



Regione Campania
 Provincia di Benevento
 Comuni di San Giorgio La Molara e Molinara



Impianto di produzione di energia elettrica da fonte Eolica e relative opere di
 connessione potenza complessiva
 pari a 48,00 MW
Impianto Eolico "San Giorgio La Molara e Molinara"

Titolo:

RELAZIONE DI CALCOLO DELLA GITTATA

Numero documento:

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| | 01 | 20.05.2021 | EMISSIONE PER AUTORIZZAZIONE | A. FIORENTINO | D. LO RUSSO | M. LO RUSSO |
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ALLEGATI:

1. Calcolo della Gittata secondo decreto-dirigenziale n.° 44 del 12-02 -2021 della regione Campania;
2. Scheda tecnica Aerogeneratore Vestas V150.

1. PREMESSA

La presente relazione viene redatta con lo scopo di analizzare i valori stimati di gittata dell'impianto eolico da realizzarsi in agro dei comuni di San Giorgio La Molara (BN) e Molinara (BN). Nel presente studio si fa riferimento al layout con turbine del tipo VESTAS V150 di potenza singola pari a 6,00 MW.

Lo studio della rottura degli organi rotanti è stato svolto in conformità a quanto riportato nel decreto-dirigenziale n.° 44 del 12-02-2021 della Regione Campania.

2. CALCOLO DELLA GITTATA

Le caratteristiche dimensionali degli aerogeneratori del tipo VESTAS V150 di progetto sono di seguito riportate:

- Diametro rotore pari a 150 m e massima velocità di rotazione pari a 12,60 rpm :

| Rotor | V150 | V162 |
|--------------------------------|------------------------|----------------------|
| Diameter | 150 m | 162 m |
| Swept Area | 17671 m ² | 20612 m ² |
| Speed, Dynamic Operation Range | 4.9 - 12.6 rpm | 4.3 -12.1 rpm |
| Rotational Direction | Clockwise (front view) | |
| Orientation | Upwind | |
| Tilt | 6° | |
| Hub Coning | 6° | |
| No. of Blades | 3 | |
| Aerodynamic Brakes | Full feathering | |

- Lunghezza Pala (Blade) pari a 73,65 m:

| Blades | V150 | V162 |
|---------------------------|--|---------|
| Blade Length | 73.65 m | 79.35 m |
| Maximum Chord | 4.2 m | 4.3 m |
| Chord at 90% blade radius | 1.4 m | 1.68 m |
| Type Description | Structural airfoil shell | |
| Material | Fibreglass reinforced epoxy, carbon fibres and Solid Metal Tip (SMT) | |
| Blade Connection | Steel roots inserted | |
| Airfoils | High-lift profile | |

Si riportano di seguito i dati utilizzati per il calcolo:

| Tipo torre | Lunghezza pala [m] | Diametro rotore [m] | Massima velocità di rotazione [rpm] | Altezza al mozzo [m] | Altezza totale [m] | Potenza [MW] | Aerogeneratori |
|-------------|--------------------|---------------------|-------------------------------------|----------------------|--------------------|--------------|---|
| VESTAS V150 | 73,65 | 150 | 12,60 | 105 | 180 | 6,0 | WTG01- WTG02- WTG03 – WTG 04 – WTG 06 – WTG 07 – WTG 08 |

Il calcolo della gittata è stato svolto in conformità a quanto riportato nel decreto-dirigenziale n.44 del 12-02-2021 della Regione Campania.

Si riporta di seguito il valore massimo ottenuto e si rinvia all'allegato "1" per la trattazione completa:

| Angolo α | n | L | H _{torre} | V ₀ | V _{x0} | V _{y0} | H _g | D | r _g | g | Gittata teorica | X _g | L _g | Gittata Effettiva |
|-----------------|-------|-------|--------------------|----------------|-----------------|-----------------|----------------|-----|----------------|------|-----------------|----------------|----------------|-------------------|
| 66 | 12,60 | 73,65 | 105,00 | 34,17 | 31,22 | 13,90 | 128,66 | 150 | 25,90 | 9,81 | 199,60 | 10,53 | 49,10 | 248,70 |

Si aggiungono di seguito alcune ulteriori considerazioni basate su dati costruttivi di dettaglio forniti dal costruttore degli aerogeneratori, a dimostrazione del fatto che non è assolutamente verosimile che un frammento di pala si stacchi dalla stessa e venga scagliato a distanze significative, men che meno è verosimile l'ipotesi che un frammento di pala si stacchi dalla stessa e segua un moto assimilabile a quello di un proiettile scagliato con una velocità di partenza pari a quella della massima rotazione del rotore.

I dati disponibili alla data di stesura della presente fanno riferimento alle specifiche della macchina Vestas V136, essendo le specifiche della macchina Vestas V150 in fase di revisione da parte del costruttore, trattandosi di un nuovo modello. Le macchine fanno però parte della medesima piattaforma e, pertanto, le considerazioni di carattere descrittivo esposte di seguito sono assolutamente valide ed applicabili anche per la Vestas V150.

- 1) Innanzitutto è opportuno sottolineare che non è ipotizzabile la rottura improvvisa e di netto di un frammento della pala con proiezione dello stesso. Con riferimento al documento VESTAS 0065-1415 V00 - Technical description of a 67 m blade le caratteristiche strutturali di una pala sono schematizzabili come da figura seguente:

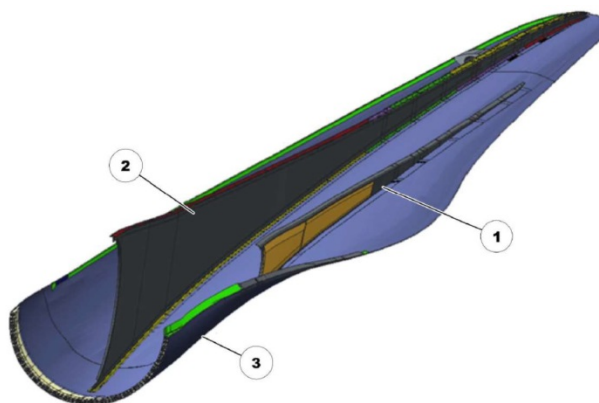


Figure 5.2: The main structural design of a 67 m blade

1 TE web
 2 Main web
 3 WW shell

Stralcio da VESTAS 0065-1415 V00 - Technical description of a 67 m blade

Ciascuna pala è quindi composta da:

- una superficie esterna (guscio o shell) fatta di materiale composito rinforzato in fibra di vetro e realizzata in due semigusci (LW shell e WW shell – mostrato in figura);
- due rinforzi interni (TE WEB e Main WEB), anch'essi in materiale composito ed internamente accoppiati ai gusci, che sostengono il carico aerodinamico della pala.

Da un punto di vista del dimensionamento strutturale, la progettazione della pala segue una serie di norme citate nel documento VESTAS "0067-7060_V00 - General Description 4MW Platform.pdf", par. 8.1. Per quel che concerne la presente analisi, si evidenzia che 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 IEC 61400-1, che impone l'utilizzo di condizioni particolarmente gravose. Le norme tecniche seguite in fase di dimensionamento sono tali da poter

rendere trascurabile l'ipotesi di un significativo danneggiamento della pala per tutta la vita utile degli Aerogeneratori (20 anni).

Ciononostante, nella remota ipotesi in cui ci sia un danneggiamento del materiale che compone i gusci o i rinforzi interni della pala, è assolutamente impossibile che si stacchi un frammento terminale della pala, dal momento che per come la pala è costruita non esistono giunzioni trasversali rispetto allo sviluppo della pala, ma esclusivamente la giunzione longitudinale tra i due semigusci. L'unica remota possibilità di danneggiamento riguarda una "separazione" parziale dei due semigusci. In questo scenario i rinforzi interni e la parte di semiguscio non danneggiata tratterrebbero la parte di guscio ipoteticamente rovinata e la macchina andrebbe automaticamente in pausa (v. osservazione al paragrafo seguente), evitando categoricamente la possibilità di proiezione di un frammento di pala alla massima velocità.

- 2) Secondariamente è necessario precisare che gli Aerogeneratori sono dotate di un sistema di sicurezza in grado di mandare in pausa la macchina a seguito di sbilanciamenti del rotore, eccessivo carico aerodinamico sulla pala o scostamenti sensibili tra velocità del vento e power curve.

Il danneggiamento di una pala che per quanto già spiegato evidentemente precede qualunque ipotesi di proiezione di un frammento della stessa farebbe funzionare il rotore in condizioni non bilanciate, e porterebbe necessariamente il sistema di sicurezza a rilevare almeno una delle tipologie di errori codificate come di seguito:

- "Tower Acceleration": dovuto a un forte sbilanciamento del rotore;
- "Power Curve Error": dovuto a un forte scostamento rispetto alla Power Curve attesa (che potrebbe essere generato da una variazione del profilo pala);
- "Tilt yaw Control": dovuto ad un eccessivo carico sulla pala misurato da un sensore.

Ciascuna di queste anomalie mette la macchina in pausa, e ferma quindi il rotore in attesa di un intervento tecnico. Non è pertanto possibile che il rotore giri alla sua massima velocità se una delle pale è danneggiata, e quindi che scagli un frammento di pala alla massima velocità ipotizzabile.

- 3) Si richiama inoltre il fatto che la macchina è dotata di un sistema di protezione contro le fulminazioni per la torre, per l'hub e per le pale. In particolare, con riferimento alle pale, si riporta di seguito uno stralcio dal documento VESTAS 0059-1120 V02 - Lightning protection and EMC che descrive il sistema di protezione dalle fulminazioni per macchine della stessa piattaforma delle V150. Analoga specifica è in fase di predisposizione per la V150.

The V126 and V136 blade

The lightning protection system for the blade consists of 4 main elements: tip protection receptors, surface protection, down conductor, and lightning band.

The tip protection receptors consist of a solid metal tip and an array of lightning receptors. The array of lightning receptors has 4 lines of receptors along the leading and trailing edge of the windward and leeward shells. The solid metal tip and the lightning receptors preferentially attract lightning which results in few lightning attachment events to the fibreglass shells or to the main portion of the blade. The solid metal tip and receptors are connected with an insulated, high-voltage cable.

A portion of the windward and leeward shells between the array of lightning receptors and the root is covered with an expanded metal foil. As with the solid metal tip and array of lightning receptors, the expanded metal foil provides a preferred lightning attachment point to protect the uncovered portion of the blade from direct lightning strikes. The expanded metal foil is connected to the array of lightning receptors and the down conductor.

The down conductor consists of insulated high-voltage cable routed along the trailing edges of the blade. The high-voltage cable are chosen in accordance with IEC 61400-24.

The down conductors terminate at the blade band at the root of the blade. The blade band serves as the interface to the LCTU. See [section 3.6 Protection of the main bearings, page 10](#), for more information about the LCTU.

Si evince che ciascuna pala è dotata:

- di un recettore in punta per i fulmini (solid metal tip);
- di un array di ricettori metallici (lightning receptors);
- di una rete metallica (expanded metal foil).

che sono collegati ad un cavo di scarico (down conductor).

Pertanto, in caso di fulminazione di una delle pale del rotore, la corrente di fulminazione sarebbe scaricata a terra e non comporterebbe alcun danneggiamento della pala. Valgono, ovviamente, in caso di ipotetico danneggiamento da parte di un fulmine, le considerazioni fatte ai punti 1 e 2.

Per quanto spiegato è del tutto evidente che, anche in caso di rottura del frammento di una pala, lo stesso rimarrebbe vincolato (sostanzialmente "appeso") alla restante parte della pala e non sarebbe proiettato. Peraltro anche nella assolutamente remota ipotesi di distacco del frammento, la maggior parte dell'energia cinetica sarebbe spesa per rompere il vincolo del frammento alla pala.

Indicazioni fornite dal costruttore, che ha una flotta operativa di oltre 60.000 unità, mostrano che il distacco di una parte di pala è un avvenimento la cui probabilità è trascurabile.



CALCOLO GITTATA MASSIMA

Il calcolo della Gittata è effettuato in funzione dell'angolo di inclinazione della pala rispetto all'orizzontale, in senso orario e ponendo l'angolo di 0°

Formula della Gittata Massima per angolo compreso tra 0° e 90°

$$G = \frac{v_{x0}(v_{y0} + \sqrt{v_{y0}^2 + 2 * g * HG})}{g} - X_g$$

dove : α = Angolo della pala rispetto all'orizzontale corrisponde all'angolo tra 91° e 180° dell'angolo velocità

$$H_G = H_{\text{torre}} + Y_g$$

$$Y_g = r_g \sin \alpha$$

r_g = posizione del baricentro pari ad 1/3 della lunghezza della pala più raggio mozzo

$$r_g = \frac{D}{2} - L + \frac{L}{3}$$

$X_g = r_g \cos \alpha$ posizione del baricentro della pala rispetto all'asse della torre

$$v_{x0} = v_0 \cos (90 - \alpha) = v_0 \sin \alpha$$

$$v_{y0} = v_0 \sin (90 - \alpha) = v_0 \cos \alpha$$

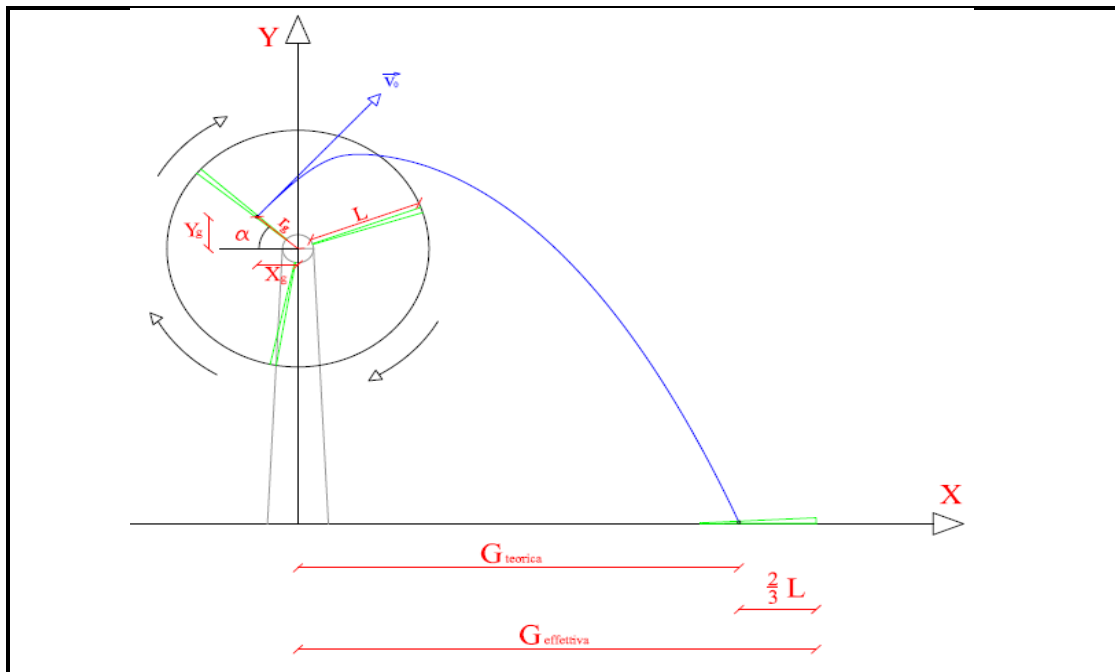
$$v_0 = \omega r_g = (2\pi n r_g)/60$$

n = numero di giri al minuto del rotore

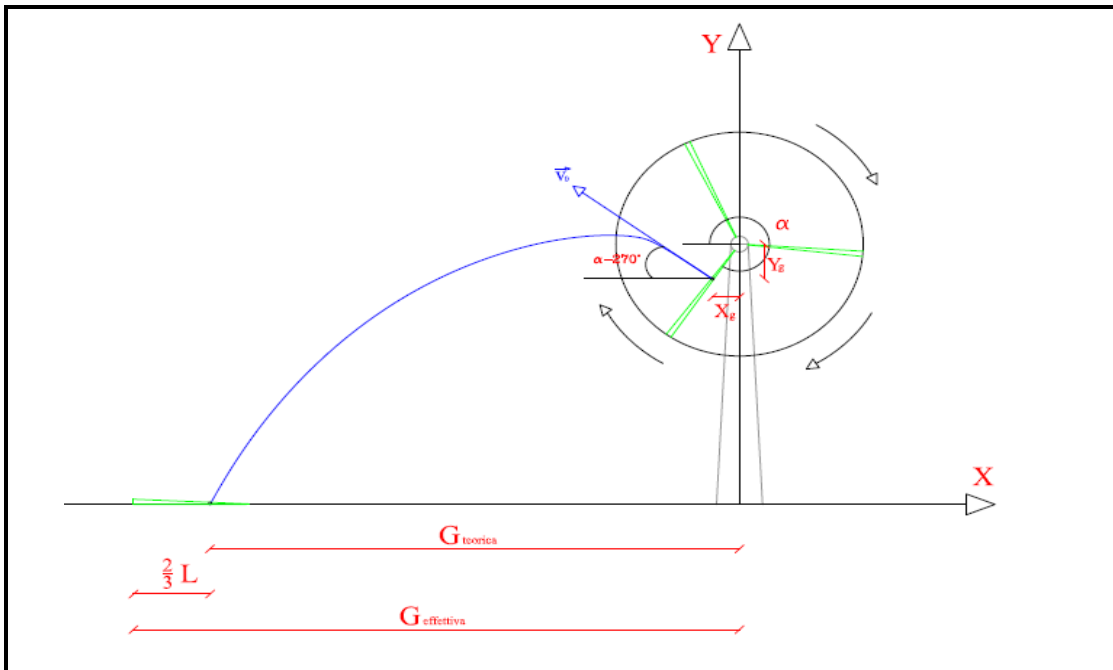
Gittata Effettiva

$$G_{\text{eff}} = G + L_g$$

Schema della Gittata per angolo compreso tra 0° e 90°



Schema della Gittata per angolo compreso tra 270° e 360°



Formula della Gittata Massima per angolo compreso tra 270° e 260°

$$G = \frac{v_{x0}(v_{y0} + \sqrt{v_{y0}^2 + 2 * g * HG})}{g} + X_g$$

Siccome abbiamo posto l'angolo 0° tra il 3° e 4° quadrante invertiamo il segno di v_{x0} e X_g

$$H_G = H_{torre} - Y_g$$

$$Y_g = r_g \sin(360 - \alpha) = -r_g \sin \alpha$$

r_g = posizione del baricentro pari ad 1/3 della lunghezza della pala più raggio mozzo

$$r_g = \frac{D}{2} - L + \frac{L}{3}$$

$$X_g = r_g \cos(360 - \alpha) = r_g \cos \alpha = -rg \cos \alpha$$

posizione del baricentro della pala rispetto all'asse della torre

$$v_{x0} = v_0 \cos(\alpha - 270) = -v_0 \sin \alpha = v_0 \sin \alpha$$

$$v_{y0} = v_0 \sin(\alpha - 270) = v_0 \cos \alpha$$

$$v_0 = \omega r_g = (2\pi n r_g)/60$$

n = numero di giri al minuto del rotore

v_{x0} negativo perché verso sinistra

Gittata Effettiva

$$G_{eff} = G - L_g$$

G negativo perché verso sinistra

da inserire

| | | |
|-------------------------------------|----------------------|-------|
| Numero di giri al minuto del rotore | n = | 12,6 |
| Lunghezza della pala in metri | L = | 73,65 |
| Altezza del mozzo in metri | H _{torre} = | 105 |

Se non è disponibile il valore di D, inserire almeno D=2L

| | | |
|---------------------|----|-----|
| Diametro del rotore | D= | 150 |
|---------------------|----|-----|

| Angolo α | n | L | H _{torre} | v ₀ | v _{x0} | v _{y0} | H _g | D | r _g | g | Gittata teorica | X _g | L _g | Gittata Effettiva |
|----------|-------|-------|--------------------|----------------|-----------------|-----------------|----------------|-----|----------------|------|-----------------|----------------|----------------|-------------------|
| 0 | 12,60 | 73,65 | 105,00 | 34,17 | 0,00 | 34,17 | 105,00 | 150 | 25,90 | 9,81 | -25,90 | 25,90 | 49,10 | 23,20 |
| 1 | 12,60 | 73,65 | 105,00 | 34,17 | 0,60 | 34,17 | 105,45 | 150 | 25,90 | 9,81 | -20,36 | 25,90 | 49,10 | 28,74 |
| 2 | 12,60 | 73,65 | 105,00 | 34,17 | 1,19 | 34,15 | 105,90 | 150 | 25,90 | 9,81 | -14,81 | 25,88 | 49,10 | 34,29 |
| 3 | 12,60 | 73,65 | 105,00 | 34,17 | 1,79 | 34,13 | 106,36 | 150 | 25,90 | 9,81 | -9,25 | 25,86 | 49,10 | 39,85 |
| 4 | 12,60 | 73,65 | 105,00 | 34,17 | 2,38 | 34,09 | 106,81 | 150 | 25,90 | 9,81 | -3,68 | 25,84 | 49,10 | 45,42 |
| 5 | 12,60 | 73,65 | 105,00 | 34,17 | 2,98 | 34,04 | 107,26 | 150 | 25,90 | 9,81 | 1,88 | 25,80 | 49,10 | 50,98 |
| 6 | 12,60 | 73,65 | 105,00 | 34,17 | 3,57 | 33,99 | 107,71 | 150 | 25,90 | 9,81 | 7,44 | 25,76 | 49,10 | 56,54 |
| 7 | 12,60 | 73,65 | 105,00 | 34,17 | 4,16 | 33,92 | 108,16 | 150 | 25,90 | 9,81 | 12,98 | 25,71 | 49,10 | 62,08 |
| 8 | 12,60 | 73,65 | 105,00 | 34,17 | 4,76 | 33,84 | 108,60 | 150 | 25,90 | 9,81 | 18,51 | 25,65 | 49,10 | 67,61 |
| 9 | 12,60 | 73,65 | 105,00 | 34,17 | 5,35 | 33,75 | 109,05 | 150 | 25,90 | 9,81 | 24,02 | 25,58 | 49,10 | 73,12 |
| 10 | 12,60 | 73,65 | 105,00 | 34,17 | 5,93 | 33,66 | 109,50 | 150 | 25,90 | 9,81 | 29,50 | 25,51 | 49,10 | 78,60 |
| 11 | 12,60 | 73,65 | 105,00 | 34,17 | 6,52 | 33,55 | 109,94 | 150 | 25,90 | 9,81 | 34,96 | 25,42 | 49,10 | 84,06 |
| 12 | 12,60 | 73,65 | 105,00 | 34,17 | 7,11 | 33,43 | 110,38 | 150 | 25,90 | 9,81 | 40,38 | 25,33 | 49,10 | 89,48 |
| 13 | 12,60 | 73,65 | 105,00 | 34,17 | 7,69 | 33,30 | 110,83 | 150 | 25,90 | 9,81 | 45,76 | 25,24 | 49,10 | 94,86 |
| 14 | 12,60 | 73,65 | 105,00 | 34,17 | 8,27 | 33,16 | 111,27 | 150 | 25,90 | 9,81 | 51,10 | 25,13 | 49,10 | 100,20 |
| 15 | 12,60 | 73,65 | 105,00 | 34,17 | 8,84 | 33,01 | 111,70 | 150 | 25,90 | 9,81 | 56,39 | 25,02 | 49,10 | 105,49 |
| 16 | 12,60 | 73,65 | 105,00 | 34,17 | 9,42 | 32,85 | 112,14 | 150 | 25,90 | 9,81 | 61,63 | 24,90 | 49,10 | 110,73 |
| 17 | 12,60 | 73,65 | 105,00 | 34,17 | 9,99 | 32,68 | 112,57 | 150 | 25,90 | 9,81 | 66,82 | 24,77 | 49,10 | 115,92 |
| Angolo α | n | L | H _{torre} | v ₀ | v _{x0} | v _{y0} | H _g | D | r _g | g | Gittata teorica | X _g | L _g | Gittata Effettiva |
| 18 | 12,60 | 73,65 | 105,00 | 34,17 | 10,56 | 32,50 | 113,00 | 150 | 25,90 | 9,81 | 71,95 | 24,63 | 49,10 | 121,05 |
| 19 | 12,60 | 73,65 | 105,00 | 34,17 | 11,13 | 32,31 | 113,43 | 150 | 25,90 | 9,81 | 77,01 | 24,49 | 49,10 | 126,11 |
| 20 | 12,60 | 73,65 | 105,00 | 34,17 | 11,69 | 32,11 | 113,86 | 150 | 25,90 | 9,81 | 82,01 | 24,34 | 49,10 | 131,11 |
| 21 | 12,60 | 73,65 | 105,00 | 34,17 | 12,25 | 31,90 | 114,28 | 150 | 25,90 | 9,81 | 86,93 | 24,18 | 49,10 | 136,03 |
| 22 | 12,60 | 73,65 | 105,00 | 34,17 | 12,80 | 31,69 | 114,70 | 150 | 25,90 | 9,81 | 91,78 | 24,01 | 49,10 | 140,88 |
| 23 | 12,60 | 73,65 | 105,00 | 34,17 | 13,35 | 31,46 | 115,12 | 150 | 25,90 | 9,81 | 96,55 | 23,84 | 49,10 | 145,65 |
| 24 | 12,60 | 73,65 | 105,00 | 34,17 | 13,90 | 31,22 | 115,53 | 150 | 25,90 | 9,81 | 101,25 | 23,66 | 49,10 | 150,35 |
| 25 | 12,60 | 73,65 | 105,00 | 34,17 | 14,44 | 30,97 | 115,95 | 150 | 25,90 | 9,81 | 105,85 | 23,47 | 49,10 | 154,95 |
| 26 | 12,60 | 73,65 | 105,00 | 34,17 | 14,98 | 30,72 | 116,35 | 150 | 25,90 | 9,81 | 110,37 | 23,28 | 49,10 | 159,47 |
| 27 | 12,60 | 73,65 | 105,00 | 34,17 | 15,51 | 30,45 | 116,76 | 150 | 25,90 | 9,81 | 114,80 | 23,08 | 49,10 | 163,90 |
| 28 | 12,60 | 73,65 | 105,00 | 34,17 | 16,04 | 30,17 | 117,16 | 150 | 25,90 | 9,81 | 119,13 | 22,87 | 49,10 | 168,23 |
| 29 | 12,60 | 73,65 | 105,00 | 34,17 | 16,57 | 29,89 | 117,56 | 150 | 25,90 | 9,81 | 123,36 | 22,65 | 49,10 | 172,46 |
| 30 | 12,60 | 73,65 | 105,00 | 34,17 | 17,09 | 29,60 | 117,95 | 150 | 25,90 | 9,81 | 127,50 | 22,43 | 49,10 | 176,60 |
| 31 | 12,60 | 73,65 | 105,00 | 34,17 | 17,60 | 29,29 | 118,34 | 150 | 25,90 | 9,81 | 131,53 | 22,20 | 49,10 | 180,63 |
| 32 | 12,60 | 73,65 | 105,00 | 34,17 | 18,11 | 28,98 | 118,72 | 150 | 25,90 | 9,81 | 135,46 | 21,96 | 49,10 | 184,56 |
| 33 | 12,60 | 73,65 | 105,00 | 34,17 | 18,61 | 28,66 | 119,11 | 150 | 25,90 | 9,81 | 139,28 | 21,72 | 49,10 | 188,38 |
| 34 | 12,60 | 73,65 | 105,00 | 34,17 | 19,11 | 28,33 | 119,48 | 150 | 25,90 | 9,81 | 143,00 | 21,47 | 49,10 | 192,10 |
| 35 | 12,60 | 73,65 | 105,00 | 34,17 | 19,60 | 27,99 | 119,86 | 150 | 25,90 | 9,81 | 146,60 | 21,22 | 49,10 | 195,70 |
| 36 | 12,60 | 73,65 | 105,00 | 34,17 | 20,09 | 27,65 | 120,22 | 150 | 25,90 | 9,81 | 150,09 | 20,95 | 49,10 | 199,19 |
| 37 | 12,60 | 73,65 | 105,00 | 34,17 | 20,57 | 27,29 | 120,59 | 150 | 25,90 | 9,81 | 153,47 | 20,68 | 49,10 | 202,57 |
| 38 | 12,60 | 73,65 | 105,00 | 34,17 | 21,04 | 26,93 | 120,95 | 150 | 25,90 | 9,81 | 156,73 | 20,41 | 49,10 | 205,83 |
| 39 | 12,60 | 73,65 | 105,00 | 34,17 | 21,51 | 26,56 | 121,30 | 150 | 25,90 | 9,81 | 159,87 | 20,13 | 49,10 | 208,97 |
| 40 | 12,60 | 73,65 | 105,00 | 34,17 | 21,97 | 26,18 | 121,65 | 150 | 25,90 | 9,81 | 162,89 | 19,84 | 49,10 | 211,99 |
| 41 | 12,60 | 73,65 | 105,00 | 34,17 | 22,42 | 25,79 | 121,99 | 150 | 25,90 | 9,81 | 165,80 | 19,55 | 49,10 | 214,90 |
| 42 | 12,60 | 73,65 | 105,00 | 34,17 | 22,87 | 25,40 | 122,33 | 150 | 25,90 | 9,81 | 168,58 | 19,25 | 49,10 | 217,68 |
| 43 | 12,60 | 73,65 | 105,00 | 34,17 | 23,31 | 24,99 | 122,66 | 150 | 25,90 | 9,81 | 171,24 | 18,94 | 49,10 | 220,34 |
| 44 | 12,60 | 73,65 | 105,00 | 34,17 | 23,74 | 24,58 | 122,99 | 150 | 25,90 | 9,81 | 173,79 | 18,63 | 49,10 | 222,89 |
| 45 | 12,60 | 73,65 | 105,00 | 34,17 | 24,16 | 24,16 | 123,31 | 150 | 25,90 | 9,81 | 176,21 | 18,31 | 49,10 | 225,31 |
| 46 | 12,60 | 73,65 | 105,00 | 34,17 | 24,58 | 23,74 | 123,63 | 150 | 25,90 | 9,81 | 178,50 | 17,99 | 49,10 | 227,60 |

| Angolo α | n | L | H _{torre} | v ₀ | v _{x0} | v _{y0} | H _g | D | r _g | g | Gittata teorica | X _g | L _g | Gittata Effettiva |
|-----------------|-------|-------|--------------------|----------------|-----------------|-----------------|----------------|-----|----------------|------|-----------------|----------------|----------------|-------------------|
| 47 | 12,60 | 73,65 | 105,00 | 34,17 | 24,99 | 23,31 | 123,94 | 150 | 25,90 | 9,81 | 180,68 | 17,66 | 49,10 | 229,78 |
| 48 | 12,60 | 73,65 | 105,00 | 34,17 | 25,40 | 22,87 | 124,25 | 150 | 25,90 | 9,81 | 182,73 | 17,33 | 49,10 | 231,83 |
| 49 | 12,60 | 73,65 | 105,00 | 34,17 | 25,79 | 22,42 | 124,55 | 150 | 25,90 | 9,81 | 184,66 | 16,99 | 49,10 | 233,76 |
| 50 | 12,60 | 73,65 | 105,00 | 34,17 | 26,18 | 21,97 | 124,84 | 150 | 25,90 | 9,81 | 186,47 | 16,65 | 49,10 | 235,57 |
| 51 | 12,60 | 73,65 | 105,00 | 34,17 | 26,56 | 21,51 | 125,13 | 150 | 25,90 | 9,81 | 188,16 | 16,30 | 49,10 | 237,26 |
| 52 | 12,60 | 73,65 | 105,00 | 34,17 | 26,93 | 21,04 | 125,41 | 150 | 25,90 | 9,81 | 189,72 | 15,95 | 49,10 | 238,82 |
| 53 | 12,60 | 73,65 | 105,00 | 34,17 | 27,29 | 20,57 | 125,68 | 150 | 25,90 | 9,81 | 191,17 | 15,59 | 49,10 | 240,27 |
| 54 | 12,60 | 73,65 | 105,00 | 34,17 | 27,65 | 20,09 | 125,95 | 150 | 25,90 | 9,81 | 192,49 | 15,22 | 49,10 | 241,59 |
| 55 | 12,60 | 73,65 | 105,00 | 34,17 | 27,99 | 19,60 | 126,22 | 150 | 25,90 | 9,81 | 193,70 | 14,86 | 49,10 | 242,80 |
| 56 | 12,60 | 73,65 | 105,00 | 34,17 | 28,33 | 19,11 | 126,47 | 150 | 25,90 | 9,81 | 194,79 | 14,48 | 49,10 | 243,89 |
| 57 | 12,60 | 73,65 | 105,00 | 34,17 | 28,66 | 18,61 | 126,72 | 150 | 25,90 | 9,81 | 195,77 | 14,11 | 49,10 | 244,87 |
| 58 | 12,60 | 73,65 | 105,00 | 34,17 | 28,98 | 18,11 | 126,96 | 150 | 25,90 | 9,81 | 196,63 | 13,72 | 49,10 | 245,73 |
| 59 | 12,60 | 73,65 | 105,00 | 34,17 | 29,29 | 17,60 | 127,20 | 150 | 25,90 | 9,81 | 197,38 | 13,34 | 49,10 | 246,48 |
| 60 | 12,60 | 73,65 | 105,00 | 34,17 | 29,60 | 17,09 | 127,43 | 150 | 25,90 | 9,81 | 198,02 | 12,95 | 49,10 | 247,12 |
| 61 | 12,60 | 73,65 | 105,00 | 34,17 | 29,89 | 16,57 | 127,65 | 150 | 25,90 | 9,81 | 198,54 | 12,56 | 49,10 | 247,64 |
| 62 | 12,60 | 73,65 | 105,00 | 34,17 | 30,17 | 16,04 | 127,87 | 150 | 25,90 | 9,81 | 198,96 | 12,16 | 49,10 | 248,06 |
| 63 | 12,60 | 73,65 | 105,00 | 34,17 | 30,45 | 15,51 | 128,08 | 150 | 25,90 | 9,81 | 199,28 | 11,76 | 49,10 | 248,38 |
| 64 | 12,60 | 73,65 | 105,00 | 34,17 | 30,72 | 14,98 | 128,28 | 150 | 25,90 | 9,81 | 199,49 | 11,35 | 49,10 | 248,59 |
| 65 | 12,60 | 73,65 | 105,00 | 34,17 | 30,97 | 14,44 | 128,47 | 150 | 25,90 | 9,81 | 199,59 | 10,95 | 49,10 | 248,69 |
| 66 | 12,60 | 73,65 | 105,00 | 34,17 | 31,22 | 13,90 | 128,66 | 150 | 25,90 | 9,81 | 199,60 | 10,53 | 49,10 | 248,70 |
| 67 | 12,60 | 73,65 | 105,00 | 34,17 | 31,46 | 13,35 | 128,84 | 150 | 25,90 | 9,81 | 199,51 | 10,12 | 49,10 | 248,61 |
| 68 | 12,60 | 73,65 | 105,00 | 34,17 | 31,69 | 12,80 | 129,01 | 150 | 25,90 | 9,81 | 199,33 | 9,70 | 49,10 | 248,43 |
| 69 | 12,60 | 73,65 | 105,00 | 34,17 | 31,90 | 12,25 | 129,18 | 150 | 25,90 | 9,81 | 199,05 | 9,28 | 49,10 | 248,15 |
| 70 | 12,60 | 73,65 | 105,00 | 34,17 | 32,11 | 11,69 | 129,34 | 150 | 25,90 | 9,81 | 198,69 | 8,86 | 49,10 | 247,79 |
| 71 | 12,60 | 73,65 | 105,00 | 34,17 | 32,31 | 11,13 | 129,49 | 150 | 25,90 | 9,81 | 198,23 | 8,43 | 49,10 | 247,33 |
| 72 | 12,60 | 73,65 | 105,00 | 34,17 | 32,50 | 10,56 | 129,63 | 150 | 25,90 | 9,81 | 197,70 | 8,00 | 49,10 | 246,80 |
| 73 | 12,60 | 73,65 | 105,00 | 34,17 | 32,68 | 9,99 | 129,77 | 150 | 25,90 | 9,81 | 197,07 | 7,57 | 49,10 | 246,17 |
| 74 | 12,60 | 73,65 | 105,00 | 34,17 | 32,85 | 9,42 | 129,90 | 150 | 25,90 | 9,81 | 196,37 | 7,14 | 49,10 | 245,47 |
| 75 | 12,60 | 73,65 | 105,00 | 34,17 | 33,01 | 8,84 | 130,02 | 150 | 25,90 | 9,81 | 195,60 | 6,70 | 49,10 | 244,70 |
| Angolo α | n | L | H _{torre} | v ₀ | v _{x0} | v _{y0} | H _g | D | r _g | g | Gittata teorica | X _g | L _g | Gittata Effettiva |
| 76 | 12,60 | 73,65 | 105,00 | 34,17 | 33,16 | 8,27 | 130,13 | 150 | 25,90 | 9,81 | 194,74 | 6,27 | 49,10 | 243,84 |
| 77 | 12,60 | 73,65 | 105,00 | 34,17 | 33,30 | 7,69 | 130,24 | 150 | 25,90 | 9,81 | 193,82 | 5,83 | 49,10 | 242,92 |
| 78 | 12,60 | 73,65 | 105,00 | 34,17 | 33,43 | 7,11 | 130,33 | 150 | 25,90 | 9,81 | 192,83 | 5,38 | 49,10 | 241,93 |
| 79 | 12,60 | 73,65 | 105,00 | 34,17 | 33,55 | 6,52 | 130,42 | 150 | 25,90 | 9,81 | 191,77 | 4,94 | 49,10 | 240,87 |
| 80 | 12,60 | 73,65 | 105,00 | 34,17 | 33,66 | 5,93 | 130,51 | 150 | 25,90 | 9,81 | 190,65 | 4,50 | 49,10 | 239,75 |
| 81 | 12,60 | 73,65 | 105,00 | 34,17 | 33,75 | 5,35 | 130,58 | 150 | 25,90 | 9,81 | 189,47 | 4,05 | 49,10 | 238,57 |
| 82 | 12,60 | 73,65 | 105,00 | 34,17 | 33,84 | 4,76 | 130,65 | 150 | 25,90 | 9,81 | 188,23 | 3,60 | 49,10 | 237,33 |
| 83 | 12,60 | 73,65 | 105,00 | 34,17 | 33,92 | 4,16 | 130,71 | 150 | 25,90 | 9,81 | 186,93 | 3,16 | 49,10 | 236,03 |
| 84 | 12,60 | 73,65 | 105,00 | 34,17 | 33,99 | 3,57 | 130,76 | 150 | 25,90 | 9,81 | 185,58 | 2,71 | 49,10 | 234,68 |
| 85 | 12,60 | 73,65 | 105,00 | 34,17 | 34,04 | 2,98 | 130,80 | 150 | 25,90 | 9,81 | 184,19 | 2,26 | 49,10 | 233,29 |
| 86 | 12,60 | 73,65 | 105,00 | 34,17 | 34,09 | 2,38 | 130,84 | 150 | 25,90 | 9,81 | 182,74 | 1,81 | 49,10 | 231,84 |
| 87 | 12,60 | 73,65 | 105,00 | 34,17 | 34,13 | 1,79 | 130,86 | 150 | 25,90 | 9,81 | 181,25 | 1,36 | 49,10 | 230,35 |
| 88 | 12,60 | 73,65 | 105,00 | 34,17 | 34,15 | 1,19 | 130,88 | 150 | 25,90 | 9,81 | 179,72 | 0,90 | 49,10 | 228,82 |
| 89 | 12,60 | 73,65 | 105,00 | 34,17 | 34,17 | 0,60 | 130,90 | 150 | 25,90 | 9,81 | 178,15 | 0,45 | 49,10 | 227,25 |
| 90 | 12,60 | 73,65 | 105,00 | 34,17 | 34,17 | 0,00 | 130,90 | 150 | 25,90 | 9,81 | 176,54 | 0,00 | 49,10 | 225,64 |

Per un angolo compreso tra 270° e 360° il valore della Gittata sarà negativo perché verso sinistra

| Angolo α | n | L | H _{torre} | v ₀ | v _{x0} | v _{y0} | H _g | D | r _g | g | Gittata teorica | X _g | L _g | Gittata Effettiva |
|-----------------|-------|-------|--------------------|----------------|-----------------|-----------------|----------------|-----|----------------|------|-----------------|----------------|----------------|-------------------|
| 270 | 12,60 | 73,65 | 105,00 | 34,17 | -34,17 | 0,00 | 79,10 | 150 | 25,90 | 9,81 | -137,24 | 0,00 | 49,10 | -186,34 |
| 271 | 12,60 | 73,65 | 105,00 | 34,17 | -34,17 | 0,60 | 79,10 | 150 | 25,90 | 9,81 | -139,76 | 0,45 | 49,10 | -188,86 |
| 272 | 12,60 | 73,65 | 105,00 | 34,17 | -34,15 | 1,19 | 79,12 | 150 | 25,90 | 9,81 | -142,28 | 0,90 | 49,10 | -191,38 |
| 273 | 12,60 | 73,65 | 105,00 | 34,17 | -34,13 | 1,79 | 79,14 | 150 | 25,90 | 9,81 | -144,80 | 1,36 | 49,10 | -193,90 |
| 274 | 12,60 | 73,65 | 105,00 | 34,17 | -34,09 | 2,38 | 79,16 | 150 | 25,90 | 9,81 | -147,30 | 1,81 | 49,10 | -196,40 |
| 275 | 12,60 | 73,65 | 105,00 | 34,17 | -34,04 | 2,98 | 79,20 | 150 | 25,90 | 9,81 | -149,78 | 2,26 | 49,10 | -198,88 |
| 276 | 12,60 | 73,65 | 105,00 | 34,17 | -33,99 | 3,57 | 79,24 | 150 | 25,90 | 9,81 | -152,25 | 2,71 | 49,10 | -201,35 |
| 277 | 12,60 | 73,65 | 105,00 | 34,17 | -33,92 | 4,16 | 79,29 | 150 | 25,90 | 9,81 | -154,69 | 3,16 | 49,10 | -203,79 |
| 278 | 12,60 | 73,65 | 105,00 | 34,17 | -33,84 | 4,76 | 79,35 | 150 | 25,90 | 9,81 | -157,11 | 3,60 | 49,10 | -206,21 |
| Angolo α | n | L | H _{torre} | v ₀ | v _{x0} | v _{y0} | H _g | D | r _g | g | Gittata teorica | X _g | L _g | Gittata Effettiva |
| 279 | 12,60 | 73,65 | 105,00 | 34,17 | -33,75 | 5,35 | 79,42 | 150 | 25,90 | 9,81 | -159,50 | 4,05 | 49,10 | -208,60 |
| 280 | 12,60 | 73,65 | 105,00 | 34,17 | -33,66 | 5,93 | 79,49 | 150 | 25,90 | 9,81 | -161,86 | 4,50 | 49,10 | -210,96 |
| 281 | 12,60 | 73,65 | 105,00 | 34,17 | -33,55 | 6,52 | 79,58 | 150 | 25,90 | 9,81 | -164,19 | 4,94 | 49,10 | -213,29 |
| 282 | 12,60 | 73,65 | 105,00 | 34,17 | -33,43 | 7,11 | 79,67 | 150 | 25,90 | 9,81 | -166,47 | 5,38 | 49,10 | -215,57 |
| 283 | 12,60 | 73,65 | 105,00 | 34,17 | -33,30 | 7,69 | 79,76 | 150 | 25,90 | 9,81 | -168,71 | 5,83 | 49,10 | -217,81 |
| 284 | 12,60 | 73,65 | 105,00 | 34,17 | -33,16 | 8,27 | 79,87 | 150 | 25,90 | 9,81 | -170,90 | 6,27 | 49,10 | -220,00 |
| 285 | 12,60 | 73,65 | 105,00 | 34,17 | -33,01 | 8,84 | 79,98 | 150 | 25,90 | 9,81 | -173,05 | 6,70 | 49,10 | -222,15 |
| 286 | 12,60 | 73,65 | 105,00 | 34,17 | -32,85 | 9,42 | 80,10 | 150 | 25,90 | 9,81 | -175,13 | 7,14 | 49,10 | -224,23 |
| 287 | 12,60 | 73,65 | 105,00 | 34,17 | -32,68 | 9,99 | 80,23 | 150 | 25,90 | 9,81 | -177,16 | 7,57 | 49,10 | -226,26 |
| 288 | 12,60 | 73,65 | 105,00 | 34,17 | -32,50 | 10,56 | 80,37 | 150 | 25,90 | 9,81 | -179,13 | 8,00 | 49,10 | -228,23 |
| 289 | 12,60 | 73,65 | 105,00 | 34,17 | -32,31 | 11,13 | 80,51 | 150 | 25,90 | 9,81 | -181,02 | 8,43 | 49,10 | -230,12 |
| 290 | 12,60 | 73,65 | 105,00 | 34,17 | -32,11 | 11,69 | 80,66 | 150 | 25,90 | 9,81 | -182,85 | 8,86 | 49,10 | -231,95 |

| | | | | | | | | | | | | | | |
|-----------------|-------|-------|--------------------|----------------|-----------------|-----------------|----------------|-----|----------------|------|-----------------|----------------|----------------|-------------------|
| 291 | 12,60 | 73,65 | 105,00 | 34,17 | -31,90 | 12,25 | 80,82 | 150 | 25,90 | 9,81 | -184,60 | 9,28 | 49,10 | -233,70 |
| 292 | 12,60 | 73,65 | 105,00 | 34,17 | -31,69 | 12,80 | 80,99 | 150 | 25,90 | 9,81 | -186,28 | 9,70 | 49,10 | -235,38 |
| 293 | 12,60 | 73,65 | 105,00 | 34,17 | -31,46 | 13,35 | 81,16 | 150 | 25,90 | 9,81 | -187,87 | 10,12 | 49,10 | -236,97 |
| 294 | 12,60 | 73,65 | 105,00 | 34,17 | -31,22 | 13,90 | 81,34 | 150 | 25,90 | 9,81 | -189,38 | 10,53 | 49,10 | -238,48 |
| 295 | 12,60 | 73,65 | 105,00 | 34,17 | -30,97 | 14,44 | 81,53 | 150 | 25,90 | 9,81 | -190,80 | 10,95 | 49,10 | -239,90 |
| 296 | 12,60 | 73,65 | 105,00 | 34,17 | -30,72 | 14,98 | 81,72 | 150 | 25,90 | 9,81 | -192,12 | 11,35 | 49,10 | -241,22 |
| 297 | 12,60 | 73,65 | 105,00 | 34,17 | -30,45 | 15,51 | 81,92 | 150 | 25,90 | 9,81 | -193,35 | 11,76 | 49,10 | -242,45 |
| 298 | 12,60 | 73,65 | 105,00 | 34,17 | -30,17 | 16,04 | 82,13 | 150 | 25,90 | 9,81 | -194,48 | 12,16 | 49,10 | -243,58 |
| 299 | 12,60 | 73,65 | 105,00 | 34,17 | -29,89 | 16,57 | 82,35 | 150 | 25,90 | 9,81 | -195,50 | 12,56 | 49,10 | -244,60 |
| 300 | 12,60 | 73,65 | 105,00 | 34,17 | -29,60 | 17,09 | 82,57 | 150 | 25,90 | 9,81 | -196,42 | 12,95 | 49,10 | -245,52 |
| 301 | 12,60 | 73,65 | 105,00 | 34,17 | -29,29 | 17,60 | 82,80 | 150 | 25,90 | 9,81 | -197,23 | 13,34 | 49,10 | -246,33 |
| 302 | 12,60 | 73,65 | 105,00 | 34,17 | -28,98 | 18,11 | 83,04 | 150 | 25,90 | 9,81 | -197,92 | 13,72 | 49,10 | -247,02 |
| 303 | 12,60 | 73,65 | 105,00 | 34,17 | -28,66 | 18,61 | 83,28 | 150 | 25,90 | 9,81 | -198,50 | 14,11 | 49,10 | -247,60 |
| 304 | 12,60 | 73,65 | 105,00 | 34,17 | -28,33 | 19,11 | 83,53 | 150 | 25,90 | 9,81 | -198,96 | 14,48 | 49,10 | -248,06 |
| 305 | 12,60 | 73,65 | 105,00 | 34,17 | -27,99 | 19,60 | 83,78 | 150 | 25,90 | 9,81 | -199,30 | 14,86 | 49,10 | -248,40 |
| 306 | 12,60 | 73,65 | 105,00 | 34,17 | -27,65 | 20,09 | 84,05 | 150 | 25,90 | 9,81 | -199,52 | 15,22 | 49,10 | -248,62 |
| 307 | 12,60 | 73,65 | 105,00 | 34,17 | -27,29 | 20,57 | 84,32 | 150 | 25,90 | 9,81 | -199,61 | 15,59 | 49,10 | -248,71 |
| Angolo α | n | L | H _{torre} | v ₀ | v _{x0} | v _{y0} | H _g | D | r _g | g | Gittata teorica | X _g | L _g | Gittata Effettiva |
| 308 | 12,60 | 73,65 | 105,00 | 34,17 | -26,93 | 21,04 | 84,59 | 150 | 25,90 | 9,81 | -199,57 | 15,95 | 49,10 | -248,67 |
| 309 | 12,60 | 73,65 | 105,00 | 34,17 | -26,56 | 21,51 | 84,87 | 150 | 25,90 | 9,81 | -199,40 | 16,30 | 49,10 | -248,50 |
| 310 | 12,60 | 73,65 | 105,00 | 34,17 | -26,18 | 21,97 | 85,16 | 150 | 25,90 | 9,81 | -199,10 | 16,65 | 49,10 | -248,20 |
| 311 | 12,60 | 73,65 | 105,00 | 34,17 | -25,79 | 22,42 | 85,45 | 150 | 25,90 | 9,81 | -198,67 | 16,99 | 49,10 | -247,77 |
| 312 | 12,60 | 73,65 | 105,00 | 34,17 | -25,40 | 22,87 | 85,75 | 150 | 25,90 | 9,81 | -198,10 | 17,33 | 49,10 | -247,20 |
| 313 | 12,60 | 73,65 | 105,00 | 34,17 | -24,99 | 23,31 | 86,06 | 150 | 25,90 | 9,81 | -197,40 | 17,66 | 49,10 | -246,50 |
| 314 | 12,60 | 73,65 | 105,00 | 34,17 | -24,58 | 23,74 | 86,37 | 150 | 25,90 | 9,81 | -196,56 | 17,99 | 49,10 | -245,66 |
| 315 | 12,60 | 73,65 | 105,00 | 34,17 | -24,16 | 24,16 | 86,69 | 150 | 25,90 | 9,81 | -195,58 | 18,31 | 49,10 | -244,68 |
| 316 | 12,60 | 73,65 | 105,00 | 34,17 | -23,74 | 24,58 | 87,01 | 150 | 25,90 | 9,81 | -194,46 | 18,63 | 49,10 | -243,56 |
| 317 | 12,60 | 73,65 | 105,00 | 34,17 | -23,31 | 24,99 | 87,34 | 150 | 25,90 | 9,81 | -193,20 | 18,94 | 49,10 | -242,30 |
| 318 | 12,60 | 73,65 | 105,00 | 34,17 | -22,87 | 25,40 | 87,67 | 150 | 25,90 | 9,81 | -191,81 | 19,25 | 49,10 | -240,91 |
| 319 | 12,60 | 73,65 | 105,00 | 34,17 | -22,42 | 25,79 | 88,01 | 150 | 25,90 | 9,81 | -190,27 | 19,55 | 49,10 | -239,37 |
| 320 | 12,60 | 73,65 | 105,00 | 34,17 | -21,97 | 26,18 | 88,35 | 150 | 25,90 | 9,81 | -188,59 | 19,84 | 49,10 | -237,69 |
| 321 | 12,60 | 73,65 | 105,00 | 34,17 | -21,51 | 26,56 | 88,70 | 150 | 25,90 | 9,81 | -186,77 | 20,13 | 49,10 | -235,87 |
| 322 | 12,60 | 73,65 | 105,00 | 34,17 | -21,04 | 26,93 | 89,05 | 150 | 25,90 | 9,81 | -184,81 | 20,41 | 49,10 | -233,91 |
| 323 | 12,60 | 73,65 | 105,00 | 34,17 | -20,57 | 27,29 | 89,41 | 150 | 25,90 | 9,81 | -182,71 | 20,68 | 49,10 | -231,81 |
| 324 | 12,60 | 73,65 | 105,00 | 34,17 | -20,09 | 27,65 | 89,78 | 150 | 25,90 | 9,81 | -180,47 | 20,95 | 49,10 | -229,57 |
| 325 | 12,60 | 73,65 | 105,00 | 34,17 | -19,60 | 27,99 | 90,14 | 150 | 25,90 | 9,81 | -178,10 | 21,22 | 49,10 | -227,20 |
| 326 | 12,60 | 73,65 | 105,00 | 34,17 | -19,11 | 28,33 | 90,52 | 150 | 25,90 | 9,81 | -175,58 | 21,47 | 49,10 | -224,68 |
| 327 | 12,60 | 73,65 | 105,00 | 34,17 | -18,61 | 28,66 | 90,89 | 150 | 25,90 | 9,81 | -172,93 | 21,72 | 49,10 | -222,03 |
| 328 | 12,60 | 73,65 | 105,00 | 34,17 | -18,11 | 28,98 | 91,28 | 150 | 25,90 | 9,81 | -170,15 | 21,96 | 49,10 | -219,25 |
| 329 | 12,60 | 73,65 | 105,00 | 34,17 | -17,60 | 29,29 | 91,66 | 150 | 25,90 | 9,81 | -167,23 | 22,20 | 49,10 | -216,33 |
| 330 | 12,60 | 73,65 | 105,00 | 34,17 | -17,09 | 29,60 | 92,05 | 150 | 25,90 | 9,81 | -164,18 | 22,43 | 49,10 | -213,28 |
| 331 | 12,60 | 73,65 | 105,00 | 34,17 | -16,57 | 29,89 | 92,44 | 150 | 25,90 | 9,81 | -161,01 | 22,65 | 49,10 | -210,11 |
| 332 | 12,60 | 73,65 | 105,00 | 34,17 | -16,04 | 30,17 | 92,84 | 150 | 25,90 | 9,81 | -157,70 | 22,87 | 49,10 | -206,80 |
| 333 | 12,60 | 73,65 | 105,00 | 34,17 | -15,51 | 30,45 | 93,24 | 150 | 25,90 | 9,81 | -154,27 | 23,08 | 49,10 | -203,37 |
| 334 | 12,60 | 73,65 | 105,00 | 34,17 | -14,98 | 30,72 | 93,65 | 150 | 25,90 | 9,81 | -150,71 | 23,28 | 49,10 | -199,81 |
| 335 | 12,60 | 73,65 | 105,00 | 34,17 | -14,44 | 30,97 | 94,05 | 150 | 25,90 | 9,81 | -147,04 | 23,47 | 49,10 | -196,14 |
| 336 | 12,60 | 73,65 | 105,00 | 34,17 | -13,90 | 31,22 | 94,47 | 150 | 25,90 | 9,81 | -143,25 | 23,66 | 49,10 | -192,35 |
| Angolo α | n | L | H _{torre} | v ₀ | v _{x0} | v _{y0} | H _g | D | r _g | g | Gittata teorica | X _g | L _g | Gittata Effettiva |
| 337 | 12,60 | 73,65 | 105,00 | 34,17 | -13,35 | 31,46 | 94,88 | 150 | 25,90 | 9,81 | -139,34 | 23,84 | 49,10 | -188,44 |
| 338 | 12,60 | 73,65 | 105,00 | 34,17 | -12,80 | 31,69 | 95,30 | 150 | 25,90 | 9,81 | -135,32 | 24,01 | 49,10 | -184,42 |
| 339 | 12,60 | 73,65 | 105,00 | 34,17 | -12,25 | 31,90 | 95,72 | 150 | 25,90 | 9,81 | -131,19 | 24,18 | 49,10 | -180,29 |
| 340 | 12,60 | 73,65 | 105,00 | 34,17 | -11,69 | 32,11 | 96,14 | 150 | 25,90 | 9,81 | -126,96 | 24,34 | 49,10 | -176,06 |
| 341 | 12,60 | 73,65 | 105,00 | 34,17 | -11,13 | 32,31 | 96,57 | 150 | 25,90 | 9,81 | -122,62 | 24,49 | 49,10 | -171,72 |
| 342 | 12,60 | 73,65 | 105,00 | 34,17 | -10,56 | 32,50 | 97,00 | 150 | 25,90 | 9,81 | -118,18 | 24,63 | 49,10 | -167,28 |
| 343 | 12,60 | 73,65 | 105,00 | 34,17 | -9,99 | 32,68 | 97,43 | 150 | 25,90 | 9,81 | -113,65 | 24,77 | 49,10 | -162,75 |
| 344 | 12,60 | 73,65 | 105,00 | 34,17 | -9,42 | 32,85 | 97,86 | 150 | 25,90 | 9,81 | -109,03 | 24,90 | 49,10 | -158,13 |
| 345 | 12,60 | 73,65 | 105,00 | 34,17 | -8,84 | 33,01 | 98,30 | 150 | 25,90 | 9,81 | -104,31 | 25,02 | 49,10 | -153,41 |
| 346 | 12,60 | 73,65 | 105,00 | 34,17 | -8,27 | 33,16 | 98,73 | 150 | 25,90 | 9,81 | -99,52 | 25,13 | 49,10 | -148,62 |
| 347 | 12,60 | 73,65 | 105,00 | 34,17 | -7,69 | 33,30 | 99,17 | 150 | 25,90 | 9,81 | -94,64 | 25,24 | 49,10 | -143,74 |
| 348 | 12,60 | 73,65 | 105,00 | 34,17 | -7,11 | 33,43 | 99,62 | 150 | 25,90 | 9,81 | -89,69 | 25,33 | 49,10 | -138,79 |
| 349 | 12,60 | 73,65 | 105,00 | 34,17 | -6,52 | 33,55 | 100,06 | 150 | 25,90 | 9,81 | -84,66 | 25,42 | 49,10 | -133,76 |
| 350 | 12,60 | 73,65 | 105,00 | 34,17 | -5,93 | 33,66 | 100,50 | 150 | 25,90 | 9,81 | -79,57 | 25,51 | 49,10 | -128,67 |
| 351 | 12,60 | 73,65 | 105,00 | 34,17 | -5,35 | 33,75 | 100,95 | 150 | 25,90 | 9,81 | -74,41 | 25,58 | 49,10 | -123,51 |
| 352 | 12,60 | 73,65 | 105,00 | 34,17 | -4,76 | 33,84 | 101,40 | 150 | 25,90 | 9,81 | -69,20 | 25,65 | 49,10 | -118,30 |
| 353 | 12,60 | 73,65 | 105,00 | 34,17 | -4,16 | 33,92 | 101,84 | 150 | 25,90 | 9,81 | -63,93 | 25,71 | 49,10 | -113,03 |
| 354 | 12,60 | 73,65 | 105,00 | 34,17 | -3,57 | 33,99 | 102,29 | 150 | 25,90 | 9,81 | -58,61 | 25,76 | 49,10 | -107,71 |
| 355 | 12,60 | 73,65 | 105,00 | 34,17 | -2,98 | 34,04 | 102,74 | 150 | 25,90 | 9,81 | -53,25 | 25,80 | 49,10 | -102,35 |
| 356 | 12,60 | 73,65 | 105,00 | 34,17 | -2,38 | 34,09 | 103,19 | 150 | 25,90 | 9,81 | -47,84 | 25,84 | 49,10 | -96,94 |
| 357 | 12,60 | 73,65 | 105,00 | 34,17 | -1,79 | 34,13 | 103,64 | 150 | 25,90 | 9,81 | -42,40 | 25,86 | 49,10 | -91,50 |
| 358 | 12,60 | 73,65 | 105,00 | 34,17 | -1,19 | 34,15 | 104,10 | 150 | 25,90 | 9,81 | -36,92 | 25,88 | 49,10 | -86,02 |
| 359 | 12,60 | 73,65 | 105,00 | 34,17 | -0,60 | 34,17 | 104,55 | 150 | 25,90 | 9,81 | -31,42 | 25,90 | 49,10 | -80,52 |
| 360 | 12,60 | 73,65 | 105,00 | 34,17 | 0,00 | 34,17 | 105,00 | 150 | 25,90 | 9,81 | -25,90 | 25,90 | 49,10 | -75,00 |

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General Description

EnVentus™

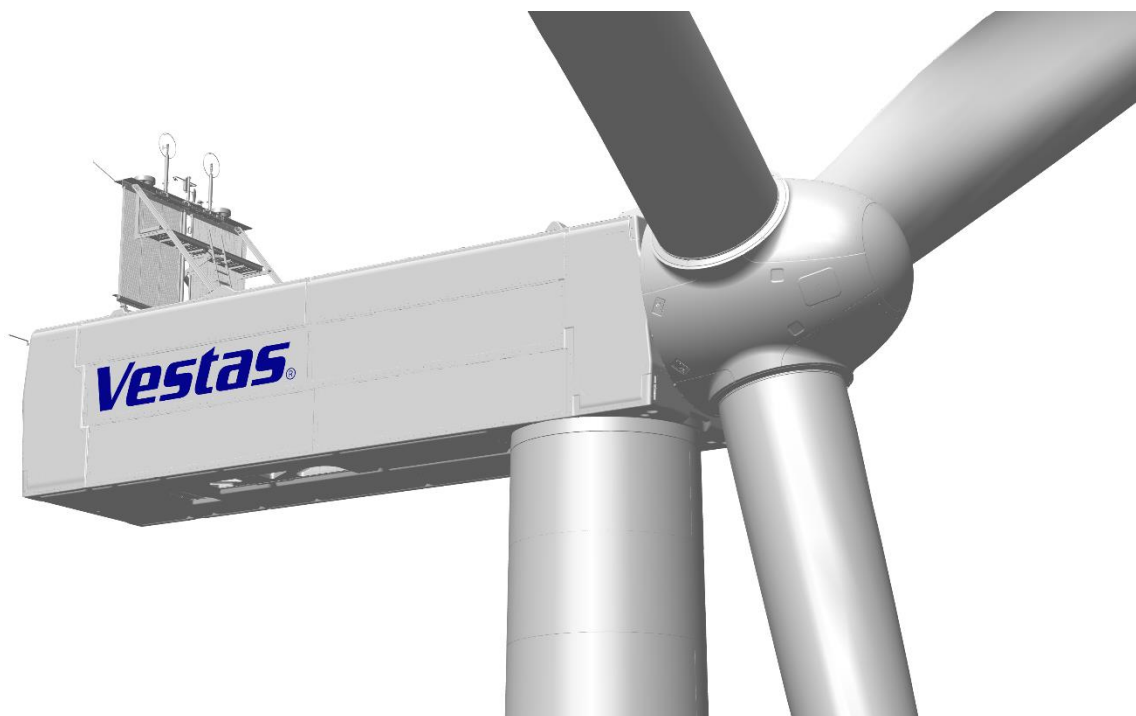


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Recipient acknowledges that (i) this General Description is provided for recipient's information only, and, does not create or constitute a warranty, guarantee, promise, commitment, or other representation (Commitment) by Vestas Wind Systems or any of its affiliated or subsidiary companies (Vestas), all of which are disclaimed by Vestas and (ii) any and all Commitments by Vestas to recipient as to this general description (or any of the contents herein) are to be contained exclusively in signed written contracts between recipient and Vestas, and not within this document.

See general reservations, notes and disclaimers (including, section 12, p. 36) to this general description.

1 Introduction

This *General Description* contains data and general descriptions of the EnVentus™ wind turbine range. The EnVentus™ turbine range consists of various turbine variants, with different rotors and ratings.

For turbine variant specific information related to wind class definitions and performance details, please refer to the accompanying Performance Specification document.

2 General Description

A wind turbine within the EnVentus™ turbine range is a pitch regulated upwind turbine with active yaw and a three-blade rotor.

The wind turbine utilises the OptiTip® concept and a power system based on a permanent magnet generator and full-scale converter. With these features, the wind turbines are able to operate the rotor at variable speed and thereby maintain the power output at or near rated power even in high wind speed. At low wind speed, the OptiTip® concept and the power system work together to maximise the power output by operating at the optimal rotor speed and pitch angle.

3 Mechanical Design

3.1 Rotor

The wind turbine is equipped with a rotor consisting of three blades and a hub. The blades are controlled by the microprocessor pitch control system OptiTip®. Based on the prevailing wind conditions, the blades are continuously positioned to optimise the pitch angle.

| Rotor | V150 | V162 |
|--------------------------------|------------------------|----------------------|
| Diameter | 150 m | 162 m |
| Swept Area | 17671 m ² | 20612 m ² |
| Speed, Dynamic Operation Range | 4.9 - 12.6 rpm | 4.3 -12.1 rpm |
| Rotational Direction | Clockwise (front view) | |
| Orientation | Upwind | |
| Tilt | 6° | |
| Hub Coning | 6° | |
| No. of Blades | 3 | |
| Aerodynamic Brakes | Full feathering | |

Table 3-1: Rotor data

3.2 Blades

The blades are made of carbon and fibreglass and consist of two airfoil shells with embedded structure.

| Blades | V150 | V162 |
|---------------------------|--|---------|
| Blade Length | 73.65 m | 79.35 m |
| Maximum Chord | 4.2 m | 4.3 m |
| Chord at 90% blade radius | 1.4 m | 1.68 m |
| Type Description | Structural airfoil shell | |
| Material | Fibreglass reinforced epoxy, carbon fibres and Solid Metal Tip (SMT) | |
| Blade Connection | Steel roots inserted | |
| Airfoils | High-lift profile | |

Table 3-2: Blades data

3.3 Blade Bearing

The blade bearings allow the blades to operate at varying pitch angles.

| | |
|--------------------|-------------------------------|
| Blade Bearing | |
| Blade bearing type | High-capacity slewing bearing |
| Lubrication | Manual grease lubrication |

Table 3-3: Blade bearing data

3.4 Pitch System

The turbine is equipped with a hydraulic, individual pitch system for each blade. Each pitch system is connected to the hydraulic rotating transfer unit in the nacelle by means of distributed hydraulic hoses and pipes. The hydraulic power unit is positioned in the nacelle.

Each pitch system consists of a hydraulic cylinder mounted to the hub and a piston rod mounted to the blade bearing. Valves facilitating operation of the pitch cylinder are installed on a pitch block bolted directly onto the cylinder.

| Pitch System | |
|--------------|----------------------|
| Type | Hydraulic |
| Number | 1 cylinder per blade |
| Range | -5° to 95° |

Table 3-4: Pitch system data

| Hydraulic System | |
|------------------|-----------------------------------|
| Main Pump | Redundant internal-gear oil pumps |
| Pressure | Max. 260 bar |
| Filtration | 3 µm (absolute) 40 µm in line |

Table 3-5: Hydraulic system data.

3.5 Hub

The hub supports the three blades and transfers the reaction loads and the torque to the Main Shaft. The hub structure also supports blade bearings and pitch cylinders.

| Hub | |
|----------|----------------|
| Type | Ball shell hub |
| Material | Cast iron |

Table 3-6: Hub data

3.6 Main Shaft

The main shaft transfers the reaction forces to the main bearing and the torque to the gearbox.

| Main Shaft | |
|------------------|--------------|
| Type Description | Hollow shaft |
| Material | Cast iron |

Table 3-7: Main shaft data

3.7 Main Bearing Housing

The main bearing housing carries the main bearings and is the connection point for the drive train system to the nacelle structure.

| Main Bearing Housing | |
|----------------------|-----------|
| Material | Cast iron |

Table 3-8: Main bearing housing data

3.8 Main Bearing

The main bearings constitute the main load transfer path for the rotor and drivetrain to the nacelle structure.

| Main Bearing | |
|--------------|------------------|
| Type | Rolling bearings |
| Lubrication | Oil circulation |

Table 3-9: Main bearing data

3.9 Gearbox

The main gear converts the rotation of the rotor to generator rotation.

| Gearbox | |
|-----------------------|--------------------------|
| Type | 2 Planetary stages |
| Gear House Material | Cast |
| Lubrication System | Pressure oil lubrication |
| Total Gear Oil Volume | 800-1000 L |
| Oil Cleanliness Codes | ISO 4406-/15/12 |

Table 3-10: Gearbox data

3.10 Generator Bearings

Generator bearings ensures a constant airgap between the generator rotor and stator. The bearings are arranged in an assembly that allows for up-tower service.

| Generator Bearing | |
|-------------------|------------------|
| Type | Rolling bearings |
| Lubrication | Oil circulation |

Table 3-11: Generator bearing data

3.11 Yaw System

The yaw system is an active system based on a pre-tensioned plain bearing.

| Yaw System | |
|----------------------|--|
| Type | Plain bearing system |
| Material | Forged yaw ring heat-treated. Plain bearings PETP |
| Yaw gear type | Multiple stages planetary gear |
| Yawing Speed (50 Hz) | Approx. 0.4°/sec. |
| Yawing Speed (60 Hz) | Approx. 0.5°/sec. |

Table 3-12: Yaw system data

3.12 Crane

The nacelle is equipped with an internal service crane (single system hoist).

| Crane | |
|------------------|--|
| Lifting Capacity | HH<149 m max 500 kg HH>149 m max 800 kg |

Table 3-13: Crane data

3.13 Towers

Tubular Steel Towers and Concrete Hybrid Towers (CHT) are available as standard for several WTG configuration and hub height options.

Tubular steel towers consist of flange joined steel sections.

Concrete Hybrid Towers consists of a concrete bottom part with a transition piece towards a tubular steel top. The concrete part is made of precast high strength concrete rings, and the tubular steel top is made of flange joined steel sections.

Towers includes modular internals, which are certified to relevant type approvals.

Available hub heights are listed in the Performance Specification for each turbine variant. Designated hub heights include a distance from tower top flange to centre of the hub of approximately 2.5m. For steel towers the designated hub height also includes a distance from the foundation section to the ground level of approximately 0.2 m depending on the thickness of the bottom flange.

For steel towers, raised foundations of up to 3 m can be made available on a site-specific basis subject to soil and project conditions which raises the hub height also by up to 3m.

Further WTG configuration and hub height options are developed as non-standard products on site-specific basis.

| Towers | |
|--------|--|
| Type | Tubular steel towers Larger diameter steel towers Concrete Hybrid Towers |

Table 3-14: Tower structure data

3.14 Nacelle Structure and Cover

The nacelle structure is in two parts and consists of a cast iron front part, the base frame, and a girder structure rear part, the rear structure. The base frame is the foundation for the drive train and transmits forces from the rotor to the tower through the yaw system. The bottom surface is machined and connected to the yaw bearing and the yaw gears are bolted to the base frame.

The crane girders are attached to the rear structure.

The nacelle cover is attached to the nacelle structure. The nacelle cover is made of fibreglass. Hatches are positioned in the floor for lowering or hoisting equipment to the nacelle and evacuation of personnel. The roof section is equipped with skylights.

The skylights can be opened from inside the nacelle to access the roof and from outside to access the nacelle. Access from the tower to the nacelle is through the base frame.

| Type Description | Material |
|------------------|------------------|
| Nacelle Cover | GRP |
| Base frame | Cast iron |
| Rear structure | Girder structure |

Table 3-15: Nacelle structure and cover data

3.15 Thermal Conditioning System

The thermal conditioning system consists of:

- A Liquid Cooling System
- The Vestas Cooler Top®
- Air cooling of the nacelle internal, and
- Air cooling of the converter including a filter function

3.15.1 Liquid Cooling

The liquid cooling system removes the heat losses from the gearbox, generator, hydraulic power unit, converter and the HV transformer.

The liquid cooling system pump unit includes a set of dynamic flow valves securing the right flow to the different systems. The pump unit also includes a heater for pre-heating the liquid in cold start-up situations, an electrical controlled valve for controlling the liquid temperature and a bypass filter for removal of particles in the cooling liquid.

3.15.2 Cooler Top®

The Vestas Cooler Top® located on top of the rear end of the nacelle. The Cooler Top® is a free flow cooler, thus ensuring that there are no electrical components in the thermal conditioning system located outside the nacelle. The Cooler Top® serves as base for the wind sensors, ice detection sensor, aviation lights and visibility sensor.

3.15.3 Nacelle Conditioning

Hot air generated by mechanical and electrical equipment is dissipated from the nacelle by a fan system located in the nacelle. The nacelle conditioning is taking ambient air into the nacelle and exhaust the hot air in the end of the nacelle.

3.15.4 Converter Air Cooling

The converter is both liquid and air cooled. The converter air cooling system comprises an air to air heat exchanger, which separates ambient air from converter internal air. The ambient air flow is provided by fan units delivering ambient air to the air to air heat exchanger through a filter. Fans on the internal side of the air to air exchanger provides the converter internal air circulation.

4 Electrical Design

4.1 Generator

The generator is a three-phase permanent magnet generator connected to the grid through a full-scale converter. The generator housing allows the circulation of cooling air within the stator and rotor.

The heat generated by the losses is removed by an air-to-water heat exchanger.

| <i>Generator</i> | |
|---|---|
| Type | Permanent Magnet Synchronous generator |
| Rated Power [P_N] | Up to 6250 kW (depending on turbine variant) |
| Frequency range [f_N] | 0-138 Hz |
| Voltage, Stator [U_{NS}] | 3 x 800 V (at rated speed) |
| Number of Poles | 36 |
| Winding Type | Form with Vacuum Pressurized Impregnation |
| Winding Connection | Star |
| Operational speed range | 0-460 rpm |
| Overspeed Limit (2 minutes) | 720 rpm |
| Temperature Sensors, Stator | PT100 sensors placed in the stator hot spots. |
| Insulation Class | H |
| Enclosure | IP54 |

Table 4-1: Generator data

4.2 Converter

The converter is a full-scale converter system controlling both the generator and the power delivered to the grid. The converter consists of 4 machine-side converter units and 4 line-side converter units operating in parallel with a common controller.

The converter controls conversion of variable frequency AC power from the generator into fixed frequency AC power with desired active and reactive power levels (and other grid connection parameters) suitable for the grid.

The converter is located in the nacelle and has a grid side voltage rating of 720 V. The generator side voltage rating is nominally 800 V but depends on generator speed.

| Converter | |
|---|-----------|
| Rated Apparent Power [S_N] @ 1.0 p.u. voltage | 6550 kVA |
| Rated Grid Voltage | 3 x 720 V |
| Rated Generator Voltage | 3 x 800 V |
| Rated Grid Current @ 1.0 p.u. voltage | 5250 A |
| Enclosure | IP54 |

Table 4-2: Converter data

4.3 HV Transformer

The transformer is a three-phase, three limb, two-winding, liquid immersed transformer. The transformer is equipped with an external water-cooling circuit. The insulation liquid used is environmentally friendly and low flammable.

The HV transformer is located in a separate locked room in the back of the nacelle. The transformer is designed according to IEC standards and is available in the following version:

- Eco-design complying to Tier 2 of European Ecodesign regulation No 548/2014 and No 2019/1783 set by the European Commission. Refer to Table 4-3.

4.3.1 General transformer data

| Transformer | | |
|---|---|------------------------|
| Type description | Eco-design liquid immersed transformer. | |
| Basic layout | 3 phase, 2 winding transformer | |
| Applied standards | IEC 60076-1, IEC 60076-16, IEC 61936-1 Commission Regulation No 548/2014 Commission Regulation No 2019/1783 | |
| Cooling method | KF/WF | |
| Rated power | 7000 kVA | 7300kVA |
| Expansion system | Open breathing | Sealed |
| No-load reactive power | ~35 kVAr ¹ | ~40 kVAr ¹ |
| Full load reactive power | ~700 kVAr ¹ | ~770 kVAr ¹ |
| No-load current | ~ 0.5 % ¹ | ~ 0.5 % ¹ |
| Positive sequence short-circuit impedance @ rated power, 95°C | 9.9 % ^{1,2} | 10.3 % ^{1,2} |

| Transformer | |
|--|--|
| Positive sequence short-circuit resistance@ rated power, 95°C | ~1.0 % ¹ ~1.0 % ¹ |
| Zero sequence short-circuit impedance@ rated power, 95°C | ~9.0 – 10 % ¹ ~9.4 – 10.4 % ¹ |
| Zero sequence short-circuit resistance@ rated power, 95°C | ~1.0 % ¹ ~1.0 % ¹ |
| Rated voltage, turbine side | |
| U_m 1.1kV | 0.720 kV |
| Rated voltage, grid side | |
| U_m 24.0kV | 19.1-22.0 kV |
| U_m 36.0kV | 22.1-33.0 kV |
| U_m 40.5kV | 33.1-36.0 kV |
| Insulation level AC / LI / LIC | |
| U_m 1.1kV | 3 / - / - kV |
| U_m 24.0kV | 50 / 125 / 138 kV |
| U_m 36.0kV | 70 / 170 / 187 kV |
| U_m 40.5kV | 80 / 200 / 220 kV |
| Off-circuit tap changer | None |
| Frequency | 50 Hz / 60 Hz |
| Vector group | Dyn11 |
| Inrush peak current | 5-8 x \hat{I}_n ¹ |
| Half crest time | ~ 0.6 - 1 s ¹ |
| Sound power level | ≤ 80 dB(A) ¹ |
| Average winding temperature rise | Class 120 (E) ≤65 K ¹ Class 130 (B) ≤75 K ¹ |
| Max altitude | 2000 m ¹ |
| Insulation system | Hybrid insulation system. Winding insulation: 120 (E), Thermally Upgrader Paper 130 (B), High temperature insulation Other materials can have different class. |
| Insulation liquid, Type/Fire point | Natural/Synthetic ester, biodegradable/ K-class (>300°C) |
| Insulation liquid, Amount | ≤ 3000 kg ¹ |
| Corrosion class | C3 ¹ |
| Weight | ≤11200 kg ¹ |
| Overvoltage protection | Plug-in surge arresters on HV bushings ¹ |
| High voltage bushings | Outer cone, interface C1 ¹ |

Table 4-3: General transformer data.

4.3.2 Eco-design – IEC 50 Hz/60 Hz version

The transformer loss limits are given at rated power as combination of load loss and no-load loss which shall fulfil the Peak Efficiency Index (PEI) of the Eco-design requirement.

The maximum losses are described by the PEI limit section of Figure 4-1 and Figure 4-2 and stretch over a range between Loss variant 1 and Loss variant 2. The loss variant values are selected based on energy loss optimization with the turbine user profile, hence the energy loss of transformers between Loss variant 1 and Loss variant 2 are comparable.

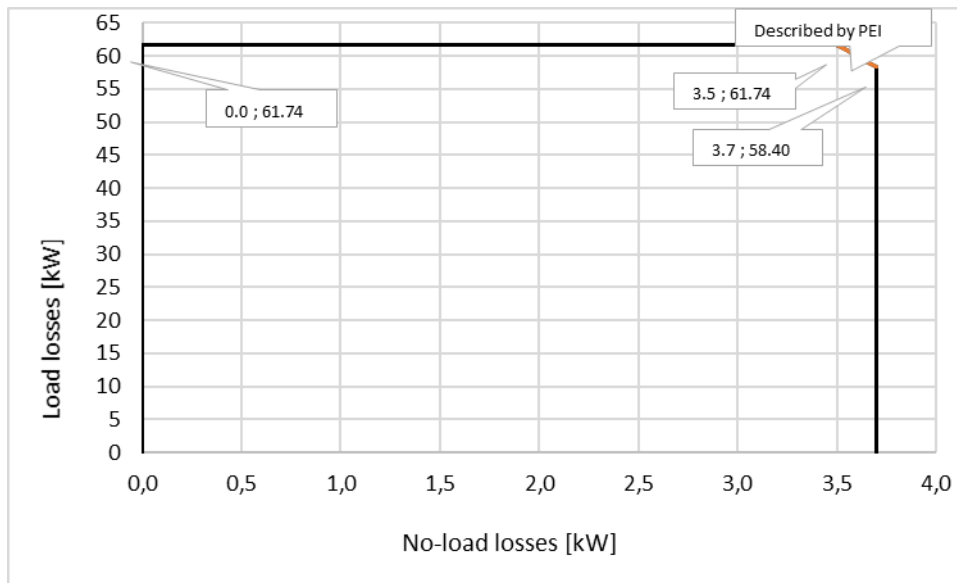


Figure 4-1: Transformer losses allowable area for 7000kVA variant

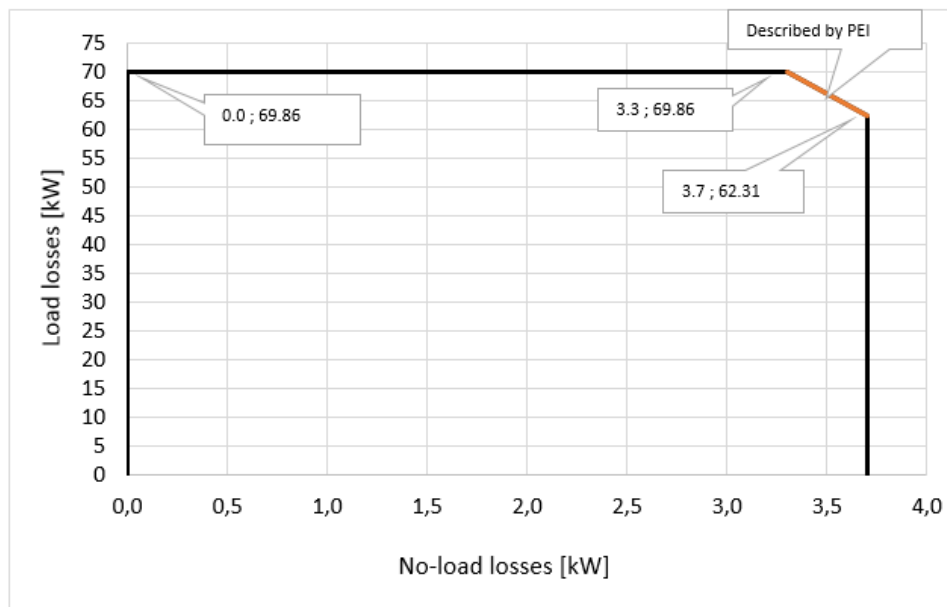


Figure 4-2: Transformer losses allowable area for 7300kVA variant

The actual load losses vary depending on the operational mode of the turbine, hence in *Table 4-4* and *Table 4-5*, the load losses are provided at different operational modes for the two loss variants. For further recalculation of load losses at different operation modes, refer to Figure 4-3.

| Transformer losses (rated power 7000kVA) | | | | |
|---|------------------------------------|-----------------------|-----------------------|-----------------------|
| Applied standards | Commission Regulation No 2019/1783 | | | |
| Peak Efficiency Index (PEI) | ≥ 99.580 | | | |
| Loss variant 1 | | | | |
| No-load loss | 3.50 kW | | | |
| Load loss @ power, 95°C | @7000kVA | @5600kVA | @5400kVA | @5000kVA |
| | ≤61.74kW | ≤39.51kW ³ | ≤36.74kW ³ | ≤31.50kW ³ |
| Loss variant 2 | | | | |
| No-load loss | 3.70 kW | | | |
| Load loss @ power, 95°C | @7000kVA | @5600kVA | @5400kVA | @5000kVA |
| | ≤58.40kW | ≤37.38kW ³ | ≤34.75kW ³ | ≤29.80kW ³ |

Table 4-4: Transformer losses for 7000kVA version

| Transformer losses (rated power 7300kVA) | | | |
|---|------------------------------------|-----------------------|-----------------------|
| Applied standards | Commission Regulation No 2019/1783 | | |
| Peak Efficiency Index (PEI) | ≥ 99.584 | | |
| Loss variant 1 | | | |
| No-load loss | 3.30 kW | | |
| Load loss @ power, 95°C | @7300kVA | @6000kVA | @5600kVA |
| | ≤69.86kW | ≤47.19kW ³ | ≤41.11kW ³ |
| Loss variant 2 | | | |
| No-load loss | 3.70 kW | | |
| Load loss @ power, 95°C | @7300kVA | @6000kVA | @5600kVA |
| | ≤62.31kW | ≤42.09kW ³ | ≤36.67kW ³ |

Table 4-5: Transformer losses for 7300kVA version



Figure 4-3: Transformer load losses scaling

- NOTE**
- ¹ Values are preliminary and could be subjected for change.
 - ² Subjected to standard IEC tolerances.
 - ³ Informative non-binding values based on operation mode.

4.4 HV Cables

The high-voltage cable runs from the transformer in the nacelle down the tower to the HV switchgear located at the bottom of the tower. The high-voltage cable can be of two different constructions:

- A three-core, rubber-insulated, halogen-free, high-voltage cable with a three-core split earth conductor.
- A four-core, rubber-insulated, halogen-free, high-voltage cable.

| HV Cables | |
|---|--|
| High-Voltage Cable Insulation Compound | Improved ethylene-propylene (EP) based material-EPR or high modulus or hard grade ethylene-propylene rubber-HEPR |
| Pre-terminated | T-Connector Type-C in transformer end. T-Connector Type-C in switchgear end. |
| Maximum Voltage | 24 kV for 19.1-22.0 kV rated voltage 42 kV for 22.1-36.0 kV rated voltage |
| Conductor Cross Sections | 3x70 + 70 mm ² (Single PE core) 3x70 + 3x70/3 mm ² (Split PE core) |

Table 4-6: HV cables data

4.5 HV Switchgear

A gas insulated switchgear is installed in the bottom of the tower as an integrated part of the turbine. Its controls are integrated with the turbine safety system, which monitors the condition of the switchgear and high voltage safety related devices in the turbine. This system is named 'Ready to Protect' and ensures all protection

devices are operational, whenever high voltage components in the turbine are energised. To ensure that the switchgear is always ready to trip, it is equipped with redundant trip circuits consisting of an active trip coil and an undervoltage trip coil.

In case of grid outage the circuit breaker will disconnect the turbine from the grid after an adjustable time.

When grid returns, all relevant protection devices will automatically be powered up via UPS.

When all the protection devices are operational, the circuit breaker will re-close after an adjustable time. The re-close functionality can furthermore be used to implement a sequential energization of a wind park, in order to avoid simultaneous inrush currents from all turbines once grid returns after an outage.

In case the circuit breaker has tripped due to a fault detection, the circuit breaker will be blocked for re-connection until a manual reset is performed.

In order to avoid unauthorized access to the transformer room during live condition, the earthing switch of the circuit breaker, contains a trapped-key interlock system with its counterpart installed on the access door to the transformer room.

The switchgear is available in three variants with increasing features, see Table 4-7. Beside the increase in features, the switchgear can be configured depending on the number of grid cables planned to enter the individual turbine. The design of the switchgear solution is optimized such grid cables can be connected to the switchgear even before the tower is installed and still maintain its protection toward weather conditions and internal condensation due to a gas tight packing.

The switchgear is available in an IEC version and in an IEEE version. The IEEE version is however only available in the highest voltage class. The electrical parameters of the switchgear are seen in Table 4-8 for the IEC version and in Table 4-9 for the IEEE version.

| HV Switchgear | | | |
|---|--------------|-------------------|-----------------|
| Variant | Basic | Streamline | Standard |
| IEC standards | ○ | ⊙ | ⊙ |
| IEEE standards | ⊙ | ○ | ⊙ |
| Vacuum circuit breaker panel | ⊙ | ⊙ | ⊙ |
| Overcurrent, short-circuit and earth fault protection | ⊙ | ⊙ | ⊙ |
| Disconnecter / earthing switch in circuit breaker panel | ⊙ | ⊙ | ⊙ |
| Voltage Presence Indicator System for circuit breaker | ⊙ | ⊙ | ⊙ |
| Voltage Presence Indicator System for grid cables | ⊙ | ⊙ | ⊙ |
| Double grid cable connection | ⊙ | ⊙ | ⊙ |
| Triple grid cable connection | ⊙ | ○ | ○ |
| Preconfigured relay settings | ⊙ | ⊙ | ⊙ |
| Turbine safety system integration | ⊙ | ⊙ | ⊙ |
| Redundant trip coil circuits | ⊙ | ⊙ | ⊙ |

| HV Switchgear | | | |
|--|--------------|-------------------|-----------------|
| Variant | Basic | Streamline | Standard |
| Trip coil supervision | ○ | ○ | ○ |
| Pendant remote control from outside of tower | ○ | ○ | ○ |
| Sequential energization | ○ | ○ | ○ |
| Reclose blocking function | ○ | ○ | ○ |
| Heating elements | ○ | ○ | ○ |
| Trapped-key interlock system for circuit breaker panel | ○ | ○ | ○ |
| Motor operation of circuit breaker | ○ | ○ | ○ |
| Cable panel for grid cables (configurable) | ○ | ○ | ○ |
| Switch disconnecter panels for grid cables – max three panels (configurable) | ○ | ○ | ○ |
| Earthing switch for grid cables | ○ | ○ | ○ |
| Internal arc classification | ○ | ○ | ○ |
| Supervision on MCB's | ○ | ○ | ○ |
| Motor operation of switch disconnecter | ○ | ○ | ○ |
| SCADA operation and feedback of circuit breaker | ○ | ○ | ○ |
| SCADA operation and feedback of switch disconnecter | ○ | ○ | ○ |

Table 4-7: HV switchgear variants and features

4.5.1 IEC 50/60Hz version

| HV Switchgear | |
|---|--|
| Type description | Gas Insulated Switchgear |
| Applied standards | IEC 62271-103 IEC 62271-1, 62271-100, 62271-102, 62271-200 |
| Insulation medium | SF ₆ |
| Rated voltage | |
| U_r 24.0kV | 19.1-22.0 kV |
| U_r 36.0kV | 22.1-33.0 kV |
| U_r 40.5kV | 33.1-36.0 kV |
| Rated insulation level AC // LI Common value / across isolation distance | |
| U_r 24.0kV | 50 / 60 // 125 / 145 kV |
| U_r 36.0kV | 70 / 80 // 170 / 195 kV |
| U_r 40.5kV | 85 / 90 // 185 / 215 kV |
| Rated frequency | 50 Hz / 60 Hz |
| Rated normal current | 630 A |
| Rated Short-time withstand current | |
| U_r 24.0kV | 20 kA |
| U_r 36.0kV | 25 kA |
| U_r 40.5kV | 25 kA |

| HV Switchgear | |
|---|--|
| Rated peak withstand current 50 / 60 Hz | |
| U_r 24.0kV | 50 / 52 kA |
| U_r 36.0kV | 62.5 / 65 kA |
| U_r 40.5kV | 62.5 / 65 kA |
| Rated duration of short-circuit | 1 s |
| Internal arc classification (option) | |
| U_r 24.0kV | IAC A FLR 20 kA, 1 s |
| U_r 36.0kV | IAC A FLR 25 kA, 1 s |
| U_r 40.5kV | IAC A FLR 25 kA, 1 s |
| Connection interface | Outside cone plug-in bushings, IEC interface C1. |
| Loss of service continuity category | LSC2 |
| Ingress protection | |
| Gas tank | IP 65 |
| Enclosure | IP 2X |
| LV cabinet | IP 3X |
| Corrosion class | C3 |

Table 4-8: HV switchgear data for IEC version

4.5.2 IEEE 60Hz version

| HV Switchgear | |
|---|---|
| Type description | Gas Insulated Switchgear |
| Applied standards | IEEE 37.20.3, IEEE C37.20.4, IEC 62271-200, ISO 12944. |
| Insulation medium | SF ₆ |
| Rated voltage | |
| U_r 38.0kV | 22.1-36.0 kV |
| Rated insulation level AC / LI | 70 / 150 kV |
| Rated frequency | 60 Hz |
| Rated normal current | 600 A |
| Rated Short-time withstand current | 25 kA |
| Rated peak withstand current | 65 kA |
| Rated duration of short-circuit | 1 s |
| Internal arc classification (option) | IAC A FLR 25 kA, 1 s |
| Connection interface grid cables | Outside cone plug-in bushings, IEEE 386 interface type deadbreak, 600A. |
| Ingress protection | |
| Gas tank | NEMA 4X / IP 65 |
| Enclosure | NEMA 2 / IP 2X |
| LV cabinet | NEMA 2 / IP 3X |
| Corrosion class | C3 |

Table 4-9: HV switchgear data for IEEE version

4.6 AUX System

The AUX system is supplied from a separate 720/400 V transformer located in the nacelle. The supply to this transformer primary side is provided from converter cabinet. All auxiliary loads in the turbine such as motors, pumps, fans and heaters are supplied from this system.

The control system (DCN's) is also supplied from the Auxiliary Power System in all areas of the turbine.

The 400 V supply from Nacelle is transferred to Tower controller cabinet, which is placed at the entrance platform of the turbine. This supply is then distributed for various 400 & 230 V loads such as service lift, working light system, additional / optional features & general-purpose loads, cabinet internal heating & ventilation. There is a 400/230 V control transformer placed inside tower cabinet which provides supply to the UPS cabinet which is placed very near to the tower cabinet.

There is a 400 V service inlet provided in the tower control cabinet to connect an external power source that allows some of the systems to operate during installation & maintenance / service activities.

The working & emergency light system in Tower & Nacelle is supplied from a small control cabinet which is placed in the entrance platform just beside the turbine entrance door. It is possible to add an optional battery cabinet to the light cabinet if extended back-up time is needed. The internal light in the hub is fed from built-in batteries in the light armature.

| Power Sockets | |
|--------------------------------------|--|
| Single Phase (Nacelle) | 230 V (16 A) (standard) 110 V (16 A) (option) |
| Single Phase (Tower Platforms) | 230 V (10 A) (standard) 110 V (16 A) (option) |
| Three Phase (Nacelle and Tower Base) | 3 x 400 V (16 A) |

Table 4-10: AUX system data

4.7 Wind Sensors

The turbine is equipped with one ultrasonic wind sensor and one mechanical wind vane. The sensors have built-in heaters to minimise interference from ice and snow.

4.8 Vestas Multi Processor (VMP) Controller

The turbine is controlled and monitored by the VMP8000 control system.

VMP8000 is a multiprocessor control system comprised of main controller, distributed control nodes, distributed IO nodes and ethernet switches and other network equipment. The main controller is placed in the tower bottom of the turbine. It runs the control algorithms of the turbine, as well as all IO communication.

The communications network is a time triggered Ethernet network (TTEthernet).

The VMP8000 control system serves the following main functions:

- Monitoring and supervision of overall operation.

- Synchronizing of the generator to the grid during connection sequence.
- Operating the wind turbine during various fault situations.
- Automatic yawing of the nacelle.
- OptiTip® - blade pitch control.
- Reactive power control and variable speed operation.
- Noise emission control.
- Monitoring of ambient conditions.
- Monitoring of the grid.
- Monitoring of the smoke detection system.

4.9 Uninterruptible Power Supply (UPS)

During grid outage, an UPS system will ensure power supply for specific components.

The UPS designed according to EN54 is built by 3 subsystems:

1. 230V AC UPS for all power backup to nacelle and hub control systems
2. 24V DC UPS for power backup to tower base control systems and ready to protect.
3. 230V AC UPS for power backup to internal lights in tower, nacelle and hub.

| UPS | | |
|---|--------------|--------------------|
| Backup Time | Standard | Optional |
| Control System* (230V AC and 24V DC UPS) | Up to 30 min | Up to 19.5 hours** |
| Emergency Lights (230V AC UPS) | 30 min | 60 min*** |
| Ready to protect (24V DC UPS) | 7 days | 37 days**** |

Table 4-11: UPS data

*The control system includes: the turbine controller (VMP8000), HV switchgear functions, and remote control system.

**Requires upgrade of the 230V UPS for control system with extra batteries.

***Requires upgrade of the 230V UPS for internal light with extra batteries.

****Requires upgrade of the 24V DC UPS with extra batteries.

It is possible to add optional battery cabinets with UPS for extended back-up time.

NOTE

For alternative backup times, consult Vestas.

5 Turbine Protection Systems

5.1 Braking Concept

The main brake on the turbine is aerodynamic. Stopping the turbine is done by full feathering the three blades (individually turning each blade). Each blade has a hydraulic accumulator to supply power for turning the blade.

In addition, there is a hydraulic activated mechanical disc brake on the medium-speed shaft of the gearbox. The mechanical brake is only used as a parking brake and when activating the emergency stop buttons.

5.2 Short Circuit Protections

| Breakers | Breaker for Aux. Power. | Breaker 1 for Converter Modules | Breaker 2 for Converter Modules |
|-----------------------------------|--------------------------|---------------------------------|---------------------------------|
| Breaking Capacity Icu, Ics | Icu 80 kA Ics 75% Icu | Icu 78 kA Ics 50% Icu | 78 kA Ics 50% Icu |
| Making Capacity Icm | 193 kA | 193 kA | 193 kA |

Table 5-1: Short circuit protection data

5.3 Overspeed Protection

The safety system integrated in the VMP8000 control system monitors the rotor speed, using a combination of sensors in the hub. In case of an overspeed situation, the safety system activates the hydraulic safety pitch system, which will feather the blades and bring the turbine to standstill.

| Overspeed Protection | |
|----------------------|-------------------|
| Sensor Type | MEMS |
| Trip Level | Variant dependent |

Table 5-2: Overspeed protection data

5.4 Arc Detection

The turbine is equipped with an Arc Detection system including multiple optical arc detection sensors placed in the HV transformer compartment and the converter cabinet. The Arc Detection system is connected to the turbine safety system ensuring immediate opening of the HV switchgear if an arc is detected.

5.5 Smoke Detection

The turbine is equipped with a Smoke Detection system including multiple smoke detection sensors placed in the nacelle, in the transformer compartment, in main electrical cabinets in the nacelle and in the tower base. The Smoke Detection system is connected to the turbine safety system ensuring immediate opening of the HV switchgear if smoke is detected.

5.6 Lightning Protection of Blades, Nacelle, Hub and Tower

The Lightning Protection System (LPS) helps protect the wind turbine against the physical damage caused by lightning strikes. The LPS consists of five main parts:

- Air termination system e.g. lightning receptors. All lightning receptor surfaces on the blades are unpainted, excluding the Solid Metal Tips (SMT).
- Down conducting system (a system to conduct the lightning current down through the wind turbine to help avoid or minimise damage to the LPS itself or other parts of the wind turbine).
- Protection against overvoltage and overcurrent.
- Shielding against magnetic and electrical fields.
- Earthing system.

| Lightning Protection Design Parameters | | | Protection Level I |
|--|---------------|---------|--------------------|
| Current Peak Value | i_{max} | [kA] | 200 |
| Impulse Charge | $Q_{impulse}$ | [C] | 100 |
| Total Charge | Q_{total} | [C] | 300 |
| Specific Energy | W/R | [MJ/Ω] | 10 |
| Average Steepness | di/dt | [kA/μs] | 200 |

Table 5-3: Lightning protection design parameters (IEC)

5.7 EMC

The turbine and related equipment fulfil the EU Electromagnetic Compatibility (EMC) legislation:

- DIRECTIVE 2014/30/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on the harmonisation of the laws of the Member States relating to electromagnetic compatibility.

The EMC performance is based on fulfilment of following standards:

Emission

- IEC/CISPR 11 at wind turbine level
- IEC 61000-6-4 for telecommunications

Immunity

- IEC 61000-6-2 for electronics installed
- IEC 61400-24 for lightning protection of electronics installed

Beside DIRECTIVE 2014/30/EU, electronics related to the functional safety evaluation shall fulfil

- IEC 62061 Safety on machinery (Directive 2006/42/EU Machinery)

5.8 RED (Radio Equipment Directive)

Related radio equipment installed in the turbine fulfil the EU legislation:

DIRECTIVE 2014/53/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 April 2014.

5.9 EMF (ElectroMagnetic Fields)

Electromagnetic fields in the wind turbine are identified to ensure safe stay for personnel during design, production, operation and service.

The following directive is basis for ensuring minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents.

DIRECTIVE 2013/35/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 June 2013.

5.10 Earthing

The Vestas Earthing System consists of individual earthing electrodes interconnected as one joint earthing system.

The Vestas Earthing System includes the TN-system and the Lightning Protection System for each wind turbine. It works as an earthing system for the medium voltage distribution system within the wind farm.

The Vestas Earthing System is adapted for the different types of turbine foundations. A separate set of documents describe the earthing system in detail, depending on the type of foundation.

In terms of lightning protection of the wind turbine, Vestas has no separate requirements for a certain minimum resistance to remote earth (measured in ohms) for this system. The earthing for the lightning protection system is based on the design and construction of the Vestas Earthing System.

A primary part of the Vestas Earthing System is the main earth bonding bar placed where all cables enter the wind turbine. All earthing electrodes are connected to this main earth bonding bar. Additionally, equipotential connections are made to all cables entering or leaving the wind turbine.

Requirements in the Vestas Earthing System specifications and work descriptions are minimum requirements from Vestas and IEC. Local and national requirements, as well as project requirements, may require additional measures.

5.11 Corrosion Protection

Classification of corrosion protection is according to ISO 12944-2.

| Corrosion Protection | External Areas | Internal Areas |
|----------------------|----------------|----------------|
| Nacelle | C5-M | C3 |
| Hub | C5-M | C3 |
| Tower | C5-I | C3 |

Table 5-5: Corrosion protection data for nacelle, hub, and tower

6 Safety

The safety specifications in this section provide limited general information about the safety features of the turbine and are not a substitute for Buyer and its agents taking all appropriate safety precautions, including but not limited to (a) complying with all applicable safety, operation, maintenance, and service agreements, instructions, and requirements, (b) complying with all safety-related laws, regulations, and ordinances, and (c) conducting all appropriate safety training and education.

6.1 Access

Access to the turbine from the outside is through a door located at the entrance platform approximately 3 meters above ground level. The door is equipped with a lock. Access to the top platform in the tower is by a ladder or service lift. Access to the nacelle from the top platform is by ladder. Access to the transformer room in the nacelle is controlled with an interlock. Unauthorised access to electrical switchboards and power panels in the turbine is prohibited according to IEC 60204-1 2006.

6.2 Escape

The primary evacuation route is through the tower via the tower ladder. In case the tower is blocked the secondary option is to descent directly from nacelle to ground via the service hatch.

It is a prerequisite that one or more descent devices are available in the turbine when there are people present in the turbine. A dedicated attachment point for a descent device is provided above the hatch.

For rescue the normal access routes can be used, in addition to this it is possible to lower an injured person to the ground through the crane hatch, the hatch in the spinner or from the nacelle roof.

The hatch in the roof can be opened from both the inside and outside. Evacuation from the service lift is by ladder.

An emergency response plan, placed in the turbine, describes evacuation and escape routes.

6.3 Rooms/Working Areas

The tower and nacelle are equipped with power sockets for electrical tools for service and maintenance of the turbine.

6.4 Floors, Platforms, Standing, and Working Places

All floors have anti-slip surfaces. There is one floor per tower section.

Rest platforms are provided at intervals of 9 metres along the tower ladder between platforms.

6.5 Service Lift

The service lift can be delivered as an option. Please contact Vestas for additional details.

6.6 Work restraint and fall arrest

The tower ladder is equipped with a fall arrest system, either a rigid anchor line or a wire.

The service areas in the turbines are equipped with anchor points. The anchor point may be used for work positioning, fall restraint, fall arrest and to attach a descent device to perform rescue or escape from the turbine.

Anchor points are coloured yellow and are tested to 22.5 kN.

6.7 Moving Parts, Guards, and Blocking Devices

All moving parts in the nacelle are shielded.

The turbine is equipped with a rotor lock to block the rotor and drive train.

Blocking the pitch of the blade can be done both automatically and manually with a mechanical blade lock.

6.8 Lights

The turbine is equipped with lights in the tower, nacelle and hub.

There is emergency light in case of the loss of electrical power.

6.9 Emergency Stop

There are emergency stop buttons in the nacelle, hub and tower.

6.10 Power Disconnection

The turbine is equipped with breakers to allow for disconnection from all power sources during inspection or maintenance. The switches are marked with signs and are located in the nacelle and bottom of the tower.

6.11 Fire Protection/First Aid

When there are people present in the turbine following fire and safety equipment must be available. In the nacelle: A first aid kit, a handheld fire extinguisher, and a fire blanket. In the tower a handheld fire extinguisher and a fire blanket at the entrance platform.

6.12 Warning Signs

Warning signs placed inside or on the turbine must be reviewed before operating or servicing the turbine.

6.13 Manuals and Warnings

The Vestas Corporate OH&S Manual and manuals for operation, maintenance and service of the turbine provide additional safety rules and information for operating, servicing or maintaining the turbine.

7 Environment

7.1 Chemicals

Chemicals used in the turbine are evaluated according to the Vestas Wind Systems A/S Environmental System certified according to ISO 14001:2015. The following chemicals are used in the turbine:

- Anti-freeze to help prevent the cooling system from freezing.
- Gear oil for lubricating the main bearing, gearbox and generator
- Hydraulic oil to pitch the blades and operate the brake.
- Grease for yaw system lubrication
- Transformer insulation liquid for HV transformer
- Various cleaning agents and chemicals for maintenance of the turbine.

8 Design Codes

8.1 Design Codes – Structural Design

The turbine design has been developed and verified in accordance with, but not limited to, the following main standards:

| Design Codes | |
|---|--|
| Nacelle and Hub | IEC 61400-1 Edition 4 EN 50308 |
| Tower (IEC) | IEC 61400-1 Edition 4 |
| Tower (DIBt) | IEC 61400-1 Edition 3 Richtlinie für Windenergieanlagen, DIBt, Ausgabe: Oktober 2012 |
| Blades | DNV-OS-J102 IEC 1024-1 IEC 60721-2-4 IEC 61400 (Part 1, 12 and 23) DEFU R25 DS/EN ISO 12944-2 |
| Gearbox | IEC 61400-4 |
| Generator | IEC 60034 (relevant parts) |
| Transformer | IEC 60076-11, IEC 60076-16, CENELEC HD637 S1 |
| Lightning Protection | IEC 61400-24:2010 |
| Safety of Machinery, Safety-related Parts of Control Systems | IEC 13849-1 |
| Safety of Machinery – Electrical Equipment of Machines | IEC 60204-1 |

Table 8-1: Design codes

9 Colours

9.1 Nacelle Colour

| Colour of Vestas Nacelles | |
|--------------------------------|-----------------------|
| Standard Nacelle Colour | RAL 7035 (light grey) |
| Standard Logo | Vestas |

Table 9-1: Colour, nacelle

9.2 Tower Colour

| Colour of Vestas Tower Section | | |
|---|--|---|
| | External: | Internal: |
| Standard Steel Tower | RAL 7035 (light grey) | RAL 9001 (cream white) |
| Standard Concrete Hybrid Tower | Concrete part: Unpainted concrete, corresponds approx. to RAL 7023 (concrete grey) Steel part: RAL 7035 (light grey) | Concrete part: Unpainted concrete, corresponds approx. to RAL 7023 (concrete grey) Steel part: RAL 9001 (cream white) |
| Option for Concrete Hybrid Tower | Concrete part can be painted with RAL 7035 (light grey) | |

Table 9-2: Colour, tower

9.3 Blade Colour

| Blade Colour | |
|--------------------------------|---|
| Standard Blade Colour | RAL 7035 (light grey). All lightning receptor surfaces on the blades are unpainted, excluding the Solid Metal Tips (SMT). |
| Tip-End Colour Variants | RAL 2009 (traffic orange), RAL 3020 (traffic red) |
| Gloss | < 30% ISO 2813 |

Table 9-3: Colour, blades

10 Operational Envelope and Performance Guidelines

Actual climate and site conditions have many variables and should be considered in evaluating actual turbine performance. The design and operating parameters set forth in this section do not constitute warranties, guarantees, or representations as to turbine performance at actual sites.

10.1 Climate and Site Conditions

Values refer to hub height:

| Extreme Design Parameters | |
|---|---------------|
| Wind Climate | All |
| Ambient Temperature Interval (Standard Temperature Turbine) | -40° to +50°C |

Table 10-1: Extreme design parameters

10.2 Operational Envelope – Temperature and Altitude

Values below refer to hub height and are determined by the sensors and control system of the turbine.

| Operational Envelope – Temperature | |
|--|---------------|
| Ambient Temperature Interval | -20° to +45°C |
| Ambient Temperature Interval (Low Temperature Operation) | -30° to +45°C |

Table 10-2: Operational envelope – temperature

NOTE

The wind turbine will stop producing power at ambient temperatures above 45°C.

For turbine variant specific information related to power performance within the operational envelope, please refer to turbine variant specific Performance Specifications.

For the low temperature operation of the wind turbine, consult Vestas for site specific evaluation.

The turbine is designed for use at altitudes up to 1000 m above sea level as standard and optional up to 2000 m above sea level.

10.3 Operational Envelope – Grid Connection

| Operational Envelope – Grid Connection | | |
|--|--|----------|
| Nominal Phase Voltage | [U _{NP}] | 720 V |
| Nominal Frequency | [f _N] | 50/60 Hz |
| Maximum Frequency Gradient | ±4 Hz/sec. | |
| Maximum Negative Sequence Voltage | 3% (connection) 2% (operation) | |
| Minimum Required Short Circuit Ratio at Turbine HV Connection | 5.0 (contact Vestas for lower SCR levels) | |
| Maximum Short Circuit Current Contribution | 1.05 p.u. (continuous) 1.45 p.u. (peak) | |

Table 10-3: Operational envelope – grid connection

The generator and the converter will be disconnected if*:

| Protection Settings | |
|---|------------|
| Voltage Above 110%** of Nominal for 1800 Seconds | 792 V |
| Voltage Above 116% of Nominal for 60 Seconds | 835 V |
| Voltage Above 125% of Nominal for 2 Seconds | 900 V |
| Voltage Above 136% of Nominal for 0.150 Seconds | 979 V |
| Voltage Below 90%** of Nominal for 180 Seconds (FRT) | 648 V |
| Voltage Below 85% of Nominal for 12 Seconds (FRT) | 612 V |
| Voltage Below 80% of Nominal for 4.8 Seconds (FRT) | 576 V |
| Frequency is Above 106% of Nominal for 0.2 Seconds | 53/63.6 Hz |
| Frequency is Below 94% of Nominal for 0.2 Seconds | 47/56.4 Hz |

Table 10-4: Generator and converter disconnecting values

NOTE

* Over the turbine lifetime, grid drop-outs are to occur at an average of no more than 50 times a year.

** The turbine may be configured for continuous operation @ +/- 13 % voltage. Reactive power capability is limited for these widened settings to an extent that is yet to be determined.

10.4 Operational Envelope – Reactive Power Capability

For turbine variant specific reactive power capability, please refer to the variant specific Performance Specification.

10.5 Performance – Fault Ride Through

The turbine is designed to stay connected during grid disturbances within the voltage tolerance curve as illustrated below:

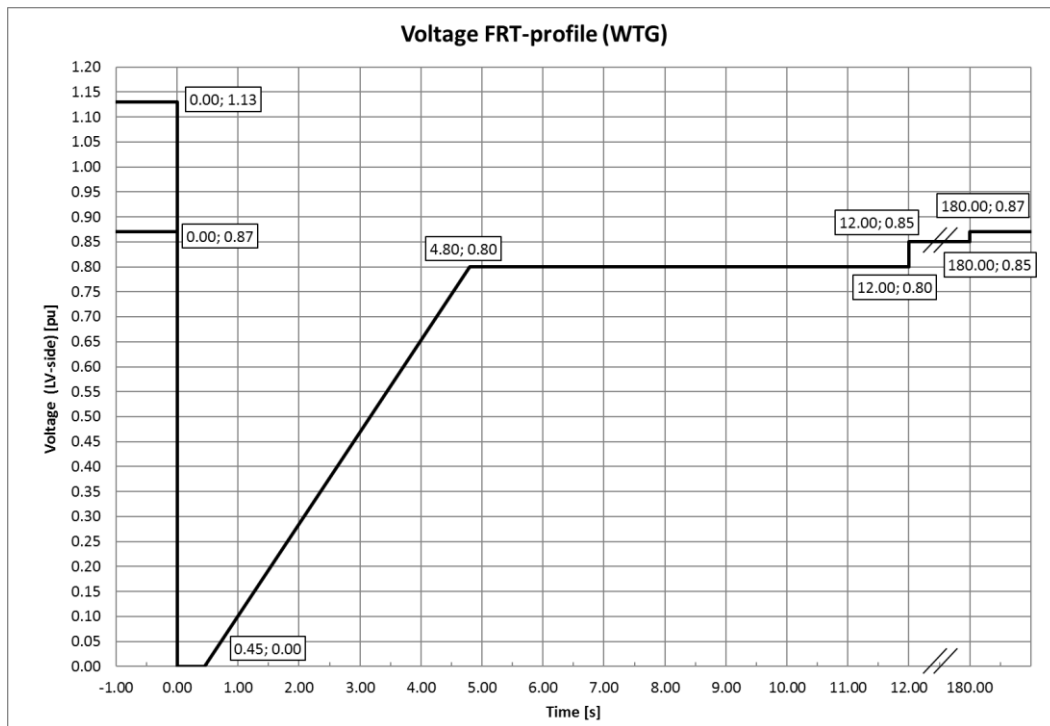


Figure 10-1: Low voltage tolerance curve for symmetrical and asymmetrical faults, where U represents voltage as measured on the grid.

For grid disturbances outside the tolerance curve in Figure 10-1, the turbine will be disconnected from the grid.

NOTE

All fault ride through capability values are preliminary and subject to change.

| Power Recovery Time | |
|--|---------------------|
| Power Recovery to 90% of Pre-Fault Level | Maximum 0.1 seconds |

Table 10-5: Power recovery time

10.6 Performance – Reactive Current Contribution

The reactive current contribution depends on whether the fault applied to the turbine is symmetrical or asymmetrical.

NOTE

All reactive current contribution values are preliminary and subject to change.

10.6.1 Symmetrical Reactive Current Contribution

During symmetrical voltage dips, the wind farm will inject reactive current to support the grid voltage. The reactive current injected is a function of the measured grid voltage.

The default value gives a reactive current part of 1 p.u. of the rated active current at the high voltage side of the HV transformer. Figure 10-2, indicates the reactive current contribution as a function of the voltage. The reactive current contribution is independent from the actual wind conditions and pre-fault power level. As seen in Figure 10-2, the default current injection slope is 2% reactive current increase per 1% voltage decrease. The slope can be parameterized between 0 and 10 to adapt to site specific requirements.

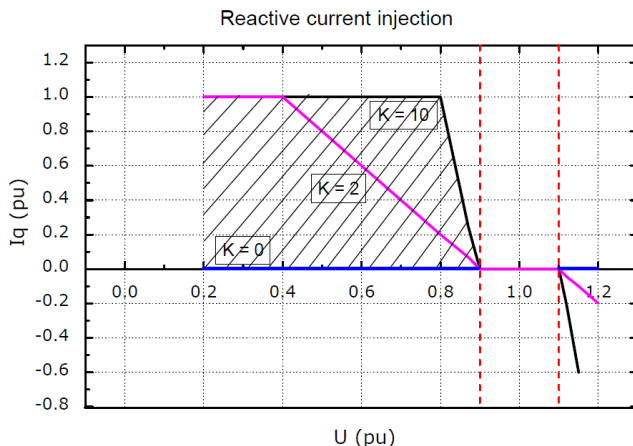


Figure 10-2: Reactive current injection

10.6.2 Asymmetrical Reactive Current Contribution

The injected current is based on the measured positive sequence voltage and the used K-factor. During asymmetrical voltage dips, the reactive current injection is limited to approximate 0.4 p.u. to limit the potential voltage increase on the healthy phases.

10.7 Performance – Multiple Voltage Dips

The turbine is designed to handle re-closure events and multiple voltage dips within a short period of time due to the fact that voltage dips are not evenly distributed during the year. For example, the turbine is designed to handle 10 voltage dips of duration of 200 ms, down to 20% voltage, within 30 minutes.

10.8 Performance – Active and Reactive Power Control

The turbine is designed for control of active and reactive power via the VestasOnline® SCADA system.

| Maximum Ramp Rates for External Control | |
|---|--|
| Active Power | 0.1 p.u./sec for max. power level change of 0.3 p.u. 0.3 p.u./sec for max. power level change of 0.1 p.u. |
| Reactive Power | 20 p.u./sec |

Table 10-6: Active/reactive power ramp rates (values are preliminary)

To support grid stability the turbine is capable to stay connected to the grid at active power references down to 10 % of nominal power for the turbine. For active power references below 10 % the turbine may disconnect from the grid.

10.9 Performance – Voltage Control

The turbine is designed for integration with VestasOnline® voltage control by utilising the turbine reactive power capability.

10.10 Performance – Frequency Control

The turbine can be configured to perform frequency control by decreasing the output power as a linear function of the grid frequency (over frequency). Dead band and slope for the frequency control function are configurable.

10.11 Distortion – Immunity

The turbine is able to connect with a pre-connection (background) voltage distortion level at the grid interface of 8% and operate with a post-connection voltage distortion level of 8%.

10.12 Main Contributors to Own Consumption

The consumption of electrical power by the wind turbine is defined as the power used by the wind turbine when it is not providing energy to the grid. This is defined in the control system as Production Generator 0 (zero).

The VMP8000 control system has a hibernate mode that reduces own consumption when possible. Similarly, cooling pumps may be turned off when the turbine idles.

The components in Table 10-7 have the largest influence on the own consumption of the wind turbine. The values given are maximum component consumption, but the average consumption can be lower depending on the actual conditions, the climate, the wind turbine output, the cut-off hours, etc.

| Main contributors to Own Consumption | V150 | V162 |
|--|--------------------------------|-------------|
| Hydraulic Motor | 2 x 22 kW | 3 x 18.5 kW |
| Yaw Motors | Max 23 kW | Max 26 kW |
| Generator Cooling Fans | 4 x 2.5 kW | |
| Water Heating | 10 kW | |
| Water Pumps | 4 kW + 7.5 kW | |
| Oil Pump for Gearbox Lubrication | 7.5 kW | |
| Controller Including Heating Elements for the Hydraulics and all Controllers | Approximately 3 kW | |
| HV Transformer No-load Loss | See section 4.3 HV Transformer | |

Table 10-7: Main contributors to own consumption data (values are preliminary).

11 Drawings

11.1 Structural Design – Illustration of Outer Dimensions

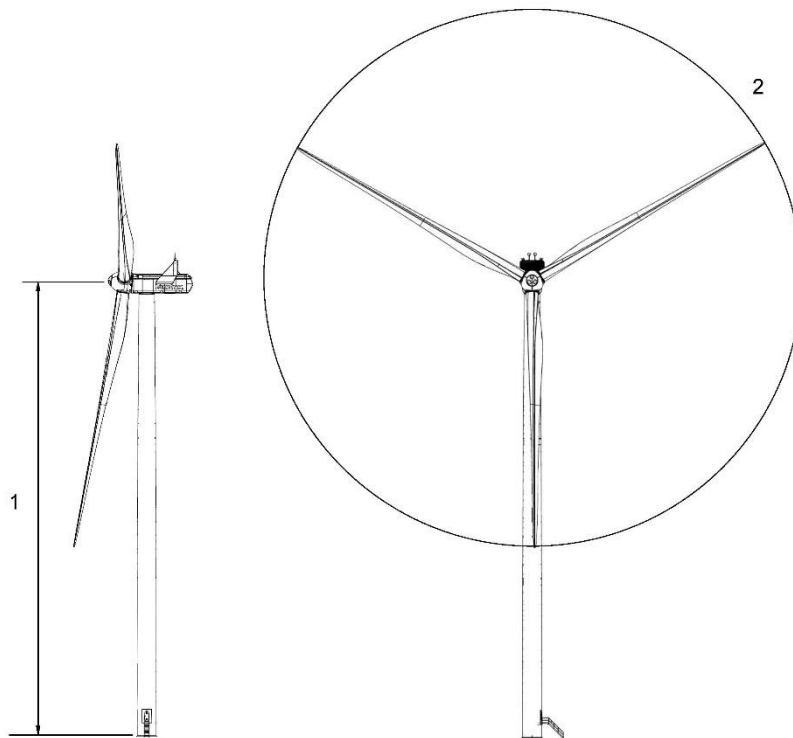


Figure 11-1: Illustration of outer dimensions – structure

- 1** Hub heights: See Performance Specification
- 2** Rotor diameter: 150/162 m

12 General Reservations, Notes and Disclaimers

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- The general descriptions in this document apply to the current version of the EnVentus™ turbines. Updated versions of the EnVentus™ turbines, which may be manufactured in the future, may differ from this general description. In the event that Vestas supplies an updated version of the EnVentus™ turbine, Vestas will provide an updated general description applicable to the updated version.
- Vestas recommends that the grid shall be as close to nominal as possible with limited variation in frequency and voltage.
- A certain time allowance for turbine warm-up must be expected following grid dropout and/or periods of very low ambient temperature.
- All listed start/stop parameters (e. g. wind speeds and temperatures) are equipped with hysteresis control. This can, in certain borderline situations, result in turbine stops even though the ambient conditions are within the listed operation parameters.
- The earthing system must comply with the minimum requirements from Vestas and be in accordance with local and national requirements and codes of standards.
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