Seismic Test Qualification of Electrical Equipment — Testing Methods in Use to EDF

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SUMMARY

The testing methods in use to EDF in order to quality by test the safety equipment of the Nuclear Power Plants have moved jointly with the guide requirements in force.

At the beginning, for the 900 MW Power Plant level, the testing method in application used the single axis test by sine beat of 10 cycles according to the specifications of the guide IEEE344-71.

When the french guide UTEC 20-420 came into force we have had to define another testing method (EDF standard : HN20 E52) which utilize the single-axis test either by a sine beat of 5-cycles or by a synthetized time history.

We present here the mains criterions allowing to justify :

- The single-axis test.
- The single frequency wave (when the Initial Response Spectrum (IRS) present a narrow band).
- The use of one sine beat of 5-cycles or one synthetized time history.
- The need of taking into account the high stress level. This oligocyclic stress fatigue explains why one beat of 5-cycles may be as severe as one time history of 20 seconds (with the same level of strong response spectrum). Then, we conclude that the durating of the testing wave applied to the equipment shall be considered as a relative parameter only.
- The weight of the SSE tests by respect to the OBE tests.
- The precautions to take in order to :
  . generate and check accurately the synthetized time history,
  . choice the test frequencies when the sine beat is used.

1. Foreword

Although FRANCE is a country of average seismicity, the problem of seismical qualification of equipment has been dealt with so as to meet the safety requirements relative to the development of nuclear stations. Thus, based on the experience acquired in this field in the U.S.A. [1], EDF has been using the single-axis testing method with 10-cycle sine beat (standard EDF-HN 29-E 51) [3] for applications of the 900 MW power level unit. This wave is simple to realize and, after filtering by the buildings, is similar to the one of the seismical wave at the level of the floors on which the electrical equipment is installed.

EDF has used the implementation of the 1300 MW generation power level technical units to use the time history testing method (standard EDF-HN 20-E 52) [4] which complies with the requirements of french guide UTEC 20-420 [2] and US guide IEEE 344-75 [5].

Table I indicates the various characteristics of these two testing methods.

We indicate hereafter the definition criteria of the testing method being presently used by EDF.

2. Characteristics of standard EDF-HN 20-E 52

2.1 Equipment typical damping

Experience shows that equipment coming as cabinets (most frequent case) has a damping in the region of 5 % of critical. This value has been used as reference for the general case.

However, damping rates of 2 % or 10 % are used for some little-damped pieces of equipment (such as pipes) or highly-damped ones.

2.2 Definition of the required response spectrum (RRS)

For the test, the horizontal RRS is defined as the envelope of the various applications envisioned for all safety apparatus of the 1300 MW technical power level per generation unit.

This horizontal RRS covers the effects of the following parameters :

- ground moduli,
- various building types,
- two horizontal axes of each building,
- equipment installation levels.

When defined like this, the RRS is more conservative than the one the equipment will be actually subjected to in the event of seism (higher level, wider spectrum). It allows simplifying the testing specifications and the tests themselves and avoids their multiplication. However, an exception to this principle is accepted when this envelope-spectrum turns out to be stringent accounting for the own specificity of a piece of equipment. We define then a spectrum which is closer to the one corresponding to its location within the station (building, floor).

The vertical RRS is taken equal to the vertical spectrum at ground level, a safety margin being added.

The safe shutdown earthquake (SSE) is defined for a horizontal acceleration at ground level of 0.15 g peak.

2.3 Test type

Experience shows that the horizontal/vertical two-axis type test is not required frequently, since :

- the vertical RRS is low with respect to the horizontal RRS,
- except for specific cases, the equipment is little sensitive to vertical seismical excitation. Often, no overall equipment resonance is recorded during vertical excitation,
- the couplings between the horizontal axes and the vertical axis are low or null within the seismical frequency range, except for some specific cases (such as equipment installed on mechanical insulators).

A two horizontal axis testing would often be justified (if such testing equipment existed) since :

- the RRS are generally identical along both horizontal axes of the equipment,
- the couplings between the two horizontal axes of the equipment are rather frequent (assymetry of weights and stiffnesses) and sometines high,
- the equipment almost always shows a sometimes acute bending resonance along these horizontal axes.

It is however considered that the effects due to couplings between the horizontal axes of the equipment are compensated by the envelope spectrum described in section 2.2 and, mainly, by the fact that the two horizontal seism components at ground level are never at maximum simultaneously.

2.4 Test waves

It is possible to use a 5-cycle sine beat or a synthetized time history.

2.4.1 5-cycle sine beat

The initial response spectrums (IRS) recorded at the levels of the floors on which the equipment is installed are of narrow-band type due to the filtering performed by the structures. A 5-cycle sine beat is then suitable for simulation of the seism's effects.

The equation of this test wave is :

$$y = A.\sin\omega_p t.\sin\frac{\omega_p}{2N}t = \frac{A}{2}\left[\cos\omega_p\left(1-\frac{1}{2N}\right)t - \cos\omega_p\left(1+\frac{1}{2N}\right)t\right]$$

defined for $0 < t < \frac{2\pi N}{\omega_p}$

where :

A : is the peak wave amplitude,

N : is the number of cycles per beat,

ω_p : is the pulse at the test frequency.

To meet the criteria required in standard UTEC 20-420 (the test response spectrum (TRS) must the 3 dB band-pass of the IRS), the peak amplitude of the 5-cycle sine beat is equal to 1.1 g for EDF's applications.

Test frequencies

The test frequencies are spaced by a half-octave ($f_p = 2^{N/2}$) so as to cover the RRS. They are also applied at the equipment resonance frequencies.

Advantages and inconvenients of the 5-cycle sine beat

In practice, actual IRSs never being supplied, we are led to take as IRS the horizontal spectrums of buildings which already are envelopes of the ground modulus ranges, of several seism types and of the building responses along two horizontal axes. Consequently, the test amplitude thus defined is more conservative as is necessary (TRS 30 to 50 % higher than the RRS - see fig. I and II).

Application of the sine beat is little practical when a test of the two-axis type is necessary.

On the other hand, the stress cycles imposed to the equipment are well known with this type of wave and the critical frequencies are localized accurately.

2.4.2 Synthetized time history

Realization

Several time history creation methods can be envisioned.

The time histories are created here from decaying sines one-sixth of an octave apart, possessing amplitudes and appearance times such that the RRS be covered.

The equation of this time history is :

$$y = \sum_{i=1}^{N} \alpha_i A_i \, e^{-\xi_i \omega_i (t - t_i)} \cdot \sin \omega_{di} (t - t_i)$$

where :

α_i = ±1 (appearance phase of component i),

t_i = appearance delay of component i,

N = total number of components,

A_i = amplitude of component i

ξ_i = decay rate of component i,

ω_{di} = pulse of component i (or decayed free pulse),

$\omega_i = \omega_{di} \, (1 - \xi^2)^{-1/2}$ = undecayed free pulse of component i.

Characteristics of the time history and its control

Duration : 20 seconds

This duration is obtained through randomization of a base signal generated over 10 seconds.

Analysis fineness :

It depends on the equipment damping. The time history must be generated and controlled with a resolution of 1/6th of an octave for a decay of 5 % (1/12th or 1/3rd of an octave if the equipment damping is equal to 2 or 10 %).

High-level stress cycles (higher than 70 % of the maximum RRS value)

The number of high-level stress cycles has been selected so that the effect of a time history be comparable to the one of a 5-cycle sine beat [6].

The number of high-level stress cycles has been obtained theoretically by adjusting :

- the time delays relative to the appearance of two components close to 1/6th of an octave,
- the decay rate of decaying sines.

Advantages and drawbacks of this type of wave

Testing performed with a time history calls for very sophisticated control means.

It is difficult to obtain a TRS with a good accuracy (accuracy equal to 30 to 50 %).

The high-level stress cycles applied to the equipment are poorly known (unless they are calculated theoretically beforehand).

The synthetized time history is recommended when the RRS is of wideband type ; when several equipment modes are coupled or when two-axis tests are required.

2.5 Number of tests

So as to simplify the implementation of the tests and to reduce their cost, five SSE-level tests are applied (instead of one SSE-level test and five OPE-level (Operating Basis Earthquake) tests as required in the guidelines) per equipment axis.

The level of the OBE being equal to one-half the one of the SSE, the effects on the equipment are not weighted anymore. An additional safety margin is created by the application of four SSEs instead of five OBEs.

3. Conclusions

We have attempted to simplify the tests and to lower their number and cost while remaining in compliance with the guidelines.

Selection of the test wave mainly depends on the type of test specified (single or two-axis).

For a single-axis test type, the two test methods lead to comparable results.

Table I : Characteristics of test methods HN20 E51 and HN20 E52.

Standard / Characteristic	HN 20 E51	HN 20 E52
- Reference guideline	IEEE 344-71	UTEC 20-420 (and IEEE 344-75)
- Power level	900 MW	1300 MW
- Year of applicability	1974	1979
- Test type	Single-axis	Single-axis (two-axis if necessary)
- Test wave	10-cycle sine beat	5-cycle sine beat (single-axis only) / Synthetized time history (single- or two-axis)
- Spectrum (for 5 % damping)	- 4.5 g horizontal - 3 g vertical	- 5 g horizontal - 1.4 g vertical (see fig. I, II)
- Test frequencies	- preset frequencies 1.25 - 1.75 - 2.5 - 3.5 - 5 - 7 - 9.5 - 13 - 18 - 24.5 Hz- - equipment resonance frequencies	- preset frequencies $1 - \sqrt{2} - 2 - 2\sqrt{2} - 4 - 4\sqrt{4} - 8$ and 12 Hz - decaying sines, 1/6th octave apart - equipment resonance frequencies
- Number of tests	5 SSEs*	5 SSEs*

* SSE = Safe Shutdown Earthquake.

References

[1] Standard IEEE 344-71 - Guide for seismic
Qualification of class 1E Equipment for Nuclear Power Generating Stations.

[2] French standard UTEC 20-420 - Guide for equipment seismic testing procedures.

[3] EDF Standard HN2OE51 (Note HJ.42-4455).
Code d'essai de tenue des matériels aux séismes (Testing method for seismic qualification equipment).

[4] EDF Standard HN2OE52 -
Tenue aux séismes des matériels de classe 1E des centrales nucléaires des paliers 1300 MW et au-delà. Essais de type mono-axial.
(Seismic qualification of class 1E equipment of 1300 MW power plant and beyond. Single-axis testing).

[5] Standard IEEE 344-75 -
Recommended practices for seismic qualification of class 1E Equipment for Nuclear Power Generating Stations.

[6] FABRIES - Note P.31-99 -
Comparaison des effets de trois méthodes d'essais de qualification de matériel aux séismes à partir d'un cas concret.
(Comparaison of the results of three seismic testing methods for equipment qualification by actuel case).

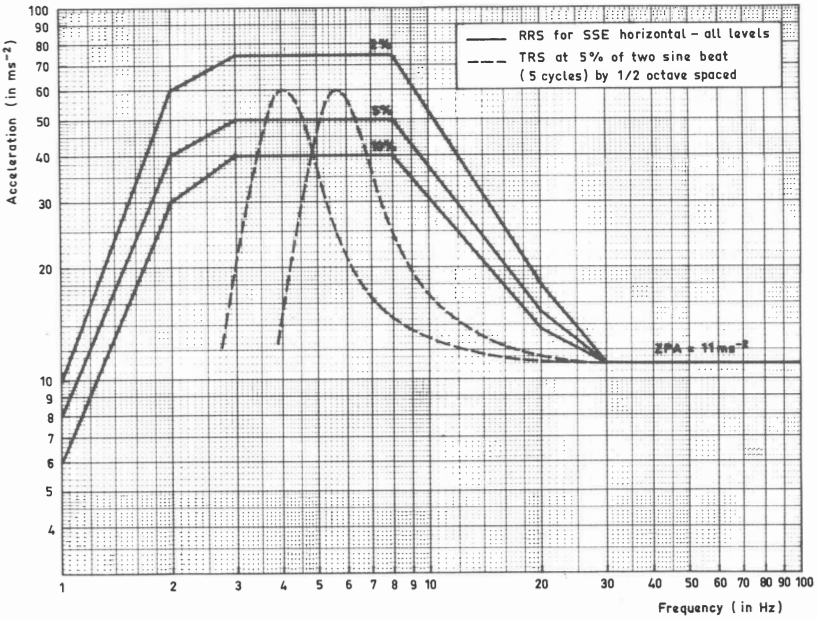

Figure 1 : Shape of the horizontal RRS.

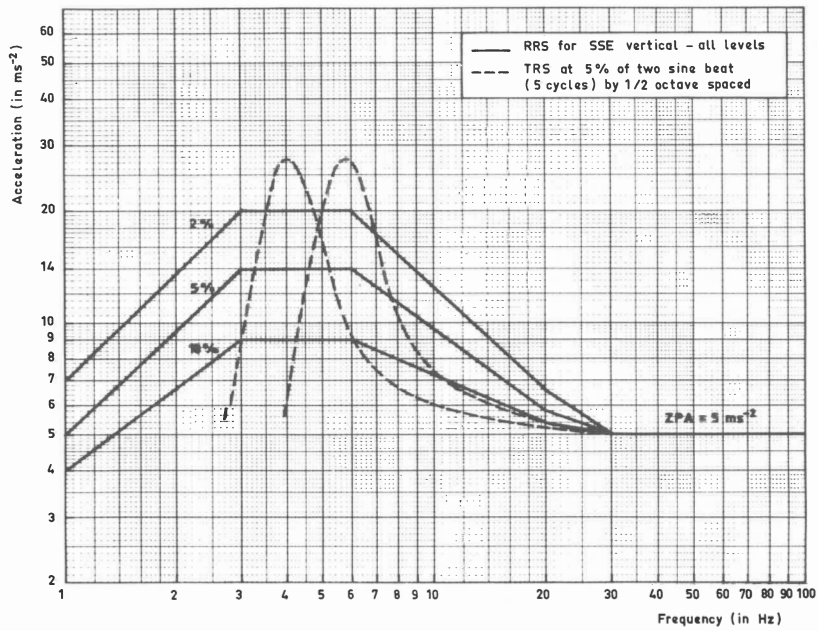

Figure 2 : Shape of the vertical RRS.