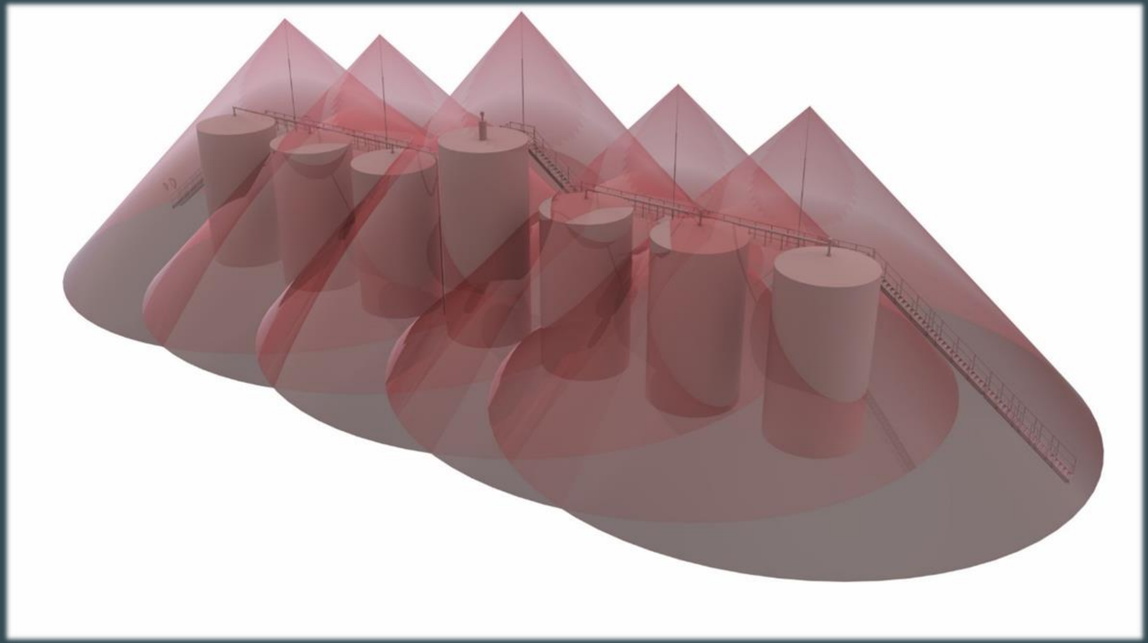
Bonded vs Isolated Lightning Protection Concepts
Application to Areas and Structures with Explosive (EX) Atmospheres

Steven Weber - Senior Engineer at DEHN, Inc.

Presentation Outline:

- Introduction and Problem Statement
- Characteristics of Lightning Current
- Bonded / Isolated Lightning Protection Systems
  - Standards definitions and interpretations (NFPA/IEC)
  - NFPA 780 – Bonding distance requirements and Annex C bonding principles
  - IEC 62305 – Separation distance requirements
  - NFPA 780 / IEC 62305 – Calculations
  - Risk assessment – What system is best?
  - XGS_Lab: XGSA_FD Simulation – Current distribution comparison
- Application to Explosive Areas
  - Implementing a Bonded LPS
  - Implementing an Isolated LPS
  - Maintenance and Inspection
- Questions?



Introduction and Problem Statement

The NFPA- and IEC-published lightning protection standards cover the requirements for bonding distance calculations (side flash distance, separation distance) to evaluate the need to bond the lightning protection system to other grounded metal parts of an installation.

This calculated value of free-space clearance is decisive for a bonded or isolated system.

It is based on the existence of a large potential difference between the LPS and the other grounded metal bodies, where an uncontrolled flash-over (dangerous sparking) can occur if the separation distance is not maintained.

A seriously dangerous condition in the presence of Explosive Atmospheres.

LPS components should maintain a separation distance from the grounded metal parts, and remain isolated – **Isolated Lightning Protection System**

LPS components installed within the calculated bonding distance require equipotential bonding to reduce the possibility of dangerous sparking – **Bonded Lightning Protection System**

Introduction and Problem Statement

Not so simple…. We overlook important aspects of implementing these systems.

- Inadequate grounding
- Inherently self-protected tanks? Material thickness? External EX zones?
- LPS design mistakes and the type/material of the components used
- Lightning current distribution into areas with Explosive Atmospheres
- Lightning current distribution into sensitive electrical/control/fire prevention equipment
- Incorrectly implementing isolated LPS component requirements and exceeding product limitations
- Inadequate surge protection measures
- Lack of maintenance and inspection

The consequences….

Recent damages – May 06, 11, 31 of 2021

Introduction and Problem Statement

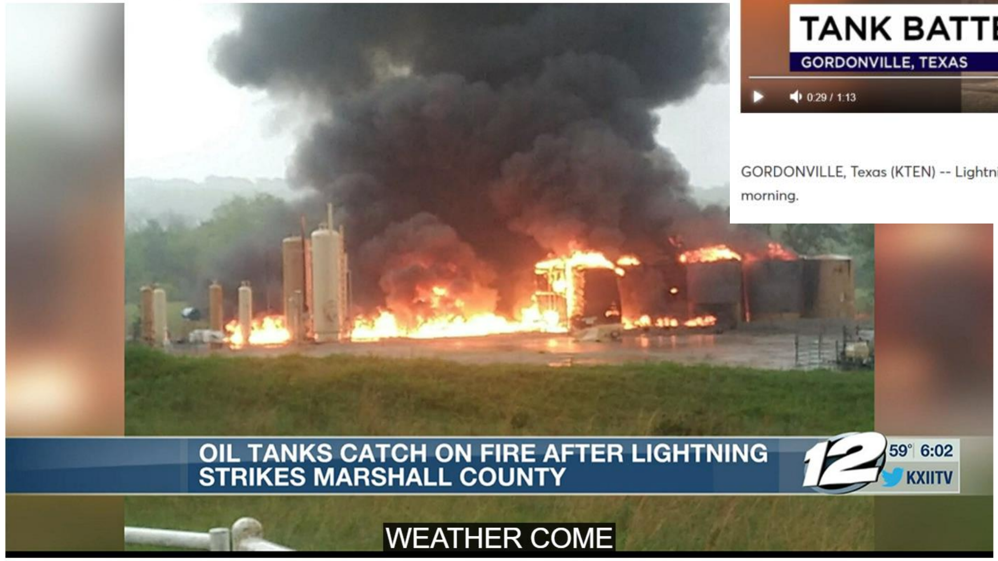
LOCAL NEWS

Lightning may have sparked oil tank fire near Brighton

Foam capable of extinguishing flammable liquids was used to bring the fire near Weld County roads 4 and 27 under control.

Author: Darren Whitehead
Published: 1:53 PM MDT May 5, 2021
Updated: 6:55 AM MDT May 6, 2021

Little City oil tanks catch fire after lig



By Caroline Cluiss
Updated: May. 11, 2021 at 6:57 PM EDT

Lightning triggers tank farm fire in Gordonville

Monday, May 31st 2021, 12:05 PM CDT
Updated: Monday, May 31st 2021, 4:27 PM CDT
By Molly O'Brien

GORDONVILLE, Texas (KTEN) -- Lightning is blamed for triggering a fire at a tank battery near Gordonville on Monday morning.

Characteristics of Lightning Current

The characteristics of lightning current and their effects:

1. Peak Value of the Lightning Current

The high magnitude of current results in excessive voltage drop across conductive parts. (Ohm's Law)

Large potential difference between unbonded metal parts result in dangerous sparking and flash-over.

2. Steepness of the Lightning Current

The steepness of the lightning current rise electromagnetically induces large voltages in all open or closed conductive loops located in the vicinity of LPS components. If the calculated separation distances is not maintained, dangerous sparking can occur.

Once bonded, a portion of lightning current will flow in these conductive parts. A risk to be evaluated?

$$U = M.\ \Delta i/\Delta t$$

M Mutual inductance of the loop

$\Delta i/\Delta t$ Steepness of the lightning current rise

Characteristics of Lightning Current

3. Charge of the Lightning Current

The charge of the lightning current is decisive for the energy conversion at the exact point of the strike termination and at all points where the lightning current occurs in the form of an arc (dangerous sparking) along an insulating clearance.

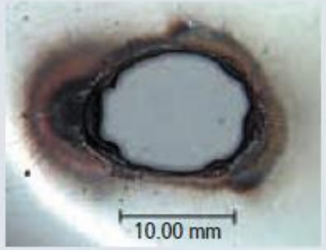
The charge transfer causes the components of the LPS to be damaged, melt or produce sparks. The placement of strike termination devices is critical when the LPS is installed to protect explosive material, or structures in explosive atmospheres.

Natural components used as strike termination devices and inherently protected tanks should exceed the minimum allowable material thickness to mitigate for this energy conversion.

4.8 mm in NFPA 780 and 5 mm in IEC 62305-3 Annex D for steel

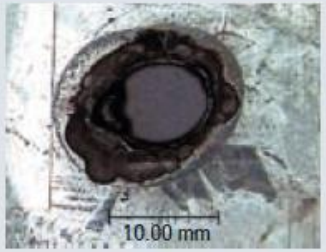
Aluminium
d = 0.5 mm; 200 A, 350 ms

Copper
d = 0.5 mm; 200 A, 180 ms



Stainless steel
d = 0.5 mm; 200 A, 90 ms

Steel
d = 0.5 mm; 200 A, 100 ms



Galvanised steel
d = 0.5 mm; 200 A, 100 ms

Characteristics of Lightning Current

4. Specific Energy

The specific energy is responsible for the temperature rise in conductors carrying lightning impulse currents and the force exerted between conductors. (Table D.3 – IEC 62305-1)

The temperature rise of LPS components routed within an area with an explosive atmosphere, should not exceed the auto-ignition temperature defined for the contents of that explosive atmosphere.

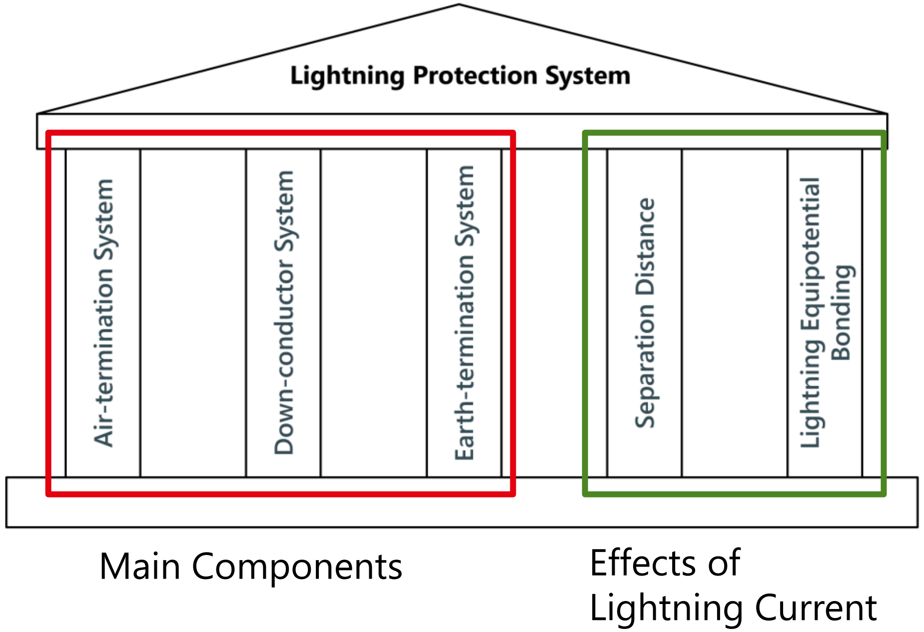
The specific energy defines the stress which causes reversable or irreversible deformation, loosening and mechanical damage to the components and arrangements of the LPS.

Additional means such a constant-tensioning utilizing spring washers on clamps and holders is one attempt to address this. Another is to use clamps and other components tested to withstand the expected lightning currents for that LPL.

Material		Cross-section [mm²]	4	10	16	25	50	100
Material	Aluminium W/R [MJ/Ω]	2.5	–	564	146	52	12	3
		5.6	–	–	454	132	28	7
		10	–	–	–	283	52	12
	Iron W/R [MJ/Ω]	2.5	–	–	1120	211	37	9
		5.6	–	–	–	913	96	20
		10	–	–	–	–	211	37
	Copper W/R [MJ/Ω]	2.5	–	169	56	22	5	1
		5.6	–	542	143	51	12	3
		10	–	–	309	98	22	5
	Stainless steel W/R [MJ/Ω]	2.5	–	–	–	940	190	45
		5.6	–	–	–	–	460	100
		10	–	–	–	–	940	190

Bonded / Isolated Lightning Protection Systems

- Standards definitions and interpretations (NFPA/IEC)
- NFPA 780 – Bonding Distance Requirements
- IEC 62305 – Separation Distance Requirements
- Risk Assessment
- XGS_Lab XGSA_FD Simulation – Current Distribution

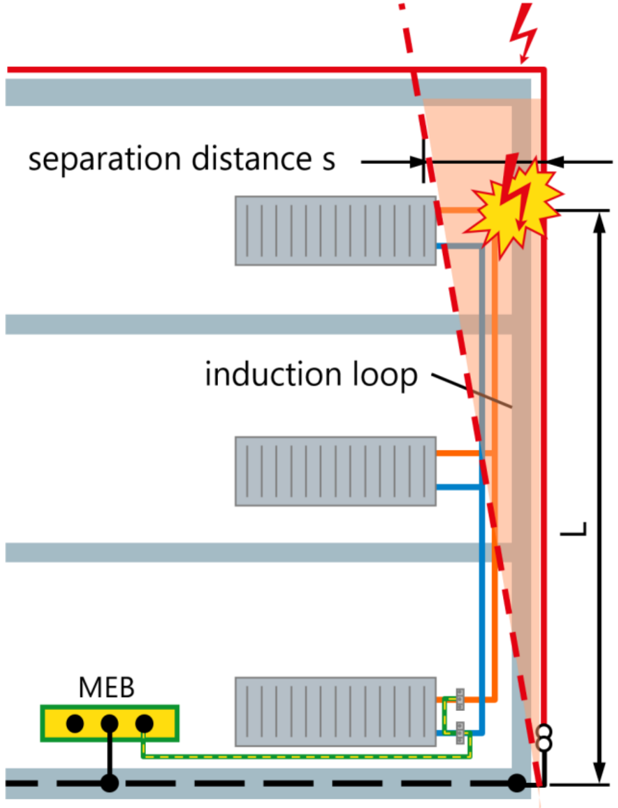


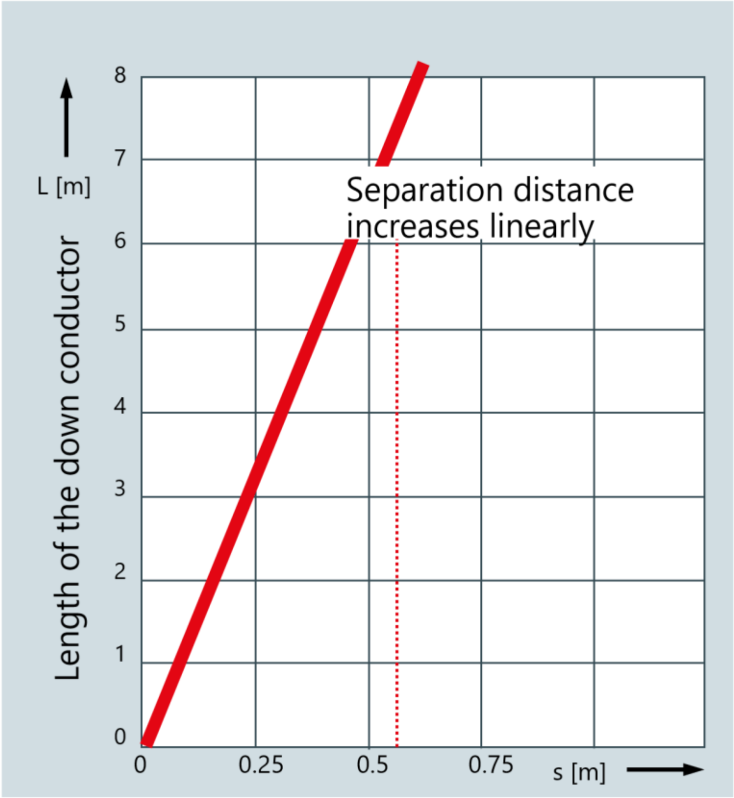
Bonded / Isolated Lightning Protection Systems

Standards definitions and interpretations

The requirement for equipotential bonding, is derived from the steepness of the lightning current rise that electromagnetically induces large voltages in all open or closed conductive grounded media on, or in a structure. There then exists additional lightning hazards (sparking) and current paths.

For structures exceeding certain height limits (60 ft), additional bonding to equalize potentials becomes important, as it gets harder to maintain enough separation distance between the LPS and grounded media.





Bonded / Isolated Lightning Protection Systems
Standards definitions and interpretations

NFPA 780: 2020: Standard for the Installation of Lightning Protection Systems

Interpretation from Annex C: Explanation of Bonding Principles:

C.1 General:

The major concern in the protection of a building is the occurrence of potential differences between the components of the LPS and other grounded metal bodies, of such magnitude the dangerous sparking can occur. In order to reduce the possibility of sparking, it is necessary to equalize potentials by bonding grounded metal bodies to the LPS – **Bonded Lightning Protection System.**

Where a structure can be designed to isolate the grounded systems from the LPS components, this should be considered. This is achieved by maintaining separation distances beyond the bonding distance requirements for building grounded systems above grade – **Isolated Lightning Protection System**

Isolating lightning protection system elements to **provide separation distance** from grounded metal bodies or increasing the number of down conductors to shorten the required bonding distances are options that can be used to overcome difficult installation problems for certain structures.

IEC 62305-3:2010

Interpretation from Annex E: E.5.1.2 Isolated LPS

An isolated external LPS should be used when the flow of the lightning current into bonded internal conductive parts may cause damage to the structure or its contents.

NOTE 1: The use of an isolated LPS may be convenient where it is predicted that changes in the structure may require modifications to the LPS.

An LPS that is connected to conductive structural elements and to the equipotential bonding system only at ground level, is defined as isolated according to 3.3.

An isolated LPS is achieved either by installing air-termination rods or masts adjacent to the structure to be protected or by suspending overhead wires between the masts in accordance with the separation distance of 6.3.

Bonded / Isolated Lightning Protection Systems

NFPA 780 – Bonding Distance Requirements

NFPA 780: 2020: Standard for the Installation of Lightning Protection Systems

Section 4.14: Common Bonding of Grounded Systems

Section 4.15: Potential Equalization

Section 4.16: Bonding of Metal Bodies

Section 4.16.2: Grounded Metal Bodies

Section 4.16.2.4: Grounded metal bodies that maintain a separation distance from the lightning protection system components that is **greater** than the distance calculated using the bonding distance formulas in 4.16.2.5 or 4.16.2.6 shall be considered **isolated** and require no further bonding except for that required in Sections 4.14 and 4.15.

NFPA 780: 2020: Standard for the Installation of Lightning Protection Systems

Section 4.16.2.5 – Structures More Than 40 ft (12m) in Height

Grounded metal bodies shall be bonded to the lightning protection system where located within a calculated bonding distance, D, as determined by the following formula:

$$D = \frac{h}{6n} \times Km$$

where:

D = calculated bonding distance

h = vertical distance between the bond under consideration and the nearest interconnection to the lightning protection system or ground

n = value related to the number of down conductors that are spaced at least 25 ft (7.6 m) apart, located within a zone of 100 ft (30 m) from the bond in question and where bonding is required within 60 ft (18 m) from the top of any structure

K_m = 1 if the flashover is through air; 0.50 if through dense material such as concrete, brick, wood, and so forth

Image courtesy NFPA 780

IEC 62305-3:2010

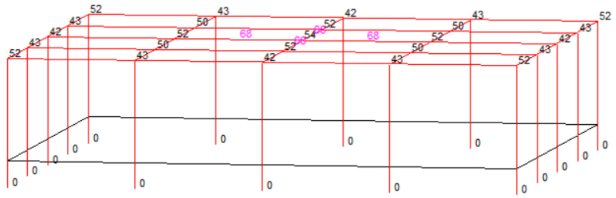
6.3 Electrical insulation of the external LPS

6.3.1 General

Electrical insulation between the air-termination or the down-conductor and the structural metal parts, the metal installations and the internal systems can be achieved by providing a separation distance, s, between the parts.

The general equation for the calculation of s is given by:

$$s = k_i \cdot \frac{k_c}{k_m} \cdot l$$



k_i depends on the selected class of LPS (see Table 10);

k_m depends on the electrical insulation material (see Table 11);

k_c depends on the (partial) lightning current flowing on the air-termination and the down-conductor (see Table 12 and Annex C);

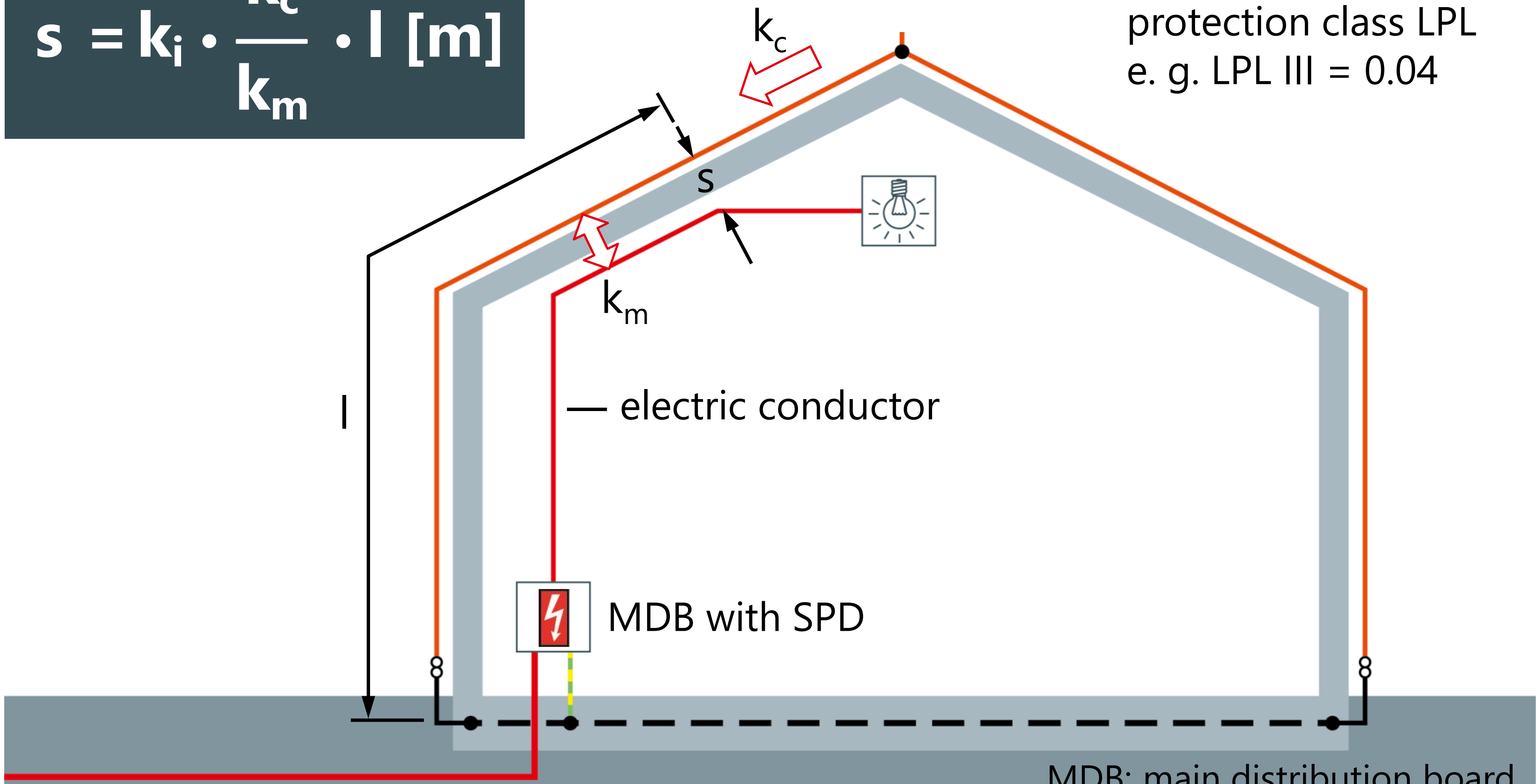
l is the length, in metres, along the air-termination and the down-conductor from the point, where the separation distance is to be considered, to the nearest equipotential bonding point or the earth termination (see E.6.3 of Annex E).

Bonded / Isolated Lightning Protection Systems

IEC 62305 – Separation Distance Requirements

$$s = k_i \cdot \frac{k_c}{k_m} \cdot l \; [m]$$

k_i=dependent on protection class LPL
e. g. LPL III = 0.04

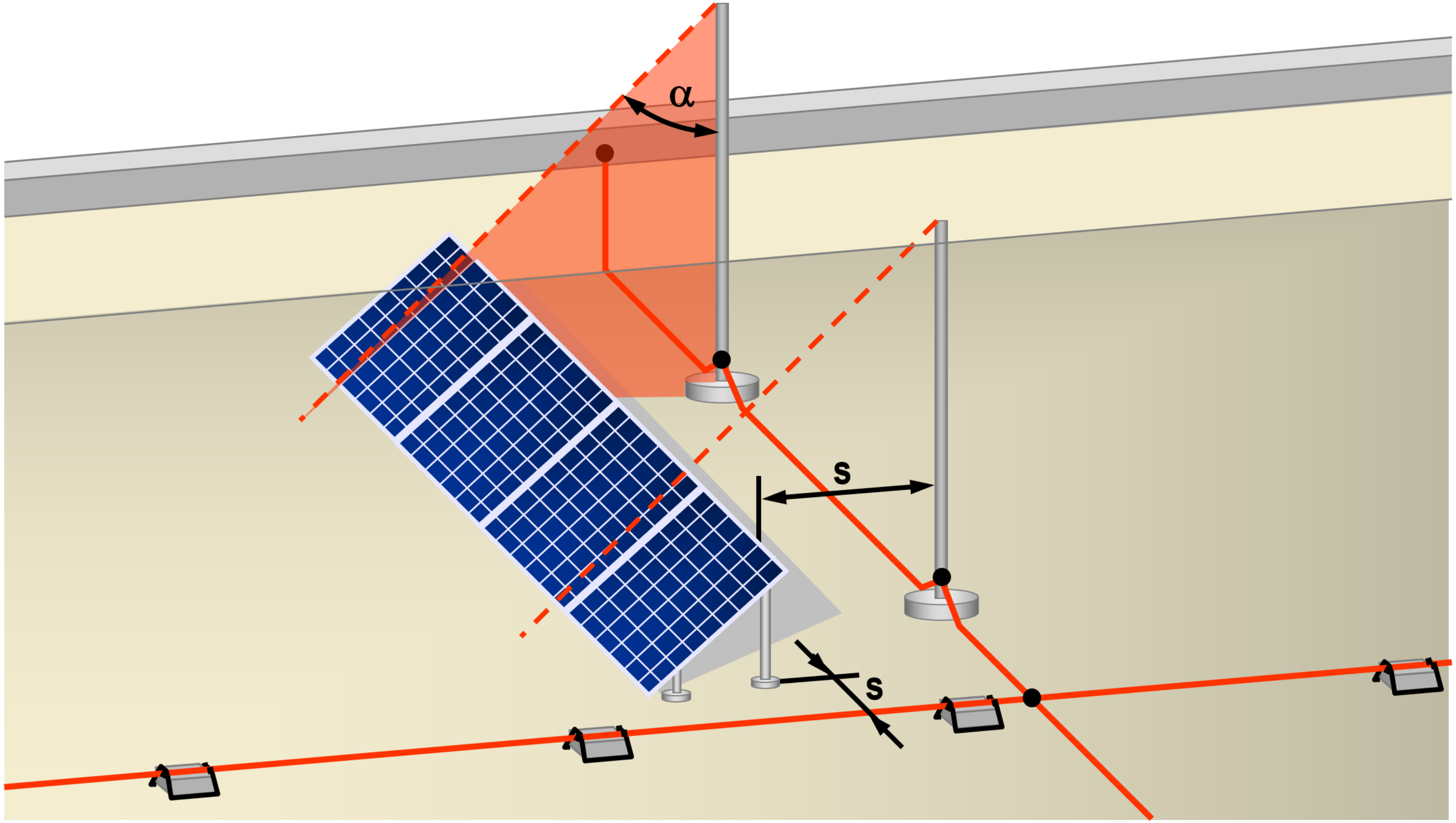


MDB: main distribution board
SPD: surge protective device

Ref.: IEC 62305-3:2010; Annex E, Figure E.38 modified

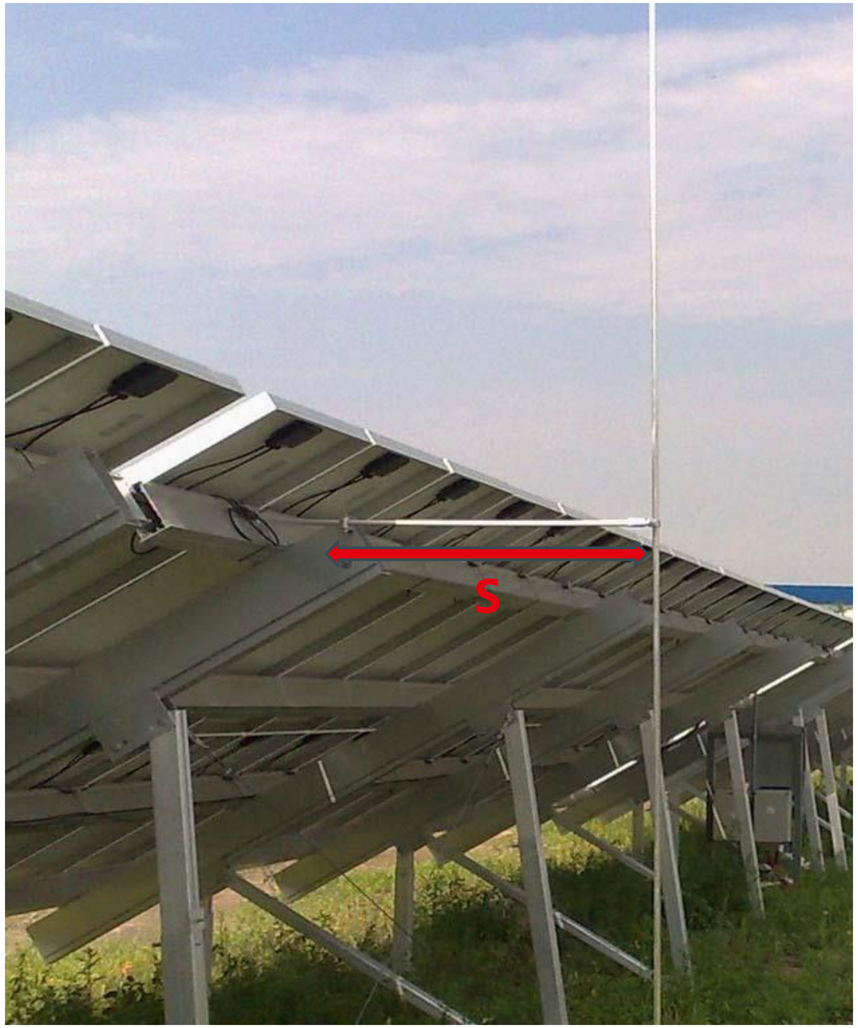
Bonded / Isolated Lightning Protection Systems

IEC 62305 – Separation Distance Requirements



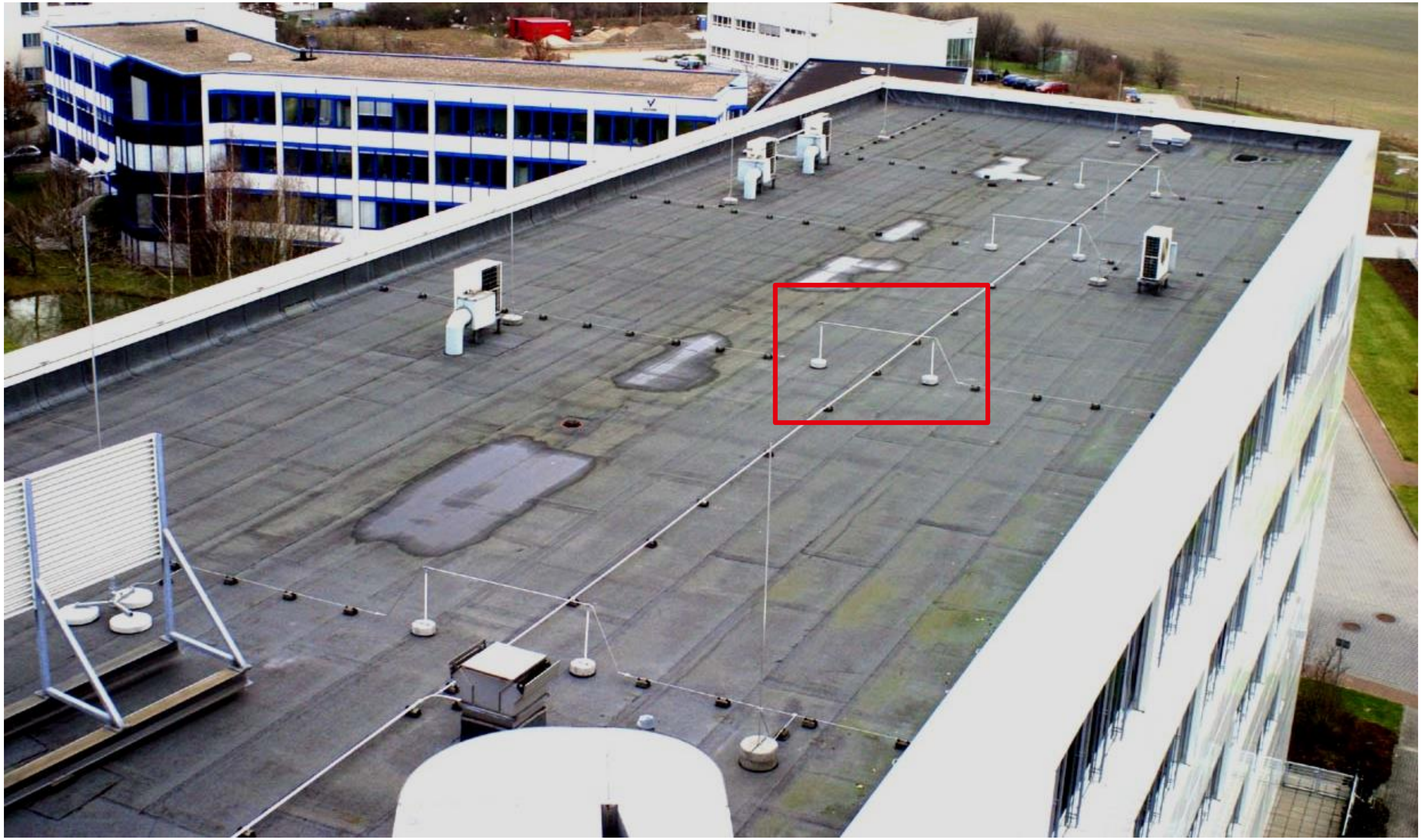
Bonded / Isolated Lightning Protection Systems

IEC 62305 – Separation Distance Requirements



Bonded / Isolated Lightning Protection Systems

IEC 62305 – Separation Distance Requirements



Bonded / Isolated Lightning Protection Systems

IEC 62305 – Separation Distance Requirements

Bonded / Isolated Lightning Protection Systems

IEC 62305 and NFPA 780 – Calculations

NFPA 780 bonding distance D and IEC 62305 separation distance S are shown to be approximately equal for an IEC class III lightning protection system.

IEC does scale proportional with the severity of LPL class and intensity of the lightning strike value, however the NFPA calculations do not.

The NFPA is primarily focused on equipotential bonding between all metal structures through the facility. An unfortunate side effect is damage to un-intended victims like roof top solar, chillers and radio equipment are injected with lightning energy or insufficiently separated from main conductors.

Work out the algebraic equivalence for D = S:

$$D = \frac{h}{6n} \; x \; Km \qquad S = \frac{Ki}{Km} \; x \; Kc \; x \; l$$

Define number of down conductors n, draw values from tables in NFPA and IEC

$$\frac{1}{n} = Kc \quad so \; for \; n = 1, Kc = 1$$

$$for \; n = 1.5 \, , Kc = .66 \quad for \; n = 2.25 \, , Kc = .44$$

$$D = \frac{Km}{6} \; x \; Kc \; x \; l$$

$$D = S$$

$$\frac{Ki}{Km} \; x \; \cancel{Kc} \; x \; \cancel{l} = \frac{Km}{6} \; x \; \cancel{Kc} \; x \; \cancel{l} \qquad for \; h = l$$

$$\frac{Ki}{Km} = \frac{Km}{6}$$

$$Ki = \frac{Km \; x \; Km}{6}$$

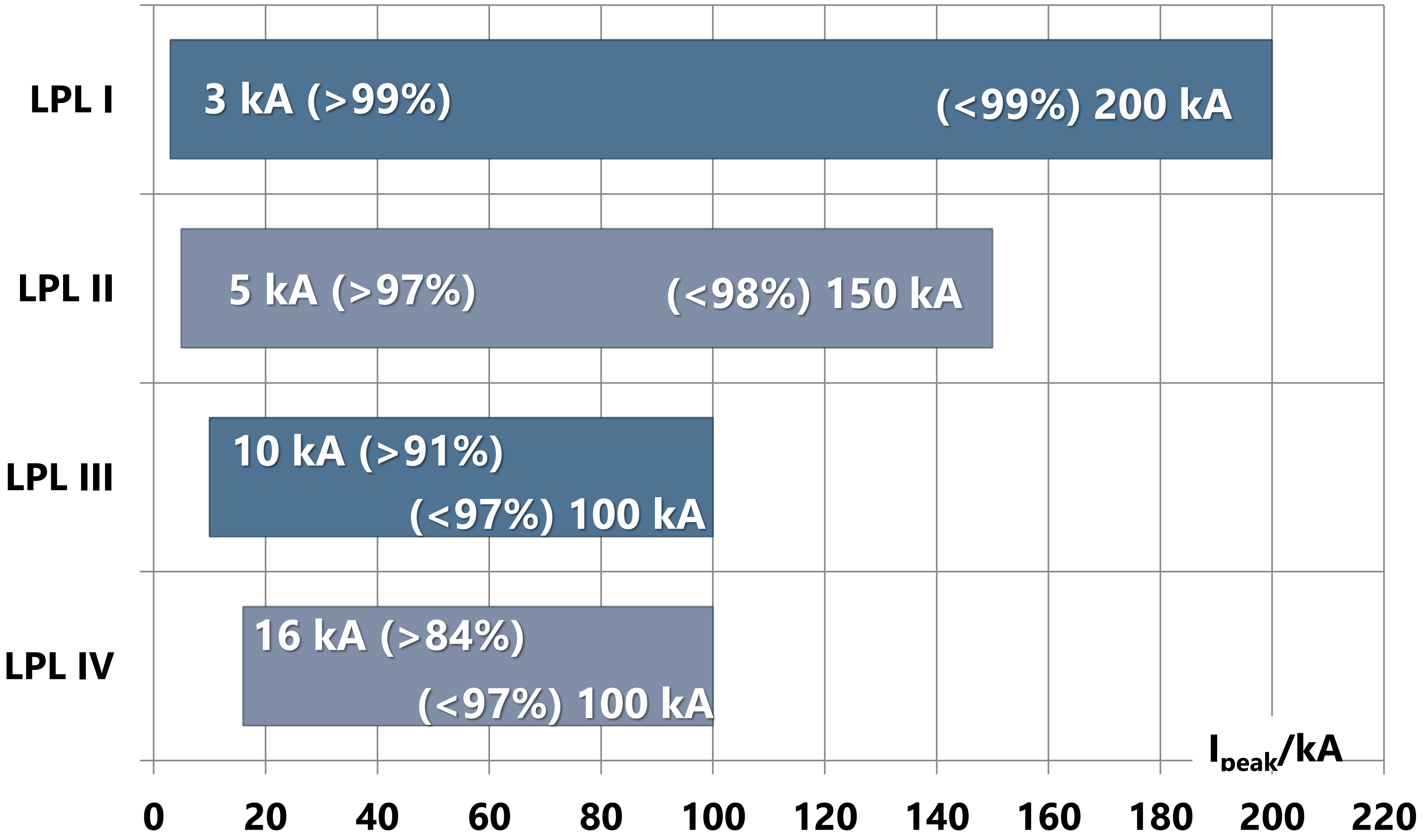
For NFPA this solves as

$$Ki = 0.0416 \quad which \; is \; congurent \; with \; IEC \; factor \; Ki = 0.04$$

$$where \; Km = 0.5, Kc \; dependant \; conductors$$

$$this \; Ki \; from \; NFPA \; 780 \; solves \; as \; the \; same factor \; as \; LPL \; Class \; III \; IEC \; 62305$$

Bonded / Isolated Lightning Protection Systems
Lightning Current Parameters



Bonded / Isolated Lightning Protection Systems

Risk Assessment – What system is best?

Is a bonded or isolated LPS the best option for a specific structure?

What are the highest calculated risk components? Sources of damage?

Will the **bonding of the LPS** to rooftop equipment/metal bodies and injection of partial lightning current into a structure result in higher probabilities of loss factors associated with the risk of loss of human life or perhaps the risk of loss of economic value? Can separation distance really be maintained for this structure? Can this risk be controlled by additional internal bonding, grounding and SPD's?

Think about a hospital, school, public buildings, data centers and especially explosive areas.

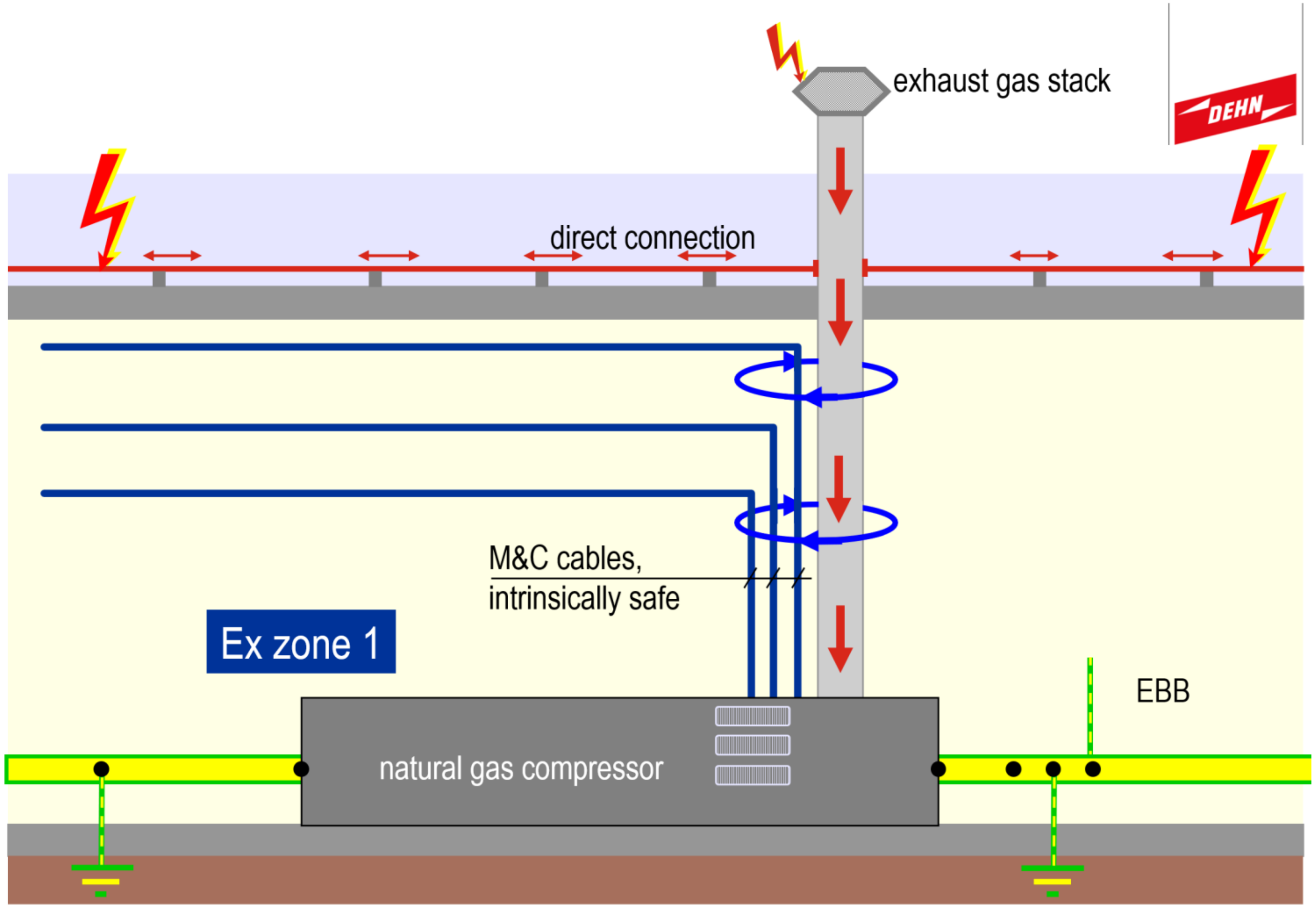
If you could capture the lightning current and keep it isolated (separated) from the building and its services and get it dispersed into the ground safely without ever touching the structure? Like it never happened. Now that's lightning protection.

Lightning masts around Substations, NASA Launch Complexes, Bio-Gas Plant Digesters, its all **isolated LPS concepts**. Technological advancements and technical specifications for isolated LPS components (IEC TS 62561-8) for developing other means of isolating lightning current more practically.

Bonded / Isolated Lightning Protection Systems

Risk Assessment – What system is best?

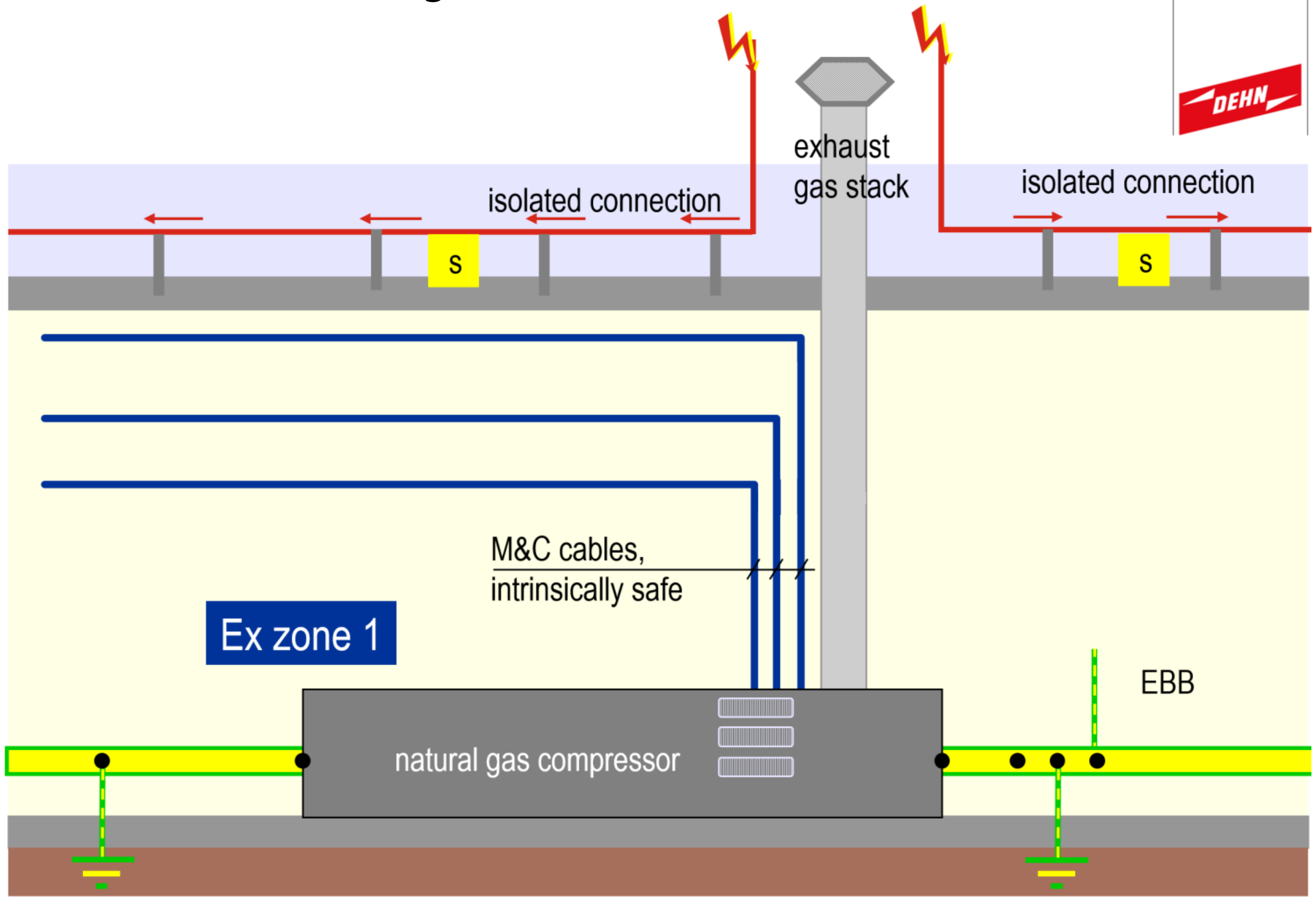
Explosive atmosphere – Ex Zone 1 around a natural gas compressor
Bonded LPS with partial lightning current injection into the structure. Risk assessment?



Bonded / Isolated Lightning Protection Systems

Risk Assessment – What system is best?

Explosive atmosphere – Ex Zone 1 around a natural gas compressor
Isolated LPS with no lightning current injection into the structure. Separation distance maintained and greater than the calculated bonding distance.

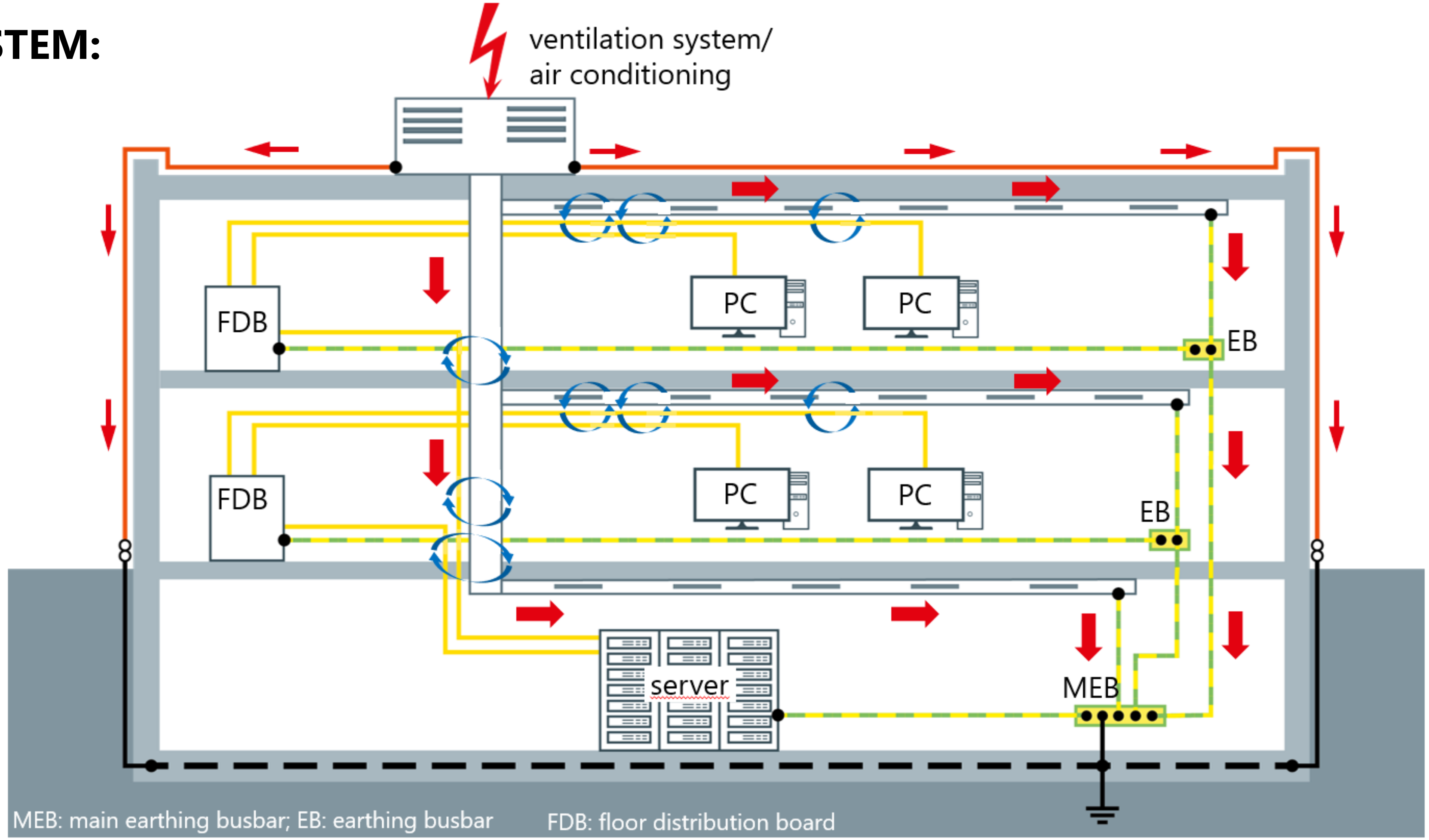


Bonded / Isolated Lightning Protection Systems

XGS_Lab: XGSA_FD Simulation – Current distribution comparison

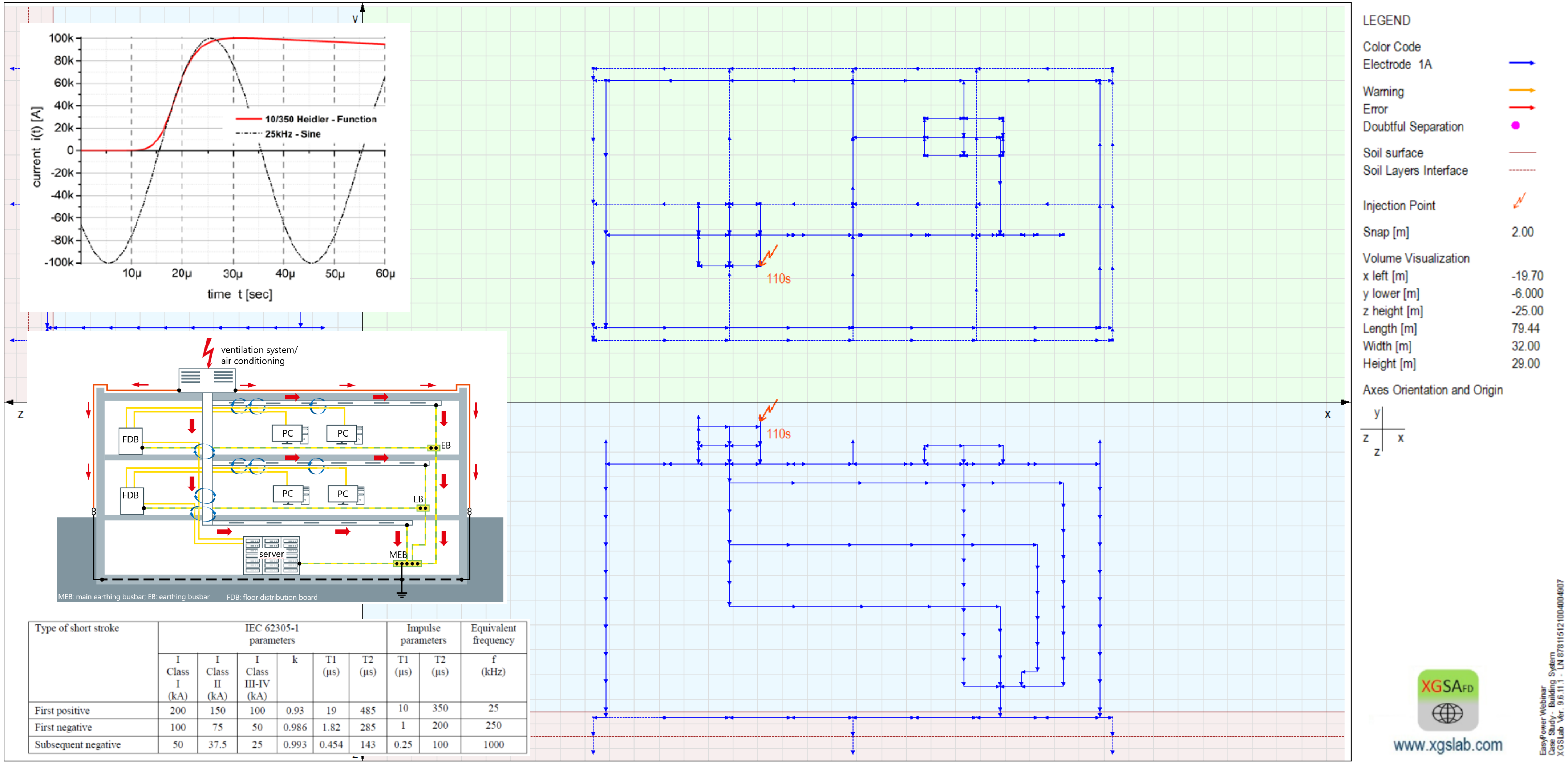
XGS_Lab: Module XGSA_FD was used to compare the current distribution in the LPS and in other grounded metal bodies of the structure for a bonded and isolated lightning protection system:

BONDED SYSTEM:



Bonded / Isolated Lightning Protection Systems

XGS_Lab: XGSA_FD Simulation – Current distribution comparison



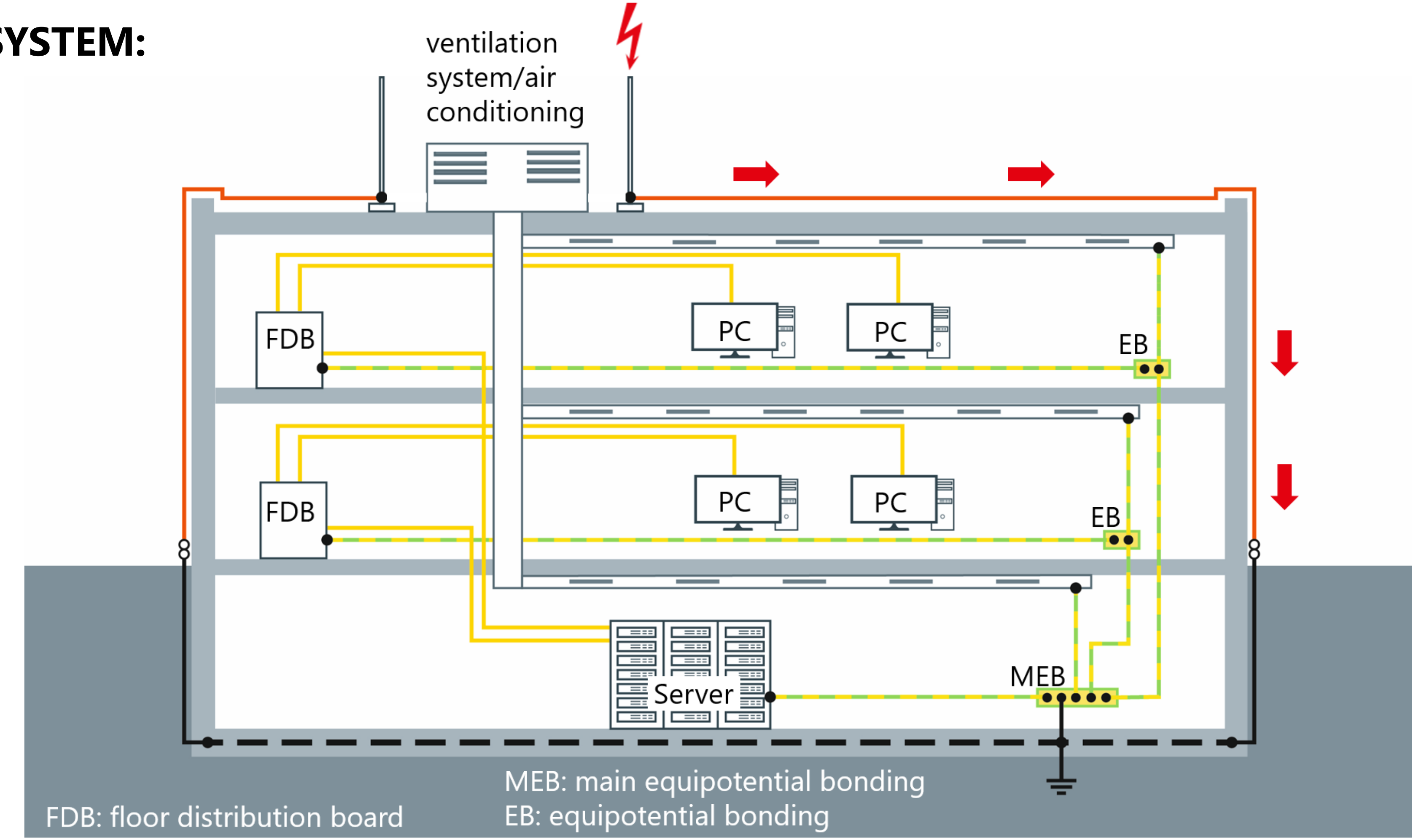
Type of short stroke	IEC 62305-1 parameters						Impulse parameters		Equivalent frequency
	I Class I (kA)	I Class II (kA)	I Class III-IV (kA)	k	T1 (µs)	T2 (µs)	T1 (µs)	T2 (µs)	f (kHz)
First positive	200	150	100	0.93	19	485	10	350	25
First negative	100	75	50	0.986	1.82	285	1	200	250
Subsequent negative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

Bonded / Isolated Lightning Protection Systems

XGS_Lab: XGSA_FD Simulation – Current distribution comparison

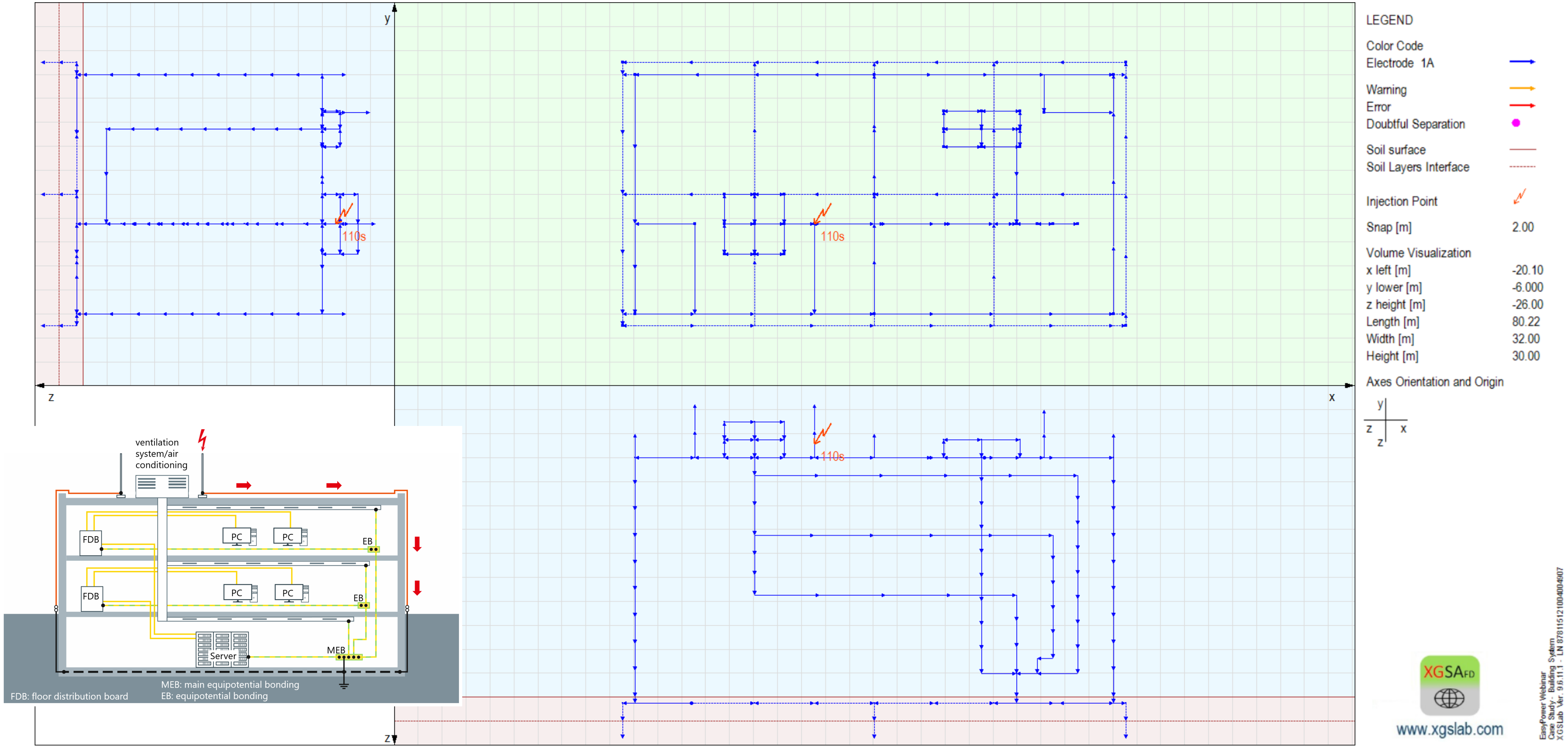
XGS_Lab: Module XGSA_FD was used to compare the current distribution in the LPS and in other grounded metal bodies of the structure for a bonded and isolated lightning protection system:

ISOLATED SYSTEM:



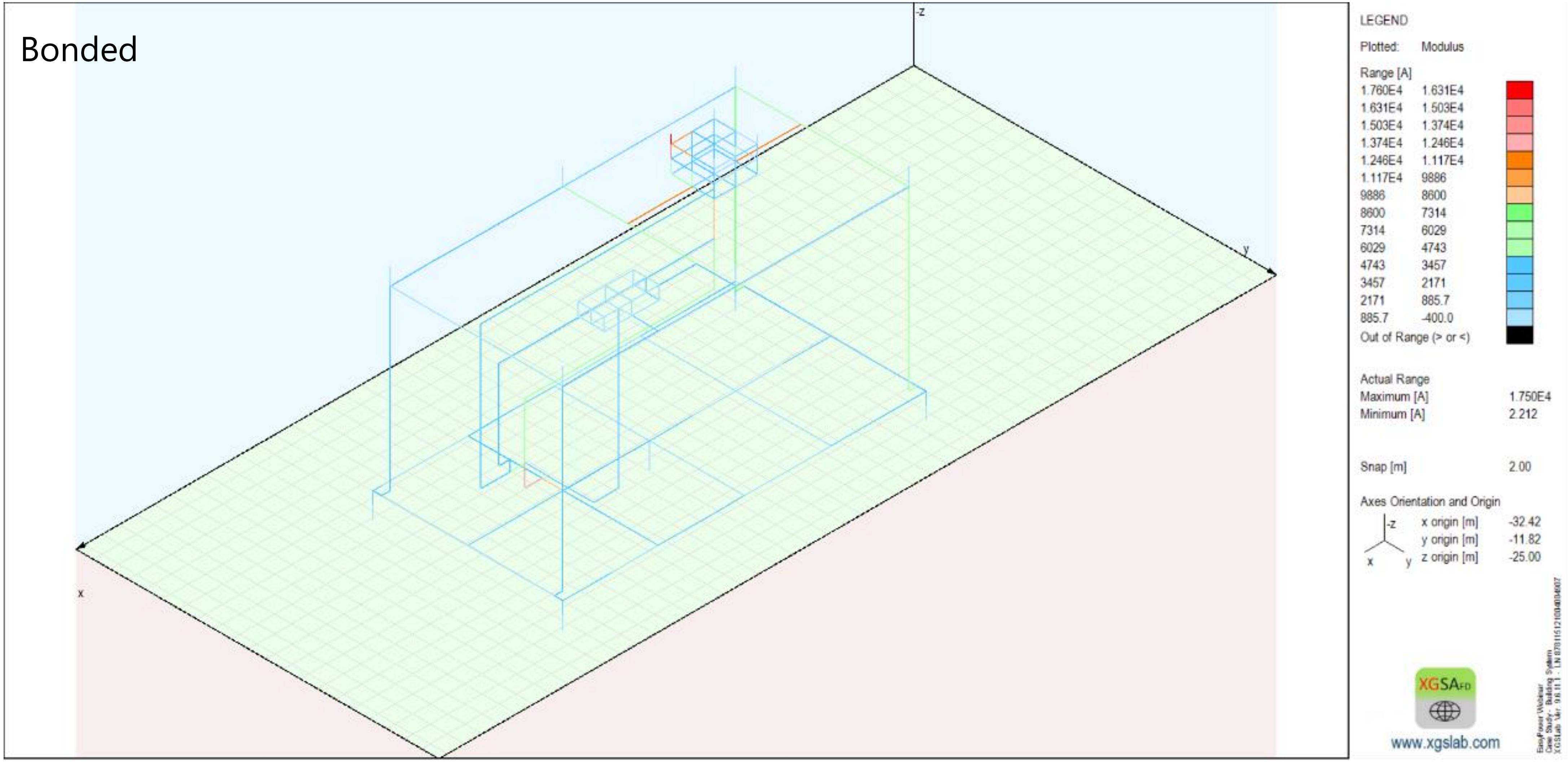
Bonded / Isolated Lightning Protection Systems

XGS_Lab: XGSA_FD Simulation – Current distribution comparison



Bonded / Isolated Lightning Protection Systems

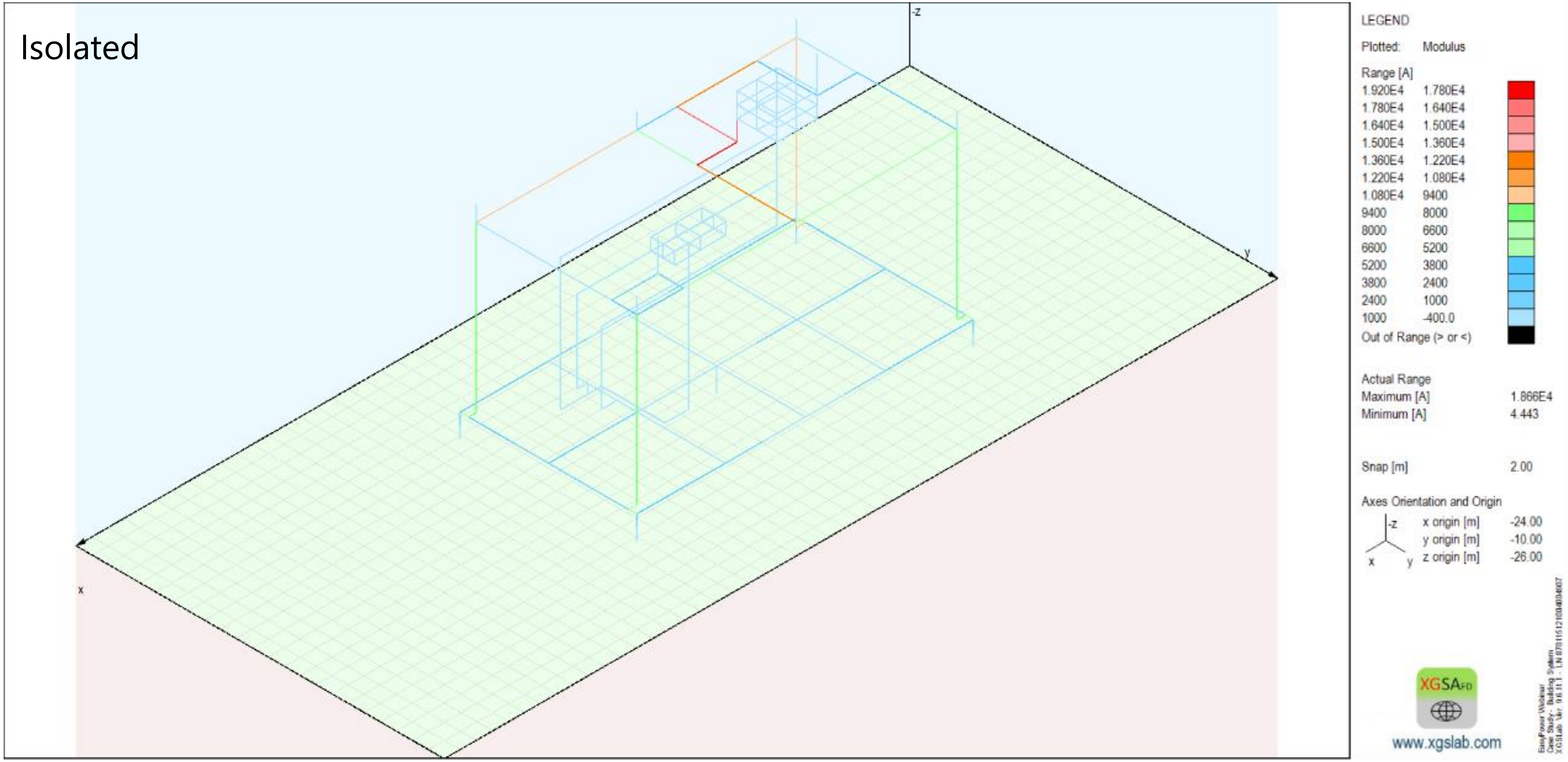
XGS_Lab: XGSA_FD Simulation – Current distribution comparison



Bonded / Isolated Lightning Protection Systems

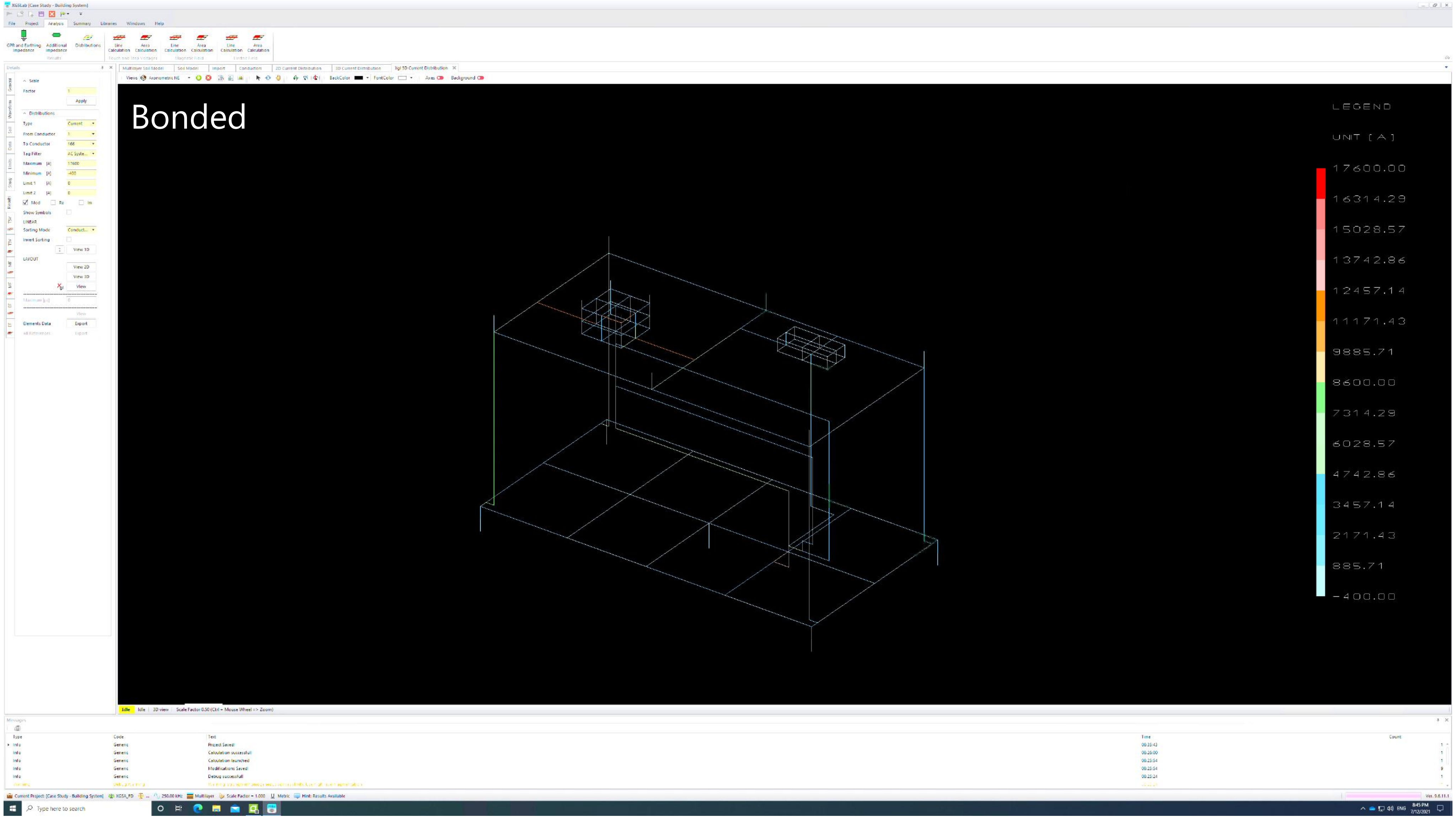
XGS_Lab: XGSA_FD Simulation – Current distribution comparison

Isolated



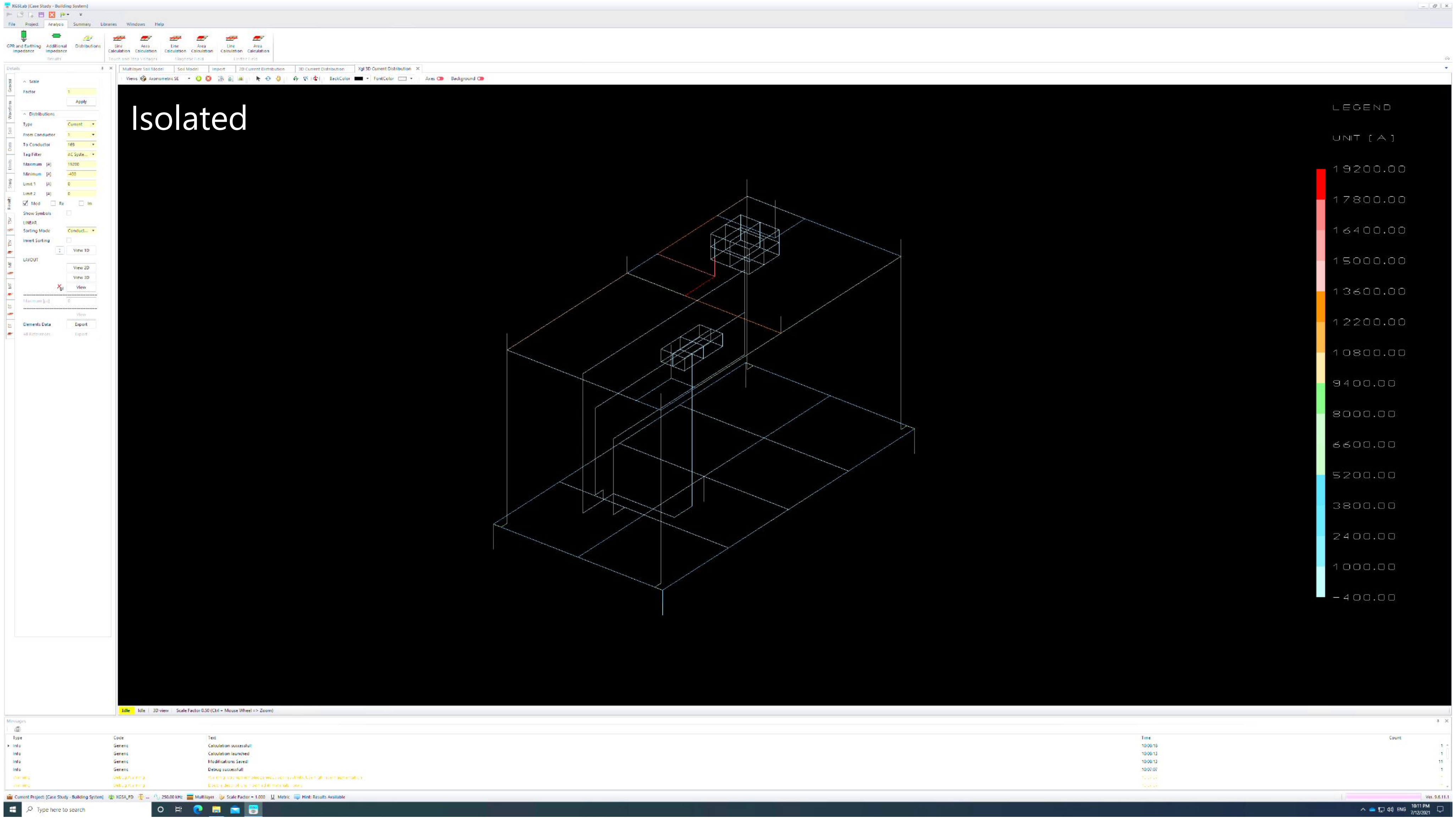
Bonded / Isolated Lightning Protection Systems

XGS_Lab: XGSA_FD Simulation – Current distribution comparison



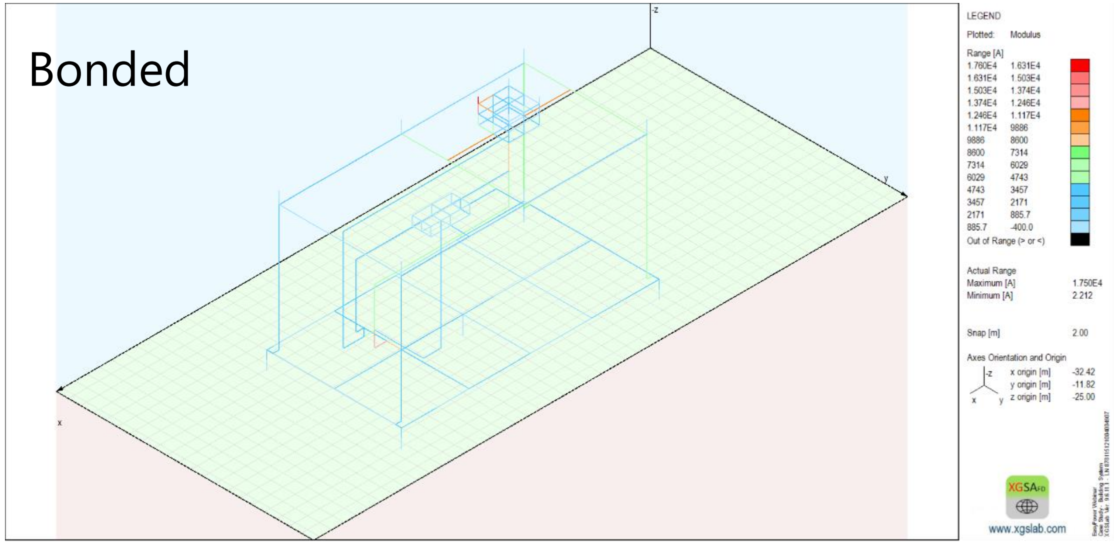
Bonded / Isolated Lightning Protection Systems

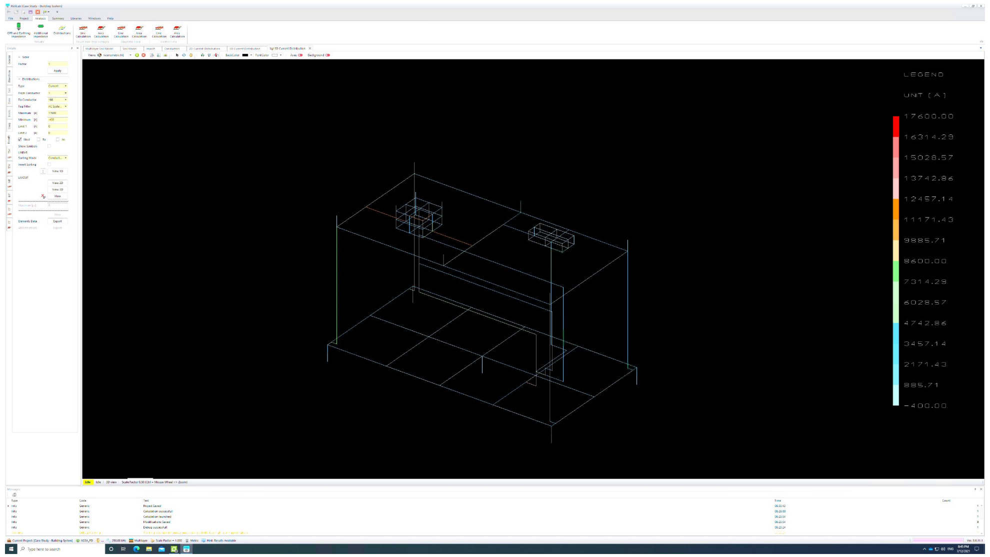
XGS_Lab: XGSA_FD Simulation – Current distribution comparison

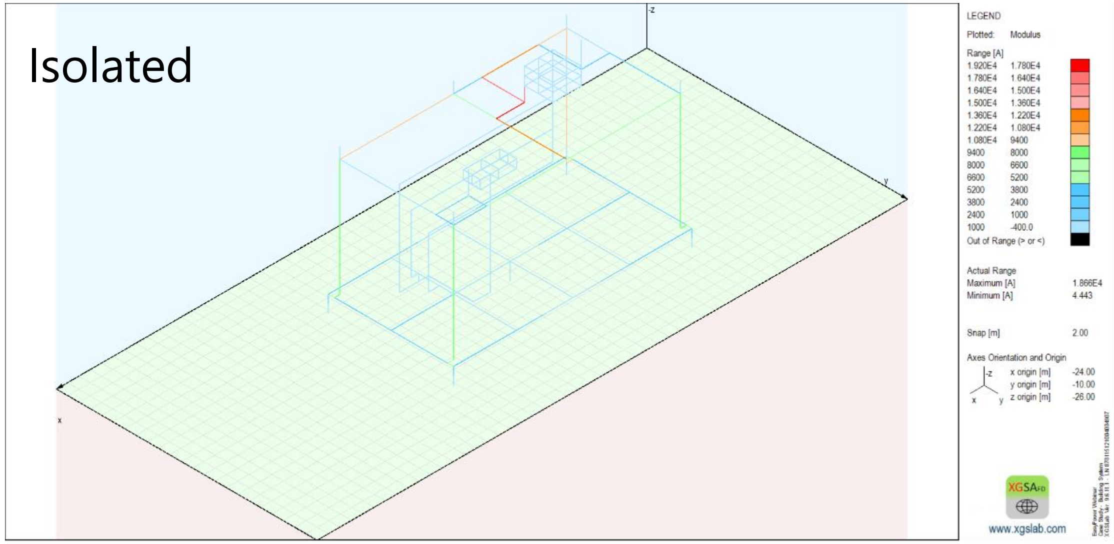


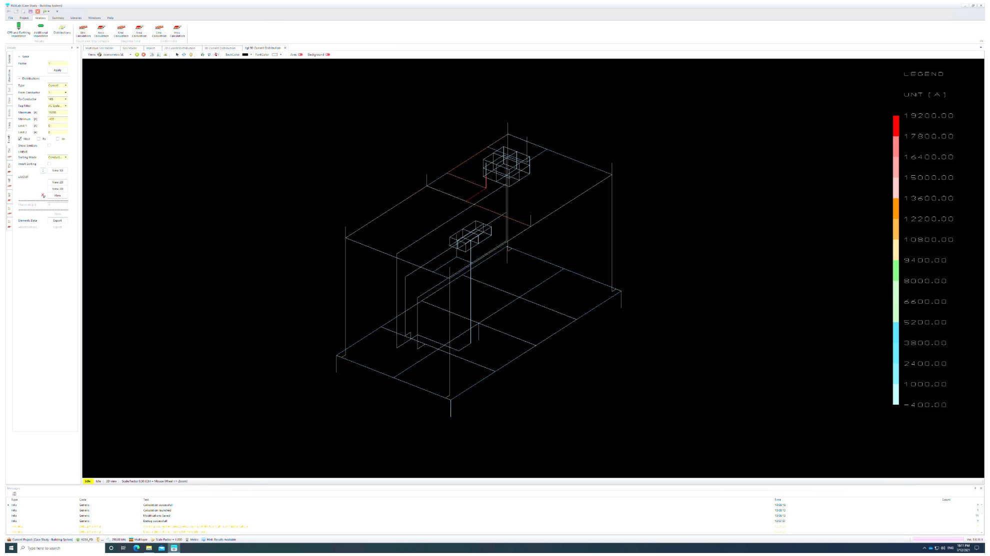
Bonded / Isolated Lightning Protection Systems

XGS_Lab: XGSA_FD Simulation – Current distribution comparison



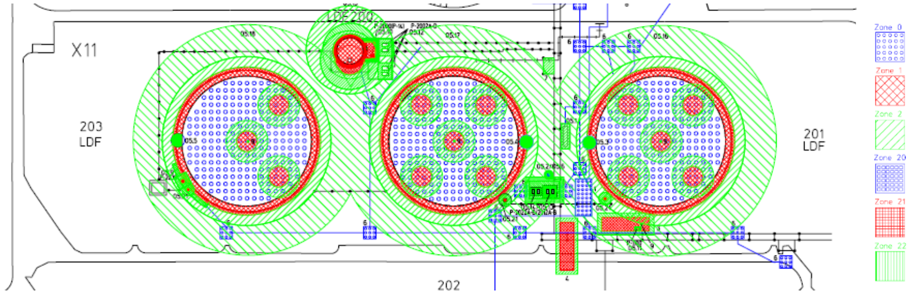






Application to Explosive Areas
Implementing a Bonded LPS

Inherently self-protecting. Direct lightning strike to tank structure acceptable?
(melting and spraying effects on the point of strikes, temperature rise of the inner surface)
thickness of not less than 5 mm of steel or 7 mm of aluminium



Tank is surrounded by an explosive atmosphere.

Using the tank structure as natural down-conductor possible?
(risk of any ignition of a possible explosive atmosphere by sparking)

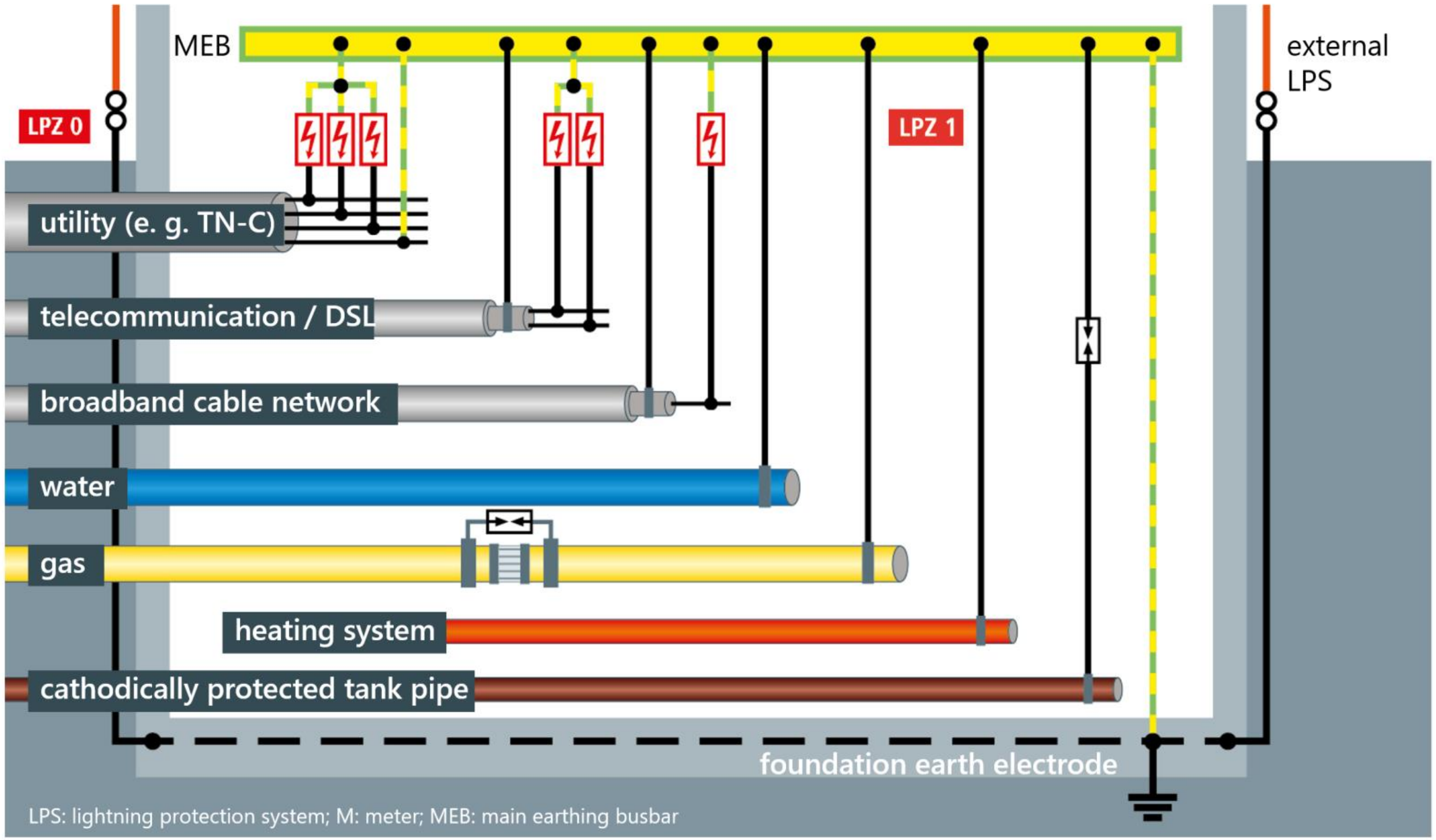
The specific application for explosive atmospheres, must take into consideration constant tensioning on fixings, component test ratings, the placement of the STD, the material of the components (temperature rise), and down-conductor routing.

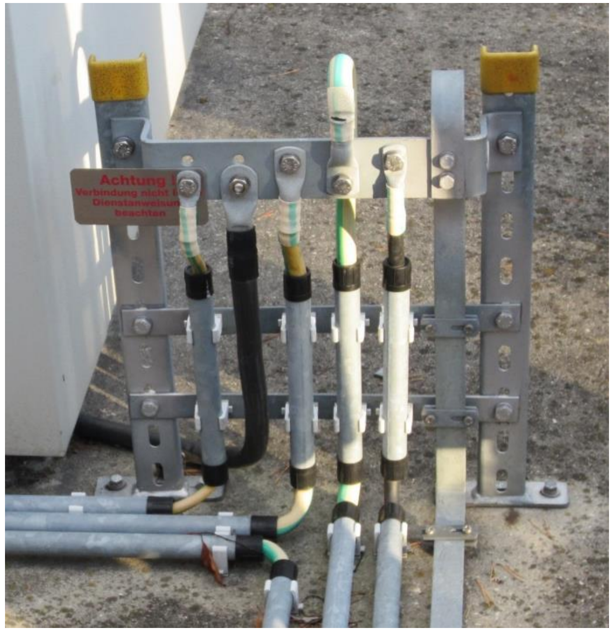
Bonded systems place a very high importance on the grounding and bonding, for the lightning current to safely move through the tank or steel structure to ground. This high current can also easily spark over small gaps to ungrounded or poorly grounded components such as metallic conduits or tank inspection covers and walkways. Type B (Ring Electrode) grounding arrangement is preferred.

Application to Explosive Areas

Implementing a Bonded LPS

Equipotential bonding is critical for all the systems in the explosive area

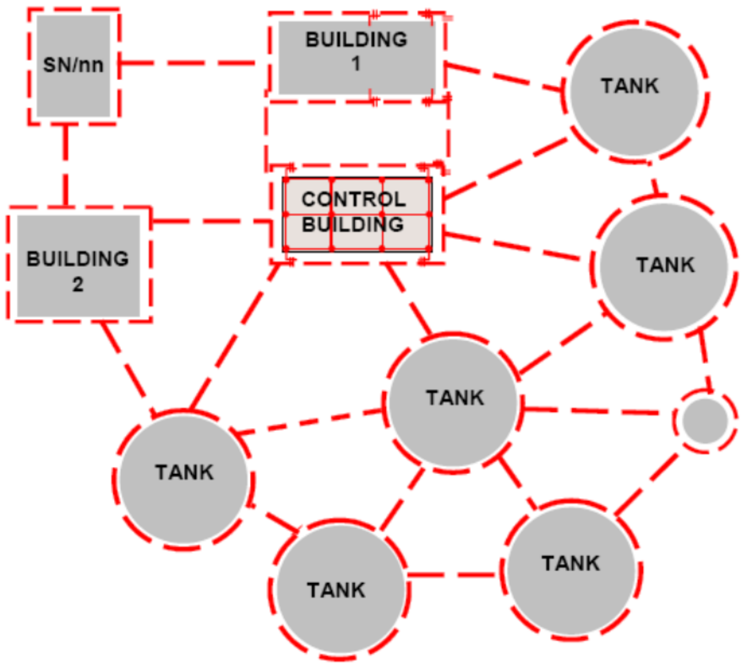


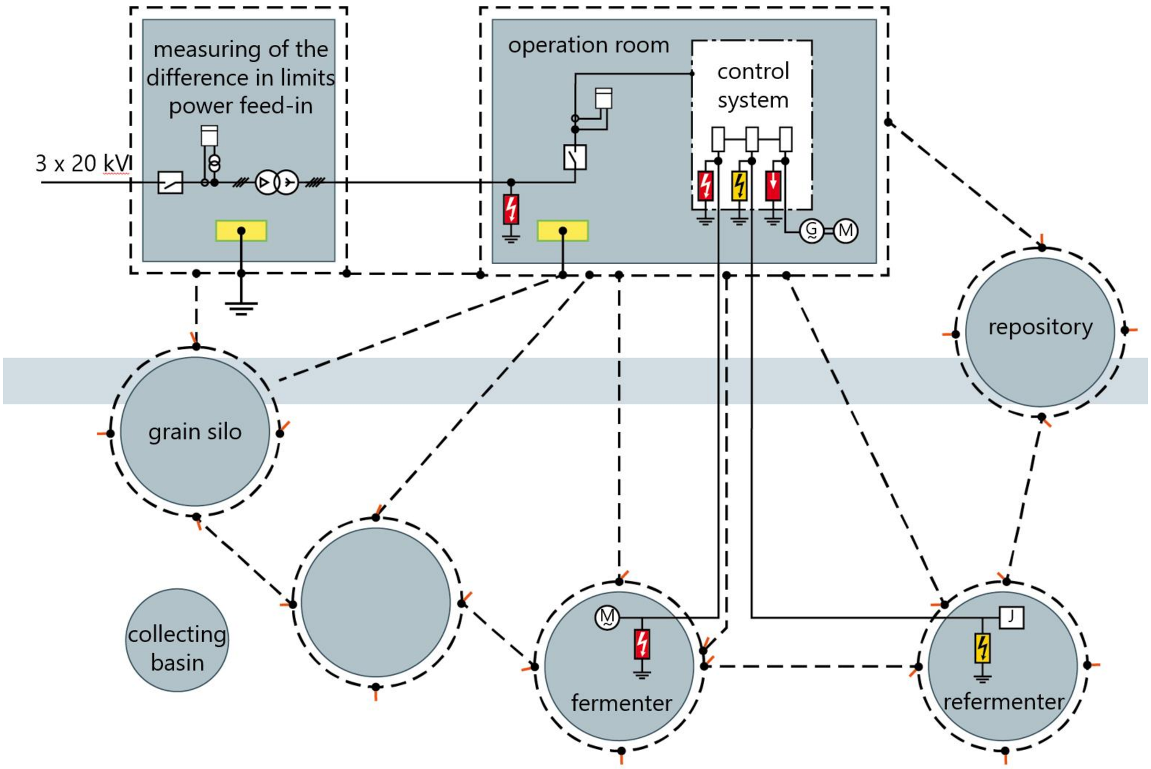


Application to Explosive Areas

Implementing a Bonded LPS

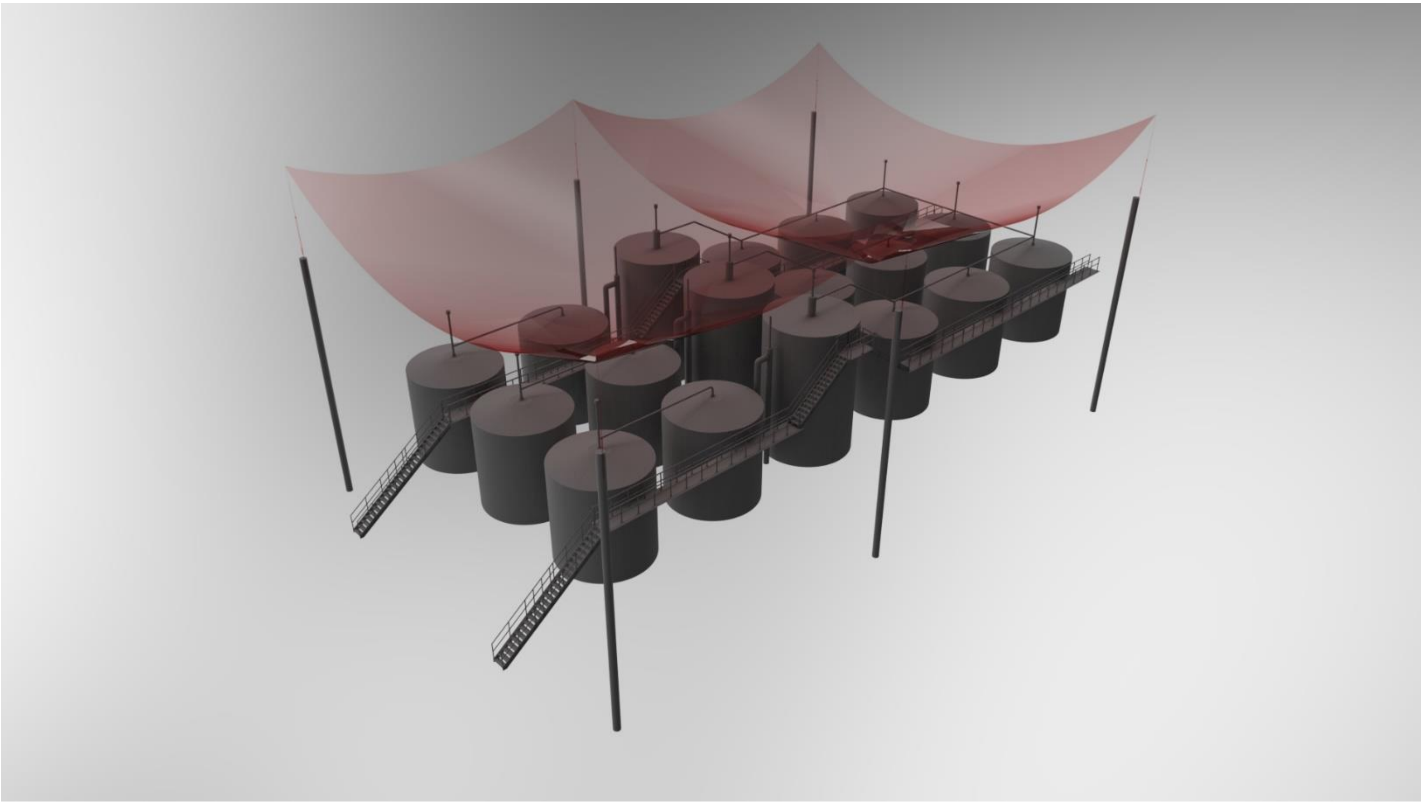
Grounding and equipotential bonding is critical for all the systems in the explosive area





Application to Explosive Areas
Implementing an Isolated LPS

An isolated LPS can be implemented by installing complete mast systems or overhead wires with adequate separation distance greater than the flash over distance calculations.



Application to Explosive Areas
Implementing an Isolated LPS

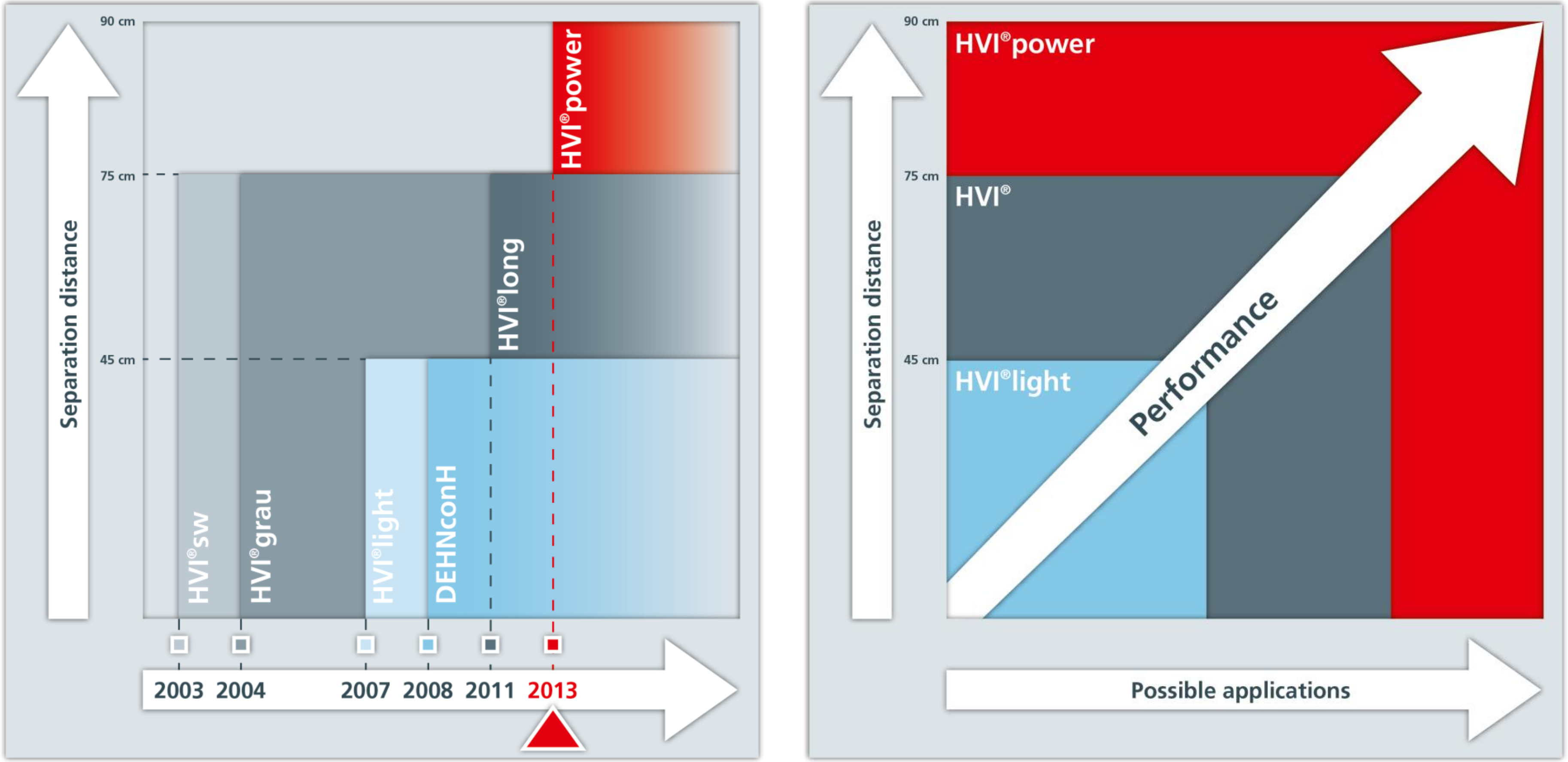
An isolated LPS can also be implemented by installing GRF stand-offs or High Voltage Insulated (HVI) conductors to achieve the necessary separation distance. (IEC TS 62561-8)

Installation of the distance holder

HVI® conductor installation

Application to Explosive Areas

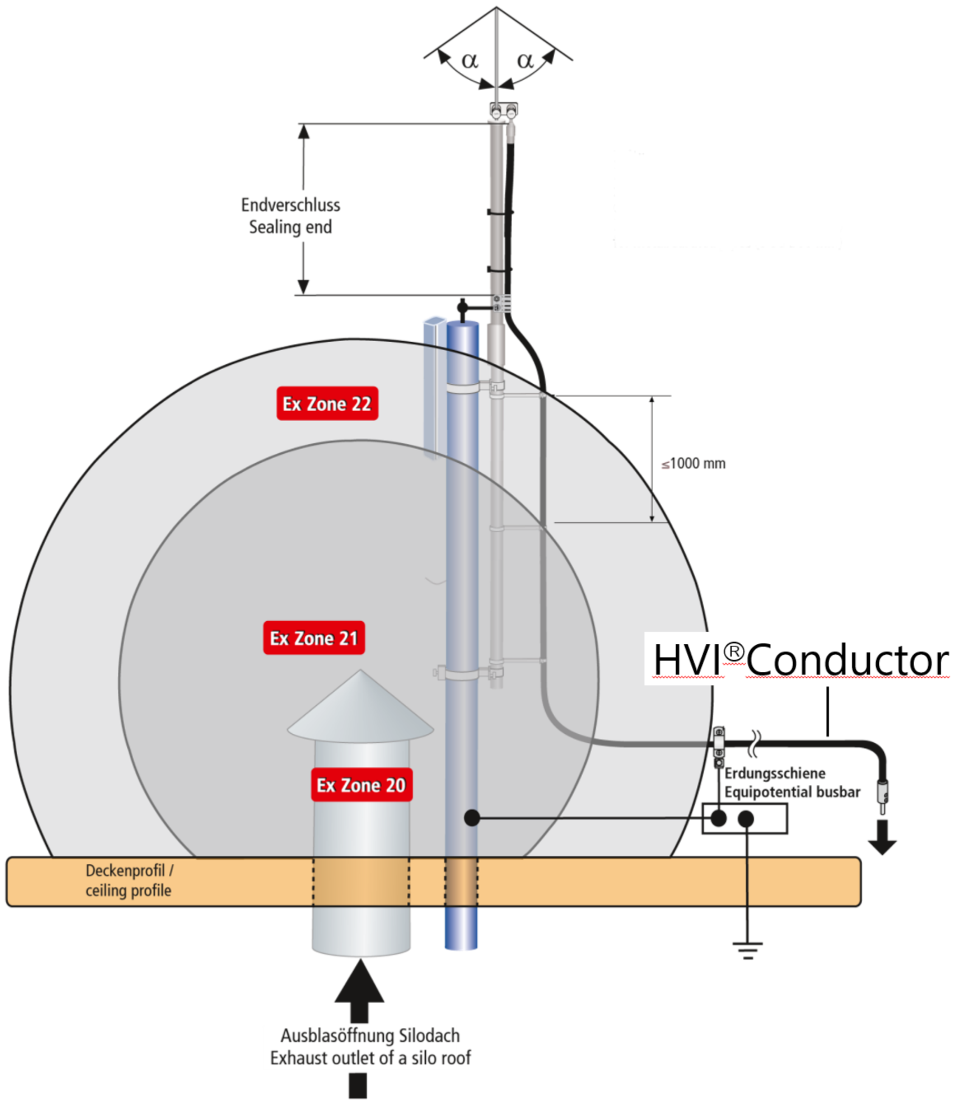
Implementing an Isolated LPS



Provided that the installation instructions are observed, HVI® Conductors may be installed in Ex zone 1 or 2 (gas, vapour, mist) or Ex zone 21 or 22 (dust).

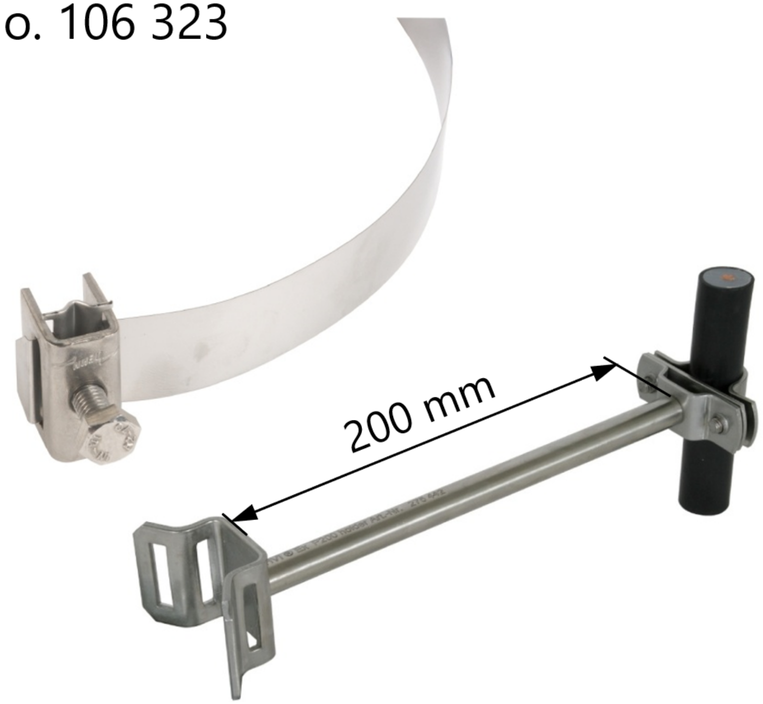
Application to Explosive Areas

Implementing an Isolated LPS



basic principle also applies to hazardous area 1 or 2

conductor holder for HVI®Conductor
HVI®Ex P200 holder, Part No. 275 442
combined with pipe clamp,
Part No. 106 323



Application to Explosive Areas

Implementing an Isolated LPS

Application to Explosive Areas

Implementing an Isolated LPS

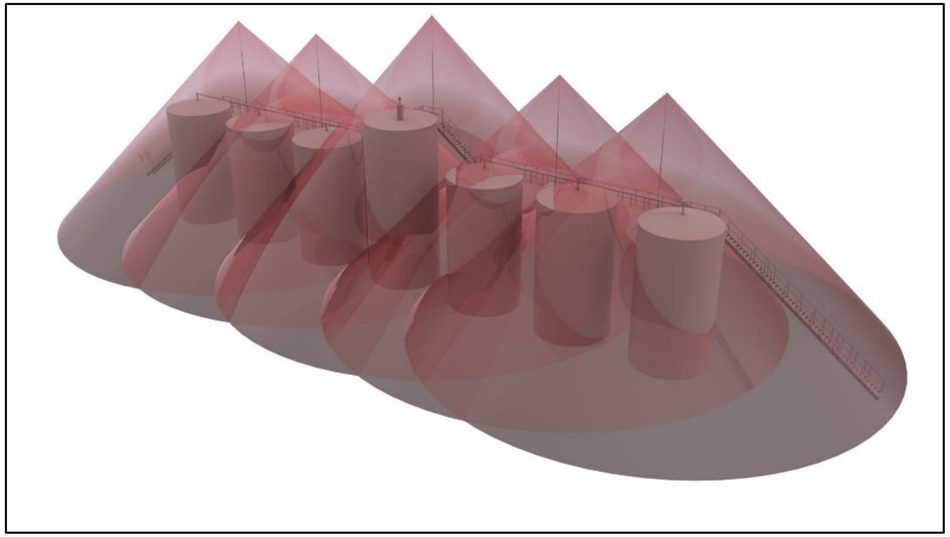
Look familiar? Now protected…

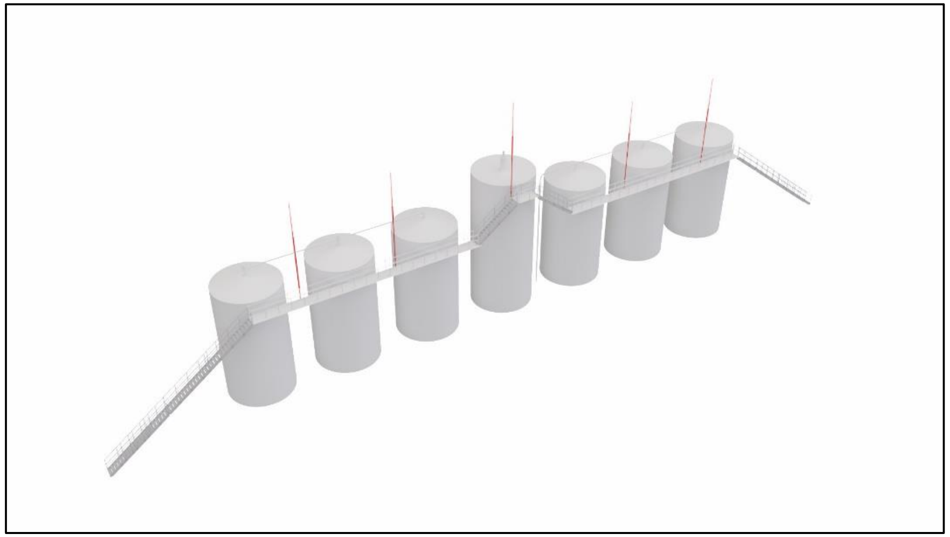
LOCAL NEWS

Lightning may have sparked oil tank fire near Brighton

Foam capable of extinguishing flammable liquids was used to bring the fire near Weld County roads 4 and 27 under control.

Author: Darren Whitehead
Published: 1:53 PM MDT May 5, 2021
Updated: 6:55 AM MDT May 6, 2021





D.6 Maintenance and inspection

D.6.5 Electrical testing requirements

The lightning protection system shall be tested electrically

a) every 12 (+- 2) months, or

b) to predict accurately an appropriate periodic inspection interval is a complex issue. The grade of inspection and the interval between periodic inspections shall be determined taking account of the type of equipment, manufacturer's guidance, if any, the factors governing its deterioration and the results of previous inspections

Questions?

DEHN protects.

Thank you for
Your attentention!