

Designing Grounding Systems that safely dissipate both Fault Currents and Lightning Current (GPR)

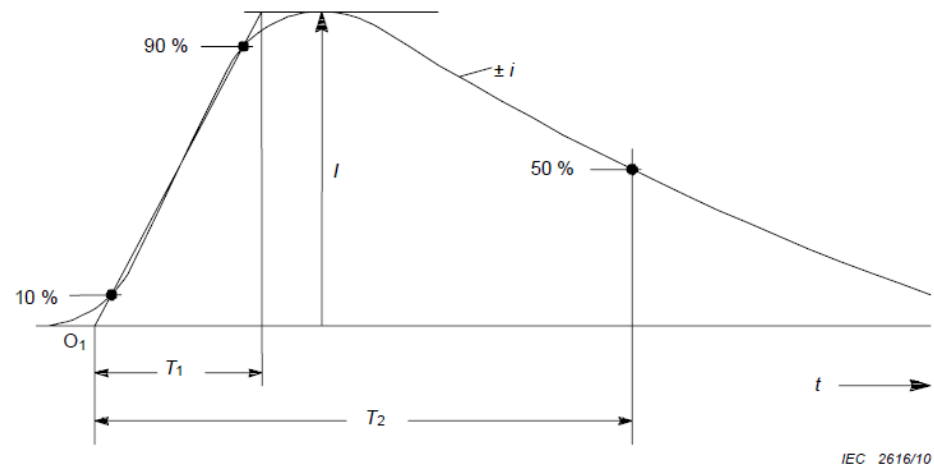
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Content to be covered:



- Grounding System Performance:
 - Power Frequency vs. Lightning Current
- Grounding Design for Power Frequency vs. Lightning Impulse Current Scenarios:
 - Human Safety Analysis (Safe Step-and Touch Voltage)
 - Illustration of GPR and Power distribution (Power Frequency vs. Lightning Impulse)
 - Comparison of Simulation Results
 - Possible mitigation techniques for Lightning GPR

Power Frequency- vs. Lightning Impulse Current – Performance Simulation

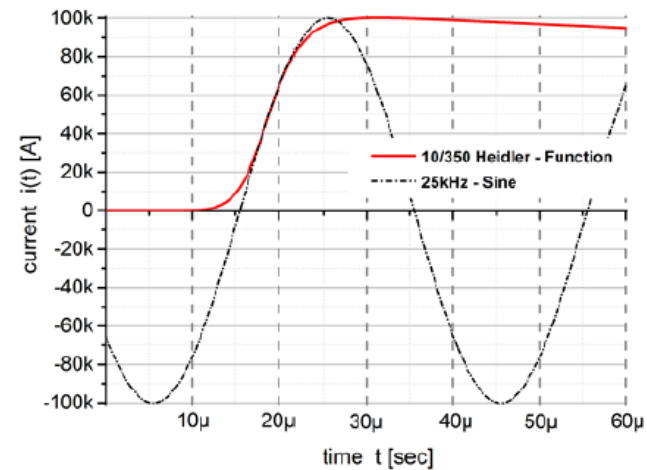


IEC 2616/10

Key

- O_1 virtual origin
- I peak current
- T_1 front time
- T_2 time to half value

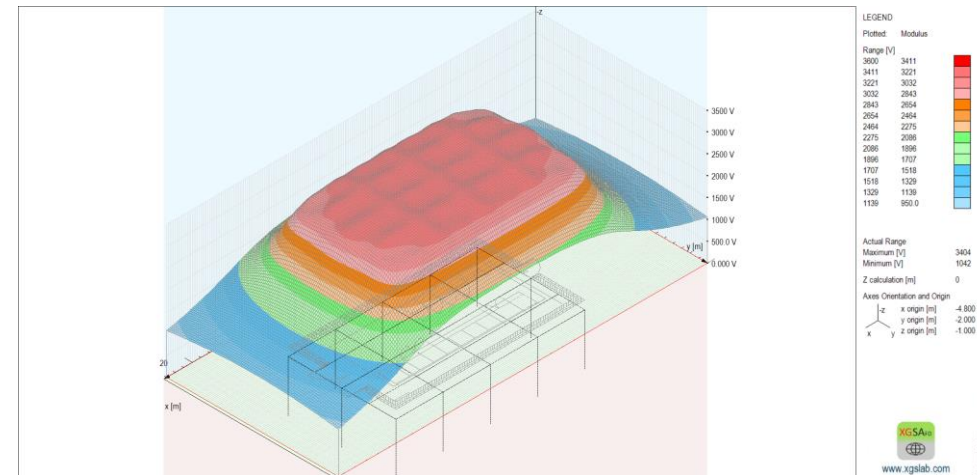
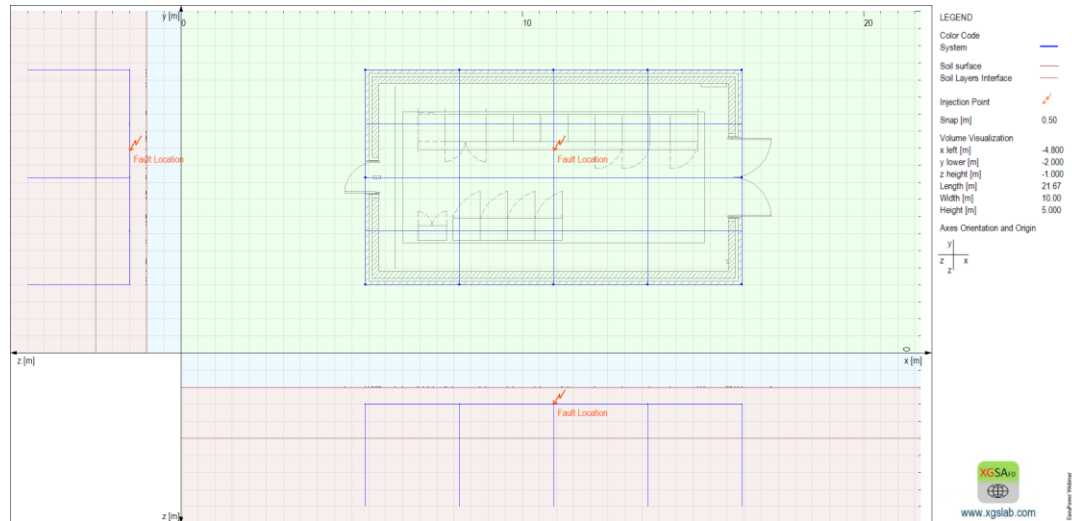
Figure A.1 – Definitions of impulse current parameters (typically $T_2 < 2$ ms)



Type of short stroke	IEC 62305-1 parameters						Impulse parameters		Equivalent frequency
	I Class I (kA)	I Class II (kA)	I Class III-IV (kA)	k	T1 (μ s)	T2 (μ s)	T1 (μ s)	T2 (μ s)	f (kHz)
First positive	200	150	100	0.93	19	485	10	350	25
First negative	100	75	50	0.986	1.82	285	1	200	250
Subsequent negative	50	37.5	25	0.993	0.454	143	0.25	100	1000

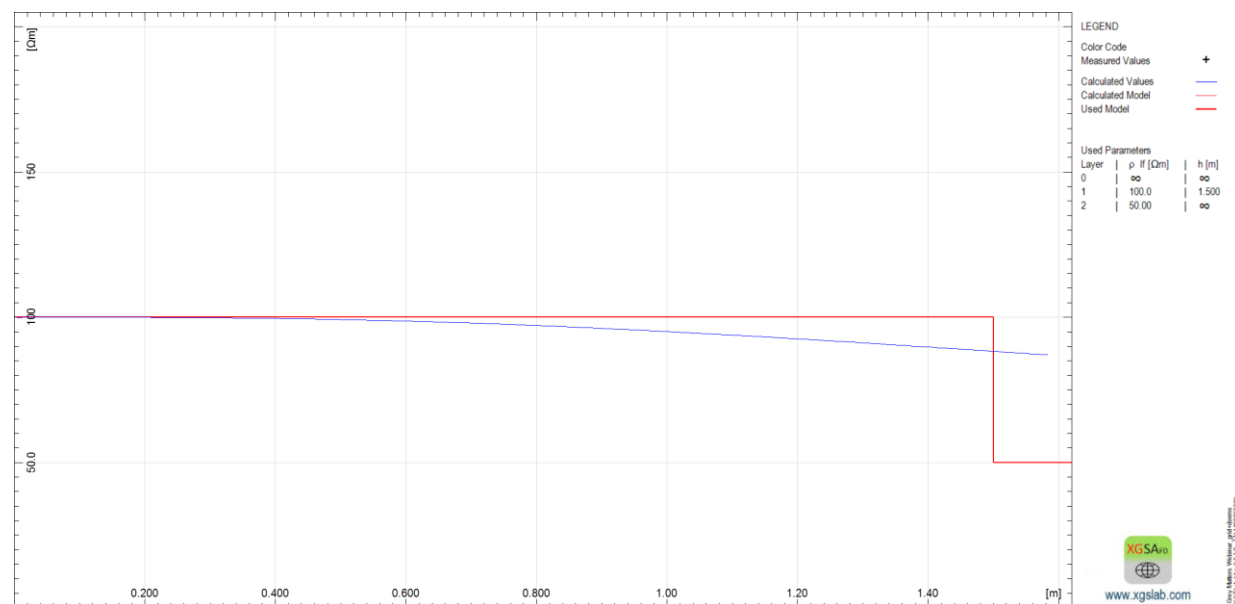
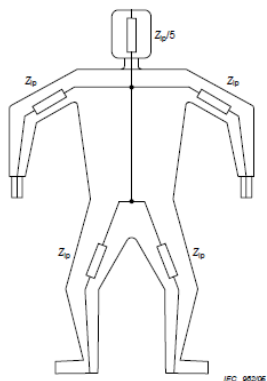
Human Safety Analysis (Safe Step-and Touch Voltage)

- Ground Potential Rise (GPR) resulting in Step- and Touch voltage conditions which can conduct through the human body.
- GPR is calculated by
 - $GPR = I_f \times R_g$ (Fault Current x Grid Resistance)
- The current that may flow through the body due to Step- and Touch voltages may not exceed the calculated allowable body current limit (I_B).



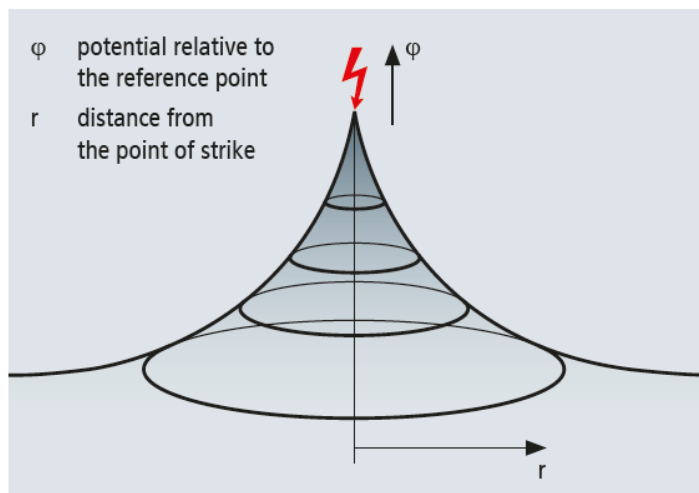
Power Frequency Fault – GPR and Touch-/Step Potential Control

- To control/mitigate the risks of GPR we need to:
 - Ensure the grounding resistance R_g is as low as possible.
 - Create an equipotential plane and equipotential between metallic parts by means of bonding.
 - Use soil covering material.
- Grounding resistance is dependent on many factors, most importantly the grid shape and soil resistivity value.



Ground Potential Rise (GPR) for Lightning Frequency

- Lightning has high frequency behaviour (0Hz – 10MHz).
- GPR steepness increases with increase in frequency.
- High Lightning current also creates high GPR levels.
- Lightning Protection Level is determined by a lightning Risk Analysis in accordance with IEC 62305-2



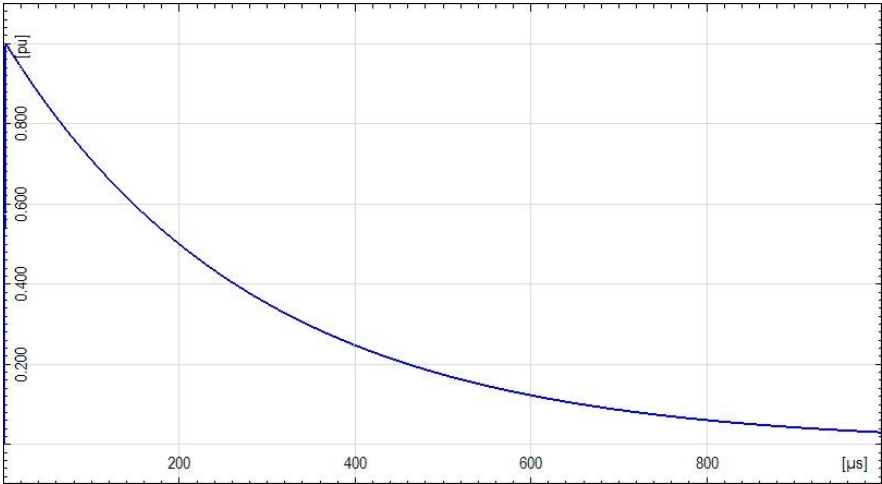
Lightning protection level	Maximum values (dimensioning criteria)	
	Maximum peak value of the lightning current	Probability that the actual lightning current is smaller than the maximum peak value of the lightning current
I	200 kA	99 %
II	150 kA	98 %
III	100 kA	95 %
IV	100 kA	95 %

Lightning protection level	Minimum values (dimensioning criteria)		
	Minimum peak value of the lightning current	Probability that the actual lightning current is greater than the minimum peak value of the lightning current	Rolling sphere radius
I	3 kA	99 %	20 m
II	5 kA	97 %	30 m
III	10 kA	91 %	45 m
IV	16 kA	84 %	60 m

Injected Lightning Impulse 1.82/285μs



- 90% of Lightning Strikes may be considered to be First Negative Impulse.

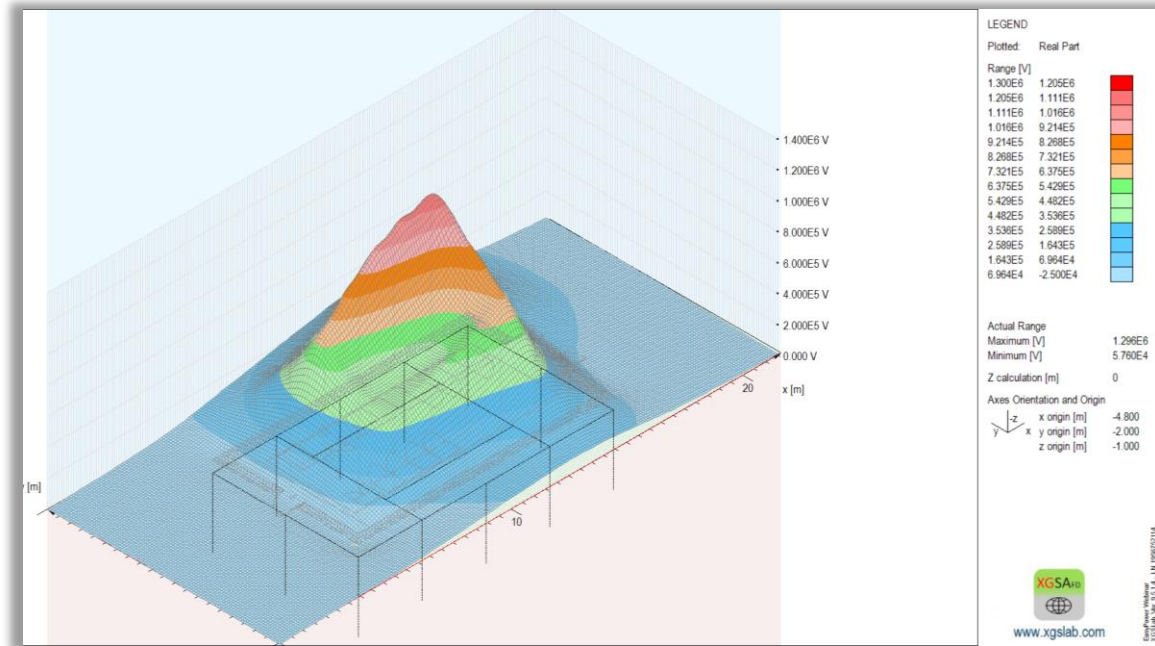
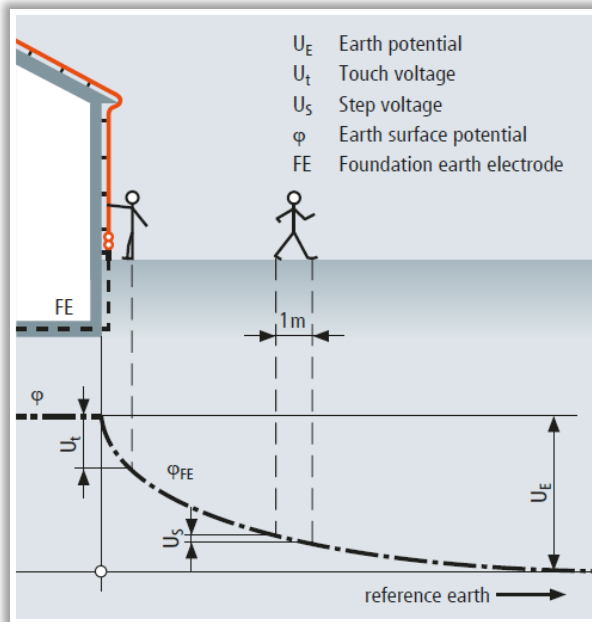


Parameters	First positive impulse			First negative impulse			Subsequent negative impulse		
	LPL			LPL			LPL		
	I	II	III-IV	I	II	III-IV	I	II	III-IV
I (kA)	200	150	100	100	75	50	50	37,5	25
k	0,93	0,93	0,93	0,986	0,986	0,986	0,993	0,993	0,993
T ₁ (μs)	19	19	19	1,82	1,82	1,82	0,454	0,454	0,454
T ₂ (μs)	485	485	485	285	285	285	143	143	143

Lightning Current Behaviour Considerations

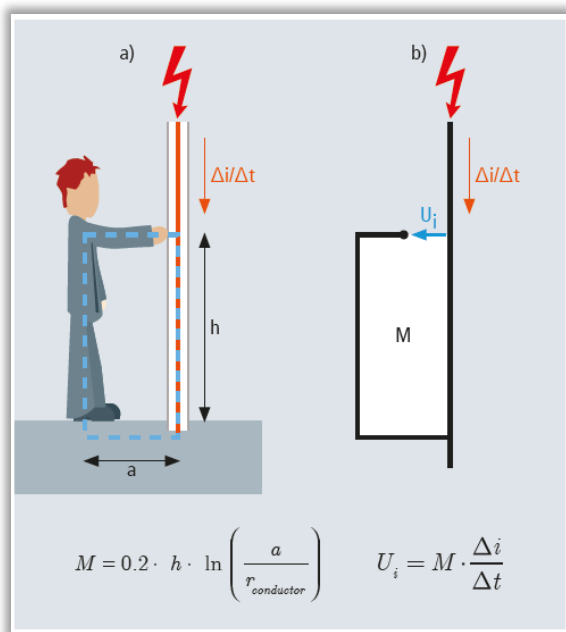


- Grounding System Safe for Power Frequency but not for Lightning Impulse Current (50kA).
 - Grounding Resistance is $\sim 10\Omega$
 - Soil Model is calculated to be a 2-Layer model.
 - No surface layer has been added.
- Lightning creates steep and large GPR around the building ($\sim 650\text{kV}$).
- Touch voltages are introduced and pose a significant risk.

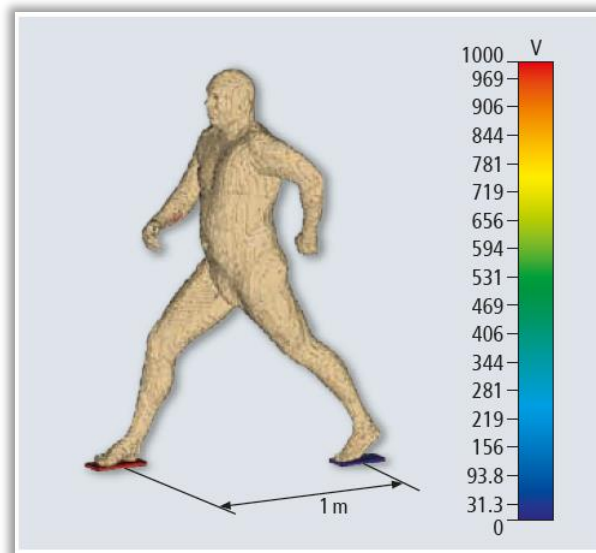


Step-and Touch voltage tolerable limits for Lightning Impulse

- The allowable values for tolerable voltage limits are different amongst standards and models.
- Step voltage in the range of 25kV may be used.
- Controlling the potential gradient is essential.
- Touch voltage mitigation is described in IEC 62305-3

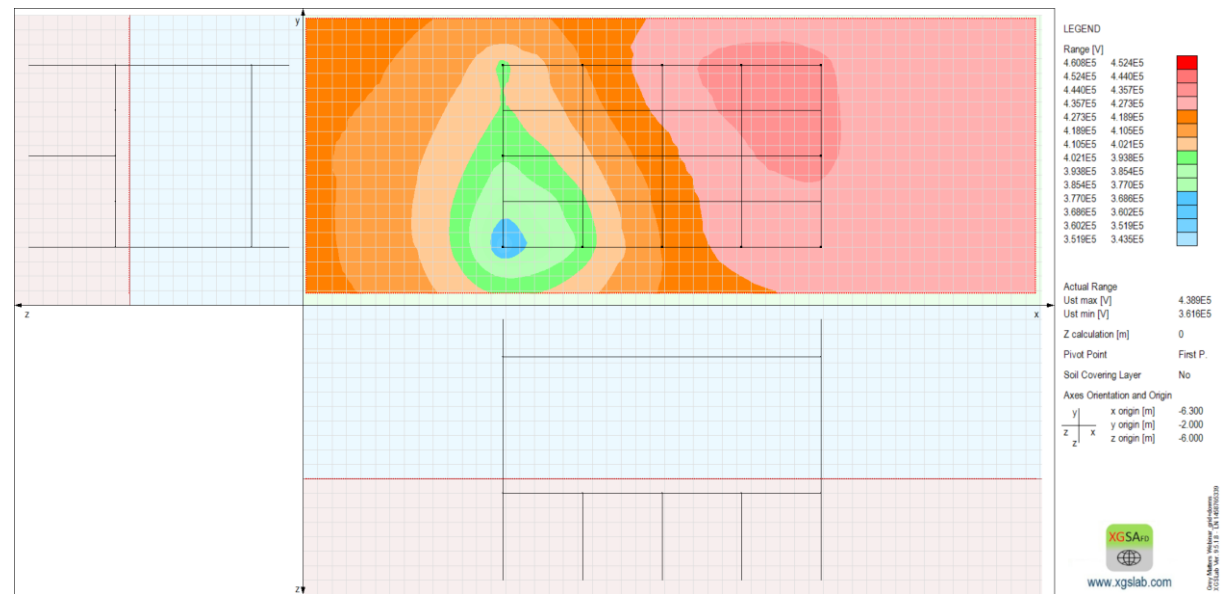
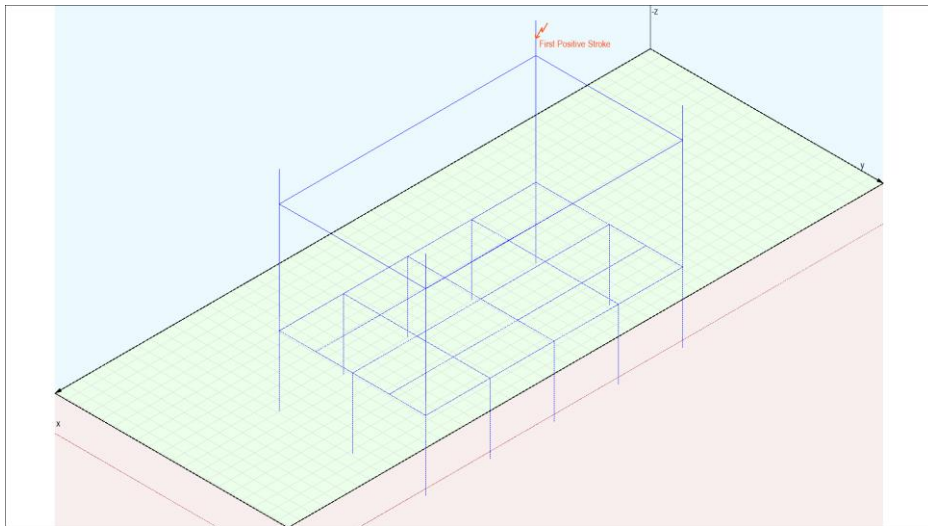


Source	U_k
IEC 60479-1 and IEC 60479-2	25 kV
Neuhaus	15 kV
Dalziel	32 kV
Electric shock simulation (HUGO)	26.6 kV



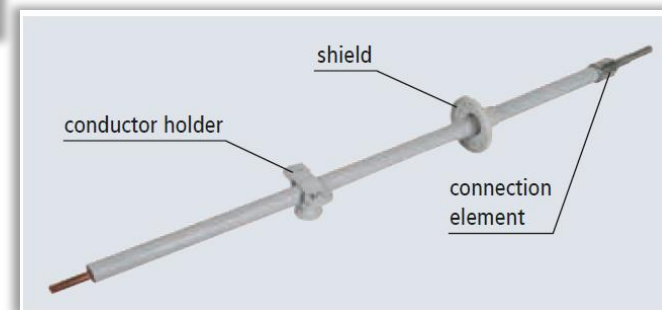
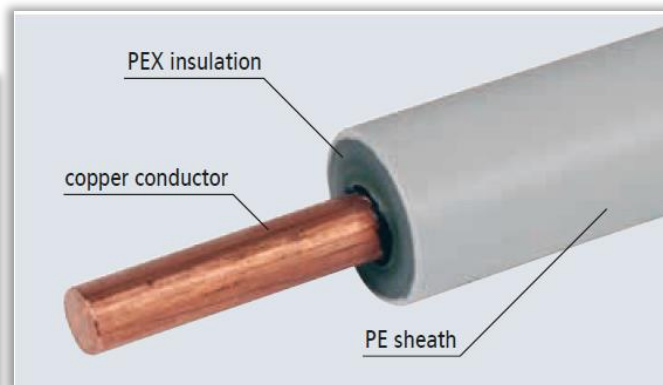
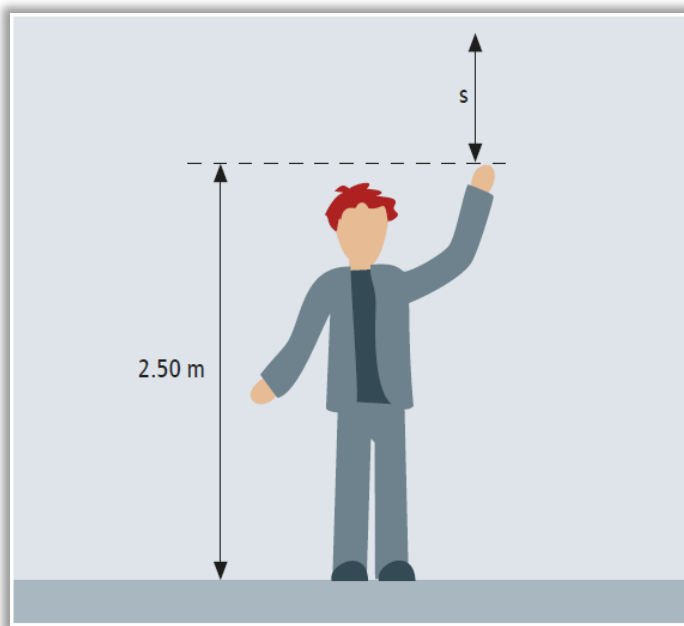
Simulation of Touch voltage during Lightning Impulse

- A Lightning protection system consisting of 4 Air-termination rods + 4 down conductors is added.
- Lightning current is injected on an Air-termination rod.
- Touch voltages are extremely high due to large Lightning current injection.



Step-and Touch voltage tolerable limits for Lightning Impulse

- Reducing the Touch voltage hazard according to IEC 62305-1:
 - Use of soil covering material 3m around each down-conductor.
 - Install warning signs to keep clearance around down-conductors.
 - Touch hazards may be ignored if the building has >10 down-conductors.
 - Make use of touch-safe insulated down-conductors (having insulation >100kV for 1.2/50 μ s Voltage shapes)



Reducing Step-Voltage using SCL

- Surface covering layers may increase the resistance between GPR and feet, improving step voltage.

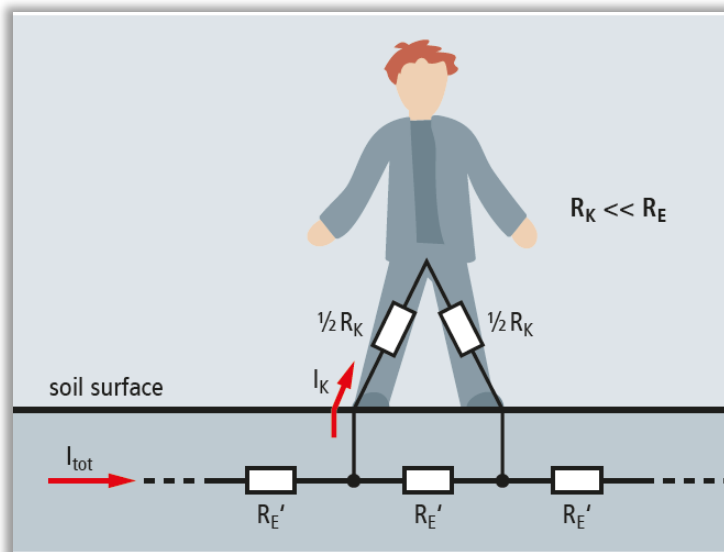


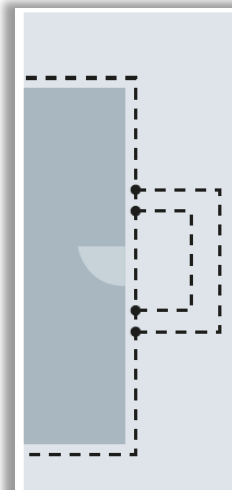
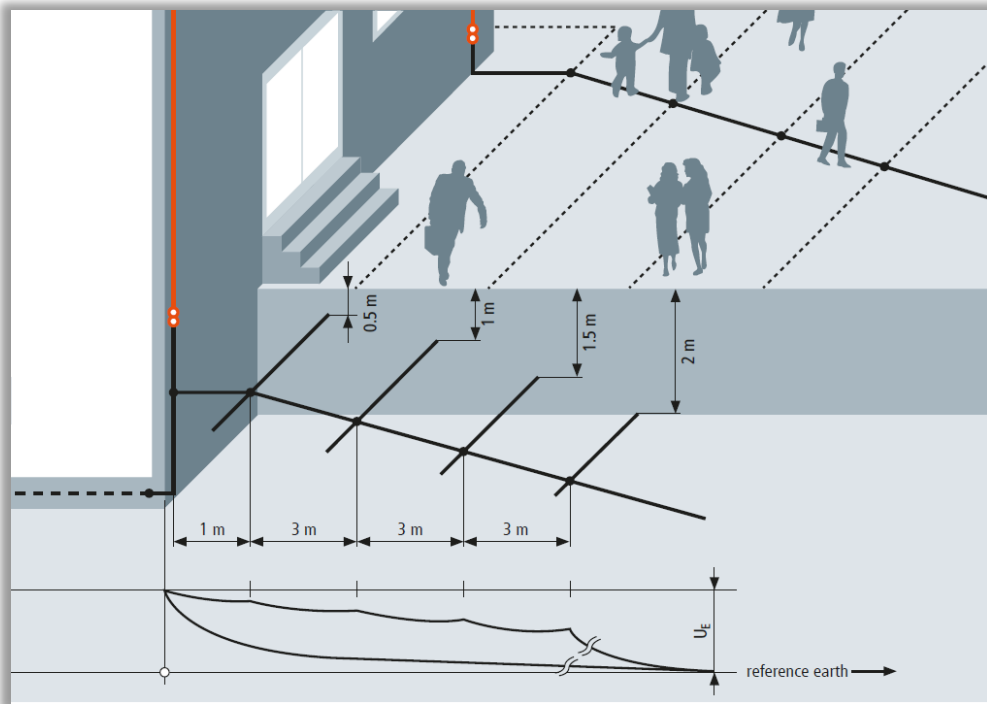
Table 7—Typical surface material resistivities

Number	Description of surface material (U.S. state where found)	Resistivity of sample, $\Omega\cdot\text{m}$	
		Dry	Wet
1	Crusher run granite with fines (NC)	140×10^6	1300 (ground water, 45 $\Omega\cdot\text{m}$)
2	1½ in (0.04 m) crusher run granite (GA) with fines	4000	1200 (rain water, 100 $\Omega\cdot\text{m}$)
3	¾ in to 1 in (0.02 m to 0.025 m) granite (CA) with fines	---	6513 (10 minutes after 45 $\Omega\cdot\text{m}$ water drained)
4	No. 4 (1 in to 2 in) (0.025 m to 0.05 m) washed granite (GA)	1.5×10^6 to 4.5×10^6	5000 (rain water, 100 $\Omega\cdot\text{m}$)
5	No. 3 (2 in to 4 in) (0.05 m to 0.1 m) washed granite (GA)	2.6×10^6 to 3×10^6	10 000 (rain water, 100 $\Omega\cdot\text{m}$)
6	Size unknown, washed limestone (MI)	7×10^6	2000 to 3000 (ground water, 45 $\Omega\cdot\text{m}$)
7	Washed granite, similar to ¾ in (0.02 m) gravel	2×10^6	10 000
8	Washed granite, similar to pea gravel	40×10^6	5000
9	No. 57 (¾ in) (0.02 m) washed granite (NC)	190×10^6	8000 (ground water, 45 $\Omega\cdot\text{m}$)
10	Asphalt	2×10^6 to 30×10^6	10 000 to 6×10^6
11	Concrete	1×10^6 to 1×10^9 ^a	21 to 200

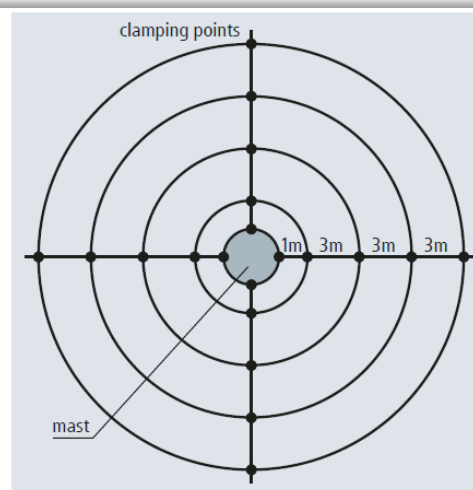
^aOven-dried concrete (Hammond and Robson [B79]). Values for air-cured concrete can be much lower due to moisture content.

Reducing Step-Voltage using Ring conductors

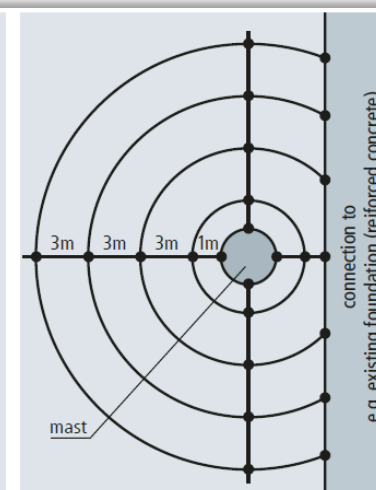
- The steepness of the GPR may be controlled by making use of grounding conductors in the shape of rings around the object/radio tower/sport event lighting etc.



Possible potential control in the entrance area of a structure



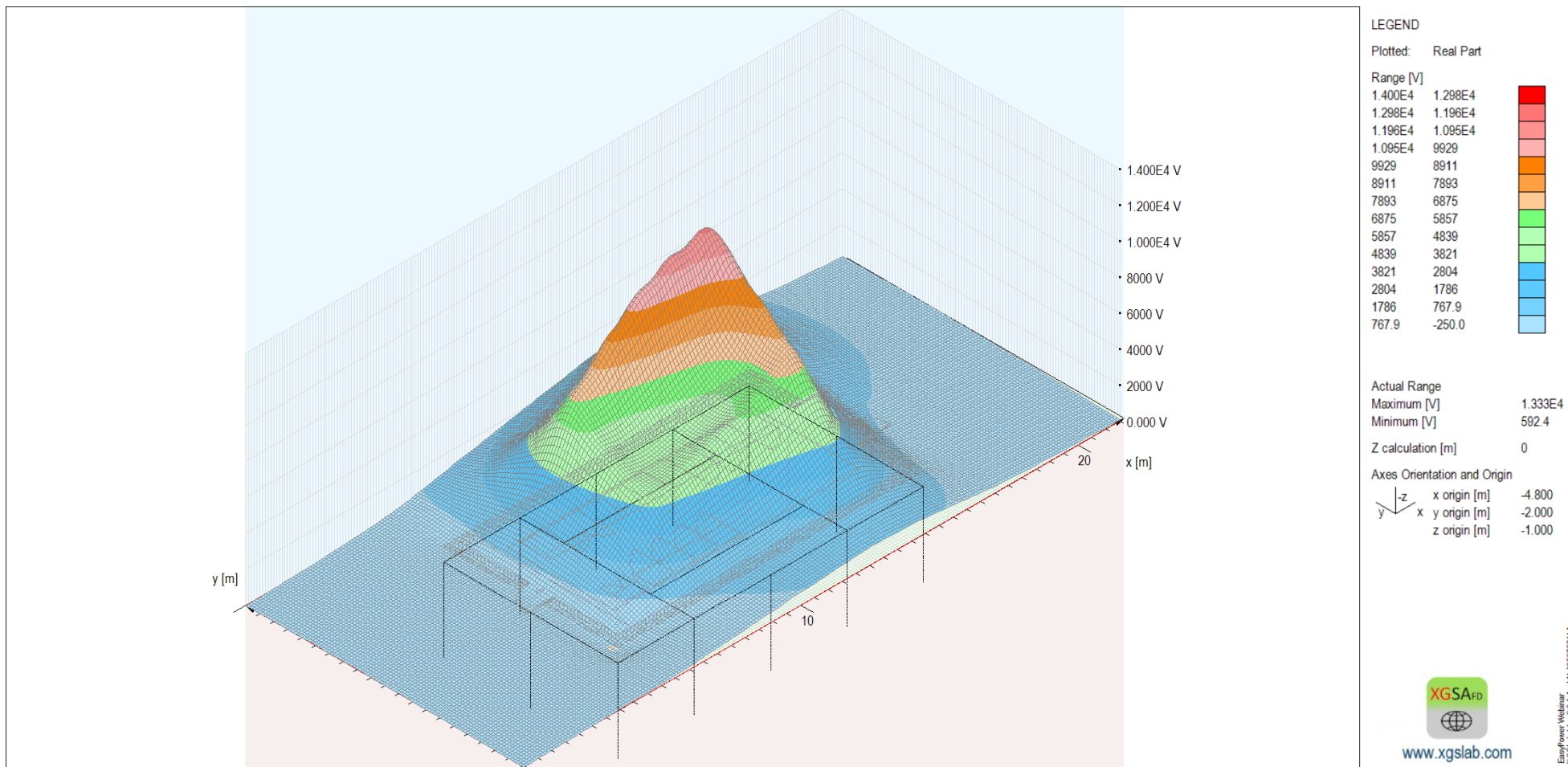
Potential control for a floodlight or mobile phone mast



Connection control at the ring/foundation earth electrode

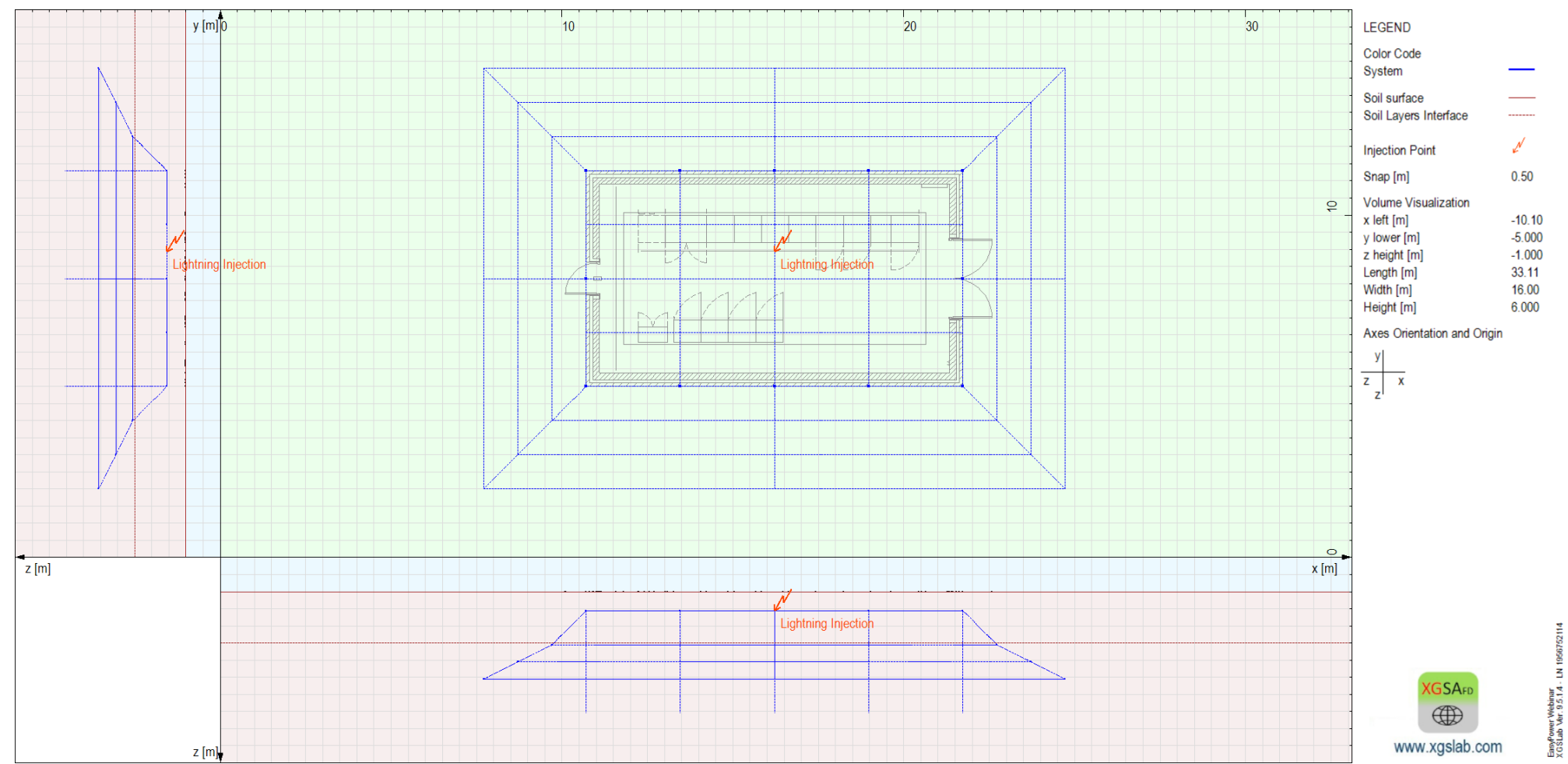
Initial Ground Potential Rise (GPR) for Lightning Frequency

- Initially no consideration for lightning in the Design for Power Frequency earth faults.
- Results in high GPS steepness and exposure to dangerously high touch- and step potentials.



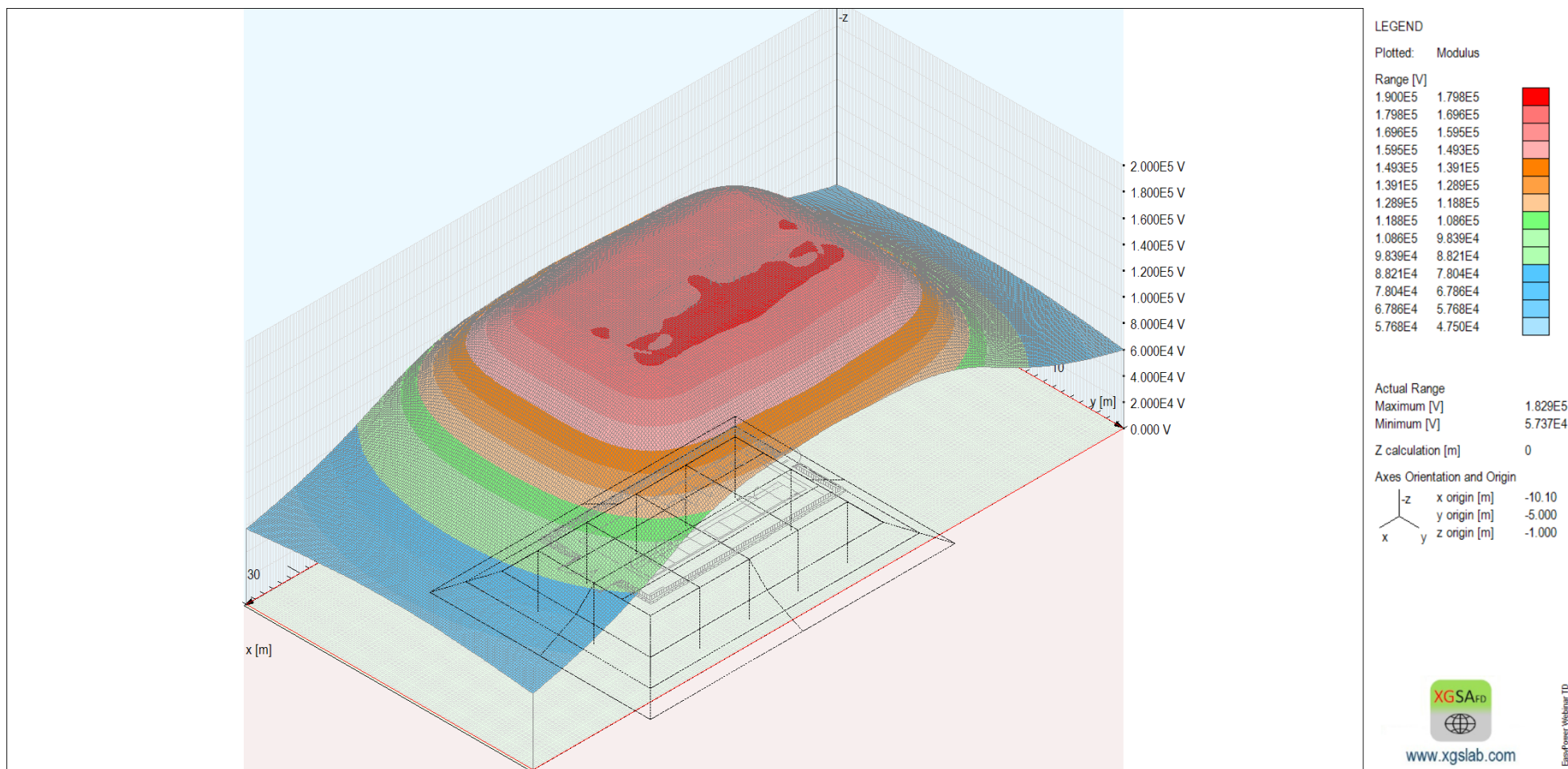
Updated Step-and Touch Voltage Results

- Modified Grid Layout to control lightning GPR.



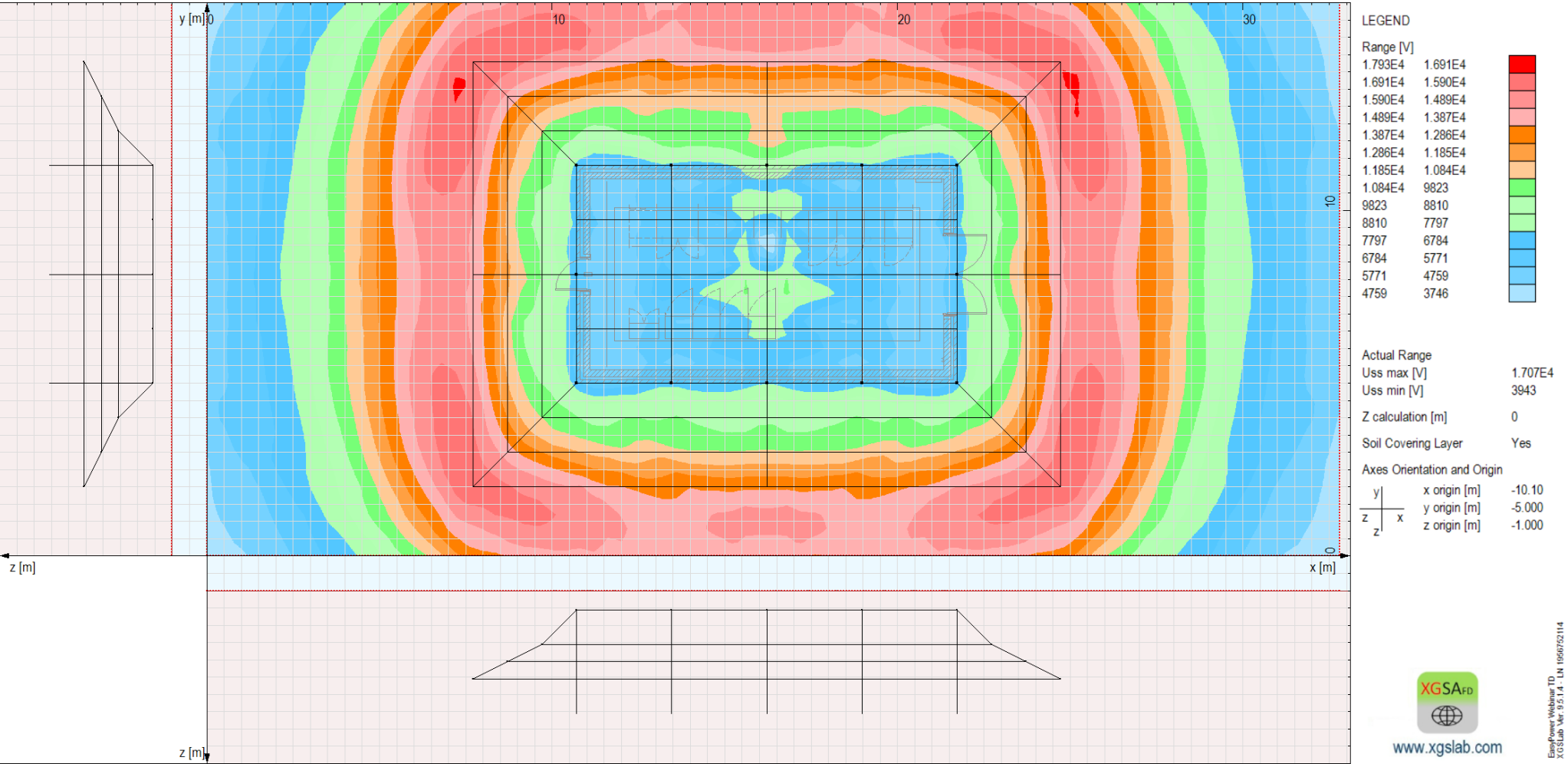
Updated Step-and Touch Voltage Results

- Updated GPR is shown. Reducing the GPR Steepness and touch- and step potential gradient exposure.



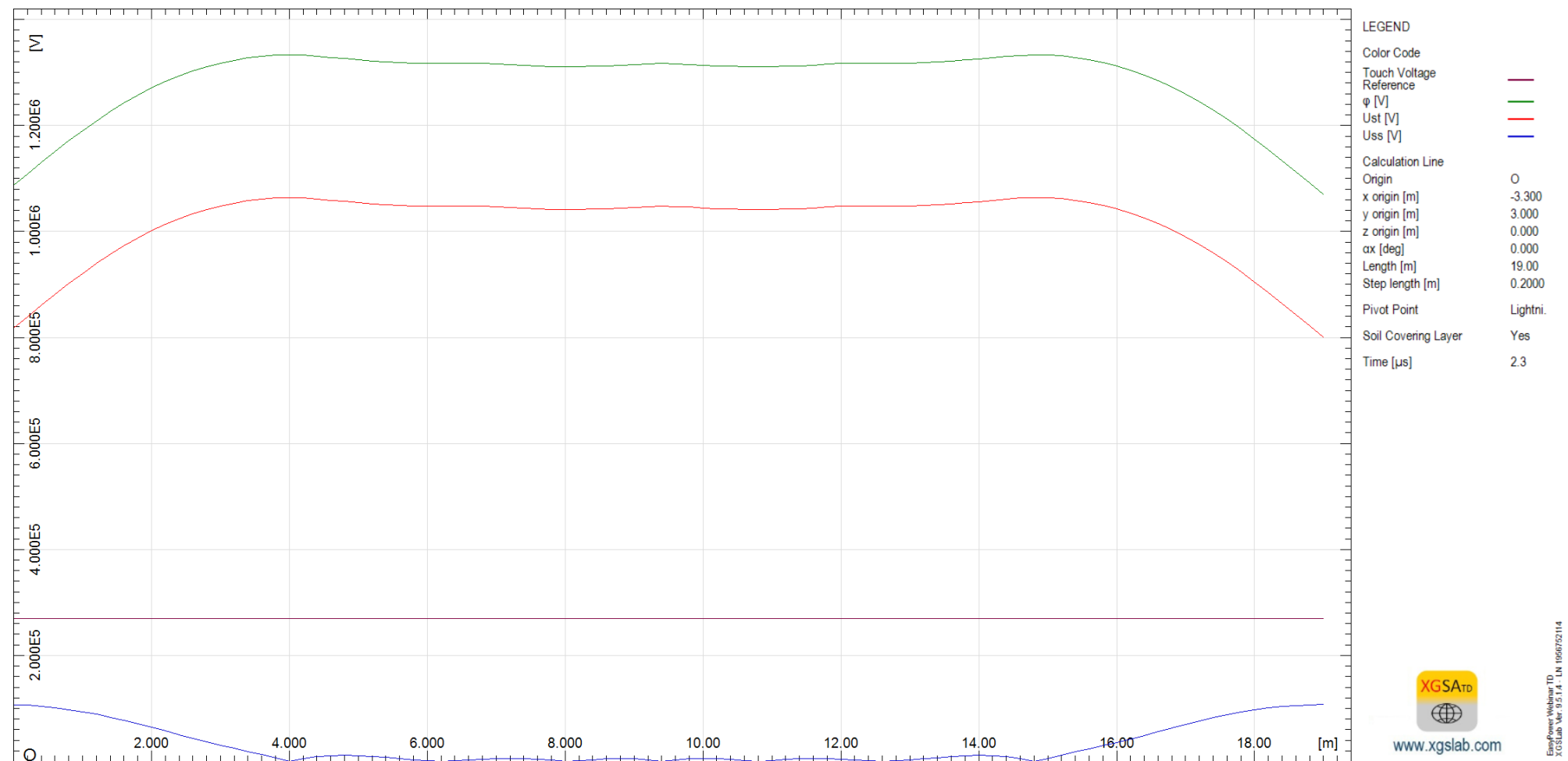
Updated Step-and Touch Voltage Results

- Updated Step Voltages below 25kV Tolerable Value.



Updated Step-and Touch Voltage Results

- Updated Step Voltages below 25kV Tolerable Value.



Conclusion



- Initial design for power frequency ground fault currents, may not address the GRP that could be present during lightning. Very important in highly populated areas or areas of high lightning ground flash densities.
- Due to High frequency behaviour and high Impulse current value, Lightning creates steep and large GPR plots.
- To reduce touch potential hazards around the building:
 - Use tested insulated down-conductors
 - Keep 3m clearance around down-conductors
 - Do not touch down-conductors
 - Touch potential might be neglected if > 10 down-conductors.
- To reduce step potential hazards:
 - Establish a potential controlling grounding grid to reduce GPR steepness
 - Use SCL to insulate feet from GPR.



DEHN protects.

Thank you for
Your attention!