HV/LV PREFABRICATED SUBSTATION PRODUCTS AND HV INSTALLATIONS IN A PREFABRICATED HOUSING

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ABSTRACT

The purpose of this article is to clarify the scope of application of HV/LV prefabricated substations and HV installations within a prefabricated enclosure which meets customer expectations. In this context, any functional analysis of an HV/LV substation within a prefabricated enclosure should at least cover the topics specified in the product standard. This is what we will be examining. We will also attempt to clarify the impacts on prefabricated substation type tests in order to understand their possible extension or call them into question with respect to HV substations. As with any prefabricated enclosure, an HV installation within a prefabricated enclosure must be safe, transportable, maintainable and sustainable and the design-to-installation processes must be controlled, with no breach of responsibility, whatever the entity.

INTRODUCTION

In June 2006, the International Electrotechnical Commission (IEC) published the first version of the new IEC 62271-202 [1] standard relative to HV/LV prefabricated substations, which cancelled and replaced the IEC 61330 standard published ten years earlier. IEC 61936-1 [2], the last edition of which is dated 2010, also deals with HV installations. Its scope is extensive, as it covers different utilisation segments, including electrical power production, transport and distribution. This standard reaches beyond the context of integrating electrical equipment into a prefabricated enclosure and only considers the prefabricated substation product standard when this function is required. The application of these standards is limited by the regulatory fields and personal safety rules that must be observed.

To maintain a discussion thread in this article, we will endeavour to deal with the various topics from the point of view of customers' functional expectations, then with regard to the assemblies.

FUNCTIONAL ANALYSES

Customers' needs are reflected in their functional expectations, which are sometimes difficult to express in specifications, without involving performance requirements.

When the product standard refers to a "prefabricated substation", it describes the minimum requirements to be met. These requirements are known to each user segment, but the quantities required for the economic amortisation of type tests and product ratings [1] can be an obstacle. In all cases, the requirements must be defined and depend on the customer's functional definition, as well as the detailed definition of operating conditions in the different phases of the product life cycle and a detailed definition of the regulatory requirements.

From these definitions, manufacturers can create a functional description of their solution, and then integrate the technical, industrial and economic performances to be achieved, with the objective of ensuring the customer's final satisfaction.

When we used the Functional Analysis System Technique (FAST) method to perform a functional analysis to design an enclosure for an electrical facility [3], we checked whether each function was covered and whether it could be validated by one of the type tests specified in the prefabricated substation product standard. Figure 1 shows the functions sorted by order of importance in this electrical equipment integration enclosure design. The total percentages for each function are given to make it possible to check when all the type tests required by the product standard are covered.

Somm		Type tests	
FCT	Name	IEC 62271-202	Total
FP5,1	To protect the components during lifespan under service conditions	IP / IK / Temp / Meca	9.3%
FP4,1	To allow the safe operation and commisioning	Diel + current	16.9%
FP2,1	To allow an easy integration of the electric material	Functionnal	24.4%
FC4,1	To allow easy connections with the local grid	NA	31.9%
FP3,1	To allow the transport of the wired electrical components	NA	38.9%
FC5,6	To allow the cooling of the electrical equipement while protecting it	Temp rise	45.6%
FC6,2	To allow a change of any failed component, mass < 15kg	NA	51.7%
FC4,6	To allow the assembly of enclosures	NA	57.8%
FC2,3	To allow internal connections	Elec tests	63.3%
FC2,1	To allow external electric connection	Elec tests	68.4%
FC3,3	To be transported by road and marine usual means	NA	73.1%
FC5,5	To avoid any penetration for non allowed workers	Functionnal	77.5%
FC4,4	To be able to be installed under climatic conditions	IP	80.4%
FC2,2	To be lifted at factory	Mechanical	82.9%
FP6,1	To allow the user to reach all components without dedicated device	Functionnal	85.0%
FC6,1	To carry out the actions of maintenance in full safety	Functionnal	87.2%
FC1,4	To be easily manufactured with usual materials	NA	89.3%
FC4,2	To be handled with tools availble on final site	NA	91.1%
FC7,3	To be compliant to environmental regulations (Reach, ROHS...)	Clause 12	92.5%
FC5,4	To allow the user to remote control the installation	EMC	93.9%
FC3,2	To be lifted on final site	NA	95.4%
FC4,3	To be installed on prerequired foundations	NA	96.6%
FC1,3	To be subcontracted	NA	97.7%
FC1,1	To be manufacturable at target cost	NA	98.8%
FC3,4	To withstand to the powerful jetting during a shipment stage	NA	99.5%
FC6,3	To allow a change of any failed component with tools on final site	Clause 10	100.0%
FC7,2	To allow a change of a component with tools mentioned in a list.	Clause 10	100.0%
FC5,7	To look like a container	NA	100.0%

Figure 1: Example of functions expected for an enclosure.

We note that the type tests cover the main functions and that the connection, transport and lifting functions are not covered by the particular verification requirements generally associated with regulations and local rules (depth of buried cables, connections, structure dimensioning, etc.). The next step of the Functional Analysis System Technique is to compile an exhaustive list of the functions to be fulfilled. The assessment criteria and a list of all the actions required to determine how this will be achieved must be compiled in accordance with a given baseline. The example in Figure 2 shows 50% of the actions required solely for the first function, which include the product standard tests and many other tests even more specifically applicable to validating the solution that will meet the customer's needs. This type of enclosure requires approximately 150 check points.

FONCTIONS	How ? N°1	How ? N°2	CRITERION	STANDARDS / SPECIFICATION	REGULATION	CHECK
FP5,1	To withstand the wind stress	Resist to the pressure	40m/s (Wind gust 250km/h / 70m/s / 300daN/m²)	Eurocodes 1 / IBC	Eurocodes + National deviation	Calculation note
FP5,1	To withstand the snow stress	Resist to the pressure	4,7kN/m²	Eurocodes 1 / IBC	Eurocodes + National deviation	Calculation note
FP5,1	To withstand the water ingress	IP	IPX4	IEC 62271-202	National regulation	Type test
FP5,1	Respect rated service conditions	Design en adapted enclosure	Relative humidity / Daily 95% & Monthly 90%	IEC 62271-1 or IEC 61936-1	National regulation	Type test
FP5,1	Respect special service conditions if any	Design en adapted enclosure	3K6/3Z6/3C4/3M1	IEC 60721-3-4	National regulation	thermal, structural, calculation note or test. Salt mist test
FP5,1	To Withstand UV and solar rays	Treatment of surface finishing adapted	/	/		Ageing test
FP5,1	Protect against overheating (Service condition, solar radiation, losses, overload	Insulate the enclosure and adpt the cooling device	Min -25°C / 35°C DAvg/30°C MAvg/ 20°C Yavg / 45°C Max if derating 5% 1120/m² max // 360W/m²/jour	IEC 60076-1 & IEC 62271-1 & IEC 60721-2-4 & IEC/ISO/IEEE 80005-1		Temperature rise test + expected transformer lifespan
FP5,1	To Withstand to the salinity. Ageing > 15 years according to 60721-2-5 (*IEC526/91 et IEC527/91*)	C5-M hight durability (H ISO 12944-2) maitained after commissioning (No drilling, modification of the structure, only on removable panel	Test 12944-6 or NSS NF EN ISO 9227 1440h 9/5 s E according to NF EN ISO 10289 or rusty degree Ri0 according to NF EN ISO 4628-3	Series ISO 12944-X ISO 9227 & ISO 4628-3		Test 12944-6 or NSS NF EN ISO 9227 1440h 9/5 s E according to NF EN ISO 10289 standard or rusty degree Ri0 according to NF EN ISO 4628-3
FP5,1	Avoid salted air penetration	To not blow directly air from outdoor to electronic component	Lifespan	/		Ageing test IEC 60068-2-11

Figure 2: Example of actions ensuring part of the main function: electrical equipment protection.

It is only when such an exercise has been completed with a view to ensuring that no element that might compromise the durability of the solution expected by the customer has been overlooked, that drafting a specification can be envisaged. Otherwise, any specification will only be a reflection of individual or cumulative experiences and it will be difficult to ensure that it is exhaustive.

Certain functions may be similar to technological components checked individually or together, and may be reproduced in other installations where a series of functions are combined.

A substation enclosure designed in this way requires far more test-based checks than those specified in the product standard. The prefabricated substation product standard cannot cover all the checks required for the functions expected. Very few HV/LV prefabricated substations, unlike those designed for distribution companies, have 100% of the type tests included in the product standard. The following examples illustrate the points that could improve the substation product standard [1].

IEC 62271-202 TYPE TESTS

The wide range of 250 to 3150 kVA liquid-immersed or dry-type transformers with a winding temperature rise of 35 to 65 K or 60 to 150 K respectively, the MV and LV switchboard variants, the different methods of operation with or without operating area, the most usual enclosure temperature rise classes (5, 10 or 20 K) and the IP23 to IP56 degrees of protection of different compartments, would, as a minimum, by combining performance levels, give more than 380 configurations [5] excluding rated voltage and current levels. The illustrations in Figure 3 contain examples of substation enclosures at the same generating facility, i.e. subject to the same regulations.

Figure 3: Customised enclosures adapted to customer needs in compliance with the product standard [1].

Figure 4 identifies the main changes commonly required by customers, their working or operating conditions which impact on type tests for a product that meets the requirements of the prefabricated substation standard [1]. We can now conclude that changes are often made and that it is better to perform type tests for such substations in the least favourable cases. For example, a very high degree of protection for temperature rise tests and a low degree of protection for internal fault tests. We should note that numerical simulation can be used for mechanical and thermal aspects that are usually affected.

Functional analysis remains the best method of ensuring that no other point that is missing from the product standard checks is overlooked in the final solution.

Verified functions	Impact on type test by any change
Insulation	Any change on interconnections
Temperature rise & class	IP, Service conditions, transformer ratings, Load factors (PV, Wind, Indust...), enclosure material
Withstand current of main and earthing circuits	Cross section, fixing distance, supplier of any device of the carrying circuit
Functional tests of the assembly	Layout and any change of component
Degree of protection (IP Code)	Services conditions, Regulation
Mechanical stress	Service condition (Wind, snow, wheel load, transportation, manufacturing process….) for each building code [3]
EMC compatibility tests	Layout , wiring on assembly, product tested alone
IAC-A, IAC-B or IAC-AB if any	IP, Tests conditions, Current and time of the fault, HV Switchgear (Energy, Volume of the exhausted gas), Transformer bushing, Layout, Outdoor accessibility, Volume of the compartment, Gaz flow, cable vault, enclosure material.
Sound level if any	IP, transformer ratings

Figure 4: Changes affecting type tests

EXAMPLES

Ventilation of HV/LV wind turbine substations

One of the performance aspects of an HV/LV prefabricated substation is the temperature rise class of the enclosure, which is often between 5 and 20 K. The choice of transformer, under specified operating conditions, determines the maximum admissible load factor. This is usually the case with power distribution. Another specific example, in addition to the one already mentioned in the functional analysis [3], is the case of a prefabricated substation for the wind power industry. The customer will specify the temperature rise class of the enclosure and IEC 60076-16 will specify the additional stresses. However, such a solution requires the problem to be addressed in its entirety and should take account of the losses generated, as well as natural cooling, which depends on wind velocity. Figure 5 gives an example of a 4 MVA substation designed for a 12.5 K (15 K) enclosure class for 47 kW of losses and shows the ventilation area required for it to be compliant with IEC 62271-202.

Figure 5: Example of a substation at the base of a wind turbine mast.

Figure 6 shows the elements to be taken into consideration in order to obtain a better enclosure specification and avoid overexposing the equipment to external operating conditions, especially when offshore wind turbines are used. In addition, the impact of solar radiation should no longer be considered negligible during low wind velocity, which limits air renewal. When using liquid-immersed transformers, we can consider that the rise in air temperature is double the enclosure class. When the wind generates high pressure on one side and low pressure on the other, the ventilation area can be reduced by a factor of three. This simulation obtains reduced ventilation sections, assuming of course, that the air circulates freely through the transformer fins. The laboratory enclosure class measured would be 25 K.

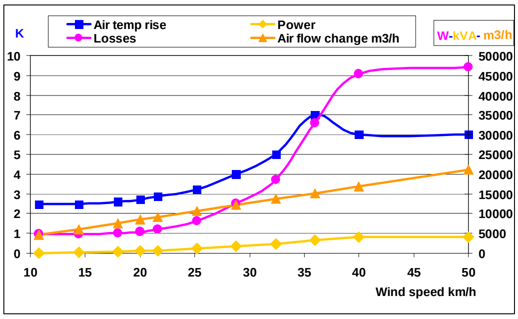

Figure 6: Air temperature rise simulations for an AN wind turbine transformer enclosure.

This example does not mean that a substation that meets the requirements of the product standard does not meet the need, but that it risks overexposing the equipment to sea spray and consequently accelerating the corrosion phenomena specified in less detail in the product standard. As this topic is included in this standard for information purposes, it needs to be investigated in greater depth as a function expected in the final solution. In fact, if no test specimen is available, the corrosion rates estimated in ISO 9223 for carbon steel metal enclosures at least 3 mm thick reveal that a protection system higher than the C5M specified in ISO 12944-5 would be required when the substation is installed less than 100 m from the sea, as illustrated in Figure 7.

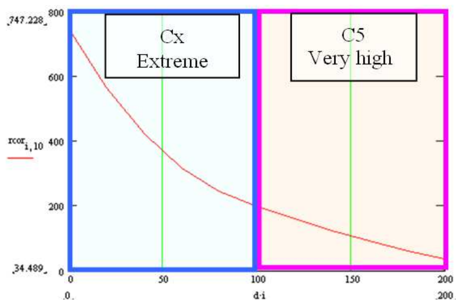

Figure 7: Corrosion rate (µm/year) ISO 9223 = f (distance from the sea (m)) IEC 60721-2-5.

E-House

Another range of substations requiring detailed functional analyses is that of substations more commonly encountered under the names E-house, Powerhouse and Package Control Room, which are intended for oil, gas or mining activities. Specific performance levels such as those required for fire and explosion resistance are needed. These structures, which are usually made of metal, are mainly found in zones where large-scale convoy transport operations are possible (Australia, North, Central and South America, Russia, the Middle East, Africa) ..... One of our units based in Brisbane Australia had to manage this type of situation and would have appreciated normative support from somewhere in between the product standard (IEC 62271-202 [1]) and the HV installation standard (IEC 61936-1 [2]), given that many of the problems it had to deal with arose from regulations such as building codes. Figure 8 shows structures that cannot be exempt from functional analyses while projects are in progress.

Figure 8: Complex installations in prefabricated enclosures (28 m * 7 m) tested prior to delivery.

Although many check points are required for this type of project, it is not exempt from the rules already applied to HV/LV substations, as the responsibilities cannot be shared. This is because the design, structural calculation, transport and also the enclosure building and electrical equipment integration process must be controlled [4]. Without a detailed specification from the functional analysis, a subcontractor cannot claim to have the elements required to ensure optimal end-customer satisfaction. For example, the deformations acceptable by different standards or regulations are unacceptable for certain equipment. A deformation of L/360 is acceptable in the structural calculations of an enclosure containing equipment according to many Building Codes, whereas a deformation greater than L/1000 is not admissible for the equipment. Compromises must therefore be found, depending on the equipment, to integrate the transport phases and the Interlocked and Full welded enclosure technologies with respect to stresses. Figure 9 shows an example of deformations that cannot be accepted by certain categories of HV equipment if continuity of service is required in the event of an earthquake. The structure will therefore have to be optimised.

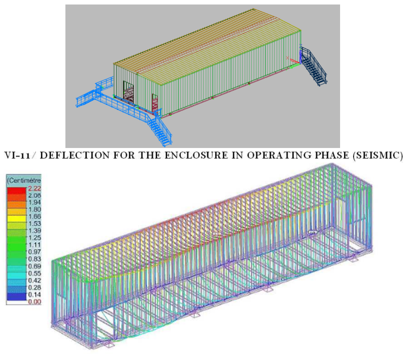

Figure 9: Enclosure deformations (20 m * 4 m) to be reduced if continuity of service is required in the event of an earthquake.

CONCLUSION

The product standard [1] will always serve as a reference for the construction of HV/LV prefabricated substations and mainly for the power distribution segment, but it must be included and supplemented by functional requirements when referenced in more complex prefabricated product specifications relating to an HV substation within a prefabricated enclosure built in accordance with the standard [2].

REFERENCES

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