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Seismic Qualification Tests on a CCV 245 kV capacitor voltage transformer

Test Report

Proj. TER-2661; Doc. RAT-TER-322/00

on behalf of ALSTOM Belgium S.A. – Beyne-Heusay, Belgium

Order n. R/100329, 19/10/99 - ISMES Prot. n.5930, 20/10/99

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SUMMARY

The present document refers to the tests carried out at ISMES, Seriate (Bergamo), Italy, on behalf of ALSTOM Belgium S.A., Beyne-Heusay (Belgium), to seismically qualify n. 1 capacitor voltage transformer type CCV 245 kV.
The tests were performed by Mr. R. Baldassarri.
The test report consists of 14 pages of text, 4 photos and 50 figures.
In the Chapter 1, the summary of main test results is reported. Chapters 2 through 10 deal about: general information about the tests, equipment identification and mounting, testing apparatuses, test procedures and results, conclusions and list of annexed figures and photos.

DISTRIBUTION LIST

- ALSTOM Belgium S.A., Beyne-Heusay (Belgium)

DESCRIPTION OF REVISION

- Rev. 0, 2000, January: first issuing

INDEX

1. SUMMARY OF MAIN TEST RESULTS

TABLE 1 – Summary of Max absolute values recorded during the Static Tests and Time-History Tests

Test No.	Test Description	Axis	Max acceleration [g]			Max Strain [με] (pos.)	Max. Top Deflection [mm]
			Control Pos. AT	C.G. Pos. A1	Top Pos. A2		
1	Static load 1726 N	X	n.r.	n.r.	n.r.	55 (E2x)	5,6
2	Static load 1718 N	Y	n.r.	n.r.	n.r.	49 (E4y)	5,2
7	Static load 1600 N	X	n.r.	n.r.	n.r.	50 (E2x)	5,1
6	Time History Test X, Y and Z 0dB level; 0,75g ZPA	X	0,86	0,84	2,00	63 (E2x)	n.r.
		Y	0,82	0,86	1,92		n.r.
		Z	0,43	n.r.	0,44		n.r.

Note: n.r. = channel not recorded.

TABLE 2 – Main resonance frequencies and relevant dynamic responses

	X axis; Test n.3; 0,05g		Y axis; Test n.4; 0,05g		Z axis; Test n.5, 0,05g	
Measuring position	Freq. [Hz] (a)	Response (b)	Freq. [Hz] (a)	Response (b)	Freq. [Hz] (a)	Response (b)
A1x	9,1	4,60	9,4	2,24	- - -	- - -
A1y	10,0	2,11	9,5	4,29	- - -	- - -
A2x	9,1	23,35	9,4	11,62	9,6	3,94
A2y	10,0	10,61	9,6	21,19	10,3	3,37
E1x	9,1	27,1	9,4	13,7	- - -	- - -
E2x	9,1	29,7	9,4	15,2	- - -	- - -
E3y	10,0	13,0	9,6	26,3	- - -	- - -
E4y	10,0	13,1	9,6	24,9	- - -	- - -

(a) The symbol "- - -" means: no significant values detected. For the acceleration signal, the table reports only the frequencies with a corresponding amplification factor > 2.

(b) The column "Response" reports the values drawn from relevant recordings, at the corresponding frequencies. These values are: amplification factors (dimensionless) for the accelerometer positions; strains (expressed in με) for strain gauge positions.

2. REFERENCE DOCUMENTS

|1| ALSTOM Belgium purchase order n. R/100329, 19/10/99.

|2| ALSTOM drawing No. 8162569, Rev. C, 15.03.99

|3| INGENDESA ETGI-1.020, Rev. 1, 1997: "Especificationes Técnicas Generales. Diseño Sísmico – Versión Resumida".

|4| EDELCA ETGS/PAS-001, Rev. 0, 1991: "Especificationes tecnicas generales de subestaciones – Consideraciones antisismicas".

|5| IEEE Std 693-1997: "IEEE Recommended Practice for Seismic Design of Substations".

|6| IEC Publication 61166, 1993: "High-voltage alternating current circuit-breakers. Guide for seismic qualification of high-voltage alternating current circuit-breakers".

|7| IEC Publication 60068-2-6, 1995: "Environmental testing. Part 2: Tests method. Test Fc: Vibration (sinusoidal)".

|8| IEC Publication 60068-2-57, 1989: "Environmental testing. Part 2: Tests method. Test Ff: Vibration - Time history method".

3. GENERAL INFORMATION

3.1. Customer

- ALSTOM Belgium S.A.
  54, Rue de Magnée
  4610 Beyne-Heusay – Belgium

3.2. Tested equipment

- Capacitor voltage transformer type CCV 245 kV, serial number No 99-XE70800/001.
  - Total weight: 4000 N.
  - Height: 2870 mm
  - Height of Center of Gravity (CG): 927 mm
  - Reference drawing: doc. |2|

The voltage transformer under test, hereinafter called "unit", is shown in the annexed photos.
During all the performed tests, the unit was oil filled (oil weight: 740 N).
The unit was tested without the pedestal, mounted directly on the shaking table.

3.3. Test date

- 1999, May 31st to June 1st.

3.4. Laboratory location [1]

- ISMES S.p.A.
  Via Pastrengo, 9
  24068 SERIATE – BERGAMO, Italy
  Phone no. +39 035 307111
  Fax no. +39 035 302999

3.5. Witnesses

- Mr. Huges Regal, ALSTOM France.

[1] The Quality System of ISMES for in-site investigations and laboratory tests in structural field is certified in compliance with UNI EN ISO9001 standard (certificate CSQ N.9151.ISM1 – IQNet No. IT-0538, July, 20th, 1999).

4. MOUNTING AND MEASUREMENTS

4.1. Mounting

The unit was fixed, without pedestal, to the ISMES "MASTER" shaking table as shown in Photo 1, by means of 4 M18 bolt with a tightening torque of 200 Nm.

4.2. Orientation and measuring positions

The reference directions and the measuring positions are shown in FIG. 2.
Reference directions were defined as: horizontal X, Y and vertical Z.
The identification of measuring positions was made using three characters:

- 1st character, letter: type of measurement A = acceleration
  E = strain
  D = deflection/displacement
  F = load
- 2nd character, number: transducer location on the unit (FIG. 2) [2]
- 3rd character, letter: sensibility direction of transducer (X, Y or Z axis).

The strain gauges always measured the strains in vertical Z direction due to the effects of the bending moment: in this case, the last character (X or Y) identifies the plane (XZ or YZ) where the relevant bending moment acts.
Details of measuring positions are shown in the annexed photos.

[2] For the motion control position on the shaking table, a letter "T" was used instead of a number.

5. TESTING AND ACQUISITION PROCEDURES

The tests were performed with reference to docs. |3|, |4|, |5| and |6|.
The following test sequence was applied:

- Static Tests: monoaxial static load applied, not simultaneously, along X and Y directions
- Sweep Sine Tests (doc. |7|): monoaxial excitation applied, not simultaneously, along X, Y and Z directions
- Seismic Tests (doc. |8|): triaxial multifrequency excitation (time-history method).

FIG. 3 shows the chronological sequence of the tests.

5.1. Static Tests (calibration tests)

The aim of static tests was:

- to calibrate the measuring chains relevant to the strain gauges on the porcelain bushing of the unit
- to verify the linearity of the response of the porcelain bushing when loaded
- to verify the structural integrity of the unit at the end of the seismic triaxial tests.

A static load was applied to the top of the bushing and it was increased up to [3] 1700 N or a strain value equal to 50 με.
In detail, the following tests were performed:

- Test n. 1: X direction
- Test n. 2: Y direction
- Test n. 7: X direction (final test after the seismic triaxial tests)

At the end of the seismic triaxial tests, according to the Customer and on the basis of the results of test n. 7 in X direction, no static test was performed in Y direction.
During these tests, the applied load, the deflection at the top of the porcelain bushing and the strains at the base of the bushing itself were measured.

5.2. Sweep Sine Tests

In order to check the resonance frequencies and damping ratio of the unit (at the first vibration mode), a frequency sinusoidal scanning was performed in each of the three reference directions X, Y and Z, not simultaneously (Tests n. 3÷5).
The tests were performed, in accordance with doc. |7|, as follows:

- frequency range: 0,5÷35 Hz
- sweep rate: 0,5 octave/min
- constant peak excitation level: 0,05 g
- cut-off frequency of low-pass filters: 60 Hz

Signals coming from the measurement positions were recorded as "absolute response functions" in the frequency domain, from which, for the acceleration signals only, the "absolute transfer functions" were calculated. [4]

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[3] The reported values are only "reference values".

[4] The *absolute response function* in the frequency domain is the amplitude (modulus and phase) of the component of the unit response having the same frequency of the fundamental of the excitation. The absolute response function in the frequency domain is a complex function of a real variable.
The *absolute transfer function* is the ratio between the absolute response function in a measuring position (output) and that in the control position (input). Being the absolute response function a complex quantity, the absolute transfer function was calculated, frequency by frequency, through the ratio of the moduli and the difference of the phases.

5.3. Seismic Tests

Triaxial multifrequency tests, in accordance with doc. |8|, were carried out with simultaneous but independent inputs into the horizontal X and Y and vertical Z axes, each producing the Required Response Spectrum (RRS) along that axis.
The RRS used during the tests was derived from the envelope of the spectra reported in docs. |3|, |4|, |5| and |6|, on the basis of the following considerations:

- Doc. |3| requires, for the horizontal X and Y directions, a Zero Period Acceleration (ZPA) equal to 0,75 g (obtained multiplying the whole RRS for a factor 1,5, being the unit tested without supporting structure) and, for vertical Z direction, a ZPA of 0,3 g;
- Doc. |4| requires a ZPA equal to 0,5 g for the horizontal directions and a vertical spectrum obtained from the horizontal RRS multiplied by 2/3 (ZPA = 0,33 g);
- Doc. |5| requires a ZPA equal to 0,5 g for the horizontal directions (level "High") and a vertical spectrum obtained from the horizontal RRS multiplied by 0,80 (ZPA = 0,4 g).
- Doc. |6| requires a ZPA equal to 0,5 g for the horizontal directions (severity AF5) and a vertical spectrum obtained from the horizontal RRS multiplied by 0,50 (ZPA = 0,25 g).

The resulting RRS's used for the seismic tests are reported in FIG. 4.

Main characteristics of the synthesized reference time histories were as follows:

- synthesis made by ISMES starting from RRS defined as indicated above, with 1/12 octave of frequency bandwidth and 2% damping
- peak accelerations: 0,75 g (X and Y directions)
  0,40 g (Z direction)
- frequency content: 1÷35 Hz [5]
- strong part of time history: >30 s
- time history duration: 65,532 s
- sampling rate: 250 Hz

Main characteristics of the digital recordings of the time histories were:

- sampling rate: 250 Hz
- n. of points: 16384
- duration: 65,532 s
- cut-off frequency of low-pass filters: 60 Hz

Test Response Spectra (TRS) were computed on the digital recordings of the control pos. AT, in a frequency range 0,5÷35 Hz, with 1/12 octave of frequency bandwidth and 2% damping.
Time history tests were performed increasing the test level up to get not only the dominance of the RRS by the TRS, but also a peak acceleration higher than the spectral ZPA (= Zero Period Acceleration): see FIG. 3 for the performed level and para 7.4 for the test results.

[5] The lower bound of the frequency range was fixed to 1 Hz, instead of 0,5 Hz, in order to avoid displacement beyond the limits of the shaking table.

6. TESTING EQUIPMENT

The block diagram relevant to the test equipment (excitation equipment, measuring transducers, excitation control and data acquisition/processing instrumentation) is shown in FIG. 1.

6.1. Excitation equipment

- ISMES "MASTER" Triaxial 4m×4m Shake Table:
  - max peak stroke 100 mm
  - max peak sinusoidal velocity 0,44 m/s
  - max peak acceleration 2 g
  - frequency range 0,5÷120 Hz

6.2. Measuring transducers

The calibration certificates of the employed transducers, issued by the Calibration Laboratory of ISMES (SIT center N. 30), are available in the archives of the ISMES Structural Engineering Area.
The transducers were as follows (see FIG. 2 for the measuring positions):

Measuring Position	Transducer Type	Manufacturer	Model	S/N	Note
ATx	Accelerometer	Endevco	2262CA-25	TH81	Dynamic tests
ATy				TM49	
ATz				10049	
A1x				10103	
A1y				10124	
A2x				10194	
A2y				10196	
A2z				10216	
A3x				10234	
A3y				10458	
A3z				A57P	
E1	Strain gauge	Micro Measurement	MM-CEA-06-250UN-350		Static and dynamic tests
E2			MM-CEA-06-250UN-350		
E3			MM-CEA-06-250UN-350		
E4			MM-CEA-06-250UN-350		
F1	Load cell	Tokyo Sokki	TCLZ-500KA	NY0485	Static test
D1x	Displacement transducer	Rayelco	P 20B	5346	
D1y				5351	

6.3. Excitation control and data acquisition/processing equipment

The control of the motion of the shaking table, the acquisition of the tests data and the calculation of Test Response Spectra (TRS) were made by ISVC-MC544 system, serial no. 1-21-22-2613:

- manufacturer: Concurrent Computer France S.A.
- 32 Mbytes RAM memory (3 CPU)
- 16 bit A/D & D/A converter
- 10 V max analog input voltage
- 5 V max digital output voltage
- 32 analog input channels
- 6 digital output channels
- 1 Gbyte disk memory

7. TESTS RESULTS

7.1. General remarks

All the performed tests are summarized in FIG. 3.
The recordings of the test results are reported in FIGS. 7÷50.

7.2. Static Tests

The results obtained from the static test are summarized in the following table:

	Axis	Load [N]	Top Deflection [mm]	Max Strain [με]	Figs.
Test n. 1	X	1726 (F1x)	5,6 (D1x)	56 (E2x)	7, 8
Test n. 2	Y	1718 (F1y)	5,2 (D1y)	49 (E4y)	9, 10
Test n. 7 (final test)	X	1600 (F1x)	5,1 (D1x)	50 (E2x)	49, 50

The values reported in the table are drawn from the relevant figures, in correspondence of the max load value.
No significant variation was found during the final tests, with respect to the initial tests.

7.3. Sweep Sine Tests

Response curves and transfer functions relevant to the Resonant Frequency Search are illustrated in the following figures:

	Direction	Control position	Measuring positions
Test n. 3	X	Fig. 11	Figs. 11÷18
Test n. 4	Y	Fig. 19	Figs. 19÷26
Test n. 5	Z	Fig. 27	Figs. 27÷34

The main resonance frequencies of the unit are summarized in FIG. 5, with relevant amplification factors (dimensionless values) for accelerometer positions and response values (expressed in με) for strain gauge positions.
The unit damping was calculated at the first resonance frequency using the following formula, based on the measurement of the width of the respective resonance peak ("half-power bandwidth"):

$$\zeta = \frac{f_1 - f_2}{2 \cdot f_0} \cdot 100$$ where:

- ζ is the percent damping (%)
- f_0 is the resonance frequency value
- f_1 and f_2 are the frequency values corresponding to the "half-power points", determined from the peak response value at f_0 divided by $\sqrt{2}$.

The obtained damping values were the following:
- a medium value of 1,9% in X direction and 3,3% in Y direction, with a minimum of 1,6% in pos. A1x during the test n. 3, X axis.

7.4. Seismic Tests

For the seismic test, the 2% damping value was chosen on the basis of the results of the sweep sine tests, according to the Customer.

The comparison between Test Response Spectra (TRS) and Required Response Spectra (RRS), the time histories at the shaking table and the response time histories recorded during the seismic tests are illustrated in the following figures:

Test No.	Excitat. level	Damping	Base motion and comparison TRS/RRS	Response time-histories
6	-6 dB	2%	35÷37	38÷41
	0 dB		42÷44	45÷48

A complete envelope of the RRSs was achieved in the frequency range 1÷35 Hz [6].
The strong part of each imposed time history (pos. AT), as defined in doc. |8|, was as follows:

- X axis: 41,51 s
- Y axis: 41,73 s
- Z axis: 41,20 s

The peak values of the acceleration recorded at the base of the unit (pos. ATx, ATy and ATz) are the following:

Test No.	Excitat. level	Ref. Acceleration [g]	ATx [g]	ATy [g]	ATz [g]
6	0 dB	0,75 (X and Y); 0,4 (Z)	0,86	-0,82	0,43

The recorded peak values for all the measuring positions are reported in FIG. 6.

No structural damage was identified on the unit by a visual inspection performed at the end of the seismic tests.

[6] See note 5 of item 5.3 relevant to the frequency content of the excitation.

8. CONCLUSIONS

The results obtained from the tests are summarized as follows:

- TRSs envelope RRSs in the frequency range 1÷35 Hz.
- Max peaks of the recorded time history are higher than the reference ZPA.
- Strong part duration are higher than 30 s.
- No structural damage was ascertained.

9. PHOTO DOCUMENTATION

Photo 1: General view of the unit on the shaking table.
Photo 2: Detail of measurement positions A2 (Top).
Photo 3: Detail of measurement positions E2x and E3y.
Photo 4: Detail of measurement positions A1 (CG), A3xyz, E1x and E3y.

10. LIST OF FIGURES

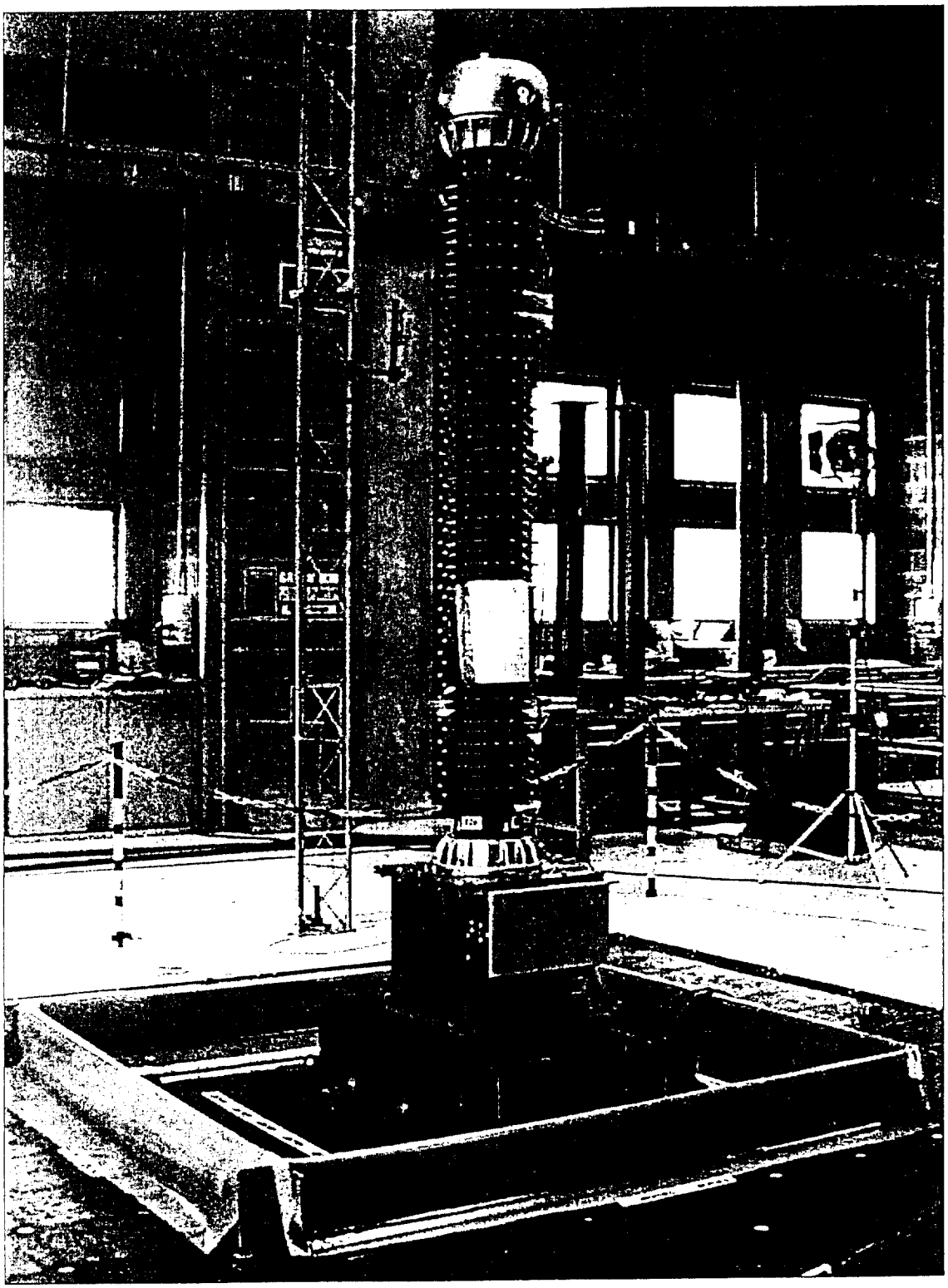

PHOTO 1