

ELECTRICAL AND ELECTROMAGNETIC INTERFERENCE IN THE CORRECT DETERMINATION OF CLASSIFIED OR HAZARDOUS AREAS IN THE PETROCHEMICAL AND OFFSHORE INDUSTRY.

1. INTRODUCTION

The aim of this work is to analyse in detail the impact of possible electrical and electromagnetic interference on the safe definition of classified areas in industrial facilities in the petrochemical industry, such as refineries and petrochemical plants, as well as offshore production platforms. In these environments, large quantities of flammable substances such as gases, vapours and petroleum-derived liquids are commonly handled and stored. The presence of these materials in conjunction with process activities represents a significant risk of explosion accidents, considering that a small spark or heat source is enough to ignite a flammable cloud.



It is therefore essential that all possible factors that could trigger an ignition are properly taken into account in the classification studies and engineering designs of the areas, in order to safely size the spatial boundaries between explosion risk zones 0, 1 and 2. Only the complete mapping of all potential sources, including those resulting from transient interference, will make it possible to establish the correct boundaries between classified areas and, consequently, the appropriate level of protection to be implemented in equipment and systems.

The main challenges in determining classified or hazardous areas in the petrochemical or offshore industry are:

- Precise mapping of all potential ignition sources, including electrical transients and electromagnetic inductions: Requires detailed survey using equipment such as a field generator, spectrum analyser and sensing, as well as document research, taking into account all electrical, mechanical and radio frequency systems, as well as lightning strikes.
- Consideration of the various environmental factors that can increase risks, such as humidity, wind, lightning, nearby activities, etc: Requires study of the local microclimate, mapping of areas that can influence with dispersion of gases or dust, restrictions on construction and operations upstream/downstream.
- Adequate modelling of the propagation of explosions in three dimensions, taking into account real structures, equipment, and obstacles: Requires **CFD** simulation capacity coupled with the physics of explosions using software such as **ANSYS**, **COMSOL** or **PHAST** with faithful **BIM/CAD** models.
- Careful assessment of the flammability and toxicity limits of all fluids present in the plant or platform: Requires laboratory tests, review of **FIS/MSDS** and pilot plant work for greater accuracy in the limits considered.
- Precise determination of zone limits for each specific type of risk present: This involves rigorous application of standards, analysis of simulation results and field measurements.
- Clear definition of responsibilities and up-to-date maintenance of the physical demarcation of zones.
- Management of changes in layout or processes that can make the initial calculations out of date.
- Continuous monitoring for early identification of potential new sources resulting from failures or operation.

2. INTERFERENCE AND ITS CONSEQUENCES

Electrical and electromagnetic interference in oil installations can occur through different mechanisms and originate from various sources, as described above. If not properly assessed, such interference represents additional potential sources of ignition, jeopardising the safety of the delimitation of classified zones.

Transient electric fields induced by atmospheric discharges or generated by insulation faults in control systems and electrical panels are subject to the induction of voltages and eddy currents in nearby circuits, which can trigger electrical arcs. The **IEC 60079-32** standard establishes requirements for the protection of electrical equipment against the occurrence of such overvoltages.

Electromagnetic waves from telecommunications systems, radar and other devices operating in the vicinity induce currents in power cables, metal structures and the chassis of motors and switchboards through electromagnetic coupling. These currents arise from the antenna effect and can cause overheating as defined in the **IEC 60079-25** standard.

Abnormal heating of surfaces by electromagnetic induction is capable of igniting a flammable atmosphere as long as the temperature is raised above the ignition point of the substance, normally between **200°C** and **650°C**. **IEC 60079-14** specifies thermal protection requirements for equipment in areas with this type of interference.

It is therefore of the utmost importance that these phenomena are mapped and taken into account when calculating the propagation of flammable substances according to the principles established by **NBR IEC 60079-10**, in order to adequately dimension the size and level of protection in **zones 0, 1 and 2**.



The main technical standards dealing with electrical and electromagnetic interference in industrial installations, particularly in hazardous areas, are:

- **IEC 60079-0**: Classification of areas where atmospheric explosives may occur.
- **IEC 60079-10-1**: Classification of areas - Considerations regarding the presence of dust.
- **IEC 60079-14**: Electrical equipment for flammable cloud explosion hazard environments - Requirements for design, manufacture, inspection, and testing.
- **IEC 60079-15**: Specifies requirements for protection of equipment against combustion dust.
- **IEC 60079-25**: Electrical equipment used for specific applications - Considerations for protection against ignition by frequent radio electromagnetic waves.
- **IEC 60079-30-1**: Test procedures - Protection against Radio Frequency Wireless Devices (**RFFD**). Defines test methods to verify compliance with RF protection requirements.
- **IEC 60079-30-2**: Test procedures - Protection against electrostatic discharge. Prescribes the procedures for testing protection against discharges triggered by electrostatic effects.
- **IEC 60079-32-1**: Protective equipment - Requirements and test methods - Protection against electric shock.
- **IEC 60079-5**: Sand-filled protective equipment.
- **IEC 60079-6**: Types of protection "e".
- **IEC 60079-11**: Explosion-proof protective equipment.
- **NBR IEC 60079-10**: Classification of areas and selection of equipment.
- **IEC 61000-4-3**: Immunity tests - RF in strictly defined frequency ranges. Test standard for checking the immunity of equipment under specific RF conditions.
- **NFPA 499**: US standard establishing safety requirements against electrical and electrostatic hazards.
- **API RP 500**: American Petroleum Institute standard on classified areas in petrochemical facilities.

These standards establish the technical requirements for protecting equipment against explosive environments and associated interference.

2.1. HOW ELECTRICAL INTERFERENCE CAN JEOPARDISE THE SAFETY OF HAZARDOUS AREAS

There are a number of ways in which electrical interference can jeopardise the safety of classified zones:

- Generating additional ignition sources not considered in the calculations. Electrical discharges induced by transients can cause arcs in non-designed locations.
- Heating equipment beyond the ignition temperature by electromagnetic induction. This can occur in regions far from the original sources.
- Propagating energies capable of igniting mixtures over larger areas than those delimited, since the real extent of the risks has not been captured.
- Inducing voltages and currents in nearby circuits capable of overheating surfaces or triggering arcs in unexpected places.

- Compromising electrical protection systems that may fail to contain any explosions within the calculated limits.
- Generating electrostatic or electromagnetic fields of greater intensity than assumed in flame propagation calculations.
- Not taking into account environmental factors that can potentiate the effects of inducing and spreading fires, such as humidity, wind, nearby objects, etc.
- They can hide or mask real ignition sources, making it difficult to detect and correct them. This is because they induce heating or discharges in different places.
- They can progressively damage electrical equipment without any faults being noticed, leading to overheating, and arcing at unpredictable times.
- The unintentional propagation of electrical/electrostatic energies by conduction through structures, cables and hoses is not adequately dimensioned.
- There is insufficient mapping of all possible sources of interference inside and outside the area, such as transmission lines, antennas, neighboring industries, etc.
- The variable operation of machinery and equipment changes their degree of susceptibility to inductions over time.
- Extreme weather events such as lightning and strong winds increase the potential for transients that were not considered in the original designs for the areas.
- Protective equipment designed for some types of risk may not be effective against other interference mechanisms.

Therefore, unevaluated interferences can underestimate the real limits of classified zones, jeopardising explosion safety.

3. MAIN POINTS OF ELECTRICAL AND ELECTROMAGNETIC INTERFERENCE WHEN DETERMINING CLASSIFIED AREAS:

- **Transient electric and magnetic fields:** These disturbances are short-lived but of high magnitude and can be induced at a distance through earthing systems by lightning strikes or electrical faults. If coupled to circuits, they are capable of generating arcs due to voltage transients.

These fields occur during lightning strikes, where currents in the order of tens of kA flow through the ground for hundreds of microseconds. The intensity of voltage peaks can exceed 1MV, inducing capacitive/inductive coupling in nearby circuits.

Standards such as **IEC 61000-4-4** and **IEC 61000-4-5** specify tests for immunity to fast electrical transients (**BURST**) and shock waves, respectively. Its energy is dissipated by conduction/radiation over distances that vary according to the impedance of the ground and existing shielding.

- **Telecommunications signals:** Radio signals, microwaves, etc. can induce alternating or continuous currents in equipment, cables, and metal structures by electromagnetic coupling. These eddy currents can heat surfaces above the ignition points under certain conditions.

RF signals such as **Wi-Fi (2.4GHz)**, **3G/4G (0.8-2.6GHz)** and **Bluetooth (2.4GHz)** induce currents by electromagnetic coupling as defined in Maxwell's equations. The intensity depends on the incident electric field E, the area A and the characteristic impedance Z of the medium, according to the formula $P=E^2*(A/Z)$.

IEC 61000-4-3 specifies immunity tests to RF electromagnetic fields. Standards such as **IEC 60079-25** and **IEC 60079-30-1** determine the maximum exposure levels for different groups of equipment.

- **Sensitive equipment:** Motors, switchboards and other equipment installed near sources of interference are more exposed to abnormal heating of insulated or conductive parts due to the antenna effect.
- **Offshore structures:** In the vicinity of the sea, humidity and salinity facilitate the ionisation of the atmosphere and the accumulation of static charges that can be discharged onto equipment, the ground, or people.

High humidity reduces the resistivity of air, soil and materials as water molecules adsorb onto their surface. Salts ionise in aqueous solution, increasing electrical conductivity. Both effects facilitate the conduction of electrical charges, expanding the possibilities for electrostatic induction heating in offshore equipment.

- **Environmental factors:** Sea air increases the conductivity of the soil and the likelihood of lightning strikes, which in turn increase the risk of electromagnetic induction.
- **Additional ignition sources:** Interference generates new ignition possibilities that need to be taken into account in explosion propagation calculations between zones. Electrical and electromagnetic interference generates transient sources capable of inducing voltages, currents and heating in equipment located outside the originally mapped and protected risk areas.

During a lightning strike, for example, voltage peaks in the order of MV can propagate through overhead and underground conductors as well as metal structures, reaching control panels in areas considered to be free of danger.

Similarly, RF signals from nearby telecoms systems can induce eddy currents in excess of the limits defined in **IEC 60079-25**, generating hot spots in motors, cables or structures located outside the zones originally envisaged in the plant's explosion propagation studies.

The occurrence of such transient ignition sources even further away from the original equipment requires a reassessment of the distance calculations between **Zones 0, 1 and 2**, as recommended by standards such as **IEC 60079-10** and **NBR IEC 60079-14**.

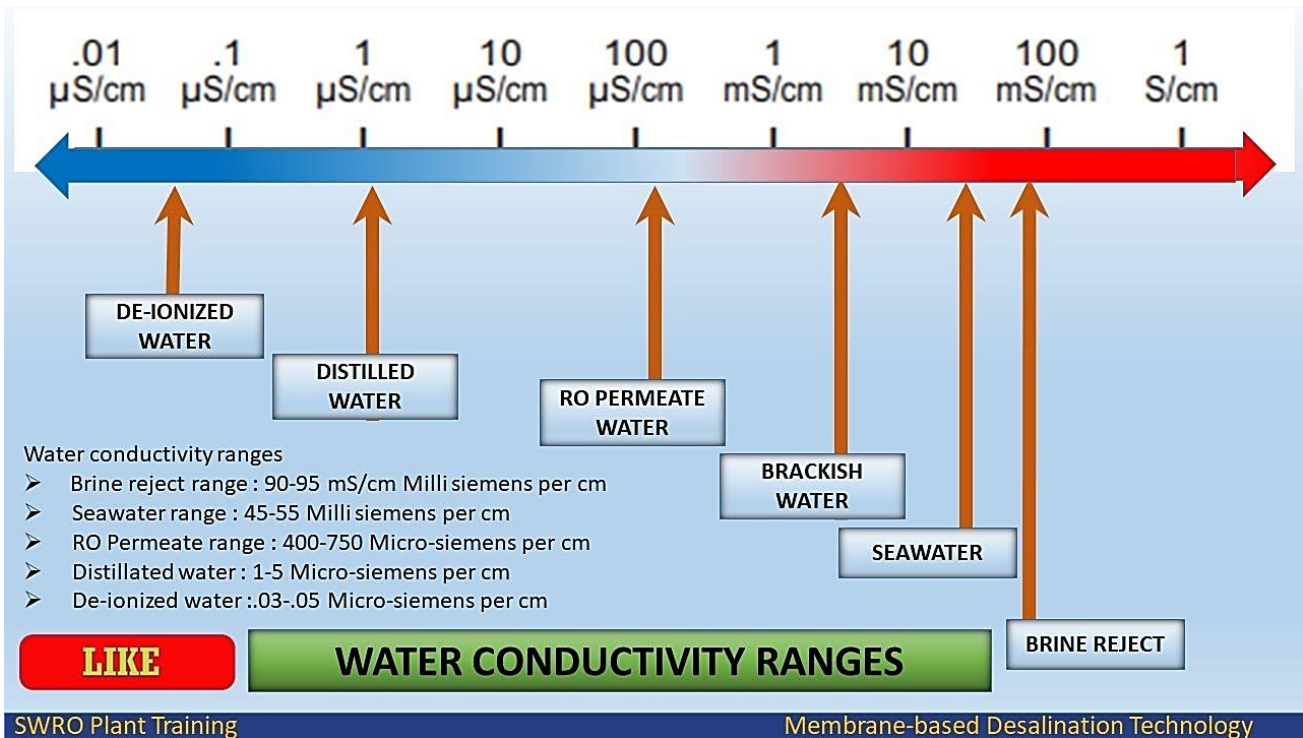
Therefore, careful mapping of these new ignition possibilities is essential to guarantee the safety of the boundaries between areas classified according to their actual risk category.

- **Underestimation of boundaries:** If not surveyed, transient sources can underestimate the true extent of classified zones.
- **Detailed mapping:** It is necessary to identify and precisely localise all possible sources in order to properly design protection.

3.1. MAIN ENVIRONMENTAL FACTORS THAT CAN INCREASE THE RISK OF ELECTRICAL AND ELECTROMAGNETIC INTERFERENCE IN INDUSTRIAL INSTALLATIONS

Various environmental factors can influence the level of risk of electrical and electromagnetic interference in industrial installations if they are not properly taken into account in protection projects.

1. **Proximity to the sea on offshore platforms** - High humidity and salinity facilitate ionization of the atmosphere and soil conductivity, amplifying electrostatic inductions. High humidity and salinity facilitate the ionization of the atmosphere and soil conductivity in different ways:
 - a) Water and dissolved salts make the air and soil more conductive, i.e. they increase the mobility of ions and electrons. This facilitates the propagation of electrical charges.
 - b) In the presence of humidity, small particles of dust in the air start to contain a thin film of water around them. This ionised film makes the particles conductive.
 - c) Water droplets or salt crystals in the atmosphere serve as preferred ionisation sites. These are regions where electric charges concentrate more easily, generating electrostatic fields.
 - d) In the soil, water and salts form an electrolyte that allows the free migration of positive and negative ions under the influence of an electric field.
 - e) Wetter areas act as preferential conductors in the ground, guiding lateral currents to structures or equipment.
 - f) In structures such as platforms, the humidity in the atmosphere increases surface conductivity, facilitating the accumulation and discharge of loads.



Thus, the presence of water and salts in the atmosphere and soil makes the medium more prone to ionization and the conduction of static currents.

2. **Frequent rainfall** - significantly increases the humidity of both the air and the soil in a region. This high humidity facilitates the occurrence of transient electrical disturbances such as lightning strikes. This is because humid air and soggy soil become more conductive, allowing electrostatic charges to propagate easily.
3. **Fog/low clouds** - These phenomena reduce the natural dissipation rate of static charges accumulated in the air, increasing their lifespan, and increasing the risk of discharges.
4. **Strong winds** - These can carry conductive dust particles through the atmosphere, which increases the risk of small, localized discharges due to the **corona effect*** on equipment protrusions or edges.
5. **High temperatures** - reduce the resistivity of the soil and the dielectric strength of the air, making these media more conducive to conduction and ionization, respectively. This facilitates the occurrence of electrical arcs.
6. **Rough terrain** - makes it difficult to ground and equipotentialise properly, generating voltage points that can cause equipment failures.
7. **Nearby vegetation** - Trees serve as a central point for loading and unloading.
8. **Nearby buildings/structures** - Can induce external electromagnetic fields in electrical circuits.

9. **Nearby industrial activities** - Nearby industrial activities can increase the risk of electrical interference in another installation as follows:
- ✓ Electric generators: These can induce noise and transient pulses that propagate through the ground or via overhead conductors to other areas.
 - ✓ Electric motors in machinery: When in operation, they can generate radio frequency electromagnetic interference due to the frequency inverter effect.
 - ✓ Electric transmission lines: If nearby, high-voltage overhead lines are potential sources of very energetic transient induction.
 - ✓ Industrial communication systems: Equipment such as radios, radar aerials and microwaves induce electromagnetic fields that can trigger receiving equipment.
 - ✓ Large electrical loads consumed: Substations or factories with high consumption can influence the voltages on neighbouring circuits during load variations.
 - ✓ Electrical maintenance: Small faults or arcs in nearby repairs can generate transients capable of propagating.
 - ✓ Dust and particle emissions: Can lead to corona effect discharges in equipment in other nearby areas.

3.2. WHAT IS THE CORONA EFFECT?

The corona effect is a physical phenomenon where small electrical discharges occur on the surface of conductors energised at high voltages, especially in areas with sharp geometries or difficult access, such as confined spaces.

This is because in these regions the electric field strength is greater than in the rest of the conductor. When a certain threshold is exceeded, the air around the conductors starts to ionise, generating small surface discharges in the shape of a corona (hence the name corona).

These discharges generally occur at voltages above **10 kV** and start from protuberances, wires, sharp edges, or areas with dirt deposits. They consume power and can produce ozone, nitrogen oxides and other gases, as well as ultrasonic noise.

The corona effect also releases charged particles that can settle on insulators and pollute them or spread through the air in the form of conductive aerosols. In winds, these particles can travel over long distances.

In environments with large stations or transmission lines, the corona effect can induce electrical and electromagnetic interference in nearby equipment, as well as degrading the system over time through erosion. This is due to the flame potential generated by the discharges.

Therefore, careful design and maintenance of these areas is essential to avoid the appearance of the corona effect and its consequences.

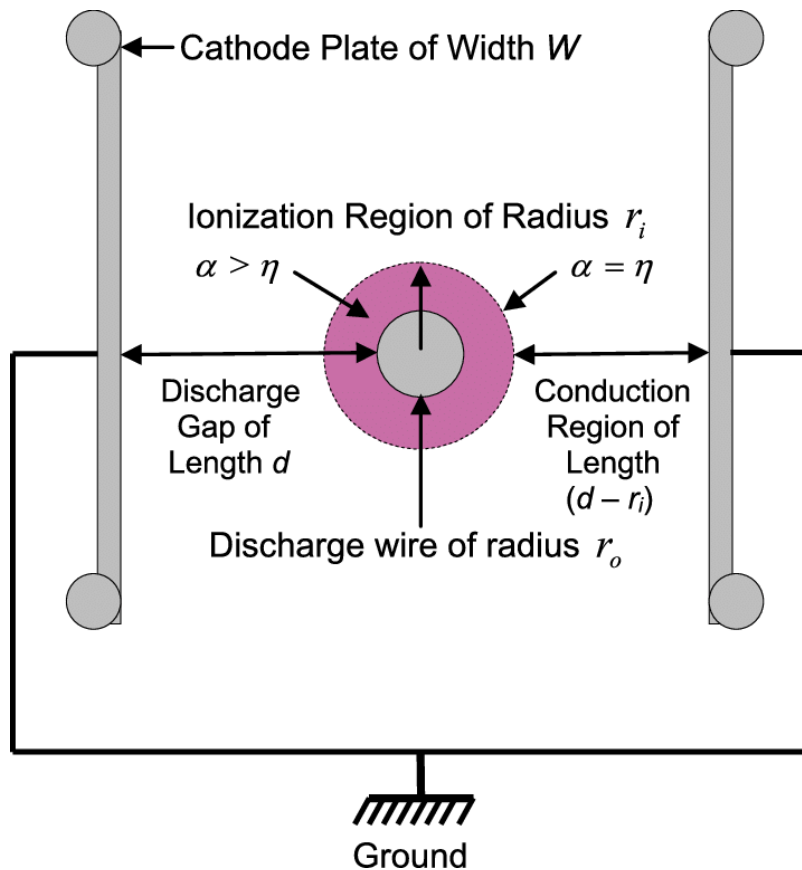
The main negative effects of the corona effect on electrical systems are:

- **Power losses:** Surface discharges consume electrical energy, reducing the efficiency of the system.
- **Erosion of materials:** The corrosive action of gases and particles generated by the corona effect causes premature wear of conductors, insulators, and structures.
- **Premature ageing:** The deterioration of materials due to corona erosion significantly reduces the useful life of equipment.
- **Noise and interference:** The ultrasonic hum and electromagnetic fields generated can interfere with communication systems, radars, among others.
- **Tripping circuit-breakers:** The local increase in the electric field induces leakage currents that can trigger false alarms.
- **Insulator pollution:** Deposits of particles released by the corona reduce the dielectric strength of insulators.
- **Partial discharges:** When severe, the corona effect can lead to electrical discharges that develop into insulation failures.
- **Risk of failure:** Promotes premature ageing which can jeopardise the system's long-term reliability.

There are a number of technologies that can be applied to mitigate the effects of the corona effect in electrical systems:

- ✓ Careful geometrisation: Design conductors and insulators with a reduction in sharp points, edges, and sharp bends.
- ✓ Coatings: Apply semiconducting or conductive materials to critical areas, such as silicon, zinc or graphite, to even out the electric field.
- ✓ Guard rings: Install earthed rings around protrusions or areas with a high electric field.
- ✓ Compression oils: Use transformer oils in insulators that form a homogeneous fluid to equalise the electric field.
- ✓ Doped oils: Adding compounds to insulating oils capable of inhibiting air ionization such as silicon carbides.
- ✓ Partial discharge monitors: Detect the occurrence of the corona effect early in order to remedy faults in the protection.
- ✓ Noise filters: Equipment to eliminate noise and interference from the corona effect signal.
- ✓ Cleaning systems: Pneumatic and liquid for periodic removal of dirt and pollutants.

The combined use of these technologies helps to mitigate the formation and effects of the corona effect.



4. MAIN POTENTIAL SOURCES OF ELECTRICAL AND ELECTROMAGNETIC INTERFERENCE IN DETERMINING AREA CLASSIFICATION

- **Lightning strikes:** Lightning induces electrical and magnetic transients of high amplitudes and rapid variations. These can propagate through earthing and discharge protection systems to internal electrical circuits, inducing dangerous overvoltages capable of causing ignitions in unconsidered locations.
- **Electrical equipment:** Small insulation defects in motors, panels or circuit breakers, for example, may not be detected during inspections. However, under certain conditions, they can generate arcs or internal hot spots capable of causing ignitions that increase the limits of classified zones.
- **Electrical faults:** such as arcs in busbars, panels or motors generate transient fields of varying intensity and duration, depending on the fault point and circuit impedance.
- **High-voltage circuits:** Overhead transmission cables close to the site are also potential sources that can induce electromagnetic interference in the installation's circuits through unwanted coupling, underestimating the safety distance in relation to zone boundaries.

- **Communication systems:** Radio, radar and microwave signals can induce eddy currents in equipment, cables, and structures through the antenna effect, heating them above ignition points if not adequately protected and extending the risks beyond the planned limits. Radio, Wi-Fi, Bluetooth, and mobile phone signals operating at various frequencies induce eddy currents as described in IEC 60079-25.
- **Generators:** In emergencies, they are more susceptible to interference that can compromise their protection and induce shorts/overheating of the internal circuits, increasing the risk areas.
- **Wiring:** Poor design favours unwanted propagation of fields and induced currents between circuits in the installation, underestimating the real coverage of zones.
- **Metal structures/equipment:** They act as antennas conducting currents capable of causing discharges or heating in abnormal situations in unexpected places.
- **Machinery:** Rotary motors can also heat moving parts by induction and cause sparks/flashes in operation that extend the boundaries of the risk zones.
- **Offshore structures:** Proximity to the sea increases the risk of electrostatic induction due to the high humidity/salinity of the environment in non-projected areas.

In short, these phenomena need to be properly mapped and taken into account so as not to underestimate the classified zones.

5. REAL CASES

Reports of accidents in refineries, where explosions occurred due to sparks in motors induced by lightning strikes or heating of cables by electromagnetic waves, demonstrate how interference can lead to catastrophic events when underestimated in engineering projects.

1. **In 1985**, an explosion at the Duque de Caxias Refinery (Reduc) in Rio de Janeiro killed 18 people. An atmospheric discharge induced voltages that damaged an emergency generator, generating sparks that spread through a cloud of hydrogen and vapour, subsequently detonating a petrol tank.
2. **In 1993**, an explosion followed by a fire at the Paulínia Refinery (Replan) killed three workers and caused US\$2.5 million in damage. An electrical fault in a motor induced sparks in a cloud of acetone within the confines of a classified area, causing it to ignite.
3. **In 2003**, a fire at the Henrique Lage Refinery (Revap) in Guarujá started after a pipe burst near an electrical substation. The short-circuit induced overvoltages in nearby cables, which spread to the pipeline and caused the burning petrol to explode.
4. **In 2009**, an explosion at a petrochemical plant in the Netherlands killed two people after radio waves emitted by military radars heated communication cables about 1km away, causing hot spots capable of igniting solvent vapours inside a distillation tower.

5. **In 2001**, at the Presidente Getúlio Vargas Refinery (Repar), an electrical fault in an industrial motor set off sparks that ignited flammable vapours outside the safety specifications, causing an explosion with four fatalities.
6. **In 2006**, at the Mataripe Refinery (Rlam), an atmospheric discharge caused over-tensioning that damaged electrical equipment at the petrochemical plant, releasing toxic gases that poisoned 14 workers.
7. **In 2012**, a refinery in the USA suffered a fire when electromagnetic waves emitted by nearby military radars overheated underground cables almost 1 kilometre away, causing sparks to spread to fuel tanks.
8. **In 2015**, Shell's facilities in Canada were struck by lightning which damaged a transformer, causing a fire which consumed part of the distillation unit after inducing overvoltage in the control systems.
9. **In 2019**, at the Getúlio Vargas Refinery in Paraná, an electrical fault spread sparks that started a toxic gas leak, poisoning 12 workers before the problem was brought under control.
10. **In 2020**, in Malaysia, a refinery was partially destroyed after lightning struck the site and triggered electromagnetic waves that overheated gas-laden pipelines, causing explosions.
11. **In 2021**, in Singapore, storm surges damaged a refinery's control panels, releasing hydrogen that ignited, injuring two employees.
12. **In 2022**, in Saudi Arabia, lightning induced electrical sparks that spread through gas pipelines in a refinery, setting fire to fuel tanks and paralysing production for months.
13. **Recently**, in India, a fire broke out at a refinery after lightning transients damaged electrical cables near rotating equipment.

These accidents demonstrate how unmapped electrical interference can spread risks beyond the designed zones, with tragic consequences when engineering projects do not adequately consider this type of additional ignition source.

6. HOW TO QUANTIFY INTERFERENCE WHEN DETERMINING CLASSIFIED AREAS

To quantify electrical interference when determining classified areas, a number of approaches can be used:

- Mapping sources of interference: Survey of installations, equipment and systems in the vicinity that could induce electromagnetic fields or electrical transients. This makes it possible to quantify the scope of these external influences. In accordance with standards such as **IEC 61000-6-1** and **CISPR 11**.

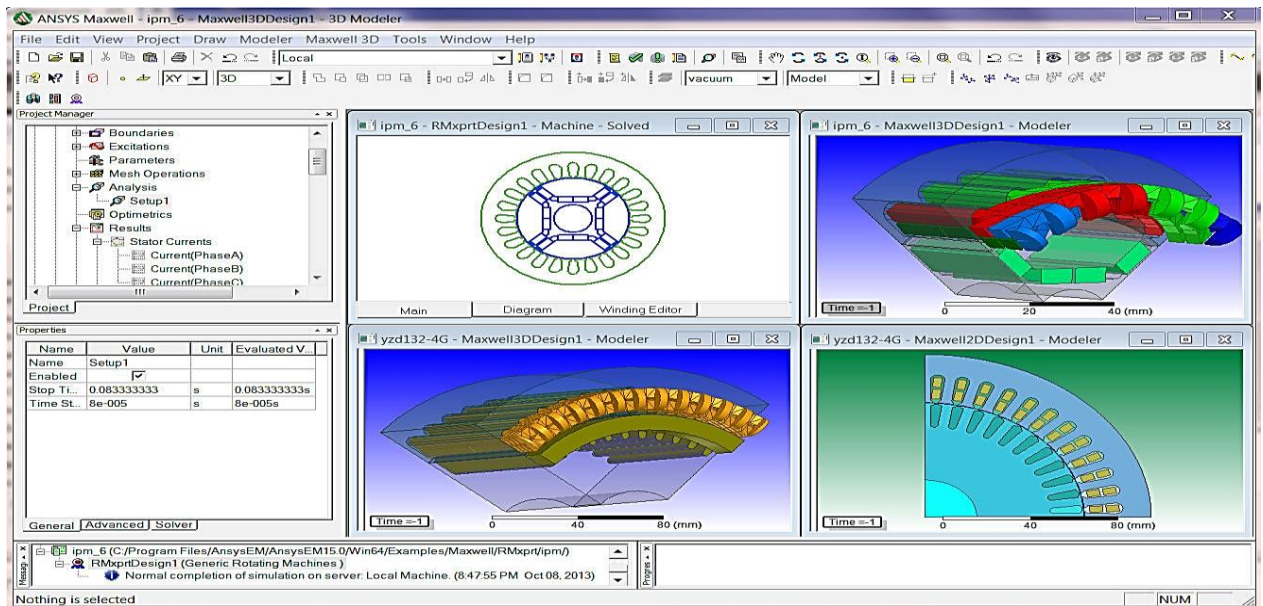
- Modelling and simulation: Using finite element software, the dispersion of the fields from the mapped sources is modelled. Computer simulation of the induced E/H fields for different fault or climate scenarios, using finite element software such as **COMSOL** or **ANSYS** on **3D** models of the plant.
- Equipment tests: Controlled simulations that determine maximum induction limits without jeopardising equipment safety. Provides data on tolerable interference levels and distances.
- Propagation calculations: Using simulation software, calculate the theoretical dispersion of fields and currents induced from the mapped sources, thus delimiting the possible "interference zones" in metres/kilometres. Calculation of the current induced in conductive meshes from the incident electric fields, using Maxwell's equations and estimating the impedance of the equivalent circuit.
- Online instrumentation: Setting up monitoring stations with electric/magnetic field sensors that quantify received interference levels in real time, **VALIDATING THE CALCULATED ZONES**.
- Statistical fault analysis: Evaluate possible correlations between incident records and detected interference peaks, to quantify impacts in terms of probability/risk.
- Standardisation of limit values: Defining maximum tolerable levels of induction to be respected in classified zones, based on the technical acquis quantified above.
- Prediction of the surface temperatures of equipment exposed to different electromagnetic field levels, considering the dielectric properties of the materials and thermal dissipation patterns.
- Calorimetry tests on representative samples subjected to different frequencies, powers and exposure times to validate the models.

This allows the size and scope of classified areas to be properly dimensioned.

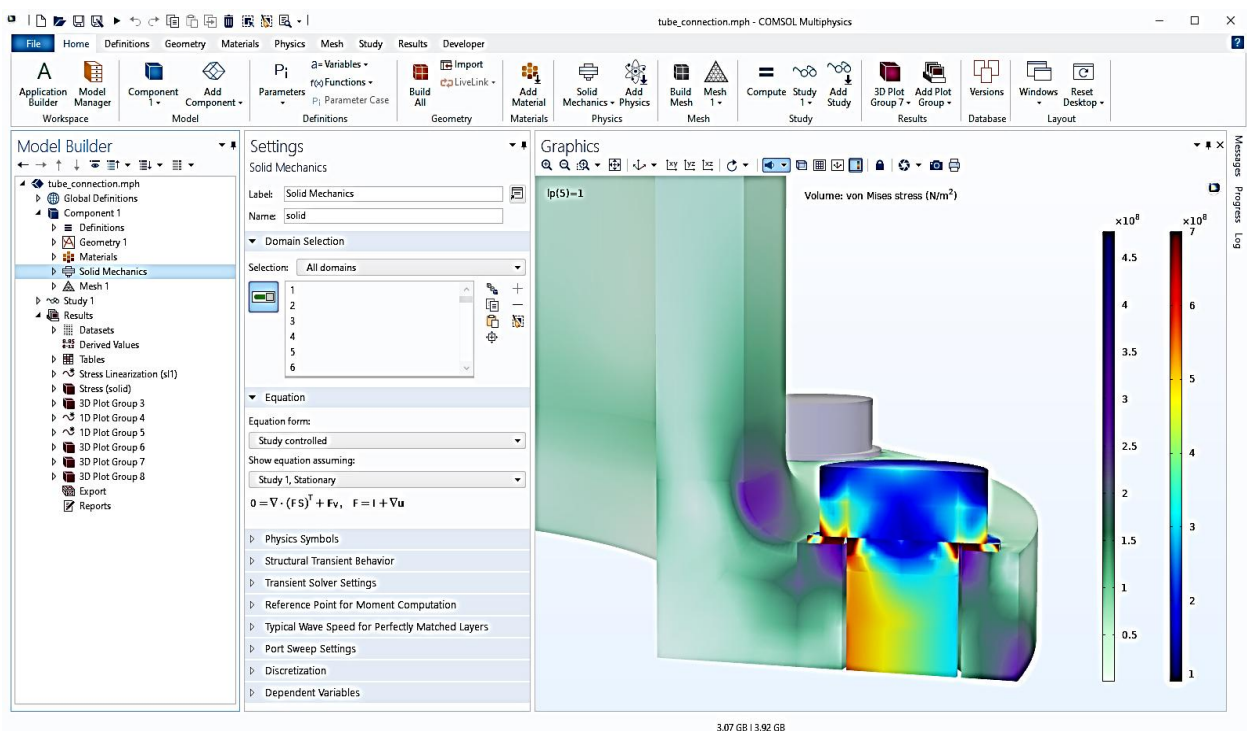
6.1. WHAT ARE THE MOST WIDELY USED SOFTWARE PACKAGES FOR MODELLING AND SIMULATING ELECTRICAL INTERFERENCE?

The main software used for modelling and simulating electrical interference in classified areas include:

- **ANSYS Maxwell**: One of the most widely used, it allows you to simulate electromagnetic propagation in time or frequency domains. Analyses the effects of shielding, cables, antennas, etc. Finite element electromagnetic simulation tool, ideal for analysing static and transient fields.



- COMSOL Multiphysics:** Powerful FEM-based simulator that allows electromagnetism to be coupled with other physical phenomena. It has modules dedicated to electromagnetism that can be coupled with fluids, thermals, fluid mechanics, etc. Useful for analysing propagation in complex systems.



- EMC Studio:** Developed by SEMCAD, it is a reference for EMC simulations following international standards. Also from SEMCAD, more specific for analysing interference in cabins, panels, and industrial electrical devices.

- **CST Studio Suite:** Software specialised in the design and analysis of antennas, cabins, and electromagnetic components. Focuses on antennas, radio communication structures and electromagnetic compatibility (EMC). Simulates inductions and electromagnetic fields.
- **Etap/Operation Technology:** PLC integrated with modules for simulating electrical networks and transients.
- **Matpower:** Open-source tool for modelling electrical power systems.
- **InCa3D:** Dedicated exclusively to modelling and simulating fire propagation using FEM.
- **Fluidyn-PANACHE:** Simulates the dispersion of toxic gases, vapours and explosions in large infrastructures.
- **FEKO:** Reference in high-frequency simulations and antennas integrated with CST and other software. Advanced tool for high-frequency electromagnetism, with extensive material databases. Analyses shielding in equipment and structures.
- **SEMCAD X:** Developed by SEMCAD, it is a reference in electromagnetic compatibility standards. Simulates EMC tests and trials.
- **CIDRAP HAZARDS:** Simulates the spread of fires, explosions, and the release of toxic gases, coupled with electromagnetic physics.

It is best to use two or more programmes in combination.

7. RISK MITIGATION RECOMMENDATIONS

Measures such as detailed mapping of interference sources, equipment testing, the use of cable shields and greater distancing from sensitive equipment must be adopted to ensure that all factors that could make a location a potential source of ignition are identified.

Detailed mapping of interference sources:

- Comprehensive survey using GIS or CAD systems of electromechanical systems such as motors, switchboards, transformers, overhead and underground electrical installations, antennas, radars, transmission lines, railways in the vicinity that could induce transient electromagnetic fields.
- Also consider natural interferences such as lightning.
- Geometrically delimit these "zones of influence" on risk propagation maps of the area, also taking into account the modelling of structures.

Equipment testing:

- Periodic tests on the electromagnetic induction limits of each piece of equipment through time and frequency domain simulations in EMC test chambers.
- Controlled simulations of electrical discharge transients to validate protection levels of MCBs, SPDs and earthing.

- Early replacement of items nearing the end of their useful life obtained through vulnerability analysis and inspection.

Use of armouring in cables and structures:

- Individual cable shields, the use of grounded metal conduits, armoured cabins and Faraday cages if there are high-level inductions.
- Effective grounding of the shields for rapid dissipation of currents through low-impedance conductors.

Greater distance from sensitive equipment:

- Respect the minimum distances established in standards such as NFPA77, IEC60079-14 and API500 for each level of protection.
- Avoid proximity to overhead and underground high/medium voltage systems, communication aerials, overhead ducts.

Constant monitoring:

- Portable equipment or fixed stations with electromagnetic probes and thermocouples for early detection of electrical transients, abnormal heating of components or variations in electromagnetic fields.
- Predictive maintenance and periodic reviews of protection items such as SPDs, earthing, MCBs and circuit breakers to ensure their integrity.
- Implementation of a complete lightning conductor system (SPDA) throughout the refinery area and its surroundings, with reaction via thermal vision, field detectors and ground loops.
- Use of transient limiting devices such as low-pass/high-pass filters, varistors, surge suppressors installed in sensitive electrical circuits such as programmable logic controllers (PLCs), motor drives and communication interfaces.
- Detailed design of electrical panels and switchboards taking into account transient overvoltages due to lightning strikes or manoeuvres with buried/air cables and the use of high resistance insulating material.
- Galvanic safety barriers between systems operating at nominally different voltages to prevent potential equalisation due to capacitive coupling.
- Control and instrumentation electrical circuits installed under pipes or tunnels that are duly shielded, using X-rays to detect damage.
- Thorough classification of sites and equipment according to API 500 and NFPA 499 standards, taking into account the degree of protection offered against explosions and electrical risks.

- Continuous revisions of the calculations and simulations of explosion propagation taking into account new sources detected or modifications implemented.
- Periodic field training with practical simulations to validate emergency protocols and safe area isolation procedures.
- Internal coordination with other nearby industries to monitor each other when areas of influence overlap.

Some other important actions:

- Periodic audits to continuously assess the efficiency of the measures implemented and identify possible bottlenecks.
- Online monitoring of the electrical and magnetic parameters of the systems through sensing and SCADA platforms, enabling rapid decision-making.
- Implementation of Asset Integrity Management software with fault prediction based on probabilistic models fed by sensors.
- Development of a preventive culture through a permanent awareness programme for all those involved.
- Hiring companies specialising in periodic Non-Destructive Inspections to assess the actual state of electrical installations.
- Partnerships with research institutions for the continuous development of innovative solutions customised for each environment.
- Carrying out simulations that replicate risk scenarios to validate actions in emergencies.
- Creation of technical reference documentation with procedures, standards, measurement records, etc.
- Compulsory insurance covering human, environmental and property damage resulting from any incidents.

The aim is to prevent accidents through a robust and evolving Electrical Risk Management programme.

8. MAIN SAFETY MEASURES USED TO MINIMISE THE RISK OF ELECTRICAL INTERFERENCE IN HAZARDOUS AREAS

The main safety measures used to minimise the risk of electrical interference in classified zones include:

- **Proper design and installation of lightning protection systems (SPDA)**

SPDAs are systems designed to protect structures and equipment from damage caused by atmospheric discharges. They consist of conductive devices that direct the discharge current towards the ground, dissipating it safely.

In hazardous areas, SPDAs are essential to protect equipment and installations that are sensitive to electric shocks. The systems must be designed in accordance with current regulations and installed by qualified professionals.

- **Use of a galvanic safety barrier between high-voltage circuits and classified areas**

Galvanic safety barriers are devices that prevent the passage of electric current between high-voltage circuits and hazardous areas. They are essential for protecting workers and the environment from the risk of electric shock.

Galvanic safety barriers can be made from a variety of materials, such as ceramic, glass or plastic. They must be sized according to the nominal voltage of the circuits involved and installed in accordance with current regulations.

- **Effective grounding of structures, equipment, and cables with low impedance**

Earthing is an essential measure to guarantee the electrical safety of any installation. In hazardous areas, earthing must be especially efficient, as the presence of flammable gases increases the risk of fires and explosions.

Earthing must be carried out using low-impedance copper cables connected to an effective earthing mesh. The earthing mesh must be sized according to the nominal voltage of the circuits involved and installed in accordance with current regulations.

- **Implementation of appropriate electrostatic designs for charge dissipation**

Electrostatic charges can cause fires and explosions in hazardous areas. It is therefore important to implement appropriate electrostatic designs to dissipate these charges safely.

Electrostatic projects must take into account the type of material used in the construction of structures and installations, the level of humidity in the environment and the presence of ignition sources. They must be implemented in accordance with current regulations.

- **Common shielding and armoring of cables, ducts, and panels against electromagnetic induction.**

Electromagnetic induction can cause electrical interference in sensitive equipment and installations. In classified areas, this interference can increase the risk of fires and explosions.

Shielding and common shielding are measures that can be adopted to protect equipment and installations against electromagnetic induction. Shielding consists of using conductive materials to wrap cables, ducts, and panels. Common shielding consists of electrically connecting all cables, ducts, and panels to each other.

- **Selection of intrinsically safe or explosion-proof electrical equipment**

Intrinsically safe or explosion-proof electrical equipment is designed to operate in classified zones without risk of fire or explosion.

Intrinsically safe equipment is designed to operate without generating sparks or electric arcs. Explosion-proof equipment is designed to withstand the explosion of gases without causing damage to its components.

- **Physical demarcation of classified areas with warning signs**

The physical demarcation of classified zones is important for alerting workers to the risks of fires and explosions. Classified zones must be demarcated with warning signs indicating the type of flammable gas present and the boundaries of the zone.

- **Periodic inspections of systems and components for early detection of defects**

Periodic inspections of electrical systems and components are essential to ensure the safety of any installation. In hazardous areas, these inspections must be carried out more frequently, as the risk of accidents is greater.

Inspections should be carried out by qualified professionals and should include checking all electrical components, including cables, equipment, protection systems and earthing.

- **Continuous monitoring of electrical parameters and over/under current protection**

Continuous monitoring of electrical parameters is important for detecting and correcting faults before they cause accidents. In hazardous areas, monitoring should include checking parameters such as voltage, current, temperature and humidity.

Monitoring can be carried out using automatic systems or manually. Automatic systems are more efficient because they allow faults to be detected in real time.

- **Operator training on risks and safety procedures**

Training operators in safety risks and procedures is essential to ensure safety. Some important points about operator training in relation to electrical and electromagnetic interference and hazardous areas:

- Understanding of the main interference mechanisms and their sources, such as capacitive coupling, magnetic induction, electromagnetic radiation, etc.
- Knowledge of applicable standards and legislation, in particular IEC 60079 and its specifications on heating, overvoltage and equipment protection.
- The importance of correctly mapping these interferences and using them in modelling and delimiting risk zones.
- Visual identification procedures and measurement of electrical and magnetic parameters with portable equipment.

- Signposting and appropriate isolation of areas in the event of readings outside the established standards.
- Safe actions to be taken during possible occurrences such as lightning strikes.
- Location and significance of the signposting of the different classified areas.
- Specific operating restrictions for each zone regarding equipment, tools, and energy release.
- Records and documentation required to maintain safety.
- Periodic refresher training to keep up to date with new standards, plant changes and practical simulations.

9. CONCLUSION

Throughout this discussion, various relevant aspects of the identification and quantification of electrical and electromagnetic interference in classified areas of the oil and gas industry have been addressed.

To summarise, the correct quantification of electrical interference is fundamental for the accurate determination of classified areas and, therefore, for the safe implementation of projects and operations in this industry. A complete and continuous risk management programme is needed to adequately deal with this challenge.

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