NEW UNDERGROUND HV/LV PREFABRICATED SUBSTATIONS FOR BETTER INTEGRATION IN THE ENVIRONMENT

Thierry CORMENIER
Schneider Electric - France
thierry.cormenier@schneider-electric.com

Patrick BRUN
Schneider Electric - France
patrick.brun@schneider-electric.com

Loïc VIEU-VIENNET
Schneider Electric - France
loic.vieu-viennet@schneider-electric.com

ABSTRACT

This paper aims to demonstrate two closely related topics. The first topic refers to the standards applicable to construction, by integrating the environment for the housing of electrical "HV/LV prefabricated transformer substations" in addition to design rules.
The second topic refers to two recent developments for underground transformer substations, including improvements made to enhance their integration in the environment.

These two products will provide the basis for design-related aspects of the first topic, in a European context. The far wider international context can only be mentioned via specific projects requiring specifications such as the seismic properties of housing.

INTRODUCTION

Building codes are sets of rules which specify the minimum acceptable design level for a structure. Their main aim is to ensure a solid structure protecting the occupant and all equipment inside a building, while guaranteeing a life cycle with no loss of integrity.

In the world of the distribution of electrical energy, the buildings housing transformer substations must satisfy crossed analysis between IEC standards and building codes. However, other similar elements are generally installed and operated in similar environments, such as fire walls, retention trays for power transformer dielectric fluids and even oil-water separators, entirely underground, as shown in Figure 1.

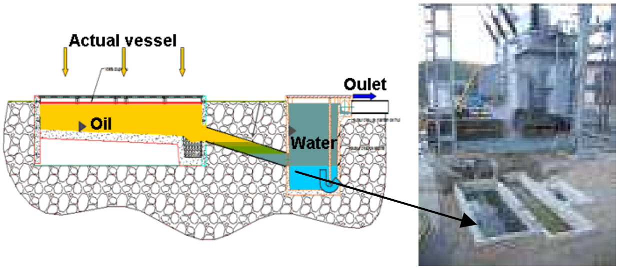

Figure 1. Underground separator for a HV substation

The HV/LV prefabricated substation is an engineering structure, and is therefore designed in accordance with IEC 62271-202 and customer specifications, using building codes.

Several building codes have been developed by groups of experts, EUROCODES (Europe), IBC (International Building Code – US) and ASCE (American Society of Civil Engineering), which become standards or directives after decrees by the competent bodies in each country.
All of these regulations share similar approaches to physical characteristics, however they differ in their coefficients and some traditional methodologies. The Schneider Electric group designs its products in Europe, therefore the EUROCODES will be mainly referred to as an example.

The two transformer substations taken as examples have integrated this new environment. Their housing is in reinforced concrete, or reinforced with fibres. Despite differing operating procedures, both of these prefabricated substations integrate innovations with a view to extending the service conditions they must face throughout their life cycle.

BUILDING CODES & PREFABRICATED SUBSTATIONS

Eurocodes

The Eurocodes harmonise all building codes in Europe and have held national standard status since 2005 in all European countries. All national standards which contradict Eurocodes must be withdrawn by 2010 at the latest.

Eurocodes cover different types of construction structures (reinforced concrete, steel structures, mixed, wood, masonry and aluminium structures), define general design rules on the basis of the limit state method and indicate design values for actions, such as deadload and other fixed loads, liveloads (operating loads), actions caused by fire, snow load, wind, temperature, traffic, etc.. The limit state design method is based on a semi-probabilistic approach and the use of partial safety coefficients for resistances and actions, reflecting the various uncertainties relating to the properties of the materials and the creation of the structure. Two limit states are defined, the Serviceability Limit State (SLS) corresponding to conditions beyond which the requirements for the specified function for the structure are no longer satisfied and the Ultimate Limit State (ULS) corresponding to the maximum load bearing capacity of the structure. This design method is internationally approved and the basis for the main building codes. Despite common rules, every country in Europe has national appendices defining differences from recommended values. Design values for wind, snow load and seismic forces therefore differ depending on the country.

Concrete structures

The basic standard for the design of concrete structures is EUROCODE 2 in Europe. Eurocode 2 covers design rules as well as the minimum characteristics of the materials used, and the installation of these materials. The concrete used must comply with EN 206-1, which defines concrete with expected performances. This standard indeed defines the minimum characteristics of concrete based on 5 classes known as the compressive strength class, the consistence class defining the rheology of the fresh concrete, the chloride content class based on the percentage of chloride, nominal upper aggregate size and the exposure class defining the environment to which the concrete will be exposed. The properties of the materials are therefore defined on the basis of typical strength values and the notion of durability is defined by the concrete cover over reinforcement bars, relating directly to the exposure class of the concrete. Steel reinforcement must also comply with EN 10080, which specifies strength and ductility.

The R&D department in charge of these developments also integrated these aspects of functional classifications from the production stage of the matter. The Programmable Logic Controllers of the concrete plant were indeed upgraded to reflect the functional expectations of the matter in quantifiable terms. The aim is to allow functional requirements to be modified according to differing national European regulations, and even International regulations.

Apprehending dynamic phenomena

Seismic forces:

Consideration of seismic forces is increasingly a requirement. This however implies in-depth knowledge of the substation site. The fundamental parameters of a seismic study are indeed an understanding of seismic actions and soil type. Simulation tools can be used to benefit from the response spectra defined according to the building code governing the design software used. The spectrum defined must be adapted or created according to the building code in the operator's country. Figure 2 shows several examples of spectra currently used.

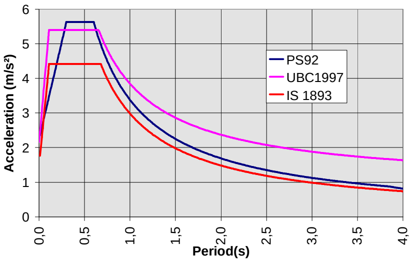

Figure 2. Comparison of French, Indian and American spectra

Impact (Transport, wind):

The new design methods can also be used to integrate accidental phenomena such as falls or gusts of wind. These actions can be modelled using amplitude, period or duration, as shown in Figure 3. Input data for models are weighted using coefficients governed by national building codes.

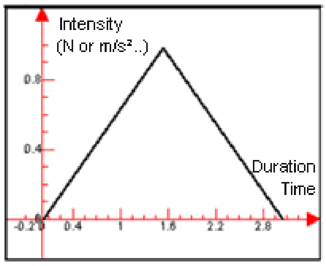

Figure 3. Description of the mechanical action on the structure

Input data can be taken from testing, or even an acceleration or impact recorders as shown in Figure 4.

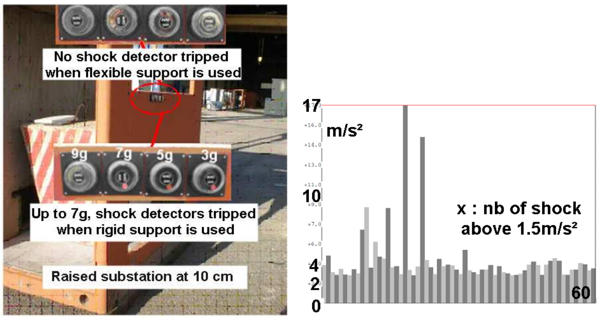

Figure 4. 10 cm fall tests and acceleration recording during maritime transport

These building codes are mandatory in terms of both regulations and from a safety and sustainable development point of view. Their impact is a means of improving quality and life cycles.

UNDERGROUND HV/LV PREFABRICATED SUBSTATIONS

Simplified compact rural substations

Alto R, called the Simplified Compact Rural Substation, is a HV/LV prefabricated compact transformer substation with no HV switchgear. This substation is equipped with a HV transformer limited to 160kVA supplied by an overhead line to an underground network, and a low voltage distribution panel equipped with two output terminals. This substation complies with the international standard IEC 62271-202, and with functional and technical specifications which are valid for several French utilities.

The electrical function of this product was already known by these utilities, however, performance has been optimised with the general use of reduced load transformers and the modifications inherent to the last IEC standard [1]. The dimensions of the excavation for this product have been reduced by 20%, and its above-ground height has also been reduced by 20%. The advantages of the environmental integration of this product lead to a height of less than 1.2 m and an anti-flooding capacity of 0.4 m. This height can be increased to 0.9 m if sealed cable penetration is used. This buried enclosure required to use Steel Fibre Reinforced Concrete (SFRC) as main material. This technology can be used to optimise the thicknesses and the functionalities of the enclosure. This technology complies with the design rules inherent to the Eurocodes. The design indeed integrates the different load scenarios (Eurocodes 2), actions (Eurocodes 1) and benefits of concrete complying with EN 206-1. The behaviour of the concrete with reinforcement fibres is defined in bending tests performed on an internal laboratory press, as shown in Figure 5,

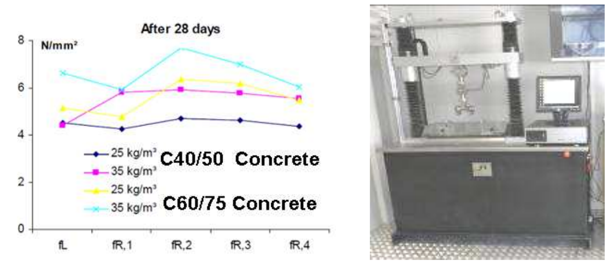

Figure 5. Bending/deformation behaviour

Let us drop the performance of the material and consider that of the substation : 24kV(Ur), 50Hz(Fr), 8kA 0.7s (Ikp), 2kA 0.7s (Iko), 160kVA (2610W), sound pressure level <41dBA, area 2m², height 1.5m above ground level, IP23D, class of enclosure 10 or 20K, lifespan 30 years.

The simplified access of the substation renders the product ergonomic (Figure 6). The low height enables top access to all parts required for commissioning, service and maintenance. The roof is divided into two sections:

- The first section can be removed manually in full and covers the low voltage switchgear.
- The second section is mobile, and in concrete, and separates the HV compartment. This section is articulated with two gas cylinders.

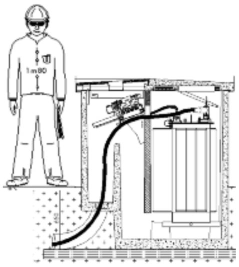

Figure 6. Ergonomics

The temperature rise class of this HV/LV substation [1] is 10 K or 20 K. The substation with a class of 20 K can be used at full load with an outdoor annual ambient temperature of 17°C, combined with the losses, the oil and windings temperature rise of the transformer (O/W 45-55 K), with no negative effects on life cycle. According to IEC 60076-7, this ambient temperature could be 20°C (Rms), however a study performed by the R&D department of the French utility EDF in coordination with the manufacturers explains the reasons [2][3]. A single air flow along the half peripheral of the roof enters through the liquid dielectric retention and leaves the substation the second half peripheral of the roof, as shown in Figure 7. Additional rear wall ventilation allows to reach the enclosure temperature rise class 10 K.

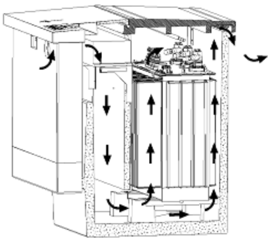

Figure 7. Air flow

This product installed in a rural area requires an acoustic power of 41 dBA according to customer specifications. The absence of a metal opening in the front wall reduces the transmission of vibration. If outdoor temperatures and load factors are more adapted for use in rural areas, the use of the product as class 20 K would appear more appropriate.

Fixed rest contacts casted in the housing to beam the transformer can be used to maintain the constant altitude of the transformer for any installed power of 50 to 160kVA as shown in Figure 8.

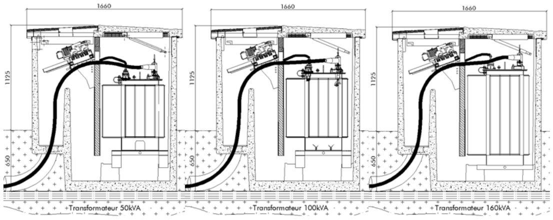

Figure 8. Positioning of the transformers 50-100-160kVA

In terms of safety, this substation must resist any failure in one HV separable connector to the earth to prove its capability to be subjected to the rated short-time withstand currents 2KA 0.7s. A baffle has been integrated in the rear roof section for this purpose, as shown in Figure 9. This baffle can maintain projections in the retention tray while maintaining the ventilation flow in the roof.

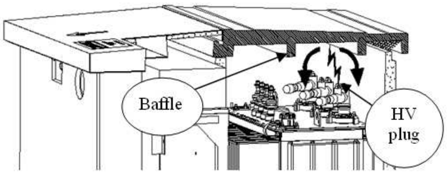

Figure 9. Baffle for plug defect

Iceberg

The Iceberg, an underground substation, is a walk in type substation equipped with HV switchgear up to 36 kV, a 1000kVA transformer or two 630kVA transformers. Two 1000kVA transformers need thermal analysis.

When designing this substation, the priority was to maintain a maximum road width of 2.5 m while delivering the assembly to the site as one component. This was the basis and held the ventilation system for the substation and the ventilation air flow, and also the layout of the HV equipment so the exhaust flows of the heat gas in case of HV internal failure.

The minimum enclosure temperature rise class is 10 K for 13750 W (1* 1000 kVA) or for 17260 W (2*630 kVA) of leakage according to the IEC standard [1], which requires nominal current supply from LV switchboards generating more joules losses than the test procedure of the previous standard, IEC 61330. To this end, only evacuation directly over the transformer, as shown in Figure 10, can be used to achieve these limitations, with no additional ventilation. 20000W as whole losses for two reduced losses 1000kVA transformer and associated LV switchboards can be evacuated easily. 55-60K as respectively oil and windings temperature rise allow to keep the same transformer lifespan and will reduce the absolute internal temperature surrounding the electronic devices participating to the smart grids.

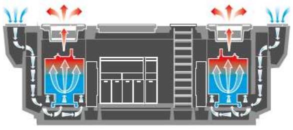

Figure 10. Air flow

Heavy rain maximum flow was checked in addition of the passed test of degree of protection IP25D. Water flow is shown in Figure 11.

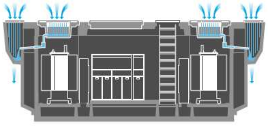

Figure 11. Water flow

These substations are tested against the arc due to an internal fault of the HV switchgears and this also differs for these substations. During the tests the position of the indicators met the requirements of a IAC AFL, as defined in IEC standard 62271-200 (Figure 12), to reach the IAC A 16 kA 1s performance as described in IEC standard 62271-202. For the IAC B 16kA 1s indicators met the requirements as defined in IEC standard 62271-202. For 24kV switchgear, the performance 21kA 1s has already passed in smaller volume but for this special case the network didn't need it.

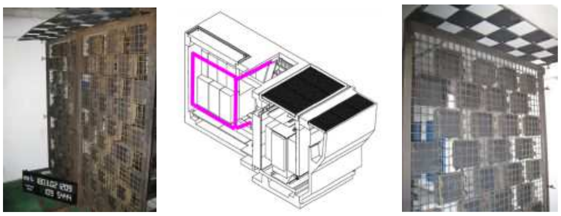

Figure 12. IAC AB 16 kA 1 s (24 kV & 36 kV)

Finally, the conformity of the enclosures with international standards required design and installation according to the Eurocodes, both for materials (EN 206-1) and structures (EN 1992-1-1), in all of the phases of the life cycle of the equipped housing, such as plant storage, lifting, transport and underground service. The design tool dedicated to civil engineering integrates the different combinations of load scenarios required by regulations (Figure 13), and only the most restrictive scenarios will be adopted. These same load scenarios integrate safety coefficients and actions.

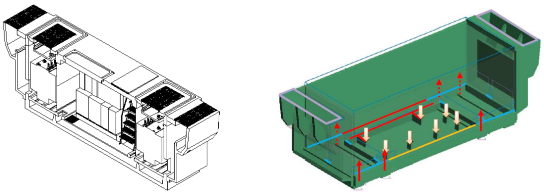

Figure 13. Example of modelling for 3D finite elements design

The design process will assess loads and the sizing of cross section reinforcement bar, however this is not enough as the building codes also define design and manufacturing provisions. These rules apply to the design of the working, anchoring and connecting of reinforcement, using calculations, as shown in Figure 14 for the product in question. External and internal reinforcement overlaps in underground structures.

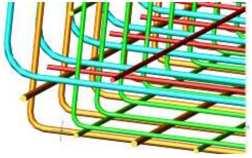

Figure 14. 3D drawing of the connecting of 2 surfaces

This same housing resists against a wheel drive live load of 6000daN or 2 simultaneous loads of 4500daN. This was tested in addition to testing according to the standard [1], together with anti-flooding capacity up to a height of 25 cm for the version with ventilation chimneys.

CONCLUSION

The developments of transformer substations must take additional loads into account, other than the loads listed in the requirements of the international standard [1]. They can be met during the whole manufacturing process as the unmolding in case of casted material, the storage, the transportation, and if any the flooding, soil pressure and fire resistance. These loads are generally the result of national regulations, where finite element design tools based on building codes can be used to achieve the appropriate precision and rapidity for housing design.

These recommendations, combined with the IEC rules mentioned in this article, demonstrate that the safety of products can be maintained with no effect on compactness, to improve their integration in the environment.

REFERENCES

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