Technical Collection
Technical paper N° 0538 CIRED 2015

Contribution of the HV/LV prefabricated substation standard and practices to the robustness of the prefabricated HV E-houses

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Abstract
The goal of this article is to show how the functions awaited by engineering and the operator of prefabricated assemblies, intended for the distribution of high and low voltage electrical energy, are provided in the permanent concern respecting regulation requirements and the standardization framework in a very competitive economic context.

23rd International Conference on Electricity Distribution
France, June 2015

Introduction

The study presented during the CIRED 2013 [3] was based on a functional analysis of prefabricated installation where certain performances could be based on the standard of the prefabricated substations IEC 62271-202[1] while others cannot. The switchgears generate loads on the structures and their performances also depend on the mechanical behaviours of these prefabricated solutions. Their control is initiated as of the phase of design until the validation of these assemblies [3][4]. This article will highlight the elected housing technology, followed by an example of the design process of electrical installation crossed with the functional analysis [3]. Then the validations of the reproducible functions will be detailed knowing that their reproducibility by analogy always depends on an associated process of execution.

The prefabricated assemblies intended for specific applications do not form part of this study, these are being covered by dedicated studies in spite of their similarities. One will find there the prefabricated assemblies intended for the shore connection [4], the photovoltaic energy production, the electrical distribution with offshore and explosive atmosphere service conditions, indeed data centres.

Functional Analysis

In this article E-house will be a prefabricated installation made up of HV and LV switchgears, where the power transformers are installed outside. As an example the list of figure 1 summarizes 80% of the functional need for an E-house enclosure and its integration of the electrical components dedicated to the distribution of electrical energy, focusing on design stage for all lifecycles.

These functions are directed towards the customer values but also with the industrials necessary to guarantee the final performances. The low cost of each function remains a constant but will not be taken as a priority in comparison with the functions of safety, of reliability and of conformity which are present in each main function.

The functions will be recalled in bold throughout the article in the body of text.

Figure 1
Functional analysis of a prefabricated E-house

Summary of required functions	Type tests IEC 62271-202 V2014	Additional subclause & checks	%
Lifespan & Uptime under service condition	6.7 / 6.101 / 6.5 IP / IK / Temp	11 (Safety) Structural, corrosion, monitoring	8%
Maintenance	Functionnal	10.4 / 11 Permanent monitoring	15%
Safe operation (Internal Arc Classification)	6.102 IAC A if any	Fire reaction & resistance	22%
Transport of the wired components	Not covered	10.1 / 11 Deflexion max	28%
Transported by road and marine	Not covered	10.1 / 11 Structure & packing	33%
Robust regional design	Not covered	Local capability	38%
Secure accessibility	6.102 IAC B / Functionnal	NA	43%
Safe operation & fast commissionning	6.2 / 6.6 / 6.10 Diel / Current / Aux	11 Platform & stairs	48%
Efficient cooling	Not covered	HVAC & Insulation	52%
Customization tools	Not covered	Time to market	56%
Rising & assembling	Not covered	Coupling module	60%
Environmental impact	IEC subclause 12	Reach + EoLi + PEP	64%
Earthing and equipotentiality	6.6 IEC 62271-1	11 Functional & regulation	67%
Protected during transportation IPX6	Not covered	10.1 IP with packing	70%
Power connection	Not covered	CT & VT box	74%
Accessibility by non worker	Not covered	Locking device	77%
Fast electrical integration	Not covered	Removable part	80%

Each following explanation will try to answer the following question: How to design in a minimum of time a solution for project, integrating HV and LV switchgears as a new electrical installation, covered by IEC 61936-1 [2] standard but guaranteeing a whole type tested performances according to the most adapted standard of prefabricated product [1] and according to complementary checks impossible to realize within the costs and time required for such installations?

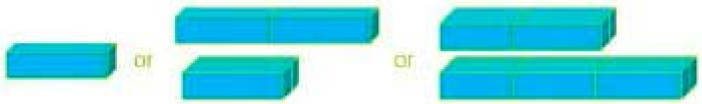
E-House

Technology

The technology of the prefabricated module taken in reference is a controllable technology by any industrial group wanting to propose the safety, quality, and flexibility aspects, for any standardization framework.

The modules are self bearing metal structures carried out with cold formed profiles of class 4 according to EN 1993-1-1 with a welded base with profiles of class 1, even 2. The profiles of class 4, defined by a width of 270mm or 400mm, a depth of 80mm, and thickness of 1.2, 1.5 or 2mm, constitute the modular elements of the wall and roof bearing the structure. Each module can be assembled according to the combinations of figure 2.

Figure 2
Combinations of modules



Ratings of the studied modules

_Length: 10 to 20 meters, Width: 3 to 5 meters
_Height: 3.5 meters from floor inside to under ceiling
_Roof slope: 2°
_Wall sides opened for coupling several modules if any
_Weight: 30 to 80T using 4, 6 or 8 lifting pads where the WLL is 20T, tested up to 80T to use it for non balanced lifting if any, without any failure.
_Equipment load: 575daN/m² and 20daN/lm on walls
_Operating loads: 718daN/m² and floor thickness 6mm
Equipment and operating loads are overlapped giving enough margins for all layouts combinations during the tendering stage, knowing the equipment area is usually under 50% of the whole area.
_Wind load 96daN/m² & Roof load: 224daN /m² for 5m width and other widths 250daN/m²
_Equipment load on ceiling: 100daN / ml at the half width using 400 * 80 * 1.5mm cold formed profile
_Deflection max for basement and cold formed wall panels: L/400 linked to switchgears to insure the transport of the wired component, and L/200 for roof panels
_Purlin spacing of basement: 0.6, 0.9 or 1.2 meter
_Available space for cable tray between primary and purlin members: 80mm
_Minimum steel grades YS 275MPa for the basement members and 275MPa for panels
_Corrosivity outdoor class C5 H ++ (NSS 2000h + condensation + pull off + cross cut for adhesion tests + 50 ageing cycles + abrasion) & indoor class C3 H according to ISO standards for better lifespan
_Wall thermal resistance: R1.9 to R2.5 K·m²/W - R10.7 to 14.2 h·ft²·°F/Btu for an efficient cooling
_Roof thermal resistance: R2 to R3 K·m²/W - R11 to R17 h·ft²·°F/Btu for an efficient cooling_Thermal resistance for basement: R2 to R4.5 K·m²/W R11 to R25 h·ft²·°F/Btu for an efficient cooling
_Outer cladding EI 120 and wall REI 120 with roof and ceiling loads, for safety
_Grounding system according to IEC 61936-1 for safety
_Degree of protection: IP55 IEC 60529
_Mechanical withstand: IK10 20J IEC 62262
_Dynamic overpressure withstand: 3psi=20kPa 0.2s (i->o if IAC performance, o->i against external blast if any) for safety

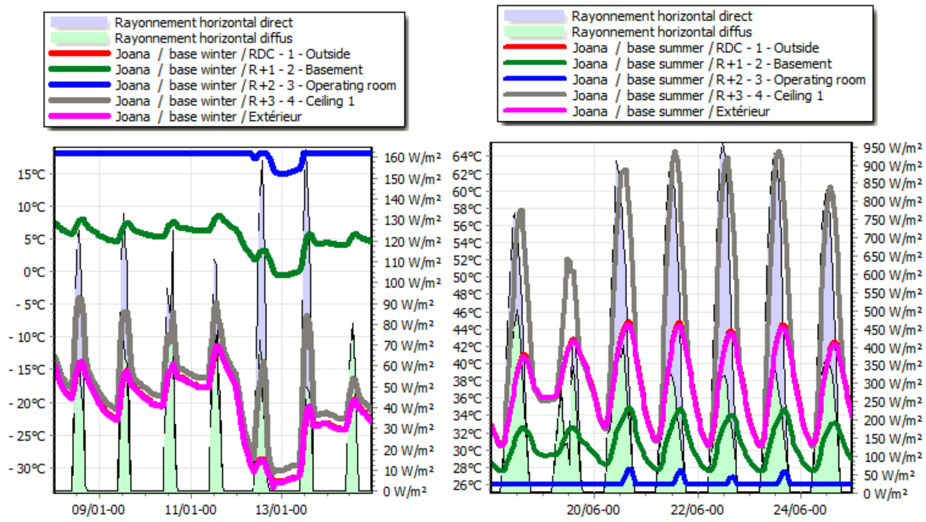
Installation approach

Since the request for consultation phase for the customer application, any solution requires an electric diagram before any integration of product. Integration will be done according to the applicable standards and regulations, pointing out the most current reference document IEC 61936-1, NFPA70 (US), AS2067 (AU).

Therefore the layout of the switchgear and controlgear shall respect the escaping route and operating and maintenance aisles. It can be referred to the standard of prefabricated substation product [1] and to standard IEC 60364-7-729.

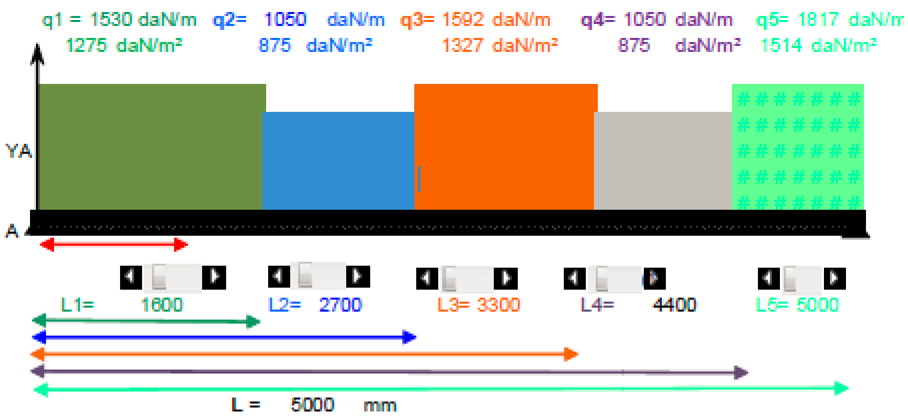
The electrical components generates joule losses which coupled with the outdoor services conditions require a checking of the indoor service conditions per thermodynamic calculation, not a CFD in this case [6] in order to check if the HVAC will insure the efficient cooling, contributing to the function lifespan under service condition, function first impacted by many other checks. Figure 3 shows the results of a simulation of various temperatures of a prefabricated module installed on pillars. From left to right, the first picture is for an operating setting at 18°C, installation de-energized, site in Russia with 40kW of heating power, and the second picture is for an operating setting at 26°C, with 10kW of losses in Qatar with 26kW of cooling power. 2.5vol/h is a worst air change used for the HVAC sizing.

Figure 3
Temperatures, coldest and warmest simulations



The layout of the electrical components once known, generates mechanical profiles of loads on the cross member of the basement. A tool has been designed to define the profile of the worst load applied to member as purlin. Interface of use is showed figure 4.

Figure 4
Example of profile of loads on a purlin



Therefore a customization tool was designed to evaluate from the phase of request for impact of each change of ratings and th available steel grades and profiles in the various geographical areas Asia, America, Europe even Russia.

The building codes retained at this stage are and the IBC. In addition to the modifiable tool has already taken more than 750 steel members data base classifiable by criteria (availability, resistance…) and defines the optimal pro checking the three criteria, the

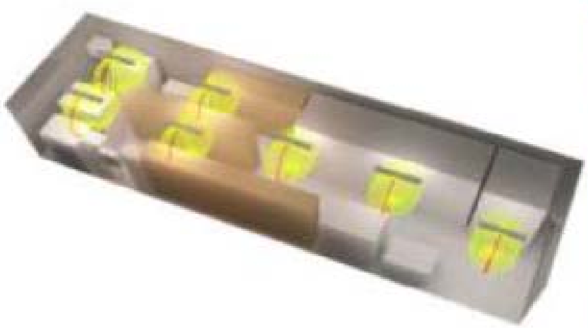
maximum constraint, the maximum deflection and the moment related to buckling of the basement and that for the operating phases of the prefabricated module.
Any design using calculations with the finite elements requires a modeling as a preliminary which in this optimization tool. This makes it possible to provide the function robust regional design extract is presented by figure 5 with one of the matri European steel members, therefore for the base intended for the Europe zone.

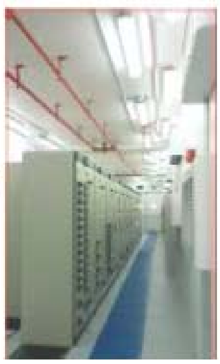
Figure 5
E-house basement, steel grade YS 275MPa

		Eurocodes / STF					
	S	0,6		0,9		1,2	
L	W	Primary	Purlin	Primary	Purlin	Primary	Purlin
10	3,0	UPN 240	IPE 140	UPN 240	IPE 160	UPN 260	IPE 180
10	3,5	UPN 240	IPE 160	UPN 260	IPE 180	UPN 280	IPE 200
10	4,0	UPN 260	IPE 180	UPN 280	IPE 200	UPN 300	IPE 220
10	4,5	UPN 280	IPE 200	UPN 300	IPE 220	UPN 320	IPE 240
10	5,0	UPN 300	IPE 220	UPN 320	IPE 240	UPN 350	IPE 270
15	3,0	UPN 300	IPE 140	UPN 300	IPE 160	UPN 300	IPE 180
15	3,5	UPN 300	IPE 160	UPN 300	IPE 180	UPN 300	IPE 200
15	4,0	UPN 280	IPE 180	UPN 280	IPE 200	UPN 320	IPE 220
15	4,5	UPN 280	IPE 200	UPN 300	IPE 220	UPN 320	IPE 240
15	5,0	UPN 300	IPE 220	UPN 320	IPE 240	UPN 350	IPE 270
20	3,0	UPN 300	IPE 140	UPN 300	IPE 160	UPN 300	IPE 180
20	3,5	UPN 320	IPE 160	UPN 320	IPE 180	UPN 320	IPE 200
20	4,0	UPN 320	IPE 180	UPN 320	IPE 200	UPN 320	IPE 220
20	4,5	UPN 350	IPE 200	UPN 350	IPE 220	UPN 350	IPE 240
20	5,0	UPN 350	IPE 220	UPN 350	IPE 240	UPN 350	IPE 270

L, W, S in meters, are respectively the length, the width and the maximum distance between two purlins. It can appear inconsistent in dimensions of shape but this reflects the variations of the quantity of lifting points Complementary tests are necessary to provide the functions safe operation and earthing andequipotentiality in order for the execution of the integration of the product and the electrical components to be realized.
The capability to withstand the earthing current within the earthing circuit is according to the IEC 61936-1standard clause 10, and can be assured by a dedicated circuit having passed a type test according to the IEC 62271-1 clause 6.6. For these same functions, other tests could be necessary like the continuity of the cable trays according to the IEC 61537 standard.
In addition to the safe operationfunction, when fire protection devices are integrated, a complementary test of enclosure tightness using extinguishing gases as the FM200 is carried out according to NFPA and ISO 14520 standards.
Also a checking of the luminosity available in the operating areas for example to 1m with 80% covered surfaces, is realizable by software in conformity with EN 13201, by taking values of lighting of 300 lux for the HV and LV accessible compartments of switchgears, 150 lux for the battery compartment and 400 lux for the operating area of the equipment. An example is showed figure 6.

Figure 6
Lighting of operating areas within E-House





Checking as type tested product

Structure

All life phases of the product, lifting, transport with stowing by way road, marine, and the operating phase with dynamic overpressures being able to be generated inside or outside, as well as the seismic constraints are checked for all orders but were already checked on a standard module of 20m*5m, by calculations to the finite elements with the two main used tools on civil work construction. This gave a model and guideline for the contracts. The cold formed steel profiles used for wall, roof and corners, as well as the modes of their assembly are preserved for all lower dimensions of any module, to be faster; on contract for longer or wider module a new calculation shall be done. In our checks, the effective parameters required for these profiles have been defined according to EN 1993 Eurocode 3 standard showed that certain inertias and module of inertia could be 40% lower than the computed values by the certified software for construction, in order to guarantee stability.
This module was validated by the CTICM EU certified organization according to EN 45011.1998 for the metal prefabricated structures. The checking was carried out as well for the cold and warm thermal behavior of the structure.

Fire resistance

A fire resistance test of bearing wall exposed by outside according to the curve ISO 834 with an aim of reaching performance REI 120 beyond the necessary REI 90 required by the IEC 61936-1 standard, has been performed and passed. This test ended by the hose stream test which is brutal cooling by fire hose over one duration of 2.15min for conformity according to ASTM E226 standard. The test carried out answers also to AS1530-4 standard. Figure 7 represents the curves of tests standardized and figures 8 the test passed according to the ISO curve.

Figure 7
Sample of standardized curves for fire resistance test

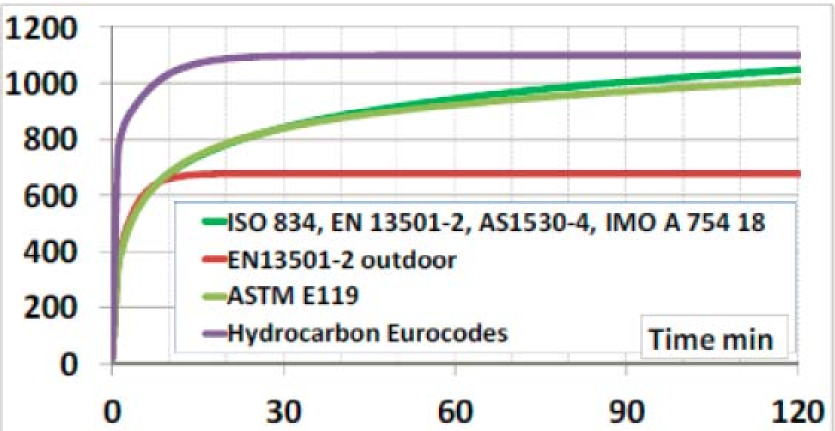


Figure 8
Fire resistance test with load bearing, hose stream, final result of the unexposed side.

This contributes to the robustness of the function as the regional design and lifespan under service condition.

Degree of protection

This test for IP5x is often carried out on models, or partial representations of product. This test represented figure 9 on a complete module contributes to provide the function lifespan under service condition while having reached performance IP55, just like the resistence tests to corrosion describes hereafter. It is obvious that the reproducibility of the test cannot be guaranteed in comparison of the original test but could be analog, when only dimensions sample vary, that technology of all assembly is preserved, and the safe operation function is assured by each enclosure of HV and LV switchgears.
However this reproduced modular technology is like prefabricated envelope in concrete, in so far as no opening or elements is added.

Figure 9
E-house IEC 60529 IP54 test pushed to IP55.

Any comparison with NEMA rating can’t be donedirectly.

Corrosion

For each geographical area and each industrial process, the tests were carried out according to following standard and they contribute to lifespan under service condition:
_NF EN ISO 2409 (04/2013) cross-cut test
_NF T 30-124 measurement of dry film thickness which cancels the dead volume represented as the fictive thickness given by the variation of roughness. This is near the ISO 2808 showed figure 10 expecting the extremes values are identified.
The value of DFT NF T 30-124: measurement -2*Ra.
The value of DFT ISO 2808: measurement – Ry/2

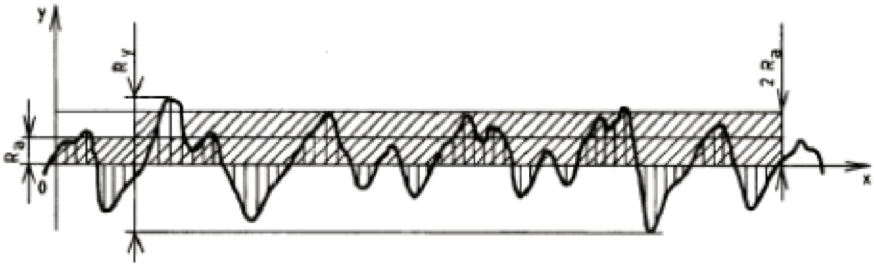


Figure 10
NF T 30124 measurement of DFT

_NF EN ISO 4624 Pull-off test for adhesion
_ASTM D968-05 Abrasion resistance of organic coatings by falling abrasive
_ISO 12944-6:
_Salt spray test according to NF EN ISO 9227
=>2000h with reversed "V" scratch according to NF EN ISO 4628 for corrosion and blistering and adhesion tests
_Continuous condensation according to NF EN ISO 6270-1 (2004), 720h blistering check according to 4628-2 and adhesion, cross-cut and pull-off tests An additional test was carried out, is related to the 50 years of experiment in the field of metallic parts of the prefabricated substations used by ERDF utility:
_NF T 30049 Artificial ageing with reversed "V" scratch, 50 cycles (rain, cold, heat, humidity, dry heat, UV)

Lifting

A design following a study by finite elements followed by a test represented figure 11, taking into account the impact of the lifting phase on the main beams of the module. The test was carried out beyond the regulation in force, which allows to use this unit with a use load factor of 4 according to the machinery directive 2006/42/EC because the test has been done up to 80T without any failure where the WLL (Working Load Limit) is 20T.
This contributes to the function safe operation.

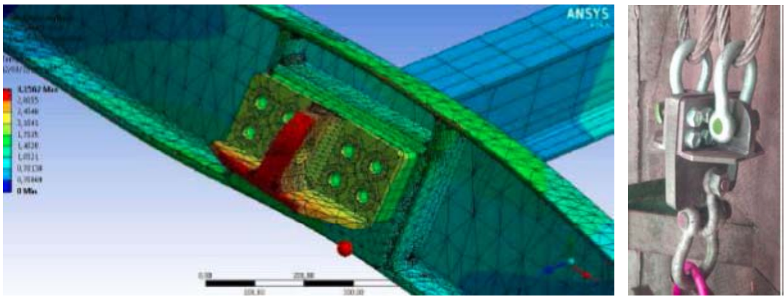


Figure 11
Simulation and test of lifting lug

Lifting

The consideration of the function maintenance which appears in second position in figure 1 reflects the functions of exchanges of any failed components with the available tools on site in allocated times, in full safety, in the phase of design of envelope for its lifespan. The standard of prefabricated substation [1] referring to the IEC 62271-1 remains directed towards curative and preventive maintenance. However we can note in this standard that stages of intervention defined by their frequency can be based on measurements. Therefore each function of figure 1, once the installation is carried out it can be assisted by a permanent monitoring by measurements in order to anticipate any possible drift of each function. That will be based on technologies of communication evolving from the preventive maintenance to the predictive maintenance, already implemented during a test of monitoring of ageing of transformer within EDF R&D laboratory [6]. The permanent monitoring such digitized prefabricated electric installations will be able to make it possible for our customers to have better control in anticipating their uptime of application, reflected by SAIDI and SAIFI indicators for the utilities, contributing by the same to the E-house lifespan under service condition function.

Furthermore, in addition to protection functions, protection relays also take into account measurement and some control functions. Most of these functions are related to the application: protection and operation of loads and therefore there is a relative independence between them and the switchboard itself. We can now identify fields where functions are directly related to the performance of switchboard, to its inner architecture and technology choices. These functions cannot be assured easily by existing relay solutions. Integrated control and monitoring must be provided directly within the electromechanical part of the switchgears, under the liability of the manufacturer.

Conclusion

The standard of the HV/LV prefabricated substations gives a framework to the refabricated installations, but remains insufficient to cover applications different from those of the utilities. Indeed in these industrial facilities many other checks are necessary because the normative framework is often covered by a lawful framework or requirements related to the application. Beyond these aspects of conformity, a significant function for the end user remains the uptime of the installations where the new technologies used for digitized HV and LV switchgears make it possible to contribute to the Condition Based Maintenance (CBM) program of the user in the management of such prefabricated electrical installations, already embedded as a strategy of services by few manufacturers.

References

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