White

Virtual Seismic Testing of a MV Primary Switchgear
According to IEC/TS 62271-210

Virtual Testing Lab (VTLab)

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White

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Abstract

The new Technical Specification IEC/TS 62271-210 gives basic guidelines for the use of numerical analysis models, such as the Finite Element Method, to assess the seismic response of high voltage metal enclosed switchgear and controlgear assemblies. However, a further study on the reliability of seismic simulations is needed in order to be able to provide more accurate virtual models and to enhance customer confidence with simulation results. This work, performed over a switchgear assembly for medium voltage distribution, will cover the conditions for the numerical analysis to be applicable, the methodology to adequately create the Finite Element model, and the acceptance criteria of the seismic virtual models and its results. The white paper guidelines advise on how to obtain a better acceptance of the new Technical Specification IEC/TS 62271-210 by means of an improved methodology where the numerical analysis criteria is further developed.

1 Introduction

In many countries there are zones of significant seismic risk or safety critical installations, e.g. nuclear power plants, which require high reliability equipment to operate under extreme conditions such as an earthquake.

According the USGS [1], in 2012 alone, 53 earthquakes above 6.0 on the Richter scale were recorded around the world. These resulted in loss of human life and caused extensive damage to infrastructure. In particular, the damage suffered by the non-structural components of the electric distribution network degrades their performance or can even cause equipment failure. The former leads to economic losses that depend directly on the time to re-establish normal operation.

Therefore, the seismic qualification of electrical distribution equipment, such as primary distribution switchgears, is increasingly demanded by electrical utilities and governments to guarantee safety and power distribution continuity in case of any type of seismic event.

Experimental vibration tests, performed with shake-tables, are widely used and have been proven as a reliable and accepted method for seismic qualification of electrical equipment. These empirical tests are set by standards such as the IEEE Std 693 [1], substations, IEEE 344 [2], equipment for nuclear powers stations, IEEE C37.81 [3], metal-enclosed power switchgear assemblies, IEC 60068-3-3 [4], equipments, or IEC 62271-207 [5], gas insulated switchgears above 52kV. More recently, the new Technical Specification (TS) IEC/TS 62271-210 [6] advises on how to perform the seismic qualification on high voltage switchgears and controlgears for rated voltages above 1 kV and up to and including 52 kV.

However, there are some cases in which experimental tests might not be technically feasible or do not constitute the most efficient way to assess seismic performance, e.g. when the assembly is too large. In those cases a combination of test and analysis is highly recommended. The aforementioned TS [6] defines general acceptance criteria for the numerical analysis models and its results.

Still, it is observed a need for further study on the reliability of seismic simulations in order to be able to provide more accurate models and to enhance customer confidence on the virtual simulation results.

In the present white paper, an example of ORMAZABAL's primary switchgear assembly for medium voltage distribution is analyzed both by testing and by the Finite Element Method (FEM), applying a novel seismic assessment methodology based on [6].

[1] USGS: US Geological Survey. http://earthquake.usgs.gov/

2 IEC/TS 62271-210

2.1 Scope and Object

This part of IEC 62271 applies to metal enclosed switchgear and controlgear assemblies complying with IEC 62271-200 [7] for metal enclosed and IEC 62271-201 [8] for insulated enclosed, ground or floor mounted, intended to be used under seismic conditions.

It specifies seismic severity levels, acceptance levels, and gives a choice of methods that may be applied to demonstrate the performance of high-voltage switchgear and controlgear assemblies for which seismic qualification is required.

The analysis types can be categorized in two main groups: analysis by experience or similarity, and numerical analysis.

2.2 Qualification by combination of Test and Analysis

A combination of test and analysis is needed because not each type of switchgear arrangement can be tested.

Furthermore, metal-enclosed switchgear and controlgear assemblies are complex devices and functional operability cannot be verified by analysis techniques alone.

According to [6] analysis may be used in validating switchgear assemblies:

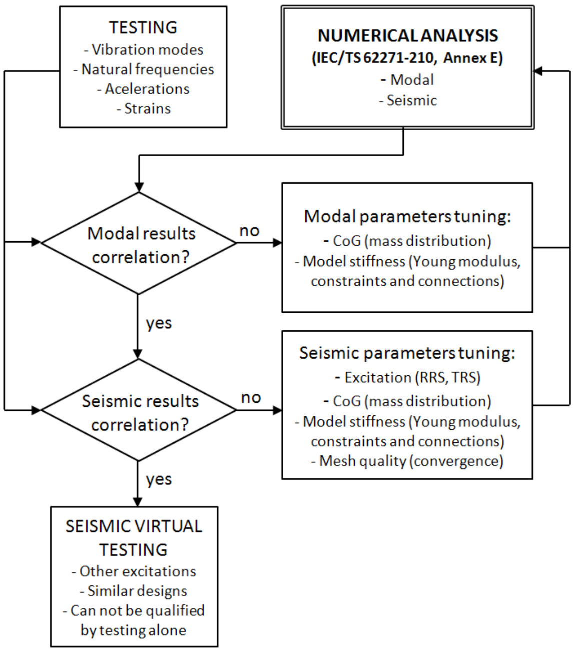
- already tested in the same configuration under different seismic conditions;
- similar to the ones already tested under the same seismic conditions but which include modifications influencing the dynamic behaviour, e.g. equipment mass and Center of Gravity (CoG);
- which cannot be qualified by testing alone (e.g. because of their size and/or complexity).

Amongst the numerical analysis methods, the FEM is recognized to be a trustworthy method as long as some quality criteria are fulfilled during the pre and post-processing of the numerical model.

3 SEISMIC ASSESSMENT METHODOLOGY

As stated above, ORMAZABAL has developed its own seismic assessment methodology based on [6]. These additional set of requirements would help simulation technology users to carry out more reliable models, and potential clients to gain confidence on the results coming out from any seismic simulation report. Picture 1 proposes further detail of the numerical analysis included in the Qualification Process Flowchart, Annex E [6].

Picture 1. Seismic Assessment Methodology. Numerical Analysis



The complete seismic assessment methodology is applied over ORMAZABAL´s CPG.1 gas insulated, single and double busbar cubicle for primary distribution.

3.1 Finite Element Model building and FEM application

The first step to build a seismic FE model is to identify the parts which act as structure (switchgear frame) and the parts which act as suspended masses (switchgear components). Afterwards, a complete FE mesh can be created joining the meshed frame with the CoG of every component. This mesh shall meet certain quality criteria regarding size and shape of the FE elements (e.g. the alternate taper ratio of shell elements less than 0.5). The model mesh is formed by 105.000 nodes and 98.000 elements.

Then, material properties need to be set and the model parameters defined: Boundary Conditions (BC) and seismic excitations.

Once the model is correctly built, it is ready to be solved.

The FEM is applied in different stages of the Product Development Process:

1) Design: The model is used to assess the seismic response of the primary switchgear family before performing any physical testing. If this stage is neglected then it is often difficult and more expensive to correct problems at a later stage.

2) Selection of a representative test sample: As [6] advises, simulation can be used to determine the worst test sample which reasonably represents the whole system for the purpose of structural and functional checks.

3) FE model correlation and tuning: Once the equipment is tested on a shake-table, the validity of the FE model is established by comparison between virtual simulation results and actual test measurements. If necessary, the FE model can be tuned to enhance its accuracy. According to the proposed methodology, see Picture 1, first the modal results should be correlated and afterwards the seismic ones.

4) Virtual Testing: The validated virtual model can be used to forecast the seismic response of the equipment under different

seismic loads. Besides, it is possible to assess similar designs applying the same excitation. Finally, simulations can also be applied in the case that the equipment can not be qualified by testing alone.

ORMAZABAL's **Virtual Testing Lab** has accredited engineers to perform and supervise any seismic simulation.

3.2 Physical testing

The seismic qualification tests of the primary distribution switchgear, see Picture 2, was carried out according to IEEE Standard 693-2005 [1] and IEC 60068-3-3:1993 [4].

Picture 2. Lateral view of the assembly on the test platform

The tests have been performed on a shake-table provided with a "bi-axial independent" action, and powered by two hydraulic actuators, a vertical one and a horizontal one, with a variable frequency and amplitude, independent from each other.

In order to record the seismic response of the equipment 6 groups of accelerometers have been placed along with 2 strain gauges.

The Test Response Spectrum (TRS), produced by the shake-table during a seismic test, envelops the ground level seismic requirements, i.e. the Required Response Spectrum (RRS). Therefore, the excitation of the shake-table is higher than the required one.

The applied RRS level corresponds to a "High Response Required Spectrum, 0.5 g", that considers a Zero Period Acceleration (ground level) of 0.5 g in horizontal direction and 0.4 g in vertical direction, reaching maximum spectral accelerations of 1.63 g for 2% damping [1].

3.3 Sensitivity study

Before tuning the FE model, a thorough sensitivity analysis of the impact of changing different input parameters over the results was carried out. The objective was to understand which parameters should be tuned in order to correlate accurately the virtual model with the physical one.

Both the discretization of the continuous model, i.e. FE mesh generation, and different physical properties were checked.

Although a very accurate mesh is not essential to obtain the fundamental modes of the model, it is crucial to calculate a reliable strain/stress response. A high quality mesh is vital to perform accurate calculations in the areas where the strain gauges are installed and to verify that the different switchgear materials withstand the seismic load without any yield or breakdown that could promote the malfunction of the equipment. For the former reasons, engineers must be sure that the mesh quality, including the connections between the switchgear frame and the CoG of the suspended components, is enough to guarantee that strain and stress results are stable, i.e. that the model results converge.

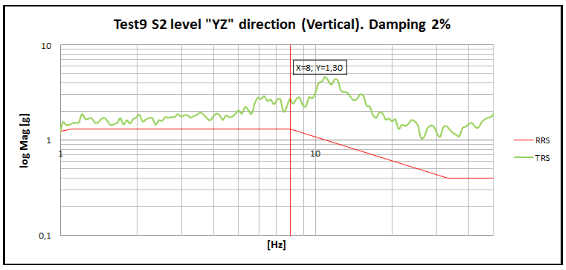
Regarding the physical properties, the model mass, stiffness and BC are the key factors to be assessed. Model mass (structural and suspended) was checked by varying the model density and the position of the CoG, whilst stiffness was modified by changing the Young´s modulus. In the case of the BC, the type of connection between the switchgear and the shake-table, represented by a large mass element, was also studied.

In the Modal Analysis the model stiffness is the more sensitive parameter. Whereas, in the case of the Seismic Analysis, the height of the CoG of the suspended masses is the more sensitive parameter for the OY acceleration, and the model stiffness is the more sensitive one for the strain value at the gauge G2 (see gauge location at Picture 6 and Picture 7).

3.4 Finite Element Model tunning

Once the sensitivity analysis has been carried out, the virtual model can be correlated taking into account the input parameters impact on the simulation results. The more sensitive a parameter is, the more accurate its value should be. The former is crucial to avoid and control calculation errors.

Picture 5. TRS enveloping the RRS



Besides, in order to achieve a good correlation, the excitation of the simulation model should be the TRS, enveloping the RRS, because it is the actual seismic load when the physical test is performed (see Picture 5).

For the Modal Analysis, ORMAZABAL has set a maximum deviation of 5% in the relevant natural frequencies to consider any virtual model results correlated with testing ones.

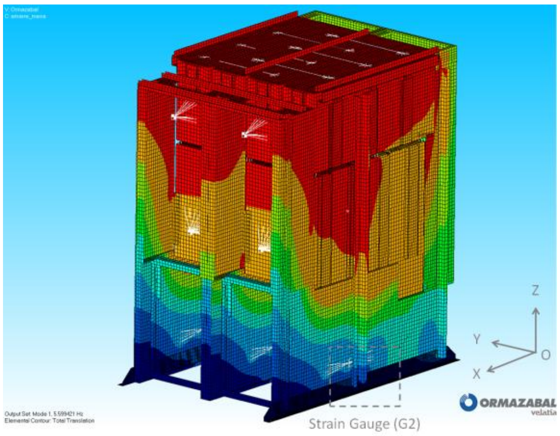
In the case of the Seismic Analysis, ORMAZABAL has set a maximum deviation of 10% in both accelerations and strains.

3.5 Results analysis

As shown in Picture 1, the process to assess a numerical analysis model requires both a modal and a seismic result correlation.

1) Criteria of FE Modal results acceptance: The virtual model is considered consistent if the calculated natural frequencies are similar to the measured ones (5% of maximum deviation) for each vibration mode. Besides, the number of calculated vibration modes must be enough to capture at least 80% of the mass in each direction.

Picture 6. Switchgear modal response



2) Modal results: For the analyzed equipment, the first two modes have an important proportion of mass involved. These two modes are: Mode 1 at 5.60Hz (95% mass in side-to-side OY direction) and Mode 2 at 20.06Hz (55% mass in front-to-back OX direction) [2] . The former natural frequencies and mode shapes match with those obtained in the resonance search tests.

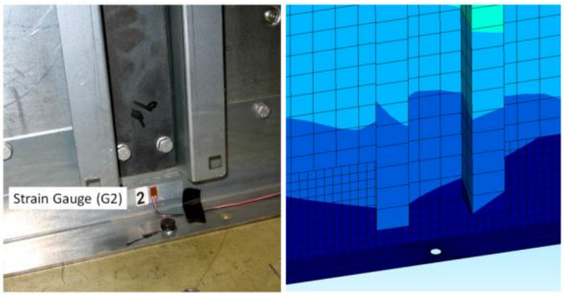
3) Criteria of FE Seismic results acceptance: The accelerations of the devices which are part of the model assembly are equal to or greater than the measured values during the test. Besides, ductile and brittle materials shall not exceed its yield strength (ductile), or the minimal stress guaranteed in flexion (brittle), provided that an accurate FE model is available.

4) Seismic results: The calculated accelerations are over the test measurements. Furthermore, the simulation model has been able to correlate accelerations within the 10% margin.

The virtual model has been also able to accurately calculate the strain measured by the strain gauges (see Picture 7).

Besides, all the structural parts of the switchgear assembly are below the maximum 1,000 micro-deformations considered as acceptance criteria[3].

Picture 7. Strain gauge (G2) position and seismic response



As stated before, to obtain accurate strain and stress results it is vital to assess that the mesh quality is enough to ensure the convergence of results, especially around the strain gauge position. Moreover, if the location of the strain gauges is close to an area where the gradient changes abruptly it is of the utmost importance to know the precise position of the gauges over the equipment.

3.6 Results extension by means of Simulation

Once the virtual model of the primary switchgear has been tuned, further Virtual Seismic Testing may be performed over the same equipment under different seismic loads, or on a similar design

[2] In the case of the OX direction, it is needed to calculate more modes to involve the 80% of the mass.

[3] The corresponding yield strength can be calculated from the strain-stress curve of the material.

but with the same seismic excitation.

4 CONCLUSIONS

This white paper advises on how to obtain further acceptance of the new Technical Specification IEC/TS 62271-210 by means of a novel methodology able to enhance the confidence on the results coming out from any seismic simulation.

The described methodology has been assessed using an already tested primary distribution switchgear, obtaining an accurate virtual model correlation with both modal and seismic measurements. Therefore, a reliable qualification of the switchgear family by combination of testing and analysis is possible.

References

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[5] IEC 62271-207, High-voltage switchgear and controlgear - Part 207: Seismic qualification for gas insulated switchgear assemblies for rated voltages above 52 kV, International Electrotechnical Commission, Ago. 2012.

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[7] IEC 62271-200, High-voltage switchgear and controlgear - Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV, International Electrotechnical Commission, Oct. 2011.

[8] IEC 62271-201, High-voltage switchgear and controlgear - Part 201: AC insulation-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV, International Electrotechnical Commission, Jun. 2006.

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