Factors Determining the Effectiveness of a Wind Turbine Generator Lightning Protection System

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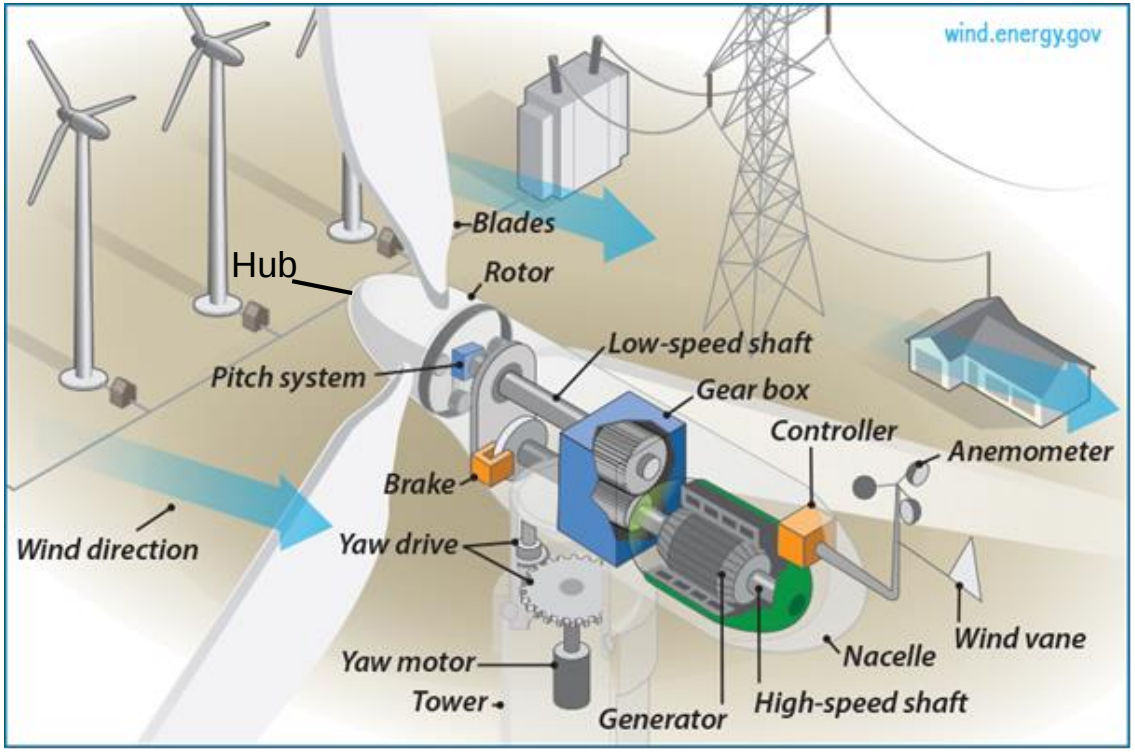
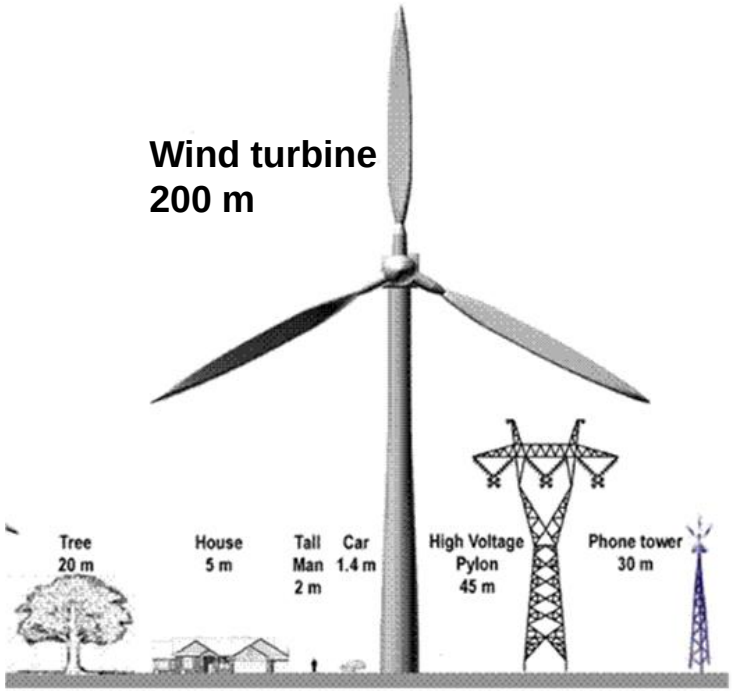
Introduction



Introduction

- The reduced costs for wind energy are due to a surge in energy generation from individual WTG by the expanding size and escalated installations at high altitudes



Wind Farm Optimization

- A wind farm layout is primarily optimized for AEP output and wake loss reduction
- Noise constraints
- Avoidance of obstacles and protected lands
- Visualization and shadow flicker issues
- Power grid connection

https://www.emd.dk/wind-energy-consultancy/wind-farm-layout-optimizations/

Wind Farm Optimization

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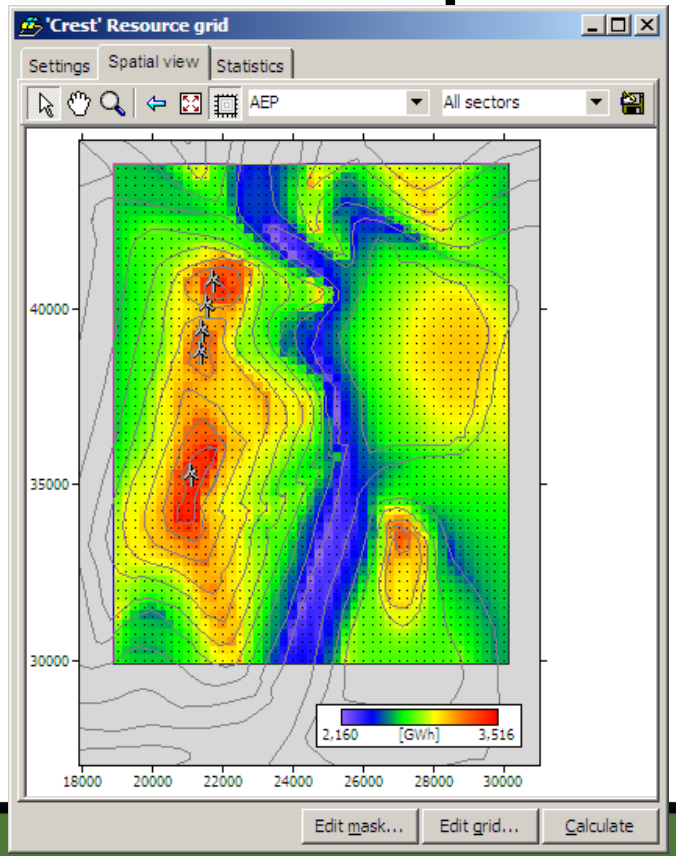
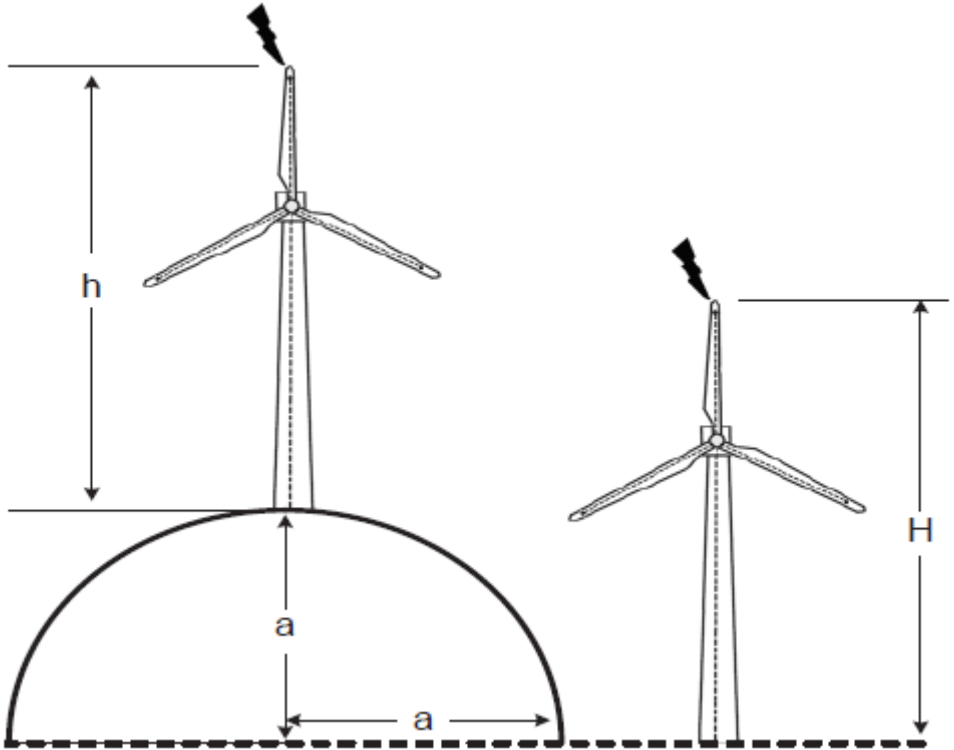
Wind Farm Optimization



https://www.wasp.dk/wasp#details__wind-resource-mapping

Wind Farm Optimization

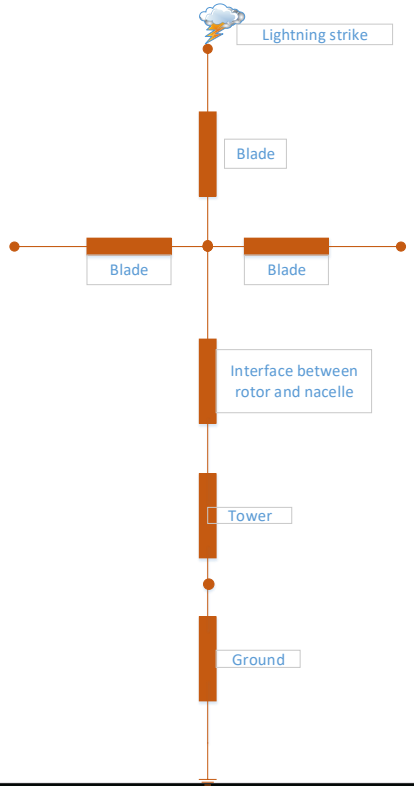


Lightning Strikes on Wind Turbines

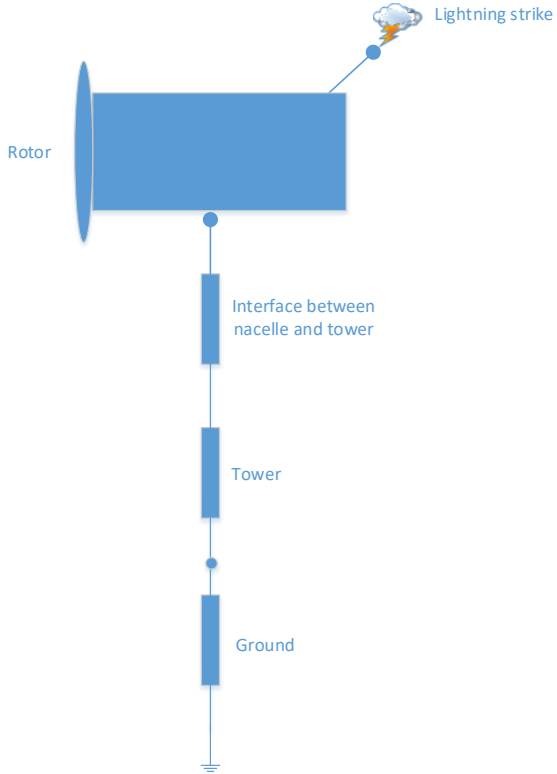
Wind Turbine Lightning Protection System

- External lightning protection system
- Internal lightning protection system
- Earthing system

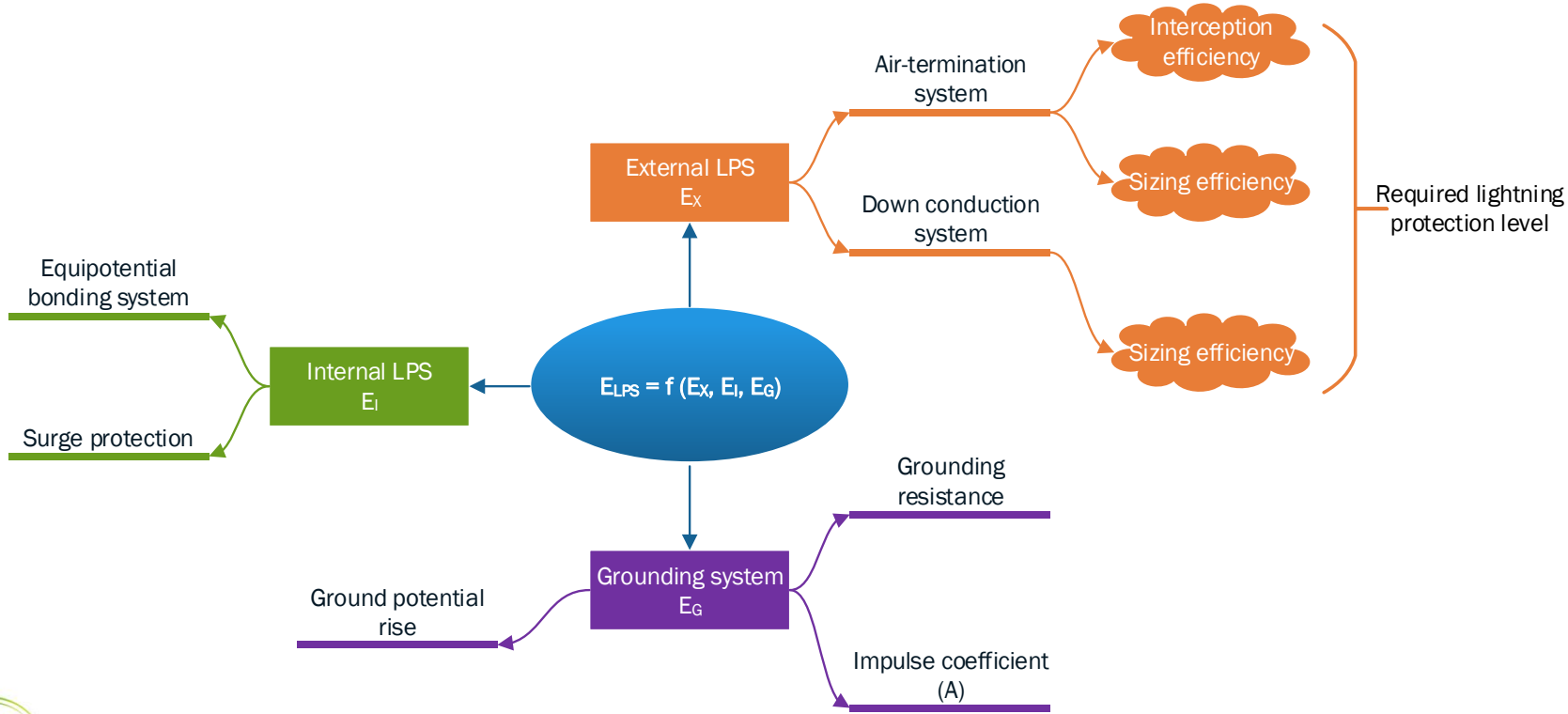
Down Conduction Path



Down Conduction Path



Effectiveness of WTG LPS



Effectiveness of WTG LPS

Table: Effectiveness of air-termination system

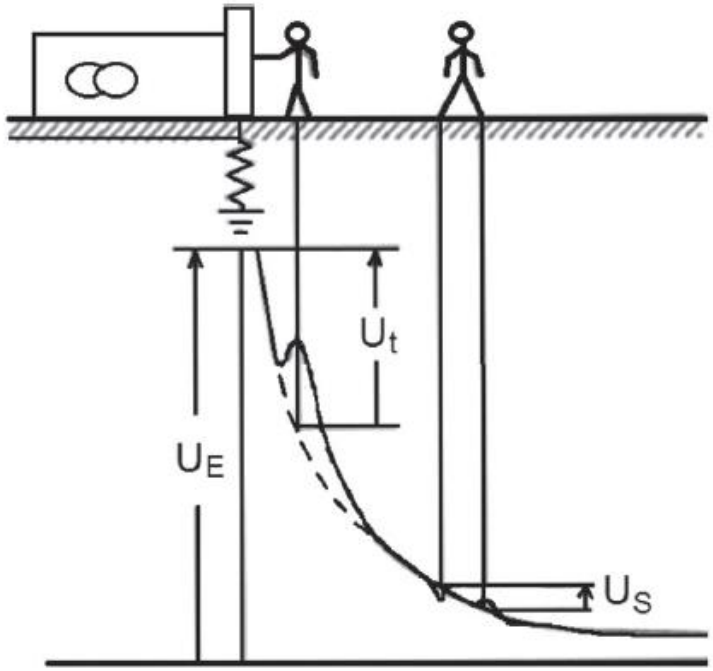
Lightning protection level (LPL)	I	II	III	IV
Sizing effectiveness	0.99	0.98	0.95	0.95
Interception effectiveness	0.99	0.97	0.91	0.84
Total effectiveness	0.98	0.95	0.86	0.8

Table: Effectiveness of down conduction system

Lightning protection level (LPL)	I	II	III	IV
Sizing effectiveness	0.99	0.98	0.95	0.95

Effectiveness of WTG Grounding

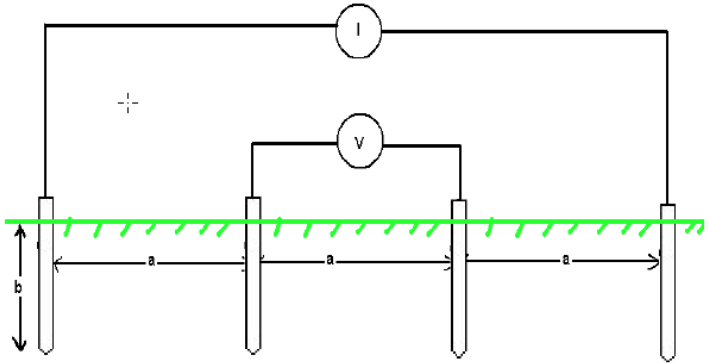
- Low-Frequency resistance
- Impulse coefficient
- Potential distribution
- Step and Touch voltages

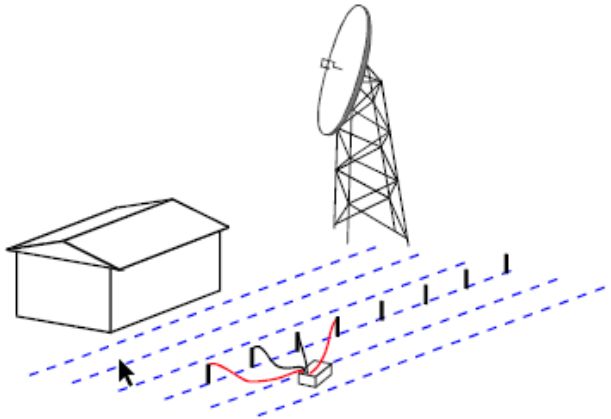


CASE STUDY

Soil Resistivity Measurement

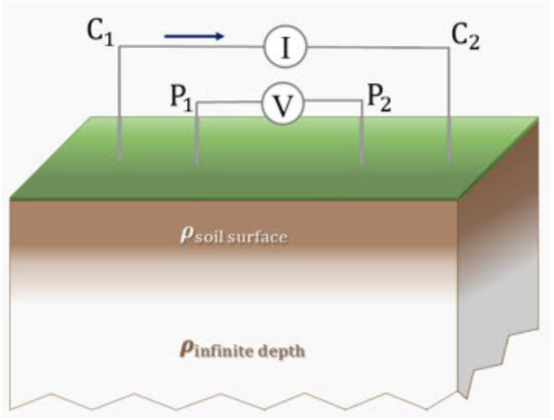
- Wenner Method

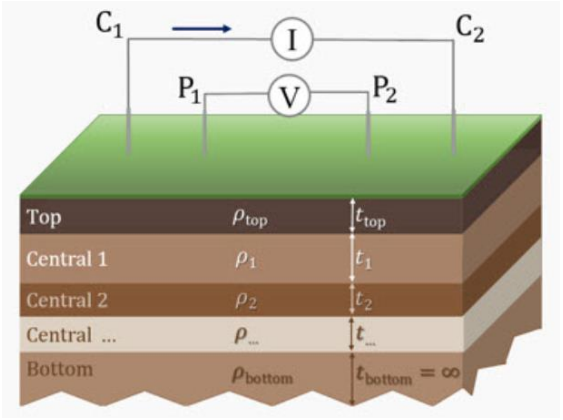


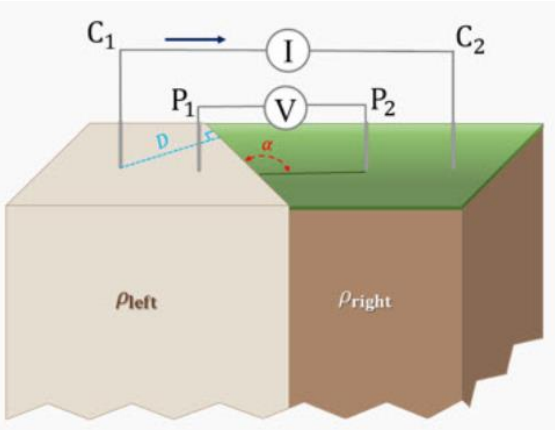


$$\rho = \frac{4 * \pi * a * R}{1 + 2 * a/\sqrt{a^2 + 4 * b^2} - a/\sqrt{a^2 + b^2}}$$

Soil Stratification







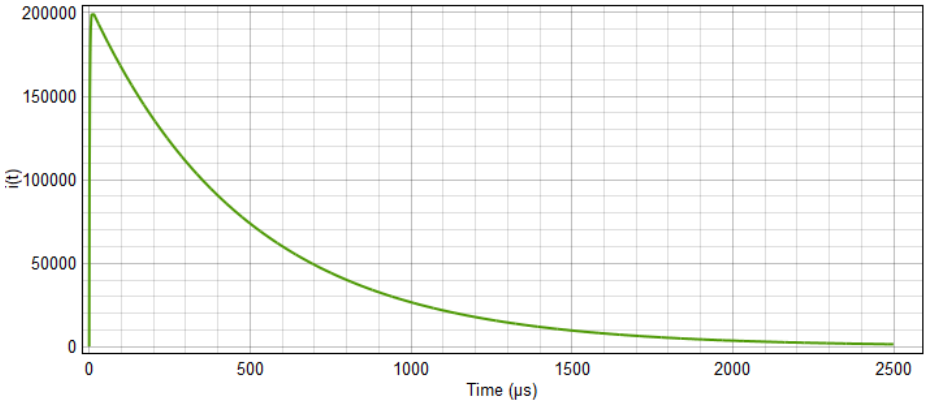
LPL Parameters

First short positive stroke			LPL			
Current parameters	**Symbol**	**Unit**	**I**	**II**	**III**	**IV**
Peak current	I	kA	200	150	100	
Short stroke charge	Q_{short}	C	100	75	50	
Specific energy	W/R	MJ/Ω	10	5,6	2,5	
Time parameters	T_1 / T_2	µs / µs	10/350			
First short negative stroke [a]			**LPL**			
Peak current	I	kA	100	75	50	
Average steepness	di/dt	kA/µs	100	75	50	
Time parameters	T_1 / T_2	µs / µs	1/200			
Subsequent short stroke [a]			**LPL**			
Current parameters	**Symbol**	**Unit**	**I**	**II**	**III**	**IV**
Peak current	I	kA	50	37,5	25	
Average steepness	di/dt	kA/µs	200	150	100	
Time parameters	T_1 / T_2	µs / µs	0,25 / 100			
Long stroke			**LPL**			
Current parameters	**Symbol**	**Unit**	**I**	**II**	**III**	**IV**
Long stroke charge	Q_{long}	C	200	150	100	
Time parameter	T_{long}	s	0,5			
Flash			**LPL**			
Current parameters	**Symbol**	**Unit**	**I**	**II**	**III**	**IV**
Flash charge	Q_{flash}	C	300	225	150	

[a] The use of this wave shape concerns only calculations and not testing.

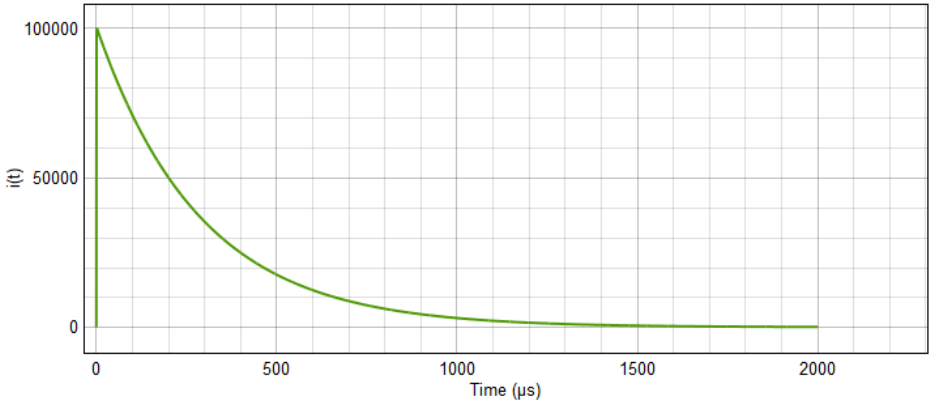
Lightning Discharge Current

- First short positive lightning discharge current waveform
- Rise time : 10 µs
- Time to half : 350 µs



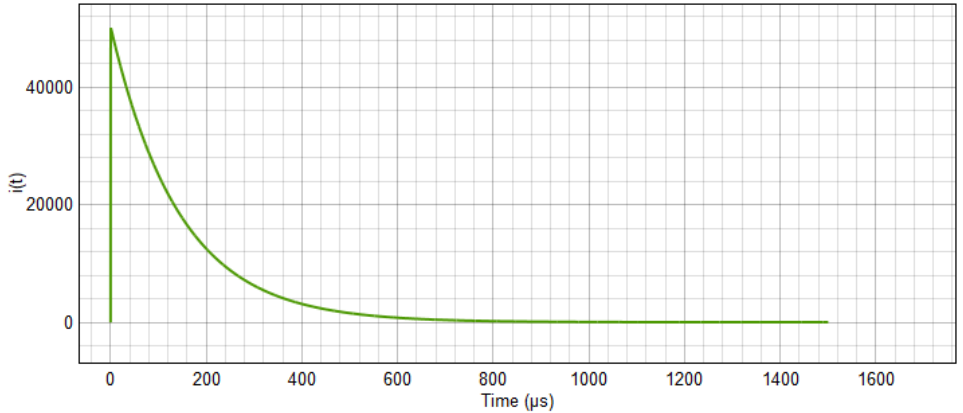
Lightning Discharge Current

- First short negative lightning discharge current waveform
- Rise time : 1 µs
- Time to half : 200 µs

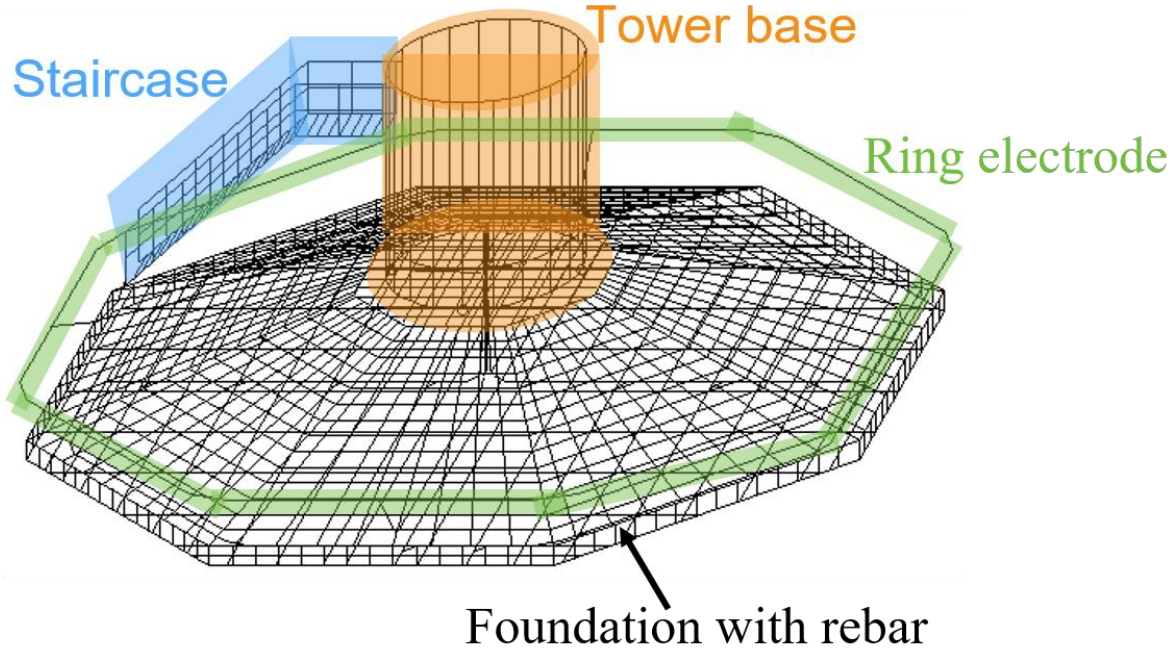


Lightning Discharge Current

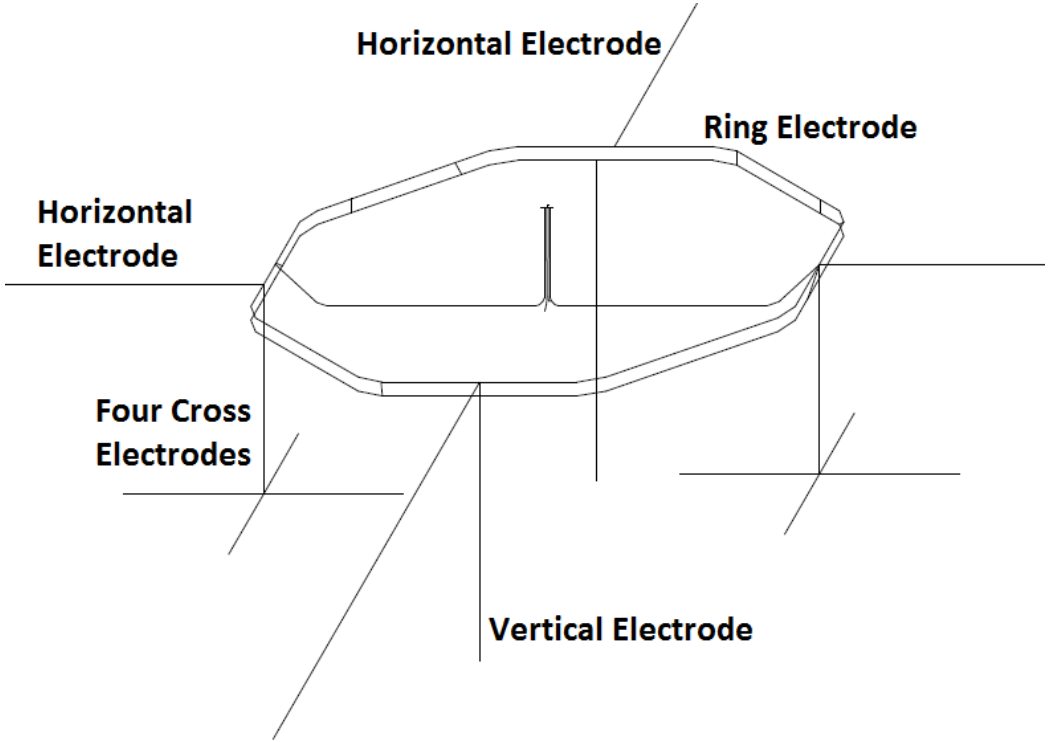
- Subsequent short lightning discharge current waveform
- Rise time : 0.25 µs
- Time to half : 100 µs



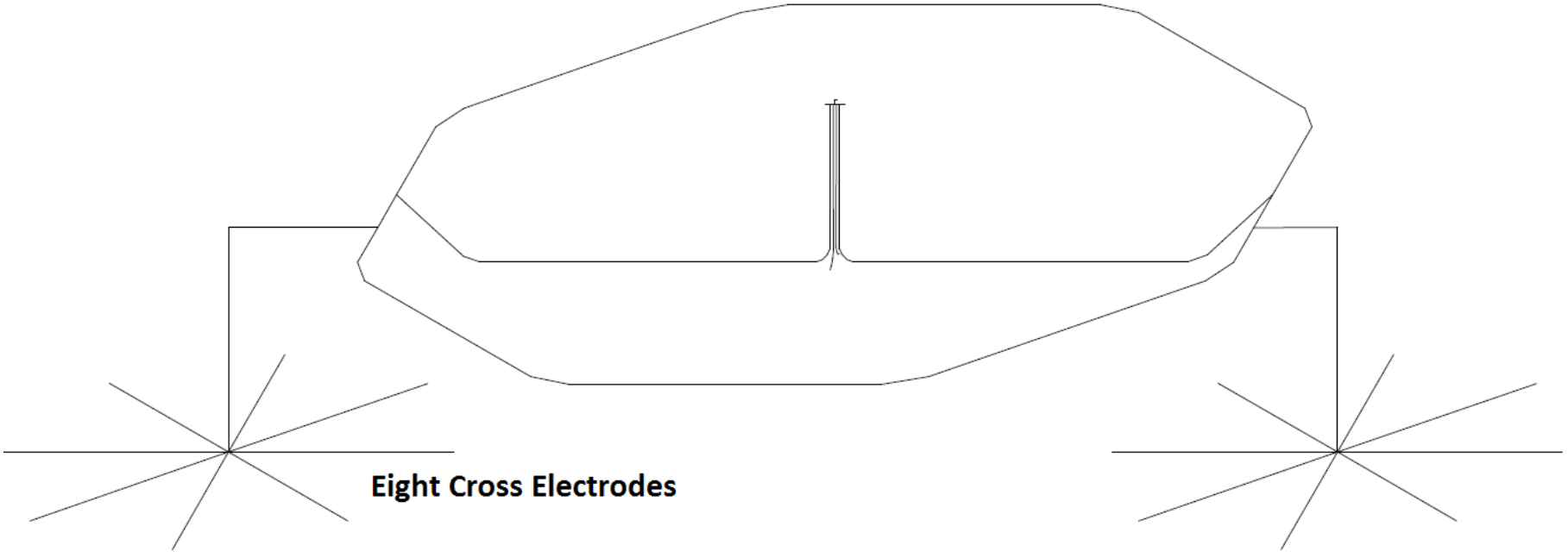
Wind Turbine Grounding System



Electrode Configurations

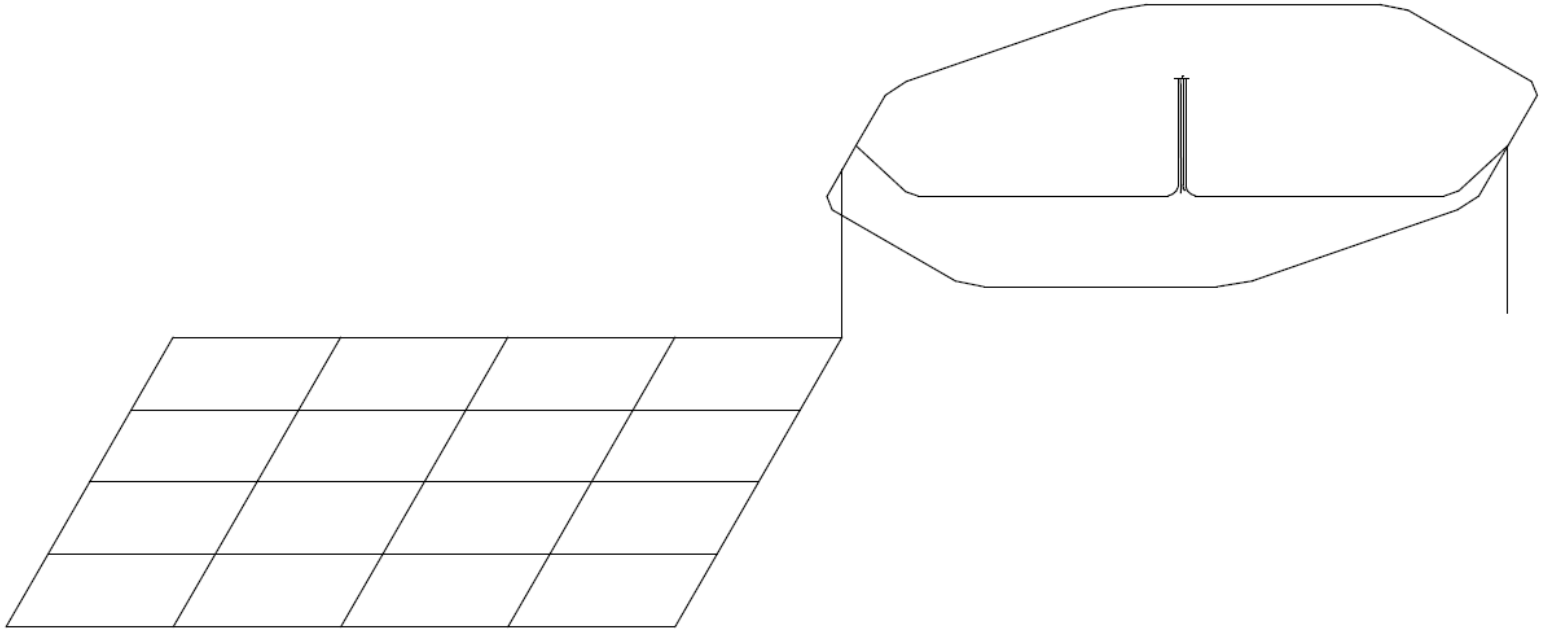


Electrode Configurations



Eight Cross Electrodes

Electrode Configurations



Results

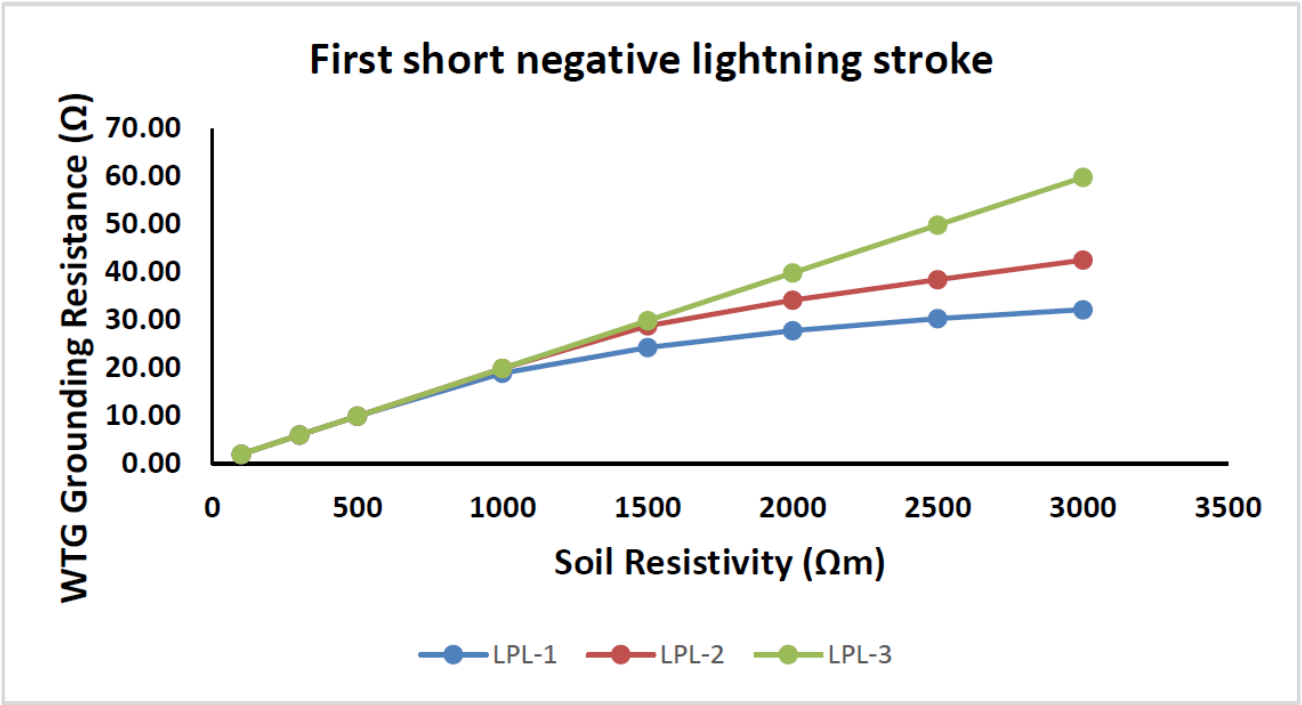


Fig. WTG grounding resistance for different lightning protection levels.

Results

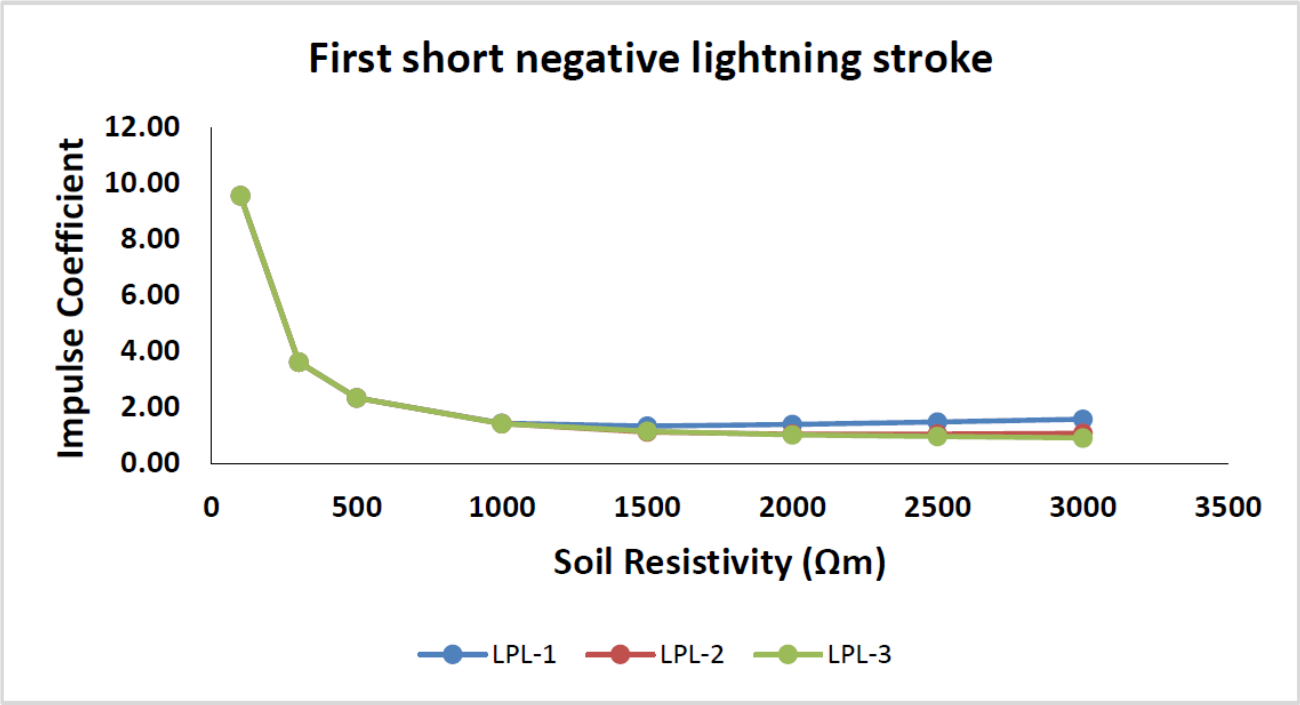


Fig. Impulse coefficient of the WTG grounding system for first short negative lightning discharge current parameters.

Results

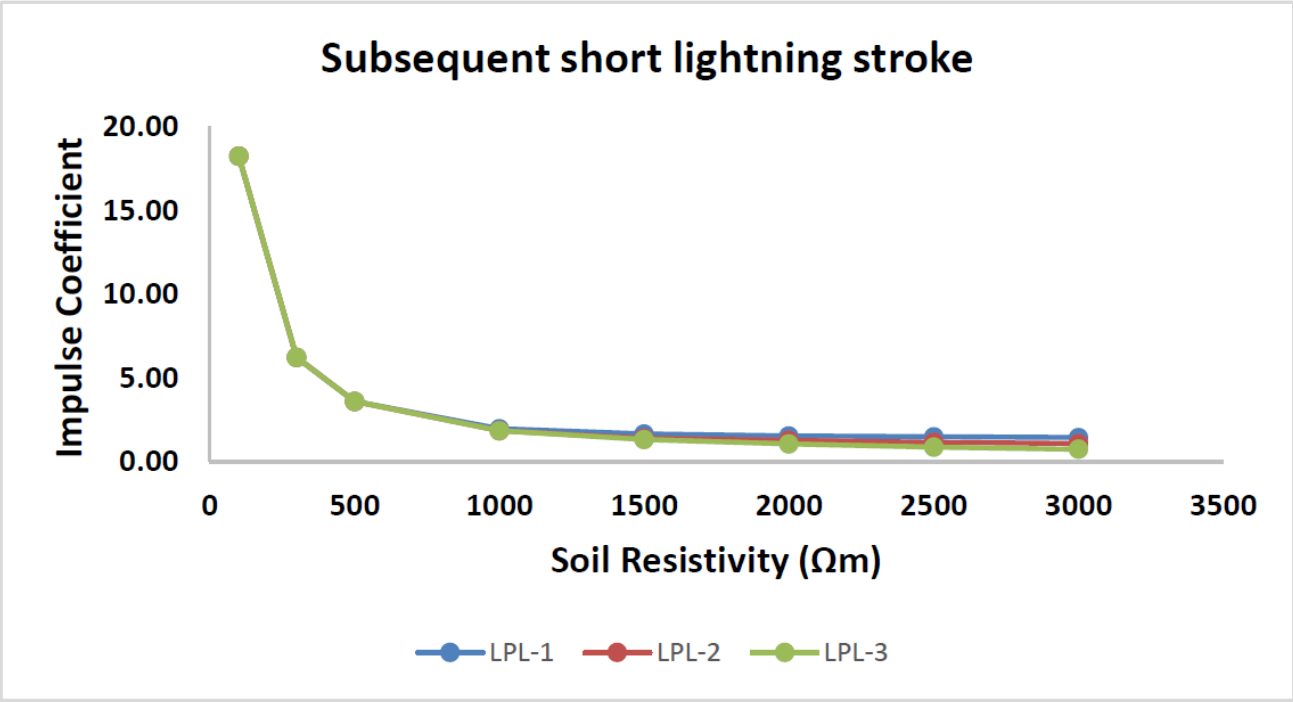


Fig. Impulse coefficient of the WTG grounding system for subsequent lightning discharge current parameters.

Results

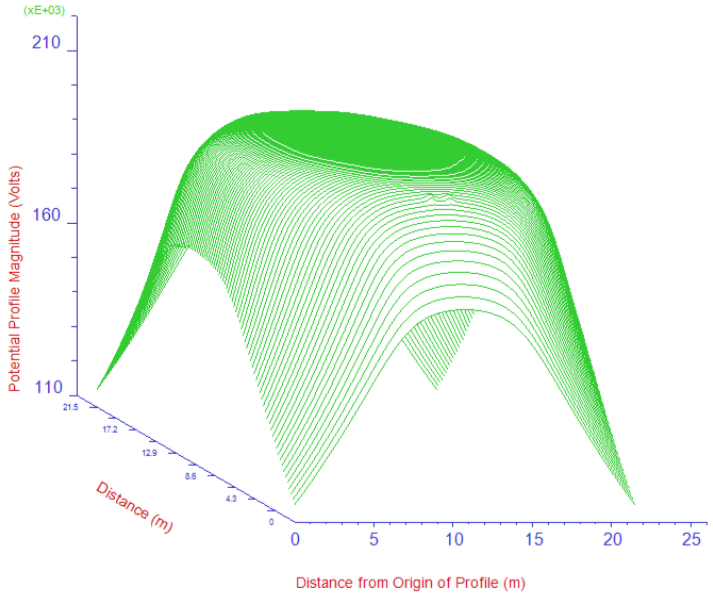


Fig. Potential distribution of the WTG grounding system at 5 kHz.

Results

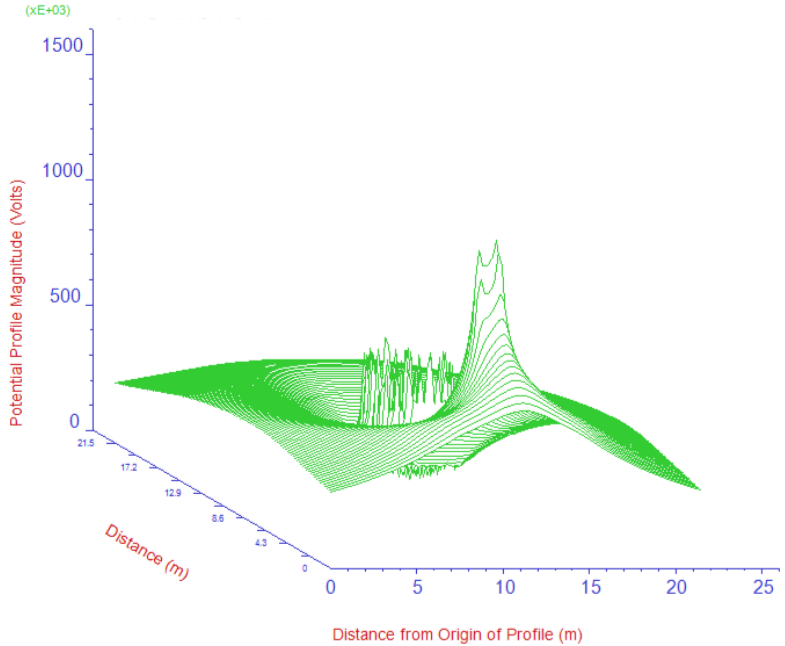


Fig. Potential distribution of the WTG grounding system at 4.1 MHz.

Results

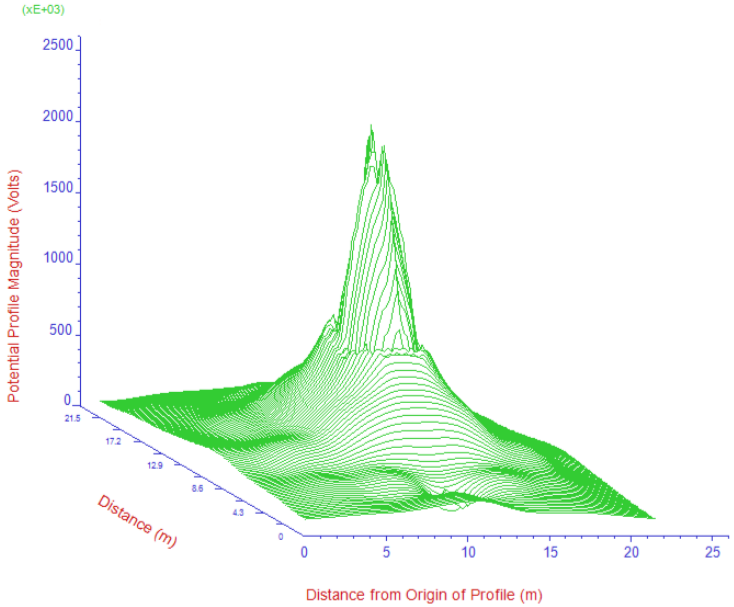


Fig. Potential distribution of the WTG grounding system at 50 MHz.

Conclusions

- Using advanced electromagnetic simulation tools it is possible to predict the behaviour of a WTG LPS at the design stage.
- Combining information about several aspects of the WTG LPS allows us to predict the overall effectiveness of the LPS.
- Having the ability to succinctly describe LPS behaviour will facilitate safer wind farms and faster adoption of wind as a form of clean, renewable energy.

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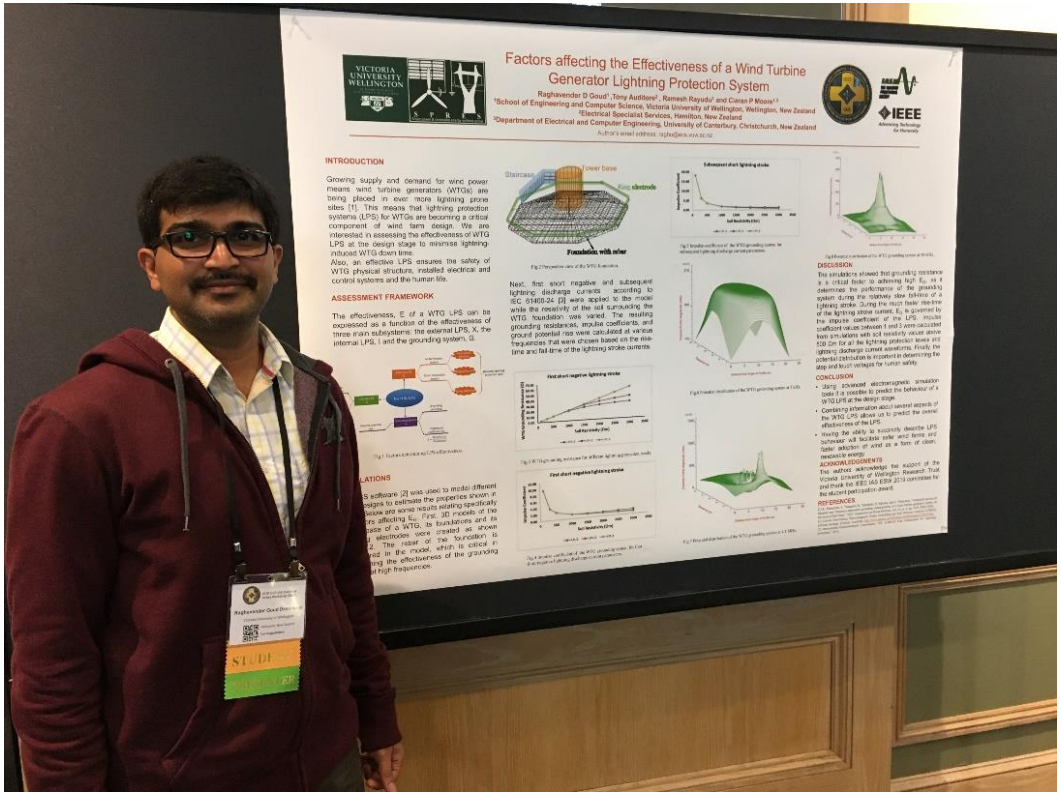

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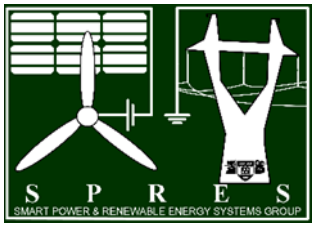
Thank you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