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# Relazione sulla gittata massima degli elementi rotanti

Progetto definitivo

Impianto eolico in agro di Matera

Comune di Matera (MT)

Località "Annunziata"

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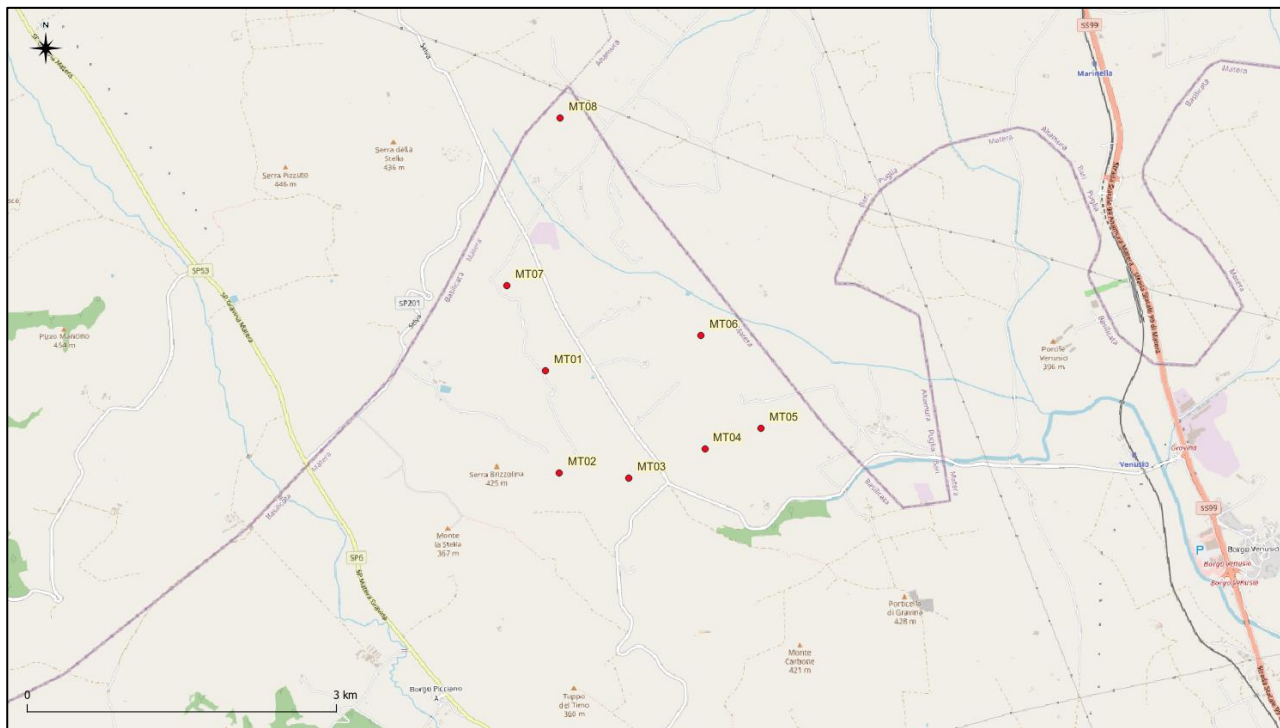
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## 1 DESCRIZIONE DELL'INTERVENTO

La presente relazione contiene l'analisi della Gittata massima degli elementi rotanti per gli aerogeneratori di un progetto per la realizzazione di un impianto eolico in Agro del Comune di Matera (MT), costituito da 8 aerogeneratori tripala (WTG) ad asse orizzontale, ciascuno di potenza nominale pari a 6,2 MW, per una potenza elettrica complessiva pari a 49,6 MW.



*Inquadramento a scala ampia dell'area di intervento con limiti comunali*

Di seguito è riportato un inquadramento su ortofoto del layout dell'impianto, in cui sono mostrate le posizioni degli aerogeneratori, la viabilità di nuova realizzazione ed il percorso del cavidotto di connessione alla rete elettrica nazionale.



*Inquadramento a scala ridotta dell'area di intervento*

Gli aerogeneratori saranno ubicati all'interno dei limiti amministrativi del Comune di Matera (MT). Si riportano di seguito le coordinate dei punti di installazione delle macchine previste in progetto.

ID	X	Y	Comune	Foglio	Particella
MT01	626548	4510766	MATERA	1	94
MT02	626756	4509805	MATERA	10	185
MT03	627347	4509769	MATERA	11	44
MT04	628086	4510049	MATERA	11	92
MT05	628630	4510252	MATERA	11	138
MT06	628048	4511148	MATERA	2	474
MT07	626271	4511684	MATERA	1	63
MT08	626683	4513259	MATERA	2	69

## 2 INQUADRAMENTO DEL PROBLEMA

La rottura accidentale di un elemento rotante (la pala o un frammento della stessa) di un aerogeneratore ad asse orizzontale può essere considerato un evento raro, in considerazione della tecnologia costruttiva ed ai materiali impiegati per la realizzazione delle pale stesse.

Tuttavia, al fine della sicurezza, la stima della gittata massima di un elemento rotante assume un'importanza rilevante per la progettazione e l'esercizio di un impianto eolico.

Le pale dei rotori di progetto sono realizzate in fibra di vetro rinforzato con materiali plastici quali il poliestere o le fibre epossidiche.

L'utilizzo di questi materiali limita sino a quasi ad annullare la probabilità di distacco di parti della pala mentre la stessa è in rotazione: anche in caso di gravi rotture le fibre che compongono la pala la mantengono, di fatto, unita in un unico pezzo (seppure gravemente danneggiato), ed i sistemi di controllo dell'aerogeneratore riducono pressoché istantaneamente la velocità di rotazione, eliminando la possibilità che un frammento di pala si stacchi e venga proiettato verso l'alto.

La statistica riporta fra le maggiori cause di danno quelle prodotte direttamente o indirettamente dalle fulminazioni.

Proprio per questo motivo il sistema navicella-rotore-torre tubolare sarà protetto dalla fulminazione in accordo alla norma IEC 61400-24 – livello I.

Pertanto possiamo sicuramente affermare che la probabilità che si produca un danno al sistema con successivi incidenti è del tutto trascurabile.

Il problema del calcolo della gittata di elementi rotanti è stato analizzato principalmente dal costruttore VESTAS<sup>1</sup>.

Nello studio citato la VESTAS ha determinato la distanza che la pala di un aerogeneratore raggiunge in caso di distacco dal mozzo mentre la pala è in rotazione per otto modelli di aerogeneratori, aventi lunghezza delle pale da 25 a 54,6 metri e velocità di rotazione da 26rpm a 17.7 rpm (ovviamente con gli aerogeneratori aventi pale di maggiore dimensione che funzionano a velocità di rotazione inferiori). Nello studio sono state considerate tre condizioni:

- moto in assenza di attrito dell'aria;
- moto in presenza di attrito dell'aria
- moto in presenza di attrito dell'aria e di rotazioni intorno agli assi della pala.

Come riportato nello studio, la prima condizione di carico è quella che dà la massima gittata, ma in realtà le forze di resistenza che si esercitano sulla pala fanno sì che la gittata reale sia inferiore di circa il 20%.

I risultati dello studio della VESTAS sono stati che, in ipotesi conservative la gittata massima per i modelli testati, diminuiva sostanzialmente all'aumentare delle dimensioni delle pale e del diminuire del numero di giri.

Fa eccezione, come si può notare, il caso della V112 3MW per la quale è stata calcolata una gittata di 147 metri, ma ciò è dovuto al fatto che l'altezza del mozzo è più elevata (119 metri) e che la velocità di rotazione è comunque più elevata rispetto alle V82, V90 e V100.

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<sup>1</sup> VESTAS - *Calcolo della traiettoria di una pala eolica in condizioni nominali di funzionamento*

Tabella 1 – Gittata calcolata nello studio Vestas citato per varie tipologie di aerogeneratore

Modello	Lunghezza pala	velocità rotazione	altezza mozzo	gittata
	<i>m</i>	<i>rpm</i>	<i>m</i>	<i>m</i>
V80 - 2MW	39	19,2	80	125
V52 - 850kW	26	25	75	130
V82 - 1,65	40	14,4	78	103
V90-2MW	44	14,9	105	118
V90-3MW	44	16,1	105	77
V100 - 1,8MW	49	16,6	95	104
V112 - 3MW	54,6	17,7	119	147

Si nota immediatamente che la massima gittata calcolata è inferiore ai 150 metri per tutte le tipologie di aerogeneratori oggetto di studio.

### 3 STUDIO DEL PROBLEMA PER IL CASO DI SPECIE

Uno studio rigoroso del problema della gittata degli elementi rotanti richiede la conoscenza di elementi progettuali che sono in possesso unicamente del costruttore delle turbine (tra questi, in particolare, l'evoluzione delle sezioni, dei pesi e dei coefficienti di portanza e resistenza lungo l'aerogeneratore).

La Regione Campania a seguito di quanto prescritto dal Decreto del Ministero dello sviluppo economico 10 settembre 2010 - Linee guida per l'autorizzazione degli impianti alimentati da fonti rinnovabili - Allegato 4 - punto 7 "Studio sulla gittata massima degli elementi rotanti nel caso di rottura accidentale" per gli impianti di produzione di energia rinnovabile da fonte eolica" ha redatto un foglio di calcolo Excel per velocizzare e facilitare il calcolo della gittata massima delle pale.

Per la presente relazione, sebbene il progetto sia ubicato sul territorio regionale della Basilicata e quindi il riferimento normativo non abbia valore di legge, si è ritenuto comunque opportuno utilizzare il foglio di calcolo predisposto dalla Regione Campania, considerandolo un utile punto di riferimento tecnico.

L'applicazione del foglio di calcolo ha prodotto i seguenti risultati sulla base delle caratteristiche dell'aerogeneratore di progetto.

Seguono di seguito sia le ipotesi adottate che i risultati del calcolo.

Numero di giri al minuto del rotore	n =	8,83	Se non è disponibile il valore di D, inserire almeno D=2L	
Lunghezza della pala in metri	L =	83,5	Diametro del rotore	D= 170
Altezza del mozzo in metri	H <sub>torre</sub> =	135		

**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° tra il 3° e 4° quadrante

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 :  $\alpha =$  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

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

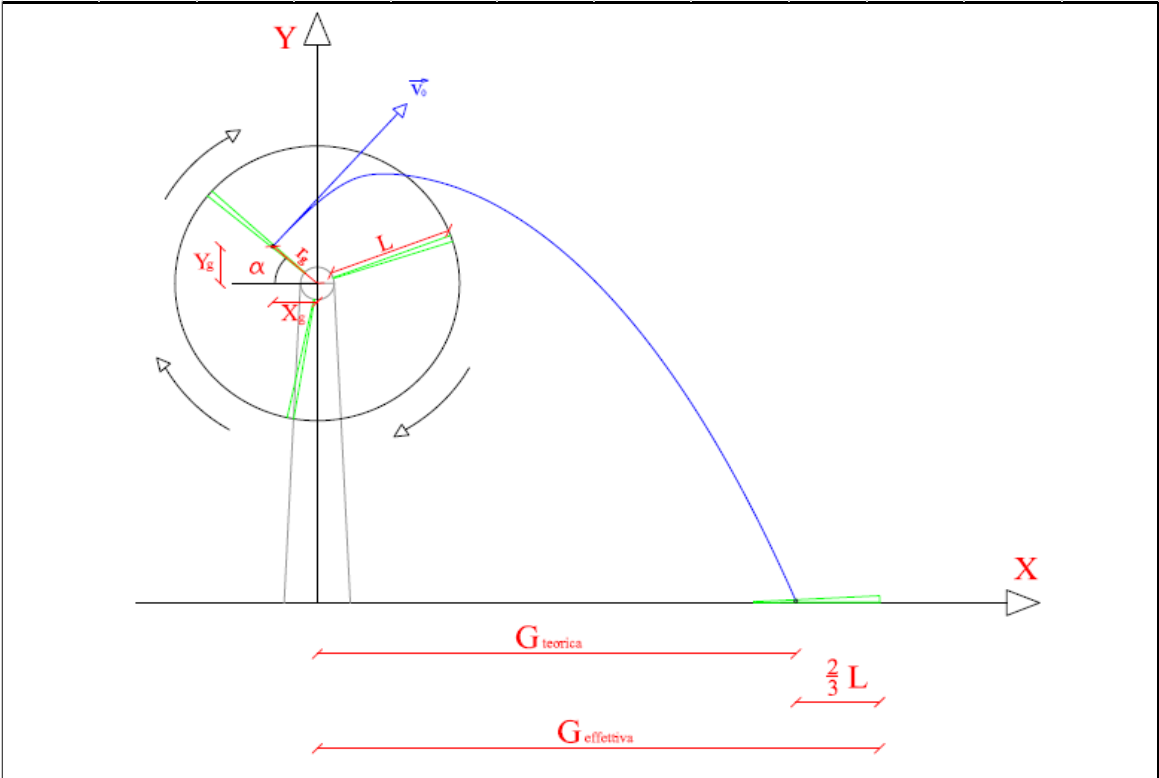
$$v_{y0} = v_0 \sin (90 - \alpha) = v_0 \cos \alpha$$

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

$n =$  numero di giri al minuto del rotore

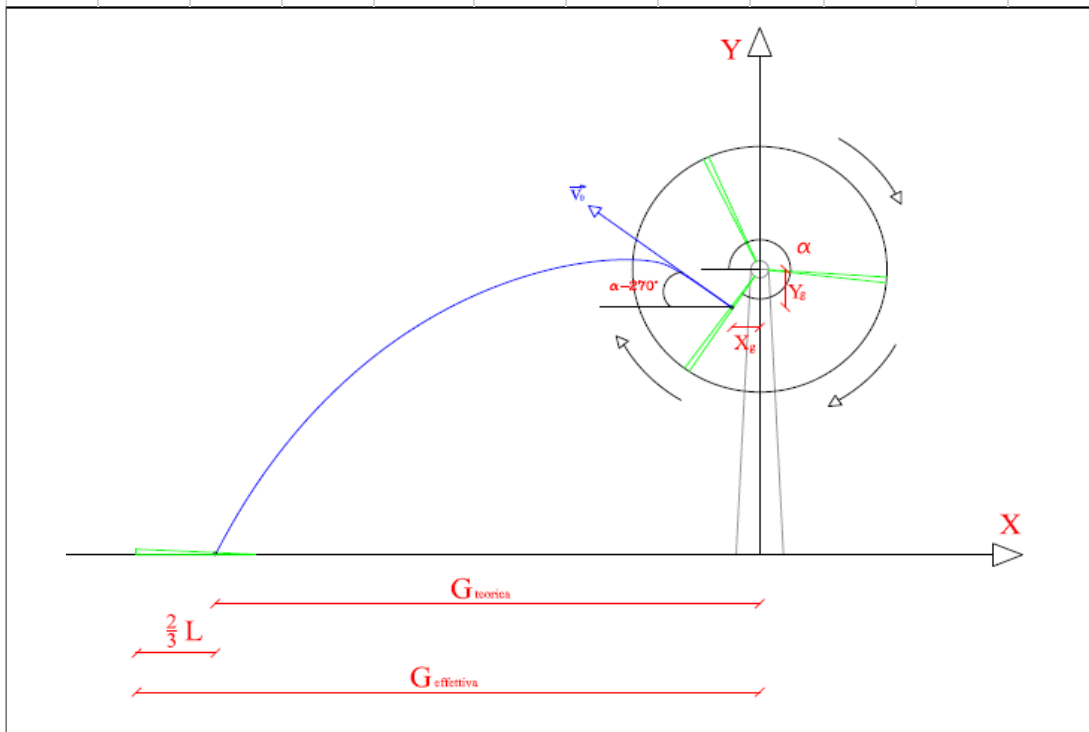
Gittata Effettiva									
$G_{eff} = G + L_g$									

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  $X_g$

$H_G = H_{\text{torre}} - Y_g$		
$Y_g = r_g \text{ sen } (360 - \alpha) = - r_g \text{ sen } \alpha$		
$r_g =$ posizione del baricentro pari ad 1/3 della lunghezza della pala più raggio mozzo	$r_g = \frac{D}{2} - L + \frac{L}{3}$	
$X_g = r_g \text{ cos } (360 - \alpha) = r_g \text{ cos } \alpha = - r_g \text{ cos } \alpha$	posizione del baricentro della pala rispetto all'asse della torre	
$v_{x0} = v_0 \text{ cos } (\alpha - 270) = - v_0 \text{ sen } \alpha = v_0 \text{ sen } \alpha$	$v_{y0} = v_0 \text{ sen } (\alpha - 270) = v_0 \text{ cos } \alpha$	
$v_0 = \omega r_g = (2\pi n r_g)/60$	$n =$ numero di giri al minuto del rotore	$v_{x0}$ negativo perché verso sinistra
<b>Gittata Effettiva</b>		
$G_{\text{eff}} = G - L_g$		
		G negativo perché verso sinistra

**La stima ottenuta, pari a 219 m, rappresenta la massima distanza alla quale può atterrare la punta della pala a seguito di distacco dall'aerogeneratore.**

Come si può notare dagli stralci cartografici nel **buffer di 219 metri dalle altre WTG non sono presenti edifici di alcuna natura.**

Si precisa, in ogni caso, che non sono presenti edifici abitabili entro una distanza di 550 metri da ciascuna WTG, condizione che pone l'impianto in condizioni di estrema sicurezza rispetto al problema della gittata degli elementi rotanti

#### 4 ANALISI DEL DISTACCO DI UN FRAMMENTO DI PALA

Si riportano di seguito anche i risultati del calcolo ottenuto, in ipotesi di moto a proiettile, per :

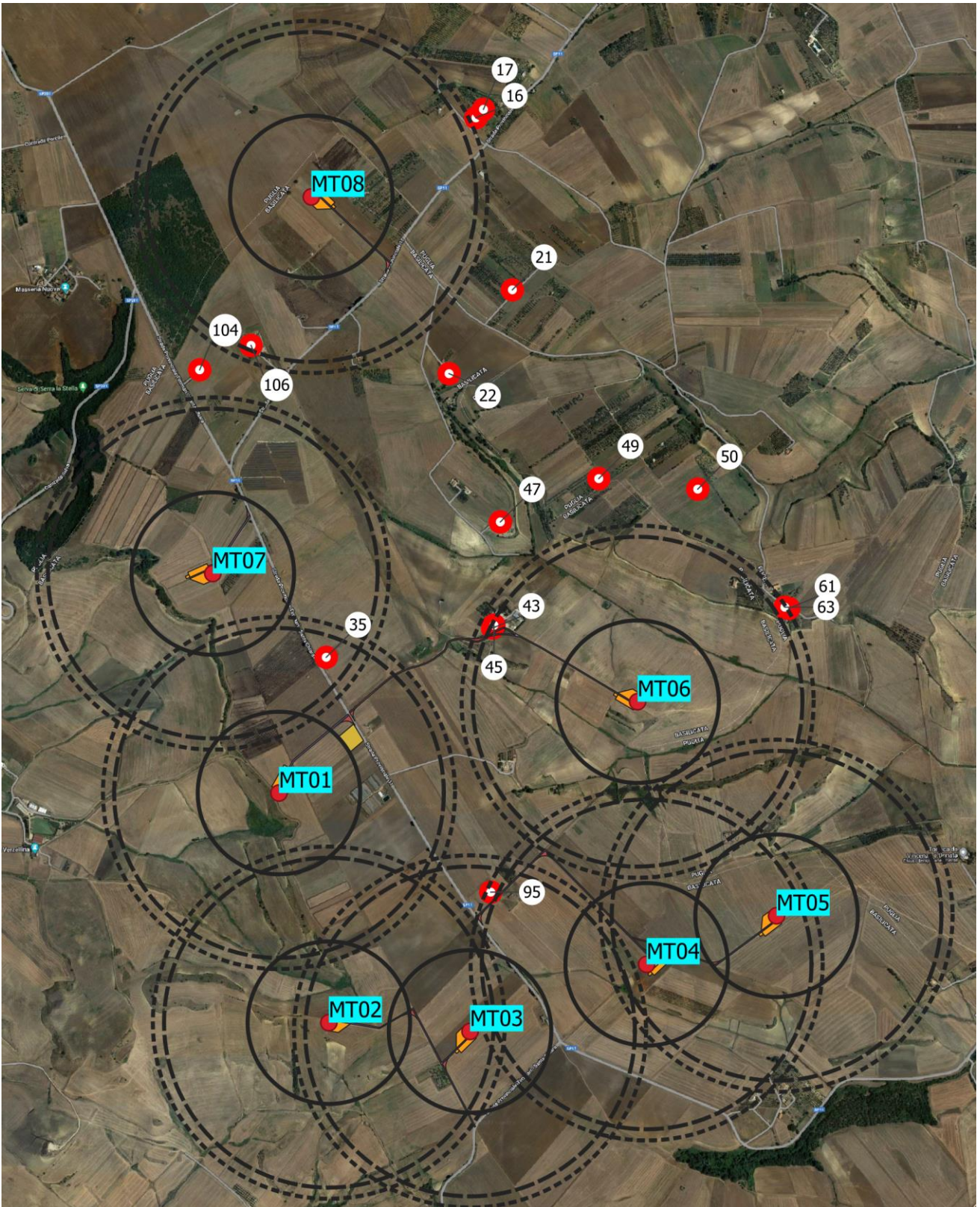
- Distacco di una porzione di pala ai 2/3
- Distacco di un frammento di lunghezza pari a 10 metri
- Distacco di un frammento di lunghezza pari a 5 metri

	2/3 della pala	Frammento di 10 metri	Frammento di 5 metri
Altezza al mozzo	135 m	135 m	135 m
Lunghezza pala	85 m	85 m	85 m
Angolo della pala	45 °	45 °	45 °
Lunghezza sezione di distacco	56.7 m	10 m	5 m
Velocità di rotazione	8.83 rpm	8.83 rpm	8.83 rpm
Distanza dal vertice del baricentro	37.8 m	6.67 m	3.335 m
Distanza dall'asse di rotazione del baricentro	47.2 m	78.3 m	81.7 m
<b>Altezza vertice pala</b>	<b>195.1 m</b>	<b>195.1 m</b>	<b>195.1 m</b>
<b>Altezza baricentro</b>	<b>168.4 m</b>	<b>190.4 m</b>	<b>192.7 m</b>
Velocità tangenziale	43.6 m/s	72.4 m/s	75.5 m/s
V0x	30.9 m/s	51.2 m/s	53.4 m/s
V0z	30.8 m/s	51.2 m/s	53.3 m/s
tempo di volo	9.8 s	13.3 s	13.7 s
h	0.0 m	0.0 m	0.0 m
distanza del baricentro	302.2 m	683.2 m	733.4 m
<b>Distanza punta pala</b>	<b>340.0 m</b>	<b>689.9 m</b>	<b>736.7 m</b>

Si specifica che il calcolo proposto **è ampiamente cautelativo** almeno per i seguenti motivi:

- Ipotizza che il distacco avvenga con la pala alla massima velocità di rotazione
- Ipotizza che il distacco avvenga esattamente all'angolo di maggior gittata
- Ipotizza che il frammento non consumi alcuna porzione della sua energia cinetica per distaccarsi dalla pala

Quest'ultima ipotesi è particolarmente cautelativa, dal momento che, ove mai si verificasse la proiezione di una parte della WTG, evidentemente la rottura del materiale della pala consumerebbe una parte rilevante dell'energia cinetica del frammento distaccato, e quindi la gittata risulterebbe notevolmente ridotta.



L'osservazione dello stralcio di ortofoto precedente consente di compilare la tabella seguente, dalla quale si evince che:

- Non ci sono ricettori in un buffer di 340 metri dalle WTG nel quale è ipotizzabile, sia pure nelle ipotesi di estrema sicurezza appena spiegate, il lancio di un frammento di pala pari ai 2/3 della pala stessa
- Ci sono sparuti ricettori nei buffer di 689 metri e 737 metri nei quali è ipotizzabile il lancio di frammenti di 5 e 10 metri, ubicati alla estrema periferia di queste aree.

WTG	Distacco 2/3 di pala	Distacco di frammento di 10 metri	Distacco di frammento di 5 metri
1	Nessun ricettore	Ricettore 35	Ricettore 35
2	Nessun ricettore	Nessun ricettore	Nessun ricettore
3	Nessun ricettore	Ricettore 95	Ricettore 95
4	Nessun ricettore	Nessun ricettore	Ricettore 95
5	Nessun ricettore	Nessun ricettore	Nessun ricettore
6	Nessun ricettore	Ricettore 43/45	Ricettore 43/45 Ricettore 61/63
7	Nessun ricettore	Ricettore 35	Ricettore 35
8	Nessun ricettore	Ricettore 106	Ricettore 106

Il fatto che i ricettori siano ubicati all'estrema periferia dell'area di lancio calcolata con ipotesi di massima sicurezza secondo quanto appena enunciato garantisce del fatto che, in effetti, non sarà possibile il lancio di frammenti di 5 e 10 metri in corrispondenza dei ricettori.

Peraltro il confronto tra la superficie di un ricettore (ordine di grandezza 100 mq) e la superficie della buffer di possibile atterraggio di un frammento di 10 metri (circa 1,5 milioni di mq) indica che, anche nel caso estremamente improbabile di distacco di un frammento di pala, ci sarebbe circa una possibilità su 15 000 di colpire un edificio considerato ricettore.

## 5 ANALISI DEI SISTEMI DI SICUREZZA DELL'AEROGENERATORE

Il modello di aerogeneratore adottato è il SIEMENS-GAMESA SG170 6.2 – 6.2 MW che ha una Potenza Nominale pari a 6,2 MW e sarà costituito da una torre di sostegno tubolare metallica a tronco di cono, per un'altezza massima complessiva del sistema torre-pale di 220 mt rispetto al suolo, con rotore di diametro massimo pari a 170m.

All'interno della documentazione tecnica prodotta dal produttore degli aerogeneratori, vengono indicati i sistemi di sicurezza dell'aerogeneratore, che si alleggeranno a fine relazione.

### 5.1 I SISTEMI DI CONTROLLO E GESTIONE DEGLI AEROGENERATORI

I sistemi di sicurezza e controllo sono valutati secondo la norma EN ISO 13849-2:2014/2014 – Sicurezza del macchinario – Parti dei sistemi di controllo relative alla sicurezza – Parte 2: Convalida.

I sistemi di sicurezza mitigano il rischio oltre ad altre misure di protezione.

Tutte le parti rotanti e le aree ad alta tensione sono coperte da protezioni che richiedono uno strumento per la rimozione.

Post valutazione del rischio sono stati individuati i seguenti sistemi di sicurezza:

- Protezione da eccesso di velocità
- Protezione da eccesso di vibrazione
- Attivazione pulsante di arresto di emergenza
- Protezione antitorsione del cavo.

La **protezione da eccesso di velocità** utilizza sensori interni per determinare la velocità del rotore e quindi confrontarla con limiti predeterminati. Quando la protezione si attiva (in caso di eccesso di velocità), manda la turbina eolica in modalità di arresto.

La **protezione da vibrazioni e urti eccessivi** è costituita da un dispositivo di rilevamento delle vibrazioni strutturali nelle turbine eoliche, posizionato sulla sommità della torre.

Il dispositivo è configurato per regolare in sicurezza il pitch della pala in caso di forti vibrazioni della sommità della torre o se la navicella è esposta a uno shock meccanico.

Il sistema è progettato per soddisfare i requisiti di sicurezza PLd di Categoria 3 secondo ISO 13849-1:2015.

Ciascuna turbina è dotata di **pulsanti di arresto di emergenza** in vari punti della navicella e della torre. La funzionalità di questi pulsanti di arresto è progettata secondo i requisiti della ISO 13850:2015, ed il sistema soddisfa i requisiti di sicurezza PLd di Categoria 3 secondo ISO 13849-1:2015.

La funzione di arresto di emergenza prevale sia sui sistemi di controllo che su quelli di protezione (arresto di imbardata, vibrazioni, velocità eccessiva....), ed è principalmente prevista per la protezione delle persone. Si basa solo su sistemi meccanici e fail-safe.

A protezione in caso di guasto del sistema di controllo dell'imbardata, la torre è dotata di una **protezione antitorsione del cavo**, che consente alla turbina eolica di girare in entrambe le direzioni rispetto alla posizione zero solo entro limiti predeterminati. Il sistema soddisfa i requisiti di sicurezza PLC di Categoria 1 secondo ISO 13849-1:2015.

## 5.2 PROTEZIONE E RILEVAMENTO DEL GHIACCIO

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Le WTG sono dotate di un sistema di rilevamento del ghiaccio che consente il funzionamento in sicurezza anche in condizioni di ghiaccio sulla pala, configurabile per lavorare in massima produzione o in massima sicurezza.

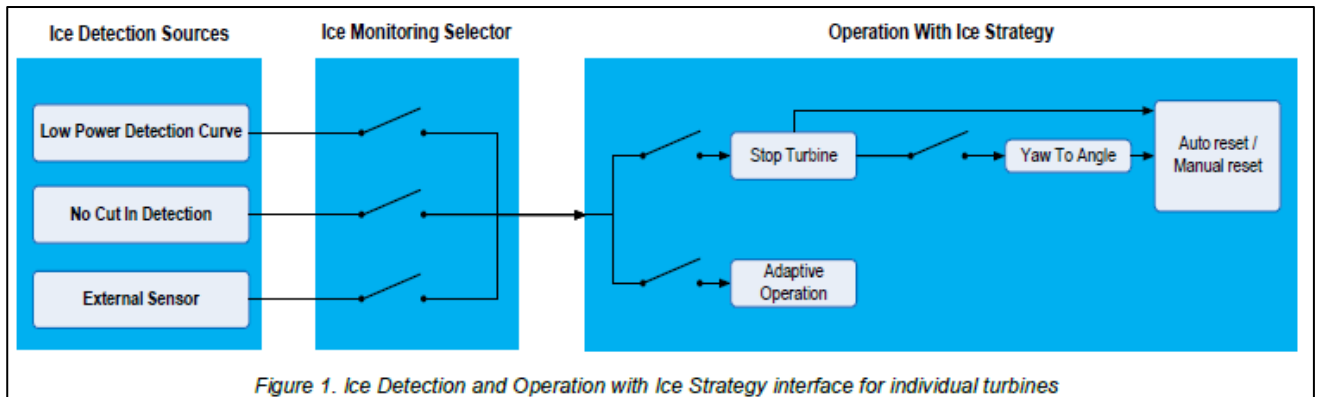
Il sistema può utilizzare per il rilevamento della presenza di ghiaccio:

- Curva di rilevamento bassa potenza (LPDC)
- Mancato rilevamento del cut-in
- Un sensore esterno, posizionato sulla navicella o sulla pala.

Una volta che il ghiaccio è stato rilevato, viene gestita la seguente risposta:

- Arrestare la turbina, in attesa di riarmo automatico o riarmo manuale
- Arrestare la turbina ed impostare l'imbardata a un angolo specifico

- Adaptive Operation, funzionamento continuo con ottimizzazione della curva di potenza

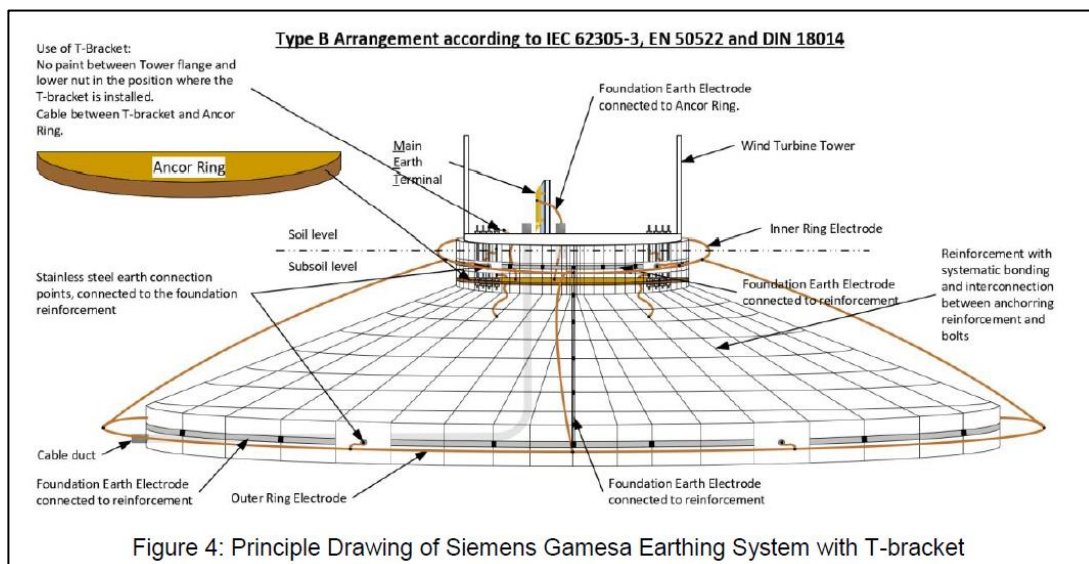


La figura seguente mostra una visualizzazione delle opzioni disponibili e di come sono collegate.

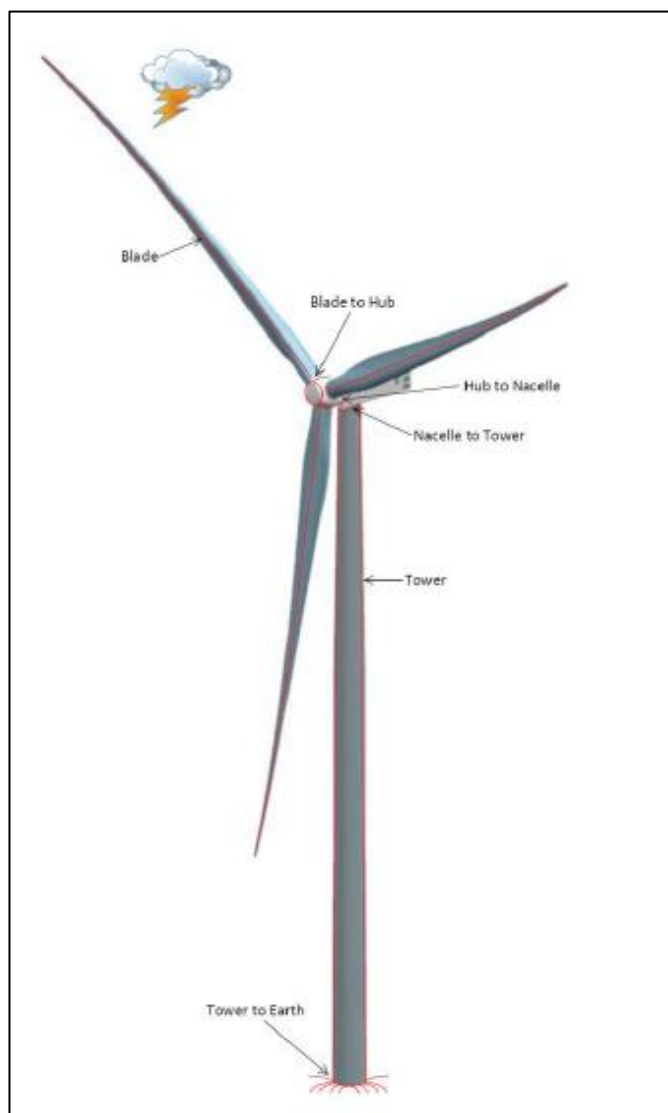
### 5.3 PROTEZIONE CONTRO LA FULMINAZIONE

La progettazione complessiva del Lightning Protection System rispetta la norma IEC 61400-24:2019 "Sistemi di generatori eolici - Parte 24 Protezione contro i fulmini" oltre che la norma IEC 62305-1:2010 "Protezione contro i fulmini - Parte 1: Principi generali, livello di protezione contro i fulmini I".

All'interno di questo sistema di protezione contro la fulminazione, la torre funge da parte di collegamento naturale fornendo un collegamento conduttivo dalla navicella alla terra. L'impianto di messa a terra dell'aerogeneratore sarà collegato ad idoneo impianto di messa a terra di completamento. Tutti i cavi che escono/entrano nella turbina eolica saranno schermati.



Schema tipico impianto di messa a terra dell'aerogeneratore



*Figura: Messa a terra dell'aerogeneratore*

Si allegano i seguenti documenti tecnici redatti dal produttore dell'aerogeneratore:

- D2047461\_007 SGRE ON Siemens Gamesa 5.X Lightning Protection and Earthing
- D2097468\_012 SGRE ON Siemens Gamesa 5.X Ice Detection Strategy and Operation with Ice
- D2097486\_003 SGRE ON Siemens Gamesa 5.X Safety System

## 6 CONCLUSIONI

### In conclusione:

- la massima gittata degli elementi rotanti che possono essere proiettati dagli aerogeneratori in progetto è certamente inferiore a 219 metri;
- Nel buffer di 219 metri dai luoghi di installazione delle torri non è presente alcun ricettore sensibile;

- Nel buffer di ipotetica gittata di frammenti di 5 e 10 metri ci sono alcuni edifici, tuttavia la distanza degli stessi dalle WTG e le ipotesi di calcolo estremamente cautelative garantiscono sulla impossibilità che un frammento di pala di 5 o 10 metri arrivino su un ricettore;
- Peraltro la superficie degli edifici è tale che, anche nel caso assolutamente irrealistico di proiezione di un frammento di pala senza che si stacchi senza consumare energia cinetica e che viaggi con moto a proiettile in assenza di attrito, sarebbe trascurabile la possibilità di colpire un edificio in virtù della ridotta superficie degli stessi se confrontata con la superficie di possibile atterraggio del frammento;
- Tutti i sistemi di protezione della turbina eolica garantiscono un corretto funzionamento ed un arresto di emergenza anche in condizioni climatiche critiche.

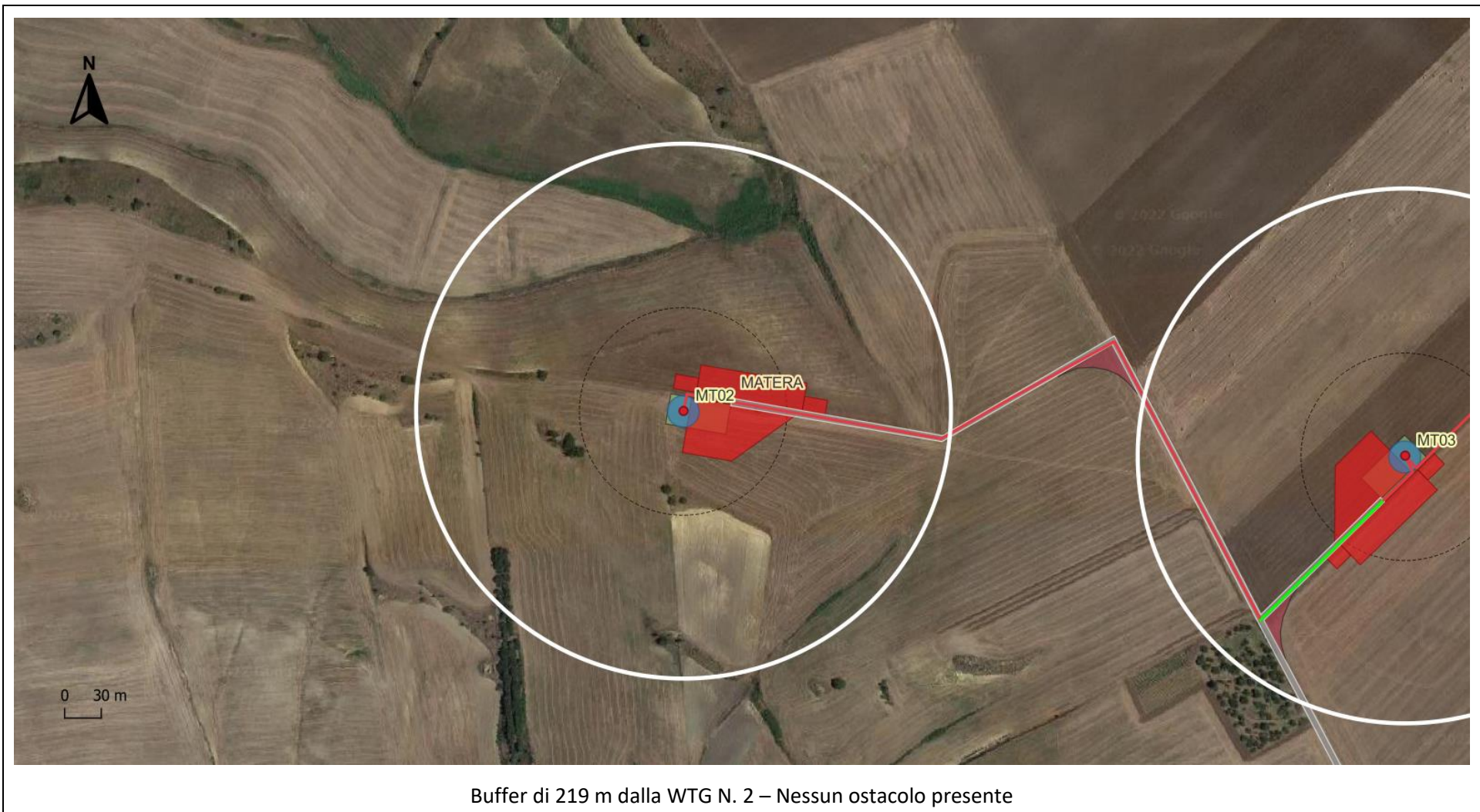
**Si ritiene che non sussistano quindi problemi di sicurezza legati alla ipotetica (remota) gittata di elementi rotanti.**



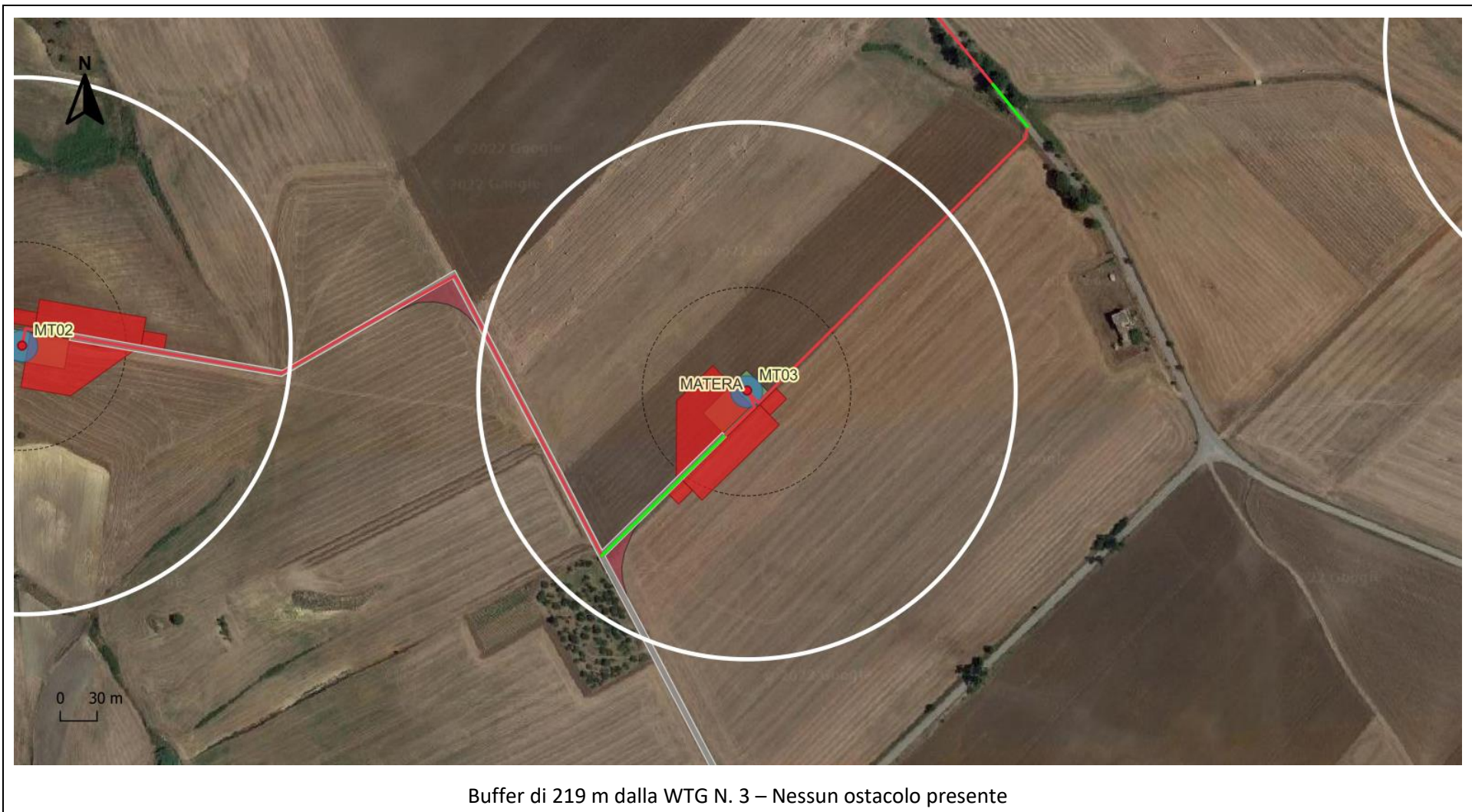
**STRALCI CARTOGRAFICI SU ORTOFOTO**  
**CON INDICAZIONE DI UN BUFFER DI 219 METRI**  
**INTORNO A CIASCUNA WTG IN PROGETTO**

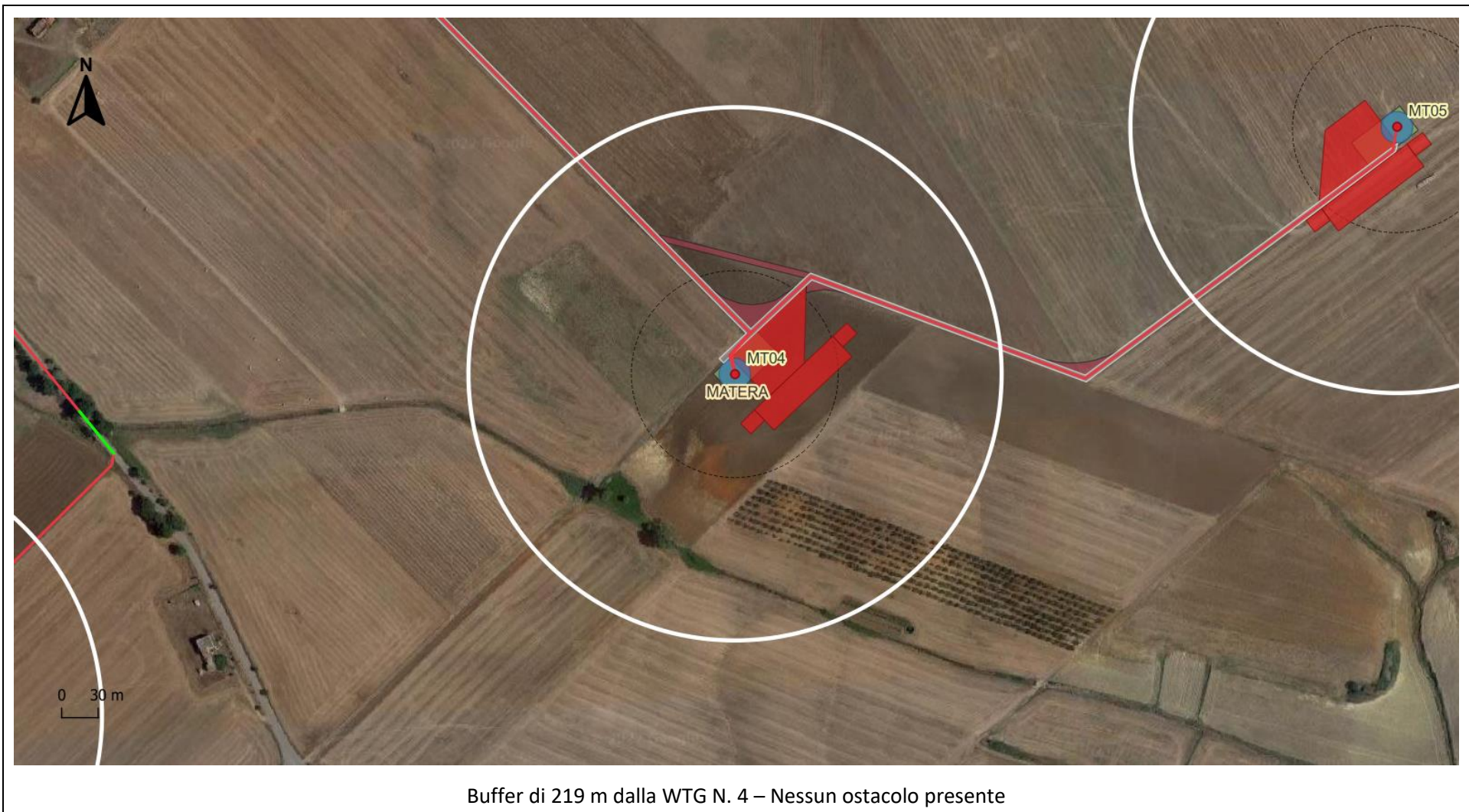


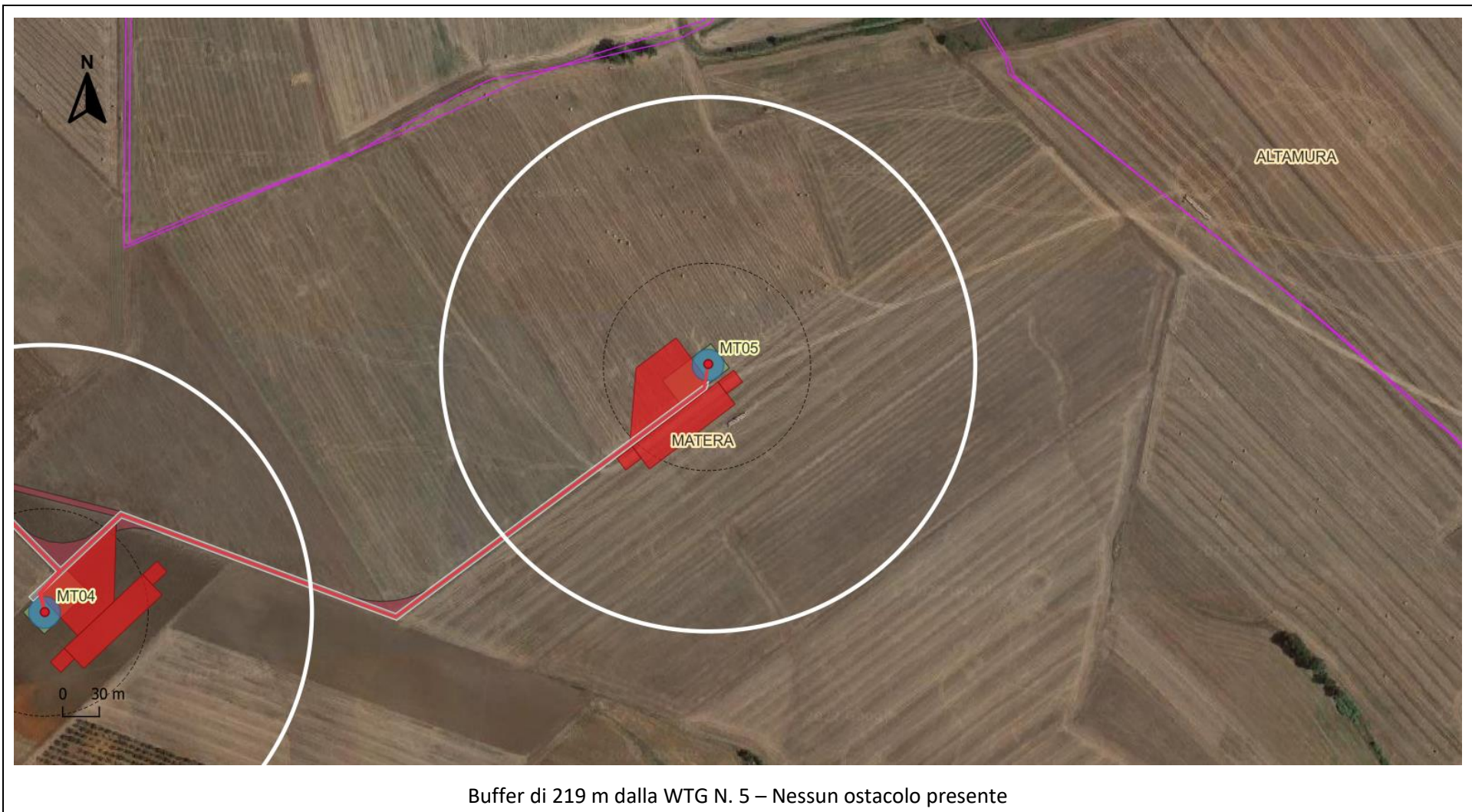
Buffer di 219 m dalla WTG N. 1 – Nessun ostacolo presente



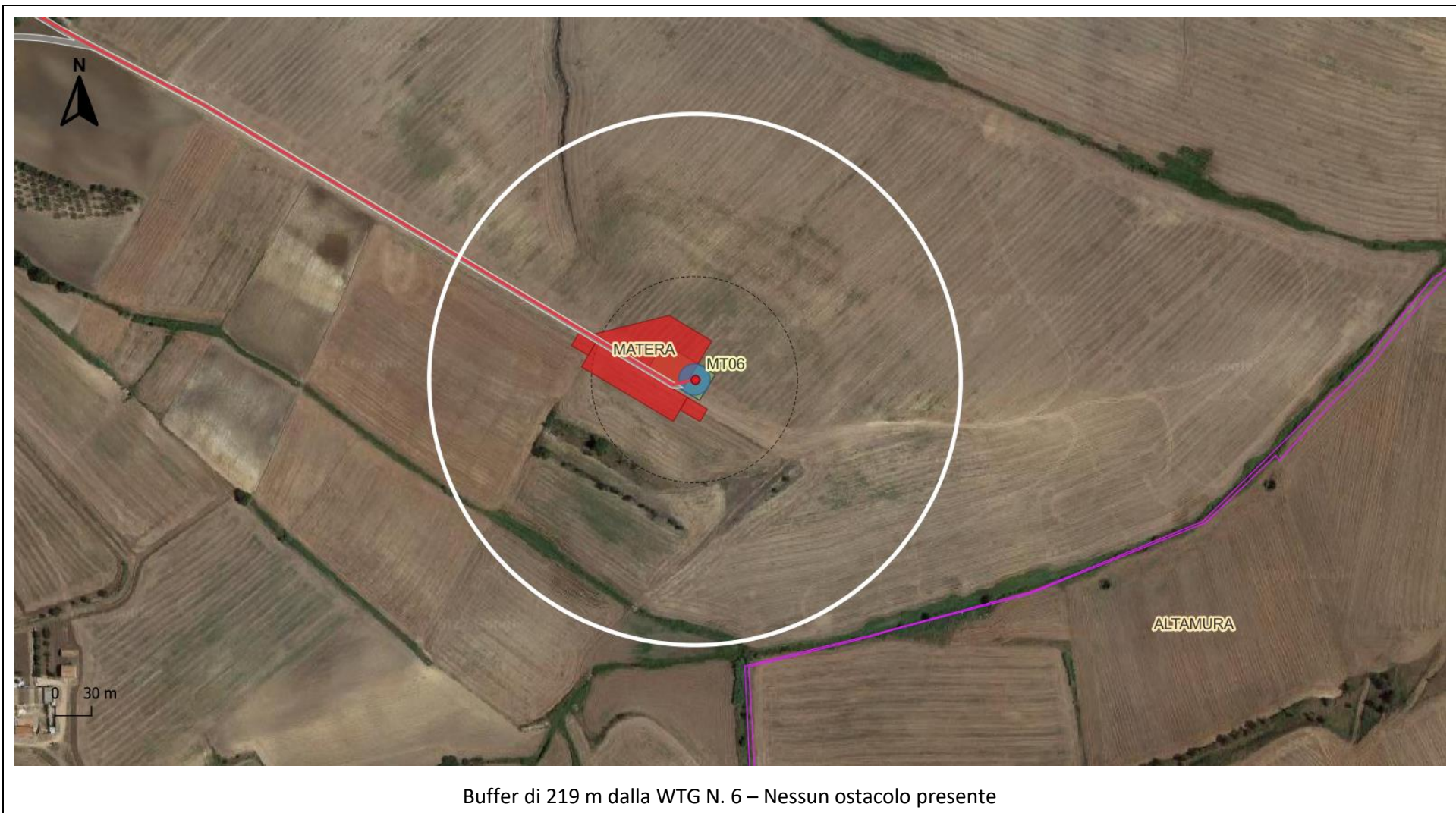
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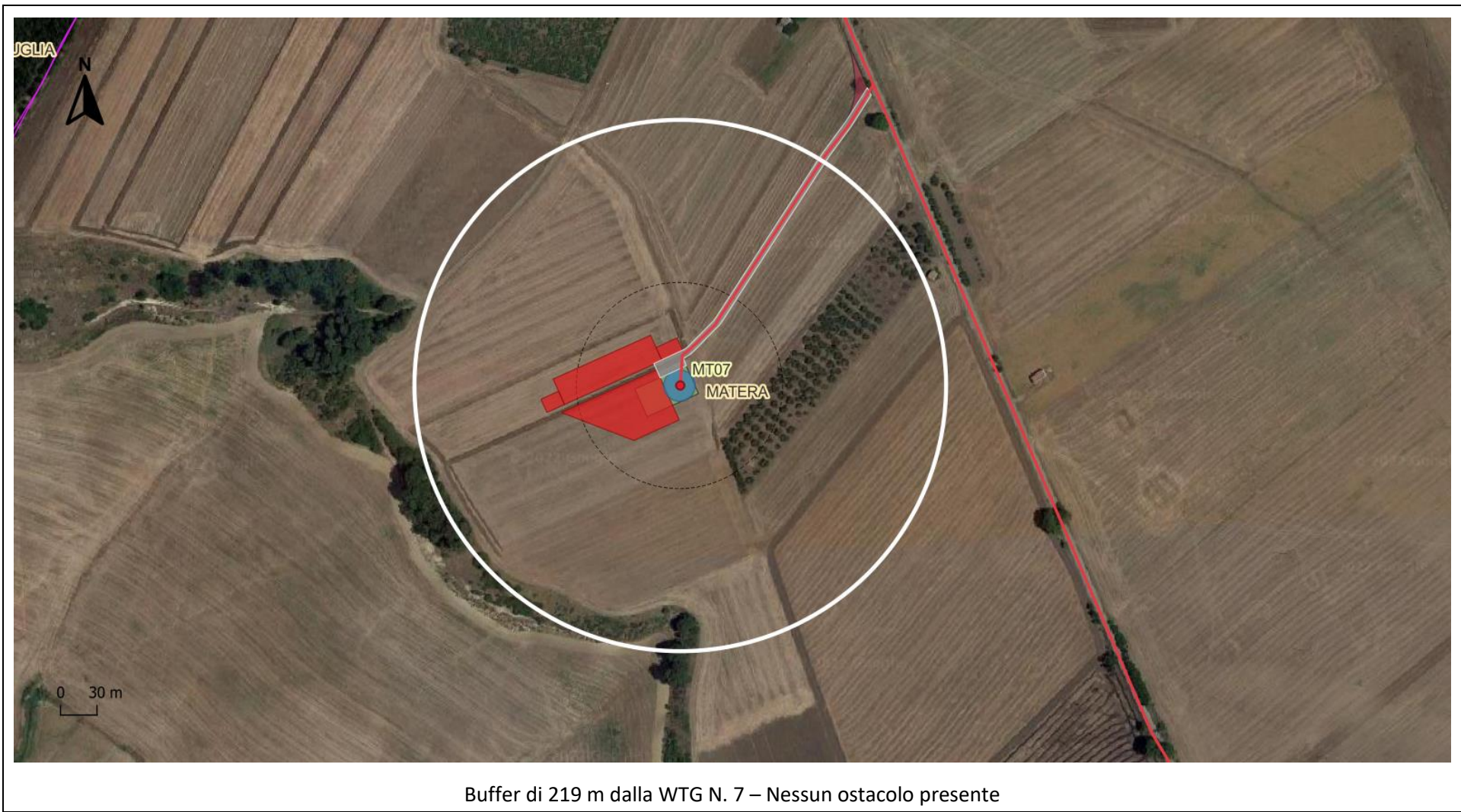




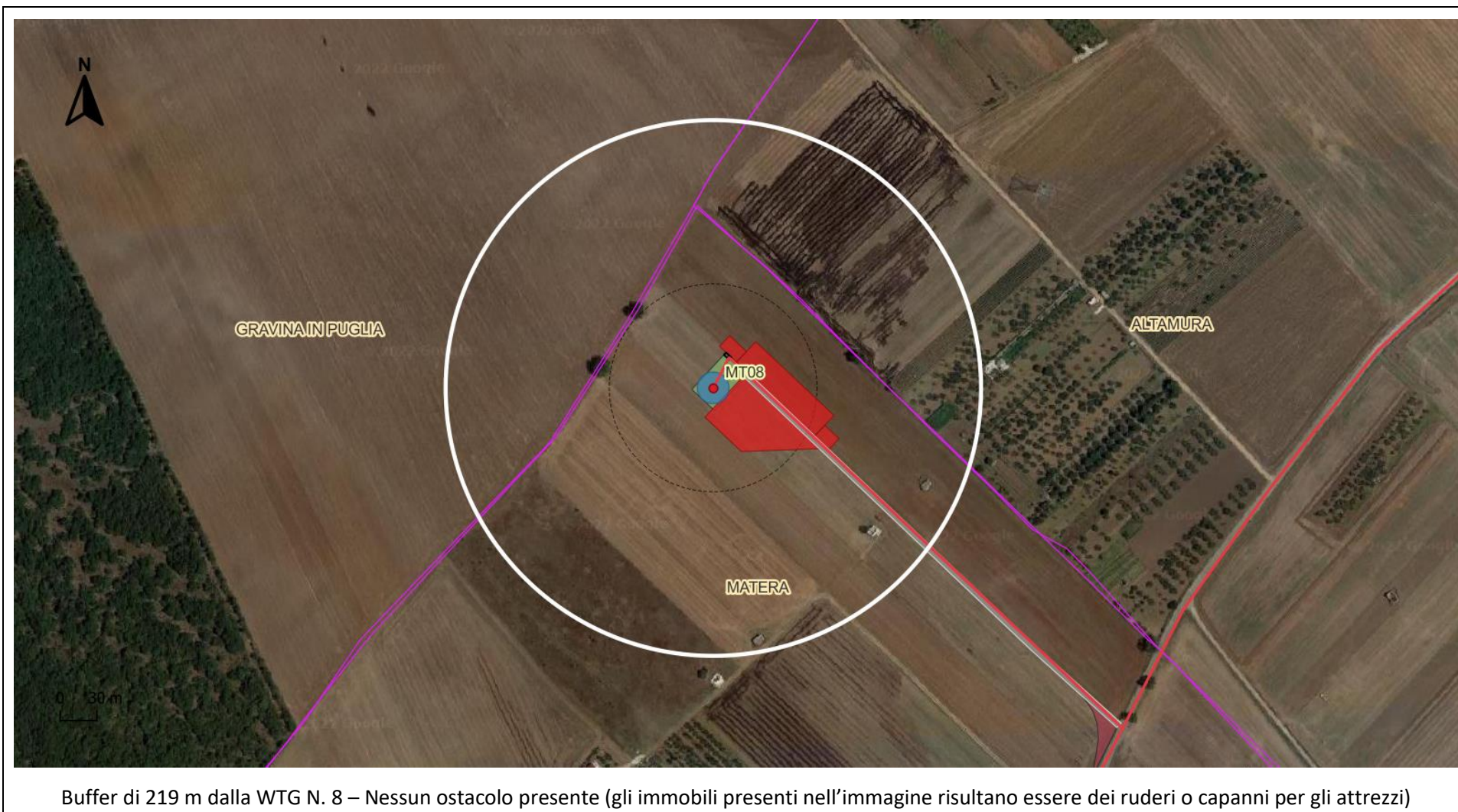


Buffer di 219 m dalla WTG N. 5 – Nessun ostacolo presente









# Lightning Protection and Earthing

## Siemens Gamesa 5.X

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D2047461/007	Approved	2021-09-20	en-US

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Doc ID	Reference
IEC 61400-24:2019	Wind turbine generator systems - Part 24 Lightning Protection
IEC 60364-1 ED 5.0:2005	Low-voltage electrical installations – Part 1: Fundamental, principles, assessment of general characteristics, definitions
IEC 60364-5-54:2011	Low-voltage electrical installations - Part 5-54: Selection and erection of electrical equipment - Earthing arrangements and protective conductors
IEC 62305-1:2010	Protection against lightning - Part 1: General principles
IEC 62305-3:2010	Protection against lightning - Part 3: Physical damage to structures and life hazard
EN 50522:2010	Earthing of power installations exceeding 1 kV a.c.
DIN 18014	Foundation earth electrode - Planning, execution and documentation
IEC 60479-1:2018	Effects of current on human beings and livestock – Part 1: General aspects
DS/EN 50522:2011	Earthing of power installations exceeding 1 kV a.c.

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## 1. Scope

This specification is valid for the foundation intended used for a Siemens Gamesa, in the future SGRE, on-shore wind turbine. This document reflects the minimum design requirements to a foundation intended for a SGRE wind turbine so the foundation will be designed to prevent certain lightning to cause damage to the wind turbine and it's installed components. In this document, SGRE provides a mechanical and technical description of the minimum requirements for a SGRE wind turbine foundation.

## 2. Definitions

SGRE	Siemens Gamesa Renewable Energy
WTG	Wind Turbine Generator
IEC	International Electrotechnical Commission
TN-S	Terre(earth) Neutral Separate
MET	Main Earth Terminal
EN	European Standard
DIN	Deutsches Institut für Normung
EMC	Electromagnetic Compatibility
HV	High Voltage
LPS	Lighting Protection System
LV	Low Voltage
PE	Protective Earth
SPD	Surge Protective Device
UPS	Uninterruptible Power Supply

## 3. Lightning Protection

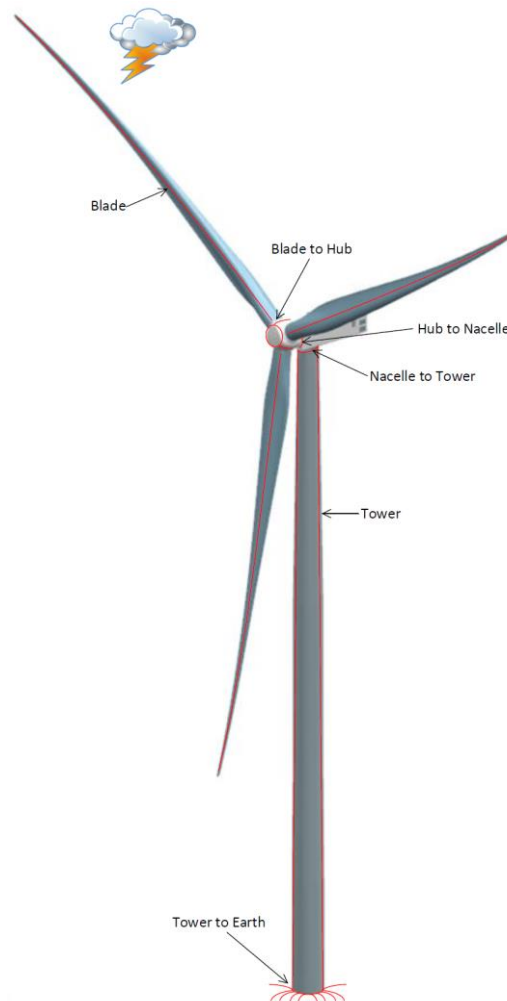


Figure 1: LPS overview drawing

### 3.1. Design Basis

The overall LPS design, see Figure 1, is done according to the standard **IEC 61400-24:2019 'Wind turbine generator systems - Part 24 Lightning Protection'** and the standards for building technology **IEC 62305-1:2010 Protection against lightning - Part 1: General principles**, lightning protection level I.

### 3.2. Tower

The tower acts as a natural bonding part providing a conducting connection from the nacelle to the earth. The wind turbine earthing system must be connected to a completing earthing system provided by the Purchaser.

### 3.3. Electrical System

Surge arrestors in the main supply and communication connections by fiber optical cables provide protection from effects of nearby lightning strikes. The power supply of the control system is based on a UPS that gives a clean electrical environment for all computers and electronics. The Faraday cages of the hub, nacelle and tower provide damping of the magnetic field coupling for all energy containing components inside, i.e. lubrication, electrical and hydraulic systems. Signaling cabling is shielded, signal cables and power cables are separated, and all cubicles/connection boxes are made of metal and fitted with dedicated bonding.

SGRE recommends that all cables leaving/entering the wind turbine being routed in a metal encapsulated manner. If metal ducts are used, these shall as minimum be metal to metal terminate to the reinforcement at the foundation entry and exit.

### 3.4. Outside placed equipment and cables

Equipment placed outside the wind turbine, e.g. a transformer placed outside the tower, must be grounded in an appropriate manner and connected to the earthing system of the wind turbine. Additionally, cables entering/leaving the wind turbine must be either shielded in an EMC correct terminated metal encapsulation or installed deep enough in the ground/foundation so that the cables are placed under the reinforcement of the earthing system.

## 4. Earth Termination System for LPS

### 4.1. General

SGRE wind turbines are equipped with an equipotential bonding and down-conductor system designed according to **IEC 62305:2010** and **IEC 61400-24:2019**. This system must be connected to an earthing system in the foundation provided by the employer.

The solution used by SGRE for gravity foundation with double electrode rings is based on **IEC 61400-24:2019 (Annex I - Earth Termination System)**, which describes the possible choice of electrode arrangement (also defined in this standard).

### 4.2. Requirements for Earthing System

The general design of the earthing system shall be designed in accordance with the requirements of **IEC 62305-3:2010 Protection against lightning - Part 3: Physical damage to structures and life hazard**.

Figure 4 on page 7 depicts a principle drawing for a wind turbine earthing system and its connections to the tower when using a T-bracket.

Figure 5 on page 7 depicts a principle drawing for a wind turbine earthing system and its connections to the tower without using a T-bracket.

The turbine tower acts as the main bonding and down conductor system ("natural down conductor" according to **IEC 62305-3:2010**, (chapter 5.3.5) of the wind turbine.

The earthing system of the wind turbine foundation consists of several components, e.g. concrete reinforcement, ring electrodes, stainless steel outlets, anchor ring, and connection clamps. The electrical connection between tower and earthing system is realized through the foundation bolts which are electrically connected to the tower for the purpose of conducting fault and lightning currents to earth. In order to connect electrical equipment, e.g. the

power unit, to the down-conductor system, the tower is equipped with PE pads (Protective Earth pads) realized as brackets. They will be directly mounted at the foundation bolts which are connected to earth.

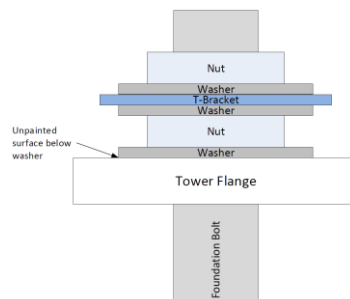


Figure 2: Example of mounting order – using T-bracket

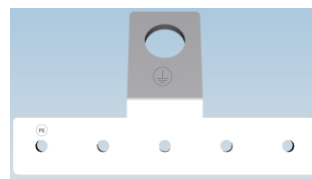


Figure 3: Example of the T-bracket/PE pad

## 5. Foundation for internal transformer

Of the below examples of foundation earthing solution SGRE recommends **Earthing without T-bracket** as the preferred choice. **Earthing connections to the anchor ring** described below are mandatory requirements for all foundation designs.

### 5.1. Earthing connections to the anchor ring

For securing compliance with IEC standards minimum two 50mm<sup>2</sup> raw copper-cables connections must be coming from the Anchor Ring and routed through the foundation and into their final point of termination.

- One 50mm<sup>2</sup> raw copper-cable to be connected from the Anchor Ring to a Tower Wall Lug or a T-bracket installed at the tower flange, as the Tower is the primary earthing path of lightning current. If T-bracket is used, paint shall be grinded off on tower flange below the washer.



Picture 1: Illustrating paint to be removed on tower flange below the washer.

- One 50mm<sup>2</sup> raw copper-cable to be connected from the Anchor Ring to the Main Earth Terminal (MET). This cable is the Protective Earth connection (PE) of the earthing system.

## 5.2. Earthing with T-bracket

The below Figure 4 is an **example** of a foundation design for a wind turbine with the MW transformer installed on a platform inside the tower or in the nacelle and **where T-bracket is used**.

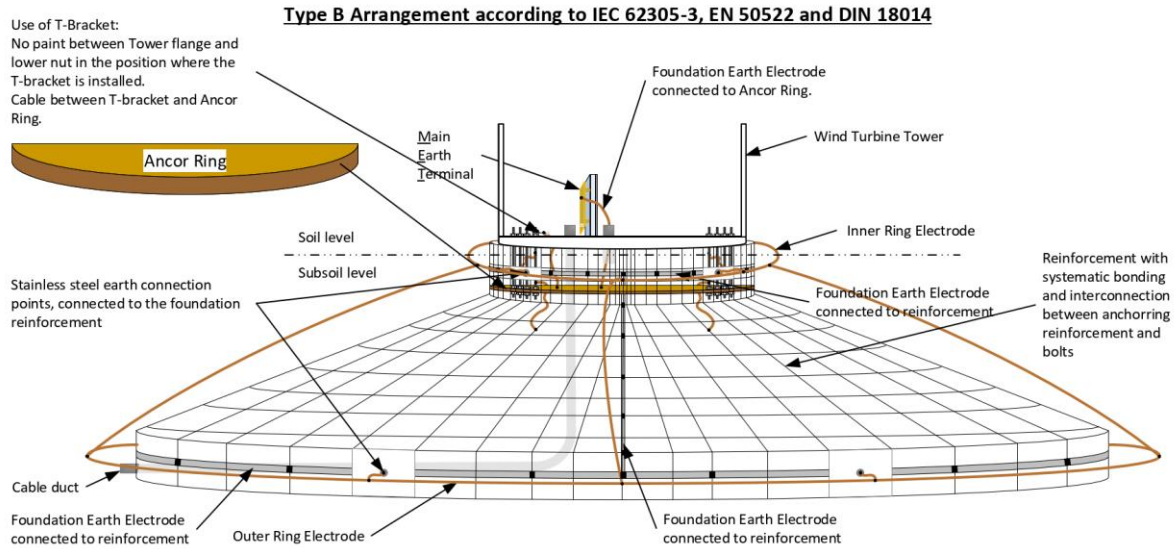


Figure 4: Principle Drawing of Siemens Gamesa Earthing System with T-bracket

## 5.3. Earthing without T-bracket

The below Figure 5 is an **example** of a foundation design for a wind turbine with the MW transformer installed on a platform inside the tower or in the nacelle and **without using the T-bracket**.

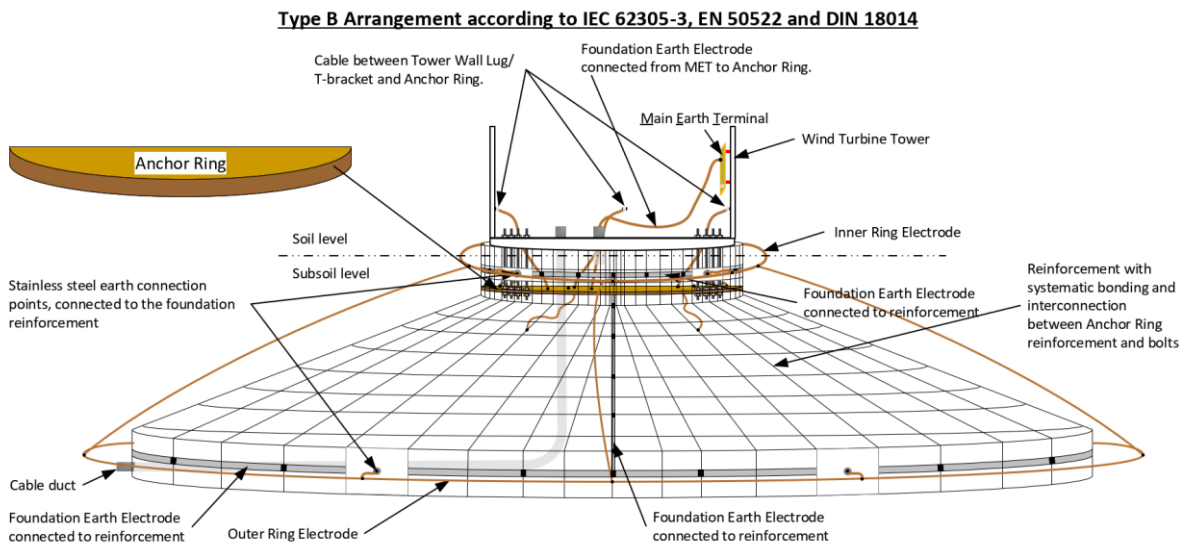


Figure 5: Principle Drawing of Siemens Gamesa Earthing System without T-bracket



## 6. Connection between Electrical Systems and the LPS

The star point earthing system of the transformer LV windings shall be connected to the wind turbine earthing system by means of a PE conductor that has to be connected to the PE Pads or the MET in the tower.

The earthing system in the SGRE wind turbine's low voltage system is according to IEC 60364-1 ED 5.0:2005 designed to be a TN-S system with separated earth and neutral in the entire system.

The cross-section area of the PE conductor shall be in accordance with **IEC 60364-5-54:2011 Low-voltage electrical installations - Part 5-54: Selection and erection of electrical equipment - Earthing arrangements and protective conductors** and if applicable, any local specific requirements shall be followed and full filled as well.



SGRE however requires that the PE conductor cross section as minimum to be at least half of the phase conductor cross section if the actual size can't be documented by calculations.

## 7. Evaluation of the earthing system

### 7.1. Lightning protection

According to **IEC 61400-24:2019** the following site-specific information shall be evaluated and documented with minimum pictures and measurements, during the construction of the foundation in order to confirm the design of the earthing system:

- soil resistivity
- earth fault current
- earth fault clearance time
- calculations
- step and touch voltage

Depending on the measured site-specific soil resistivity, the ring earth electrode(s) shall be determined accordingly. Additional earth electrodes may be required if the length of the earthing system is insufficient.

To reduce the risk of a direct lightning strike into HV-cables laid in the soil and to reduce the lightning induction into the cables as well as to improve the global park earthing system, SGRE recommends installing additional bare copper cables above the cable routes of at least 50 [mm<sup>2</sup>].

### 7.2. Permissible step- and touch voltage

In order to fulfill the requirements for the safety of persons regarding the permissible step and touch voltage according to **IEC 60479-1:2018**, the general procedures stated in **DS/EN 50522:2011** shall be applied.

## 8. Pre-design

If the Employer is responsible for the design of the foundation, and/or the design of an external transformer solution, the employer shall provide a list to SGRE of what and how the WTG foundation design and/or the external transformer solution, seen from an earthing system approach, will be documented to fulfill the applicable standards mentioned in this document.

SGRE is not obligated to review the provided list as it is the Employers responsibility to secure that all constructed designs at the time of delivery is compliant with all applicable standards and has been evaluated and documented accordingly.

In cases that causes major damages to the wind turbine and its components, which could be related to incorrect earthing system design, the standard SGRE root causes analysis, includes among other an evaluation of the compliance of the actual earthing system based on the Employer provided documentation and documentation list.

## 9. Annex – e.g. check list for the WTG with internal transformer

Task	Requirement	Result	Comments
Soil resistivity report (Before installation of foundation)	The soil resistivity shall be measured before installation of the foundation. The result shall be used for determination of the need earthing electrode according to IEC 61400-24:2019 section 9.4 Selection criteria and calculation must appear clearly in the report. Pictures, drawings etc. must be include in the report		
Soil resistivity report (After installation of foundation)	The soil resistivity shall be measured after installation of the foundation, with foundation as the starting point. The result shall confirm the compliances of the installed earthing electrode. (IEC 61400-24:2019 section 9.4) Pictures, drawings etc. must be include in the report		
Earthing Resistance Report	Lower than 10 [ohm] (if possible, as recommended in IEC 62305-3 section 5.4.1) The report must include an installation plan, including a layout of the earthing system with details of connections points, the use of connectors, clamps and welds, the positions and amount of outlets and their type and quality. A service and maintenance manual, describing how often and how to inspect and maintain the earthing system, must made in agreement between the designers and the operator of the wind turbine. (IEC 61400-24:2019 section 9.5) Pictures, drawings etc. must be include in the report		
WTG Foundation			
– Reinforcement	Pictures		
– Ring electrodes, connection to reinforcement.	Pictures / min 50 [mm <sup>2</sup> ]		
– Earthing Cable, connection to reinforcement.	Pictures / min 50 [mm <sup>2</sup> ]		
Cable ducts			

– If metal, minimum connected to reinforcement at foundation and tower entry/exist.	Pictures		
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# Ice Detection Strategy and Operation with Ice

## Siemens Gamesa 5.X

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# Ice Detection Strategy and Operation with Ice

## 1. General

Siemens Gamesa Renewable Energy's (SGRE) Ice detection and Operation with Ice system offers functionality that extends the range of operation during ice conditions. The main configurable options determine if maximum production or maximum safety is required.

The following options for ice detection sources can be used:

- Low power detection curve (LPDC)
- No cut-in detection
- **Optional extra:** External sensor detection, nacelle- or blade-based.

Once ice has been detected through any of the selected sources the following ice detection response is handled by the Operation with Ice strategy where the following options are available:

- Stop the turbine, either awaiting automatic reset or manual reset
- Stop the turbine, combined with yawing to a specific angle
- Adaptive Operation, continued operation optimizing the power

Figure 1 shows a visualization of the available options and how they are connected.

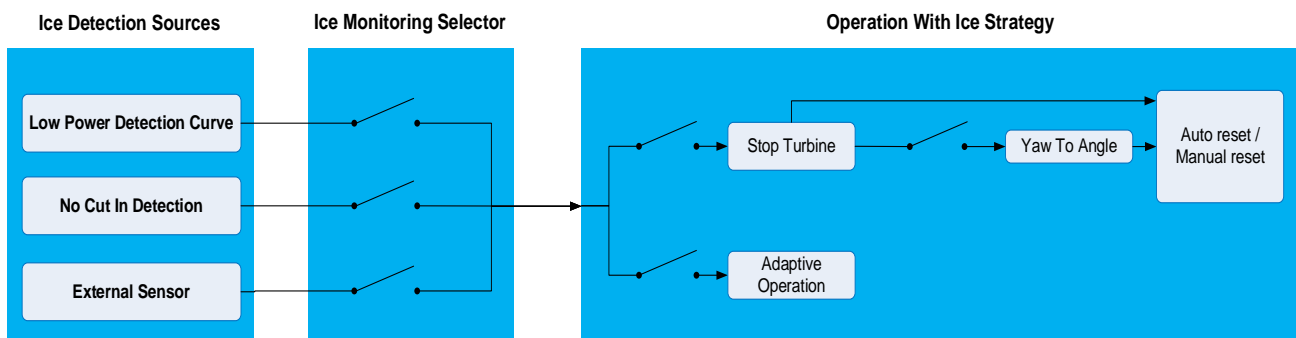


Figure 1. Ice Detection and Operation with Ice Strategy interface for individual turbines



Adaptive Operation used as the Operation with Ice strategy requires the Low Power Detection Curve and No Cut in Detection to be used, it is therefore not compatible with the external sensor.

Ice build-up on the turbine can possibly cause damage to objects and people in the vicinity. The ice detection and Operation with Ice system will not protect against ice being thrown from the turbine(s). What the system does is either optimize performance and yield maximum production despite ice on the turbine or stop the turbine to prevent operating with ice. There may be ice on blades upon start and/or stop of the turbine. It is the sole responsibility of the owner of the turbine to ensure that the public is protected from ice being thrown from the turbine. The Owner must always ensure that the operation of the turbine complies with all restrictions applicable to the turbine, irrespective of whether such restrictions follows from permits, legislation or otherwise. SGRE accepts no responsibility for any violation of requirements.

## 2. Ice Detection Sources

### 2.1. Low Power Detection Curve (LPDC)

The LPDC functionality is an integrated part of the turbine controller, thus not requiring additional sensors.

LPDC is a requirement to be active when the *Operation with Ice Strategy: Adaptive* is selected.

LPDC detects ice when power production degrades due to ice build-up on the blades during operation when the turbine produces power in cold weather by comparing the actual power production to the sales power curve shown in Figure 2 when the ambient temperature is below 5° C (configurable). LPDC is based on a percentage of the sales power curve with a minimum separation to the sales power curve.

If production falls below the “LPDC Ice Detection” (Blue) curve shown in Figure 2, the selected Operation with Ice strategy is activated.

If *Operation with Ice Strategy: Adaptive Operation* is selected and the production increases above the “LPDC Ice Detection” curve, Adaptive Operation is deactivated.

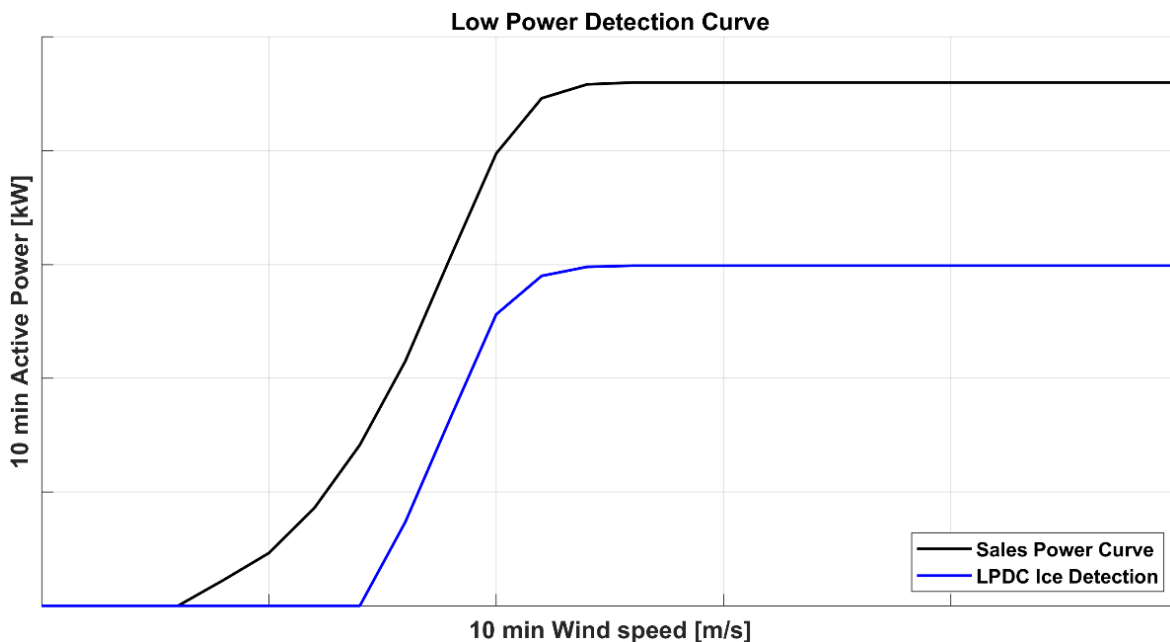


Figure 2: Illustration of Low Power Detection Curve (LPDC)

### 2.2. No Cut-in

The No Cut-in functionality is an integrated part of the turbine controller, thus not requiring additional sensors. No Cut-in is a requirement to be active when *Operation with Ice Strategy: Adaptive Operation* is configured.

No Cut-in is an ice detection method that indicates when there is enough wind for the wind turbine to produce power, but the turbine is unable to cut-in, connect to the grid, and produce power for a period of time due to severe ice build-up in cold weather.

If *Operation with Ice Strategy: Adaptive Operation* is selected as the ice detection response strategy, the turbine will cut-in and connect to the grid at an adapted power production level given the conditions. See further below in chapter “Operation with Ice Strategy: Adaptive Operation”.



## 2.3. External Sensor Options

The external ice detector sensor functionality is an optional extra system that can be used to create a response directly from the sensor on the turbine. Most often the sensor reports data to SCADA which controls the turbines at the site with respect to stopping them. It is intended for installation on wind turbines located in areas where there is a risk that ice can build up on either the turbine nacelle or blades and there are personal safety or legislation concerns that required the turbine to be stopped instantly when ice is detected. Compared to the LPDC and No Cut-in ice detection source options are designed to detect when performance is impacted where ice may already exist on the turbine.

The external sensor is only compatible with Operation with Ice Strategy:

- Stop the turbine
- Stop the turbine, yawing to a specific angle

The external sensor communicates with the Supervisory Control and Data Acquisition (SCADA) system. Typically, only a few external sensors are installed on a given site, and SCADA can be configured to stop the entire site or clusters or individual turbines if deemed necessary.

There are two separate types of use for the external sensor:

- External sensor is selected as the turbines ice detection source (Figure 1) for individual turbines, which allows the individual turbine itself to react to the sensor. Additionally, SCADA can still react to the signal and stop turbine(s) at the site.
- External sensor is not selected as the turbines ice detection source (Figure 1), so the individual turbine itself will not react to the external sensor, but SCADA can still react to the signal and stop turbine(s) at the site.

## 2.4. External Sensor Types

### 2.4.1. Nacelle Based Ice Detection Sensor (Optional)

The nacelle ice detection sensor is an optional system intended for installation on wind turbines located in areas where ice can build up on the turbine. The purpose of the ice detector system is to provide the turbine controller information about potential risk for ice on the turbine. The ice detection system can detect in-cloud icing as well as freezing rain. Depending on requirements when ice is detected an ice alarm can initiate a turbine stop.

The system can come with a valid certification from accredited institutes.

### 2.4.2. Blade-Based Ice Detection Sensor (Optional)

An additional option is to install a blade-based ice detection system. Such system includes a set of sensors (accelerometers) on each blade, plus a central monitoring unit. The ice detection is performed by analysis of blade eigenfrequencies with respect to ice accumulation. Therefore, the system needs a calibration prior to enter service (varying, and up to 3 months depending on the conditions and WTG configuration).

Ice detection is possible at standstill and during operation. No minimum rotation per minute (rpm) is required, however a minimum wind speed of 2 m/s is required to ensure sufficient excitation of blade.

The system can also come with a valid certification from accredited institutes.

## 2.5. Options and logging in SCADA

Possible options in SCADA to configure the usage of the external sensor on site level (independent of the individual turbine interface):

- Set predefined ice conditions using ice parameters
- Enable or disable automatic stop of individual turbines
- Enable or disable automatic restart of individual turbines
- Group turbines for auto stop and auto restart. SGRE recommends using SCADA to group ice sensor installed turbines along with turbines on which ice sensors are not installed.

Ice parameters are set in the SCADA interface. Depending on requirements, ice parameters can be modified to configure new ice conditions through the SCADA interface. Below is a list of the parameters:

- **Ice Restart Delay:** Turbines that are stopped due to ice are restarted only if ice is not reported from the sensor during the “Ice Stop Delay” in seconds configured by the user.
- **Ice Stop Delay:** Turbines are stopped due to ice only if ice is detected on turbine(s) for more than the ice stop delay in seconds configured by the user.
- **Ambient Temperature Duration:** Duration in seconds for how long the ambient temperature for ice detection should be exceeded to restart the turbines which are stopped due to ice.
  - E.g. above 5°C for 600 seconds
- **Ambient Temperature Threshold:** This parameter defines the temperature which must be exceeded to restart turbines stopped due to ice detection.
  - E.g. above 5°C for 600 seconds
- **Ice Control Start Time and Ice Control End Time:** Configured turbines will be stopped due to ice detection when the actual time is between Ice Control Start Time and Ice Control End Time. When the current time falls outside the range specified in Ice Control Start Time and Ice Control End Time, the turbines are restarted.

The alarms are presented in the ‘Alarm log’ of the Web WPS SCADA interface.

**History, Alarm Log,**

Max Records: 150 | From Date: 21-02-2012 | To Date: | Group: Turbine | Station: (All) | Secondary Faults: 0

Alarms:  Active Only |  Display Events | Filtername: | Save Filter | Delete Filter |  Include Alarms from Service

Alarms: (Filter :Brake), (Filter :Converter Alarms), (Filter :Environment), (Filter :Gear) | Selected: | Load data | Import

Include |  Exclude

From Time	To Time	Duration	Group	Station	Code	Description	Parameter	User	Comment
28-02-2012 - 08:54:04	28-02-2012 - 09:20:00	00:25:56	Turbine	T05	8210	Stopped, due to icing			
			Turbine	T01	8215	Ice has been detected			Add

Figure 3. Presentation of alarms related to the ice detection system in Web WPS SCADA

## 3. Operation with Ice Strategy

### 3.1. Operation with Ice Strategy: Stop Turbine

Stopping the turbine is often used in scenarios where it is not safe to keep running the turbine during icing conditions, e.g. where potential wildlife, people or equipment can be damaged/hurt. Only if using the external sensor can this approach be seen as safe, as the external sensors are often mounted on the nacelle and will detect when ice is forming and not based on production as the “Low Power Curve Detection” and “No Cut In” features do.

*Operation with Ice Strategy: Stop Turbine* makes sure the turbine is stopped when ice is detected. Additional option is possible in combination with the stop: Yaw to Angle.

Regardless of how *Operation with Ice Strategy: Stop Turbine* is configured, it is possible to determine if the turbine should auto reset or manually reset. The following options exist for auto reset:

- A stopped turbine with an ice detection alarm is reset after X hours
- A stopped turbine with an ice detection alarm requires manual reset
- A stopped turbine with an ice detection alarm that is yawed to a specific angle due to safety constraints is reset after X hours
- A stopped turbine with an ice detection alarm that is yawed to a specific angle due to safety constraints requires manual reset

### 3.2. Operation with Ice Strategy: Adaptive Operation

*Operation with Ice Strategy: Adaptive Operation* provides customers with a way to optimize the wind turbine so that it continues operation when ice builds up on the blades and ice detection is triggered, thereby limiting shutdown events. By allowing continued operation, ice accumulates more slowly on the blades compared to if it were at a standstill. Therefore, the yield of production with ice buildup will increase due to adaptation/optimization to icing conditions through pitch angle and speed-power modification.

*Operation with Ice Strategy: Adaptive Operation* offers a limited power production under managed loads and thereby reduces the turbines' shutdown events. *Operation with Ice Strategy: Adaptive Operation* is a wind turbine controller software functionality for optimizing performance, allowing the turbine to maintain operation in ice conditions.

When ice is detected via the LPDC or No Cut-in ice detection sources, *Operation with Ice Strategy: Adaptive Operation* finds the optimal operational setup in order to maximize production by first modifying the speed power curve (as shown in Figure 4). *Operation with Ice Strategy: Adaptive Operation* increases the rotor speed to avoid the blades stalling and the turbine from cutting out. The speed will not exceed nominal speed.

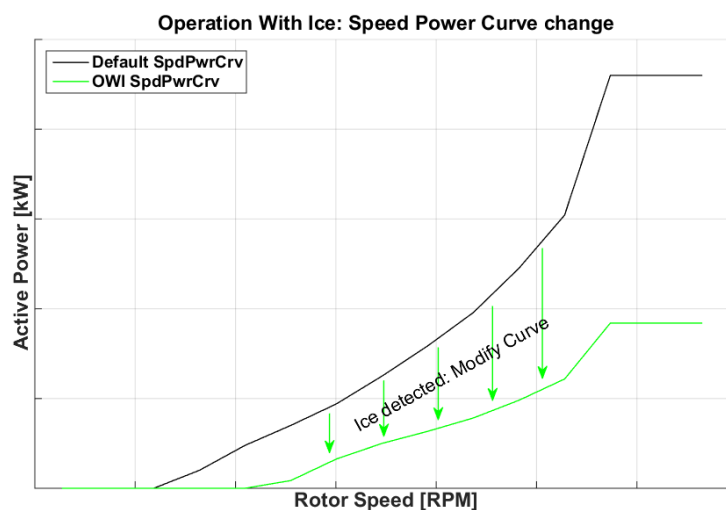


Figure 4. Illustration of OWI Speed-Power curve modification

Use of the *Operation with Ice Strategy: Adaptive Operation* functionality may under certain conditions increase the noise emissions from the turbine, and the noise emissions may exceed the levels indicated in the turbine supply agreement. Any noise levels indicated or warranted in the turbine supply agreement shall not be applicable in the event of operation of the turbine with the *Operation with Ice Strategy: Adaptive Operation* functionality activated.

It is the sole responsibility of the owner of the turbine to ensure that the turbine operating with *Operation with Ice Strategy: Adaptive Operation* functionality activated complies with any noise restriction applicable, irrespective of whether such limits follow from permits, legislation or otherwise. Siemens Gamesa accepts no responsibility for any violation of such limits.

# Safety System

## Siemens Gamesa 5.X

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# Safety System

## 1. Description

Siemens Gamesa Renewable Energy (SGRE) identifies and mitigates risks based on the risk assessments process, according to EN ISO 12100:2011 - Safety of machinery – General principles for design – Risk assessment and risk reduction.

The outcome of the risk assessment process includes the identification of hazards which have different risk levels. The high-level risks which are not possible to sufficiently mitigate through changes inherent to the design or through other protective measures are then mitigated using a safety-related part of the control system. These safety systems are designed according to EN ISO 13849-1:2015 – Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design.

After the design is done, these safety systems are evaluated according to EN ISO 13849-2:2014 – Safety of machinery – Safety-related parts of control systems – Part 2: Validation.

As described, safety systems mitigate risk in addition to other protective measures. These measures include the use of guards, mechanical locks, and electrical locks in the design. All rotating parts and high voltage areas are covered with guards which require a tool for removal. Before dismounting the guards, instructions to the user require that either a mechanical lock must be set or any hazardous energy isolated. These instructions ensure that risks from unintended hazardous effects are eliminated.

For all high risks identified in the risk assessment which require the use of a safety system, there is always a primary layer operational safety function. This is a layer of monitoring and control which is part of the operational turbine controller. This covers the high voltage protection system, all temperature and pressure monitoring, and also overcurrent, overspeed, and vibration monitoring on an operational level.

The safety systems are designed to operate independently of this primary layer monitoring as a separate secondary layer in order to ensure that a controller failure does not lead to the loss of a protection function.

As an outcome of the risk assessment, the following safety systems have been identified:

- Overspeed protection
- Excessive vibration protection
- Emergency stop button activation
- Excessive cable twist protection

## 2. Safety system architecture

This section describes the overall safety system architecture as shown in Figure 1:

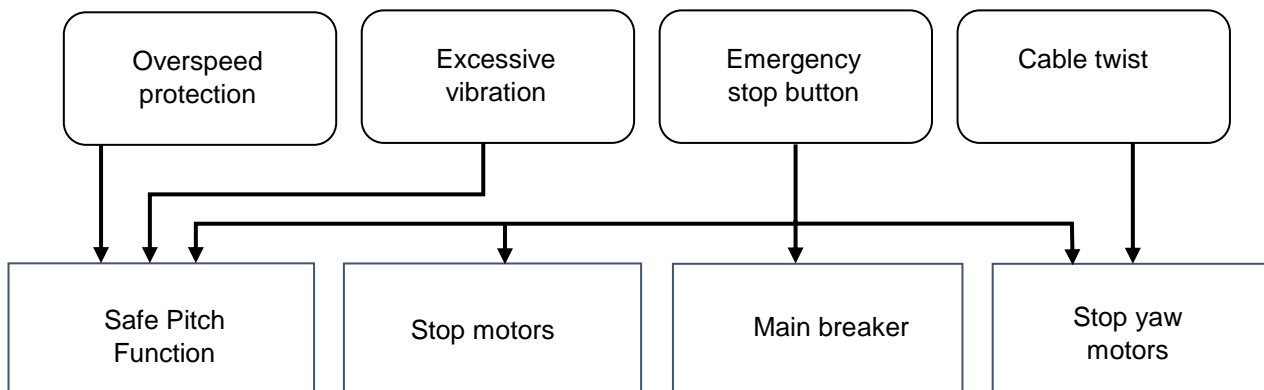


Figure 1: Common Safety Functions.

Where safety-related parts of the control system depend on logical control units, the parameters used to configure these components can only be changed by physically replacing components (the component must be physically replaced for changing configuration). Each component has a unique part number. Local or remote configuration of safety-related components in the turbine is not possible.

## 3. Safety system input functions

### 3.1. Overspeed Protection System

The overspeed protection system is comprised of an overspeed detection device and the safe pitch function. This device uses internal sensors to determine the rotor speed and then compares this to predetermined limits. When the device activates, it sends the wind turbine to stop mode.

The system is designed to fulfill the requirements of a Category 3, PLd safety system according to ISO 13849-1:2015.

### 3.2. Excessive Vibration and Shock Protection System

The excessive vibration and shock protection system consists of a tower-top vibration sensing device, which is designed for monitoring structural vibrations in wind turbines. This device is used as the tower-top vibration sensing device. It will activate the safe pitch function in case of large tower-top vibration or if the nacelle is exposed to a mechanical shock.

The system is designed to fulfill the requirements of a Category 3, PLd safety system according to ISO 13849-1:2015.

### 3.3. Excessive Cable Twist Protection System

In case the yaw control system fails, a cable twist switch is mounted in the tower in order to prevent damage to the cables. It allows the wind turbine to turn in either direction from the zero position only a predetermined amount.

This system is designed to fulfill the requirements of a Category 1. PLc safety system according to ISO 13849-1:2015.

## 3.4. Emergency Stop Button Activation

The turbine is equipped with emergency stop buttons in various places in the nacelle and tower. The functionality of these stop buttons is designed according to the requirements of ISO 13850:2015 – Safety of machinery – Emergency stop function – Principles for design.

This system is designed to fulfill the requirements of a Category 3, PLd safety system according to ISO 13849-1:2015.

The emergency stop function overrides both control and protective systems (devices that protect the WTG when it is running out the design limits. i.e yaw stop, vibrations, over-speed...), and is mainly provided for protection of people. It relies only on mechanical and fail-safe systems in the turbine.

## 3.5. The emergency stop function evolves the following actions:

Pitch goes to the emergency state (pitch is moved towards feather position by means of the emergency pitch circuit) in every situation that can activate the emergency stop. Since the electrical safety circuit is opened, no other sub-system operations like yawing, heating, cooling, lubrication, etc. can remain in operation. The pitch system will go to emergency but not the power converter. Power should not be removed just ramped down.

## 4. Safety system output functions

The safety system output functions are the systems which ensure that upon activation of one of the input functions, any hazardous situation is mitigated through an output action.

### 4.1. Safe Pitch Function

The safe pitch function is an output part of several safety systems. The sub-system consists of an independent hydraulic pitch system for each blade. Each system has a backup reserve of energy via a piston accumulator.

The three pitch systems are kept as separate circuits to prevent a failure of one component causing the malfunction of the pitch systems for the other two blades. When all valves are without power, the blades pitch to full stop (feather position).

Safe pitch system has been defined as 2oo3 (turbine can stop safety with one stuck blade, without exceeding design loads).

### 4.2. Main breaker function

The main breaker disconnects the converter and generator from the grid. The turbine controller is also able to cut out the main breaker by its hardwired fail-safe interface.

#### 4.2.1. Stop motors function

This function powers off the motors in the turbine.

#### 4.2.2. Stop Yaw Motors Function

This function powers off the motors in the yaw system.