SECURITY AND LIFESPAN IMPROVE THE PERFORMANCES OF HV/LV TRANSFORMER SUBSTATIONS

Thierry CORMENIER
Areva T&D SDS – France
thierry.cormenier@areva-td.com

Patrick BAILLY
Areva T&D SDS – France
patrick.bailly@areva-td.com

ABSTRACT
The aim of this paper is to show the approach carried out by the HV/LV prefabricated substation department from Areva T&D to obtain a total-security and to minimise the environmental impact of these products at the end of their life, and this in accordance to the latest requirements from the standard of the HV/LV prefabricated substation [1]. This approach necessitates the breakdown of each of the stages from design to commissioning of these products. These transformer substations, up to now considered as an envelope enclosing electrical equipment, are involved in the revelation of the performance of the whole assembly. Throughout the paper various test results will confirm each hypothesis.

SAFETY
In this section on the safety of HV/LV prefabricated substations we shall come across standards aspects encountered in experience feedback, but first of all we restate that safety is the absence of the risk of unacceptable injury and that we are faced with electrical equipment which can only be operated by personnel qualified and trained in electrical hazards. As such the work carried out by the main production sites and the advanced-technology centre responsible for this activity in Areva T&D is OHSAS 18001 certified.

In the following analysis it is important to disassociate safety due to the design of the HV/LV prefabricated substation which meets its product standard, from its manufacture and from its installation. As well as the ratings for HV/LV substations, certain additional details generally depend on the installation in which the product is going to be located. Installation is governed by a regulatory framework, from IEC 61936-1, but generally revised at national level and applied by network managers and manufacturers, in an environment in which the project manager has his real role as guarantor of final safety for the assembly.

Safety from the design stage
The following section refers to electrical, mechanical, and thermal sections, and those linked to an arc due to an internal fault, encountered in the HV/LV substations standard [1].

Earthing
Earthing of metal enclosures or frames, connections provided for this purpose and any other point as scheduled in the prefabricated substations standard [1] allow improvement of protection against indirect contacts. The main earthing conductor must be designed to carry short-circuit current and its rated peak value according to the earthing condition of the installation's neutral. Rules for testing the earthing system are given in standard IEC 61936-1. Developing this subject around safety we may remember that definition of the contact voltage graph can be verified using document IEC/TS 60479-1. In effect, several asymptotic curves between 50V and 100V can be obtained by varying the resistance of the human body according to the type of contact (limbs of body, surface, condition (dry or damp)) as a function of the percentage of the population not
exceeding the chosen resistance value, this being combined with standard time zones, and whether or not additional resistance is taken into consideration, as identified in document HD637S1 replaceable by the projects prEN50522 et FprEN61936-1 in Europe. Let's now return to the product rather than its installation, dealing with degrees of protection.

**IP coding**
A minimum degree of protection IP23D, defined by standard IEC 60529, is required for the prefabricated substation enclosures. This degree of protection, or a choice adapted from a more demanding coding system, prevents direct contact by the public. The use of HV equipment in an enclosure, insulated HV or LV interconnections, HV/LV transformers with insulated HV terminals and hooded LV terminals and LV distribution boards in an IP2X enclosure, mean that the degree of protection of each of these prevents any possible direct contact by the operator. The degree of protection for the enclosure may be different for equipment and transformer compartments. However, the standard for enclosures mentions that the degree of protection for prefabricated substations can be reduced when the doors of the substation or a compartment are open during operation or inspection. In such a case, if the operator is dealing with a substation with operation aisle, the additional precautions to be taken are less than those to be taken in the case of a compact substation where the equipment is directly exposed to the outside when the doors are open. Therefore the choice of the degree of protection must also be associated not only with the layout of components in the transformer substation, but also with the climatic conditions in which they will be installed. The IEC 60721-X-Y series of standards gives assistance for definition of environmental criteria.

**Mechanical stresses**
Roof loads or even wheeled loads in the case of buried substations, wind pressure on the sides of the enclosure and 20-Joule mechanical impacts are mechanical stresses identified, in addition to those transient stresses caused by an arc due to an internal fault if any. But there are certainly other stresses which our research department must deal with in designing the enclosure for a prefabricated substation. Notably, these are delivery by road, sea or even air, seismic stresses, manufacture stresses where concrete materials are involved. Besides mechanical impact, checks are done by calculation and generally according to applicable structural codes such as Eurocodes, ASTM codes or others, whether the enclosures are metal, concrete or a material with equivalent fire reaction in the meaning of the substations standard [1].

**Maximum temperatures**
The advantage of different degrees of protection according to the compartment of the substation is that it allows better ventilation of the transformer room when classes of enclosure of 10K or lower are necessary, whilst limiting heating of electronic components in the equipment room, and satisfying clause 9 of Table 3 in IEC 62271-1. Figure 1 allows intersection of IEC criteria with those of the burn thresholds defined by standard EN ISO 13732-1. The hatched area from 0.5 to 1s corresponds to a duration evaluated for an involuntary contact with rapid withdrawal. The zone from 2 to 4s is a voluntary contact with the duration necessary for equipment handling.

![Figure 1: Low burn thresholds of materials.](image)

Access to the transformer is often maintained in prefabricated substations and this is often as a result of examples of installation given in customers' specifications. As a preventive safety measure, the HV/LV substation department of Areva T&D advocates a separation which facilitates natural ventilation of the transformer and therefore its lifespan. This is after having carried out a temperature rise test, according to the substation standard, correlated with artificial solar radiation of 1000W/m², as shown in Figure 2.

![Figure 2: Temperature rise test with artificial irradiance.](image)

**Internal fault**
A prefabricated substation which meets the requirements of the prefabricated substations standard [1] is designed, in principle, to avoid internal faults. This standard has been modified with respect to its preceding version IEC 61130, for the substations of type IAC (Internal Arc Classification), with the accessibility B (General public, door closed), with a mandatory type test with an arc due to an internal fault, initiated by 3-phase wire fuse in switching compartment, as far as possible from its supply. An example of a chronophotography for such a test at 20kA 1s inside secondary distribution switchgear from Areva T&D is shown in Figure 3. The lower test represents a type A (Operator, doors open) test for the same current and duration values.
These tests were carried out while degassing the transformer compartment, keeping the lowest degree of protection IP23D and in this case a substation of temperature rise class 5K [1] for 12500W of losses. In this configuration, a substation of temperature rise 20K being normally more enclosed owing to climatic conditions, will give cotton indicators less exposure to hot gases from the equipment. On the other hand this compartment will be more exposed to mechanical stresses caused by overpressure, which steadily decrease with the increase in performance of equipment complying with IEC 62271-200. To be able to better understand these stresses caused by the problem of an internal arc in HV/LV prefabricated substations, we can consider different categories of hot gas management valid for any type of substation whatever, with operation aisle, compact, half-buried or buried. These categories are:
- Degassing carried out in the transformer compartment.
- Degassing carried out in the underground technical space.
- Degassing carried out in the operating space.

These categories can be combined. Degassing in the operating space is what occurs when the equipment is tested according to standard IEC 62271-200, which can therefore be installed in volumes meeting the test conditions and according to the manufacturer's installation recommendations. When the equipment is installed in a confined space this is trickier and it is for this reason that any manufacturer seeks to increase the IAC performance by reducing volumes adjacent to the equipment. Figure 4 shows the FBX 24 kV equipment with no change to its original volume and attaining IAC AFL 20kA 1s performance.

In addition to the electrical, mechanical, thermal aspects and those linked to an arc due to an internal fault given in standard IEC 62271-202, standard IEC 62271-1 gives the precautions taken by manufacturers and those having to be taken by users and deals with the operational aspects of high-voltage equipment.

Security in manufacture

The "Prefabricated substations" industrialisation departments, in close collaboration with the R&D departments, analyse requirements for product compliance, develop the necessary tools for their manufacture and produce process methods procedures. There is the use by self-compacting of the different concrete materials implemented up to final inspection, observing the routine tests of the standard for HV/LV prefabricated substation [1]. Fabrication of metal enclosures is carried out in observance of technical specifications. Supplier’s approval and follow-up remain indispensable.

Security for transport, installation, operation, maintenance and end of life

The section on the standard for prefabricated substations giving the rules for transport, installation, operation and maintenance is enlarged by a section on the end-of-life cycle in its new version [1]. A complete section is dedicated to the end-of-life cycle for high-voltage equipment in the latest standard IEC 62271-1.

Transport

For transformer substations, complete control of the loading, transport and unloading phases is essential. In effect, stowage of the assembly is to be taken into consideration right from the design phase and manufacturer’s instructions serve to define expected operations in line with the assumed stresses defined at the design stage. Sea or air transport codes can complete the civil engineering structures codes, taking into account dynamic aspects for construction materials like concrete, metal or any others mentioned in the prefabricated substations standard.
Installation
Installation of the HV/LV prefabricated substation finished product is mentioned by the subclause 10.2 of IEC standard 62271-202 and is integrated in a global electrical installation governed by IEC 61936-1 which any built substation must comply with.

Maintenance
Prefabricated substations do not in general require any maintenance. Some harsh environments could however necessitate preventive maintenance action, whence the need to rely on section 8 of the prefabricated substations standard [1] for the choice of prefabricated substations according to the service.

End-of-life cycle
The end-of-life cycle for HV/LV substations must cover all parts of the assembly. It must give the appropriate information to allow the end user to carry out dismantling, recycling and removal of the prefabricated substation at the end of its life. This information will take into account protection of workers and the environment. It must also deal with the different methods according to the materials used and will be given a value. An example of the logistics retained for French production sites is shown in Figure 6 and is taken from the chapter end-of-life cycle of the walk in type substations guide.

Figure 6: French flow lines for AREVA T&D HV/LV substations end-of-life cycle.

LIFESPAN
The lifetime of an HV/LV transformer substation is very closely linked to the lifespan of the transformer and therefore to its temperature rises. To verify different models of thermal behaviour, several tests have been carried out. First of all to check the thermal behaviour of the transformer in relation to the IEC 60076-7 loading guide for oil-immersed power transformers and the temperatures encountered inside a public distribution substation of reduced elevation and height, an external temperature rise test with variable load was performed in the R&D department of the French utility ERDF. This test started at the beginning of 2008 and is continuing. For this Areva T&D provided ERDF with all the power equipment and data processing. The transformer is fitted with a fibre-optic sensors and supplies a variable load. Data from a weather station associated with the substation’s enclosure temperature measurements are uploaded to a system which can accept all current communications protocols, allowing the data to be distributed by e-mail each week. Leaving the R&D departments of ERDF and Areva T&D to process the data and draw results from such a test on transformer, the Areva T&D transformer substation division has continued its practical applications of its enclosure thermal models correlated with climatic databases [2]. In the context of this test we have sought to examine the effect of solar radiation and wind on temperature measurements taken in the hottest period of July, every quarter of an hour, with a mean load factor of 1.09. Figure 7 shows the data for this week, explained below:
- Day 1: Sunshine and wind
- Days 2 & 5: Cloud cover and no wind
- Days 3 & 6: Partial sun and some breeze
- Day 7: Cloud and wind

Figure 7: Plots of solar radiation, wind speed, internal temperatures and transformer oil temperatures.

Figure 8 shows comparative graphs, where precision declines as a function of cloud cover and even more as the wind increases.

Figure 8: Simulated or measured temperatures of air and oil inside the substation.

The measured and simulated top oil transformer temperatures are for a load factor of 1.09. It is essential to take into consideration that this test over a period of a year had the aim of accelerated ageing and in no way observes
recommendations in the standards. In effect, for a 10K temperature rise class (8K in the present case) and a mean ambient temperature of 20°C, the mean load factor should be 0.9. To verify that, we used a tool developed by Areva T&D, reflecting IEC 60076-7. The load factor is therefore accelerated x 13 for a load factor of 1.09 with respect to a load factor of 0.9 simulated over seven days, whence the ageing is to be divided by 7 on the graphs in Figure 9, if we want to know it for one day. The ambient temperature is the temperature measured at the half of height of the transformer.

![Figure 9: Transformer load simulation applied to photovoltaic production](image)

![Figure 10: A photovoltaic step-up and converter substation assembly.](image)

**CONCLUSION**

Both the manufacturers and the standards system take account of security and durability aspects, so as to improve the reliability and the lifespan of the substations. Going further in this way requires researches going beyond the main function of electricity distribution. These become more and more detailed to allow optimisation of the performance set for a HV/LV prefabricated substation, therefore increasing its overall performance.

**REFERENCES**

