
DISTRIBUTION SOLUTIONS

Technical Application Papers No. 20

Installation and operating principles for medium voltage switchgear



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1. Introduction

Medium voltage switchgear has now achieved an extremely high level of reliability. Stringent regulations and experience acquired with millions of panels installed world-wide in many different conditions and difficult locations have ensured that operating faults are rare events in percentage terms, often due to negligent maintenance and failure to comply with the requirements.

The purpose of this guide book is to address the main issues concerning the installation site, provide end users with indications as to what sort of information manufacturers require, and the measures to adopt to ensure the switchgear continues to function correctly over time.



Figure 1: example of a medium voltage substation with UniSec switchgear

2. Relevant regulations

2.1 Normal service conditions

The regulation governing medium voltage switchgear is IEC 62271-200, High-voltage switchgear and controlgear, Part 200: A.C. metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV. Regarding non-specific aspects involving switchgear, this Standard often refers to the general Standard for medium voltage switchgear and controlgear, i.e. IEC 62271-1: 2017, High voltage switchgear and controlgear Part 1: Common specifications for alternating current switchgear and controlgear.

Sub-clause 9.1 of IEC 62271-200 (Information to be given with enquiries, tenders and orders) specifies that enquirers requesting an offer or placing an order for metal-enclosed switchgear and controlgear, should not only provide the main electrical characteristics of the system but also the service conditions if different from standard, i.e.

- minimum and maximum ambient air temperature;
- unusual exposure to vapour;
- moisture;
- smoke/fumes;
- explosive gases;
- excessive dust or salt;
- thermal radiation;
- the risk of earth tremors or other vibrations due to causes external to the equipment to be delivered.

In short, any condition deviating from the normal service conditions or affecting the satisfactory operation of the equipment.

The normal service conditions are specified in art. 4 of IEC 62271-1, which establishes the following limits for indoor switchgear:

- The ambient air temperature must not exceed 40 °C and its average value, measured over a 24 h period, must not exceed 35 °C. The minimum ambient air temperature is: -5 °C.

- The effect of solar radiation need not be taken into account.
- The altitude must not exceed 1000 m
- The ambient air must be free from significant pollution by dust, smoke/fumes, salts, corrosive or inflammable gases or vapours.
- The humidity conditions must be the following:
 - the average relative humidity value measured over a period of 24 hours must not exceed 95%;
 - the average water vapour pressure value measured over a period of 24 hours must not exceed 2.2 kPa;
 - the average relative humidity value measured over a period of 1 month must not exceed 90%;
 - the average water vapour pressure value measured over a period of 1 month must not exceed 1.8 kPa.

Condensation may occasionally form in these conditions owing to sharp temperature changes in very damp weather. In order to withstand the effects of high humidity levels and condensation, switchgear and controlgear designed and tested for such conditions should be used. These effects can be extremely critical and include insulation failure and corrosion of metal parts. Condensation can be prevented from forming by adopting certain expedients when constructing buildings, by installing ventilation and heating systems in the rooms or using dehumidifiers.

- Vibrations due to causes external to the switchgear and earth tremors are insignificant compared to those caused by the device's standard functioning. By definition, such conditions require the absence of significant earthquake risk.

Without specific instructions from the user, the manufacturer may suppose that there is no such risk.

2. Relevant regulations

2.2 Special service conditions

IEC 62271-1 also establishes special service conditions for which it provides standard levels. The following conditions are analyzed:

- Altitude exceeding 1000 m: the rated insulation withstand level must be multiplied by factor K_a according to the following formula, shown in IEC 60071-2, chapter 4:

$$K_a = e^{m(H/8150)}$$

where:

- H is the altitude in meters;
- m is a constant and equals to 1 for short-time withstand voltage at power frequency and for lightning impulse.

Precautions need not be taken for auxiliary apparatus up to 2000 m. For higher altitudes the reference is Standard IEC 60664-1.

- Pollution: if the switchgear must be installed in a polluted environment, the pollution level should be specified when higher than "very light", which is the normal one according to IEC/TS 60815-1. Levels to be specified are: "light", "medium", "heavy" and "very heavy". For indoor installation, please consult IEC/ TS 62271-304 standards.
- Temperature and humidity: the following ranges are to be preferred for indoor installations where the temperature differs considerably from the standard service conditions:
 - 25 °C and +40 °C for cold climates;
 - 15°C e +40°C for moderate climates.
 The Standard underscores how in certain regions, sudden temperature and/or atmospheric pressure changes may occur with the formation of condensation indoors when warm, humid wind is also present. In tropical indoor conditions, the average relative humidity value measured over a period of 24 hours can reach as much as 98%.

- Anomalous vibrations, tremors, oscillations: wherever there are unusual conditions, the user must specify the requirements for the particular application required. The user must specify the severity level as indicated in IEC/TS 62271-210 if the apparatus must be installed in an earthquake zone.
- Wind speed: the Standard mentions that very strong wind may be present in certain regions and must be specified by the user. In actual fact, these requirements apply to outdoor switchgear and controlgear.
- Other parameters: consult IEC 60721 Part 1, Part 2 and Part 3, when special environmental conditions are predominant in the place in which the switchgear and controlgear are to be installed.

Standard IEC 62271-200 specifies that metal-clad switchgear and controlgear designed for use in harsher conditions than those of standard service must be classified in "design class" 1 or 2 according to IEC/TS 62271-304, so as to demonstrate their ability to withstand such severe conditions.

2.3 Condensation and pollution

As mentioned in the previous chapter, for installation in polluted environments, reference can be made to IEC/TS 62271-304, High voltage switchgear and controlgear - Part 304 Design classes for indoor enclosed switchgear and controlgear for rated voltages above 1 kV up to and including 52 kV to be used in severe climatic conditions.

This Standard must be used if the service conditions are harsher than those envisaged by Standards IEC 62271-1 and 62271-200 for condensation and pollution, but is not applicable to corrosion phenomena.

The Standard establishes the following classes of service conditions:

| | | |
|----------------------|---|--|
| C₀ | Condensation does not normally occur (not more than twice a year) | - Temperature and humidity controlled environment. - The building or room provides protection from daily variations of outside climate. |
| C_L | Non-frequent condensation (not more than twice a month) | - Location without temperature and humidity control. - The building or room provides protection from daily variations of outside climate but condensation cannot be excluded. |
| C_H | Frequent condensation (more than twice a month) | - Location without temperature and humidity control. - The building or room provides only minimal protection from daily variations of outside climate, so that frequent condensation may occur. |
| P_L | Light pollution | - Same as established by IEC 62271-1, i.e. not significantly polluted by dust, corrosive and/or inflammable gas, smoke/fumes, vapours or salt. - Precautions have been taken to curb pollution in the case of severe pollution. |
| P_H | Heavy pollution | - Does not include zones subject to conductive dust or industrial fumes that produce conductive build-up. - Precautions have not been taken to curb pollution, or the switchgear is near a source of pollution. |

As an example of polluted environments, the Standard suggests the following characteristics:

Locations with slight pollution P_L:

- areas without industries and a low density of housing with heating systems;
- rural areas;
- mountainous areas.

All these areas must be situated at least 10 to 20 km from the sea and must not be exposed to dominant winds from the sea itself.

Locations with heavy pollution P_H:

- areas with industries that are not particularly polluting and/or with an average density of housing with heating systems;
- areas exposed to wind from the sea but not too close to the sea (at least several kilometers distant);
- areas with a high density of industries and suburbs of large cities with a high density of heating systems;
- areas close to the sea.

Based on the combination of the previous classes, the Standard establishes three degrees of severity of service conditions:

| | |
|----------|--------------------|
| Degree 0 | CoPL |
| Degree 1 | CLPL o CoPH |
| Degree 2 | CLPH o CHPL o CHPH |

where degree 0 corresponds to the standard service conditions defined by IEC 62271-1.

The Standard also defines three design classes corresponding to the three degrees of severity of service conditions described above: Classes 0, 1 and 2.

| | |
|----------------|---|
| Design Class 0 | - No tests required. - Conformity to IEC 62271-200 is the only requirement |
| Design Class 1 | - Tests required: - Level 1 ageing test (sub-clause 8.1) - Positive assessment of test results according to diagnostic procedure (sub-clause 9) |
| Design Class 2 | - Tests required: - Level 2 ageing test (sub-clause 8.2) - Positive assessment of test results according to diagnostic procedure (sub-clause 9) |

The ageing tests are defined as follows by the Standard:

| | |
|---------------------|---|
| Level 1 ageing test | Three identical tests lasting 7 days in a climatic test room |
| Level 2 ageing test | Seven identical tests lasting 7 days in a climatic test room (the level 2 test is identical to the level 1 test except that for level 2, four additional climatic cycles are to be applied) |

Lastly, the switchgear is assessed on the basis of the following diagnostic procedure:

- 1) no disruptive discharge must have occurred during the climatic cycles of the ageing test;
- 2) no disruptive discharge must have occurred during the dielectric test in the climatic room;
- 3) the doors and switching devices can be subjected to an optional mechanical assessment during which parameters such as operating times, torque values, contact speed, operation of the interlocks can be considered. The results of such assessments must be compatible with the tolerance values provided by the manufacturers.

2. Relevant regulations

2.4 Vibrations, tremors, oscillations

As mentioned previously, the user must specify any unusual conditions regarding vibrations, earth tremors and oscillations.

The severity level of earthquake zones must be specified as indicated in IEC/TS 62271-210, High Voltage Switchgear and Controlgear - Part 210: Seismic qualification for metal enclosed and solid-insulation enclosed switchgear and controlgear assemblies for rated voltages above 1 kV and up to and including 52 kV.

The Standard establishes two severity levels:

- level 1, recommended for peak ground/floor accelerations up to 0.5 g;
- level 2, recommended for peak ground/floor accelerations up to 1.0 g.

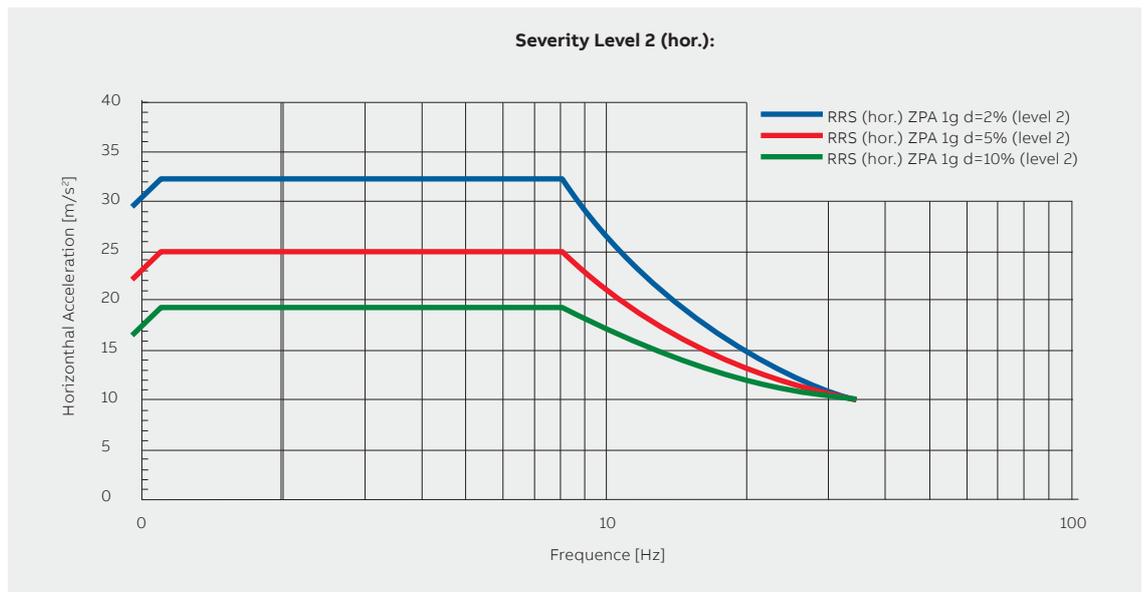
The Standard also defines the form of the spectrum (or Required Response Spectra, or RRS), which must be able to simulate the various conditions related to the intensity, depth and distance from the epicenter of the earthquake, the type of ground and the height at which switchgear installed on the upper floors is located.

The RRS corresponding to severity level 2 indicated in the Standard are given below.

Once the test has been performed, the Standard establishes two acceptance classes:

- Class 1: the switchgear must continue to be functional during and after the test. It could require successive maintenance and replacement of certain parts to ensure it remains operative over time.
- Class 2: the switchgear must continue to be functional during and after the test. Successive maintenance must not be necessary.

The criteria and inspections required in order to assign the class are defined in detail by the Standard.



Severity Level 2 (horizontal) – Zero period acceleration (ZPA) = 1 g

3. Different environmental conditions and their impact on the service conditions of substations

The first thing to consider is that substations are not normally sealed from the outdoor environment, thus the conditions of this latter affect conditions inside the substation to a considerable extent.

The air pressure, for instance, will be the same both inside and outside the structure.

The condition of the building or room will obviously affect conditions inside the substation and should therefore be very carefully assessed. When it comes to temperature, the amount of heat transmitted by the sun towards the inside of the substation depends on the materials used to construct the building, i.e. on their thermal conductivity.

If the materials provide a good degree of thermal insulation, the outdoor temperature changes from day to night and vice versa become less

drastic. Consequently, condensation is less likely to form. However, the doors are usually made of metal and are thus excellent thermal conductors. Depending on their position, they are able to transfer a fair amount of heat inside the substation and this gives rise to significant temperature changes.

Part of the heat is produced inside by the actual electrical apparatus itself. This heat depends on the current and, thus, the substation load. Significant load variations can produce extensive temperature changes.

Since the temperature inside a substation affects the life of the switchgear and controlgear, the degree of natural or forced ventilation in the building or room must always be carefully assessed.



Figure 2: example of a substation where water is infiltrating through the ceiling



Figure 3: example of external damage through which water can seep

Besides increasing the evaporative cooling effect, driving rain can cause humidity problems if the incoming cables in a substation are not sufficiently sealed to ward off heavy rainfall.

Before making and installing ducts and raceways, the groundwater level must be assessed during the different seasons so that the cables can be properly sealed and water prevented from entering since, besides seeping through the doors, water can even enter through the basement of the actual building if this has been badly designed or is suffering from neglect.

3. Different environmental conditions and their impact on the service conditions of substations



Figure 4: example of a cable cubicle containing water

Since it depends on the temperature, relative humidity can vary considerably owing to the causes above. It can also lead to the formation of condensation, especially in the coldest parts of the building.

The process by which the water vapour in the air turns into condensation is described below. When, owing to a certain temperature and pressure value, water in the air is at its maximum, the air is said to be saturated. Conditions being equal, the ratio between the quantity of water in the air and the quantity in saturated air is called relative humidity. Since this latter depends (pressure being equal) on temperature, it means that relative humidity increases as the temperature drops (quantity of water in the air being equal). When the relative humidity value is high, just a slight temperature change can cause condensation to form. In actual fact, the temperature to consider is that of the air near to the object in question but most especially, the temperature of the object itself is of fundamental importance. This is why condensation is most likely to occur in the coldest parts or on the coldest objects of the substation, e.g. near the floor, on metal walls or near the least insulated areas like windows or air intakes.

Unfortunately, a high degree of relative humidity and the simultaneous presence of pollutants such as dust and salts affect partial discharge, surface and corona discharge phenomena in a negative way since in time, these can lead to disruptive discharge involving the electrical apparatus and switchgear.



Figure 5: example of a substation where thick dust and other pollutants have built up on the apparatus

4. Partial discharge

By definition, partial discharge is an electric discharge that only partially affects the dielectric between two conductors. Even though small quantities of energy are involved, partial discharge still causes the dielectric material to slowly but progressively deteriorate and in time, can lead to disruptive discharge that could negatively affect the device or switchgear concerned.

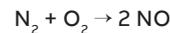
There are different types of partial discharge: internal, surface and corona.

Internal discharge is due to the presence of small voids in the dielectric, which normally form during the manufacturing phases of the product. These voids contain air or gas with a lower dielectric constant than the surrounding insulating material. The electric field in the voids is thus greater and can overcome the dielectric

strength of the internal gas, giving rise to electric discharge. Successive discharge may occur for lower voltage values and can progressively deteriorate the material until final disruptive discharge occurs.

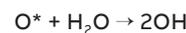
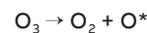
As to interaction with the environmental conditions in the substation, surface discharge is the most important sort of discharge since it is facilitated by the surface conditions themselves when dampness mixed with pollutants (salts, fumes/smoke, dust, etc.) is present. Surface discharge occurs when a large part of the electric field is parallel to the surface. It is often harmless for the insulation material but able to cause repeated air discharges near the surface itself. This sort of discharge deteriorates the surface layer of the insulation material. It leaves visible tracking that proceeds at a speed that also depends on humidity and pollution until a complete and disruptive discharge occurs. The third case, also important in this particular instance, is corona discharge. This sort of discharge forms in air in the presence of high electric fields, especially on a level with sharp tips or edges and in the so-called triple point junctions of the conductor, dielectric and air. It produces ozone O_3 .

Gases containing nitrogen oxides produced by the combustion of fossil fuels in the presence of air are a feature of polluted environments. At the high temperatures reached during the combustion process, part of the nitrogen and oxygen in the air combine together to form NO , the nitrogen monoxide radical:

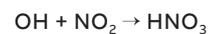


The higher the flame temperature, the more NO is produced. Nitrogen monoxide is rapidly oxidized by the oxygen to nitrogen dioxide NO_2 . Both NO and NO_2 are called nitrogen oxides NO_x .

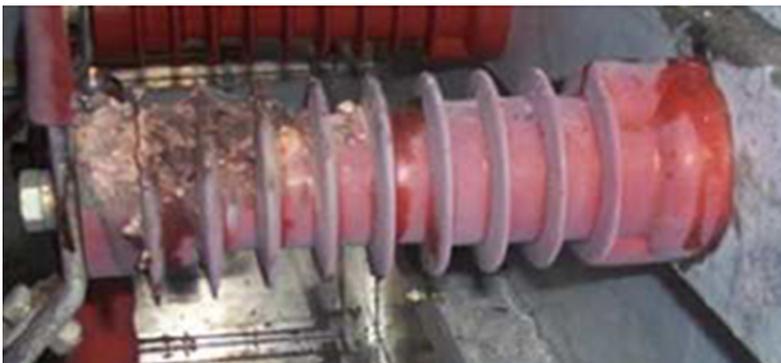
In the presence of moisture, ozone combines with the water to form hydroxyl radical OH :



Lastly, leading to the formation of nitric acid:



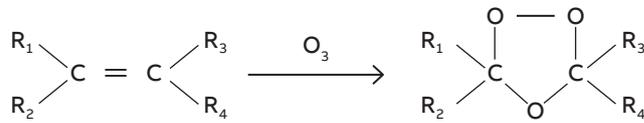
Nitric acid attacks the surrounding metal surfaces and forms conductive deposits that facilitate surface discharge. Ozone itself progressively deteriorates polymeric insulation until complete discharge occurs by tracking.



Figures 6 and 7: examples of surface and disruptive discharge

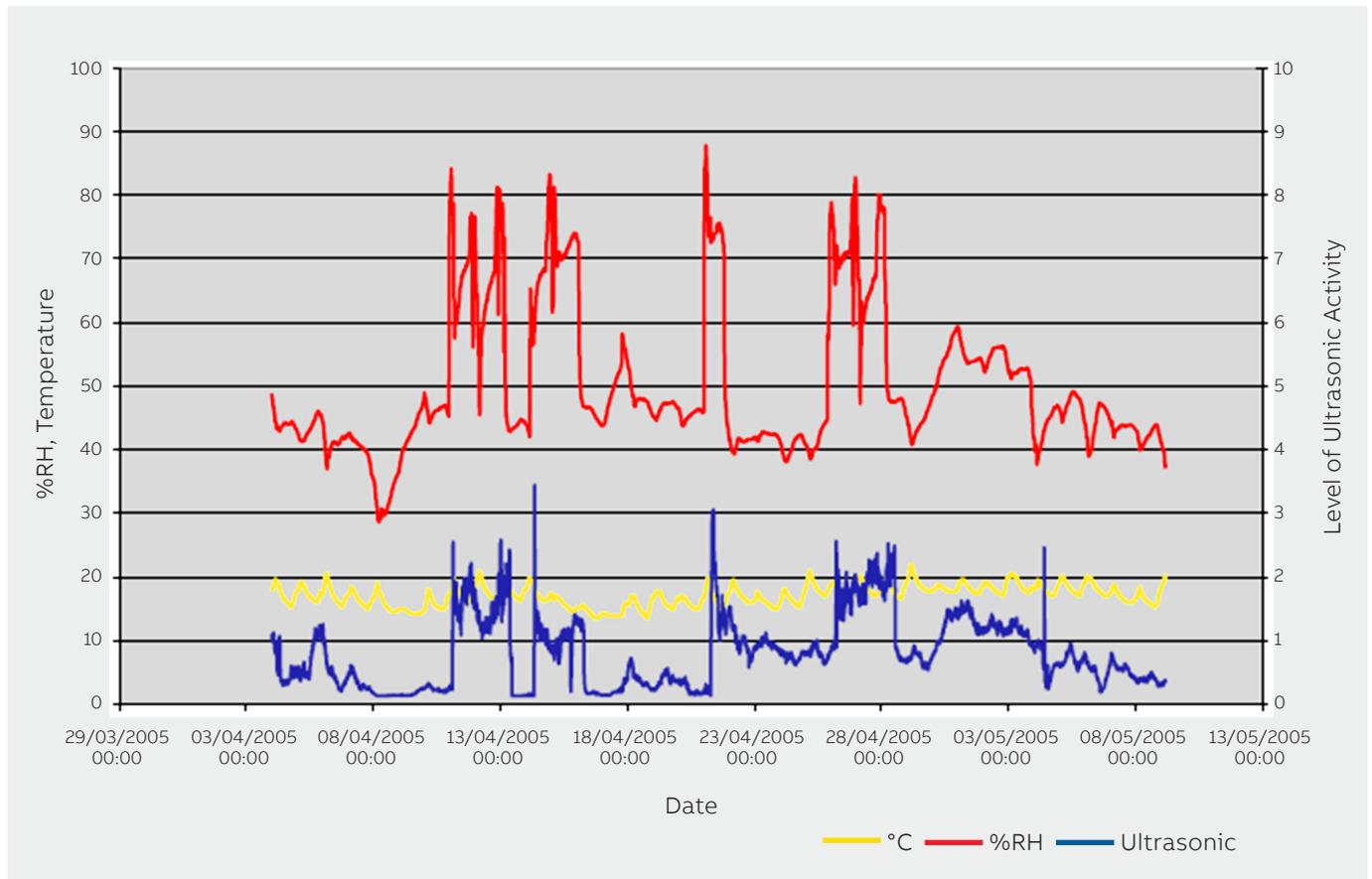
4. Partial discharge

Here again, the phenomenon is facilitated by the presence of moisture and pollutants. Polymeric insulating materials, especially unsaturated rubber, are particularly liable to deteriorate under the action of ozone, which is able to trigger reactions leading to breakage of the polymer chains. Susceptibility to attack increases as the number of carbon-carbon double bonds in the chemical structure grows, since these are where the reactions with O_3 take place.



Two effects can be produced: breakage of the chain of carbon atoms or cross-linking among chains of carbon atoms. In the former case, breakage of long carbon sequences causes the material to become more fluid and to lose its tensile strength. In the latter case, links form among parallel chains and this leads to less elasticity and increased fragility. Both effects give rise to the phenomenon generically known as ageing.

The presence of humidity and pollution increase the above phenomena and, consequently, of their negative effects on the equipment. In the graph below, based on a test performed on equipment returned back from an installation, it is clear the correlation between relative humidity and level of partial discharge (EA Technology source).



5. Suggestions on how to design a substation correctly (best practice)

With reference to Standard IEC 61936, Power installations exceeding 1 kV a.c. – Part 1: Common rules, the entire sub-clause 7.5 is dedicated to the requirements for buildings used as substations. The Standard underscores how areas containing switchgear and controlgear must be designed to prevent the ingress of water and to minimize condensation. The materials used for the walls, ceilings and floors on the ground shall not be damaged by water penetration or leakage. More specifically, the constituent materials of the external enclosures shall be capable of withstanding the attacks of atmospheric elements (rain, sun, aggressive wind, etc.). The Standard specifies that indoor climate conditions shall be established e.g. by adequate cooling, heating, dehumidifying, ventilation (so-called HVAC systems) or by adequate design of the building. Generally speaking, use of natural ventilation is to be preferred. Forced ventilation systems must be monitored. Ventilation openings should not be positioned in front of, or in the vicinity of MV switchgear and must be able to prevent the ingress of foreign bodies or vermin.

When HVAC systems are chosen, care must be taken to prevent chemically aggressive substances, which may be hazardous to the correct function of the equipment in the

installation, from entering the substation. Filters or heat exchangers must be provided if necessary.

If there is no MV/LV transformer, the thermal conductivity of the substation walls must be 0.3 to $3 \text{ W}\cdot\text{K}^{-1}\cdot\text{m}^{-1}$, such as to thermally insulate the substation. Since the entrance doors are areas where a great deal of heat is exchanged with the outside environment, great attention must be paid to their positions and to the choice of materials and finishes.

Firstly, the substation must be watertight, especially its floor and roof.

This means that not only must it be built in accordance with modern criteria as to watertightness but that, prior to construction, the groundwater level must be checked during various periods of the year, as well as the behaviour of the soil and surrounding land when subjected to heavy rainfall. By and large, a correct assessment of the environmental conditions must be based on a set of historical data recorded daily, monthly or on a seasonal basis as (appropriate). Surveys prior to installation dedicated to a specific situation may not be sufficiently comprehensive to determine whether the environment-product are compatible. Following these analyses, the substation may have to be installed on a raised deck. If it is installed at ground level, drainage ducts for the rain will have to be installed to prevent this water from penetrating inside the substation. Particular care must be paid to the entrance doorways to ensure that water is unable to drip onto the door or collect in front of it.

Cable entries must be sealed to prevent water, polluted air or vermin from entering. The cable trenches must be covered to prevent moisture and polluted air from penetrating inside the substation. If water could accumulate in the cable trenches, it is advisable to install a water trap with an extractor pump activated by the water level. Particular care must be taken if the substation floor is the raised type, with ample space for power and auxiliary cables where outdoor air can enter. Condensation could easily form in the lower parts of the MV switchgear unless the floor is properly sealed.



Figure 8: example of a ventilation opening with grating

5. Suggestions on how to design a substation correctly (best practice)

The actual structure of the substation (if in disrepair) and its entrance doors are the points where dust, corrosive and/or inflammable fumes or gas, vapours or salt can enter. The first step to take is to ensure that the outer cladding is proof



Figure 9: sealed cable entry

against such pollutants. The doors must be equipped with closing mechanisms that prevent them from remaining open after the personnel have entered. A further barrier could be to build an antechamber immediately after the entrance door to the substation.

Keeping a slightly higher pressure in the substation than outdoors thanks to the action of the HVAC system could make it more difficult for pollutants to penetrate inside.

It is important to install filters on the air intakes. Lastly, the floors should be treated so as to prevent dust from settling as far as possible, and must be easy to clean.

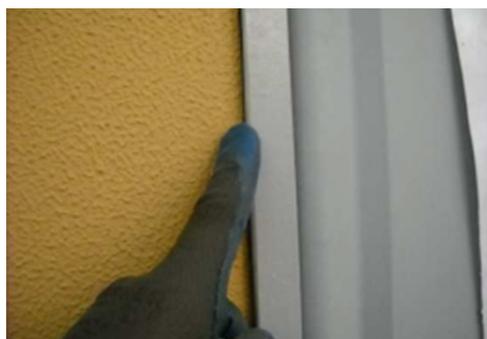
If a high percentage of relative humidity over long periods of time is inevitable, it is advisable to include anti-condensation heaters for the cable compartments and circuit-breakers of the different switchgear functional units in the Product Technical Requirement report. The building should be equipped with humidity controllers and thermostats able to trigger an alarm if the climatic conditions become critical or, better still, temperature and humidity data loggers to assess the trend of these two parameters in different parts of the building during the day and in different seasons.

Routine maintenance of the building and critical areas is essential if the interior part of a substation is to be kept under control. For example, such tasks could include inspection of the state of the building (especially the roof and external walls), cleaning of rainwater drain pipes, state of air gratings, cable glands and gaskets, state of door and window seals, cleanliness and presence of foreign bodies, etc.

Since the maintenance schedule for the apparatus installed in the substation as given in the Installation Operation and Maintenance Instructions refers to standard environmental conditions, it must be revised in accordance with the manufacturer as to the type of maintenance tasks required and their frequency if the apparatus must function under special conditions.



Figure 10: example of an MV substation with UniGear switchgear



Figures 11 and 12: example of an entrance door and seal inspection

6. Conclusions

As mentioned, the Standard merely defines the limits of service conditions but does not suggest remedial actions able to mitigate the negative effects of non-standard conditions on switchgear and controlgear on the basis of their causes and intensity. The first step is to take note of the service conditions and, if they are found to be more severe than the standard ones, to inform the manufacturers so as to define the limits and possible solutions.

Further measures, which may apply to the building in which the substation is situated, will be drawn from experience and good building practice.

The table below outlines the previous chapters in a proactive but by no means exhaustive way. The measures described do not constitute a construction specification but are simply a technical guide to help the specialists who must choose and design the best solutions for the specific situations concerned.

| Service conditions | Cause | Possible measures |
|--|--------------------------|---|
| Standard (sect. 2.1) Severity class 0 (IEC/TS 62271-304) | No particular cause | No particular measure |
| | | Natural ventilation |
| Special (sect.2.2) Severity classes 1 and 2 (IEC/TS 62271-304) | Temperature and humidity | Water- and pollutant-proof external building materials; |
| | | Insulated ceiling and walls (thermal conductivity from 0.3 to 3 W•K ⁻¹ •m ⁻¹) |
| | | HVAC system for cooling, heating, dehumidifying, ventilation |
| Pollutants (dust, salt, vapours, smoke, fumes, etc.) | | Thermally insulated doors, light in colour and positioned correctly; |
| | | Prevent puddles of water from forming in front of the entrance door |
| | | Install the substation at the correct height, which will depend on the groundwater level, amount of rainfall and soil characteristics |
| | | External drainage ducts |
| | | Watertight raised flooring |
| | | Sealed cable entries |
| | | Water trap and automatic extractor pump in the cable trenches |
| | | Anti-condensation heater in the cable compartment at least |
| | | Installation of humidity controllers and thermostats in the building and trend monitoring over time |
| | | Routine maintenance of the apparatus and building interior and exterior |
| Vibrations, tremors, oscillations | | Keep a slightly higher pressure in the substation by means of the HVAC system with filters on the air intakes |
| | | Sealed cable entries |
| | | Self-closing doors |
| | | Antechamber between entrance door and indoor rooms |
| | | Easily cleaned, treated floors |
| Earthquake-proof building | | Routine maintenance of the apparatus and building interior and exterior |
| | | Earthquake-proof switchgear and apparatus |



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