# NEW HV/LV TRANSFORMER SUBSTATION WITHIN A BUILDING INTENDED FOR OTHER NON ELECTRICAL USES WITH ADVANCED FUNCTIONALITIES

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## *ABSTRACT*

*Different standards and requirements exist for high-voltage/low-voltage (HV/LV) distribution substations and we usually think in terms of concrete or metallic substations, either walk-in type or underground, but sometimes they are located within a building intended for other non-electrical uses. For these kinds of substations the same requirements as prefabricated ones should be fulfilled in terms of safety, environment and smart grid operation and should be combined with existing building regulations.*

## INTRODUCTION

The lack of space in urban environments, leads to place HV/LV distribution substations within a building intended for other non-electrical uses (figure 1). Traditionally these are constructed by installing the main electrical components (high voltage switchgear, distribution transformer and low-voltage distribution panel) within a closed electrical operating area, usually in a room within a building. These HV/LV distribution substations should comply with requirements defined by utilities in type projects, local legislation, standards (for example Eurocode EN 1990) and regulations. All these requirements should be complied with each installation conditions.

Figure 1

This paper summarizes the main requirements of such HV/LV distribution substations from three points of view: safety, environment and smart grid exploitation.
In addition, it highlights the suitability of a specific solution of CEADS (Compact Equipment Assembly for Distribution Substation), due to the specific requirements and new features demanded.

## SAFETY REQUIREMENTS

### Internal arc requirements

An internal arc fault can occur in electrical equipment when operating conditions for which the equipment has been designed are not met or a failure occurs, caused for example by improper installation or manipulation. The guide in clause 8.104 of the IEC 62271-202 standard indicates the most common origins of internal arc faults and how to reduce their chance of occurrence.

As these HV/LV distribution substations are located within a building for other non electrical uses or in spaces of unrestricted access, they must comply with the requirements of internal arc test, as is indicated in local regulations, for example. in ITC-RAT-16 of Spanish Regulation for HV Electrical Installations.

Figure 2

There are several international standards specifying internal arc classification and testing such as IEC 62271-200 (metal-enclosed switchgear for rated voltages above 1 kV and up to and including 52 kV), IEC 62271-201 (solid-insulation enclosed switchgear for rated voltages above 1 kV and up to and including 52 kV), IEC 62271-202 (high-voltage low-voltage pre-fabricated substation), IEC 62271-212 (Compact Equipment Assembly for Distribution Substation) and IEC/TR 61641 (guide for testing enclosed low-voltage switchgear and controlgear assemblies under conditions of arcing due to internal faults). They include several classifications according to different accessibilities, short circuit current and arc duration.

The internal arc classification means that main elements

and all HV compartments must withstand internal arc test and all defined criteria to assess possible injury to persons in proximity. The installation condition must respect test conditions, in order to ensure the right behaviour.

So, an IAC (Internal Arc Classified) equipment is considered a safe equipment when installed according to manufacturer´s instructions, that previously have been successfully tested.

## Fire safety requirements

This section describes the critical factors to evaluate HV/LV distribution substations performance in case of fire, and requirements to be fulfilled in terms of safety, security of the building structure and fire propagation.

### Fire resistance of building structure

Firstly, mandatory requirements are reviewed in terms of legislation. Secondly, the intrinsic risks for this type of HV/LV distribution substations are assessed taking into account specific requirements not detailed in the standards, but critical to correctly classify the risks. Finally, the building structure requirements are analyzed according to real fire tests performed.

### Mandatory regulations

The rooms for HV/LV distribution substations within a building intended for other non electrical uses, must comply with specific requirements and local legislation. For example, in Spain, due to ITC-RAT-14 of Spanish Regulation, these installations must comply with the Technical Building Code – Basic Document – Fire Safety (CTE-DB-SI). Specific aspects not indicated in this regulation of HV Electrical Installations are construction material characteristics, fire resistance of partitioning structures and evacuation of persons.

Basically the CTE-DB-SI classifies the HV/LV distribution substation risk depending on next parameters: power of each transformer unit and total installation power, and fire point temperature of transformer dielectric liquid (see table 1).

| CLASSIFICATION | | Total installed power $P_T$ and each transformer $P_u$. | | |
|---|---|---|---|---|
| | | $P_T \leq$ 2520 KVA<br>$P_u \leq$ 630KVA | 2520 KVA< $P_T \leq$ 4000KVA<br>630KVA< $P_u \leq$ 1000KVA | $P_T >$ 4000KVA<br>$P_u >$ 1000KVA |
| Fire point T° dielectric liquid | Dry or $_T >$ 300ºC | LOW RISK | LOW RISK | LOW RISK |
| | $_T \leq$ 300ºC | LOW RISK | MEDIUM RISK | HIGH RISK |

Table 1

Depending on the HV/LV distribution substation risk obtained, several requirements are asked in CTE-DB-SI (Sections SI1 to SI6). For example, in Section SI6, minimum fire resistance of building structure is required, as shown in table 2.

| Special conditions risk areas integrated into buildings | | | |
|---|---|---|---|
| *Characteristic* | *Low risk* | *Medium risk* | *High risk* |
| Fire resistance of the bearing structure | R 90 | R 120 | R 180 |
| Fire resistance of the walls and ceilings separating the area from the rest of the building | EI 90 | EI 120 | EI 180 |

Table 2

Other requirements, such as fire detection and extinguishing systems, for special fire risk areas integrated into buildings are indicated in section SI 4.

### Other regulations that may apply

Beyond the standards, there are other technical regulations, whose applicability is not clear depending on location or building use, but may be useful to assess in more detail the risk of HV/LV distribution substation from a point of view of weighted fire load and fire damage, caused by accidental fire. For example, Technical Application Regulation of RSCIEI (Spanish fire safety regulation in industrial buildings) could be used.

Based on this Regulation, it is possible to classify the risk level of an installation taking into account the heating value ($q_i$) of all existing materials included in the HV/LV distribution substation (low-voltage distribution panel, high-voltage switchgear, interconnections and distribution transformer dielectric coolant).

The result obtained with this Regulation seems more accurate than the one obtained with CTE-DB-SI, where only the transformer insulation coolant technology is taken into account.

The heating value ($q_i$) of all HV/LV distribution substation materials and occupied area, are introduced into the formula below in order to obtain the fire load density ($Q_s$):

$$Q_s = \frac{\sum_i^i G_i \, q_i \, C_i}{A} R_a \; (MJ/m^2)$$

*$Q_S$ = fire load density, weighted with sector or fire area, in $MJ/m^2$.*
*$G_i$ = mass, in kg, of each one of the fuels (i) that exist in the sector or fire area (including combustible building materials).*
*$q_i$ = heating value in MJ/kg, of each of the combustible materials (i) that exist in the fire sector area.*
*$C_i$ = dimensionless coefficient which weights the degree of harmfulness (combustibility) of each of the fuels (i) that exist in the fire sector area.*
*$R_a$ = dimensionless coefficient that corrects the danger degree (activation) inherent in industrial activity initiated in the fire sector area, production, assembly, processing, repair, storage, etc. When there are several activities in the same sector, it will be taken as a risk factor activation ($R_a$) the one of the activity with bigger risk of activation, as long as such activity occupy at least 10 percent of the surface of the fire sector area.*
*A = constructed fire sector area or occupied surface of fire area, in $m^2$.*

Once the fire load density ($Q_s$) is calculated, it is possible to classify the risk level according to table 3:

| Intrinsic risk level | | Fire charge density weighted and corrected | |
|---|---|---|---|
| | | Mcal/m² | MJ/m² |
| Low | 1 | $Q_s \leq 100$ | $Q_s \leq 425$ |
| | 2 | $100 < Q_s \leq 200$ | $425 < Q_s \leq 850$ |
| Medium | 3 | $200 < Q_s \leq 300$ | $850 < Q_s \leq 1275$ |
| | 4 | $300 < Q_s \leq 400$ | $1275 < Q_s \leq 1700$ |
| | 5 | $400 < Q_s \leq 800$ | $1700 < Q_s \leq 3400$ |
| High | 6 | $800 < Q_s \leq 1600$ | $3400 < Q_s \leq 6800$ |
| | 7 | $1600 < Q_s \leq 3200$ | $6800 < Q_s \leq 13600$ |
| | 8 | $3200 < Q_s$ | $13600 < Q_s$ |

Table 3

The fire load density have been studied for different HV/LV distribution substations, obtaining the following conclusions:

- The transformer dielectric fluid represents approximately 90% of the total fire load density, as table 4 shows. According to this study, this percentage varies slightly, depending on the type of dielectric coolant.

| Transformer fluid | Kg | $q_s$ Total | $q_s$ Dielectric fluid | % $q_s$ Total |
|---|---|---|---|---|
| Mineral oil | 396 | 17.087 | 15.759 | 92 % |
| Silicone oil | 405 | 11.340 | 10.012 | 88 % |
| Natural ester | 396 | 15.664 | 14.336 | 92 % |

Table 4

- The total amount of transformer dielectric coolant is a very important factor for the total fire load. This means that fire load density and therefore the risk, is different if we compare grouped or associated CEADS, with integrated ones. This comparison, for example, with mineral oil as transformer coolant, is shown in table 5:

| CEADS type | Kg | $q_s$ Diel. (MJ) | Area (m²) | $Q_s$ | Risk |
|---|---|---|---|---|---|
| Associated Grouped | 396 | 17.087 | 3,9 | 6.727 | HIGH 6 |
| Integrated | 823 | 39.104 | 3,12 | 18.800 | HIGH 8 |

Table 5

It can be concluded that integrated CEADS has a higher risk level than associated or grouped type, due to its higher fire load.

So, the fire resistance of building structure requirements are much higher for integrated CEADS type.

**Real fire load tests**

To verify the conclusions drawn above, **Ormazabal** has performed real tests to characterize the fire load and enclosure fire resistance of a HV/LV distribution substation.

With the method developed by S. H. Ingberg, it is possible to estimate the fire resistance of the structure based on thermal loads equivalents in wood weight. Only the fire load criterion is taken in consideration.

Applying this test method in a HV/LV distribution substation of **Ormazabal**, it is obtained a fire load equivalent to a time of 21 minutes in the normalized curve (EN 1363-1). See figure 4.

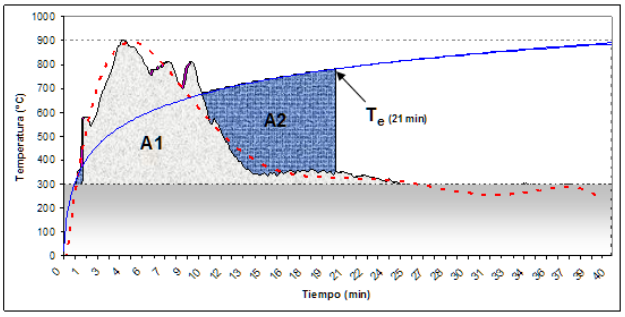


Figure 4: Calculation of the equivalent time ($T_e$) according to the Ingberg method.

This time obtained with real tests, according to the fire resistance classification system, means a necessity of EI30 class enclosure.

According to CTE-DB-SI regulation, in a less onerous scenario, the fire resistance required for the building structure is EI90.

So, it can be concluded that the intrinsic risk of HV/LV distribution substation, proposed from **Ormazabal**, is even lower than the requirements set out in the regulations.

**Firewall extinguishing system**

One of the risks in a HV/LV distribution substation is the possible fire of dielectric liquid used in the distribution transformer.

To minimize this risk and the possible damages, it is important firstly; to contain the eventual oil spill within a tank, in order to not spread it, even on fire, to the facilities nearby. The tank must be oil tight and capable to contain the total amount of oil.

Secondly, it is necessary to have a firewall extinguishing system over this tank to cool the fire and cause its rapid and natural extinxtion.

One option for a firewall extinguishing system are pebble beds designed to be effective in order to reduce the oil temperature below its ignition temperature, around 165 – 180 ºC, and to prevent possible reignitions.

The use of CEADS with reduced quantity and less-flammable liquids (high fire point liquids) plus the use of an oil collecting pit with a fire extinguishing system, reduces drastically the fire hazard present in the installation.

## ENVIRONMENTAL REQUIREMENTS

### Electromagnetic fields requirements

These HV/LV distribution substations are usually near to residential, commercial or business office areas, so its design must also be focused on reducing the electromagnetic fields (EMC) generated on its surroundings, according to local legislation and related standards.
In addition, emissions should be checked against the limits established in the recommendation of the Council of the European Union of 12 July 1999 (D.O.C.E. of 30-7-99), prior to commissioning of the HV/LV distribution substation.

The electromagnetic fields depend, amongst other factors, on the HV/LV distribution substation design as well as on the utility type project. Other very important factors are the arrangement of incoming and outgoing cables, transformer and HV/LV loads, etc.

Due to these factors, it is difficult to be certain about the emission of electromagnetic fields generated by these HV/LV distribution substations, if it is composed of additional elements which do not ensure repetitive installations under the same conditions.

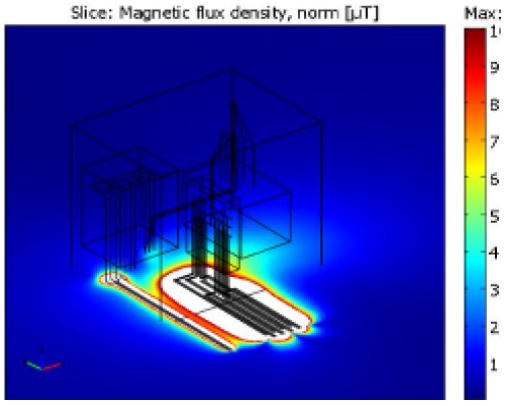


Figure 5

This could be solved through the design of a specific prefabricated CEADS solution (type tested according to EN/TR 62271-208:2009 and type project, as well as manufactured and routine tested in the factory as a unit) to ensure the repetitiveness of installation conditions.

### Noise and vibration requirements

HV/LV distribution substations within a building intended for other non-electrical uses must comply with the requirements defined in regulations and local legislation. In Spain, these are the Noise Law 37/2003 and Technical Building Code – Basic Document – Noise Protection (CTE-DB-HR). The principal requirements are:

- The closed electrical operating area within a building intended for other non electrical uses must comply with DnTA ≥ 55 dB(A) (airborne sound insulation) and Lnw ≤ 60 dB (impact sound insulation)
- The noise perceived by a user of the building where the HV/LV distribution substation is installed must be lower than Ln = 30 dB(A), in the most restrictive case at night.
- The emission or noise level to the outside at night should be lower than Ln = 45 dB(A), in the most restrictive case.

In annex B of standard IEC 62271-202, the test conditions to evaluate the noise attenuation effect of the HV/LV distribution pre-fabricated substation enclosure are indicated. These tests seem more suitable for substations with enclosure because they are repetitive as they are delivered as turnkey solutions. In contrast, the noise requirements of HV/LV distribution substations within a building intended for other non-electrical uses are more demanding.

In any case, for these HV/LV distribution substations, a predictive study of CEADS noise characterization can be done according to standard ISO 9613-2. With this simulation, it is possible to define an acoustic map as illustrated in figure 6. This acoustic map would make possible to adopt, if necessary, additional measures in order to fulfil the noise requirements defined by local regulations.

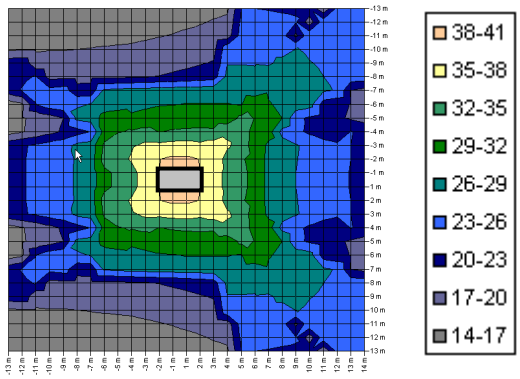


Figure 6: Example of sound emitting-boundary (4m high) for a pfu-4 type 400 kVA transformer substation.

In addition, these CEADS within a building intended for other non-electrical uses must incorporate a system that absorbs the vibrations produced during its operation. An attenuation of anti-vibration system at excitation frequency is recommended in order to limit vibration transmission.

### Heating and ventilation requirements

These HV/LV distribution substations could have

different installation conditions and different electrical components, depending on each project, and as they have no enclosure, the temperature rise test of IEC 62271-202 would not be applicable.

However, in order to ensure correct operation and to avoid a premature aging of equipment, it is important to test these HV/LV distribution substations according to the same criteria of IEC 62271-202 standard, but where the building intended for other non-electrical uses applications would be the enclosure, reproducing the same installation conditions as indicated in type projects.
So, these HV/LV distribution substations should be correctly designed and temperature rise tested according to IEC 62271-202, to ensure the right behaviour in all installation conditions.

## SMART GRID REQUIREMENTS

The HV/LV distribution substation must be ready to be integrated in smart grids. They should offer continuity of service, low failure rate, self-diagnostic capability, monitoring and automation of low-voltage network, intelligent data concentrator, low-voltage monitoring (energy balancing, automatic phase detection, low-voltage phase mapping, etc), monitoring and automation of high-voltage network.

This involves the integration of new requirements such as:

- Arrangement for smart distribution management unit.
- Low-voltage network data concentrator, low-voltage monitoring and communications devices.
- High-voltage network supervision and automation.
- Full interoperability with meters and back-end management systems.
- Low-voltage network monitoring (three phase voltages, currents, active, reactive and apparent power, power factor, hourly and daily load profiles, fuse blowing detection, unbalanced lines detection, overheating and online data metering, etc).
- Segregated access to high-voltage, low-voltage, low-voltage smart distribution management and meter collecting data depending on maintenance staff training.
- Ready for communication.

## CONCLUSIONS

Closed electrical operating area within a building intended for other non-electrical uses is a very sensitive installation. The design of this type of substation must take into account specific requirements in terms of safety, environment and the smart grid.

Compact Equipment Assembly for Distribution Substations (CEADS) must have a specific and standardized design to fulfil all requirements described.
This could be achieved with an integrated design of all elements in a specific enclosure with a fire resistance (integrity and insulation) adapted to the tested fire load.
This solution must be IAC, temperature rise, EMC and noise tested as a pre-fabricated unit, with manufacturing and routine tests performed in factory, to achieve the desired repetition and reliability levels.
This offers a solution with high added value and smart grid readiness which reduces the cost and complexity of such projects for utilities, avoiding the study and validation of different installations one by one.

Figure 7

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