Renewables

LIFE EXTENSION AND OPTIMIZATION OF WIND FARM

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UL RENEWABLES
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QUÉBEC - 7th February 2019

Navigating today’s global market
is riskier and more complex than ever before

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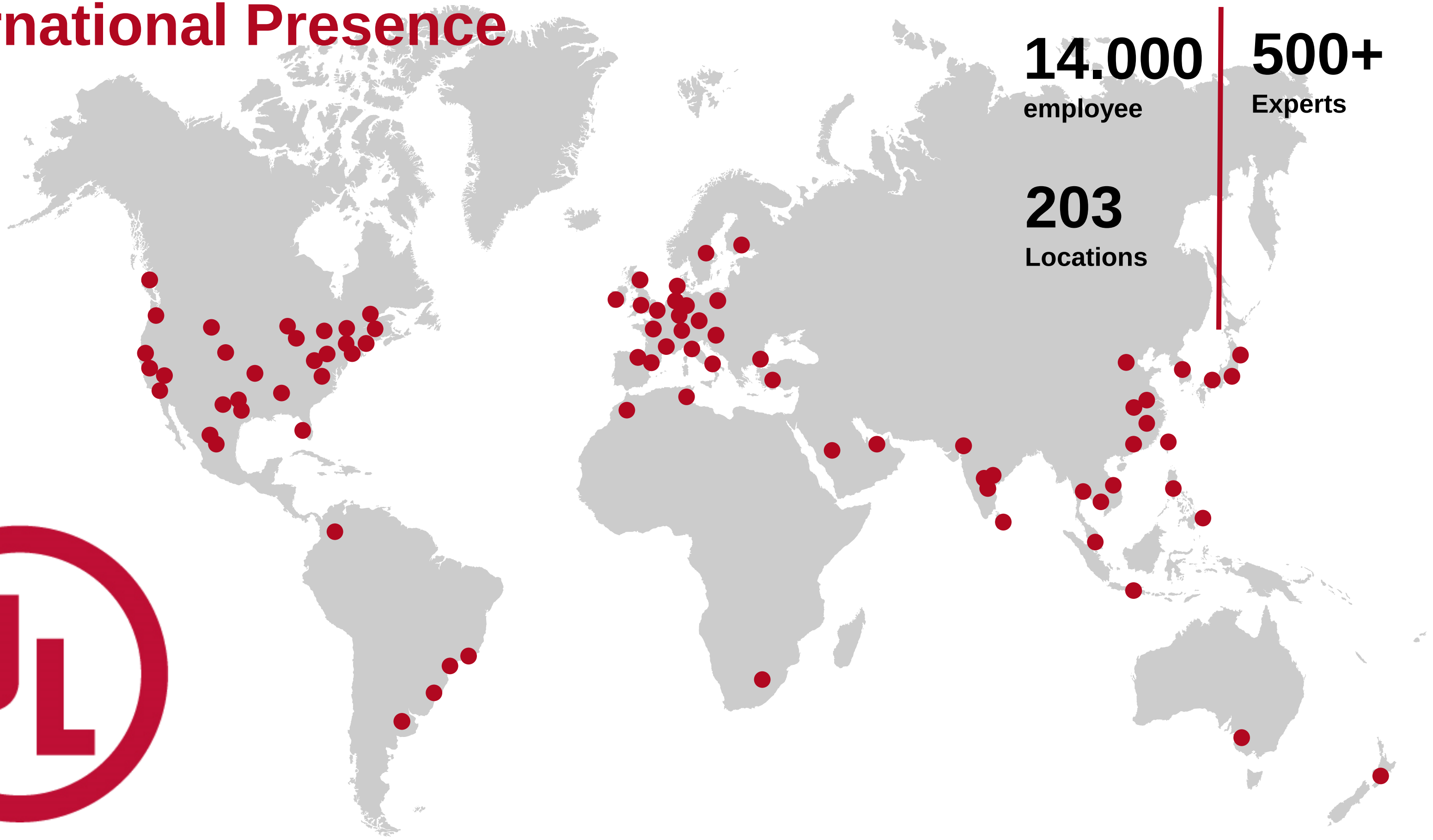


14.000
employee

203
Locations

500+
Experts

How to deal with aging Wind Farms?

Aging Wind Farms

- **Pioneering early wind markets,** like Germany, Denmark, US, Spain or Italy, **are aging** and due to this have generate important **opportunities** for asset owners

- By **2020**, about **50 GW** of onshore wind capacity worldwide will be **older than 15 years**. Even now, about **15 GW** are in this range and the oldest wind turbines are overpassing the 20-year mark

- Despite the repowering incentives seen in the past in Countries like Germany or Denmark, nowadays European tariff cuts seem to support **innovative cost-saving actions** on old wind turbines versus more capital-intensive repowering options

- So, the question is:
  should we replace old units, keep them flying, or do something else?

NORMAL OPERATION **REPOWERING** **LTE PROGRAMS**

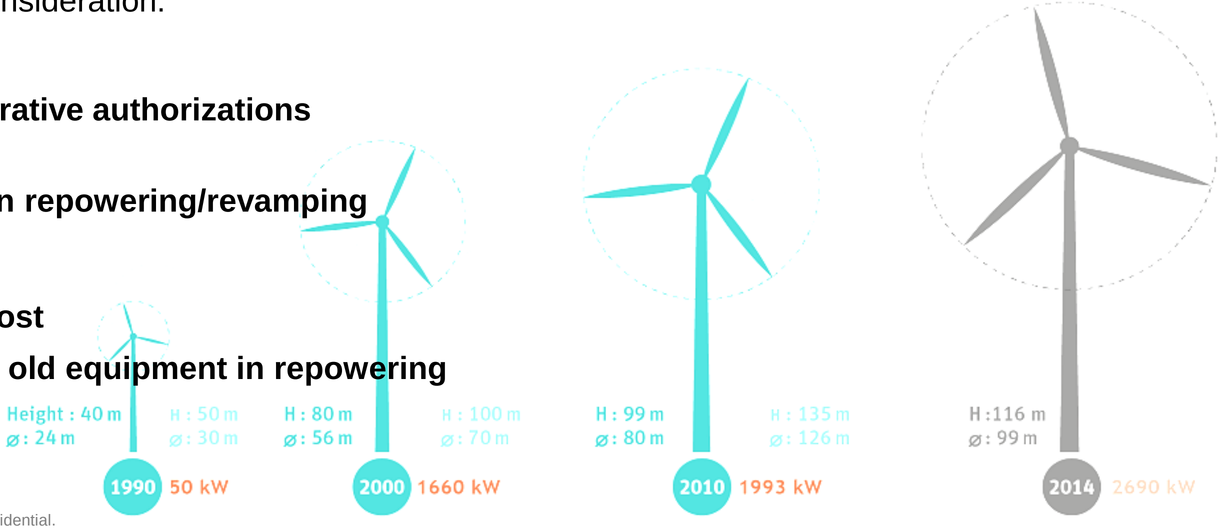
Aging Wind Farms

OPTION PRESENTED IS:

LIFE TIME EXTENSION (LTE) - After a residual life study and under a new maintenance program including targeted inspections, continue operating the power over the design life. In some cases some extraordinary investment **(REVAMPING)** is needed to keep cost and energy availability under control.

Important aspect to be taken into consideration:

- **Regulatory frame, administrative authorizations and environmental factors**
- **Increase of energy output in repowering/revamping**
- **Current lifetime consumed**
- **Trends of availability and cost**
- **Financial status or value of old equipment in repowering scenario**



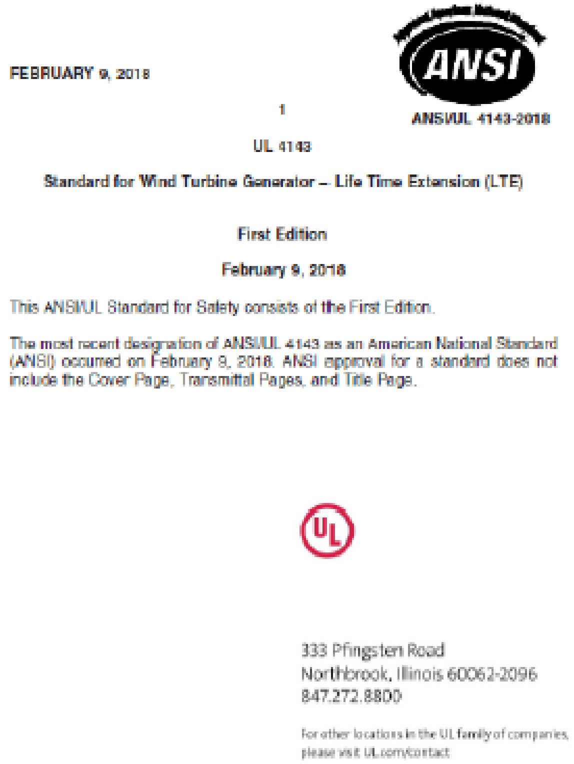
UL GUIDELINE ANSI/UL 4143

ANSI/UL 4143

UL 4143

STANDARD FOR SAFETY

Wind Turbine Generator – Life Time Extension (LTE)



FEBRUARY 9, 2018

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ANSI/UL 4143-2018

UL 4143

Standard for Wind Turbine Generator – Life Time Extension (LTE)

First Edition

February 9, 2018

This ANSI/UL Standard for Safety consists of the First Edition.

The most recent designation of ANSI/UL 4143 as an American National Standard (ANSI) occurred on February 9, 2018. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, and Title Page.

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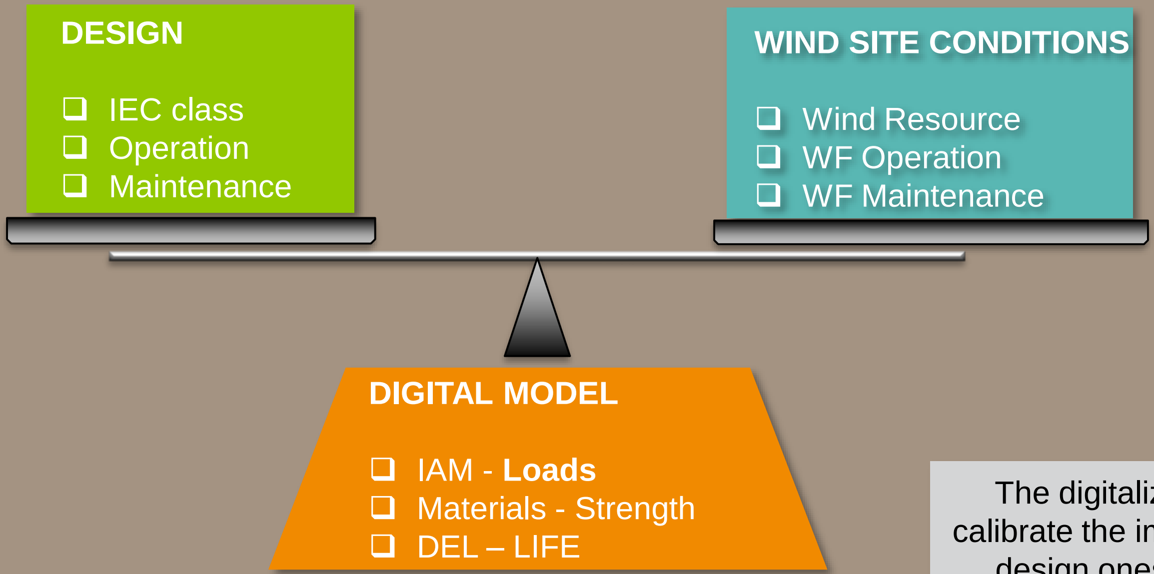
Methodology, how we do it?

RUL – How we do it?.



DESIGN

- ☐ IEC class
- ☐ Operation
- ☐ Maintenance

WIND SITE CONDITIONS

- ☐ Wind Resource
- ☐ WF Operation
- ☐ WF Maintenance

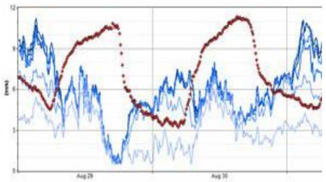
DIGITAL MODEL

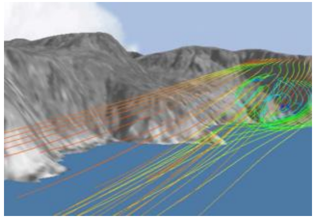
- ☐ IAM - **Loads**
- ☐ Materials - Strength
- ☐ DEL – LIFE

The digitalization of machine and materials allows to calibrate the impact of the conditions of the site versus the design ones. The correct characterization of the real conditions is key to the accuracy of the study.

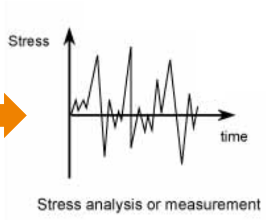
Uncertainty in LTE análisis (RUL).

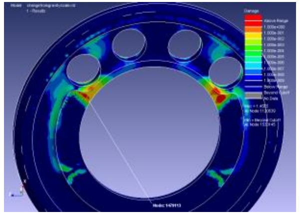
Wind



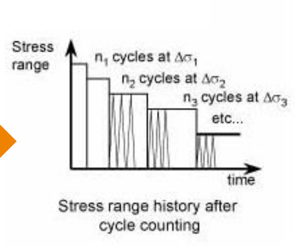


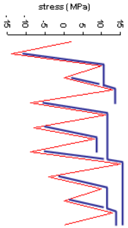
Loads



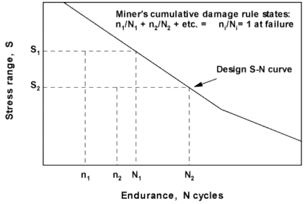


DEL





Fatigue

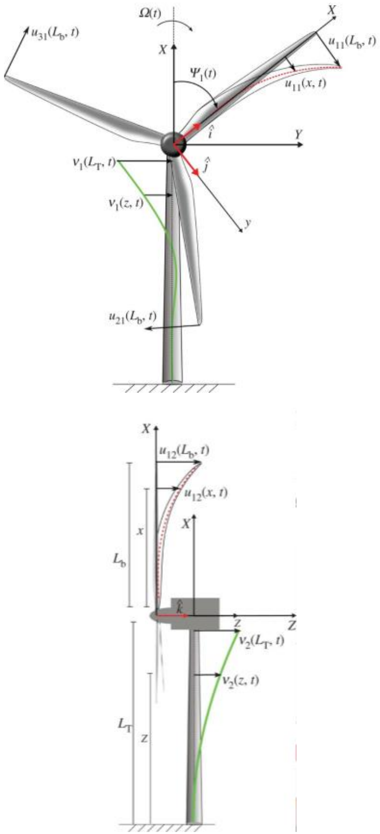


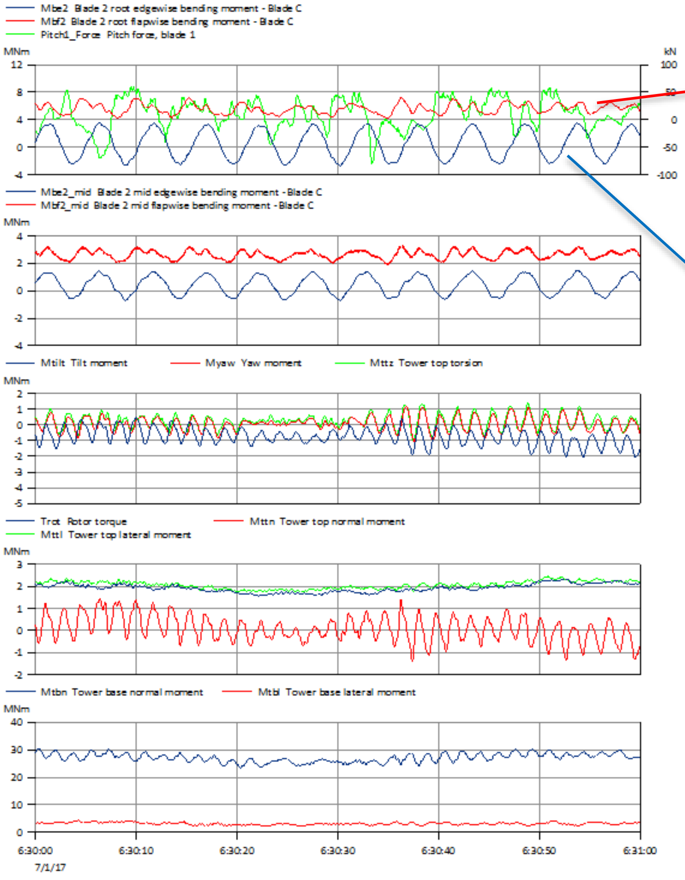
RUL

Uncertainty Sources:

- **Wind Conditions:** speed, shear, inflow…
- **O&M Conditions:** Starts and Stops, idling… etc
- **WT Design:** Type, rotor, gearbox…

Fatigue Loads

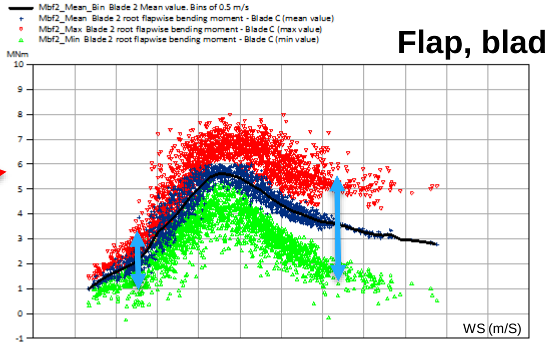




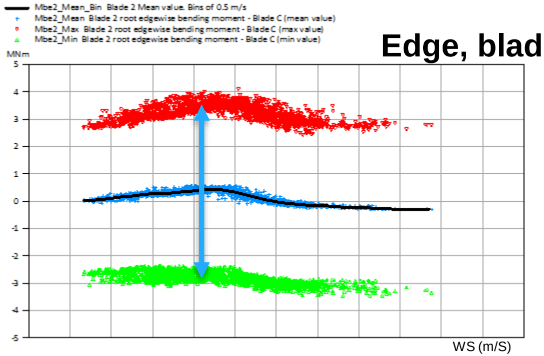
Serie temporal campaña cargas UL DEWI [10m/s, 15%IT]

h:m:s

Flap, blades



Edge, blades



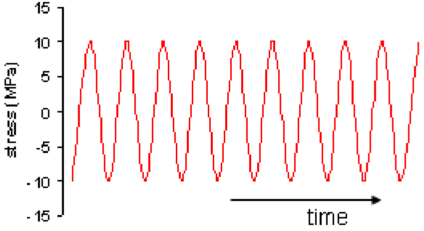
Fatigue depends on the difference between maximum and minimum load values. In flap the turbulence (and to a lesser extent other variables such as the shear) introduce the cycles; while in edge, it is the own weight of the blade that generates a sinusoidal behavior

Damage Equivalent Loads (DEL)

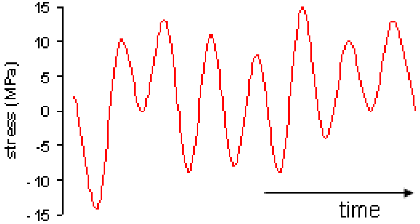
To quantify a spectrum of variable loads, the "DEL"
The "rainflow counting" method is used to convert the variable spectrum to a constant value.

$$DEL = \left[\sum_i \frac{S_i^{\,m} \times N_i}{N_{eq}} \right]^{1/m}$$

S_i: amplitude load i
N_i: number of cycles load i
N_{eq}: total number of cycles
m: material exponent

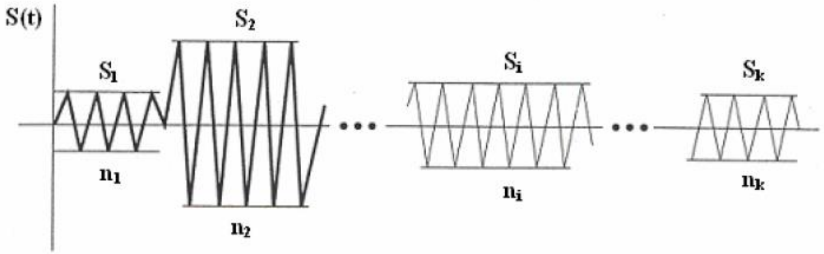


Uniform



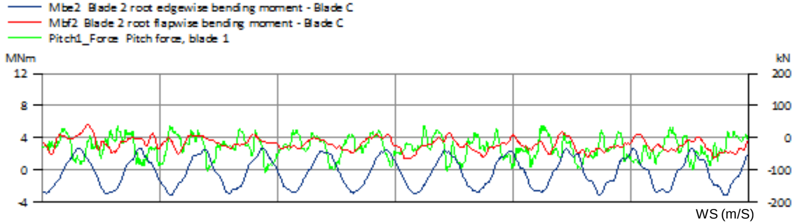
Variable

The constant m of the material manages to relate to a 1 / m ratio the load level with the fatigue cycles (S-N curves)

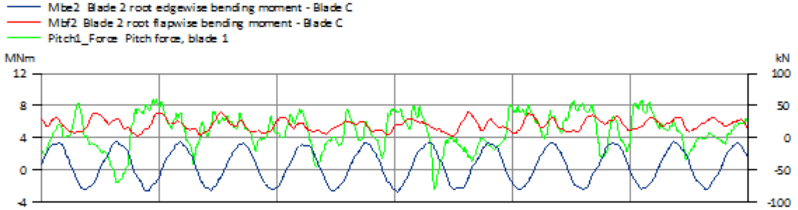


Damage Equivalent Loads (DEL)

Ejemplo: influencia IT



Serie temporal campaña cargas UL DEWI [15m/s, 11%IT]



Serie temporal campaña cargas UL DEWI [10m/s, 15%IT]

There is great influence on flap and almost nothing on edge. Each variable affects different areas of operation, composing a complex and multivariable load scenario

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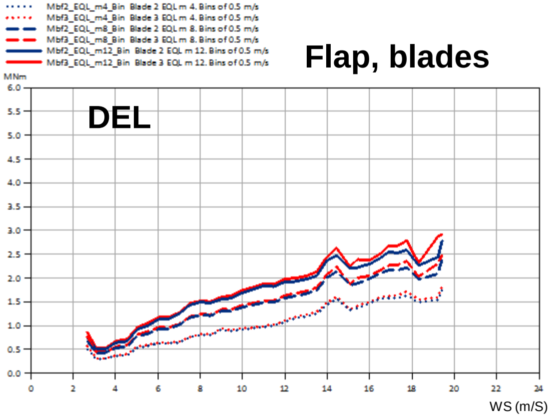
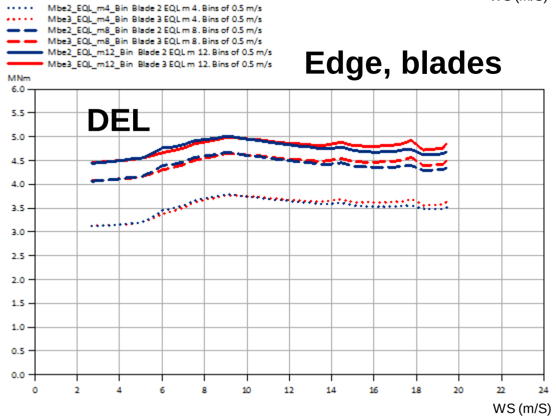


Flap, blades

Variables

- Speed
- IT
- Shear
- Others



Edge, blades

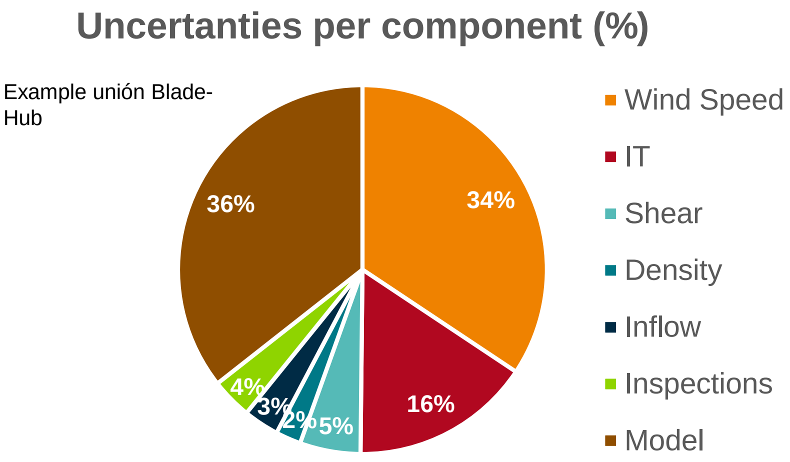
Variables

- Component Properties
- Others

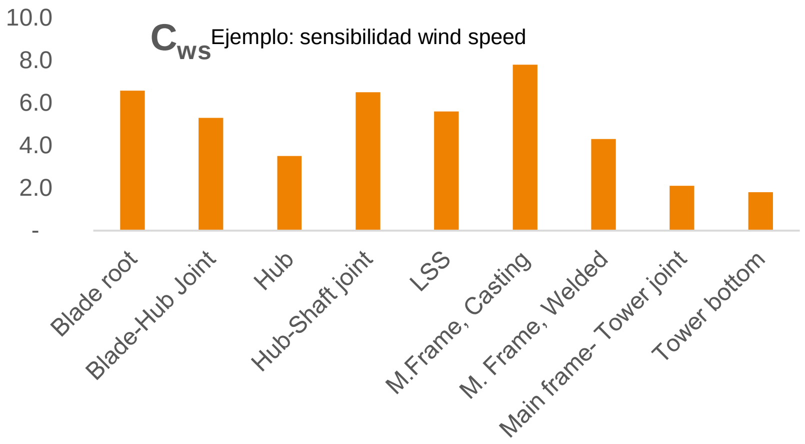
The precise characterization of each parameter is critical to construct a reliable life estimation scenario. An example: an error of 10% in IT, can lead to errors of up to 50% in useful life in certain components

Sensibilidad e incertidumbre

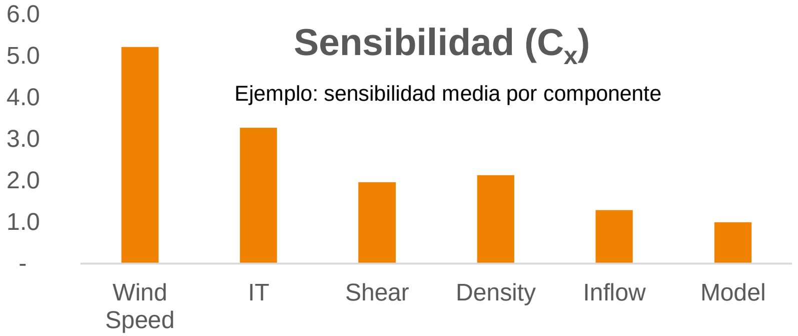
Sensitivity: Factor by which the variation in life is quantified based on the variation in loads. Varies for each parameter and component



Example unión Blade-Hub



Ejemplo: sensibilidad wind speed



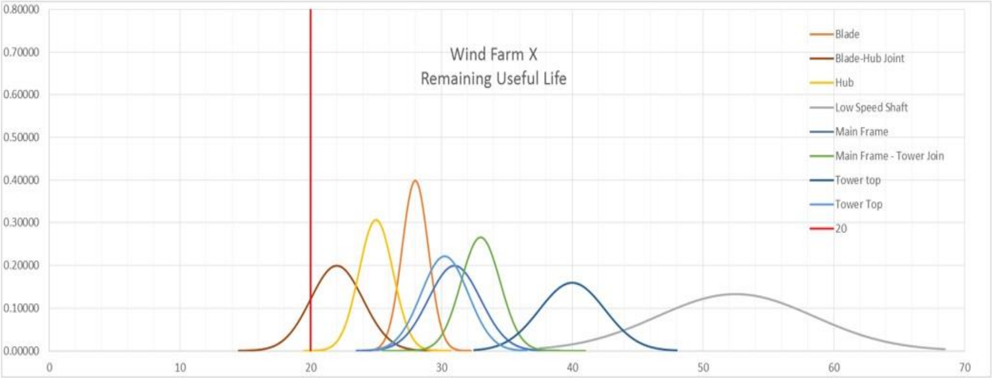
Ejemplo: sensibilidad media por componente

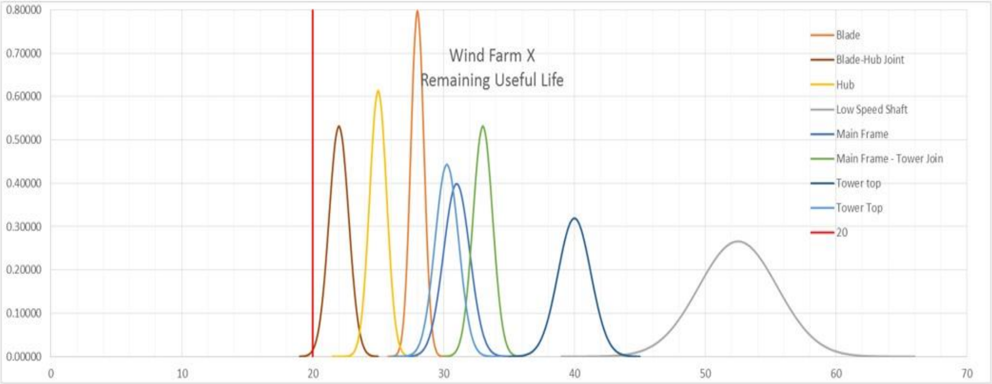
The distribution of uncertainties varies enormously component by component and project by project. Depending on the quality of the starting data, the behavior of the machine in loads and the particular sensitivity to each parameter.

It is necessary to run countless load cases to model the sensitivity.

The sensitivity, very high for some parameters, requires that the uncertainty of the parameter is very low so as not to trigger uncertainties in life. Example: Ux = 10%, Cx = 3 => ULTE = 30%

Uncertainty in Life





The central value of the Gaussians corresponds to the calculation results, while the amplitude of them is related to the uncertainty. The more "crushed" the Gaussian bell is, the smaller the uncertainty, which means less risks.

How to reduce Uncertainty. Met data.

Wind Speed: **Met Data** vs SCADA.

- Met data:
  - Quality Measurements => **Calibrations / Maintenance** [1]
  - MCP: Accurate processing of data [2]
  - Flow Model => Linear (WASP) / CFD / **NWP** (WindSite UL) [3]
- SCADA:
  - Nacelle anemometer=> Corrections NTF. IEC 61400-12-2 [4]
  - Production Correlations

Wind measurements periods=> **Complete** / Parcial (Extrapolation)?

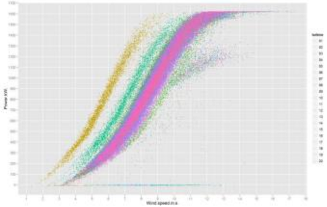
IT: Measure / calculated. [5]

[1]

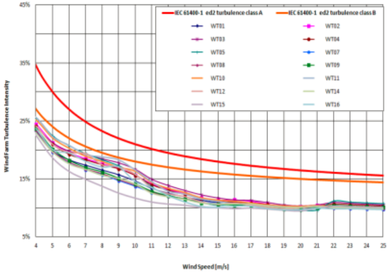
[2]

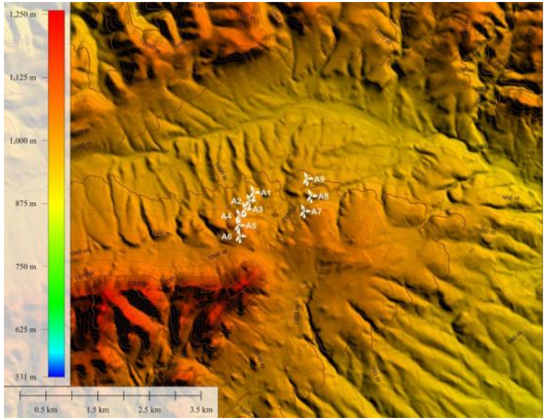
[3]

[4]



[5]

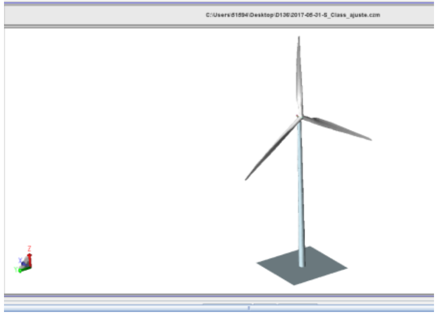




[4] Accurate Modeling Importance: Mesoscale models of numerical weather prediction (NWP)

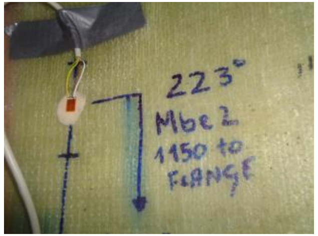
In general, there is no reliable tower data during the entire life of the park. The solution lies in relying on well-processed production data and precise flow modeling (such as NWP coupled with micro-scale).

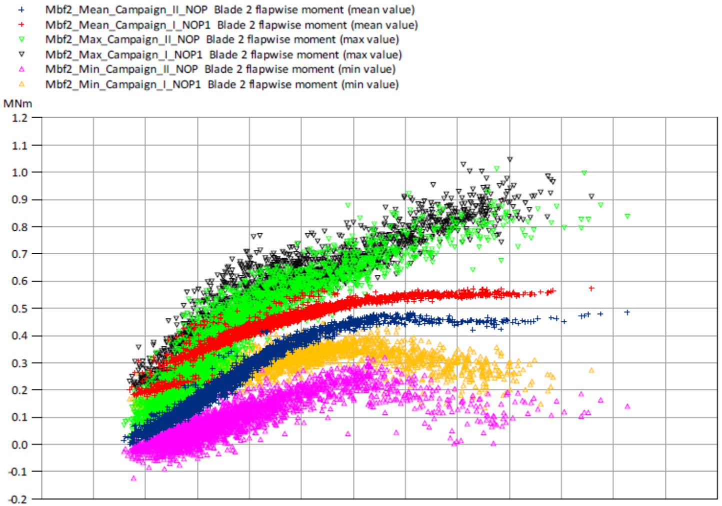
Aerolinestic Model Validation.
Power Curve tests / Mechanical Loads

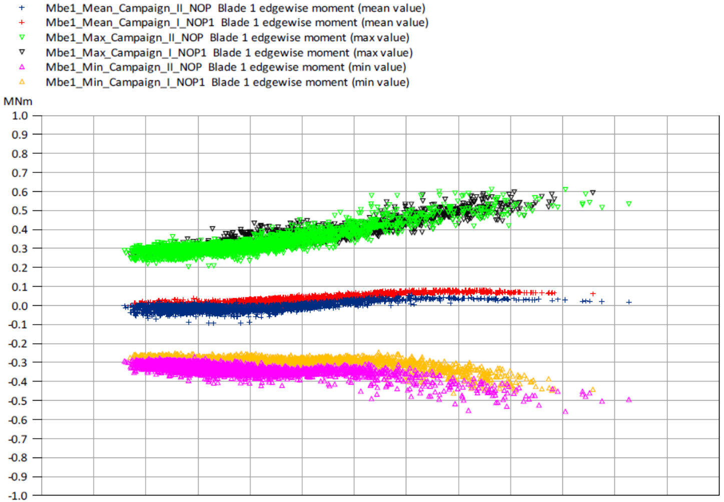


The aero-elastic model introduces a large part of the uncertainty:

- Independent aero model (IAM) / OEM model
- Dimensions / Geometries / Materials / Weights / Rigidity.
- The control of the machine also significantly affects the dynamic response.

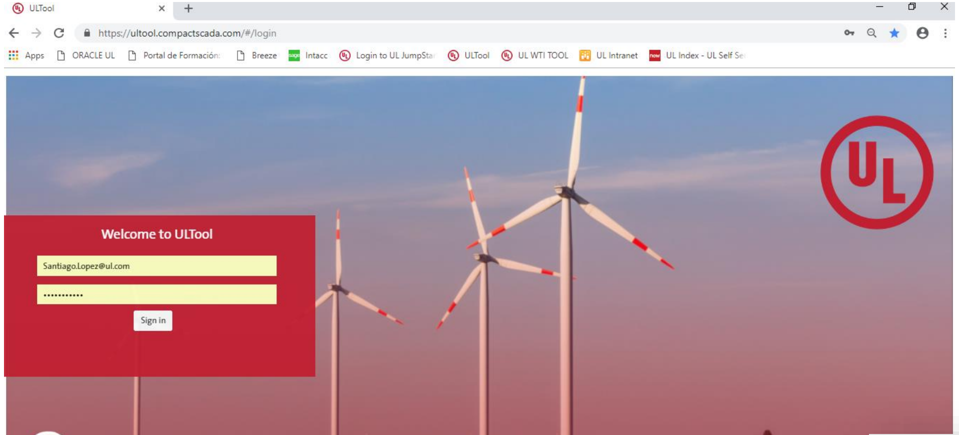






It can be reduce the uncertainty of the model (one of the most “impact") with measurement campaigns that allow to adjust the loads.

Robust Monitoring Tool with Analytics



Welcome to ULTool

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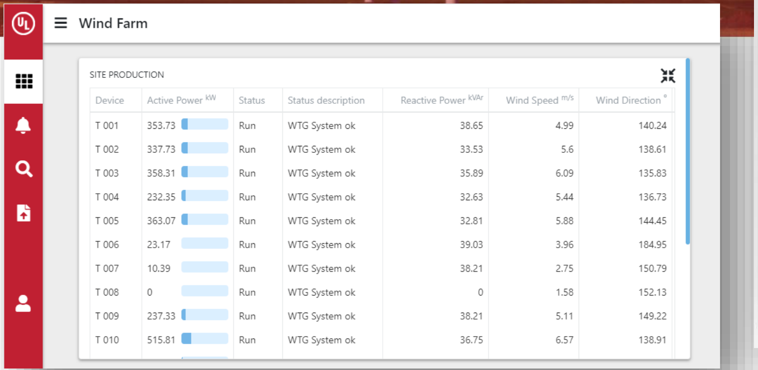
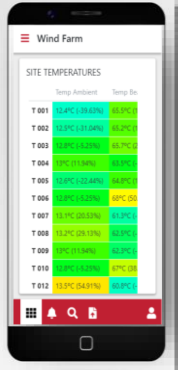


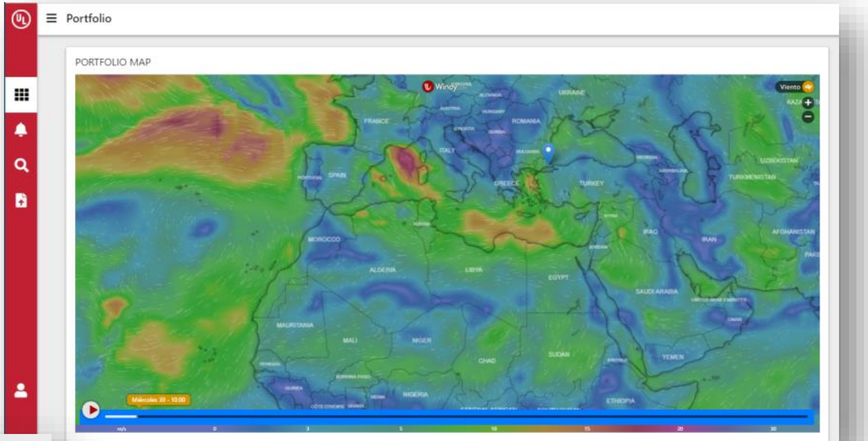
SITE PRODUCTION

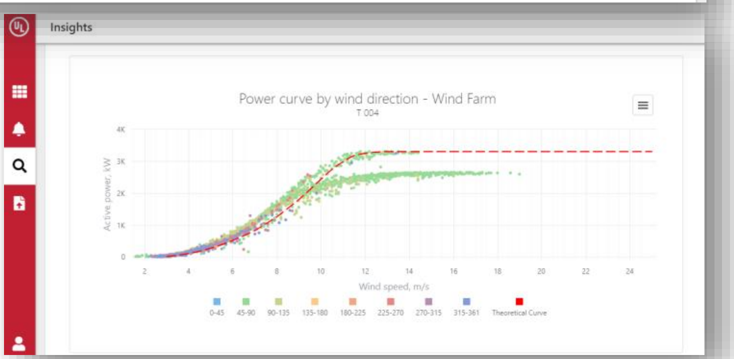
Device	Active Power kW	Status	Status description	Reactive Power kVAr	Wind Speed m/s	Wind Direction °
T 001	353.73	Run	WTG System ok	38.65	4.99	140.24
T 002	337.73	Run	WTG System ok	33.53	5.6	138.61
T 003	358.31	Run	WTG System ok	35.89	6.09	135.83
T 004	232.35	Run	WTG System ok	32.63	5.44	136.73
T 005	363.07	Run	WTG System ok	32.81	5.88	144.45
T 006	23.17	Run	WTG System ok	39.03	3.96	184.95
T 007	10.39	Run	WTG System ok	38.21	2.75	150.79
T 008	0	Run	WTG System ok	0	1.58	152.13
T 009	237.33	Run	WTG System ok	38.21	5.11	149.22
T 010	515.81	Run	WTG System ok	36.75	6.57	138.91



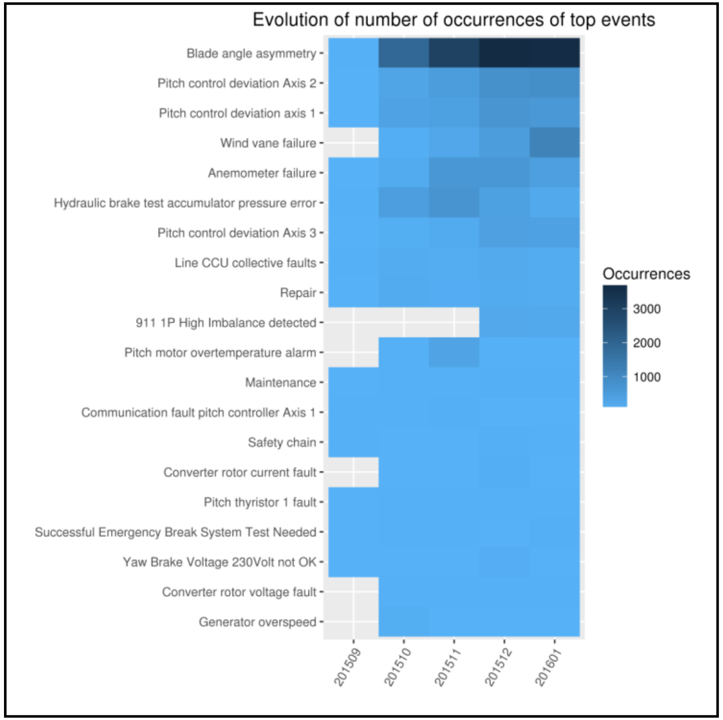
SITE TEMPERATURES

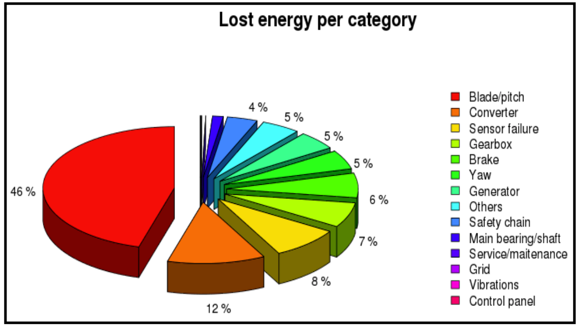
	Temp Ambient	Temp Be
T 001	12.4°C (-39.63%)	65.5°C (1
T 002	12.5°C (-31.04%)	65.2°C (1
T 003	12.8°C (-5.25%)	65.7°C (2
T 004	13°C (11.94%)	63.5°C (-
T 005	12.6°C (-22.44%)	64.8°C (1
T 006	12.8°C (-5.25%)	68°C (50.
T 007	13.1°C (20.53%)	61.3°C (-
T 008	13.2°C (29.13%)	62.5°C (-
T 009	13°C (11.94%)	62.3°C (-
T 010	12.8°C (-5.25%)	67°C (38.
T 012	13.5°C (54.91%)	60.8°C (-

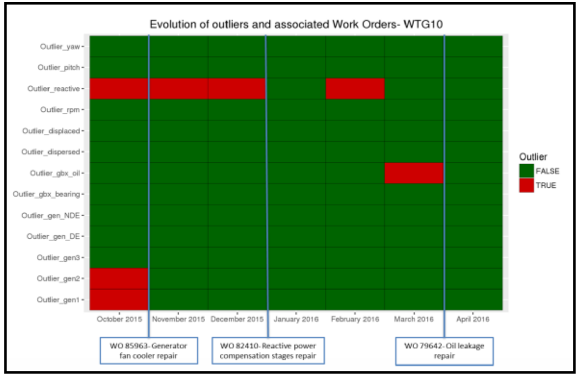




Robust Monitoring Tool with Analytics







Identifying the types of alarms that cause the most losses will help to identify the most involved components of the park.

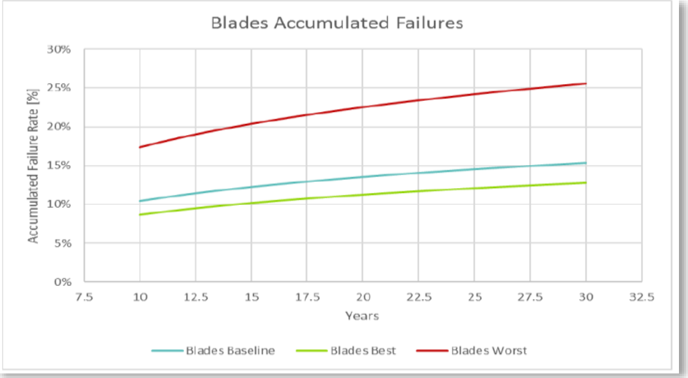
Detailed analysis of all O & M records against IEC design conditions is necessary to accurately adjust the life diagnosis. Advanced software and procedures must be available to obtain the proper treatment of all data.

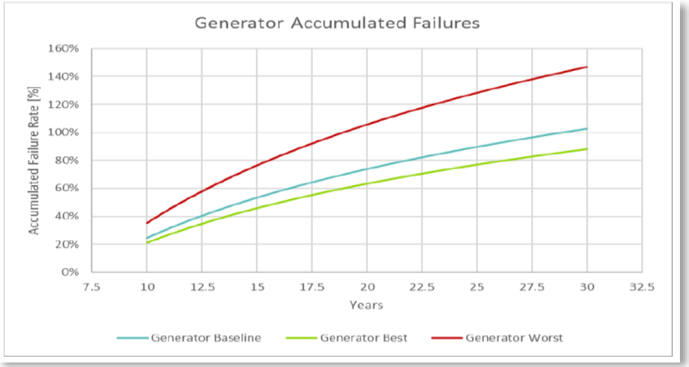
Non Structural Components

Key Points:

1. On site conditions and components actual state
    - Evaluating specific phenomenon related with site
    - Components inspections in order to get actual status
    - O&M historical review
2. UL´s Components failure rate database
    - Using the specific site conditions
    - Correlating the model with the actual status and historical failure rate on site

The "non-structural" components have a major influence on the expenses of OPEX and therefore the financial model, with a reduced criticality in compliance with requirements in terms of security.





Diagnóstico. Inspecciones.

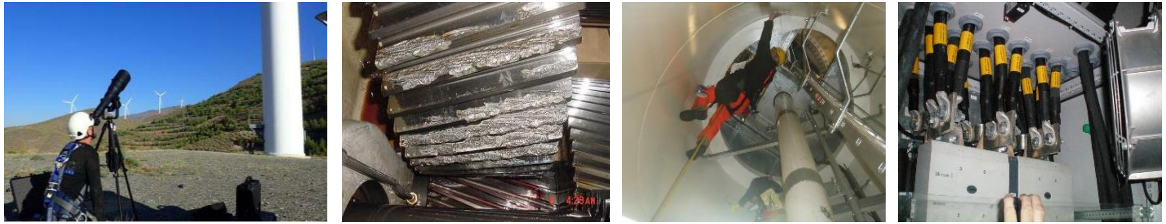
LTE critical inspections:

Cracks main frame, hub, tower, (Visual inspections / penetrating liquids)
Cracks in blades (Visual inspections)
Welding verification (ultrasound)

Bolt connections: blades - hub, hub - slow shaft, tower-foundations
Foundation:
- Differential displacements
- Extraction of samples

Gearbox
- Video-endoscopies
- Oil and grease analysis

General status of the turbine
- Wiring, protections, corrosion, coatings, leaks, etc.



UL International GmbH – Sucursal en España / DEWI Spain
ISO / IEC 17020: Wind Turbine Inspections. Ansoaín (Spain)

The inspections allow to corroborate the analytical results. UL DEWI includes an uncertainty component depending on the% of machines inspected on the total.

RUL results are used to set up a selective and optimized inspection plan throughout the extended life of the park as a basis for the Supervision of the asset.

LTE PROGRAM

To manage risks an keep them under control, **a life time extension program (LTE) must be put in place in the wind farm** This program must include previously to the end of design lifespan.

on-site inspections and load measurement to track fatigue accumulation to define, together with the already implemented predictive monitoring and quality program, a plan of targeted inspections and monitoring.

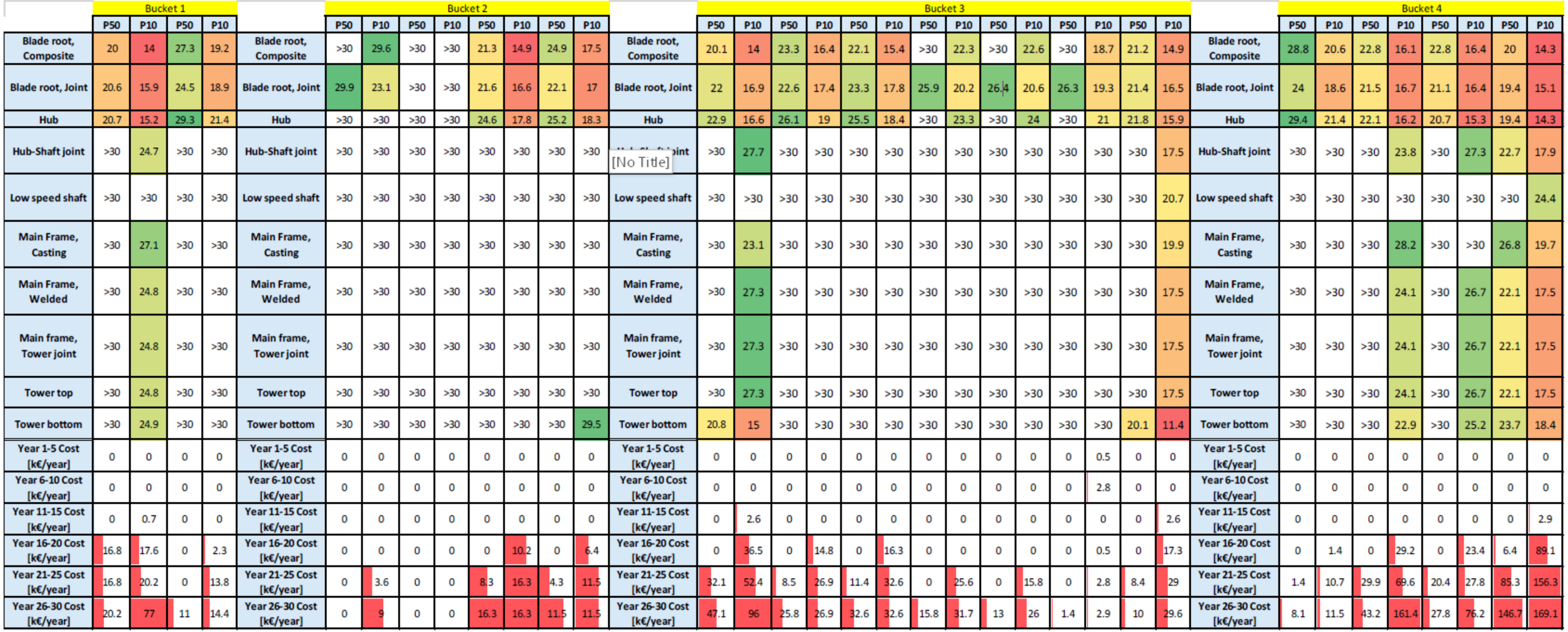
In some specific cases, this **life extension plan must be completed with some investment – revamping –** typically on turbine upgrades and retrofits (drive train, main frame, blades, PLC), or advanced controls to manage fatigue loads / increase production.

LTE including **revamping allows to keep costs and energy availability under control at low CapEx investment and also increase energy production** typically up to 5%

LTE program mainly consists on:

1. Modeling and analysis of remaining life assessment. Tech Doc and load models are mandatory.
2. Inspection and diagnosis
3. Third party certification
4. Revamping when needed
5. Life assurance and risk control listed activities fine tuned at wind farm level, and a specific monitoring plan.
6. Quality WF audits by means of selected inspections

Gestión de la vida. Escenario proyección.



	Bucket 1			
	P50	P10	P50	P10
Blade root, Composite	20	14	27.3	19.2
Blade root, Joint	20.6	15.9	24.5	18.9
Hub	20.7	15.2	29.3	21.4
Hub-Shaft joint	>30	24.7	>30	>30
Low speed shaft	>30	>30	>30	>30
Main Frame, Casting	>30	27.1	>30	>30
Main Frame, Welded	>30	24.8	>30	>30
Main frame, Tower joint	>30	24.8	>30	>30
Tower top	>30	24.8	>30	>30
Tower bottom	>30	24.9	>30	>30
Year 1-5 Cost [k€/year]	0	0	0	0
Year 6-10 Cost [k€/year]	0	0	0	0
Year 11-15 Cost [k€/year]	0	0.7	0	0
Year 16-20 Cost [k€/year]	16.8	17.6	0	2.3
Year 21-25 Cost [k€/year]	16.8	20.2	0	13.8
Year 26-30 Cost [k€/year]	20.2	77	11	14.4

	Bucket 2							
	P50	P10	P50	P10	P50	P10	P50	P10
Blade root, Composite	>30	29.6	>30	>30	21.3	14.9	24.9	17.5
Blade root, Joint	29.9	23.1	>30	>30	21.6	16.6	22.1	17
Hub	>30	>30	>30	>30	24.6	17.8	25.2	18.3
Hub-Shaft joint	>30	>30	>30	>30	>30	>30	>30	>30
Low speed shaft	>30	>30	>30	>30	>30	>30	>30	>30
Main Frame, Casting	>30	>30	>30	>30	>30	>30	>30	>30
Main Frame, Welded	>30	>30	>30	>30	>30	>30	>30	>30
Main frame, Tower joint	>30	>30	>30	>30	>30	>30	>30	>30
Tower top	>30	>30	>30	>30	>30	>30	>30	>30
Tower bottom	>30	>30	>30	>30	>30	>30	>30	29.5
Year 1-5 Cost [k€/year]	0	0	0	0	0	0	0	0
Year 6-10 Cost [k€/year]	0	0	0	0	0	0	0	0
Year 11-15 Cost [k€/year]	0	0	0	0	0	0	0	0
Year 16-20 Cost [k€/year]	0	0	0	0	0	10.2	0	6.4
Year 21-25 Cost [k€/year]	0	3.6	0	0	8.3	16.3	4.3	11.5
Year 26-30 Cost [k€/year]	0	9	0	0	16.3	16.3	11.5	11.5

	Bucket 3													
	P50	P10	P50	P10	P50	P10	P50	P10	P50	P10	P50	P10	P50	P10
Blade root, Composite	20.1	14	23.3	16.4	22.1	15.4	>30	22.3	>30	22.6	>30	18.7	21.2	14.9
Blade root, Joint	22	16.9	22.6	17.4	23.3	17.8	25.9	20.2	26.4	20.6	26.3	19.3	21.4	16.5
Hub	22.9	16.6	26.1	19	25.5	18.4	>30	23.3	>30	24	>30	21	21.8	15.9
oint [No Title]	>30	27.7	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	17.5
Low speed shaft	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	20.7
Main Frame, Casting	>30	23.1	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	19.9
Main Frame, Welded	>30	27.3	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	17.5
Main frame, Tower joint	>30	27.3	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	17.5
Tower top	>30	27.3	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	17.5
Tower bottom	20.8	15	>30	>30	>30	>30	>30	>30	>30	>30	>30	>30	20.1	11.4
Year 1-5 Cost [k€/year]	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0
Year 6-10 Cost [k€/year]	0	0	0	0	0	0	0	0	0	0	0	2.8	0	0
Year 11-15 Cost [k€/year]	0	2.6	0	0	0	0	0	0	0	0	0	0	0	2.6
Year 16-20 Cost [k€/year]	0	36.5	0	14.8	0	16.3	0	0	0	0	0	0.5	0	17.3
Year 21-25 Cost [k€/year]	32.1	52.4	8.5	26.9	11.4	32.6	0	25.6	0	15.8	0	2.8	8.4	29
Year 26-30 Cost [k€/year]	47.1	96	25.8	26.9	32.6	32.6	15.8	31.7	13	26	1.4	2.9	10	29.6

	Bucket 4							
	P50	P10	P50	P10	P50	P10	P50	P10
Blade root, Composite	28.8	20.6	22.8	16.1	22.8	16.4	20	14.3
Blade root, Joint	24	18.6	21.5	16.7	21.1	16.4	19.4	15.1
Hub	29.4	21.4	22.1	16.2	20.7	15.3	19.4	14.3
Hub-Shaft joint	>30	>30	>30	23.8	>30	27.3	22.7	17.9
Low speed shaft	>30	>30	>30	>30	>30	>30	>30	24.4
Main Frame, Casting	>30	>30	>30	28.2	>30	>30	26.8	19.7
Main Frame, Welded	>30	>30	>30	24.1	>30	26.7	22.1	17.5
Main frame, Tower joint	>30	>30	>30	24.1	>30	26.7	22.1	17.5
Tower top	>30	>30	>30	24.1	>30	26.7	22.1	17.5
Tower bottom	>30	>30	>30	22.9	>30	25.2	23.7	18.4
Year 1-5 Cost [k€/year]	0	0	0	0	0	0	0	0
Year 6-10 Cost [k€/year]	0	0	0	0	0	0	0	0
Year 11-15 Cost [k€/year]	0	0	0	0	0	0	0	2.9
Year 16-20 Cost [k€/year]	0	1.4	0	29.2	0	23.4	6.4	89.1
Year 21-25 Cost [k€/year]	1.4	10.7	29.9	69.6	20.4	27.8	85.3	156.3
Year 26-30 Cost [k€/year]	8.1	11.5	43.2	161.4	27.8	76.2	146.7	169.1

Projection life by component with associated uncertainty.
Allows to estimate additional costs above the O & M contract

LTE Example Report

LTE REPORT

Index:

- Executive summary
- Definitions
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- Technical Background
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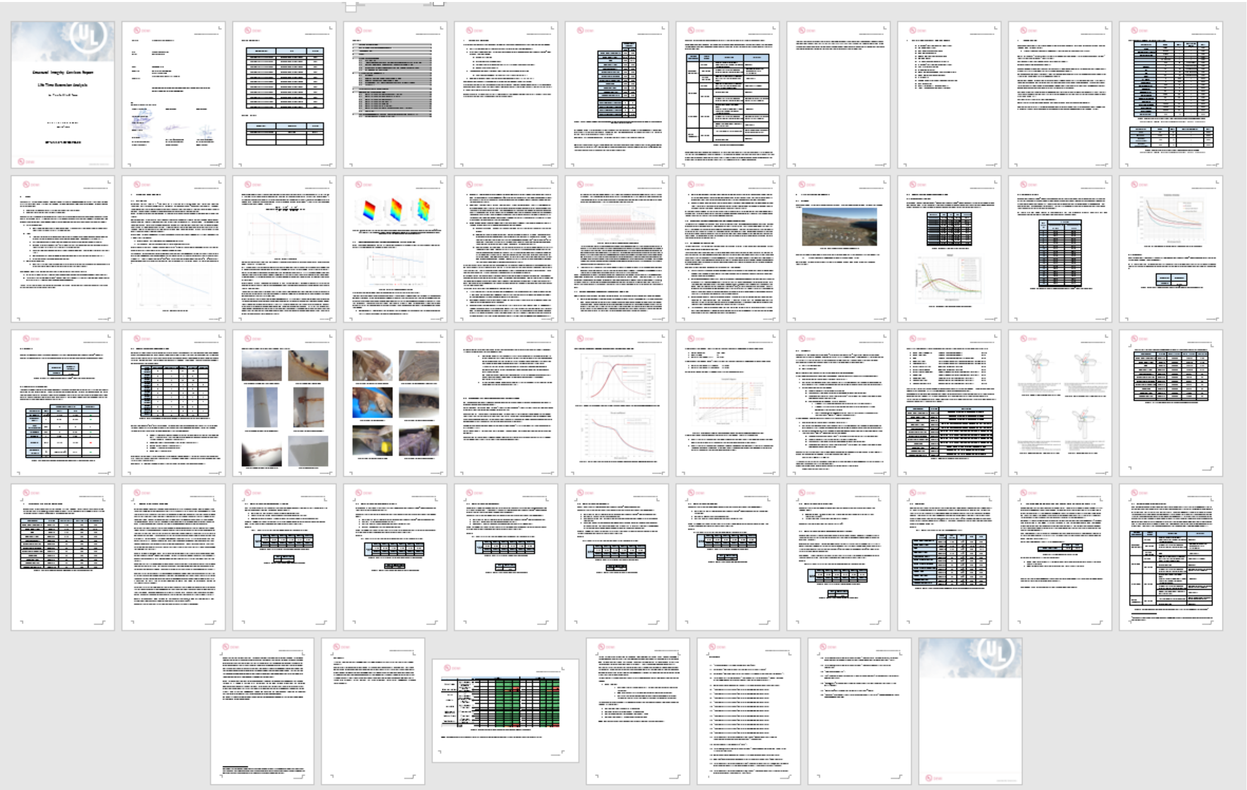
  - Wind data
  - Turbine data
  - Operation Data
  - IAM
  - Loads
  - Fatigue
- Results
  - Per component
  - Per Turbine
  - Per Sector
- Uncertainty
- Inspections
- Specific Analysis
- OPEX projection and LTE Program
- Recomendations



Wind and Operation Conditions

Table X. Number of high loads events per wind turbine

Event	Yaw	Pitch	Overspeed	Grid Loss	Emergency Stops
WT01	286	3	4	40	1
WT02	779	8	6	43	2
WT03	741	5	3	44	0
WT04	794	2	0	35	2
WT05	1224	10	0	48	1
WT06	587	6	2	44	0

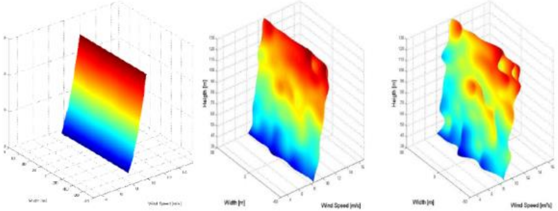
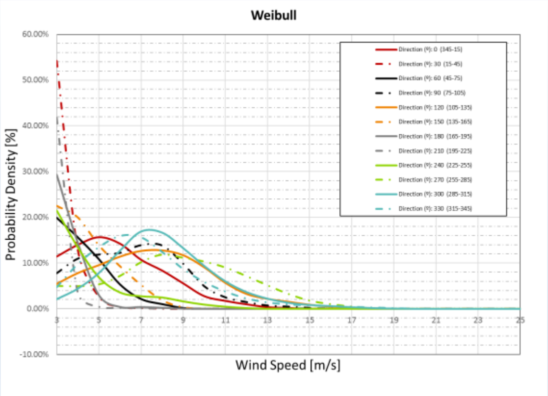
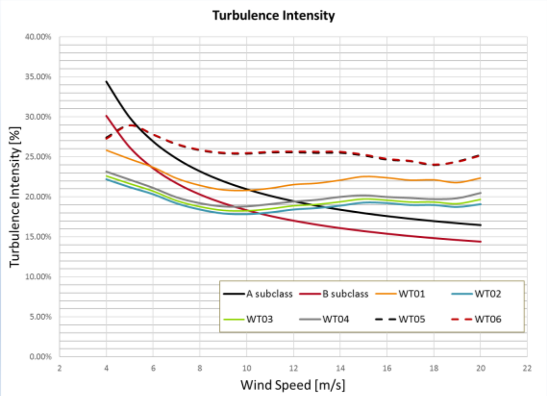


Table N. Wind shear, XXX Wind Farm

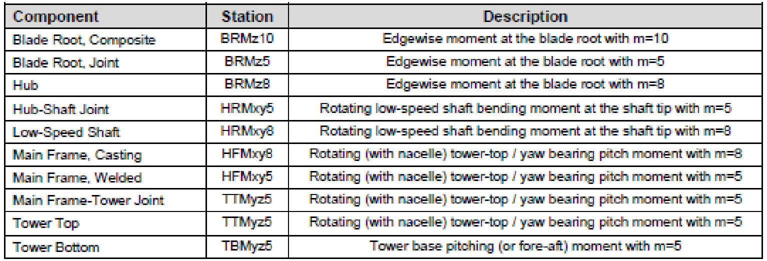
Wind Direction	Wind shear [m/s]
0º (345º - 15 º)	0.26
30º (15º - 45 º)	0.07
60º (45º - 75 º)	0.37
90º (75º - 105 º)	0.42
120º (105º - 135 º)	0.32
150º (135º - 165 º)	0.18
180º (165º - 195 º)	0.15
210º (195º - 225 º)	0.19
240º (225º - 255 º)	0.43
270º (255º - 285º)	0.49
300º (285º - 315 º)	0.37
330º (315º - 345 º)	0.32
Average	0.35



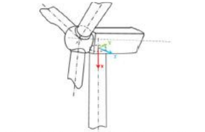


Digital Model

Table 5.7: Nomenclature of loads used for LTE analysis



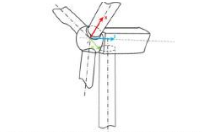
Component	Station	Description
Blade Root, Composite	BRMz10	Edgewise moment at the blade root with m=10
Blade Root, Joint	BRMz5	Edgewise moment at the blade root with m=5
Hub	BRMz8	Edgewise moment at the blade root with m=8
Hub-Shaft Joint	HRMxy5	Rotating low-speed shaft bending moment at the shaft tip with m=5
Low-Speed Shaft	HRMxy8	Rotating low-speed shaft bending moment at the shaft tip with m=8
Main Frame, Casting	HFMxy8	Rotating (with nacelle) tower-top / yaw bearing pitch moment with m=8
Main Frame, Welded	HFMxy5	Rotating (with nacelle) tower-top / yaw bearing pitch moment with m=5
Main Frame-Tower Joint	TTMyz5	Rotating (with nacelle) tower-top / yaw bearing pitch moment with m=5
Tower Top	TTMyz5	Rotating (with nacelle) tower-top / yaw bearing pitch moment with m=5
Tower Bottom	TBMyz5	Tower base pitching (or fore-aft) moment with m=5



The tower top coordinate system has its origin at the top of the tower in the tower top center. It is attached to the tower and it is "fixed" to ground.

- Axis x, vertically downwards in the tower axis
- Axis y, so that x, y and z rotate clockwise
- Axis z, wind dominant direction (wind north to south), attached to the tower and normal to the tower axis in the horizontal plane.

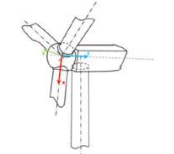
Figure 5.7: Tower-top/yaw coordinate system



The hub -coordinate system has its origin in the hub center or any other point in the rotor axis. It rotates with the rotor.

- Axis x, in plane containing the main-shaft axis and blade 1 pitch axis, normal to the main-shaft axis and blade root to tip positive. It rotates with the rotor.
- Axis y, so that x, y and z rotate clockwise. It rotates with the rotor.
- Axis z, in direction of the rotor axis (main-shaft axis down-wind positive)

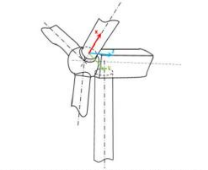
Figure 5.8: Rotating hub/shaft coordinate system



The hub coordinate system has its origin in the hub center, as the intersection of the blades pitch angle. It does not rotate with the rotor.

- Axis x, in vertical plane containing the main-shaft axis, normal to the axis and downwards positive
- Axis y, so that x, y and z rotate clockwise
- Axis z, in direction of the rotor axis (main-shaft axis down-wind positive)

Figure 5.9: Hub Fixed/Nacelle coordinate system



The blade coordinate system has its origin at the blade root, rotates with the rotor and its orientation to the rotor hub is fixed.

- Axis x, in direction of the pitch axis, from blade root to tip positive
- Axis y, chord axis, oriented to the blade leading edge positive
- Axis z, contained in the plane of main-shaft axis and pitch axis and downwind positive.

Figure 5.10: Blade coordinate system

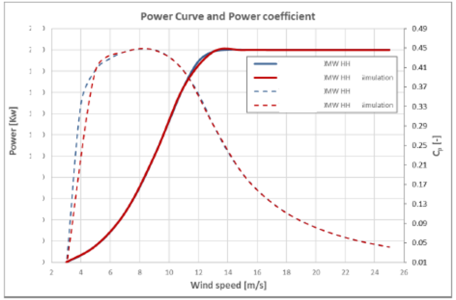


Figure 5.4: Power curve and power coefficient (Cp) of pitch-regulated wind turbine 0MW HH7 WT model validation)

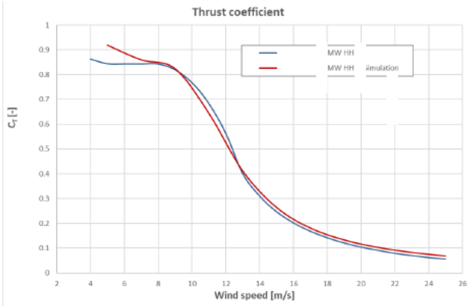
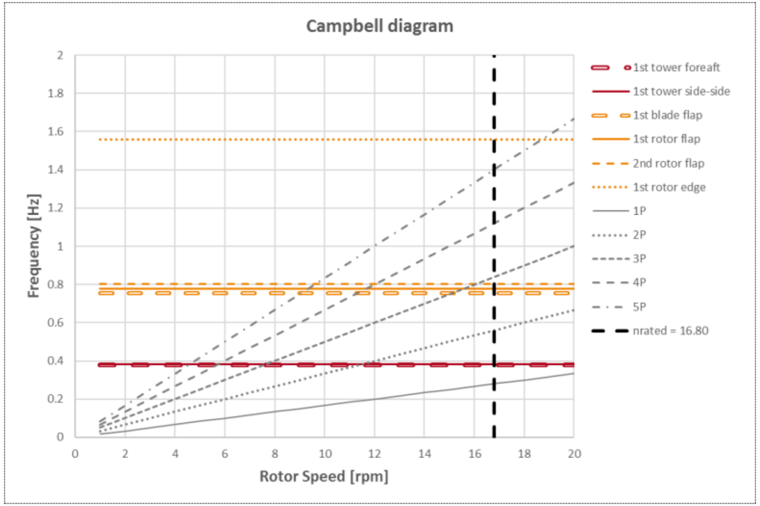


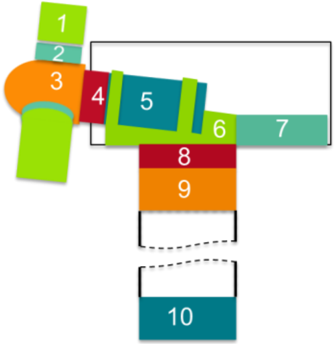
Figure 5.5: Thrust coefficient (CT) curve of pitch-regulated wind turbine HH WT model validation)

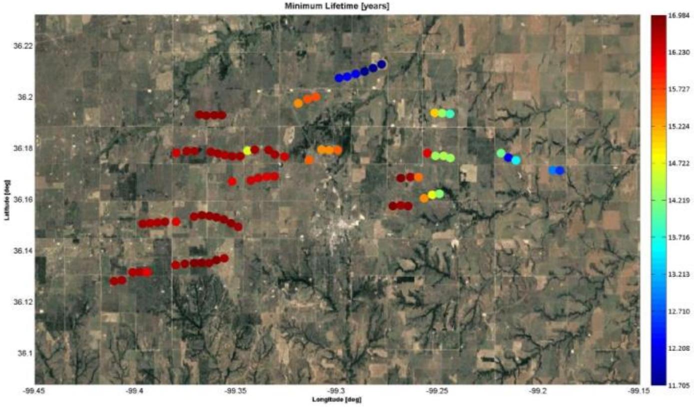


Results per turbine and component

Table 6.2: Life time P50-values per component for 2.XMW HH80 at XXXWind Farm

	Lifetime per Component in P50 load scenario									
Wind Turbine	**Blade Root, Composite**	**Blade Root, Joint**	**Hub**	**Hub-Shaft Joint**	**Low-Speed Shaft**	**Main Frame, Casting**	**Main Frame, Welded**	**Main Frame, Tower Joint**	**Tower Top**	**Tower Bottom**
WT01	16.3	17.2	16.7	22.7	18.5	17.6	19.7	20.0	20.0	19.8
WT02	17.0	20.0	22.5	>40	38.3	36.3	>40	>40	>40	>40
WT03	16.4	19.6	21.6	39.2	34.5	33.2	39.6	39.9	39.9	>40
WT04	16.8	20.0	21.9	39.7	35.2	33.8	>40	>40	>40	>40
WT05	16.7	19.2	19.5	26.8	17.2	19.0	23.2	23.6	23.6	21.8
WT06	16.7	19.1	19.3	26.3	18.9	18.9	23.0	23.3	23.3	22
Average WF	18.0	19.2	20.3	33.0	26.3	23.5	31.5	31.8	31.8	31.9
Min WF	16.3	17.2	16.7	22.7	17.2	17.6	19.7	20	20	19.8





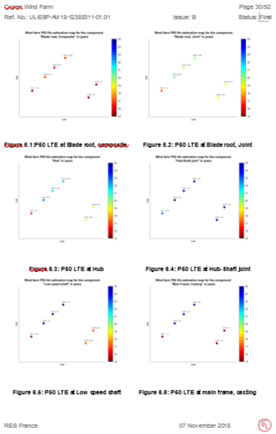

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Figure 6.1:P50 LTE at Blade root, composite

Figure 6.2: P50 LTE at Blade root, Joint

Figure 6.3: P50 LTE at Hub

Figure 6.4: P50 LTE at Hub-Shaft joint

Figure 6.5: P50 LTE at Low speed shaft

Figure 6.6: P50 LTE at main frame, casting

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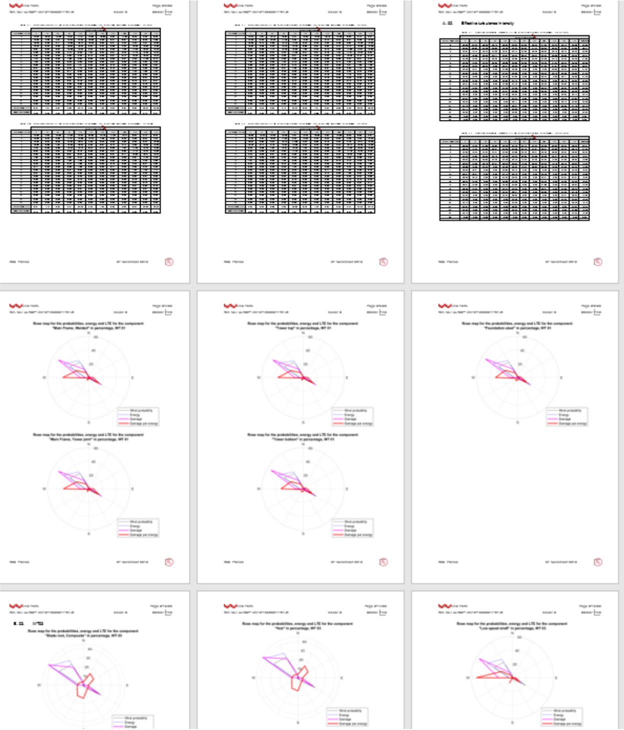
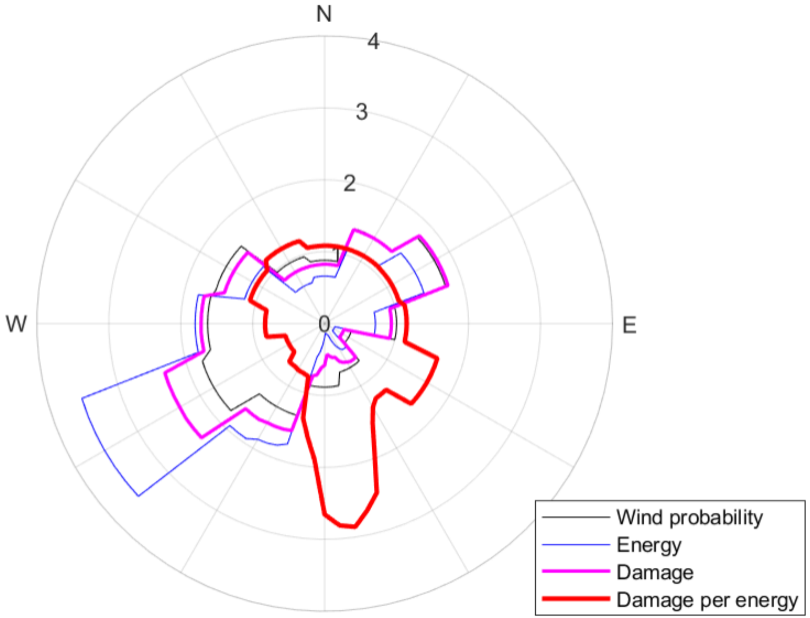
#	Component	P50	P10	O&M proposal
1	Blade root compo.	**>30**	*19.5*	*VI/year + Thermography if required*
2	Blade root metallic	**23.9**	*18*	*VI with tap test /year + NDT/ 2 years*
3	Casted Hub	**28.2**	*18*	*NDT / 4 years*
4	Hub to shaft joint	**>30**	*>30*	*Acc. to OEM Main. Plan*
5	Low speed shaft	**>30**	*>30*	*Acc. to OEM Main. Plan*
6	Casted Mainframe	**>30**	*>30*	*Acc. to OEM Main. Plan*
7	Weld mainframe	**>30**	*>30*	*Acc. to OEM Main. Plan*
8	Mainfra. To tower	**>30**	*>30*	*Acc. to OEM Main. Plan*
9	Tower top	**>30**	*>30*	*Acc. to OEM Main. Plan*
10	Tower bottom	**>30**	*>30*	*Repair acc. OEM + VI/year*

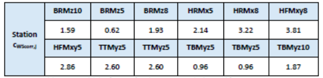
Results per turbine, component and sector



Rose map for the probabilities, Energy and LTE in percentage

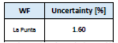


Sensitivity Factors, Uncertainty Calculations, P-values



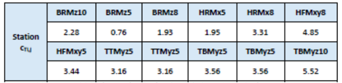
Station $c_{WScorr,j}$	BRMz10	BRMz5	BRMz8	HRMx5	HRMx8	HFMxy8
	1.59	0.62	1.93	2.14	3.22	3.81
	HFMxy5	TTMyz5	TTMyz5	TBMyz5	TBMyz5	TBMyz10
	2.86	2.60	2.60	0.96	0.96	1.87

Table 14: Sensitivity factors for the average wind speed for La Punta WF



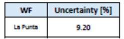
WF	Uncertainty [%]
La Punta	1.60

Table 15: Uncertainty related to wind speed in La Punta WF



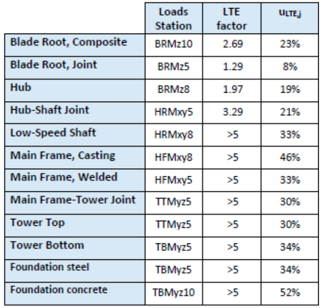
Station $c_{TI,j}$	BRMz10	BRMz5	BRMz8	HRMx5	HRMx8	HFMxy8
	2.28	0.76	1.93	1.95	3.31	4.85
	HFMxy5	TTMyz5	TTMyz5	TBMyz5	TBMyz5	TBMyz10
	3.44	3.16	3.16	3.56	3.56	5.52

Table 16: Sensitivity factors for the for the turbulence intensity for La Punta WF



WF	Uncertainty [%]
La Punta	9.20

Table 17: Uncertainty related to turbulence intensity for La Punta WF



	Loads Station	LTE factor	$u_{LTE,j}$
Blade Root, Composite	BRMz10	2.69	23%
Blade Root, Joint	BRMz5	1.29	8%
Hub	BRMz8	1.97	19%
Hub-Shaft Joint	HRMxy5	3.29	21%
Low-Speed Shaft	HRMxy8	>5	33%
Main Frame, Casting	HFMxy8	>5	46%
Main Frame, Welded	HFMxy5	>5	33%
Main Frame-Tower Joint	TTMyz5	>5	30%
Tower Top	TTMyz5	>5	30%
Tower Bottom	TBMyz5	>5	34%
Foundation steel	TBMyz5	>5	34%
Foundation concrete	TBMyz10	>5	52%

Table 7.1: Life time P90-values per component for 2.XMW HH80 at XXX Wind Farm

	Lifetime per Component in P90 load scenario									
Wind Turbine	**Blade Root, Composite**	**Blade Root, Joint**	**Hub**	**Hub-Shaft Joint**	**Low-Speed Shaft**	**Main Frame, Casting**	**Main Frame, Welded**	**Main Frame, Tower Joint**	**Tower Top**	**Tower Bottom**
WT01	12.8	15.2	14.1	15.6	11.5	10.6	16.9	17.1	17.1	14.1
WT02	13.1	17.9	17.3	16.3	13.7	11.8	15.1	15.6	15.6	15.2
WT03	12.9	17.5	16.5	14.8	13.3	11.6	13.8	14.3	14.3	13.9
WT04	12.9	17.8	16.8	15.1	13.4	11.8	14.1	14.6	14.6	14.7
WT05	13.7	16.7	14.1	10.2	11.8	10.6	18.2	18.5	18.5	18.0
WT06	13.7	16.7	16.0	17.0	11.8	10.6	18.1	18.4	18.4	18.0
Average	13.2	17.0	15.1	16.5	12.6	11.2	11.0	11.4	11.4	17.5
Min WF	12.8	15.2	14.1	15.6	11.5	10.6	16.9	17.1	17.1	14.1

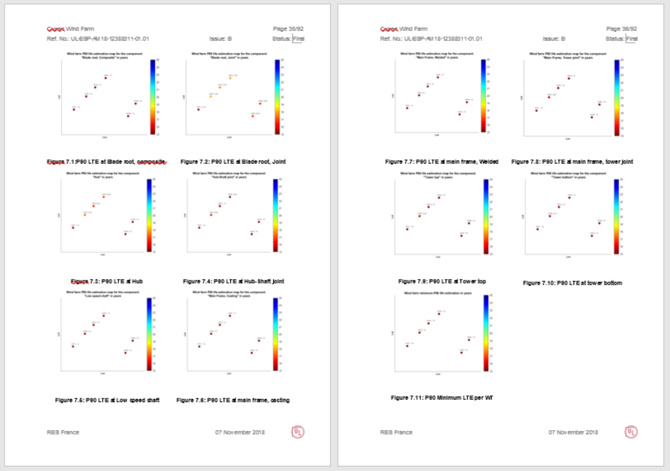


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Figure 7.1: P90 LTE at Blade root, composite
Figure 7.2: P90 LTE at Blade root, Joint
Figure 7.3: P90 LTE at Hub
Figure 7.4: P90 LTE at Hub-Shaft joint
Figure 7.5: P90 LTE at Low speed shaft
Figure 7.6: P90 LTE at main frame, casting

RES France
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Figure 7.7: P90 LTE at main frame, Welded
Figure 7.8: P90 LTE at main frame, tower joint
Figure 7.9: P90 LTE at Tower top
Figure 7.10: P90 LTE at tower bottom
Figure 7.11: P90 Minimum LTE per WT

RES France
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Inspections


ESP-AM18-12179531-01.00

Some graphical report of inspection is shown in next figures:

Figure 9 General view of 6 of the 11 wind turbines

Figure 12 Tower bottom corrosion

Figure 10 Tower mid joint corrosion – external

Figure 13 Corrosion at yaw gear and bolts

Figure 11 Tower mid joint corrosion - internal

Figure 14 Blade damages


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Figure 15 Corrosion at access ladder to nacelle

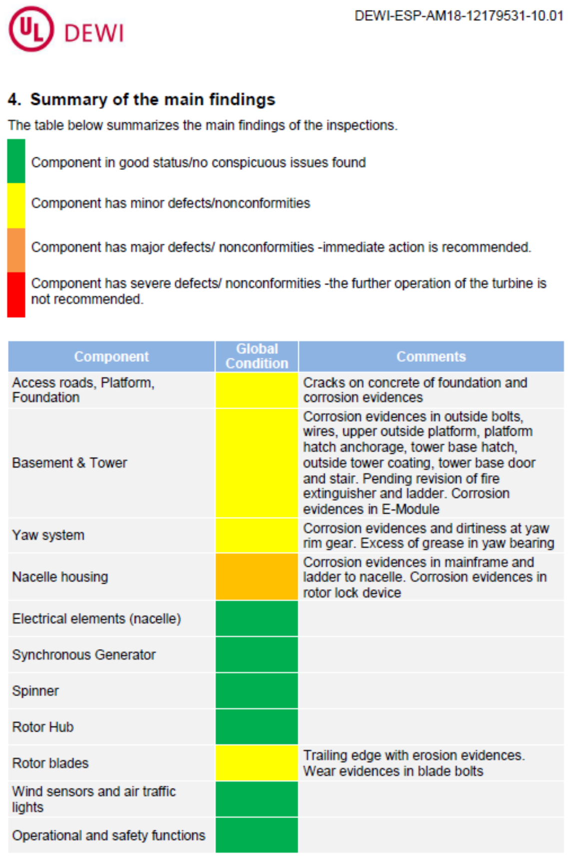
Figure 18 Corrosion at upper platform safety railing

Figure 16 Corrosion at blade bolts

Figure 19 Corrosion at yaw gear and bolts

Figure 17 Corrosion at nacelle mainframe

Figure 20 Corrosion at yaw gear and bolts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4. Summary of the main findings

The table below summarizes the main findings of the inspections.

🟩	Component in good status/no conspicuous issues found
🟨	Component has minor defects/nonconformities
🟧	Component has major defects/ nonconformities -immediate action is recommended.
🟥	Component has severe defects/ nonconformities -the further operation of the turbine is not recommended.

Component	Global Condition	Comments
Access roads, Platform, Foundation	🟨	Cracks on concrete of foundation and corrosion evidences
Basement & Tower	🟨	Corrosion evidences in outside bolts, wires, upper outside platform, platform hatch anchorage, tower base hatch, outside tower coating, tower base door and stair. Pending revision of fire extinguisher and ladder. Corrosion evidences in E-Module
Yaw system	🟨	Corrosion evidences and dirtiness at yaw rim gear. Excess of grease in yaw bearing
Nacelle housing	🟧	Corrosion evidences in mainframe and ladder to nacelle. Corrosion evidences in rotor lock device
Electrical elements (nacelle)	🟩	
Synchronous Generator	🟩	
Spinner	🟩	
Rotor Hub	🟩	
Rotor blades	🟨	Trailing edge with erosion evidences. Wear evidences in blade bolts
Wind sensors and air traffic lights	🟩	
Operational and safety functions	🟩	

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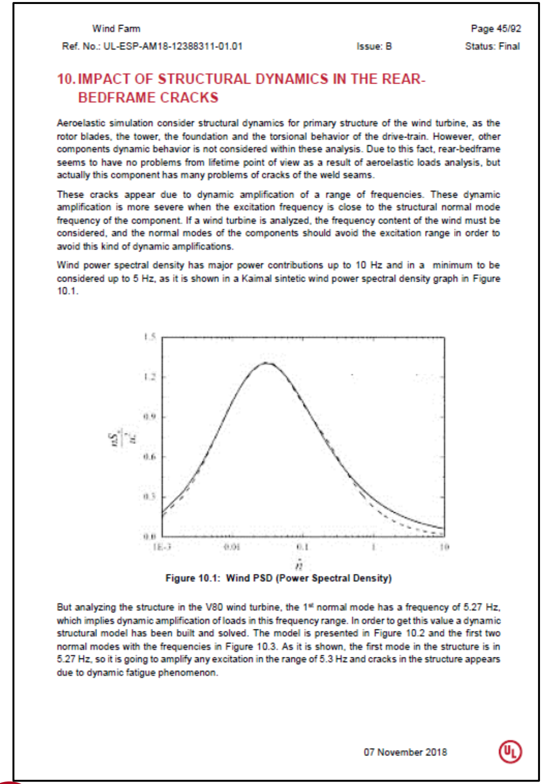


10. IMPACT OF STRUCTURAL DYNAMICS IN THE REAR-BEDFRAME CRACKS

Aeroelastic simulation consider structural dynamics for primary structure of the wind turbine, as the rotor blades, the tower, the foundation and the torsional behavior of the drive-train. However, other components dynamic behavior is not considered within these analysis. Due to this fact, rear-bedframe seems to have no problems from lifetime point of view as a result of aeroelastic loads analysis, but actually this component has many problems of cracks of the weld seams.

These cracks appear due to dynamic amplification of a range of frequencies. These dynamic amplification is more severe when the excitation frequency is close to the structural normal mode frequency of the component. If a wind turbine is analyzed, the frequency content of the wind must be considered, and the normal modes of the components should avoid the excitation range in order to avoid this kind of dynamic amplifications.

Wind power spectral density has major power contributions up to 10 Hz and in a minimum to be considered up to 5 Hz, as it is shown in a Kaimal sintetic wind power spectral density graph in Figure 10.1.

Figure 10.1: Wind PSD (Power Spectral Density)

But analyzing the structure in the V80 wind turbine, the 1st normal mode has a frequency of 5.27 Hz, which implies dynamic amplification of loads in this frequency range. In order to get this value a dynamic structural model has been built and solved. The model is presented in Figure 10.2 and the first two normal modes with the frequencies in Figure 10.3. As it is shown, the first mode in the structure is in 5.27 Hz, so it is going to amplify any excitation in the range of 5.3 Hz and cracks in the structure appears due to dynamic fatigue phenomenon.

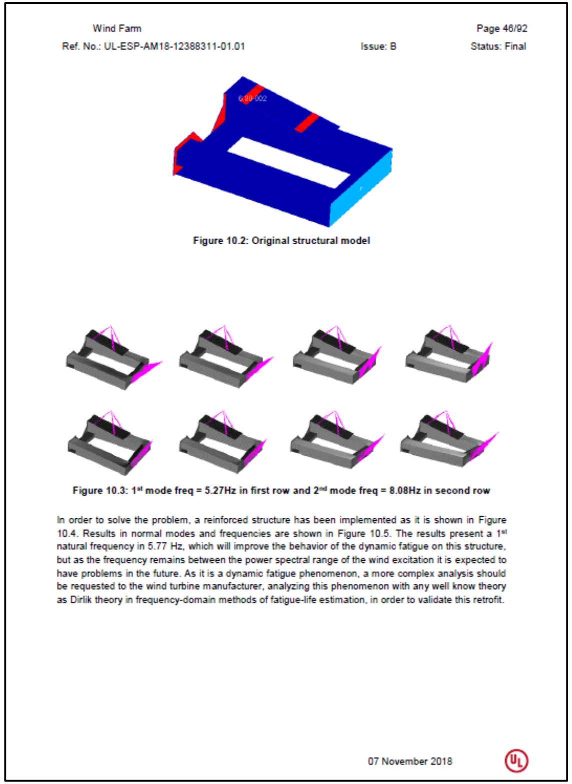
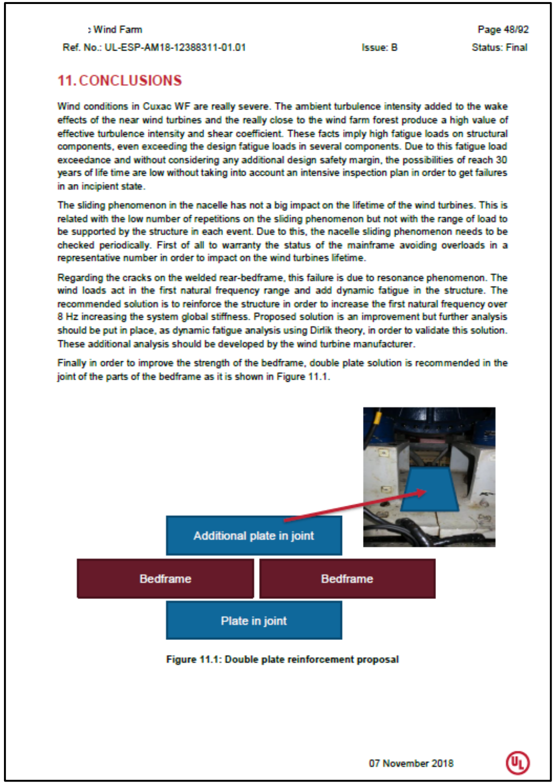


Figure 10.2: Original structural model

Figure 10.3: 1st mode freq = 5.27Hz in first row and 2nd mode freq = 8.08Hz in second row

In order to solve the problem, a reinforced structure has been implemented as it is shown in Figure 10.4. Results in normal modes and frequencies are shown in Figure 10.5. The results present a 1st natural frequency in 5.77 Hz, which will improve the behavior of the dynamic fatigue on this structure, but as the frequency remains between the power spectral range of the wind excitation it is expected to have problems in the future. As it is a dynamic fatigue phenomenon, a more complex analysis should be requested to the wind turbine manufacturer, analyzing this phenomenon with any well know theory as Dirlik theory in frequency-domain methods of fatigue-life estimation, in order to validate this retrofit.



11. CONCLUSIONS

Wind conditions in Cuxac WF are really severe. The ambient turbulence intensity added to the wake effects of the near wind turbines and the really close to the wind farm forest produce a high value of effective turbulence intensity and shear coefficient. These facts imply high fatigue loads on structural components, even exceeding the design fatigue loads in several components. Due to this fatigue load exceedance and without considering any additional design safety margin, the possibilities of reach 30 years of life time are low without taking into account an intensive inspection plan in order to get failures in an incipient state.

The sliding phenomenon in the nacelle has not a big impact on the lifetime of the wind turbines. This is related with the low number of repetitions on the sliding phenomenon but not with the range of load to be supported by the structure in each event. Due to this, the nacelle sliding phenomenon needs to be checked periodically. First of all to warranty the status of the mainframe avoiding overloads in a representative number in order to impact on the wind turbines lifetime.

Regarding the cracks on the welded rear-bedframe, this failure is due to resonance phenomenon. The wind loads act in the first natural frequency range and add dynamic fatigue in the structure. The recommended solution is to reinforce the structure in order to increase the first natural frequency over 8 Hz increasing the system global stiffness. Proposed solution is an improvement but further analysis should be put in place, as dynamic fatigue analysis using Dirlik theory, in order to validate this solution. These additional analysis should be developed by the wind turbine manufacturer.

Finally in order to improve the strength of the bedframe, double plate solution is recommended in the joint of the parts of the bedframe as it is shown in Figure 11.1.

Figure 11.1: Double plate reinforcement proposal

LTE PLAN

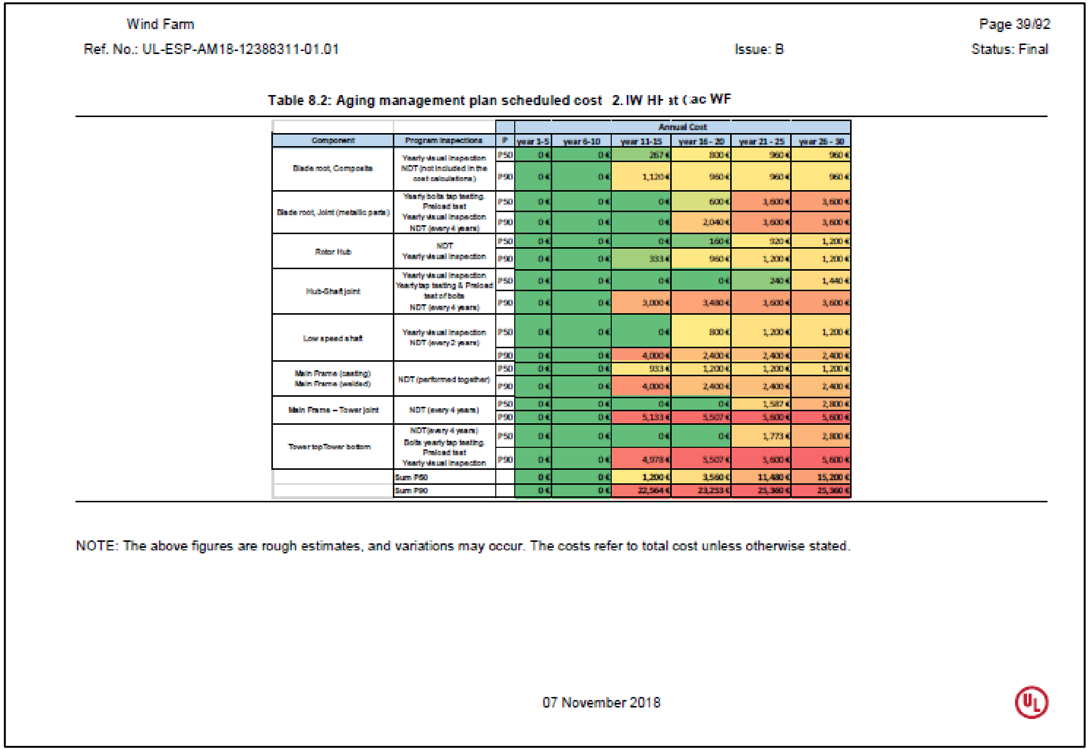


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Table 8.2: Aging management plan scheduled cost 2.IW HF at (ac WF

			Annual Cost					
Component	Program Inspections	P	year 1-5	year 6-10	year 11-15	year 16 - 20	year 21 - 25	year 26 - 30
Blade root, Composite	Yearly visual inspection NDT (not included in the cost calculations)	P50	0 €	0 €	267 €	800 €	960 €	960 €
		P90	0 €	0 €	1,120 €	960 €	960 €	960 €
Blade root, Joint (metallic parts)	Yearly bolts tap testing. Preload test Yearly visual inspection NDT (every 4 years)	P50	0 €	0 €	0 €	600 €	3,600 €	3,600 €
		P90	0 €	0 €	0 €	2,040 €	3,600 €	3,600 €
Rotor Hub	NDT Yearly visual inspection	P50	0 €	0 €	0 €	160 €	920 €	1,200 €
		P90	0 €	0 €	333 €	960 €	1,200 €	1,200 €
Hub-Shaft joint	Yearly visual inspection Yearly tap testing & Preload test of bolts NDT (every 4 years)	P50	0 €	0 €	0 €	0 €	240 €	1,440 €
		P90	0 €	0 €	3,000 €	3,480 €	3,600 €	3,600 €
Low speed shaft	Yearly visual inspection NDT (every 2 years)	P50	0 €	0 €	0 €	800 €	1,200 €	1,200 €
		P90	0 €	0 €	4,000 €	2,400 €	2,400 €	2,400 €
Main Frame (casting) Main Frame (welded)	NDT (performed together)	P50	0 €	0 €	933 €	1,200 €	1,200 €	1,200 €
		P90	0 €	0 €	4,000 €	2,400 €	2,400 €	2,400 €
Main Frame – Tower joint	NDT (every 4 years)	P50	0 €	0 €	0 €	0 €	1,587 €	2,800 €
		P90	0 €	0 €	5,133 €	5,507 €	5,600 €	5,600 €
Tower top/Tower bottom	NDT(every 4 years) Bolts yearly tap testing. Preload test Yearly visual inspection	P50	0 €	0 €	0 €	0 €	1,773 €	2,800 €
		P90	0 €	0 €	4,978 €	5,507 €	5,600 €	5,600 €
	Sum P50		0 €	0 €	1,200 €	3,560 €	11,480 €	15,200 €
	Sum P90		0 €	0 €	22,564 €	23,253 €	25,360 €	25,360 €

NOTE: The above figures are rough estimates, and variations may occur. The costs refer to total cost unless otherwise stated.

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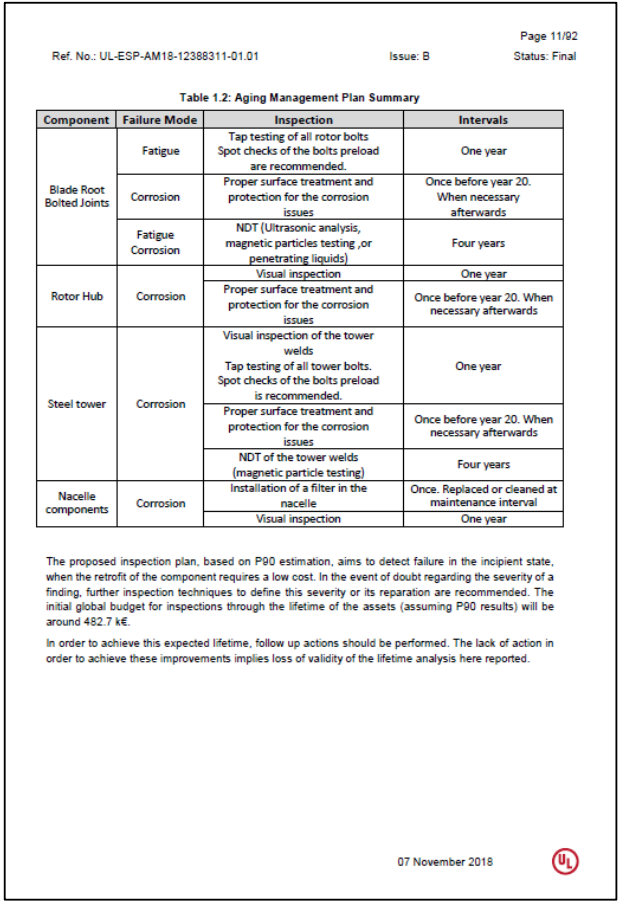

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Table 1.2: Aging Management Plan Summary

Component	Failure Mode	Inspection	Intervals
Blade Root Bolted Joints	Fatigue	Tap testing of all rotor bolts Spot checks of the bolts preload are recommended.	One year
	Corrosion	Proper surface treatment and protection for the corrosion issues	Once before year 20. When necessary afterwards
	Fatigue Corrosion	NDT (Ultrasonic analysis, magnetic particles testing ,or penetrating liquids)	Four years
Rotor Hub	Corrosion	Visual inspection	One year
		Proper surface treatment and protection for the corrosion issues	Once before year 20. When necessary afterwards
Steel tower	Corrosion	Visual inspection of the tower welds Tap testing of all tower bolts. Spot checks of the bolts preload is recommended.	One year
		Proper surface treatment and protection for the corrosion issues	Once before year 20. When necessary afterwards
		NDT of the tower welds (magnetic particle testing)	Four years
Nacelle components	Corrosion	Installation of a filter in the nacelle	Once. Replaced or cleaned at maintenance interval
		Visual inspection	One year

The proposed inspection plan, based on P90 estimation, aims to detect failure in the incipient state, when the retrofit of the component requires a low cost. In the event of doubt regarding the severity of a finding, further inspection techniques to define this severity or its reparation are recommended. The initial global budget for inspections through the lifetime of the assets (assuming P90 results) will be around 482.7 k€.

In order to achieve this expected lifetime, follow up actions should be performed. The lack of action in order to achieve these improvements implies loss of validity of the lifetime analysis here reported.

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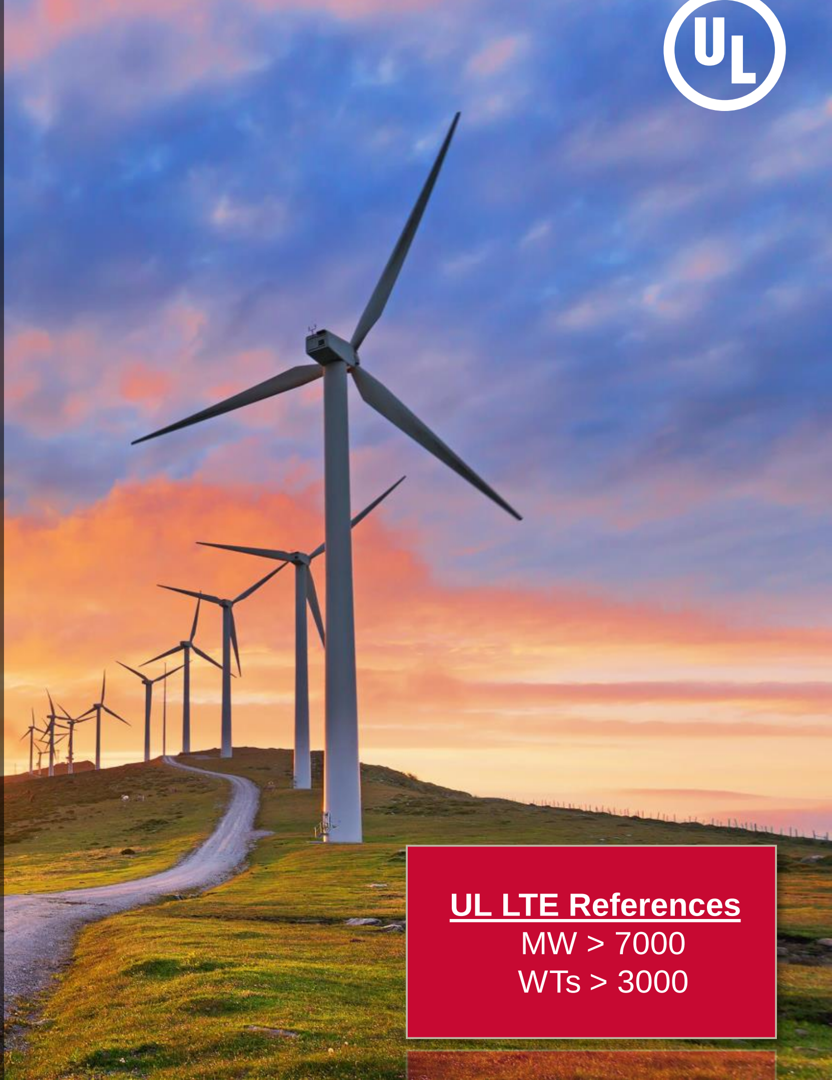
- Any life extension scenario of wind assets must go through the accurate estimation of the remaining life, including uncertainty that projects the financial and security risk.

- The analytical model is based on the study of many external and operational parameters with their different uncertainties and life sensitivities. The great sensitivity in life of many of them requires very precise techniques and means to reduce uncertainties.

- Many techniques can be used for characterization, through wind, operation and machine monitoring; each of them will have more or less precision and also cost. The choice will depend on the quality and quantity of data available as well as the level of uncertainty (risk) that can be assumed for financial and security models.

- For a robust analysis, it is necessary to have companies with global capabilities of first order in monitoring, wind modeling, load simulation, inspection and machine knowledge.

- A life extension program must be put in place in the wind farm when arriving the life design time end (Y20). This program must include on-site inspections, load measurement to track fatigue accumulation, predictive actions and condition based maintenance activities.



UL LTE References
MW > 7000
WTs > 3000

Renewables

LIFE EXTENSION AND OPTIMIZATION OF WIND FARM

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UL International GmbH – Sucursal en España is accredited by IAS (under AA-759) according to ISO/IEC 17020:2012 as „Inspection Agency - Type A (Third-Party) Inspection Body".

QUÉBEC - 7th February 2019

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