RCWIND

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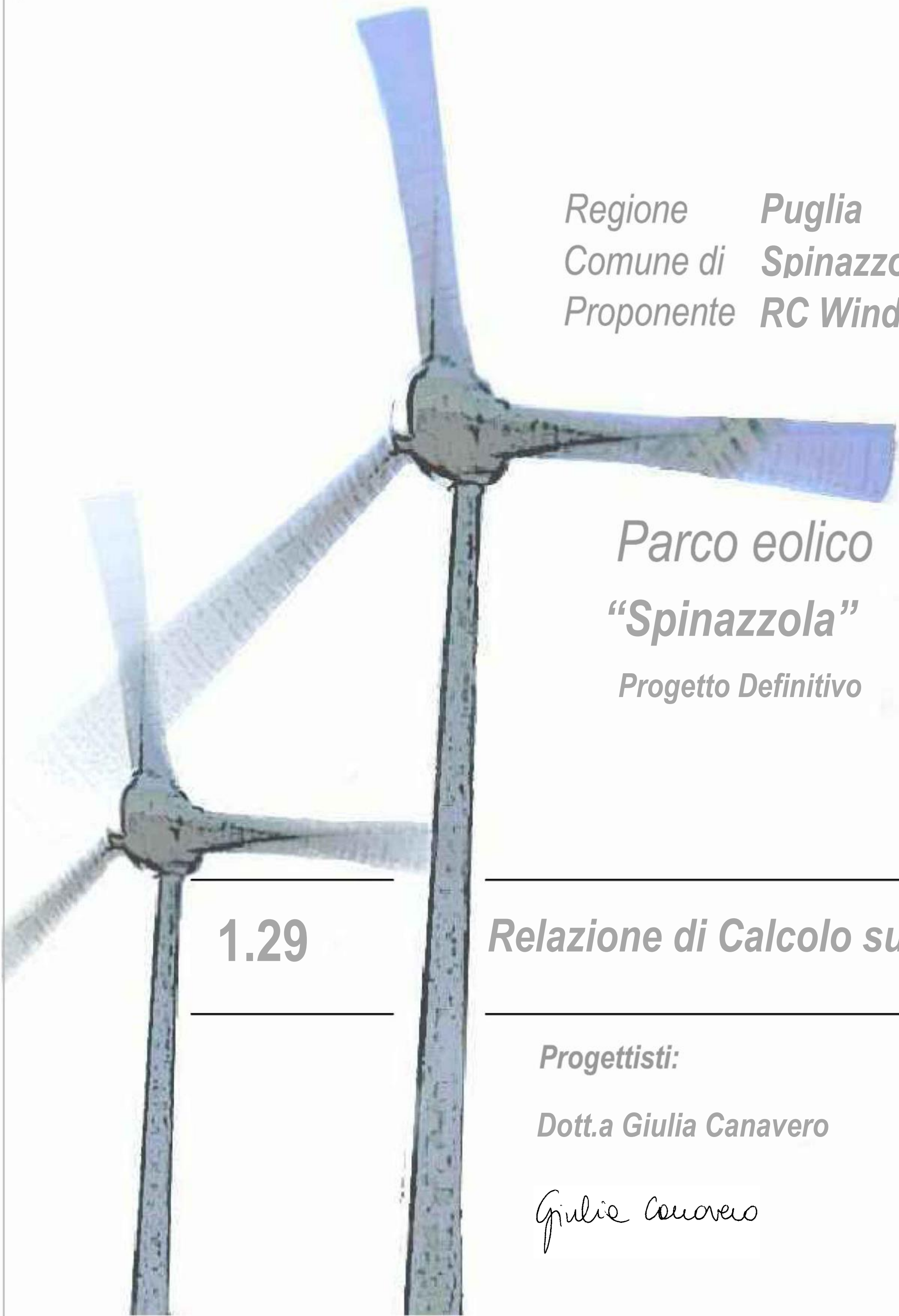

Regione Puglia
Comune di Spinazzola (BT)
Proponente RC Wind Srl

Parco eolico "Spinazzola"

Progetto Definitivo

1.29 Relazione di Calcolo sulla Gittata

Progettisti:

Dott.a Giulia Canavero

Giulia Canavero

Data	Rev.	Descrizione	Elaborato	Controllato	Approvato
25.05.2018	A	Prima emissione	G.Canavero	G.Canavero	P.Fazzino

Comm. 90 Elaborato: SPN-1.29-A_Relazione Calcolo Gittata

INDICE

1. INTRODUZIONE

La seguente relazione ha l'obiettivo di determinare la massima distanza che raggiunge una pala di un aerogeneratore in fase di distacco mentre la macchina è in funzione.

In letteratura sono annoverati pochissimi casi di danni causati dalle pale delle turbine in caso di rottura accidentale. Si tratta infatti di una circostanza eccezionale e comunque i rischi connessi, soprattutto per la salute pubblica, sono estremamente bassi.

Il distacco o la rottura della pala sono eventi che si verificano per condizioni operative al di fuori del normale *range* di funzionamento delle macchine. Gli aerogeneratori che si utilizzeranno sono provvisti di sistemi di sicurezza che intervengono quando le condizioni di funzionamento sono tali da compromettere la funzionalità della macchina e la sicurezza pubblica.

A tal riguardo, a conforto di quanto detto prima e a titolo d'esempio, si allegano due documenti tecnici forniti dal produttore di turbine Senvion/Repower, valevoli in linea teorica per qualsiasi altro produttore di aeroturbine:

- Allegato 1 - Product description: a pag. 9 viene descritto il sistema rotorico della turbina con tutti gli accorgimenti di sicurezza che vengono adottati a livello costruttivo; a pag. 23 vengono descritti i sistemi di rilevamento del ghiaccio della turbina. Uno dei sistemi di controllo rileva le vibrazioni del rotore fermando la turbina in caso del superamento di una determinata soglia limite; questo sistema (che si attiva prevalentemente in caso di formazione di ghiaccio sulla pala e sbilanciamento/vibrazioni eccessive del rotore) agisce anche in caso di fratture incipienti della pala che inducono vibrazioni/sbilanciamenti del rotore;
- Allegato 2 - Maintenance manual: nella prima sezione del documento si evidenziano i controlli semestrali sulle pale per rilevare eventuali non conformità.

Il sistema di controllo della macchina e le ispezioni periodiche in fase di manutenzione riducono enormemente la probabilità di accadimento del lancio della pala.

2. BREVE DESCRIZIONE DEL PROGETTO

Il progetto qui presentato consiste nella posa di 9 aerogeneratori di potenza nominale massima pari a 3,6 MW per un totale di 32,4 MW situati nel comune di Spinazzola (BAT).

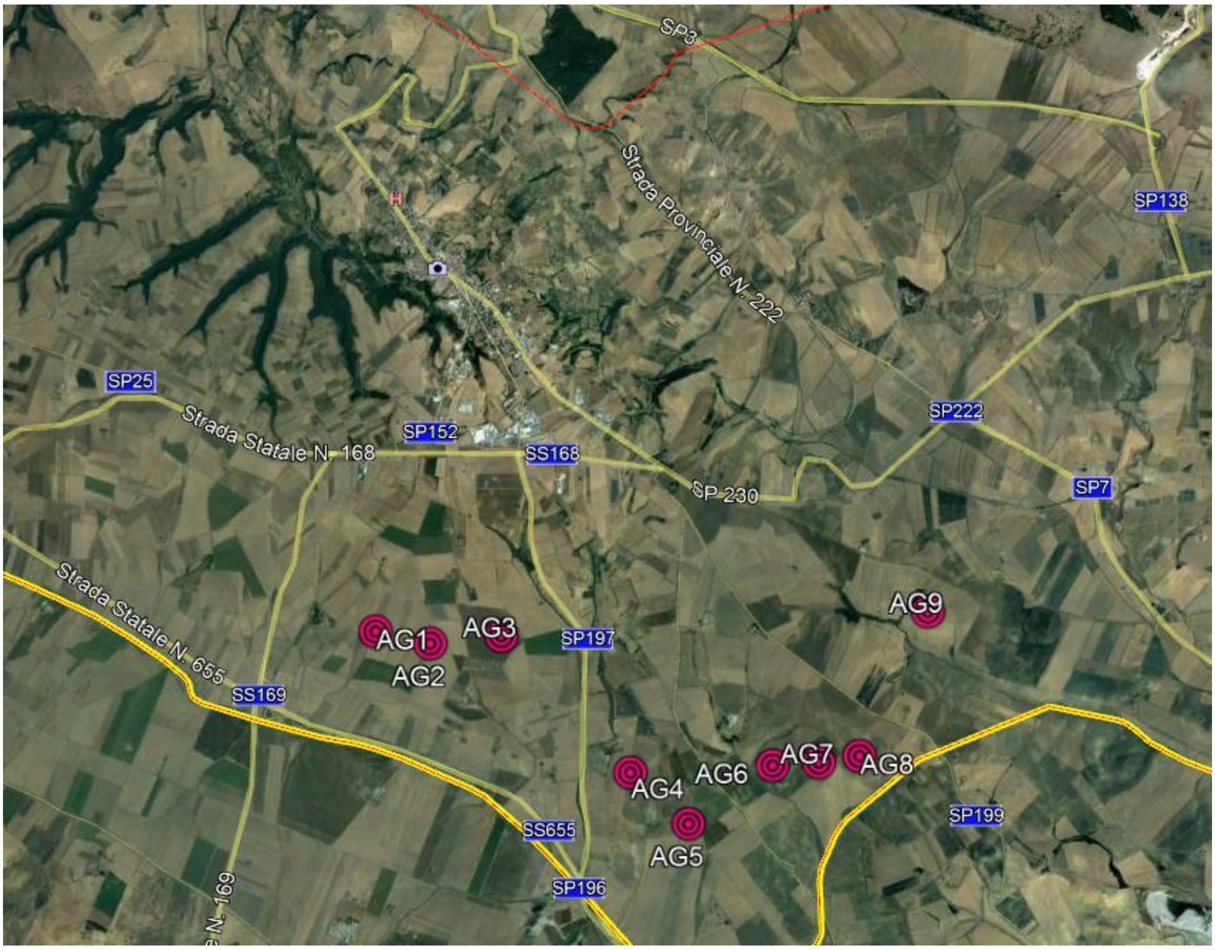

Figura 1 - Lay-out su ortofoto

La turbina di riferimento ha altezza al mozzo pari a 112 m e diametro del rotore pari a 138 m.

3. EQUAZIONI DEL MOTO

Le equazioni del moto di un punto materiale soggetto solo alla forza di gravità sono:

$$x = 0$$

$$y = -g$$

dove $g = 9{,}8\ m/sec^2$ è l'accelerazione di gravità.

La legge del moto soluzione di queste equazioni è:

$$x(t) = x_0 + v_x t$$
$$y(t) = y_0 + v_y t - \frac{1}{2} g t^2$$

dove (x_0; y_0) è la posizione iniziale del punto materiale, e (v_x; v_y) è la sua velocità. La traiettoria del punto materiale intercetta il suolo al tempo T tale che y(t) = 0.

4. GEOMETRIA DEL PROBLEMA

Il presente studio deve essere ricondotto alla composizione di due movimenti sopra un sistema di assi cartesiani noto, con l'asse x coincidente con l'asse orizzontale alla base dell'aerogeneratore, ovvero il suolo, e l'asse y coincidente con l'asse verticale centrale dell'aerogeneratore.

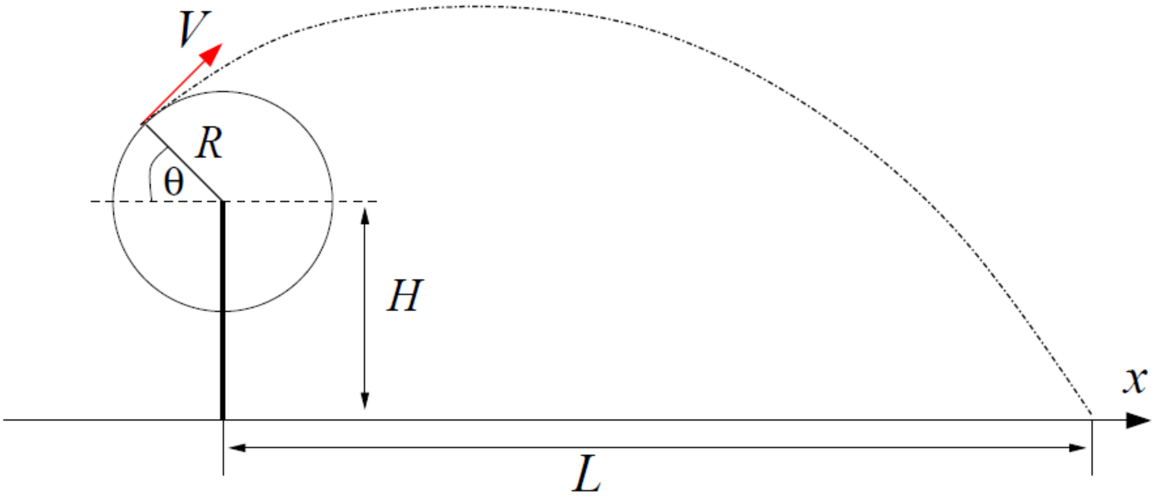

Figura 2: Schematizzazione esemplificativa

La posizione e la velocità iniziale sono determinati dall'angolo θ e dalla velocità tangenziale V della pala al momento del distacco. Essi sono legati alla posizione ed alla velocità iniziale dalle relazioni:

$$x_0 = - R\cos(\theta)$$

$$y_0 = H + R\sin(\theta)$$

$$v_x = V \sin(\theta)$$

$$v_y = V \cos(\theta)$$

La gittata L è la distanza del punto di impatto al suolo della pala proiettata.

5. CALCOLO DELLA GITTATA

Gli aerogeneratori che si prevedono di installare nel parco eolico sono di potenza nominale pari a 3,6 MW, con altezza massima al mozzo pari a 112 m e rotore di diametro massimo pari a 138 m (dimensioni assimilabili all'aerogeneratore Enercon E138, che si prenderà ad esempio). La massima velocità del rotore raggiunta da questa tipologia di aerogeneratore è pari a 15,38 giri al minuto.

Lo studio della gittata di un elemento rotante dell'aerogeneratore si basa sull'ipotesi di considerare l'elemento come un corpo rigido, ovvero un insieme di particelle soggette a forze tali da mantenere costanti nel tempo le loro distanze relative. Pertanto, il moto di un corpo rigido è traslatorio quando tutte le particelle che costituiscono il corpo subiscono lo stesso spostamento qualsiasi sia l'intervallo di tempo considerato. In un moto traslatorio, rettilineo o curvilineo, ogni segmento che congiunge due punti qualunque del corpo rigido, durante il movimento, resta parallelo a se stesso, quindi tutti i punti descrivono traiettorie uguali e sovrapponibili. Il moto traslatorio di un corpo rigido resta dunque conosciuto quando è noto il moto di uno qualunque dei suoi punti.

Tutti i punti del corpo rigido in rotazione si muovono con la stessa velocità angolare, pertanto si considera il centro di applicazione della velocità il baricentro del corpo.

Nello studio si considera il moto del corpo bidimensionale, traslatorio e curvilineo, rappresentato da un punto materiale (baricentro) lanciato in aria obliquamente sottoposto all'accelerazione di gravità costante g diretta verso il basso ed ad velocità iniziale data dalla rotazione delle pale.

Lo studio della gittata massima degli elementi rotanti viene effettuato ipotizzando una condizione conservativa del moto in cui vengono trascurate le forze di resistenza che agiscono sulla pala.

Semplificare la trattazione del moto significa effettuare lo studio nelle condizioni peggiorative, poiché in assenza di forze viscose la condizione sopra definita è quella che dà la massima gittata. Ciò è vero finché si trascura la resistenza esercitata dall'aria sul corpo in movimento, che agendo in verso opposto alla velocità tende costantemente a diminuire la velocità del corpo.

Il moto reale è difficilmente schematizzabile in quanto dipende dalle caratteristiche aerodinamiche e dalle condizioni iniziali (rollio, imbardata e beccheggio) della pala, ma comunque, con le condizioni da noi ipotizzate, è possibile affermare di essere a favore di sicurezza.

Le ipotesi fatte in questo studio considerano il caso peggiore, ossia di distacco dal rotore con un angolo di 45° sul piano verticale, senza l'intervento di nessuno dei numerosi sistemi di sicurezza di cui sono provvisti gli aerogeneratori considerati. Si suppone dunque che l'eventuale rottura della pala avvenga nelle condizioni più gravose ovvero:

- alla velocità massima del rotore, pari a 15,38 giri/minuto;
- nel punto di ascissa e ordinata in cui la gittata è massima, con angolo = Π /4;
- con il centro di massa posizionato ad 1/3 della lunghezza della pala, in prossimità del mozzo.

La traiettoria iniziale è determinata principalmente dall'angolo di lancio e dalle forze generalizzate agenti sulla pala. La pala, quindi, quando inizierà il suo moto continuerà a ruotare (conservazione della quantità di moto). L'unica forza inerziale agente in questo caso è la forza di gravità.

La durata del volo considerato è determinata considerando la velocità verticale iniziale applicata al centro di gravità. Il tempo risultante è usato per calcolare la distanza orizzontale (gittata) nel piano e fuori dal piano. La gittata è determinata dalla velocità orizzontale al momento del distacco iniziale.

L'aerogeneratore delle dimensioni massime previsto, ossia tipo Enercon E138, possiede:

- altezza al mozzo dell'aerogeneratore H = 112 m;
- lunghezza della pala dell'aerogeneratore Lp = 69 m;
- distanza dal mozzo del Centro di Massa della pala R = Lp /3 = 23 m;
- Massima Velocità Angolare Rotore V_{ang} = 15,38 Giri/Minuto * 2 Π/60 = 1,61 Rad/sec.

L'ordinata di massima velocità y_0 al momento di rottura è data dalla somma dell'altezza del mozzo con la componente verticale del Centro di Massa:

$$y_0 = H + R * \sqrt{(2)}/2 = 128{,}2 \text{ m}$$

Analogamente l'ascissa di massima velocità x_0, al momento di rottura risulta:

$$x_0 = - R * \sqrt{(2)}/2 = -16{,}3 \text{ m}$$

La velocità lineare al Centro di Massa v è desunta dalla Velocità Angolare V_{ang}, ossia:

$$v = V_{ang} * R = 37 \text{ m/sec}$$

Le componenti verticale v_y ed orizzontale v_x di tale velocità lineare al Centro di Massa si ottengono conseguentemente:

$$v_x = v_y = v * \sqrt{(2)}/2 = 26{,}19 \text{ m/sec}$$

Il tempo di decelerazione verticale T_y necessario perché la componente verticale della velocità sia nulla è dato dalla formula:

$$T_y = v_y / 9,8 \text{ m/sec}^2 = 2,67 \text{ sec}$$

L'altezza massima Hmax raggiunta si ottiene dalla formula:

$$Hmax = y_0 + v_y * T_y - 1/2*g*T_y^2 = 163,2 \text{ m}$$

Il tempo di caduta Tmax necessario affinché l'elemento rotante precipiti a terra dalla sommità si ottiene dalla relazione:

$$Tmax = \sqrt{(Hmax / 4,9 \text{ m/sec}^2)} = 5,77 \text{ sec}$$

La gittata massima L percorsa dall'elemento rotante distaccatosi dall'aerogeneratore nelle condizioni più sfavorevoli risulta quindi:

$$L = v_x * (Tmax + T_y) + x_0 = 204,8 \text{ m}$$

Nei casi reali, l'impatto a terra sarà verosimilmente a distanze inferiori rispetto a quanto sopra stimato, sia per le condizioni iniziali al momento del distacco, che non necessariamente saranno quelle teoriche per una gittata massima, sia per i moti rotazionali della pala, dovuti ai momenti delle forze resistenti, che comporteranno ulteriori dissipazioni di energia e condizioni generalmente meno favorevoli per il moto.

Tuttavia si ritiene opportuno fare alcune considerazioni aggiuntive per tenere conto di elementi che determinerebbero un incremento della distanza massima raggiunta dalla pala, per la determinazione di una distanza massima più conservativa.

Aggiungendo i 46 m di lunghezza tra il baricentro (cui sono riferiti i calcoli) e la punta della pala, si ottiene un risultato di 250,8 m.

$$Lmax = 204,4 \text{ m} + 46 \text{ m} \approx 250 \text{ m}$$

Si ritiene, perciò, che **la distanza calcolata e ritenuta utile ai fini del layout di progetto sia estremamente cautelativa**.

6. INTERFERENZA CON STRADE E CASE

Riportando un cerchio di raggio 250 m in pianta si vede che nessuna strada sarebbe eventualmente coinvolta nel caso ipotetico e remoto di un distacco della pala (Figura 3).

Figura 3 - Lay-out e strade

Per quanto riguarda gli edifici (vedi Figura 4) si vede che nessuno è situato in un raggio di 250 m dalle turbine.

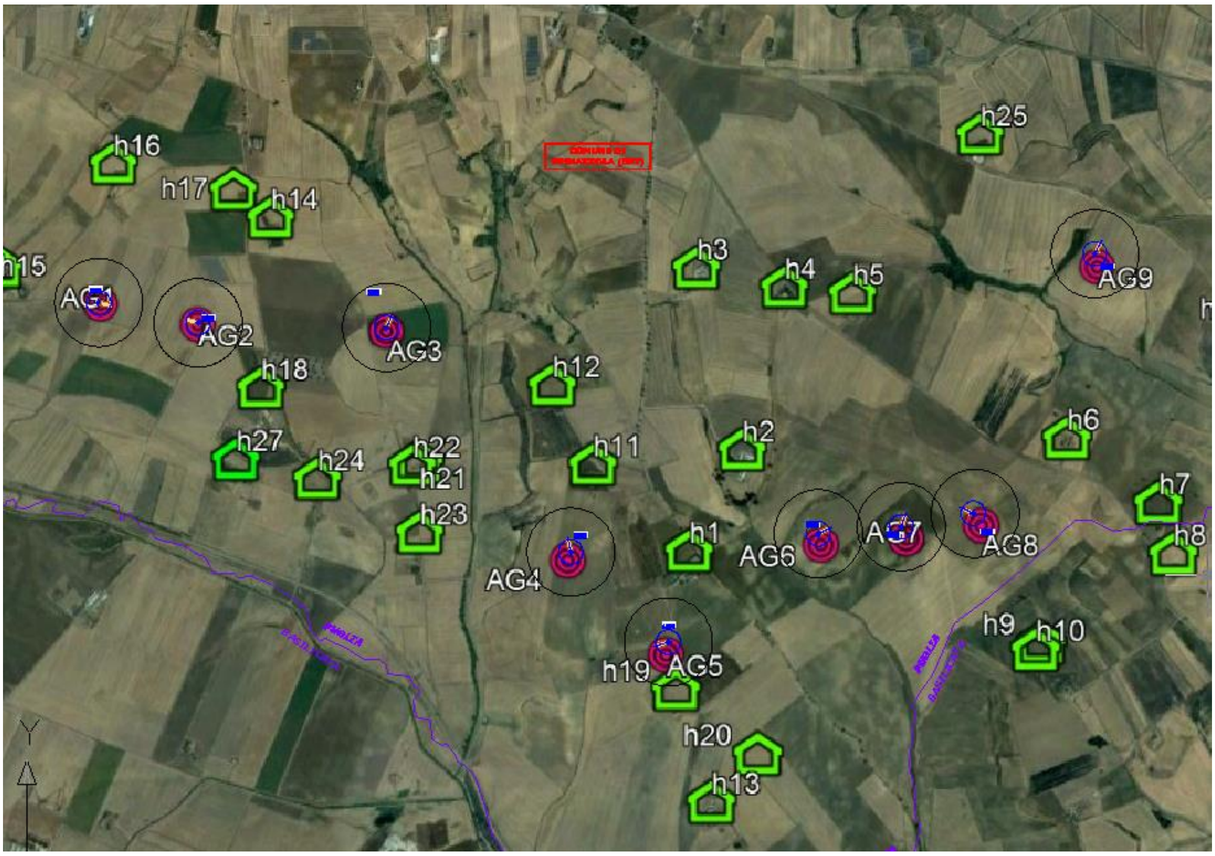

Figura 4 - Lay-out ed edifici

7. CONCLUSIONI

Premesso che la determinazione della reale distanza raggiunta da una pala distaccatasi dal rotore di un aerogeneratore è decisamente complessa a causa dell'influenza di un elevato numero di fattori, si è ottenuto un valore di riferimento con un modello semplificato ma conservativo, che tenesse conto di elementi significativi per la stima della distanza massima.

Dai calcoli condotti e dalle considerazioni e valutazioni svolte, si arriva alla conclusione che, per una macchina tipo Enercon E138, una pala che si distacchi in condizioni nominali di funzionamento arrivi a circa 250 m di distanza dalla torre.

Nessun edificio o strada è situato all'interno di un raggio di 250 m dalle turbine.

Si allega inoltre lo studio Vestas, Allegato 3, dal titolo "Calcolo della traiettoria di una pala eolica in condizioni nominali di funzionamento" (Giugno 2008), che arriva a valori di gittata paragonabili a quanto qui ottenuto.

8. ALLEGATI

- Allegato 1 – Repower: Product description;
- Allegato 2 – Repower: Maintenance manual;
- Allegato 3 – Vestas: Calcolo della traiettoria di una pala eolica in condizioni nominali di funzionamento.

REpower 3.0M122

[3.0M/122m/50Hz]

Product description

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Disclaimer

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Related documents

At the time the translation of this document was prepared, no English versions of the documents with German titles existed. The text in parentheses solely serves as an explanation and does not necessarily correspond with the actual titles of any later translations.

The documents listed in the following table do not simply become part of the agreement by being mentioned in this product description.

Title	Document no.
Electrical properties according to FGW	D-3.5-GP.EL.05-A-*
Electrical properties according to IEC	D-3.5-GP.EL.06-A-*
Fire safety REpower	SD-0.0-ES.EI-4-EN
General Information - Lightning protection, earthing and potential equalization	GI-2.5-EC.LP.01-A-A
Internal transformer system [3.XM/50Hz/Europe and Australia only] - Product description	PD-3.1-EC.TS.01-A-*
General Information – Particle counter	GI-0 0-WT SO 00-A-*
Standard conditions of use 3.0M122 [3.0M/122/50Hz]	SD-3.5-WT.SC.01-A-*
Standard grid conditions	SD-3.1-EC.GR.01-B-*

* The individual documents appear as contractual annexes in their respectively valid revisions as warranted by the project-specific selection of REpower products by the customer.

List of abbreviations and units

Abbreviation/unit	Explanation
DIBt	Deutsches Institut für Bautechnik
EMC	Electromagnetic compatibility
ETS	External transformer system
FGW	FGW e.V - Fördergesellschaft Windenergie und andere Erneuerbare Energien -
f_N	Nominal frequency
GRP	Glass-fiber reinforced plastic
GL	Germanic Lloyd
HV	High voltage (nominal grid voltage ≥ 60 kV)
IEC	International Electrotechnical Commission
IGBT	Insulated Gate Bipolar Transistor
ITS	Internal transformer system
I_N	Rated current
MV	Medium voltage (nominal grid voltage > 1 kV and < 60 kV)
n	Nominal speed
LV	Low voltage (nominal grid voltage ≤ 1 kV)
P_G	Nominal generator power
P_N	Nominal WEC power
PPE	Personal protective equipment
P_T	Nominal transformer power
RAL	Deutsches Institut für Gütesicherung und Kennzeichnung e. V.
SCADA	Supervisory Control and Data Acquisition
U_C	Agreed voltage, medium voltage (supply voltage)
U_N	Nominal voltage
WEC	Wind energy converter (wind turbine)

List of figures

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1. General information

The *REpower 3.XM* series is the latest REpower product platform for onshore wind turbines (WEC). It was developed on the basis of the continuous ongoing development and operating experience of more than 2000 installed wind turbines of the series MD and MM and the series 5M/6M. The development of the *REpower 3.XM* series is based without change on the advantages of the MD and MM series, such as ease of maintenance, conservative design loads and powerful components that are adapted to the distribution of forces, environmental friendliness and excellent grid properties.

The first product in the series is the *REpower 3.4M104.* This is a WEC with a nominal power of 3,370 kW on the medium voltage side of the transformer (corresponding to 3,400 kW on the low voltage side of the transformer). Another version in the series is the *REpower 3.2M114.* This is a wind turbine with a nominal power of 3,170 kW on the medium voltage side of the transformer (corresponding to 3,200 kW on the low voltage side of the transformer).

1.1 Technical design

After intensive analysis of existing and new turbine and component technologies the design of the series *REpower 3.XM* represents an evolutionary further development based on the experiences from the MD and MM series. The characteristics of the technical design of the *REpower 3.XM* are therefore:

- Variable generator speed control system with a six pole doubly-fed asynchronous generator (DIFG)
- Ease of maintenance
- Liquid-cooled converter system
- Transport requirements similar to those of 2 MW wind turbines (e.g., series REpower MM)
- Individual electric pitch adjustment with “fail-safe” design
- 3-point bearing of the drive train
- "Tilted cone" design and rotor blades pre-bent to the front for the best possible weight distribution and safe load transmission
- Reliable gearbox design
- Ladder-guided service-lift (Standard)
- Internal dry type cast resin transformer system with forced air cooling

2 Mechanical system

2.1 Rotor

The rotor consists of three rotor blades that are flange-mounted on the cast hub via a pivoted double row four-point contact bearing. The rotor blades can thus be adjusted along their linear axis via electrical pitch drives that rotate with the blades. The electrical blade pitch is used to limit the rotational speed of the rotor and the power output. Furthermore, the pitch system is the main brake of the WEC. In order to ensure the continued operation of the blade adjustment in the event of a power failure or malfunction, each blade has its own, independent storage battery set that rotates with the blade.

In the partial load range, i.e. when the WEC is operated below the rated power, the turbine works at a constant blade pitch and variable speed to exploit the optimum rotor aerodynamics. Within the nominal load area, i.e. when the WEC has reached its maximum rotor speed, it operates with a constant nominal torque which is given by the generator. Changes of the wind speed are controlled by the blade pitch. Wind energy from strong gusts can be stored by an acceleration of the rotor and only then converted into damped electrical energy via the blade pitch and fed into the grid.

The use of the “tilted-cone” concept with a 4° tilted blade connection on the hub and pre-bent rotor blades in conjunction with a 5° incline of the whole drive train allow an extremely short overhang of the nacelle between the rotor and the tower. This provides a good weight balance of the whole nacelle and a safe load transfer into the tower top without transmitting a high flux of force over a long distance via the main frame.

In case of a major component replacement near the drive train the rotor may remain in the wind turbine (see also chapter 2.2.2 drive train).

To assist with maintenance work at the rotor hub it is accessible directly from the nacelle through openings between the blade root connections.

Technical rotor data	
Rotor diameter	122.0 m
Swept area	11,690 m^2
Speed range	Approx 11.25 (+15 %) min^{-1}
Max. tip speed	72 m/s
Rotor axis inclination	5 °
Rotor cone angle	4 °
Sense of rotation	clockwise (right)
Rotor position	Up-wind

Table 1: Technical rotor data

2.1.1 Rotor blades

The blade design of the *REpower 3.0M122* combines a rigid structure, capable of even withstanding strong gusts, with a lightweight construction to minimize the transfer of forces onto the nacelle. This is made possible by using a sandwich construction from glass-fiber reinforced plastic (GRP) with the necessary material properties.

The rotor blades of the *REpower 3.0M122* have been adjusted with a view to a high aerodynamic efficiency and reduction of noise emissions.

A special blade coating protects them against the negative effects of UV radiation and moisture. To prevent erosion the blade leading edges are further protected by additional measures (e.g., anti-erosion film etc.).

The rotor blades are in the blade color light gray (RAL 7035), a bright standard color for the tower and the nacelle also. This reduces the effects of reflections without affecting the power characteristic of the *REpower 3.0M122*. The rotor blade can optionally have rotor blade markings applied.

Technical rotor blade data	
Number of rotor blades	3
Rotor blade length	59.8 m
Rotor blade material	Glass-fiber reinforced plastic (GRP) in sandwich construction
Rotor blade color	RAL 7035

Table 2: Technical rotor blade data

2.1.2 Blade Pitch system

The rotor blades are connected to the rotor hub via the blade bearings in a pivotable manner and can be adjusted individually around the longitudinal axis using the pitch system. For this purpose each rotor blade has its own pitch system. The co-rotating blade pitch drives are designed as DC motors and act via the planetary gearbox and pinion on the external gearing of the bearing.

A quickly operating synchronizing controller is used to synchronize the individual pitch systems. To ensure safe operation also during grid failure or a fault, each rotor blade has its own co-rotating battery set.

Technical blade pitch data	
Principle	Electric individual blade pitch
Power control	Blade pitch and speed control
Maximum blade angle	91 °
Pitch rate at safety shut-down	approx. 6-7 °/s
Pitch Drives	DC motors, battery-buffered, synchronized

Table 3: Technical blade pitch system data

2.2 Nacelle

To meet the demand for an innovative wind turbine, the nacelle of the *REpower* 3.0M122 has – as with all current REpower Systems wind turbines – been designed by a renowned designer. The result is an aerodynamically adapted design that, based on existing experience, offers improvements for service and maintenance. Maintenance can be performed with the nacelle closed, but it can also be partially opened for major component replacements.

The entry from the tower into the nacelle can be obtained via one hatch in the main frame. An additional maintenance platform has been installed to reach the components below the main frame.

The control cabinets of the converter system and the corresponding cooling system in the *REpower 3.0M122* are housed in the nacelle.

All systems can be operated via the control system from the nacelle. An emergency stop push-button has been installed for safety. All rotating/moving parts within the nacelle are generally protected by covers to prevent the risk of injury.

Glass-fibre reinforced plastic (GRP) has been chosen as material for the nacelle enclosure, as it offers a reliable protection and is lightweight. The nacelle enclosure also has the additional functions of noise insulation and maintaining the operating temperature.

2.2.1 Yaw system

The nacelle is connected to the tower via a four point contact bearing. The yaw system of the nacelle is provided by four electric gear motors. Hydraulic brake calipers hold the nacelle in the wind direction and the adjustment motors during idle free from loads that may e.g., result from an inclined air flow towards the rotor. In the de-energized state the brakes are engaged.

Electronic wind direction sensors with corresponding software control the activation times and the direction of rotation of the motors. They also ensure the automatic cable untwist if the wind turbine has rotated several times in the same direction during changed wind directions. If the yaw motors are active, the brakes are released.

Technical yaw system data	
Type	4 gear drives, 18 yaw brakes
Yaw rate	0.5 °/s
Bearing	Four point bearing with external toothing

Table 4: Technical yaw system data

2.2.2 Suspension Concept

The drive train is supported at three points immediately above the head flange of the tower. The fore side suspension is carried out by a generously dimensioned spherical roller bearing. The two other suspension points are the torque arms of the gearbox which are balanced by elastomer bushings. The three point suspension allows a safe load transfer along with a significant tolerance of the drive train alignment.

2.2.3 Gearbox

The gearbox has been designed as a planetary/spur gearbox. The toothing has been adjusted for efficiency and noise emission. The torque support of the gearbox is supported by elastic bushings on the main frame which rest on the main frame on pads. The elastic suspension permits effective noise and vibration decoupling from the main frame. The gearbox design was carried out in accordance with the REpower gearbox guidelines. These demand greater safety factors than e.g., the DIN/ISO or GL (Germanic Lloyd) guidelines.

Technical gearbox data	
Type	Three-stage planetary/spur gear
Nominal power	approx. 3,280 kW
Nominal torque	approx. 2,780 kNm
Gear ratio	approx. 106.5

Table 5: Technical gearbox data

2.2.4 Particle counter

The particle counter is a standard component in all REpower wind turbines (WEC).

The particle counter is a simple and highly efficient inline diagnosis sensor for identification of ferrous (FE) and non-ferrous (NFE) metal particles in the gear box oil lubrication system. Based on an inductive measuring principle it detects metal particles in the oil flow which indicate abrasion or other abnormal component behavior.

Using a particle counter, WEC operators can systematically monitor the gearbox's condition and proactively schedule appropriate actions to eliminate potential failures which might lead to a component failure. Hence, it is a cost-effective means to effectively ensure a high level of operational readiness at the lowest possible costs.

A detailed functional description of the particle counter is available in the document– Particle counter - general information, see also chapter "Related documents" in this document.

2.3 Tower

The tower has been designed as a hybrid tower (combination of concrete and steel tower). A door opening is provided in the tower base to allow for a weather-proof ascent inside the tower. The ascent to the nacelle is an integrated elevator system. Each tower segment is equipped with platforms and emergency lighting.

The transformer is located in the tower base and is protected against unauthorized access. The wind turbine can also be operated via a control display from the tower base. To make the ascent to the upper sections of the wind turbine safe and comfortable, there is the using an integrated elevator system.

The energy transmission within the tower takes place via shielded busbars that also contribute to minimizing electromagnetic interference.

Technical tower data	
Hub height*	136-139 m
Design	Concrete/steel tower
Diameter at the top flange	3.0 m
* The hub heights depend on the foundation design.	

Table 6: Technical tower data

2.4 Service lift

Each *REpower 3.0M122* is equipped with an elevator system. The elevator system may be used by max. two persons and may not exceed a maximum load of 250 kg. The ladder-guided elevator system has been designed for a comfortable transport as it contributes to a lower fatigue for the service personnel and thereby assists in maintenance work.

The ascent and descent with the elevator system are via a stop/go push-button system using a dead man's switch installed in the elevator system. Automatic operation is also possible for the transportation of materials and tools. In addition to the top tower platform below the nacelle, all other internal platforms, such as the lowest level above the electrical system, are accessible via the elevator system. The elevator cables and safety cables are connected to the cross bracing at the top of the tower.

3 Electrical system

3.1 Principle of operation

The system is equipped with a variable speed generator/converter system. This facilitates an operation of +/- 40 % of the synchronous speed. The variable speed operation offers in connection with the electric pitch system very good results with regard to energy yield, efficiency, mechanical load, and quality of the power output. The system prevents overvoltages and load peaks to the best possible extent. The generator control enables an even power output with minimum fluctuation during partial load operation. During nominal load operation the wind turbine power output is almost constant. The principal ability to generate reactive power facilitates the targeted reactive power management in accordance with the requirements of the customer and the grid operator through optional products.

The principle of operation of this variable speed generator is based upon the concept of the asynchronous doubly-fed induction generator with a converter using IGBT technology. The system ensures the continuous power output by means of voltage and frequency values that have been adapted to the grid independently from the rotor speed. Speed and power adjust automatically to the prevalent wind conditions. The wind turbine is accordingly operated in the following operating ranges:

The generator supplies 100% of the electrical power to the energy supply grid in the sub-synchronous range (partial load range). Slip power which is fed from the generator via the slip rings of the generator to the rotor is provided additionally.

- The generator directly supplies approx. 83 % of the electrical power to the energy supply grid in the super-synchronous range (nominal load range). Management via the converter is not required in that context. The remaining approx. 17 % of the power is fed from the rotor via the converter into the energy supply grid.

Besides many other system benefits, the low losses, permitting a high total efficiency, and the excellent availability, resulting from the compact design with a minimum number of components, should be mentioned.

3.2 Technical data of the medium voltage side of the wind turbine

3.2.1 Standard wind turbine configuration

The *REpower 3.0M122* standard design has been defined as shown in *Table 7: Standard configuration, medium voltage side of the wind turbine*

Parameter	Value
Nominal power	P_N = 2,970 kW (MV side)
power factor	cos φ ~ 1
Nominal voltage (medium voltage side)	10 kV / 20 kV / 30 kV
Terminal voltage range (medium voltage)[1] of the wind turbine (cos φ = 1)	90 % ≤ U_N ≤ 110 %
Nominal frequency	50 Hz
Nominal current at cos φ = 1 and nominal voltage	I = 171 A [10 kV] I = 86 A [20 kV] I = 57 A [30 kV]
Nominal generator speed	n = 1,200 RPM

Table 7: Standard configuration, medium voltage side of the wind turbine

The REpower wind turbine remains connected to the grid during stationary operation even with frequency fluctuations between 47.5 Hz and 52.0 Hz within a permissible voltage range. In the frequency range of 47.0 Hz to 47.5 Hz the REpower wind turbine also remains connected to the grid for max. one minute. Figure 1 is a graphic depiction of both the stationary and dynamic frequency range in relation to the active power.

[1] The automatic tap changer of the wind farm transformer must ensure that the grid voltage does not drop below the nominal voltage for prolonged periods of time. If the nominal voltage is constantly undercut, the electrical power output may be reduced.

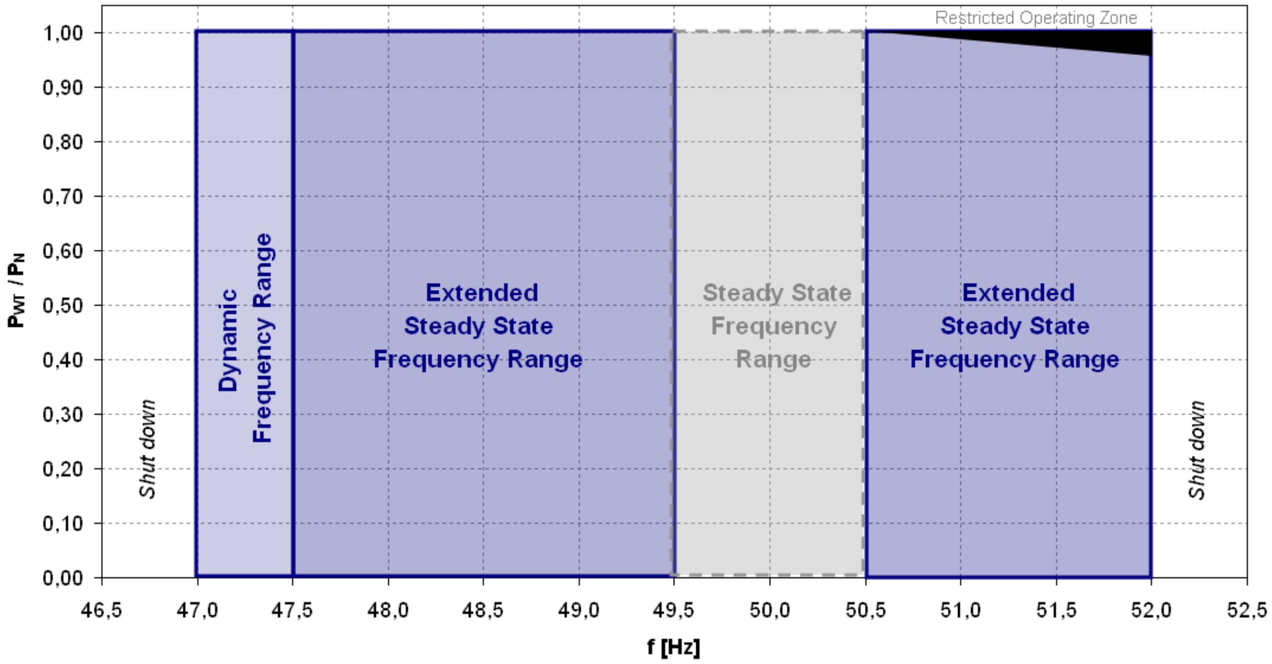

Figure 1: Steady State & dynamic frequency range

The standard protection configuration for the wind turbine for minimum and maximum frequencies are adjustable parameters that can be chosen in accordance with the permissible ranges shown in figure 1.

Within the "restricted operating zone" (black area in figure 1) the active power output might be reduced. The reactive power range of the wind turbine can be limited in the extended stationary and dynamic frequency range. During extreme situations a disconnection from the grid is possible.

The capability and control options of the wind turbine or wind farm can be extended by adding optional *REpower grid products* and/or *REguard products* to contribute to compliance with project-specific grid requirements and control the wind farm as a power plant.[2]

The electrical properties of the REpower 3.0M122 are defined in the documents "Electrical properties according to FGW" and "Electrical properties according to IEC", see chapter "Related documents" in this document.

The values in table 7 can be maintained if the grid quality matches the parameters specified in the document “Standard grid conditions", see "Related documents" in this document.

[2] The corresponding values from table 7 and table 8 change when adding optional products.

3.2.2 Standard wind turbine grid protection

The grid protection of the control system measures the current and voltage in each phase, guaranteeing a three-phase grid monitoring. The grid monitoring analyzes the currents, voltages and time graphs to disconnect the generator and converter from the grid for their own protection as soon as one of the events listed in table 8 occurs.

Trigger criterion	**Typical trigger value**	**Comment**
Over voltage [U >] (symmetrical/asymmetrical)	$1.1*U_N$	Setting values shall be defined together with the responsible network operator
Under voltage [U <] (symmetrical/asymmetrical)	$0.90*U_N$	Setting values shall be defined together with the responsible network operator
Over Frequency [f >]	50.5 Hz	Setting values shall be defined together with the responsible network operator
Under Frequency [f <]	49.5 Hz	Setting values shall be defined together with the responsible network operator
Max. current asymmetry	10 A	Trigger period ≤ 5 s
Phase shift	± 6 °	without delay

Table 8: Standard grid protection configuration on the medium voltage side of the wind turbine

The standard grid protection configuration can be adjusted project-specific dependent on the additionally acquired *REpower grid products*.

After one of the events in table 8 occurs, the wind turbine automatically re-synchronizes with the grid as soon as it is available again.

3.3 Main electrical components

3.3.1 Generator

Technical generator data	
Concept :	Asynchronous double-fed generator with rotor power recovery to the grid via the frequency converter. The stator winding is synchronised to the low-voltage side, and is connected directly to the grid with a soft cut-in.
Speed range:	n = 650 to 1200 rpm (dynamic up to 1400 rpm) To each speed a specific maximum power value is assigned whose average value may not be exceeded for design reasons.
Design:	Six pole, 3 phase slip ring induction generator
Model:	IM B3 according to DIN IEC 60034 code I IM 1001 according to DIN IEC 60034 code II
Size:	630
Protection class:	IP 54 (slip ring: IP 23)
Cooling:	Cooling via air/air heat exchanger. Cooling air flow is generated by an external fan. Cooling air induction from the nacelle.
Sensors:	PT 100 to monitor the bearingtemperature PT 100 to monitor the windingtemperature Brush wear warning
Miscellaneous:	Covers prevent the contact with rotating components. Grounded generator housing to prevent static charges. To minimize vibration and noise emissions the generator is supported on the main frame on sound and vibration decoupled elements.

Table 9: Technical generator data

3.3.2 Converter

Technical converter data	
Concept:	Frequency converter for double-fed induction generator with DC link.
Operating mode:	Control/regulation of active and reactive power. Recovery of the rotor power via the generator and converter on the grid side inverter.
Power transistor	IGBTs
Protection class:	IP 54, induction field: IP 21
Cooling:	Air flow cooling of the converter housing. Liquid cooling system for IGBTs.

Table 10: Technical converter data

3.3.3 Transformer system

The transformer and the medium voltage switchgear are installed inside the tower. For the customer this has the advantage of no further planning permissions being required for an additional building.

For further details please see the document “Internal Transformer System [3.XM/50Hz]”.

3.4 Own consumption

The own consumption of the wind turbine in standby mode is made up of the individual consumption of the following components:

- Control system (control computer and converter)
- Yaw system
- Hydraulic pump
- Heating for gearbox, generator and control cabinets
- Battery charger
- Pitch drive during different operating states
- Obstacle light

The own consumption is approx. 40 kW (10 minute average value). The requirement depends largely on the installation location of the wind turbine. The own consumption is particularly high if the wind speed is less than 4 m/s whilst temperatures are below freezing. Consumption values may differ by several units dependent on location, near the coast or further inland. As a rough estimate between 8300 and 16,000 kWh per annum may be assumed for locations with average wind speeds, with up or down deviations possible. These details do not take the requirement of connected components (e.g., transformer, auxiliary units and medium and low voltage cabling) into account.

4 Safety device

4.1 General safety

As all REpower wind turbines the *REpower 3.0M122* has been designed with a view to highest operational safety. This generally includes:

- aerodynamic brake in fail-safe design through independent individual pitch adjustment
- control-independent safety chains
- protection against the escape of fluid through labyrinths and collection containers
- covers for rotating components in the machine to protect individuals
- generous space in the nacelle for maintenance and service
- access to the rotor hub from inside the nacelle

4.2 Brakes

Braking is aerodynamic by moving the rotor blades into the 90° position. Each individual adjustment device of the three rotor blades operates entirely independently. In case of a grid failure the adjustment motors are supplied by their independent battery sets.

The movement of a single rotor blade is sufficient to move the wind turbine into a safe speed range. This results in a triple redundant system.

The secondary brake system is a mechanical disk brake that is also engaged if one of the primary safety systems fails and thus ensures the safe stoppage of the rotor in conjunction with the blade pitch.

The brake systems are designed as fail-safe systems. This means that if only one of the brake system components fails or malfunctions the wind turbine immediately moves into a safe state.

4.3 Lightning protection

The wind turbine is equipped with a lightning protection system designed by lightning protection experts and complies with protection class 1 required by the international standard IEC 61400-24 Edit.1 “Wind turbines - section 24: lightning protection" and IEC 62305-1 "Lightning protection - paragraph 1: General". The discharge is from the rotor over slip rings and dischargers on the tower. This way, the current of the bolt of lightning is discharged via foundation and/or deep grounding mechanisms into the ground.

5 Control system

5.1 Cut-in/out strategy

The design parameters for the wind turbine operation are within the range of the following 10 minute average values of the wind speed:

Cut-in/out strategy	
Cut-in wind speed	3.0 m/s
Rated wind speed	approx. 11.5 m/s
Cut-out wind speed	22.0 m/s

Table 11: Cut-in/out strategy

5.2 Control system

The control system *REguard Control B* permits an integration of the *REpower 3.0M122* into the REpower SCADA system *REguard*. *REguard Control B* is a microprocessor-based control system. Optical fibers are used for signal transmission. The wind turbine must be equipped with *REguard Monitoring Advanced* or *Professional* as default. *REguard Monitoring* permits the direct access to the control system *REguard Control B* and other *REguard* components installed at the location, such as *REguard Power Management Unit* or *REguard Meteo Station.* Dependent on the user access level *REguard Monitoring* visualizes current operating data as well as data saved on the control device.

The control device is installed in the nacelle. An additional display permits operational control from the tower base.

Technical control system data	
Principle	Microprocessor
Signal transmission	Optical fiber
Remote monitoring	REguard Monitoring

Table 12: Technical control system data

5.3 Measures in case of ice accretion

As ice accretion on wind turbines, especially on rotor blades, may lead to an increased hazard to the environment, different measures can to be taken in order to reduce this hazard caused by ice throw.

5.3.1 Ice Detection

REpower wind turbines are equipped with a redundant and state-of-the-art ice detection system as assessed by TÜV Nord, which enables the turbine operating system to detect ice during operation as well as during stand still. This is realized by the following means:

- Comparison measurement of anemometers
- Analysis of the measured values during turbine operation
- Wind turbine protection by vibration monitoring

These monitoring functions trigger status codes in REpower's turbine control system.

5.3.2 Turbine behaviour in case of ice detection

In case of ice detection the wind turbine automatically shuts down. The restart of the turbine is conducted automatically when icing conditions can be excluded.

If the absence of ice has been reported after a visual on-site inspection, it is also possible to restart the turbine manually under specific conditions.

Shutdown and restarting of the wind turbine are recorded in the operating computer's event protocol and are available for subsequent verification purposes.

The configuration of Repowers measures in case of ice accretion can be adapted turbine specifically in case an annual wind turbine site assessment has been carried out and the resultant risk class allows different turbine behaviour.

6 Dimensions and weights

The *REpower 3.0M122* has been generally designed for ease of transport and erection. For this reason the weights are roughly within the range of the REpower MM series. The option to install, and where necessary transport, the nacelle and drive train separately permits the use of comparable crane equipment as for the wind turbines of the 2 MW class (e.g. REpower MM series).

6.1 Weights

Weight	
Rotor blade:	approx. 15 t
Rotor hub (incl. pitch system):	approx. 23 t
Nacelle (excl. rotor and drive train):	approx. 55 t
Drive train	approx. 52 t

Table 13: Weight

6.2 Dimensions

Rotor blade dimensions	
Length:	approx. 59.8 m
Height:	approx. 4.0 m

Table 14: Rotor blade dimensions

Rotor hub dimensions	
Diameter:	approx. 4.2 m
Height:	approx. 3.8 m

Table 15: Rotor hub dimensions

Nacelle dimensions	
Length	approx. 13 m
Height	approx. 4.2 m
Depth	approx. 4.3 m

Table 16: Nacelle dimensions

Drive train dimensions (rotor, bearing, shaft and gearbox)	
Length:	approx. 6.9 m
Height:	approx. 3.4 m
Depth:	approx. 3.1 m

Table 17: Drive train dimensions

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REpower Systems

REpower 3.XM

Wind Power Turbine

Maintenance manual

Original

Change Index

Revision	Date of Issue	Replaces Following Pages	Changes
A	2008-08-28	All	First issue of the maintenance manual (only German)
B	2010-01-29	All	Tower for 96,5-100m HH added, first English version

Other Applicable Documents

Designation	Document no.	Revision no.	Date of Issue

General

Regular maintenance in accordance with the maintenance manual is absolutely essential in order to maintain the operating safety of the system.

Maintenance work may only be performed by properly trained personnel. Appropriate technical qualifications, as well as instruction provided by the manufacturer of the wind power plant, are required.

After maintenance and inspection have been completed, system approval must be confirmed by maintenance personnel in the maintenance report.

Personal Safety

The safety precautions included in the operating instructions must always be adhered to!
Observe the 5 safety rules for electrical devices

- Isolate power
- Secure against re-connection
- Check whether the equipment is voltage-free
- Earth and short-circuit the equipment
- Any adjacent live parts are to be covered or to be blocked off

Maintenance Tasks

The maintenance tasks are described in the maintenance manual. All maintenance tasks must be properly executed and documented. Drive and power transmission components, as well as safety equipment functions, must be tested at least once every two years by a recognised expert. This deadline can be extended to 4 years, if the operating company enters into a maintenance contract with the manufacturer or a suitable maintenance service provider, and if the respective contractor executes the maintenance tasks in a responsible fashion.

Individual maintenance and inspection tasks for the various components are defined in the maintenance manual. Dimensions, limit values and setting values which must be adhered to be specified.

Proper execution of each task must be confirmed by maintenance personnel. In the case of significant deviations, the REpower Service Department must be informed.

The tightening torques and test torques of all relevant screw connections are listed, which must be checked during the performance of maintenance work. Screws may only be tightened with a calibrated torque wrench!

All listed screw connections must be tested during initial maintenance one month after initial start-up.

During subsequent semi-annual maintenance procedures, all screw connections must be subjected to careful visual inspection and tightness testing. Certain connections must also be tightened in accordance with a specified pattern. In this case, testing is restricted to the specified number of screws. **Screws which have been tested by means of tightening must be identified.** At the next maintenance interval, the other screws must be tested.

Perform **visual inspection and test tightness** of all screws within the assembly means to test visually and manually if the screw is loose.

If any of the tested screws do not meet the required tightness specification, all of the screws of the affected connection must be tested.

Screw connections are secured using a lubricant which demonstrates a friction coefficient μ_{tot} of 0.08 (e.g. Molykote G-Rapid plus). When individual screws are replaced, it must be assured that a lubricant with the same friction coefficient is used. **Screw connections with remark "Delivery Condition" in column "Lubrication" are pre lubricated delivered. The delivery condition must not be modified.**

Required lubrication tasks are also included for all components which require regular lubricant inspection. Lubricant types and required quantities are listed.

Attention: The utilised lubricants and their manufacturers are included in the lubrication schedule for each respective system. The use of other lubricants without approval from the system manufacturer is impermissible, because incorrect lubricants, or mixing different lubricants, may result in significant damage to the affected components!

Escaped lubricants must be removed and disposed of in an environmentally friendly manner on principle.

last revision index:	Maintenance no.:	Maintenance work	Interval		Notes / description / desired values					Maintenance evaluation				
		Caution: Locked electrical operating establishment. Access is restricted to skilled electricians or individuals with electrical training, and untrained individuals must be accompanied by one of the aforementioned trained professionals.	1st month x	1/2 yearly or annually■	**Screw tightening torques**					Inspection of test items without	Inspection of test item with problem (please describe)	Problem remedied	Inspector	Date
					Number of ( ) total	Screw (nut)	Lubrication Molykote (μ=0.08)	Tightening/ check torque [Nm]	Spanner size fixed wrench = S, Allen = I					
					Lubricant									
					Medium	Filling volume	Notes							
	1	**General controls**												
	1.1	Corrosion/cracks/damage	x	o	**If cracks/damage is found in the support structures, decommission the wind turbine and inform REpower Service.** Especially on the main frame 3.XM carry out a visual inspection for cracks at the following locations: A. Near gearbox torque support: attachment of the three cross-bars to the bottom of the top straps B. Near rotor bearing: inclination of the inside plates towards the bottom plate **In case of corrosion immediately repair the faulty areas in accordance with the paint specification**									
	1.2	Leakage, water ingress	x	o	Establish causes, dry and seal the areas (paneling, control cabinets)									
	2	**Rotor blades (general)**												
	2.1	Blade surface, blade tip, receptor	x	o	Surface inspection with magnifying glass for: 1. smoke residue 2. chippings, bubbles 4. general condition 4. erosion			1st blade number:	Condition:					
								2nd blade number:	Condition:					
								3rd blade number:	Condition:					
	2.2	Lightning arrester elements	x	o	Check for tight fit, fractures, corrosion, transition between blade and lightning arrester, blade interior									
	2.3	Lightning counter cards	x	o	If available, label and replace 3 x lightning counting cards (evaluation of the cards during service), if lightning strikes were recorded the blade tip must be inspected for damage.									
	3	**Rotor blade bolts**												
	3.1	Rotor blade RE 50.8 3 x Rotor blade - blade bearing 1st semi-annual maintenance: 3 x 96 bolts subsequent maintenance: 3 x 12 bolts	x		All (3 x 96)	ISO 4032 M30-10	Molykote and Delta Tone, Delta Seal GZ	1st stage: 235Nm 2nd stage: 180°	46 S					
					Loosen nut, clean thread and contact surface and lubricate generously with Molykote, tighten nut with 235Nm, turn nut another 180°									
				o	3 x 96 3 x 12	ISO 4032 M30-10	Molykote and Delta Tone, Delta Seal GZ	1150Nm	46 S					
	4	**Blade bearings**												
	4.1	Blade bearing condition incl. gearing cover	x	o	Check the condition and the tight fit of the cover. Check brushes for condition and tight seat, replace brushes if necessary. Open upper shell of console cover and carry out visual inspection of gearing and seal. Check for cracks, porosity, leakage.									
	4.2	3 x blade bearings - rotor hub	x		all (3 x 104)	M30-10.9	Molykote G-Rapid plus	1365 / 1400	46 S					
			every 2 years		3 x 13									
				o	Carry out visual and tightness inspections of all screws in the connection									

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		Caution: Locked electrical operating establishment. Access is restricted to skilled electricians or individuals with electrical training, and untrained individuals must be accompanied by one of the aforementioned trained professionals.	1st month x	1/2 yearly or annually ■	**Screw tightening torques**					Inspection of test items without	Inspection of test item with problem (please describe)	Problem remedied	Inspector	Date
					Number of ( ) total	Screw (nut)	Lubrication Molykote (µ=0.08)	Tightening/ check torque [Nm]	Spanner size fixed wrench = S, Allen = I					
					Lubricant									
					Medium	Filling volume	Notes							
	4.3	Tracks (automatic self-lubrication system)		o	Lubricate in accordance with lubrication schedule	approx. 6 kg (incl. filling volume for gearing)	If the lubrication grease consumption differs, check pump actuation If lubrication grease consumption is too low, also check whether a red pin is visible in the pressure valve; in this case the lubrication line is blocked. Replace full or damaged grease receptacles.							
	4.4	Gearing (autom. self-lubrication systems)	x	o	Lubricate in accordance with lubrication schedule	as required (for manual relubrication)	Check whether the teeth of the self-lubrication system in the adjustment range (0 - 90°) are coated completely, otherwise see item 4.3 Check pump. Manually re-lubricate the remaining range (90 - 360°) for corrosion protection if necessary							
	5	**Pitch system**												
	5.1	Blade pitch gearbox oil level check		■	Move gearbox into horizontal position (rotor blade on the left when facing the rotor) Unscrew oil level inspection plug. The oil level must reach up to the bottom edge of the thread (obsolete if no oil escapes visibly from the gearbox, also inspect rotary shaft seals towards connection to motor using inspection holes, see also item 5.3)									
	5.2	Blade pitch gearbox oil change	every 5 years		Refill volume [in liters]:		1:	2:	3:					
					Oil	approx. 3x7.5 liters	Oil type according to oil label on the gearbox.							
	5.3	E motor gearbox seal		o	If an inspection screw is present: seal replacement required if after loosening the lock screw oil escapes from the cap.									
	5.4	Pitch motor fan operation		o										
	5.5	Pitch motor carbon brush check	every 2 years		Minimum gap brush spring to brush guide: 3mm. If necessary replace the carbon brushes in accordance with the instructions of the system supplier (manual)									
	5.6	Limit switch 95° function	x	o	Actuate manually, evaluate message log and reset status, check switch for tight fit.									
	5.7	Voltage monitor for pitch batteries	x	■	Check and, if necessary, adjust the voltage monitors for the pitch batteries in accordance with TO 001.									
	6	**Rotor hub**												
	6.1	3 x blade pitch gearbox - rotor hub	x		All (3 x 30)	M16-10.9	Molykote G-Rapid plus	200 / 210	24 S					
			every 2 years		3x4									
				o	Carry out visual and tightness inspections of all screws in the connection									
	6.2	6 x converter box - rotor hub	x		All (6x6)	M16-8.8	Molykote G-Rapid plus	135 / 141	24 S					
			every 2 years		6x2									
		Elastomer bearing	x	o	Carry out visual and tightness inspections of all screws in the connection									
	6.3	Main box - rotor hub	x		All (6)	M16-8.8	Molykote G-Rapid plus	135 / 141	24 S					
			every 2 years		2									
				o	Carry out visual and tightness inspections of all screws in the connection									
	6.4	Spinner star - rotor hub	x		All (12)	M20-8.8	Molykote G-Rapid plus	280 / 293	30 S					
			every 2 years		3									
				o	Carry out visual and tightness inspections of all screws in the connection									

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		Caution: Locked electrical operating establishment. Access is restricted to skilled electricians or individuals with electrical training, and untrained individuals must be accompanied by one of the aforementioned trained professionals.												
	6.5	Rear spinner holder	x		All (18)	M16-8.8	Molykote G-Rapid plus	135 / 141	24 S					
			every 2 years		3									
				o	Carry out visual and tightness inspections of all screws in the connection									
	6.6	Blade bearing cover, console - rotor hub	x		All (12)	M10-8.8	Molykote G-Rapid plus	36 / 38	17 S					
			every 2 years		10									
				o	Carry out visual and tightness inspections of all screws in the connection									
	6.7	Blade bearing cover - rotor hub	x		All (30)	M12-8.8	dry	89 / 93	19 S					
			every 2 years		10									
				o	Carry out visual and tightness inspections of all screws in the connection									
	6.8	Rotor hub - rotor shaft	x		All (96)	M42-10.9	Molykote G-Rapid plus	4200 / 4400	65 S					
			every 2 years		20									
				o	Carry out visual and tightness inspections of all screws in the connection									
	7	**Rotor bearing (240/1120)**												
	7.1	Empty lubrication grease collection area	x	o	Visually inspect escaped lubrication grease. In case of abnormalities take a sample for examination. Caution: Discharged lubrication grease must be disposed of properly									
					Discharged volume of lubrication grease	Condition of the lubrication grease: Color	Soiling	Consistency						
					approx. Kg									
	7.2	Rotor bearing self-lubrication system (refill lubrication grease)		o	Lubricate in accordance with lubrication schedule	approx. 2 kg	If the lubrication grease consumption differs, check pump actuation If lubrication grease consumption is too low, also check whether a red pin is visible in the pressure valve; in this case the lubrication line is blocked.							
	7.3	Check the lightning protection mechanis	x	o	Visual inspection of the brushes and spark gaps, min. brush length = 20mm, replace if necessary Inspection of the contact surface, spring force and tight fit Visual inspection for pitting in the brush tracks of the rotor disk									
	7.4	Bearing housing - main frame	x		All (16)	M42-10.9	Molykote G-Rapid plus	3770 / 3960	65 S					
			x		All (4)	M48-10.9		5670 / 5954	75 S					
			every 2 years		4									
				o	Carry out visual and tightness inspections of all screws in the connection									
	8	**Rotor lock**												
	8.1	Locking bolt		o	Lubrication grease	as required	Grease until fresh lubrication grease is discharged; move the locking bolt in and out over its full stroke							

last revision index:	Maintenance no.:	Maintenance work	Interval		Notes / description / desired values					Maintenance evaluation				
		Caution: Locked electrical operating establishment. Access is restricted to skilled electricians or individuals with electrical training, and untrained individuals must be accompanied by one of the aforementioned trained professionals.	1st month x	1/2 yearly or annually ■	**Screw tightening torques**					Inspection of test items without problem	Inspection of test item with problem (please describe)	Problem remedied	Inspector	Date
					Number of ( ) total	Screw (nut)	Lubrication Molykote (μ=0.08)	Tightening/ check torque [Nm]	Spanner size fixed wrench = S, Allen = I					
					Lubricant									
					Medium	Filling volume	Notes							
	9	**Gearbox**												
	9.1	Oil level check	x	o	Eickhoff: check at the level indicator. The filling level should reach up to the center of the oil level indicator (to be checked at rest 4h after switching off the wind turbine whilst at operating temperature).									
	9.2	Oil change	every 3 years		Oil	approx. 580 liters)	Filling level in accordance with item 9.1							
					If the values from the oil analysis do not correspond to the oil manufacturer specifications, a second sample must be taken. Only if the second sample confirms the results of the first sample should an oil change be carried out.									
	9.3	Take an oil sample for oil analysis		o	**Only use oil sampling containers from Wear Check** Oil samples must be taken from the drain cock of the Internorm filter block. Flush prior to sampling (min. 4 x, approx. 500ml in total), label sample taken, only use specified containers, ensure cleanliness during and after sampling. Give oil samples to the responsible master service technician or coordinator. **See also TO 021 Rev.: B "Instructions for oil sampling at the main gearbox".**									
	9.4	Check ventilation filter		■	**Mahle paper filter:** Visual inspection for condition, replace if necessary **Anselm oil bath filter:** For the oil change loosen the 3 pan head screws M4 x 8mm at the top filter cover and remove the cover. If necessary unscrew the filter from the gearbox using the 3 assembly holes offset by 120° and dispose of the oil. Refit the filter to the gearbox using Teflon tape near the threat and fill with fresh gear oil up to the oil level marking. The filling level marking is visible in the bevel screwed into the filter. Overfilling does not cause any harm. Refit the filter cover.									
	9.5	Elastomer bearing	x	o	Check for cracks, separations and abrasion, deformation									
	9.6	Grounding	x	o	Check the grounding for tight fit									
	9.7	Gearbox shaft (Eickhoff)	x		All (30)	M48-10.9	Delivery condition	5670 / 5954	75 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
	9.9	Gearbox bearing support - main frame	x		All (4 x 4)	M48-10.9	Molykote G-Rapid plus	5670 / 5954	75 S					
			every 2 years		2x2									
				o	Carry out visual and tightness inspections of all screws in the connection									

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					Number of ( ) total	Screw (nut)	Lubrication Molykote (μ=0.08)	Tightening/ check torque [Nm]	Spanner size fixed wrench = S, Allen = I					
					Lubricant									
					Medium	Filling volume	Notes							
	9.10	**Oil cooling and filter circuit**												
	9.10.1	Check oil filter (full flow filter)	x	o	**Replace filter insert either annually or no later than 10 days after the corresponding status message** Replacement: open filter housing and remove filter. Caution: hot oil! Open the drain plug at the filter housing and allow the remaining oil to drain. Check for chipping etc. in the sump of the filter housing. Insert the new filter and screw housing back together.									
	9.10.2	Condition of hoses Condition of pipes and threaded joints	x	o	Visual inspection of attachment and for damage, in particular check condition of the hoses (damage / abrasion of the hose walls and hose band clips) **Replace if necessary**									
			every 6 years		Replace the hose of the oil cooling and filtration system									
	9.10.3	Check for leaking oil	x	o	Seal the systems. Remove any discharged lubricants and clean the turbine!									
	9.10.4	Fan		o	Check fan operation and visual inspection of the cooler for soiling If necessary clean contamination from cooler with hand brush or vacuum cleaner!									
	10	**Slip ring unit**												
	10.1	Condition of slip ring unit	every 5 years		**Preparation:** Ensure a clean environment (clean if necessary), ensure adequate ventilation, place rotor lock, disconnect (400V pitch, pitch lighting, pitch UPS), remove plug on stator side, remove torque supports, open inspection cover **360° visual inspection:** If necessary clean sliding tracks with detergent XZ3-1 (Dietrich item no. 810033), observe instructions on the spray bottle, move inspection cover to 6 o'clock (180°), excess detergent must drain off, explosive gases must escape, allow sliding tracks to dry **Re-oiling:** Re-oil with spray oil (Dietrich item no. 081281), spray slip rings and wires in the positions 0°, 90°, 180°, 270° for approx. 1 sec per slotted hole, observe instructions on spray bottle, for degassing leave 10 min, each in the 12 o'clock position and 10 min. in the 6 o'clock position (with open inspection cover)									
			all											
			every 10 years		Revision replacement of the complete slip ring unit or revision of the complete slip ring									
	11	**Safety brake (active brake)**												
	11.1	Brake disk surface	x	o	Check for cracks, grooves, nicks									
	11.2	Brake pad surface and thickness	x	o	Remove brake pads and inspect, then continue with 11.3 or 11.4 (record pad thickness)									
	11.3	Replace brake pads	as required		Minimum brake pad thickness: SIME - BCH 85 CRT: up to 2mm remaining pad thickness			Actual brake pad value: SIME - BCH 85 CRT: __________mm						
	11.4	Visual inspection of brake calipers Check for leaking oil	x	o	Seal the systems. Remove any discharged lubricants and clean the turbine!									
	11.5	Brake caliper - gearbox	x		All (16)	M24-10.9	Molykote G-Rapid plus	760/800	36 S					
			every 2 years		4									
				o	Carry out visual and tightness inspections of all screws in the connection									

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					Number of ( ) total	Screw (nut)	Lubrication Molykote (µ=0.08)	Tightening/ check torque [Nm]	Spanner size fixed wrench = S, Allen = I					
					Lubricant									
					Medium	Filling volume	Notes							
	12	**Coupling (general)**			**Designation of the fitted coupling: (attach designation visibly near the coupling / cover)**									
	12.1	Condition of the coupling	x	o	Check for cracks in the paint, deformation or fracture of the lamellae, damage to the insulation pipe, if necessary take pictures									
	12.2	Condition of the sliding hub (intermediate tube area)	x	o	Check for torsion, chipping and heat effects									
		Coupling RADEX-N 300 specific drawing no.: 466029 Manufacturer: KTR												
	12.3	Coupling hub - sensor disk	x		All (1)	M16-10.9	dry	290 / 305	14 I					
		Sliding hub connection to gearbox	x		All (12)	M24-10.9	Delivery condition	840 / 880	19 I					
		Sliding hub connection to generator	x		All (12)	M24-10.9	Delivery condition	840 / 880	36 S					
		Coupling lamellae	x		All (12)	M24-10.9	Delivery condition	840 / 880	36 S					
		Intermediate tube connection	x		All (24)	M16-10.9	Delivery condition	250 / 260	24 S					
				o	Visual and tightness inspections of all screws of the connections									
		Coupling ARPEX- ARV-6 KRZ - drawing no.: ARV06-0520-1000 Manufacturer: Flender - Atec												
	12.4	Coupling hub - sensor disk	x		All (8)	M8-10.9	Delivery condition	30 / 32	13 S					
		Coupling lamellae (locking screw)	x		All (2x 6)	M16-8.8	Loctite 243	170 / 180	24 S					
		Coupling lamellae (clamping bolt)	x		All (2x 6)	M16-10.9	Loctite 243	250 / 260	24 S					
		Sliding hub connection to gearbox	x		All (12)	M16-10.9	Delivery condition	250 / 260	8 I					
		Sliding hub connection to generator	x		All (12)	M16-10.9	Delivery condition	250 / 260	24 S					
					The faces of the tapered bushing and the tapered pin must be flush after tightening.									
				o	Visual and tightness inspections of all screws of the connections									
	13	**Generator**												
	13.1	Grounding		o	Check for tight fit									
	13.2	Lightning protection mechanism		o	Check the operation of feedback messages of the safety monitoring of the lightning protection Visual inspection of the lightning protection devices (triggered?)									

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	13.3	Carbon brushes /brush holder Slip ring space and alternator shaft clamping set	x (only for abnormalities)	o	Visual inspection of carbon brushes (wear inspection): By calculating the average abrasion (new brush length minus current brush length divided by durability). Via the average brush abrasion calculate the remaining durability (at least up to the next maintenance). If necessary replace brushes (use identical brush brand and type, observe direction of travel) and run in newly as per manufacturer instructions. Check brush pressure and brush holder and replace, if necessary For cleaning see slip ring space!	Brush alignment on the slip rings: center: _____ left: _____ right: _____	Soiling of the slip ring space severe: _____ medium: _____ low: _____					
					Documentation of the brush lengths. (Counting from top left to bottom right) Rotor brushes: VEM: L_{min} = 16mm (L_{new} = 50mm) Winergy: L_{min} = 16mm (L_{new}: MM_old = 50mm / MM_new = 100mm) Grounding brushes: VEM: L_{min} = 16mm (L_{new} = 32mm) Winergy: L_{min} = 25 mm (L_{new} = 50mm) List in mm K1 = ________ L1 = ________ M1 = ________ E1 = ________ K2 = ________ L2 = ________ M2 = ________ E2 = ________ K3 = ________ L3 = ________ M3 = ________ K4 = ________ L4 = ________ M4 = ________							
					Documentation of the brush contact pressure as far as possible (counting from top left to bottom right) K1=__________ L1= __________ M1=___________ E1= _________ K2=__________ L2= __________ M2=___________ E2= _________ K3=__________ L3= __________ M3=___________ E3= _________ (alternator tensioning set brushes) K4=__________ L4= __________ M4=___________ E4= _________ (alternator tensioning set brushes) K5=__________ L5= __________ M5= ___________ K6=__________ L6=__________ M6=___________ K7=__________ L7= __________ M7=___________ K8=_________ L8= __________ M8= ___________ K9=__________ L9= __________ M9=____________ Spring type: -spring tape ___________ -holding down clamp____________							

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					Slip ring condition: Slip ring element: K L M E Slip ring inlet (mm): ____ ____ ____ ____ Condition of the contact surface: ____ ____ ____ ____ A - normal looking running surface with even color light to dark brown B - running surface with strongly developed streaks and lines C - torn contact surface with slight scoring D - uneven checked contact surface E - light dotting of various density distributed randomly on the contact surface F - severe burning with oxidized surface G - other comments:									
	13.6	Generator base - main frame	x		All (16)	M16-8.8	Molykote G-Rapid plus	135 / 141	24 S					
			every 2 years		All									
				o	Carry out visual and tightness inspections of all screws in the connection									
	13.7a	Power cable rotor - terminal box VEM	x		All (12 + 1)	M16-8.8 in Cu	dry	75	24 S					
			every 2 years		All									
				o	Carry out visual and tightness inspections of all screws in the connection									
	13.7b	Power cable rotor - terminal box Loher / Winergy	x		All (12 + 1)	M16-8.8 in Cu	dry	160	24 S					
			every 2 years		All									
				o	Carry out visual and tightness inspections of all screws in the connection									
	13.8a	Power cable stator - terminal box VEM	x		All (15 + 1)	M16-8.8 in Cu	dry	75	24 S					
			every 2 years		All									
				o	Carry out visual and tightness inspections of all screws in the connection									
	13.8b	Power cable stator - terminal box Loher / Winergy	x		All (15 + 1)	M16-8.8 in Cu	dry	160	24 S					
			every 2 years		All									
				o	Carry out visual and tightness inspections of all screws in the connection									
	13.9	Generator bearing self-lubrication system (refill lubrication grease)	x	o	Evaluate old lubrication grease from collection container for even consistency and if necessary remove and take sample.									
	13.10	Maintenance protocol	x	o	Maintenance as per generator manufacturer instructions Complete the maintenance protocol of the generator manufacturer									

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					Number of ( ) total	Screw (nut)	Lubrication Molykote (μ=0.08)	Tightening/ check torque [Nm]	Spanner size fixed wrench = S, Allen = I					
					Lubricant									
					Medium	Filling volume	Notes							
	14	**Hydraulics (HAWE unit no.: H4 022) (active rotor holding brake)**												
	14.1	Oil level check	x	o	The oil level should be at the center of the level indication									
	14.2	Oil change		■	Oil	approx. 12 liters	As per level indication, flush rotor holding brake after filling with fresh oil See manufacturer instructions.							
	14.3	Check oil filter	x	o	Check pressure differential display of the oil filter with the pump running. Oil filter change when reaching the permitted differential pressure, no later than item 14.4									
	14.4	Filter change		■	Carry out together with oil change where possible									
	14.5	Check for leaking oil	x	o	Seal the systems. Remove any discharged lubricants and clean the turbine!									
	14.6	Check the ventilation filter	x	o	Visual inspection for external damage									
	14.7	Hydraulic accumulator	every 10 years		Replace reservoir									
	14.8	Condition of hoses Condition of pipes and threaded joints	x	o	Visual inspection of attachment and for damage, in particular check condition of the hoses (damage / abrasion of the hose walls and hose band clips) Replace if necessary									
			every 10 years		Replace all hoses of the hydraulic system									
	14.9	Pressure sensor on/off switching point	x	o	Switch on / switch off pressure level: P = 160 bar			Actual values: P_{in} = ___________ bar P_{out} = ___________ bar						
	14.10	Pressure level, pressure-limiting valve Yaw brake module (yaw movement)	x	o	Desired value: residual pressure p_{rest} = 15 bar ± 1 bar			Actual value: p_{rest} = _______ bar						
	14.11	Pressure level, pressure reduction valve (active rotor holding brake module)	x	o	Desired value brake pressure: SIME - BCH 85 CRT: 88 ± 1 bar			Actual value pressure level: SIME - BCH 85 CRT: _______						
	15	**Converter cooling**												
	15.1	Condition of hoses Condition of pipes and threaded joints	x	o	Visual inspection of attachment and for damage, in particular check condition of the hoses (damage / abrasion of the hose walls and hose band clips) **Replace if necessary**									
			every 10 years		Replace all hoses of the hydraulic system									
	15.2	Check for leakage	x	o	Seal the systems. Remove any discharged lubricants and clean the turbine!									
	15.3	Coolant check	every 2 years		Take coolant sample (250ml) and check for suitability.									
	15.4	Expansion tank preset gas pressure	x	■	Check gas pressure in the expansion container and adjust if necessary p_{gas}=1.5bar (gas pressure), p_{fl}=2.5bar (fluid pressure)			Actual value: p_{gas} = _______ bar p_{fl} = _______ bar						

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					Number of ( ) total	Screw (nut)	Lubrication Molykote (μ=0.08)	Tightening/ check torque [Nm]	Spanner size fixed wrench = S, Allen = I					
					Lubricant									
					Medium	Filling volume	Notes							
	16	**Yaw brakes**												
	16.1	Brake disk surface		o	Check for cracks, grooves, nicks									
	16.2	Brake pad surface and thickness		o	Inspect brake pads, if necessary continue with item 16.3									
	16.3	Replace brake pads	as required		Minimum remaining pad thickness Svendborg BSAB 90-S-500: 2 mm									
	16.4	Visual inspection of brake calipers Check for leaking oil	x	o	Seal the systems. Remove any discharged lubricants and clean the turbine!									
	16.5	Yaw brake - main frame	x		All (18 x 8)	M27-10.9	Molykote	1100 / 1155	41 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
	17	**Yaw bearing**												
	17.1	Yaw bearing condition	x	o	Visual inspection of gearing and seal, clean if necessary									
	17.2	Check the lightning protection mechanism	x	o	Visual inspection of the brushes and spark gaps, min brush length = 20 mm, replace if necessary. Inspection of the contact surface, spring force and tight fit									
	17.3	Tracks (manual lubrication)		o	Lubrication grease	20x125g per nipple (5.0kg /a in total)	Apply 125g lubrication grease per lubrication nipple. Always rotate the nacelle during the lubrication process.							
	17.4	Tracks (equipped with automatic self-lubrication system)		o	Lubrication grease	approx. 3.5 kg (with lubrication pinion)	If the lubrication grease consumption differs, check pump actuation If lubrication grease consumption is too low, also check whether a red pin is visible in the pressure valve; in this case the lubrication line is blocked.							
	17.5	Gearing (manual lubrication)	x	o	Lubrication grease	as required	Complete coating of the teeth							
	17.6	Gearing (equipped with autom. self-lubrication systems)	x	o	Lubrication grease	as required (for manual relubrication)	Check whether the teeth of the self-lubrication system in the adjustment range are coated completely, otherwise see item 417.6 Check pump. Re-lubricate the remaining range manually.							
	17.7	Yaw bearing - main frame	x		All (120)	M27-10.9	Molykote G-Rapid plus	100 / 1050	41 S					
			every 2 years		20									
				o	Carry out visual and tightness inspections of all screws in the connection									
	17.8	Tower head - yaw bearing	x		All (120)	M30-10.9	Molykote G-Rapid plus	1365 / 1400	46 S					
			every 2 years		20									
				o	Carry out visual and tightness inspections of all screws in the connection									
	18	**Yaw adjustment mechanism**												
	18.1	Gearbox oil level check		■	Refill volume:	1: liters	2: liters	3: liters	4: liters					
					Counting the drives from left to right facing the rotor hub. The inspection glass should be filled 3/4.									
	18.2	Gearbox oil change	every 5 years at the latest		Oil according to type label.	4 x approx. 16 liters	The inspection glass should be filled 3/4.							

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	18.3	Yaw gearbox E-motor	x	o	Functional test of the E-motors (noise)									
	18.4	Cable twist cam switch	x	■	Check the travel in both directions until the cam switch trips and check the cable twist									
	18.5	Yaw gearbox tightness		o	Seal systems if oil escapes and clean wind turbine									
	18.6	Yaw gearbox - main frame	x		All (4 x 24)	M20-10.9	Molykote G-Rapid plus	400 / 420	17 I					
			every 2 years		4x4									
				o	Carry out visual and tightness inspections of all screws in the connection									
	19	**Cabling / electrical system in nacelle**												
	19.1	Cracks / damage to cables	x	o	Visual inspection of cable routing and external damage									
	19.2	Suspension / attachment of cables	x	o	Particular visual inspection of cable loop, to do so move nacelle into the 0° position									
	19.3	Nacelle lighting	x	o	Functional check of nacelle lighting									
	19.4	**Sensors**												
	19.4.1	Vibration analyzer at gearbox support			4	M6	dry	finger-tight	10 S					
				■	Carry out visual and tightness inspections of all screws in the connection									
					4	M6	dry	finger-tight	10 S					
				■	Carry out visual and tightness inspections of all screws in the connection of the elastomer bearings Visual inspection of the elastomer bearings for cracks and porosity									
				■	Visual inspection of electrical connections: cable routing, tight fit and external damage									
			x	■	Functional test: vibration move analyzer manually, check display indication									
	19.4.2	Vibration analyzer at main frame			4	M6	dry	finger-tight	10S					
				■	Carry out visual and tightness inspections of all screws in the connection									
				■	Visual inspection of electrical connections: cable routing, tight fit and external damage									
			x	■	Functional test: actuate brake program, check display indication									
	19.4.2	Vibration switch at main frame			2	M4	dry	finger-tight	Slotted or Allen					
				■	Carry out visual and tightness inspections of all screws in the connection									
				■	Visual inspection: weight attached properly? Wire angled?									
				■	Visual inspection of electrical connections: cable routing, tight fit and external damage									
			x	■	Functional test: in "manual STOP" actuate vibration switch, a change to the brake program 200 takes place and the safety chain triggers.									
	19.4.3	Rotor hub speed sensor at rotor shaft / rotor bearing housing	x	o	Visual inspection of electrical connections: cable routing, tight fit and external damage									
	19.4.4	Gearbox speed sensor at rotor shaft / gearbox	x	o	Visual inspection of electrical connections: cable routing, tight fit and external damage									
	19.5	Control cabinet grounding Control cabinet door grounding Load support grounding	x	o	Check for tight fit									

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					Number of ( ) total	Screw (nut)	Lubrication Molykote (μ=0.08)	Tightening/ check torque [Nm]	Spanner size fixed wrench = S, Allen = I					
					Lubricant									
					Medium	Filling volume	Notes							
	20	**Tower (fittings)**			**Designation / dimension of the tower:**									
	20.1	Ladder / runner rail attachment	x	o	Check for damage, functional test of the sampling points and interlocks (if applicable)									
			x	o	Check all attachments of the ladder and fall protection system for tight fit.									
			x	o	Enter next inspection by qualified person in item 26.9.									
	20.2	Cables and lines	x	o	Visual inspection of all cables and lines for routing and damage									
	20.3	Lighting	x	o	Functional test of lighting, external lighting and emergency lighting									
	20.4	Check ladder and platform for soiling	x	o	Clean ladder and platform									
	20.5	Door, door lock, hinges		o	Check door for ease of movement, if necessary adjust hinge and lock, lubricate hinges									
	20.6	PPE		o	If PPE present, enter inspection date in item 26.9									
	20.7	Door filter mat		o	If present: check condition, if necessary replace									
	20.8	Rail system	x	o	Visual inspection of the busbar, inspection of the elastomer bearings for cracks, separations etc., inspection of grounding and decoupling									
				■	Insulation measurement of the rotor bar incl. power cable: Disconnect the rotor connection to generator and converter, test voltage = 1000V, Desired value R_{min} ³ 10 MOhm, R_{ist} = ____________MOhm									
				■	Insulation measurement of the stator bar incl. power cable: Disconnect the stator connection to generator and converter, test voltage = 1000V, Desired value R_{min} ³ 10 MOhm, Rist = ____________MOhm									
	20.9	Rotor power cable: top busbar terminal box	x		All (6+1 + 1)	M12	dry	80 / 80	19 S (18 S)					
			every 2 years											
				o	Carry out visual and tightness inspections of all screws in the connection									
	20.10	Stator power cable: top busbar terminal box	x		All (21 + 3)	M16	dry	100/100	24 S					
			every 2 years											
				o	Carry out visual and tightness inspections of all screws in the connection									
	20.11	Rotor power cable: bottom busbar terminal box	x		All (6 + 1)	M12	dry	80 / 80	19 S (18 S)					
			every 2 years											
				o	Carry out visual and tightness inspections of all screws in the connection									
	20.12	Stator power cable: bottom busbar terminal box	x		All (15 + 3)	M16	dry	100 / 100	24 S					
			every 2 years											
				o	Carry out visual and tightness inspections of all screws in the connection									
	20.13	Power cable attachment	x	■	Carry out visual and tightness inspections of the power cable attachments.									
	20.14	Threaded cable connections of power ca	x		Check for tight fit									
	20.15	Various tower grounding devices	x	o	Check grounding for tight fit (tower, door, platforms, tower base, control cabinet)									

last revision index:	Maintenance no.:	Maintenance work	Interval		Notes / description / desired values					Maintenance evaluation				
		Caution: Locked electrical operating establishment. Access is restricted to skilled electricians or individuals with electrical training, and untrained individuals must be accompanied by one of the aforementioned trained professionals.	1st month x	1/2 yearly or annually■	**Screw tightening torques**					Inspection of test items without	Inspection of test item with problem (please describe)	Problem remedied	Inspector	Date
					Number of ( ) total	Screw (nut)	Lubrication Molykote (μ=0.08)	Tightening/ check torque [Nm]	Spanner size fixed wrench = S, Allen = I					
					Lubricant									
					Medium	Filling volume	Notes							
	20.16	**Elevator system / ladder climbing support**												
	20.16.1	Elevator system, all types		■	Annual inspection by qualified person in accordance with the inspection instruction protocol kept in the wind tu									
			every 4 years		Inspection by an expert surveyor									
			x	o	Check motor, brake, gearbox and cables for damage and soiling, lightly oil cable									
			x	o	Check: notice sign "PPE and rescue device must be carried" present?									
	20.16.2	Elevator system, Hailo	every 250 h		Replace drive unit (Tirak), inform REpower Service.									
	20.17a	**Tower NH 78-80m IEC 61400 - 1 Ed.2 TC2A / DIBt WZIII(2004) and WZIV control profile near shore standard profile (DIN 1055-4:2005-03)**												
		Foundation flange	x		All (100)	M56-10.9	Nut pretreated	10.000 / 10.500	90 S					
			every 2 years		20	M56-10.9	Nut pretreated	10.000 / 10.500	90 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
		Connection flange 1	x		All (116)	M48-10.9	Nut pretreated	6.500 / 6.825	80 S					
			every 2 years		24	M48-10.9	Nut pretreated	6.500 / 6.825	80 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
		Connection flange 2	x		All (96)	M48-10.9	Nut pretreated	6.500 / 6.825	80 S					
			every 2 years		20	M48-10.9	Nut pretreated	6.500 / 6.825	80 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
		Connection flange 3	x		All (88)	M42-10.9	Nut pretreated	4.500 / 4.725	70 S					
			every 2 years		18	M42-10.9	Nut pretreated	4.500 / 4.725	70 S					
				o	Carry out visual and tightness inspections of all screws in the connection									

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					Number of ( ) total	Screw (nut)	Lubrication Molykote (µ=0.08)	Tightening/ check torque [Nm]	Spanner size fixed wrench = S, Allen = I					
					Lubricant									
					Medium	Filling volume	Notes							
	20.17b	**Tower NH 96.5-100m IEC 61400 - 1 Ed.2 TC2A / DIBt WZIII(2004) and WZIV control profile near shore standard profile (DIN 1055-4:2005-03)**												
		Anchor bolt	x		All (136)	M48-8.8	Molykote G-Rapid plus	700kN with hydraulic clamping cylinder Caution: tighten screws	75S					
			6 months											
			12 months											
			24 months											
				■	14	M48-8.8		700kN	75 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
		Foundation flange	x		All (96)	M64-10.9	Nut pretreated	15.000 / 15.750	100 S					
			every 2 years		20	M64-10.9	Nut pretreated	15.000 / 15.750	100 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
		Connection flange 1	x		All (104)	M56-10.9	Nut pretreated	10.000 / 10.500	90 S					
			every 2 years		21	M56-10.9	Nut pretreated	10.000 / 10.500	90 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
		Connection flange 2	x		All (136)	M42-10.9	Nut pretreated	4.500 / 4.725	70 S					
			every 2 years		28	M42-10.9	Nut pretreated	4.500 / 4.725	70 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
		Connection flange 3	x		All (124)	M36-10.9	Nut pretreated	2.800 / 2.940	60 S					
			every 2 years		25	M36-10.9	Nut pretreated	2.800 / 2.940	60 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
		Connection flange 4	x		All (80)	M36-10.9	Nut pretreated	2.800 / 2.940	60 S					
			every 2 years		16	M36-10.9	Nut pretreated	2.800 / 2.940	60 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
	20.18	**All towers**												
		Head flange	x	o	Visual inspection at the radius of the head flange and at the weld seam for chipping paint.									

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	22	**Control system / converter**												
	22.1	Converter heating / fan operation		o	Based on the thermostats, then adjust to desired values, see converter circuit diagram									
	22.2	General visual inspection		o	Covers, interlocks, doors etc., missing components (e.g. screws)									
	22.3	Maintenance protocol	x	o	Maintenance as per converter manufacturer instructions Complete the maintenance protocol of the converter manufacturer									
	22.4	Rotor power cable: Converter cabinet connection	x every 2 years		All (15)	M12-8.8	dry	80 / 80	19 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
	22.5	Rotor power cable: Converter cabinet connection (PE)	x every 2 years		All (1)	M12-8.8	dry	80 / 80	19 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
	22.6	Stator power cable: Converter cabinet connection	x every 2 years		All (15 + 1)	M16-8.8	dry	100/100	24 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
	22.7	Stator power cable: Converter cabinet connection (PE)	x every 2 years		All (1)	M16-8.8	dry	100/100	24 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
	22.8	Transformer cable: converter connection (L1 - L3)	x every 2 years		All (15)	M16-8.8	dry	100 / 100	24 S					
				o	Carry out visual and tightness inspections of all screws in the connection									
	22.9	Transformer cable: converter connection (PE)	x every 2 years		All (2)	M16-8.8	dry	100 / 100	24 S					
				o	Carry out visual and tightness inspections of all screws in the connection									

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		Caution: Locked electrical operating establishment. Access is restricted to skilled electricians or individuals with electrical training, and untrained individuals must be accompanied by one of the aforementioned trained professionals.	1st month x	1/2 yearly or annually■	**Screw tightening torques** Number of ( ) total / Screw (nut) / Lubrication Molykote (μ=0.08) / Tightening/ check torque [Nm] / Spanner size fixed wrench = S, Allen = I **Lubricant** Medium / Filling volume / Notes	Inspection of test items without	Inspection of test item with problem (please describe)	Problem remedied	Inspector	Date
	23	**Dry transformer in the tower base**			**Service and maintenance measures of the dry transformer and the switchgear need to be performed in accordance with the instructions as provided by the respective manufacturer. As a minimum, the following measures need to be performed at the intervals specified below.**					
	23.1	-Transformer room in the tower base	X		Visual inspections: general condition					
	23.2	- Revision covers	X	o	Check the locking and closing system for proper functioning					
	23.3	- Floor	X	o	Visual inspection: Formation of cracks, chippings, discolorations, moisture, corrosion					
	23.4	- Tower base in the transformer area	X	o	Visual inspection: Corrosion, moisture from condensation (wipe dry)					
	23.5	- Cable bushings	X	o	Visual inspection: Condition, abrasions of the cable insulation, tightness of the grommets					
	23.6	- Transformer fan	X	■	Functional test: check for vibration, clean any soiling					
	23.7	- Air inlet to the transformer room	X	■	Visual inspection: Clean or replace filter					
	23.8	- Air outlet from the transformer room	X	■	Visual inspection of the outlet air system. Functional test: Check, clean ventilator					
	23.9	- Safety systems	X	■	Condition check: voltage test instrument, warning and notice signs					
	23.10	- Fire protection systems	X	■	Condition check: fire extinguisher (inspection date), functional test: smoke/fire detector					
		Dry transformer								
	23.11	- Vibration and noise	X	o	Check for uncommon vibrations and noise while the transformer is switched on					
	23.12	- Steel construction	X	o	Visual inspection: General condition, paint chippings, corrosion					
	23.13	- Coil element	X	o	Visual inspection Immaculate condition, cleaning with compressed air, vacuum cleaner, cleaning cloth					
	23.14	- Support blocks for transformer winding	x	o	Check for tight fit					
	23.15	- Transformer terminal boxes	x	o	Visual inspection: check for damage					
	23.16	- Electric arc monitoring	x	o	Carry out functional test					
	23.17	- Protection devices *	X	■	Functional test: overcurrent triggering, short circuit triggering, diff. protection triggering (if applicable)					
	23.18	- Temperature protection devices *	X	■	Functional test: >Temperature warning, >temperature triggering					
	23.19	Insulation test	every 10 years		Release all connections, then measure resistances: Compare measured value to test report / HV - MV / MV - LV / LV ground					

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		Caution: Locked electrical operating establishment. Access is restricted to skilled electricians or individuals with electrical training, and untrained individuals must be accompanied by one of the aforementioned trained professionals.	1st month x	1/2 yearly or annually■	**Screw tightening torques** Number of ( ) total **Lubricant** Medium	Screw (nut) Filling volume	Lubrication Molykote (μ=0.08) Notes	Tightening/ check torque [Nm]	Spanner size fixed wrench = S, Allen = I	Inspection of test items without	Inspection of test item with problem (please describe)	Problem remedied	Inspector	Date
	23.20	**Cable connections** LV connection cables L1, L2, L3, PE) MV connection cables (L1, L2, L3,PE) HV connection cables (L1, L2, L3) cable sealing ends, ground connections	X	o	Visual inspection: excessive heating (insulation melted, discoloration of the connections)									
			X	o	Perform visual and tightness inspections of all screws and connections									
					Max. torque for stepping adjustment screws and screws that are directly sealed into the OS coil (e.g. screws of the triangular connections):									
			X	■	All	M 8-Nordlock+Cu	dry	10	13 S					
			X	■	All	M 10-Nordlock+Cu	dry	20	16 / 17 S					
			X	■	All	M 12-Nordlock+Cu	dry	35	18 / 19 S					
					max torque of the HV, MV and LV connections with busbars, expansions joints, and terminal as well as grounding connections:									
			X	■	All	M 8-Nordlock	dry	25	13 S					
			X	■	All	M10-Nordlock	dry	47	17 S					
			X	■	All	M12-Nordlock	dry	83	19 S					
			X	■	All	M16-Nordlock	dry	203	24 S					
			X	■	All	M 10-Cu	dry	40	16 / 17 S					
			X	■	All	M 12-Cu	dry	70	18 / 19 S					
			X	■	All	M 16-Cu	dry	140	24 S					
			X	o	Visual inspection: screen grounding,									
		Note: * in conjunction with testing the MV switchgear												

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	24	**MV switchgear**								
	24.1	- General	X		Visual inspection: cleanliness and tightness against dust and foreign objects, corrosion, chipping paint					
	24.2	- SF6 gas pressure	X		Check: If in the "red range" disconnect immediately! Do not reactivate, initiate repair by manufacturer					
	24.3	- Capacitive voltage measurement	X	■	Functional check of all phases in all fields					
	24.4	- Switch drives	X	■	Functional test: all interlock conditions, ease of movement					
	24.5	- Feedback touchpad	X	■	Functional test: Switches, pushbuttons, signal lamps, displays, instruments					
	24.6	- Wiring	X	o	Visual inspection: Damaged insulation, core identification, cable label, terminal identification					
	24.7	- Protective relay	X	■	Functional test with relay test instrument: Parameter values, proper triggering, retrieving the memory					
	24.8	- Auxiliary contacts	X	o	Visual inspection: contact melting loss, soiling (clean if applicable)					
	24.9	- MV terminal connections	X	o	Visual inspection: attachment, screen grounding,					
	24.10	- MV cables	X	o	Visual inspection: attachment brackets, bending radius, damaged insulation					
	24.11	- Control elements	X	■	Visual inspection and functional test: Switching crank, grounding drive, warning and notice signs					
		Transformer field								
	24.12	- Circuit breakers	X	■	Functional test, reading out the switching counter					
	24.13	- Load circuit breakers + HH circuit	X	■	(if applicable) functional test, visual inspection of the HH circuit breakers (only replace in sets)					
	24.14	- Grounding switch	X	■	Functional test					
		Cable fields								
	24.15	- Load circuit breaker	X	■	Functional test					
	24.16	- Grounding switch	X	■	Functional test					
	25	**LV cables, MV cables, control cables**								
	25.1	- Transformer - converter	X	o	Check the tightness of all connections, tightening torque. Visual inspection of all cables; in that context, check for damage to the cable sheath, cable grommets, bending radii, cable connections, cable attachments					
	25.2	- Transformer - switchgear	X	o						
	25.3	- Grounding connection /potential equal	X	o						
	25.4	- Switchgear - next wind turbine	X	o						
	25.5	- Switchgear transducer	X	o						

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	26	**Safety functions**								
	26.1	Circuit breakers	x	o						
	26.2	Self test inspection	x	o						
	26.3	Tower base emergency stop switch	x	o						
	26.4	Nacelle emergency stop switch	x	o						
	26.5	Rotor overspeed switch	x	o						
	26.6	Generator overspeed switch	x	o						
	26.7	Vibration switch	x	o						
	26.8	Cable twist limit switch	x	o						
	26.9	Nacelle fire extinguishers (3x) Tower fire extinguisher (1x) PPE (where applicable) First-aid kit Nacelle load lowering device All ladders and fall arresters	x	o	Date of the next fire extinguisher inspection (nacelle) by qualified person: __________________ Date of the next fire extinguisher inspection (tower) by qualified person: __________________ Date of the next inspection of the PPE by qualified person: __________________ First-aid kit expiry date: nacelle:________________ tower: __________________ Date of the next inspection of the load lowering device by qualified person:__________________ Date of the next inspection of ladder and fall protection by qualified person:__________________					
	27	**Cleaning the wind turbine**								
	27.1	Cleaning, waste disposal	x	o	Clean any contamination before leaving the wind turbine. **All waste must be disposed of properly.**					
	27.2	Checking all paintwork	x	o	Check the paint of all components in the wind turbine, repair if necessary					
	28	**Foundation**			**Foundation surface visible and accessible (visual inspection is possible) ___** **Foundation covered with soil (visual inspection is not possible) ___**					
	28.1	Condition of the joint between tower and foundation	x	o	Check sealing tape of foundation flange					
	28.2	Check for cracks	x	o						
	28.3	Foundation grounding	x	o	Grounding log present: yes___ no___ Date of the most current grounding log: ___________					
	29	**WT environment**			**In case of abnormalities inform the master service technician**					
	29.1	Visual inspection, condition	x	o	General condition, vandalism, other abnormalities of the wind turbine environment					

Maintenance protocol

Maintenance interval:	___ 1st full maintenance	___ 1/2 yearly repeated subsequent maintenance

Wind turbine manufacturer:	**Hours of operating:** h
Wind turbine serial no.	**Energy yield:** kWh
Commissioning date:	**Energy supply:** kWh
Location:	
Operator:	

Maintenance personnel:

____

____

Date of maintenance: ______________________________

____

Confirmation:

The maintenance has been performed properly and completely in accordance with the maintenance specifications.

Signature	Signature	Date

VESTAS

CALCOLO DELLA TRAIETTORIA DI UNA PALA EOLICA IN CONDIZIONI NOMINALI DI FUNZIONAMENTO

Sommario

1. Introduzione

L'obiettivo di questo lavoro è determinare la distanza che una pala di un aerogeneratore raggiunge nel caso di distacco dal mozzo mentre la macchina è in funzione.

Il calcolo è stato effettuato su sei aerogeneratori VESTAS V52 , V80, V82, V90 1.8MW, V90 2MW, V90 3MW.

Il primo aerogeneratore, V52, ha una pala di lunghezza pari a 25 m e una velocità di rotazione massima a regime di 26 rpm posto su una torre di altezza pari a 55 m.

Il secondo aerogeneratore, V80, ha una pala di lunghezza pari a 39 m e una velocità di rotazione massima a regime di 19,2 rpm posto su una torre di altezza pari a 67 m.

Il terzo aerogeneratore, V82, ha una pala di lunghezza pari a 40 m e una velocità di rotazione massima a regime di 14,4 rpm posto su una torre di altezza pari a 78 m.

Il quarto aerogeneratore, V90 1.8 MW, ha una pala di lunghezza pari a 44 m e una velocità di rotazione massima a regime di 14,9 rpm posto su una torre di altezza pari a 80 m.

Il quinto aerogeneratore, V90 2 MW, ha una pala di lunghezza pari a 44 m e una velocità di rotazione massima a regime di 14,9 rpm posto su una torre di altezza pari a 80 m.

Il sesto aerogeneratore, V90 3 MW, ha una pala di lunghezza pari a 44 m e una velocità di rotazione massima a regime di 16.1 rpm posto su una torre di altezza pari a 80 m.

Per la pala della V80 si è fatto uno studio completo ipotizzando tre condizioni: la prima, più conservativa, include solo le forze di inerzia ed esclude le forze viscose; la seconda include le forze viscose; la terza considera il moto della pala completo. Come si evince dai risultati riportati in appendice, la prima condizione di carico è quella che dà la massima gittata, ma in realtà le forze di resistenza che si esercitano sulla pala fanno si che la gittata reale sia inferiore di circa il 20%.

Per la pala V52, V82, V90 1.8MW-2MW e V90 3MW si è fatto uno studio considerando la condizione più conservativa e cioè considerando le sole forze inerziali ed escludendo l'attrito, per cui i risultati ottenuti sono da considerare il 20% maggiori di quelle reali.

2. Risultati

I risultati ottenuti sono riportati in appendice.

I risultati dell'analisi indicano che con lo studio più complesso (caso 3), la gittata della pala, per la V80, è inferiore a 110 m; nel caso peggiore ma non reale (caso 1), è di poco superiore a 130, la gittata della pala per la V52 è di ca. 105.5 m, per la V82 è di ca. 105 m, per la V90 1.8-2 MW è di ca. 108 m e infine per la V90 3 MW è di ca. 96 m (per la V52, V82 V90 1,8-2 MW e per la V90 3 MW, unico caso studiato quello conservativo ma non reale per cui il risultato è maggiore del 20% rispetto al reale).

3. Metodologia ed ipotesi

Da un punto di vista teorico, se non si considerano le forze aerodinamiche la massima gittata si ottiene quando la pala si distacca dal rotore con un angolo di 45° (135° in posizione azimutale).

Le forze di resistenza che agiscono sulla pala in realtà rendono minore il tempo di volo e quindi la gittata. Il moto reale è molto più complesso, in quanto dipende dalle caratteristiche aerodinamiche e dalle condizioni iniziali (rollio, imbardata e beccheggio della pala).

4. Velocità di rotazione

La velocità di rotazione del rotore considerata al momento della rottura della pala per la V52 è pari a 31 rpm.

La velocità di rotazione del rotore considerata al momento della rottura della pala per la V80 è pari a 20 rpm.

La velocità di rotazione del rotore considerata al momento della rottura della pala per la V82 è pari a 15,84 rpm.

La velocità di rotazione del rotore considerata al momento della rottura della pala per la V90 1.8MW è pari a 16,39 rpm.

La velocità di rotazione del rotore considerata al momento della rottura della pala per la V90 2MW è pari a 16,39 rpm.

La velocità di rotazione del rotore considerata al momento della rottura della pala per la V90 3MW è pari a 15,7 rpm.

La velocità di distacco della pala dal rotore è stata incrementata del 16% passando da 26 a 31 rpm per la V52, del 5% per la V80, passando così da 19 a 20 rpm; per la V82 e V90 1.8MW-2MW, invece, è stata incrementata del 10% passando così da 14,4 a 15,84 e da 14,9 a 16,39 rpm rispettivamente, per la V90 3 MW è stata incrementata del 5 % passando da 14,9 a 15,7 rpm).

5. Forze agenti sulla traiettoria pala

Le ipotesi fatte in questo studio considerano il caso peggiore, esso avviene quando la pala si distacca dal rotore con un angolo di 45° sul piano verticale (cioè 135° azimuth).

La determinazione delle forze e dei momenti agenti sulla pala a causa di una rottura istantanea, durante il moto rotatorio, è molto complessa. La traiettoria iniziale è determinata principalmente dall'angolo di lancio e dalle forze generalizzate inerziali agenti sulla pala. Queste includono anche, per esempio, oltre all'impulso anche i momenti di flapwise, edgewise e pitchwise agenti al momento del distacco. La pala, quindi, quando inizierà il suo moto continuerà a ruotare (conservazione della quantità di moto). L'unica forza inerziale agente in questo caso è la forza di gravità. La durata del volo considerato è determinata considerando la velocità verticale iniziale applicata al centro di gravità. Il tempo risultante è usato per calcolare la distanza orizzontale (gittata) nel piano e fuori dal piano.

La gittata è determinata dalla velocità orizzontale al momento del distacco iniziale.

Le forze inerziali sono modellate considerando un flusso irrotazionale e stazionario.

6. Caratteristiche della pala

Le caratteristiche delle pale, input della simulazione, sono riportate in tabella.

	(Outboard) Section of blade	Plan area Plane XY	Plan area Plane XZ	Plan area Plane YZ	Mass
		m^2	m^2	m^2	kg
V90 1,8MW	44	87.84	25.69	2.37	6660
V82	40	86	23.2	2.08	6200
V80	39	81.46	22.8	2.38	6300
V52	25.3	53.83	14.67	1.55	1900
V90 2MW	44	87.84	25.69	2.37	6660
V90 3MW	44	87.84	25.69	2.37	6700

7. Casi di studio

Tutte le condizioni di rottura sono state assunte avvenire quando il rotore è in posizione upwind e con una velocità del vento pari a 25 m/s. Questa condizione è anch'essa conservativa in quanto dà la massima gittata fuori dal piano.

Sono state calcolate tre traiettorie nelle seguenti ipotesi:

7.1 Caso 1: Moto irrotazionale

Assenza di moti intorno agli assi XX, YY e ZZ. L'asse XX è allineato con la traiettoria. L'asse YY giace sul piano verticale. Questa ulteriore assunzione fa si che questo caso sia il peggiore ipotizzabile, in quanto definisce la condizione ideale di massima gittata.

Quindi:

- ✓ Nessuna forza di portanza agisce nella direzione in-plane;
- ✓ La massima resistenza è generata nella direzione out-of-plane;
- ✓ La resistenza nel piano agisce sulla sezione nel piano XZ.

7.2 Caso 2: Moto irrotazionale

L'asse XX è allineato con la traiettoria. L'asse YY giace sul piano orizzontale. Quando la pala ha raggiunto questa posizione non ci sono ulteriori moti intorno agli assi XX, YY e ZZ.. In questo caso la traiettoria risultante è del tipo "a giavellotto". Questa ulteriore assunzione fa si che questo caso sia il caso teorico peggiore ipotizzabile, in quanto definisce la condizione ideale di massima gittata.

Quindi:

- ✓ La traiettoria in alto è aumentata dalla forza di portanza generata dalla pala, per cui la gittata è maggiore che in assenza di portanza.

Tre casi sono stati modellati:

- ✓ **Caso 2a.** L'effetto della portanza sul tempo di volo è zero. La soluzione (approssimata) per questo è data dal caso 1 solo nella direzione in-plane.
- ✓ **Caso 2b.** L'effetto della portanza sul tempo di volo è aumentato del 5%.
- ✓ **Caso 2c.** L'effetto della portanza sul tempo di volo è aumentato del 5%, in questo caso si ottiene il maggior tempo di volo.

7.3 Caso 3: Moto irrotazionale complesso

In questo caso si studia il moto della pala al distacco del rotore nel suo complesso considerando anche i moti di rotazione intorno agli assi XX, YY e ZZ. Questo caso è il caso più reale della traiettoria di una pala. La rotazione della pala intorno all'asse ZZ è causato dalla conservazione del momento della quantità di moto. L'incidenza del vento out-of-plane sulla pala genera un momento intorno all'asse YY (centro di massa e centro aerodinamico della pala non sono coincidenti). Il vento incidente out-of-plane sulla pala genera ancora un momento intorno all'asse XX (centro di massa della sezione di pala lungo la corda non coincide con il centro aerodinamico).

La resistenza della pala sia in-plane che out-of-plane è generata dalla rotazione intorno agli assi XX e YY. Per semplificare lo studio si è assunta l'area della pala pari alla stessa in direzione XY moltiplicata per il quadrato del coseno di 45°.

La portanza in-plane è generata dalla rotazione intorno al piano XX. In questo caso si è assunto un aumento del 10% del tempo di volo dovuto alla portanza.

Tre casi sono stati modellati per tener conto dell'effettivo valore della resistenza:

- ✓ **Caso 3a.** Cd (in-plane e out-of-plane) = 0,5
- ✓ **Caso 3b.** Cd (in-plane e out-of-plane) = 1,0
- ✓ **Caso 3c.** Cd (in-plane e out-of-plane) = 1,5.

8. Esperienze e note statistiche

E' necessario enfatizzare che dal punto di vista progettuale la combinazione di coefficienti di sicurezza per i carichi, i materiali utilizzati e la valutazione delle conseguenze in caso di rottura rispettano quanto prescritto dalla norma IEC61400-1. In accordo a tale norma le pale degli aerogeneratori sono considerate "fail safe".

Questo paragrafo è stato redatto al fine di presentare alcuni degli elementi fondamentali per poter valutare la reale possibilità del distacco di una pala, o di frammenti di questa, dagli aerogeneratori Vestas.

L'esperienza pratica su tutta la flotta operativa di 4.959 unità (Giugno 2007) ha mostrato che in caso di distacco di pala o parti di essa il moto è stato di tipo "rotazionale complesso" e le distanze raggiunte sono normalmente risultate inferiori a quelle stimate con i calcoli semplificati qui riportati.

Frammenti di pala, solitamente di piccole dimensioni, per la maggior parte staccatisi a causa di azioni esterne (tipica la fulminazione atmosferica) o imperizia umana, sono stati ritrovati a non più di 40-50m dalla base dell'aerogeneratore.

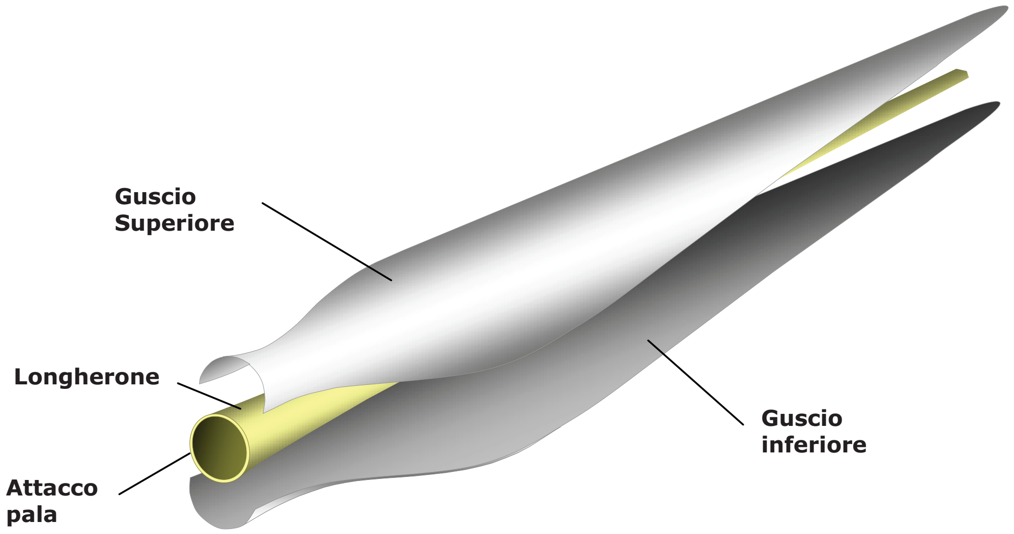
Tralasciando gli incidenti dovuti a cause eccezionali (uragani, tifoni), nei successivi paragrafi vengono descritti alcuni eventi e la valutazione tecnica alla base dell'analisi dei rischi sviluppata per eliminare la possibilità di reiterazione dell'incidente.

8.1 Distacco di una delle pale dal rotore

Questo tipo di incidente, che comporta il distacco di una pala completa dal rotore dell'aerogeneratore, può essere determinato della rottura della giunzione bullonata fra la pala ed il mozzo.

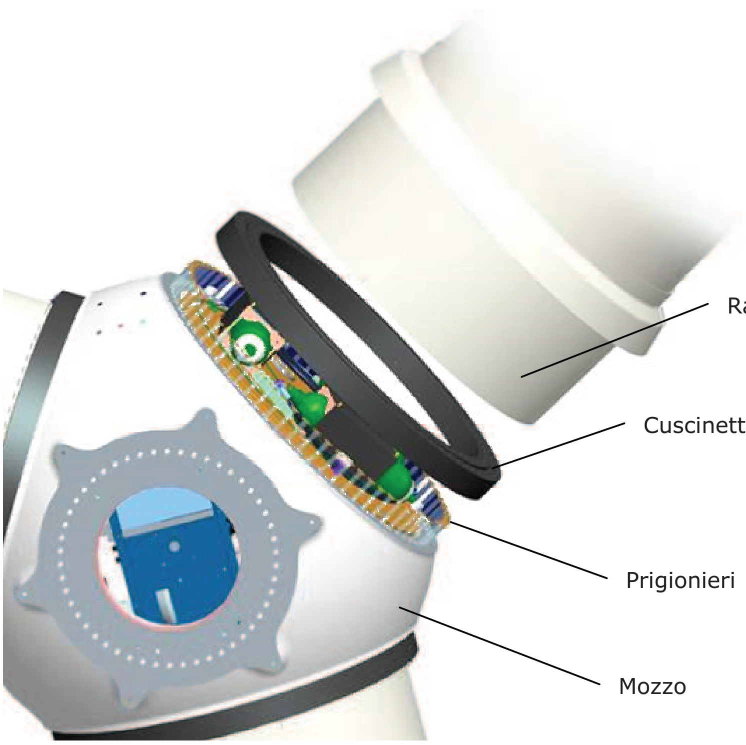
In occasione di tali tipi di evento, la pala ha raggiunto il terreno ad una distanza inferiore ai cento metri.

Le pale sono costituite da una parte strutturale (longherone) posizionata all'interno della pala e da una parte esterna (gusci) che ha sostanzialmente compiti di forma. Le tre parti, il longherone e i due gusci, sono uniti fra loro mediante incollaggio e, alla fine del processo produttivo, costituiscono un corpo unico.



Il longherone è dotato di attacchi filettati che consentono di collegarlo al mozzo con bulloni (prigionieri) serrati opportunamente durante l'installazione della turbina. Il precarico conferito ai prigionieri durante il serraggio ha un'influenza determinante sulla resistenza dei prigionieri stessi ai carichi di fatica e, per questo motivo, è previsto un controllo di tale serraggio durante le operazioni di manutenzione programmata della turbina.

L'evento si è manifestato a causa di incorretti interventi di manutenzione programmata cui l'aerogeneratore va sottoposto così come riportato nel manuale del costruttore. Per cui l'errata verifica del serraggio ed una plausibile riduzione del precarico possono aver determinato la rottura per fatica dei prigionieri ed al distacco della pala.



8.2 Rottura (apertura) dell'estremità di pala

Questo tipo di incidente si è quasi sempre manifestato in concomitanza di fulminazioni di natura atmosferica.

Tutte le pale prodotte dalla Vestas sono dotate di un sistema di drenaggio della corrente di fulmine costituito da recettori metallici posti all'estremità di pala e lungo l'apertura della pala, da un cavo che collega i recettori alla radice pala e da un sistema di messa a terra. In questo modo si riesce a drenare una buona parte delle correnti indotte dalle fulminazioni atmosferiche senza danni alle pale.

In qualche caso, in cui la corrente di fulmine ha presumibilmente ecceduto i limiti progettuali (fissati dalle norme internazionali) si può manifestare un danneggiamento all'estremità di pala che si apre per la separazione dei due gusci, ma che, normalmente, non si distacca dal corpo della pala. E' possibile che frammenti di guscio possano staccarsi, ma si tratta comunque di parti molto leggere in confronto alla resistenza che oppongono all'aria e che quindi non possono essere oggetto di calcoli di gittata come quelli che si possono effettuare sul corpo pala.

Estremità di pala danneggiata da fulminazione atmosferica.

9. Conclusioni

I Casi 1, 2a, 2b e 2c dimostrano che, se la traiettoria di volo è 'irrotazionale', allora la distanza raggiunta dalla pala da 25,3 m (V52) sarà di circa 105.5 m, dalla pala da 39 m (V80) sarà di ca. 130 m, dalla pala da 40 m (V82) sarà di circa 105 m e da 44 m (V90 1.8MW-2MW) sarà di ca. 108 m, mentre dalla pala da 44 m (V90 3MW) sarà di ca. 96 m, il caso peggiore per la gittata è il caso 1 (2a) per il tempo invece è il 2c.

Il Caso 3 mostra che, quando il flusso è rotazionale, la distanza raggiunta dalla pala sarà di ca. 106 m per la V80.

Il caso reale da considerare è il caso 3 per cui si può concludere che la gittata di una pala V52 (25,3 m di lunghezza) è di circa 80.4 m, V80 (39 m di lunghezza) è di ca. 106 m, mentre per la pala V82 sarà di ca. 84 m, V90 1.8MW-2MW (44 m di lunghezza) sarà di ca. 87 m, V90 3 MW sarà di ca. 77 m (20% in meno della gittata nel caso ideale, caso 1)

Dalle note operative esposte si può concludere che ha senso effettuare un calcolo di gittata della pala intera in quanto esiste un punto di discontinuità, l'attacco bullonato che unisce la pala al mozzo, ed esiste un'ipotesi, seppur remota, sulla possibilità di cedimento di tale attacco.

Il calcolo di gittata nei casi di distacco di frammenti o porzioni di guscio, per le ragioni spiegate in precedenza, risulta problematico e privo di basi computazionali, in quanto lo stabilire le dimensioni del pezzo di guscio distaccato è del tutto aleatorio e non dipendente da una causa specifica come quelle collegabili ad una discontinuità, un difetto di progettazione o di realizzazione della pala.

Il caso di distacco di porzioni di pala si potrebbe trattare effettuando un'analisi del rischio che è dato dal prodotto fra la probabilità di occorrenza della specifica rottura e la gravità delle

conseguenze. Una simile analisi comporterebbe comunque delle assunzioni arbitrarie fra le quali le dimensioni del pezzo di pala interessato al distacco e uno studio probabilistico sull'occorrenza e la gravità delle conseguenze.
Per effettuare queste valutazioni è necessaria la conoscenza di tutta una serie di circostanze circa gli eventi di questo tipo e la base statistica degli eventi incidentali dovrebbe essere notevolmente ampia, la qual cosa non verificata nella realtà.

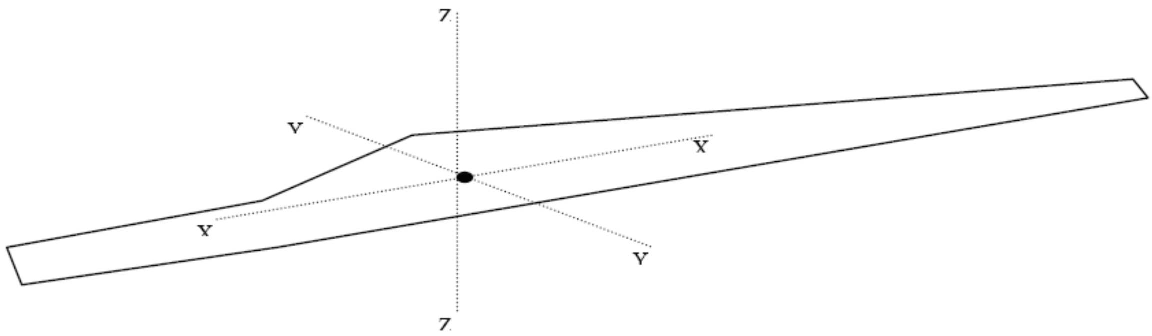


FIGURE 1 – SISTEMA DI COORDINATE USATO PER LA PALA

(YY – Flapwise, XX – Pitchwise, ZZ – Edgewise)

10. Riferimenti

"Blade throw calculation under normal operating conditions" VESTAS AS Denmark July 2001

11. Appendice

Caso 1	**Pala V80**	**Pala V90 1.8MW**	**Pala V82**	**Pala V52**	**Pala V90 2MW**	**Pala V90 3MW**
Velocità di rotazione	20	16.39	15.84	31	16.39	15.7
Tempo di volo	6.27	5.44	4.56	4.92	5.44	4.52
Distanza in plane	104.4	86.37	94.91	60.88	86.37	81.81
Distanza out of plane	80.1	64.73	45.31	79.95	64.73	50.82
Distanza Vettoriale	131.6	108	105	100.491	108	96.31

Gli altri casi sono stati studiati solo per la V80 quindi non risultano essere rilevanti per il caso in questione.