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A Technical Basis for Guidance of Lightning Protection for Offshore Oil Installations

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Abstract

Lightning strikes to flammable materials in Offshore Oil Installations (OOI) can cause devastating accidents. Explosions from flammable materials are a personnel safety danger. Loss of function and loss of production due to upsets of analog and digital low voltage systems is another. This paper describes the underlying basis for guidance of protection of Offshore Oil Installations (OOI) from direct lightning strikes and from secondary electromagnetic effects. A technical basis for guidance to address lightning protection designs has evolved from studies by the Electrical Research Institute (IIE).

Index Terms

Lightning, Lightning Protection, Offshore Oil Installations, Electromagnetic Fields.

1 INTRODUCTION

In the Central-South Mexican Gulf of México coastline the lightning season runs from early May to early October [1]. Historically, the peak danger months are June, July, August and September. Abundant moisture, atmospheric instability and storm triggering sea breezes combine at this time. Moisture is almost always available in the summer where the Gulf of Mexico and the warm Atlantic Gulf Stream combine. Instability is a function of surface heat and cooler air aloft, something present for most of the summer season. The trigger needed to produce thunderstorms is provided by the sea breeze that forms on the Atlantic and Gulf coasts. The steep thunderstorm gradient runs from northwest to south, with the southern areas more prone to lightning activity. It is forecast by some that increases in global warming will lead to more frequent and severe storm activity. Such weather conditions generate lightning attacks to OOI operations. OOI must have well-designed and well-maintained lightning protection systems (LPS) as defenses to avoid catastrophic effects that might endanger personnel and equipment.

A review of applicable lightning protection codes and standards has shown that none of them directly address the requirements for OOI. This paper proposes an underlying basis for guidance of protection of OOI from direct lightning strikes and their induced (secondary) effects. This guidance is based on external lightning protection (air terminals, down conductors and grounding) together with an internal lightning protection (equipotential bonding, shielding and Surge Protection Devices SPD).

A LPS protection plan can be calculated according to several elements: External Lightning Protection (including Common Bonding Network); Internal Lightning Protection; and Shielding Effectiveness. Each will be partially described.

2. EXTERNAL LIGHTNING PROTECTION

When lightning strikes an OOI, transient currents are conducted with resulting spurious signals. They can be introduced into equipment by one or more mechanisms: capacitive, magnetic, inductive coupling, direct arc-over and potential rise. The primary effects of direct lightning strikes on OOI are shown in figure 1. These are direct damages to equipment containers and electrical systems resulting in loss of production, risk of fire and explosion, generation of spurious signals, etc. A means to mitigate such damages is the installation of an external lightning protection system (ELPS).

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In Mexico the best-known source of information for ELPS is ANSI/NFPA 780 [2]. It is the introductory document for protecting many types of facilities. However, International Electrotechnical Commission (IEC) 62305 series is the recognized entity for the Mexican Standardization Association. The recently released Mexican Lightning Protection Standard [7] is based on IEC 62305 criteria. Unfortunately, none of the above three documents provide specific guidance for the protection of OOI.

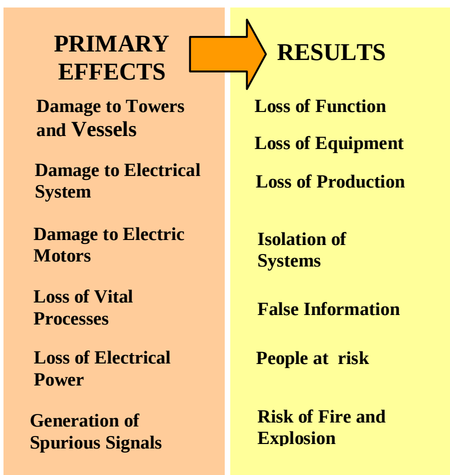

Figure 1: Primary effects of direct lightning incidence in Offshore Oil Installations (OOI).

OOI are unique structures: they have two key assumptions where lightning is concerned: they are potentially flammable installations and (b) there structures generally are metallic. The former assumption implies that a risk assessment be performed as described by IEC 62305-2 [4]. For the sake of reality this process can be omitted since the OOI should be equipped with the maximum level of protection. The latter assumption implies that extensive metal frameworks of structures are "self-protecting." However, an important question can arise: what about the apparatus or devices that are outside of the protective zone of the "natural" metallic air terminal as formed by the structure itself?. How this situation can be determined? No codes, standards or recommendations for lightning protection of OOI deal with this problem in a systematic way.

It is useful to review some existing standards and recommendations. The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations. Standard E-CR-001 [11] for OOI establishes, in section 6.5.2 the following: "No additional installations will be required for the lightning protection, provided the unit consist of bolted and welded steelwork that will provide a continuous current path from the highest point of the unit to the main earth". However, Det Norske Veritas (DNV), an independent foundation with the objective of safeguarding life, property and the environment has established in Electrical Installations Standard DNV-OS-D201 Chapter 2, Section 2, part I-600 [12], that lightning protection with air terminals should be considered under certain conditions, for instance, when masts above vessels are made of non-conductive material. The Standard establishes the size of air terminals (reaching a minimum high of 150 mm over the mast) and down conductors (terminated to the nearest point of the metal hull) carrying lightning current, with double the diameters of those contained in IEC 62305-1 [3] recommendations.

On the other hand, IEC standards, worldwide organization for standardization comprising all national electrotechnical committees, deal with this topic in several *related* standards. For instance IEC 92 [13], establishes lightning conductors only if the ship has wooden masts. As with NORSOK E-CR-001, IEC 92 recommends doubled size diameters for lightning conductors and the same characteristics for their terminations or ultimate connections. The Amendment 2 of IEC 60092-401 [13] establishes (in section 51.2.3) that "Vent outlets for flammable gases located at or near the top masts on tankships are to be protected by air terminals which extend at least 2 m above the vent outlet...". This protection element is compulsory irrespective of the thickness of the tankship. IEC 60092-502 [14], relating to electrical installations in ships, recommends in section 5.6.1 that "Account shall be taken of the risks due to lightning attachment", and in section 5.6.2, "Consideration should be given to the risk and effects of lightning attachment to high level gas or vapour vents, or adjacent structures"; however, it does say nothing about *how to do the protection.*

International Standard IEC 61892-6 [15] deals with lightning protection for mobile and fixed offshore units.

Eventhough sections 16.2.1 and 16.2.2 establish the requirements of a protective system, section 16.2.3 establishes the following "A protective system need not to be fitted to any unit of non-metallic construction, where a low resistance path to earth will be inherently provided by bolted and welded steelwork from the highest point of the unit to earth", which is is misunderstood in many cases. But again, the recommendations are not enough to make a comprehensive design for lightning protection in OOI installations.

Standards for land-based installations with risk of fire and explosion, such as ANSI/NFPA 780 [2], IEC 62305-3 [5], AS 1768 [6], BS 6651 [7], API 2003 [8] and NMX-J-549-ANCE-2005 [9] give the following general recommendations:

a. If dangerous materials are encased in metal of adequate thickness, other than by ensuring adequate earthing, lightning protection may not be required at all. (Here, *lightning protection* means *air terminals*).
b. In case of obvious risk to life and property, install every means possible for protection.
c. Use ring earth electrode for each lightning protection system, interconnecting neighbouring structures.
d. Observe bonding or safety distance (assuming $k_c=1$ of IEC 62305-3 [5]) to avoid arc flashing.
e. Use flametraps for vents emitting flammable vapors or dusts.
f. Install isolated LPS, having suspended air terminals 2 m apart from structure to be protected, by using protection level II (according to Annex D of IEC 62305-3 [5]).

According to the above information, it could be dangerous not to establish any lightning protection based solely on the metallic condition of the structure of the OOI. Instead (according to author´s opinion), it may be practical to combine the information content of related standards with practical experience gained in real situations so as to establish the following protection scheme for ELPS:

1. Verify that all equipment and devices are within the extensive metal framework of the OOI´s structure.
2. Verify that the extensive metal framework of the structure is electrically continuous. If not, install jumpers between major metallic parts or use another suitable measure.
3. Install a Common Bonding Network in each level where equipotential bonding for equipment and devices is needed.
4. If there are devices or equipment relocated and likely to be hit by lightning, or where a hazardous area is located directly under a metal sheet that may be punctured by lightning, install an external lightning protection based on air terminal(s) with a covering zone according to a level I or II of protection recommended by Annex D of IEC 62305-3 [5], by using rolling sphere method over and around the volume of the OOI. Air terminals should be attached in its base to the metal framework of OOI´s (which will work as a "natural" down conductor as well) and attached to the Common Bonding Network.
5. Wherever possible, the electronic equipment should be brought under the protective zone LPZ O_B to protect it against direct lightning flashes.
6. In case of a direct lightning flash, no melting or spray effects shall be ensured, except at the striking point of the air terminal.
7. Do not use piping carrying readly-combustible or explosive mixtures as a down conductor natural component. Otherwise, ensure that thickness and equipotential bonding are satisfied at the extremes of the pipe, provided its length does not generate arc-flashing conditions.
8. Use doubled diameter sizes of IEC 62305-1 [3] recommendations for air terminals and down conductors for land-based installations.
9. "Made" down conductors intended to carry lightning current could be neccesary only when the electrical continuity of the path for the lightning current is not ensured. If installed, they should be joined to the main hull (or main base pillars –not neccesarily up to sea water level) of the OOI following the shortest length and the cable should be bare or with suitable insulation, according to IEC 62305-3 [5] recommendations.

10. Corrosion-resistant metals (materials resistant to sea water and galvanic action between dissimilar metallic elements) should be applied for external lightning protection.

It should be noted that, irrespective of the striking point of a direct lightning strike and the type of air terminal (made or natural) and down conductor (made or natural), all the metallic structure will work as a frame to conduct lightning current. This condition makes it very hard or impractical (if not impossible) to apply an isolated lightning protection system for the whole OOI. By making the extensive metal framework of the OOI structure a pathway for the lightning current, the number of "natural" down conductors is increased to a high value, thus reducing the risk hazard of dangerous sparking and reducing the risk of touch voltages to tolerable levels. The risk of step voltage also is reduced to a safer value provided the elements of the extensive metal framework all are at the same potential. This can be verified by equipotential bonding measurements.

The metal work of processing towers and related vessels located at the OOI also are exposed to lightning strikes. Here, many small size pipes, valves, vent outlets for flammable gases, sensitive PLCs and VSDs as well as signalling cables makes it imperative they be protected against direct lightning. Many transient-related problems have been generated in these topside elements, even though the body of the tower or vessels may not have experienced primary damage.

Particular attention should be paid to topsides of I&C, Electric Power and Control rooms. The walls and the roof of these rooms are generally made of continuous steel sheets which satisfy the recommended thickness for direct lightning strikes, acting as a quasi-Faraday Cage. However, damage may occur when an air conditioning system (or other unprotected systems such as motors or ductwork) is installed on the roof which makes the room vulnerable to lightning hazard. Here, air terminals can be usedso as to avoid a direct impact upon the vulnerable system. Finally, metallic roofs of turbines shed generally are not designed to withstand lightning current, so they should be protected against direct lightning strike by installing air terminals.

Any ground connection involves an equi-potential reference to Earth (huge mass, i.e. the planet) for land-based installations. This grounding can be more effective or less effective according to the soil condition, moisture, temperature and the geometry of the driven elements. So, do Grounding and Earthing mean the same thing when an OOI is concerned?

There are two main types of steel framed installations for OOI: floating on water (such as ships) and embedded on the sub-sea floors. Strictly speaking the "earthing" term is misused in OOI structures because "protective earth conductor" or "safety earth conductor" are connected to the Common Bonding Network (CBN), characterized by the eq-ring conductor and the metallic structure. Therefore, the word "earth" is inappropriate.

For ships, IEC 92 [13] specifies in section 67 "…verify that…earthing leads are connected to the frames of apparatus and to the hull". IEC 60092-401 [13] establishes in section 52.2.1, that "Metallic enclosures shall be earthed to the metal hull or to the protective system…". It is then clear that grounding leads should be connected to the hull by the shortest route for floating OOI. What about sea floor structures?. In these cases, the grounding leads should be connected to the main pillars of the OOI by an equipotencial ring ("eq-ring" in this work). In this scheme, the frame of metallic enclosures should be radially connected to the eq-ring conductor located beneath platform´s floor, as shown in figure 2, and this ring, in turn, should be joined to the main pillars, as shown in figure 3. Volume is more important than low resistance. Thus a buried "ring electrode encircling the structure" is more efficient than a number of driven rods. This is similar to eq-ring conductors used in several-storeys structural steel buildings. The common bonding network together with the interconnected extensive metal framework of the OOI minimize potential differences and reduce the magnetic field. A common bonding network should never be used as a power or signal return path.

Standard DNV-OS-D201 [12] specifies in section I-701 "Aluminium superstructures that are provided with insulating material between aluminium and steel in order to prevent galvanic action are to be **earthed** to the hull…with wires or bands…with a maximum connection distance of 10 m". This is important because many problems encountered in grounding systems of OOI are related to corrosion generated by galvanic action for the use of dissimilar metals; the distance of 10 m should be less when radio interference is concerned. Standard E-CR-001 [11] refers to local recommendations for grounding system.

Connections between eq-ring conductors, grounding lead conductors and main pillars of the OOI should be exothermic instead of the compression or bolted types, where possible. There are circumstances where exothermic connections are "not suitable" and compression or bolted types should be employed.

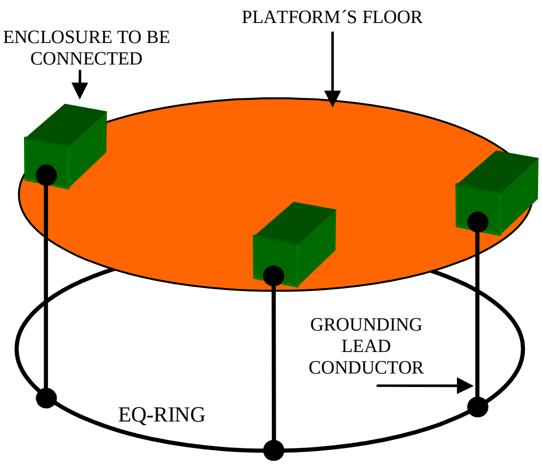

Figure 2: Radial connection from enclosures to the nearest equipotential ring (eq ring) of the platform´s floor or level. The leads must follow the shortest length (straight line - avoiding pronounced curves or bends).

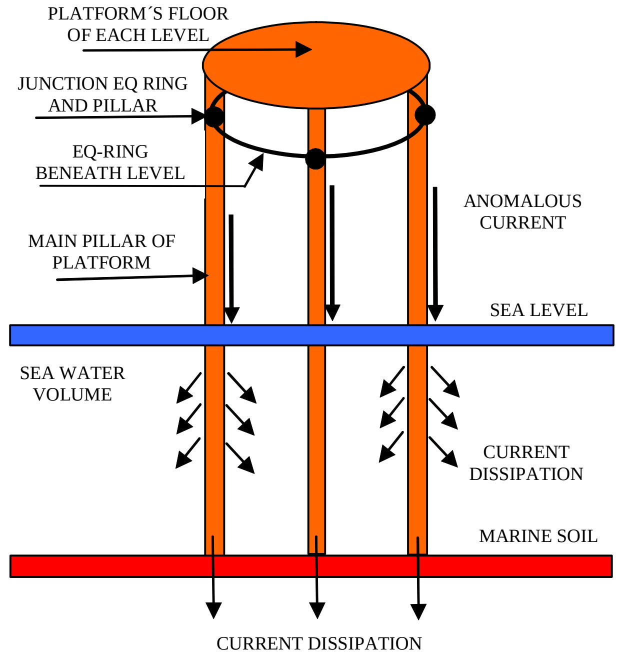

Figure 3: Anomalous current path from equipotential rings (eq ring) and main pillars, which are considered the lowest impedance elements in OOI of bottom founded structures type. The current is dissipated mostly into marine soil and in lesser extent in sea water volume.

3. INTERNAL LIGHTNING PROTECTION

Important parts of this subject are equipotential bonding, safe distances and surge protection devices. For the case of OOI structures with extensive metal framework, the risk of dangerous touch voltages, dangerous sparking within the structure and safety distance are drastically reduced when equipotential bonding is satisfied in all parts of the extensive metal framework. All metallic objects must be inter-connected everywhere at the OOI. This can be verified with a simple Ohm-meter measuring continuity.

An internal bonding network for electrical systems is related to grounding of primary and distribution electrical panels, power-level devices (motors, circuit brakers and transformers) and electronic and I&C systems. This internal bonding network must be installed irrespective of the installation of air terminals, as encouraged by IEC 62305-3 [5]. The boundary, as far as lightning guidance is concerned, depends upon the type of electrical supply. If the OOI generates its own electrical supply, then generators are the issue: if not, the boundary begins from service entrance (including the main transformer) and ends up at digital and analog system or the final load.

Equipment housed inside the OOI structure is protected from direct lightning effects. However, lightning-related transients can follow a variety of paths reaching power-level devices and I&C sensible devices. I&C devices are particularly vulnerable to transients, which can enter from power supply connections and sensor signals paths or be induced directly from lightning channel and metallic structures carrying lightning current. This interaction becomes very complex because lightning does not behave always in the same manner nor impact the same place.

Internal bonding schemes for the low and medium distribution system, as well as electrical devices must follow the safety rules contained in the National Electrical Code 2005 (90.2(B)(1)FPN). Further actions to be accomplished from lightning protection viewpoint are the following:

a. Place a master bonding bar near the main distribution panel.
b. Connect bonding conductor to master bonding bar. This should be referenced to the Motor Control Central.
c. Secondary distribution panels must be provided with separated neutral and grounding bars in a TNS electrical system.
d. Install safety and reference grounding conductors.
e. I&C cabinets provided with isolated bonding bars.
f. Reference grounding grid for telecommunication and control rooms (if necessary).
g. Bonding conductors shall be capable of withstanding the part of the lightning current flowing through them evaluated according with Annex E of IEC 62305-1 [3], specially among bonding bars.
h. Install suitable bonding bars for Surge Suppression Devices SPD.
i. Take care of corrosion effects on metallic conductors and enclosures.

In the case of I&C circuits, devices and cabinets, figure 4 shows the lightning protective scheme, including ELPS (if neccesary), common bonding network and internal grounding system. Protective zones, radial bonding arrangement and shielding are those specified in IEC 62305-3 [5].

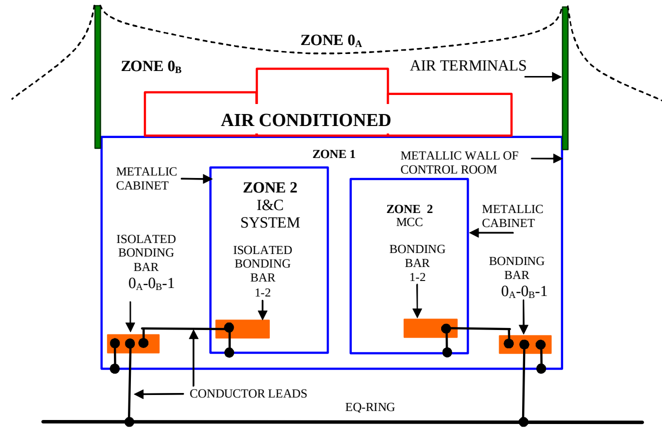

Figure 4: Typical lightning protective scheme for a control room containing motor control center (MCC) and I&C devices and circuits in an OOI.

Note in figure 4 the following:

1. Air terminals are installed only when vulnerable systems are not shielded by any higher metallic element. ELPS can be omitted if there are no devices or systems at risk at all on the roof of the control room.
2. Lightning current will flow through air terminals and walls of the control room, which will be acting as a Faraday Cage.
3. Bonding bars for I&C systems are isolated from metallic walls of cabinets.
4. Bonding bars for Motor Control Center (MCC) can be isolated or non-isolated from metallic walls of cabinets and room.
5. Cabinets and control room are made of continuous metallic sheets, with adequate thickness to satisfy standards requirements for lightning current flow
6. Cabinets for I&C systems should be isolated from metallic floor and walls of the control room

Surge Protection Devices (SPD) are a vital lightning defense. In the case of electric, electronic and I&C circuits and devices in OOI, milli-joules of energy may be enough to cause operational upsets and damage, so it is clear that additional protection measures are necessary to protect some of this equipment. This is recommended in IEC 62305-4 [6]. Many hundreds of mega-joules of lightning energy are likely to couple with these circuits and equipment, provoking "failures of electrical and electronic systems due to lightning electromagnetic effects", as indicated in IEC 62305-2 [4]. A protection measures system against lightning electromagnetic pulses, named LPMS in IEC 62305-4 [6], is formed by two basic measures in a lightning protection zone (LPZ) concept, including local zones or the whole installation: (a) spatial or internal line shielding (against radiated fields) and (b) use of SPD´s (against conducted surges), which shall be coordinated.

IEEE Std 1100 [18] addresses filtering and grounding of service lines and others conductors that ingress/egress the LPS boundary zones, and IEC 62305-3 [5] and IEC 62305-4 [6] specify arrangements of SPDs within the lightning protection zones, particularly at transition points and with special emphasis in coordination between an SPD and the equipment to be protected. So too does IEEE C62.41 [21] offers guidelines for the application of surge protection devices.

Some important aspects to be followed when SPDs are installed are:

a. SPDs for lightning protection of low-voltage installations are designed to handle only a portion of the total lightning current. Therefore, it is important to take care of shielding for signal or power cables.
b. Protection levels of the selected SPDs have to meet the requirements of the insulation coordination and the inmunity levels of the equiment to be protected IEC 61000-4-5 [20].
c. The SPD´s test requirements shall comply with IEC 61643-1 [21] for power systems and IEC 61643-21 [23] for telecommunication and signal systems.
d. Selection and installation of coordinated SPD protection shall comply with IEC 61643-12 [22] and IEC 60364-5-53 [25] for power systems and IEC 61643-22 [24] for telecommunication and signal systems
e. SPD´s shall be located at well-identified critical points of protective zones, specially at interfaces of voltage levels and physical enclosures.
f. SPD´s shall be located as close as possible to the entrance point of the incoming line or to the equipment being protected, with the ground conductor as short-and-straight as possible.
g. First SPD shall manage the majority of the partial lightning current. Subsequent SPD´s need to be designed only to cope with the remaining threat from the interface LPZ 0_A to LPZ 1 plus the induction effects from the electromagnetic field within LPZ 1 and higher protective zones.
h. At the interface LPZ 0_A to LPZ 1, Clase I tested SPD shall be used to divert partial lightning currents.
i. At the interface LPZ 0_B to LPZ 1, Clase II tested SPD shall be used to divert mainly lightning-induced surge current.
j. At interfaces LPZ 1 to LPZ 2 and higher protective zones, Class II tested SPD or Clase III tested SPD shall be used to divert mainly lightning-induced surge current.
k. Take into account the type of SPD (voltage limiting and voltage switching) when coordination is applied.
l. Characteristics of internal SPD´s incorporated in the equipment to be protected may affect the coordination of SPD´s requirements.
m. For interconnections of LPZ of the same order by power or signal cables, SPD´s can be omitted when cables are shielded by cable screen or metalic ducts, provided they are able to carry the partial lightning current and the voltage drop along the shield is not too high.
n. Where practicable, SPD´s should be positioned outside locations where dangerous material is present or outside hazardous zone. SPD´s positioned inside locations should be of explosion-proof type or positioned inside hazardous zone should be contained within an approved enclosure.
o. When internal systems conductors are screened or located in metal conduits, they shall be bonded. Moreover, it is a good practice to bond them via SPD´s.

4. SHIELDING EFECTIVENESS

Shielding of OOI can be achieved by some or all of the following: air terminals for lightning attachment (direct impact, LPZ 0_A): control of radiated lightning electromagnetic fields and their effects (LPZ 0_B to LPZ 1): control of conducted lightning-generated transients at the interfase of protective zones (LPZ 0_B to LPZ 1, LPZ 1to LPZ 2): and bonding leads, bonding bars and eq-rings.

Shielding effectiveness given by air terminals for direct lightning strike will depend on the level of protection used, according to IEC 62305-1. Bonding leads, bonding bars and eq-rings also provide shielding.

Shielding effectiveness for radiated lightning electromagnetic fields and their effects on sensible electronic devices, sensors and cables inside enclosures will depend on the configuration and material of the barrier. For cases of lightning-generated magnetic induction effect, the magnetic field of the first stroke can be characterized by a typical frequency of 25 kHz and the magnetic field of the subsequent strokes can be characterized by a typícal frequency of 1 MHz, as defined in IEC 62305-4 [6].

Shields function on the basis of two major electromagnetic phenomena: reflection from a conducting surface and absortion in a conductive volume. For plane waves (far fields), the combined effect of these losses –attenuation- (reflection and absortion) determines the effectiveness of the shield. If the components in the enclosure are to be protected from outside fields, then the enclosure material should have a maximum combination of absortion and reflection losses. Reflection is independent of the barrier thickness and is a function of the material´s conductivity, magnetic permeability and frequency. Absortion is the transformation of the wave energy in the shield to heat, frequently defined by the term skin depth, and it is not directly related to near-or far- field conditions.

Thus, shielding effectiveness varies with frequency, shield geometry, positioning of the victim within the shield, type of field being attenuated, directions of incidence and polarization. Moreover, shielding effectiveness definition for electric and magnetic fields will be identical if the fields concerned are uniform plane waves and the media on each side of the barrier are identical For example, for 20 mil copper (1/2 mm), the combined attenuation is about 140 dB (10^7:1) and for 20 mil steel, the combined attenuation is about 180 dB (10^9:1) for 25 kHz signal (first stroke), and these attenuation values are higher for 1 MHz signals (subsequent strokes) [16]. Cases analyzed in IEC 62305-4 [6] for shielding effectiveness are only for gridlike spatial shields, from which an analysis of the shielding effectiveness of metallic framed structures of the OOI itself and others can be done. For example, for 1 mm width copper/aluminium gridlike spatial shield, magnetic attenuation becomes about 80 dB for 25 kHz and for 1 MHz, but for 5 m width, magnetic attenuation is only about 5 dB.

The above analysis indicates that perfectly welded sealed rooms are ideal for lightning shielding effectiveness, However, openings like doors, windows, side panels, I/O panels, ventilation ports and cables that ingress/egress can compromise the integrity of the shielding effectiveness, especially by conducted signals. Thus, all openings should correctly be treated, according to IEC 62305-4 recommendations [6].

5 CONCLUSIONS

Several standards are recommended for endorsement to address issues associated with lightning protection of Offshore Oil Installations (OOI). Lightning-related events and their effects on OOI call for a guidance from which a systematic lightning protection approach can be applied in order to minimize the risk of loss of production, loss of equipment, loss of function and fire and explosion which could endanger people.

The proposed guidance should cover technical aspects systematically arranged such as protection against direct lightning strike, equipotential bonding, grounding and grounded conductors, shielding effectiveness, surge protective devices SPD and the use of suitable and reliable materials.

6 ACKNOWLEDGEMENT

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7 REFERENCES

1. Decker D., National Weather Service, Melbourne, http://www.floridadisaster.org/hwaw/day1/lightning.htm.
2. ANSI/NFPA 780: 2004, "Standard for the Installation of Lightning Protection Systems**".**
3. IEC 62305-1:2006, "Protection of structures against lightning". Part 1: General principles.
4. IEC 62305-2: 2006, "Protection of structures against lightning. Part 2: Risk management".
5. IEC 62305-3:2006, "Protection of structures against lightning. Part 3: Physical damage to structures and life hazards".
6. IEC 62305-4:2006, "Protection of structures against lightning. Part 4: Electrical and electronic systems within structures".
7. NMX-J-549-ANCE-2005 "Protection against lightning – specifications, materials and methods of measure", Mexican Standard (in Spanish).
8. Australian Standard AS 1768 (Int): 2003, "Lightning Protection".
9. British Standard BS 6651: 1999, "Code of Practice for Protection of Structures Against Lightning".
10. American Petroleum Institute API 2003: 1998, "Protection against ignitions arising out of static, lightning and stray currents".
11. NORSOK Standard, "Electrical Installation of Offshore Installations", E-CR-001, Rev. 3, 1997.
12. DNV Offshore Code DNV-OS-D201, "Electrical Installations", 1993.
13. IEC 92: 1980, "Electrical installations in ships. Part 401: Installation and test of completed installation". Amend. 2 – IEC 60092-401, 1997-04.
14. IEC 60092:1999-02, "Electrical installations in ships. Part 502: Tankers – Special features".
15. IEC 61892-6:1999-02, "Mobile and fixed offshore units-Electrical Installations – Part 6 : Installation".
16. IEC 60079: 2002, "Electrical apparatus for explosive gas atmospheres. Part 14: Electrical installations in hazardous areas (other than mines)".
17. Clayton P. R., "Introduction to Electromagnetic Compatibility", John Wiley and Sons, Inc. 1992. IEEE Std 1100: 1999, "Recommended practice for powering and grounding electronic equipment".
18. IEEE Std 1100: 1999, "Recommended practice for powering and grounding electronic equipment".
19. IEEE Std C62.41: 1995, "Recommended practice on surge voltages in low voltage AC power circuits".
20. IEC 61000-4-5: 1995, "Electromagnetic compatibility (EMC)–Part 4. Testing and measurement techniques– Section 5. Pulse magnetic field immunity test".
21. IEC 61643-1:1998, "Surge protective devices connected to low-voltage power distribution systems. Part 1: Performance requirements and testing methods.
22. IEC 61643-12:2002, "Surge protective devices connected to low-voltage power distribution systems. Part 12: Selection and application principles.
23. IEC 61643-21:2000, "Low voltage surge protective devices. Part 21: Surge protective devices connected to telecommunications and signalling networks: Performance requirements and testing methods.
24. IEC 61643-22:2004, "Low voltage surge protective devices. Part 22: Surge protective devices connected to telecommunications and signalling networks: Selection and application principles.
25. IEC 60364-5-53:2001, "Electrical installations of building. Part 5-53: Selection and erection of electrical equipment: Isolation, switching and control.
26. Kisner R.A., Wilgen J.B., Ewing P.D., Korsah K., and Moore M.R., "A technical basis for guidance on lightning protection for nuclear power plants", Fourth American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentations, Controls and Human-Machine Interface Technologies (NPIC&HMIT 2004), Columbus, Ohio, September, 2004.