THE SEISMIC QUALIFICATION OF ELECTRICAL EQUIPMENT SYSTEMS IN LOVIISA NPP AUTOMATION RENEWAL PROJECT

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ABSTRACT :

This paper describes the seismic strength qualification program for the electrical equipment systems to be renewed in Loviisa nuclear power plant automation renewal project.
The test type of the seismic strength of electrical equipment is the shaking table test for Safe Shutdown (SSE) earthquake. The aim of the test is to demonstrate the seismic strength of electrical equipment according to YVL2.6 standard of Finnish Radiation Protection Centre (STUK). In the test program the adequacy of the excitation time history of the shaking table is secured with an appropriate coefficient in which case it is also possible to quantify the protection margins of the seismic strength. In the case when one dimensional shaking table is used the three dimensional strength of the equipment item is secured by augmenting the test excitation with appropriate coefficients. In case of need, the proper three dimensional testing is used for validating the results of one dimensional test. The detailed test program follows the criteria laid out in the IEC – 60980 [1] and IEC - 60780 [2] standards.
The scope of the testing program is the six most important electrical equipment item types which are to be renewed in the scope of the renewal project. The basic data of an equipment item type to be tested is as follows: 1) the location inside the plant, 2) the description of the structure of the item; 3) connections to other equipment; 4) the functional criteria for accepted performance.
The end result of the test for each equipment item is the testing report describing the detailed conduct of each test and the behavior of the test item during the test and conclusion concerning the seismic adequacy of the item.

KEYWORDS: automation renewal project, seismic strength of electrical equipment, shaking table

1. Introduction

This paper deals with the electrical equipment seismic qualification task connected with the automation renewal project of Loviisa nuclear power plant. The Finnish Nuclear Regulatory Agency (STUK) required the evaluation of the seismic robustness of the electrical equipment, which are to be installed in the newly constructed buildings of Loviisa nuclear power plant automation renewal project. The purpose of this evaluation program was to ensure the seismic safety of the plant. Taking into account the fact that the electrical cabinets to be installed in the new buildings represented so called industry quality with conventional structural design and with conventional components, the test program was initiated to demonstrate the seismic robustness of the equipment. The program and testing procedures were developed and the corresponding document was submitted for regulator for approval.

The equipment to be tested was chosen in such a way that it presented adequately the whole chain of electric power distribution in the automation renewal project. The test program was drawn up based on YVL2.6 [3] nuclear regulatory guide. The instrumentation and recording devices used in the qualification tests were set up according to the reference [4]. The support structures used to fix the equipment to the shaking table were designed so that they were similar to the supports used in actual installation of the devices. The acceleration sensors were so located in the shaking table and in the vicinity of supports fixing the device to the table that it was possible to assess the strength of the supports.

The design response spectrum to be used in the equipment qualification process was chosen to be the envelope curve of all floor response spectra that have been calculated for the new buildings in the automation renewal project. The separate envelope curves were developed for horizontal and vertical directions. The relative damping coefficient for the envelope curves was 2%. The conservative synthetic acceleration history was generated with the help of the design spectrum for horizontal direction and for vertical direction. The acceleration histories were used as the control signals of the shaking table. The shaking table was bi-axial and it was possible to excite the table only in one horizontal direction. To compensate for the missing second horizontal direction the acceleration history of the existing horizontal direction was multiplied on a number of 1.4.

2. General description of the experimental test program

Five different typical electrical equipment categories were tested. The categories to be tested were: (2) Rectifier cabinet with the equipment identification notation of EK; (2) 400VAC alternate current switch cabinet with the equipment identification notation of 22FV13VO012; (3) 24VDC direct current switch gear cabinet with the equipment identification notation of DS; (4) the alternate current switchgear cabinet for air conditioning with the equipment identification notation of 22FV08J0022; (5) the battery fuse box with the equipment identification notation of 20EK86.

In the tests of the EK rectifier neither electric interference nor structural damages was observe so the rectifier passed the test acceptably. After the seismic tests the device was sent for further functional testing to the manufacturer. The aim of these additional factory tests was to investigate if any changes had been taken place in the electric properties of the rectifier. The factory tests did not indicate any changes in the electric properties of the rectifier.

In the test of the 400VAC alternate current cabinet there were not observed any interruptions in the distribution of electricity, not any changes in the isolation state of the cabinet nor any structural damages. The resonance frequencies changed during the test only insignificantly. The fastening of the cabinet was made by welding. The horizontal supports in the cabinet upper edge restricted distinctly the movements of the cabinet.

In the test of the 24VDC direct current switch gear cabinet there were not observed any interruptions in the distribution of electricity, not any changes in the isolation state of the cabinet nor any structural damage. The resonance frequencies of the cabinet changed indicating the property change of the structures of the cabinet during the test but the property change did not affect the operation of the cabinet and no visible damages were detected.

In the test of the the alternate current switchgear cabinet 22FV08J0022 there were not observed any interruptions in the distribution of electricity, not any changes in the isolation state of the cabinet nor any structural damage. Because the cabinet is not fixed from its central part in its actual plant installation, the supporting structures were reduced to horizontal girders which were made from steel rods with square cross-section.

No structural damage was observed in the testing of accumulator fuse box 20EK86.

3. Detailed description of qualification test in case of the rectifier (EK)

3.1 Test equipment

The test is carried out by biaxial servo-hydraulic shaking table which is described in Figure 1. A schematic sketch showing the rectifier, the test directions and the locations of the response accelerometers is given in Figure 2. The acceleration responses of the test specimen were measured by tri-axial piezoelectric accelerometers with signal conditioner units and by single axis piezoelectric accelerometers with signal conditioner units. The acceleration signals were sampled by a data acquisition system built into the control system of the testing system console.

For functional monitoring of the rectifier during the seismic test runs the input side of the rectifier was connected to 3-phase 400VAC and its output was loaded with a resistive load of approximately 0.15752. The current was about 183 A and the output voltage 28.75V. During the seismic test runs the NC contacts K1 (Main contactor), K36 (Switch-off alarm), K39 (Remote alarm) and K54 (Remote Switch-on) were monitored with respect to contact bounces. The monitoring was done by a Programmable Logic Controller. The circuit used for monitoring the contact function of a normal closed contact is presented in Figure 3. If the contact in the monitoring circuit opens 24VDC signal to the input of the PLC disappears. The timer will then start and after 3ms the output to the PLC relay 1001 will be affected. By the hold circuit the relay remain affected even if the contact achieves its closed state.

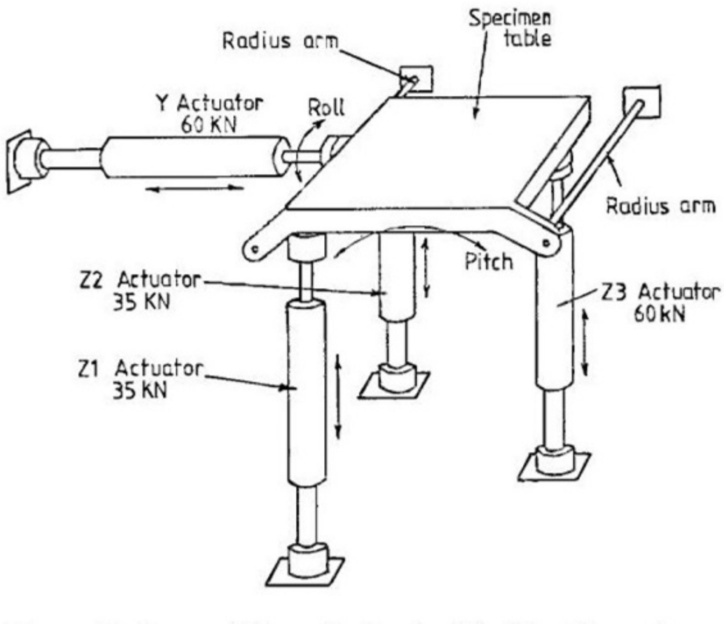

Figure 1. Schematic sketch of the biaxial shaking table

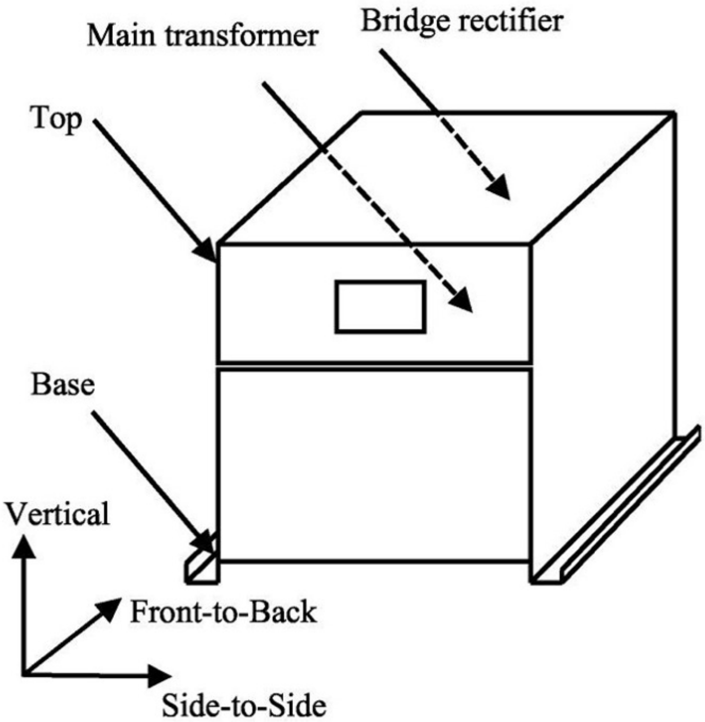

Figure 2. A schematic sketch of the test object showing the test directions and the locations of the response accelerometers

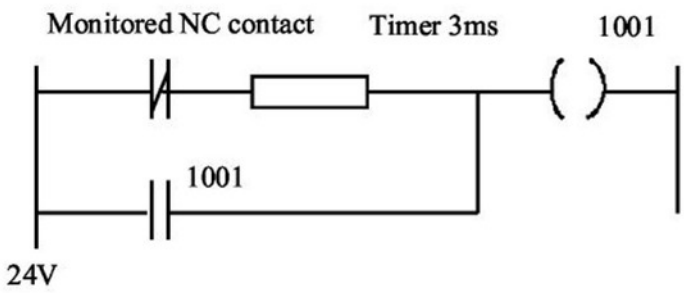

Figure 3: The circuit used for monitoring the functional properties of EK rectifier

4. Excitation for Seismic qualification tests of EK rectifier

The earthquake testing was done with multi-frequency biaxial excitation. Test runs with the rectifier rotated 90° around its vertical axes were performed so that the excitation in both the Side-to-Side &Vertical directions and the Front-to-Back & Vertical directions were obtained. To define the bi-axial excitation for the shaking table the envelope floor spectra for new buildings in the automation renewal project were used. The time histories, fitted to these envelope spectra were used as drive signals to the shaking table. The horizontal and vertical excitation spectra are shown in Figures 4 and 5. The photograph of the EK rectifier test specimen is given in Figure 6.

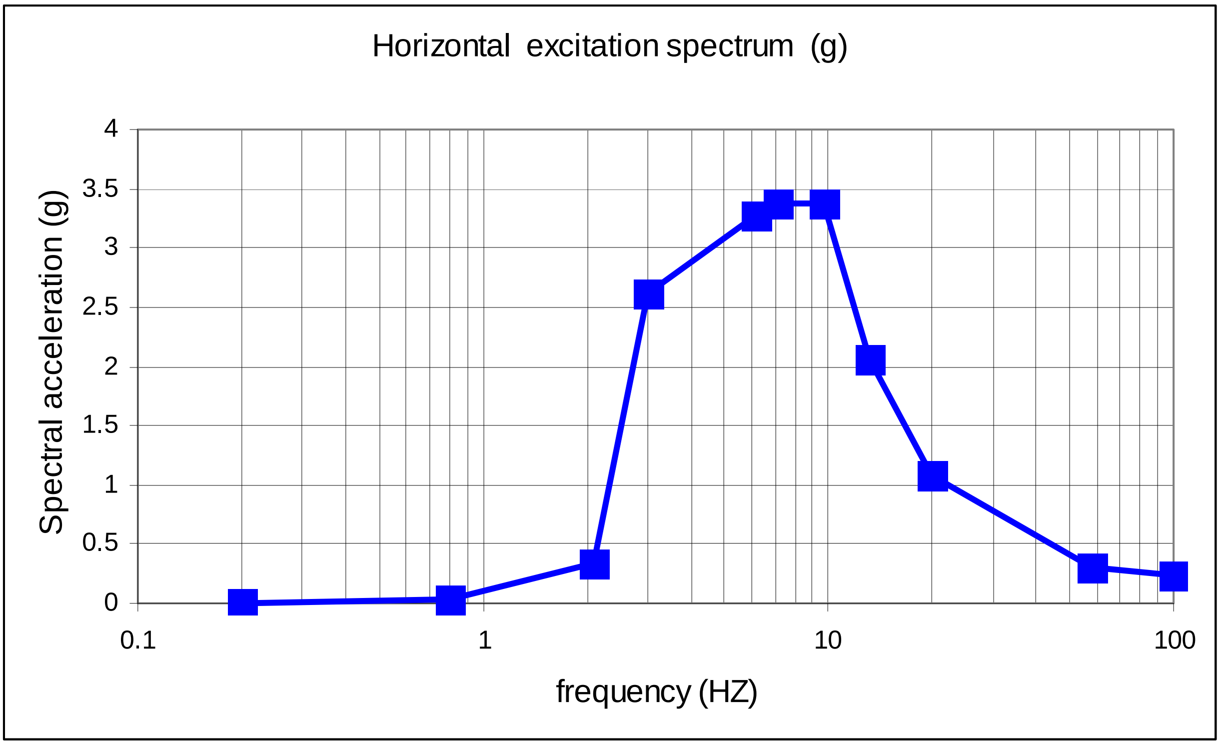

Figure 4. The excitation spectrum for the shaking table in the horizontal direction

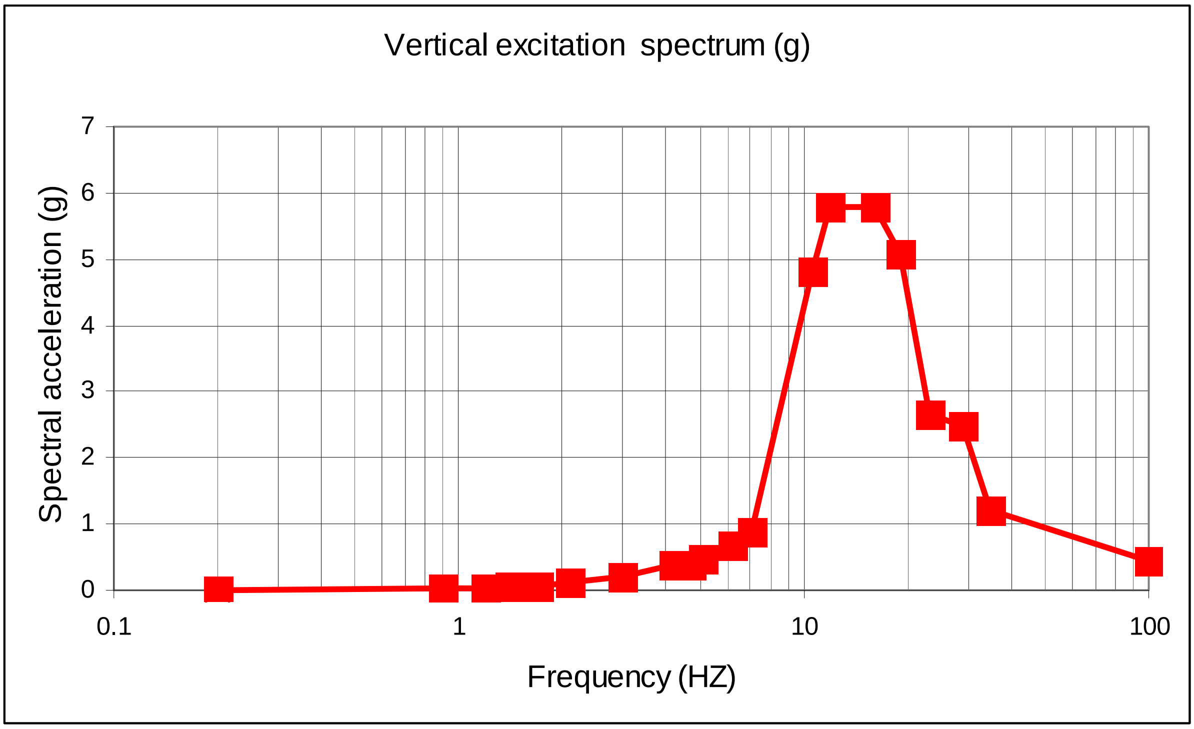

Figure 4. The excitation spectrum for the shaking table in the vertical direction

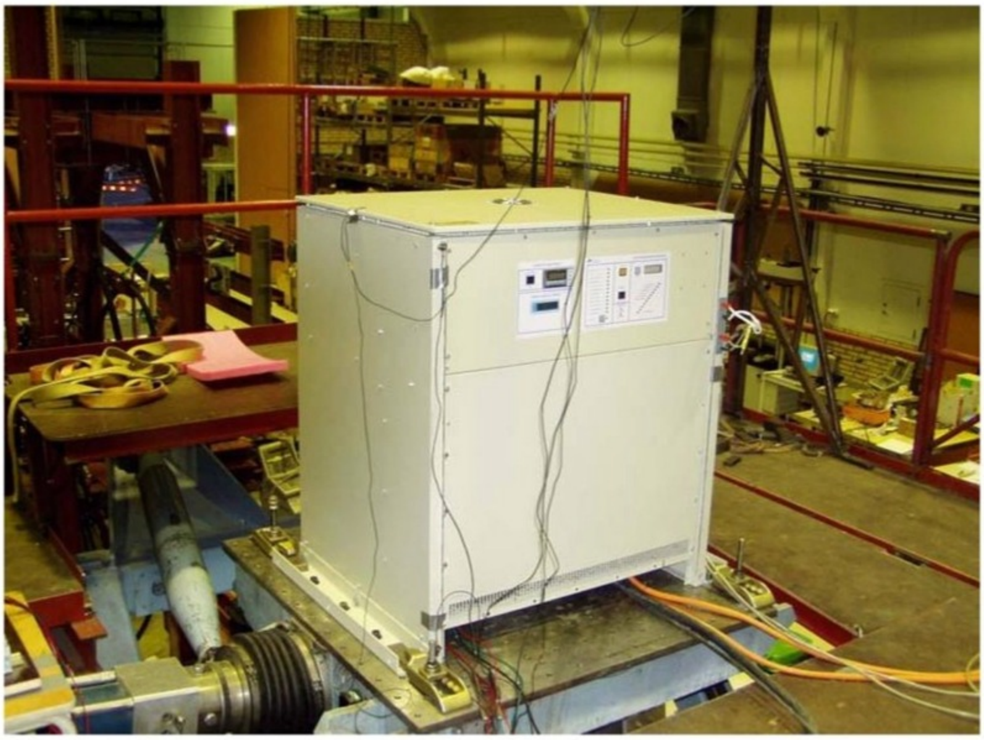

Figure 6. The EK rectifier mounted on the shaking table for testing in the Side-to-Side & Vertical directions

5. Results of the seismic qualification of EK rectifier

The result presentation contains recorded acceleration time histories and plots of the response spectra processed for monitored locations in test specimen. The summary of all recorded results during the seismic qualification of EK rectifier is shown in Table 1.

Test#:	Excitation direction	Sensor Location & Direction
#03	Side-to-Side & Vertical	Shaking Table Vertical Shaking Table Horizontal Rectifier Top Side to Side Rectifier Top Vertical Rectifier Base Side to Side Rectifier Base Vertical Point A Vertical (Main transformer) Point B Side to Side (MainTransformer)
#08	Front-to-Back & Vertical	Shaking Table Vertical Shaking Table Horizontal Rectifier Top Front to Back Rectifier Top Vertical Rectifier Base Front to Back Rectifier Base Vertical Point A Vertical (Main transformer Point B Front to Back (MainTransformer) CFB (Bridge rectifier)

Table 1 EK rectifier recorded results from the seismic qualification test runs

The test results and corresponding amplifications in the graphical form enumerated in Table 1 are presented in Figures 7 and 8.

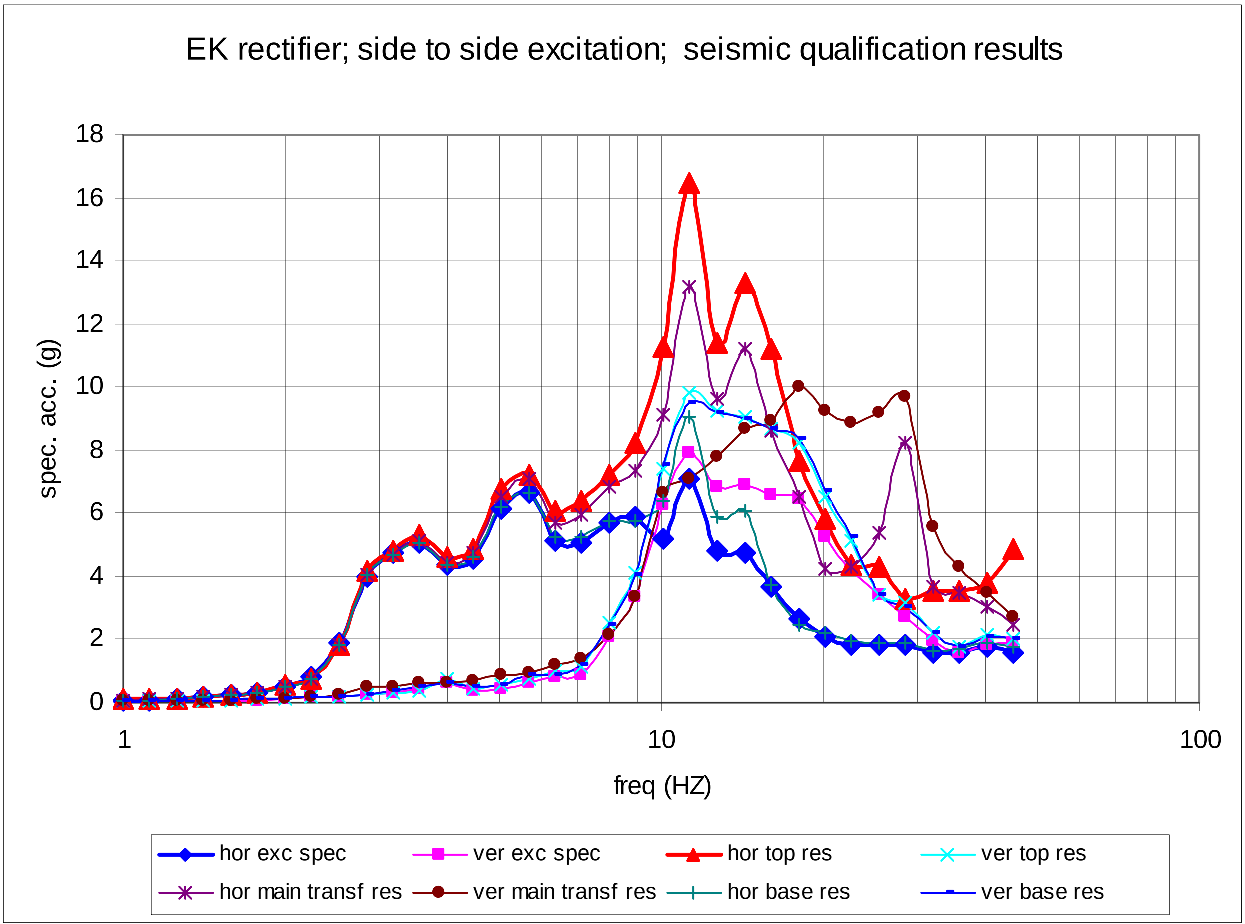

Figure 7. Seismic qualification test results for EK rectifier in graphical form; Excitation direction side to side

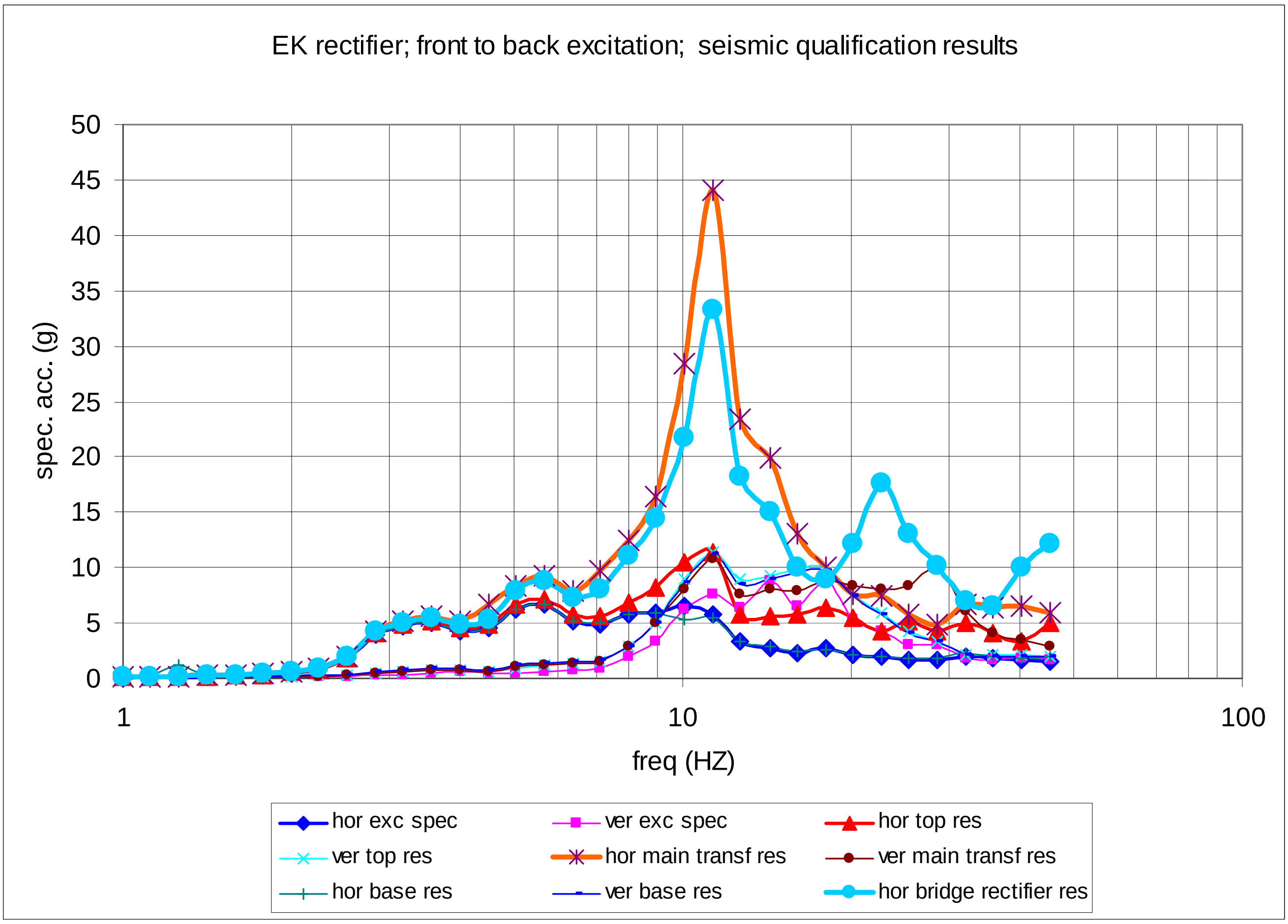

Figure 8. Seismic qualification test results for EK rectifier in graphical form; Excitation direction front to back

6. Conclusions

All the tested specimens passed the qualification test criteria. No deviations or damages were detected in the tested equipment. The differences in the supporting structures of the tested specimens compared to actual supports of the equipment installed in the nuclear power plant were conservative in regard to the seismic robustness. The acceleration histories that were used in qualification the tests were very conservative compared to calculated floor acceleration time histories of the automation renewal buildings. The maximum observed amplification factor in side to side direction in the seismic qualification tests of the EK rectifier was 2.324. It was measured at top edge sensor of the rectifier cabinet.

The maximum observed amplification factor in front to back direction in the seismic qualification tests of the EK rectifier was 7.56. It was measured at the main transformer sensor inside of the rectifier cabinet. From the resonance search with the white nose sweep the main transformer lowest frequency was find to be at 13.9 HZ. At actual shaking table qualification test the main transformer maximum response was found at frequency 11.3 HZ. This means that there is nonlinear behavior in the support of main transformer inside the rectifier cabinet.

REFERENCES

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[2] International Electrotechnical Commission, IEC 60780 Ed. 2.0 b:1998, “Nuclear power plants - Electrical equipment of the safety system – Qualification”.

[3] Finnish Radiation Protection Centre (STUK), "Seismic events and nuclear power plants", 19 December 2001, YVL 2.6, APPENDIX An example of an acceptable ground response spectrum corresponding to peak ground acceleration PGA = 1g and the relative damping ratio ξ = 5%, This Guide remains in force as of 1 June 2002 until further notice. It replaces Guide YVL 2.6, issued on 19 December 1988., ISBN 951-712-618-2 (print), ISBN 951-712-619-0 (pdf), ISBN 951-712-620-4 (html), ISSN 0783-2346

[4] C37.81-1989, "IEEE guide for seismic qualification of class 1E metal-enclosed power switchgear assemblies", Switchgear Committee of the IEEE Power Engineering Society, USA