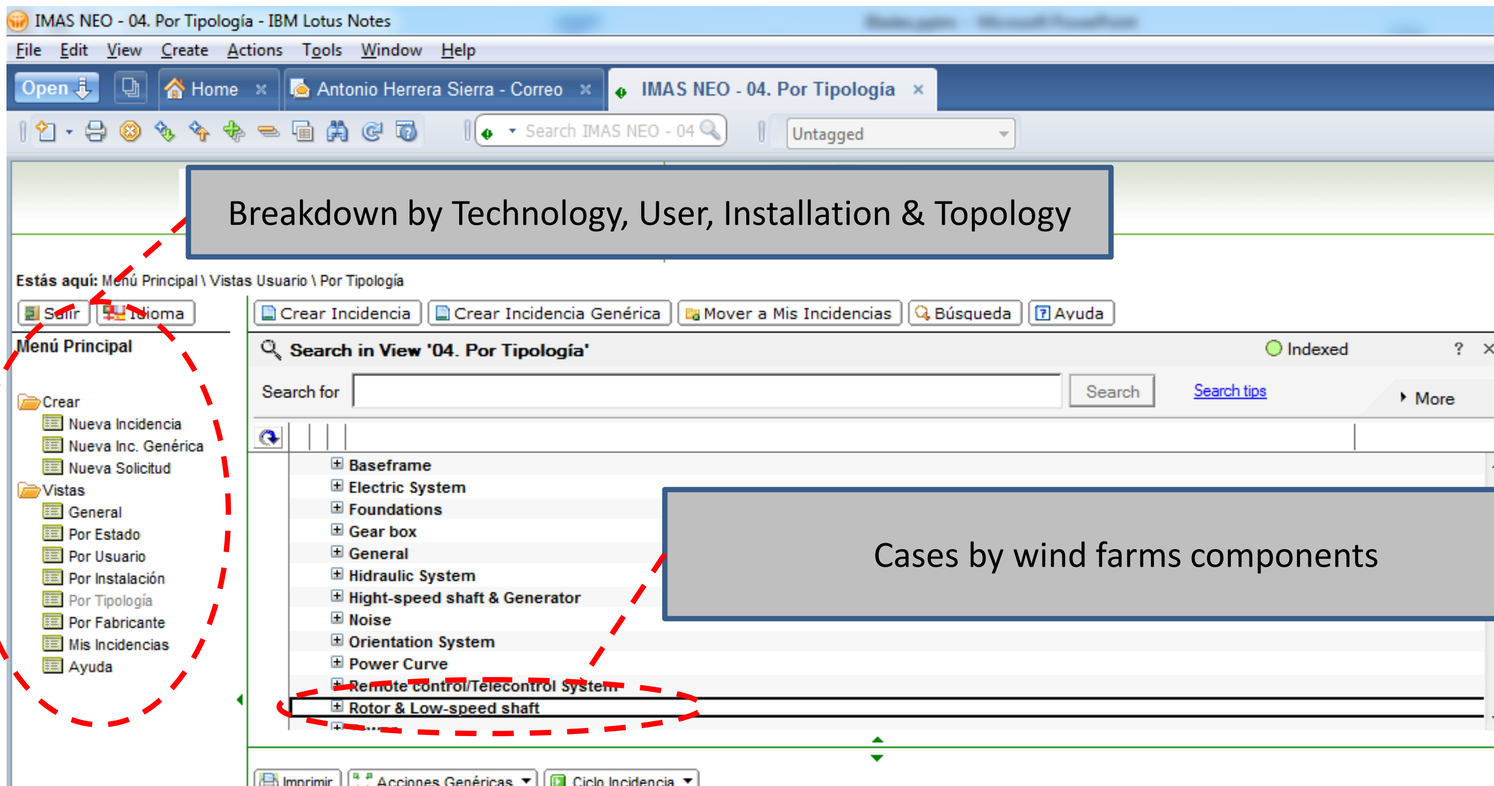
Information Management

5272 WTGs which implied 15816 blades

Data Base with the traceability and solution of each failure occurred in the fleet



Breakdown by Technology, User, Installation & Topology

Cases by wind farms components

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Information Management

⊟ Rotor & Low-speed shaft			
⊞ HYG-HYG/12/00001	SL	Grietas en Palas LM37.3	
⊟ KOR-KOR/12/00001	SL	Failure on blade beam	
	14/12/2012 09:42:33	Evaluación - Antonio Herrera Sierra	
	13/12/2012 14:13:05	Identificación Coordinador - José Ángel Díaz Álvarez	
	13/12/2012 12:43:05	Informe - Antonio Herrera Sierra - Información Gamesa	
	10/10/2012 10:45:08	Apertura incidencia - Antonio Herrera Sierra	

Open Incidence:
- Brief Description
- Attached information and pictures

Assessment:
- Technical assessment
- First approach of solution

* País:	España	Departamento:	
* Tipo de Instalación:	Wind Power Plant	* Instalación:	P.E. Korse / P.E. Korse
* Sistema:	Wind Turbine Generator (WTG)	* Tipología:	Rotor & Low-speed shaft
* Fabricante:	Gamesa	* Modelo:	G-90

Descripción

* Título: Failure on blade beam

* Descripción:
Failure has been produced in one blade of AG-3 in Korzse. This failure has occurred in other EDPR wind farms

* Criticidad: ◉ Alta ○ Media ○ Baja

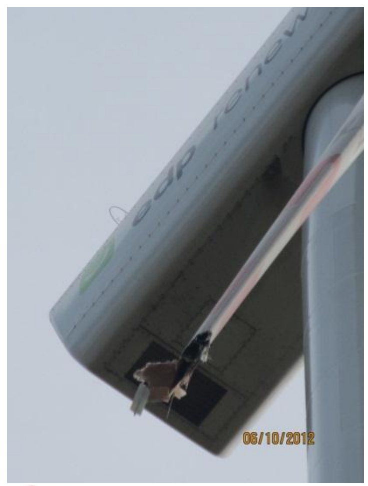
Alcance de la Incidencia:
This failure is a fabrication problem which can affect to the rest of the wind farm.

Field Report WF Korsze AG-3.pdf IMG_0909.jpg IMG_0913.jpg IMG_0916.jpg IMG_0919.jpg IMG_0921.jpg IMG_0930.jpg IMG_0934.jpg IMG_0944.jpg IMG_0946.jpg

Antonio Herrera Sierra — Fecha: 14/12/2012 09:42:33

* Evaluación:
G8X blades have developed different failures topology (broken beam, mid radius cracks, peel-off shells and lightning). The scope is analyzed the failure produced and ask technical information Gamesa in order to detect what's root cause analysis. This incidence can relate to Guadeltaba incidences due to is the EDPR-EU wind farm where major blades failures have been developed.

Posibles Repercusiones Futuras:
Out guarantee risks



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Work Methodology (I)

O&M Notification → Engineering Group

First Approach

- Call Conference site and regional manager
- First failure pictures
- Go to site and survey the failure zone

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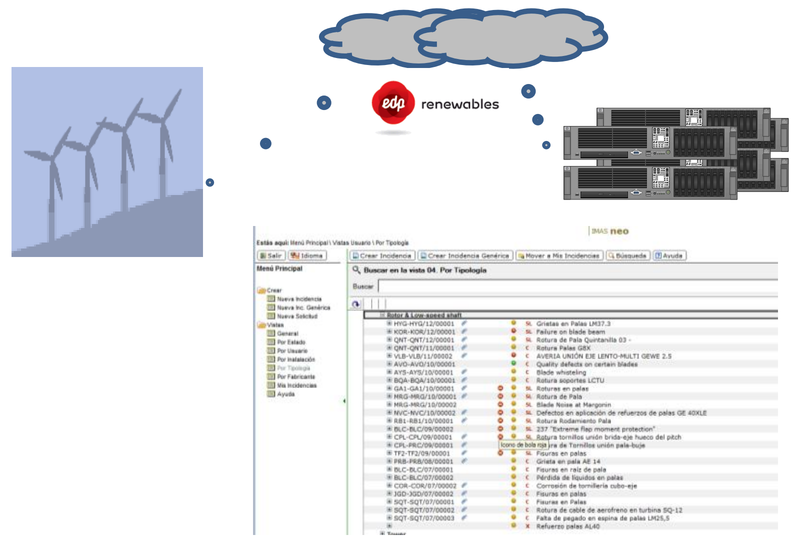
Work Methodology (II)

Information Analysis



- Post-process site information
- Download operation information (log book, Scada data etc.)
- Cross information with other stored cases and WTG manufacturer

Solution Proposal

- Incident report
- Follow-up recommendations

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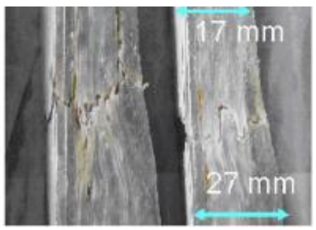
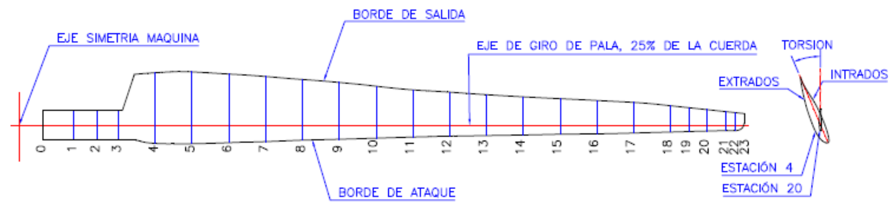
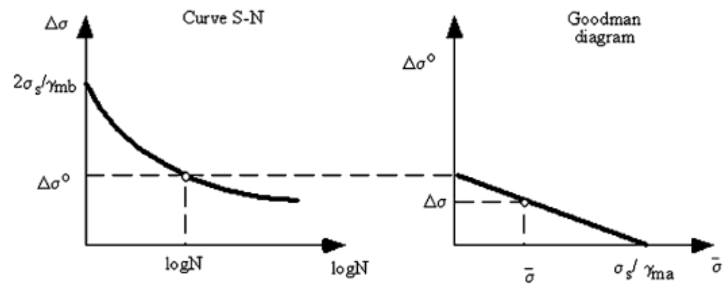
Design Failure – Root cracks

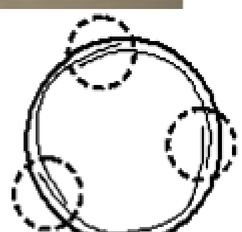






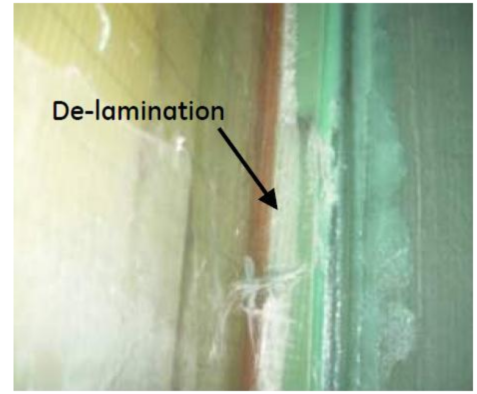
$$D = 6.919 \times 10^{-3} \frac{N_{max}}{((\sigma_s/\bar{\sigma}) + 2.67)^9}$$

This stress is influenced by concentrated factor, which was higher due to manufacturer process

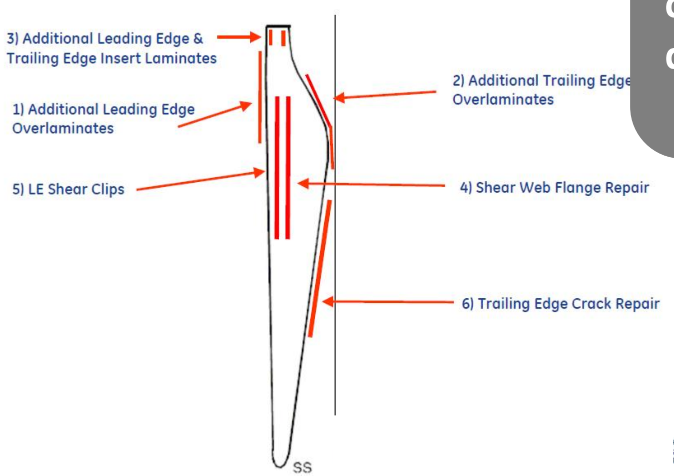


Design Failure – Root cracks and web delamination

Bad blade design induced that 1 year after operation started some blades collapse.



All fleet was repaired, EDPR was close of WTG manufacturer to define the correct reparation.



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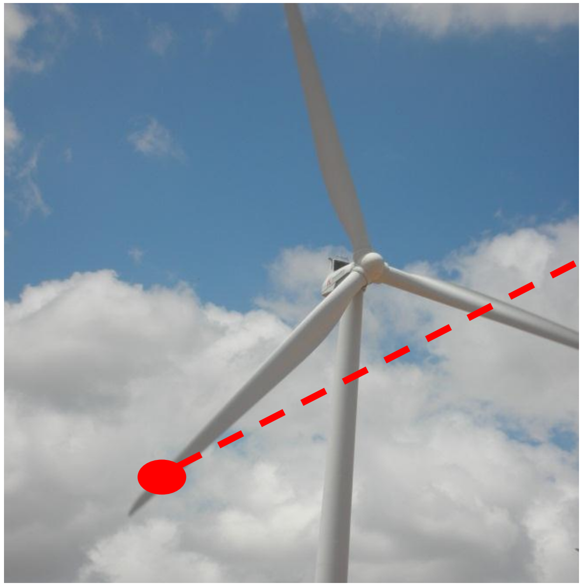
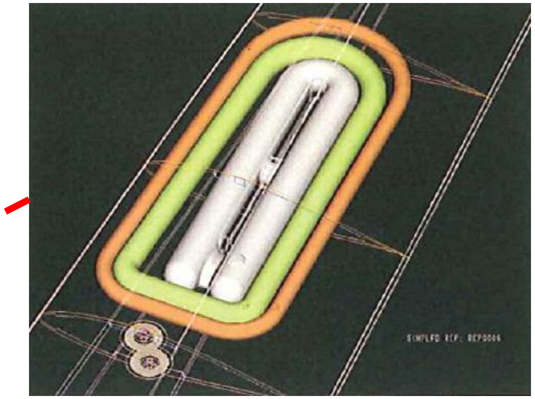
Design Failure – Edgewise vibration (I)





Blades with dampers which permit damping the edgewise vibration.

Visual inspections and increase of shutdowns permit detect the problem.

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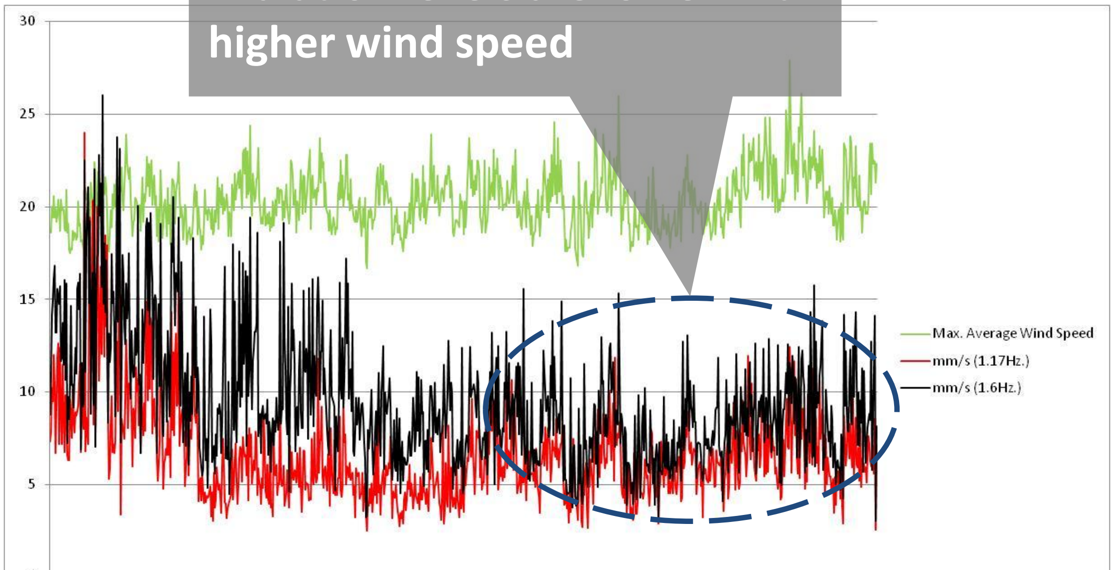
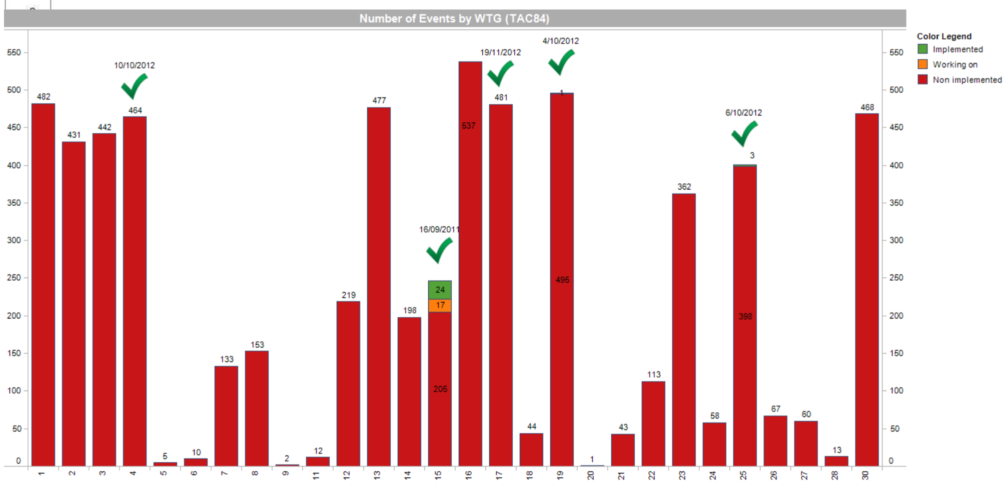
Design Failure – Edgewise vibration (II)

Vibration levels are lower with higher wind speed





Sum of Number of Records (copy 2) and Number of Records (DOTS) for each WTG. For pane Sum of Number of Records (copy 2): Color shows details about Color Legend. The marks are labeled by sum of Number of Records (copy 2). For pane Number of Records (DOTS): The marks are labeled by Finish of Implementation. The context is filtered on EventText, TimeFrom and windfarmId. The EventText filter keeps 393 Vibration TAC84. The TimeFrom filter ranges from 1/1/2011 12:00:00 AM to 11/21/2012 09:08:00 PM. The windfarmId filter keeps BELCHITE.

Level Vibration Decrement continue from dampers were repaired in the two alarm frequencies

- 1.17 Hz – 0.45 m/s^2 First Center Frequency
- 1.66 Hz – 0.45 m/s^2 Second Center Frequency

Retrofit applied has solved the losses due to WTGs shutdowns

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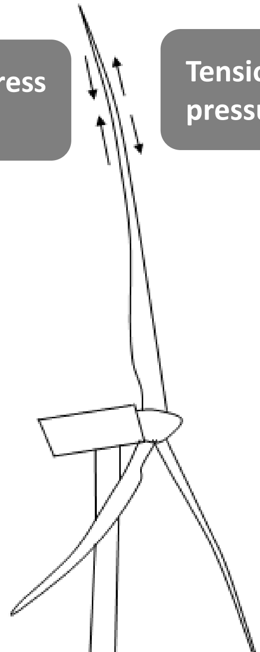
Manufacturing process – Wrinkles

Compression stress in suction shell



Tension stress in the pressure shell

Wrinkles induced that in the compressed laminated appears micro-buckling which induced a crack that grow up in all thickness.

RCA

- Error during lay-up.
- Error during curing process.

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Lightning

- The IEC 61400-24 establishes the annual frequency of lightning flashes attaching a wind turbine calculated as:

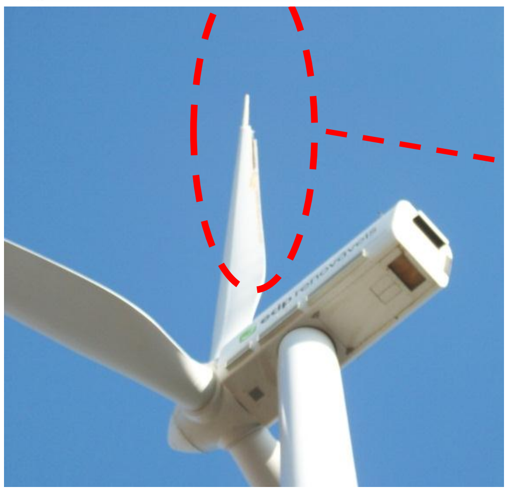
$$\boxed{\text{Efficiency}= 1- N_{cna} / N_{dtotal} > 0{,}98 \text{ for a LPL I according to IEC 61400-24:2010}}$$

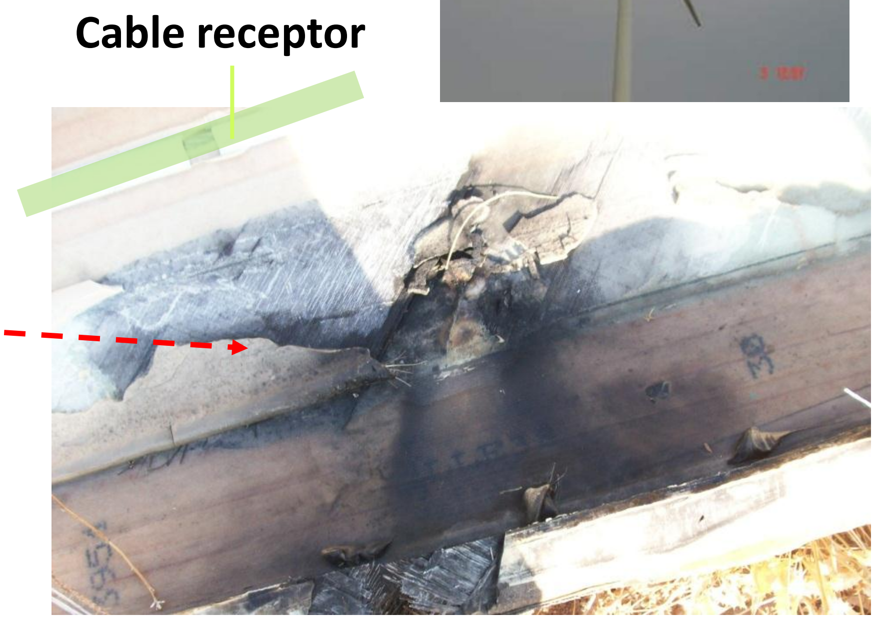
, being:

$$\boxed{N_{dTotal} = N_d \cdot N_{WT}}$$

$$\boxed{N_D = N_g \cdot A_d \cdot C_d \cdot 10^{-6}}$$

N_{Dtotal}: Number of annual expected lightning flashes in WF
N_{WT}: Number of wind turbines in the WF
N_D: Number of annual expected lightning flashes
N_G: Number of lightning flashes per year and square Km
A_D: Collection area of the structure
C_D: Environmental factor





Lightning was not absorbed by tip receptor.

- Necessity to improved tip zone
- Introduce upgraded as Diverter Strips

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Erosion

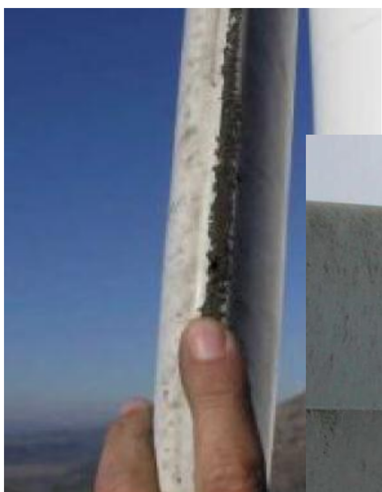
The tip of a blade travels in 1 week a distance equivalent to a round to the world.

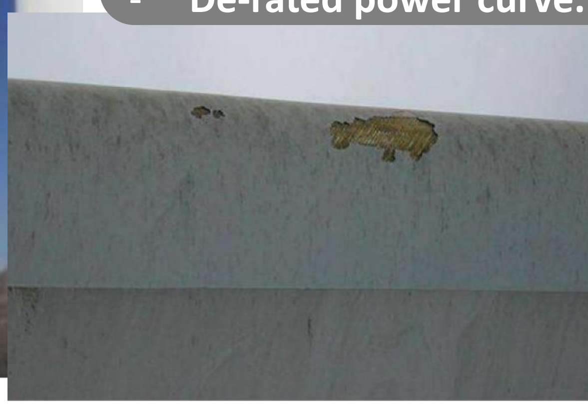
Blade tip linear speed = 250 km/h

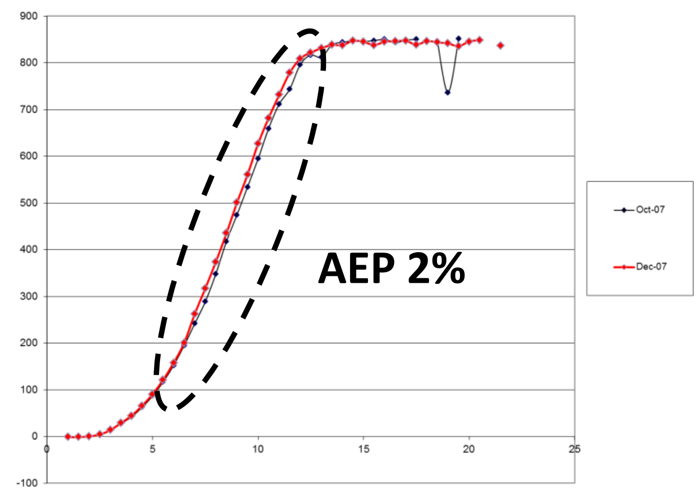
24 h / 7 d → 42 000 km

Earth perimeter = 40 077 km

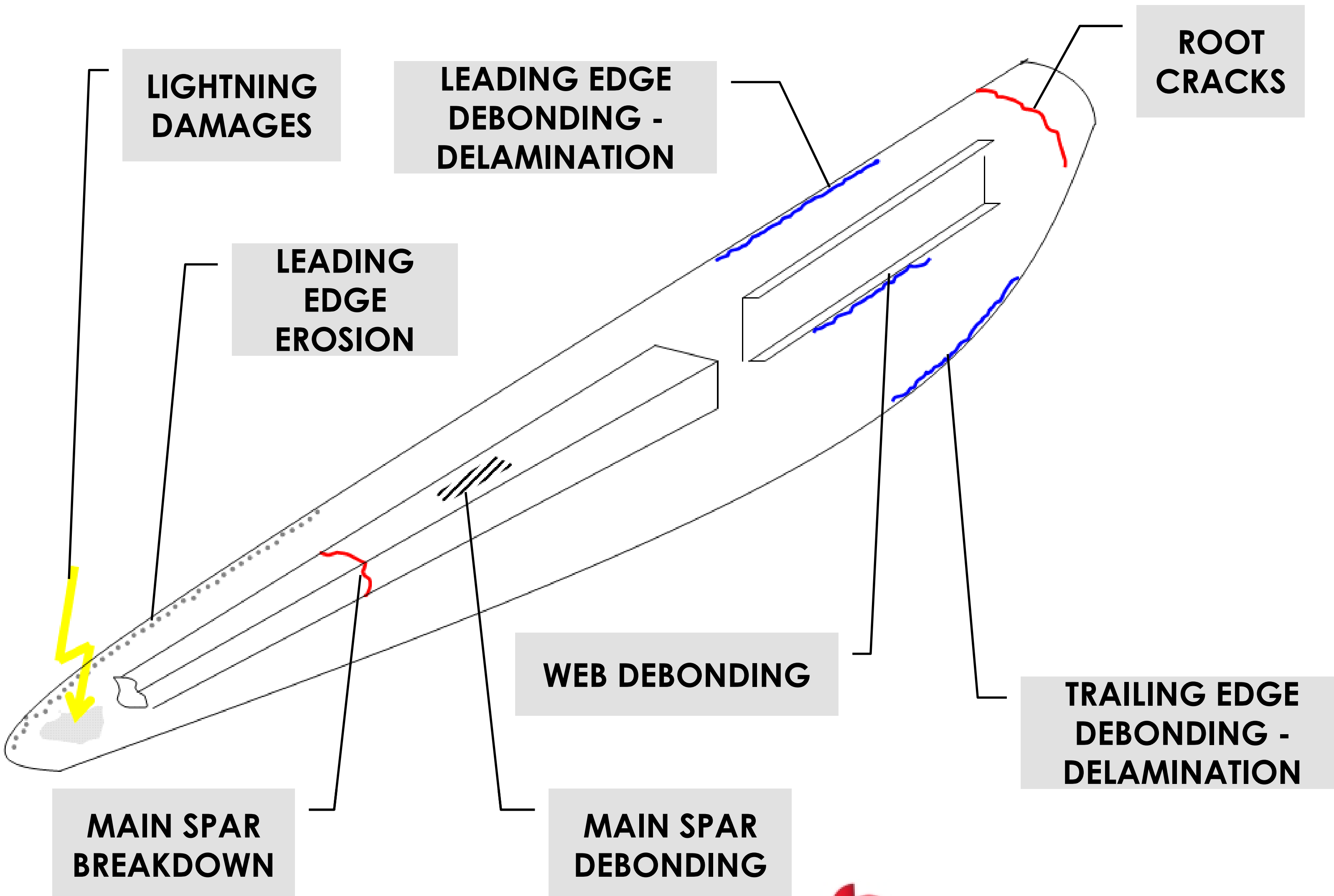
- **Lack of protection against UV and water.**
- **De-rated power curve.**







Summary of blades damages



CAUSES:

- Wrinkles
- Undulations
- Waviness
- Bonding defects
- Resin voids
- Dry areas
- Delaminations
- Ply drops
- Buckling
- Lightning
- Friction wear

Main challenges and future scenarios

- Most of blade failures and deteriorations can be repaired and there is a market of ISP with enough capacity to do it. But in a few occasions (example lightning) damages are so important that it is not possible to repair and it is needed to replace.... Are there blade stored anywhere? **Is any company interested in sharing stocks of blades?**

- Material degradations with temperature, humidity, UV radiation? **Is it a certain risk the physicochemical degradation of the composites in 20-25 years?**

- In industry in general there is an important tradition manufacturing and repairing electrical and mechanical devices, so the service market created for wind industry has the benefit of this knowledge. But it is not the case of blades, where there is not a tradition. So we are repairing with 1-2 years warranty period, but maybe a potential failure will require 3-5 years to develop. **Certified repairs and companies?**

- Introduce new advanced NDT techniques to control manufacture problems. Increase Q&A measures

It is needed to change the present short term business relationship of selling/purchasing between WT manufacturer/owner to a long term collaborative relationship between the blade manufacturer/owner.

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Question?

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