

## Seismic Qualification by test of Rectifier Profitec 2000S and Inverter Transokraft for Units 3 & 4 of WWER-440 MW NPP Kozloduy

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### ABSTRACT

The objective of the seismic qualification tests performed on the rectifier and inverter, produced by AEG SVS, was to certify that this equipment can perform its functions before, during and after an earthquake defined as Required response spectra (RRS) for the specified location of installation. RRS were specified as an envelope of Floor response spectra (FRS) from Review level earthquake (RLE) and Local earthquake (LE) for the mounting elevation of the equipment at Units 3 & 4 of Kozloduy NPP. The seismic qualification tests were performed according to the applicable international standards and codes for such kinds of tests, separately for each of the three components of the seismic excitation X, Y and Z direction. Five tests with Operational basis earthquake (OBE) followed by one with Safe shutdown earthquake (SSE) excitation for each direction were performed for the rectifier and the inverter.

Because of very high weight of the equipment (rectifier has weight of ~ 1.8 tons), a secure lateral upgrade of the two cabinets to an existing steel structure was realized for prevention of damage of the actuator for the tests in Z direction.

Resonance search tests were performed for each cabinet using sinusoidal excitation at low level input motion 0.1g in each principle axis. Records of the response for each of the three directions of the applied sine-sweep were done and transfer functions were generated. Magnification was calculated as well as the damping coefficients in the two cabinets for each resonance frequency, for each channel (five accelerometers applied at height of each cabinet) for the three directions of excitation.

Functional tests of the equipment were done before, during and after seismic qualification tests. During the test of the rectifier it was traced whether it operates properly and charges an accumulator battery (reserve charge). During the test of the inverter it was traced whether it operates properly through power supply from the rectifier and supplies AC consumers and also whether the inverter operates properly through switch to reserve power supply from accumulator battery and supplies AC consumers. Registration of the current and voltage values during seismic qualification tests was made through an oscilloscope by I&C engineer. Maximum, minimum and average values of voltage for high and low levels of seismic excitation were calculated and presented on graphics.

The analysis of the results of voltage and current values generated through all seismic qualification tests showed that the rectifier and the inverter performed their function properly during and after the applied seismic excitation. No mechanical damages were registered to the tested cabinets, as well as to their fixings to the seismic platform. Cabinets of this type were installed in the Units 3&4 of NPP Kozloduy.

### INTRODUCTION

This paper presents seismic qualification by test of a rectifier type Profitec 2000S D400 G216/500 BWLrug-Kpx and an inverter type Transokraft 80kVA G220 D400/116 2rfg-P80+EUE, produced by AEG SVS, later installed in Units 3 & 4 of WWER-440 MW NPP Kozloduy.

The purpose of the seismic qualification tests, performed on the rectifier and the inverter, was to certify that the referenced herein equipment "can" / "can not" perform its functions before, during and after an earthquake defined as Required Response Spectra (RRS) as required by the applicable standards and codes [1], [2], [3], [4], [5], [6] and also to demonstrate their satisfactory mechanical behavior (integrity) and anchorage.

In this paper are presented an overview of the: technical input data for the rectifier and the inverter; data for the shaking table and the seismic test instrumentation; data for the way of mounting on the shaking table and necessity of upgrade of the cabinets to existing stand during the seismic tests in vertical direction; data for the seismic test excitation and definition of RRS; data from the resonance search tests, including calculation of damping and transfer functions, and seismic qualification tests; steps for the functional tests and the tracking and registration of the rectifier and inverter operational state. Finally are presented conclusions about the functionality and structural integrity of the tested cabinets.

### TECHNICAL INPUT DATA FOR RECTIFIER AND INVERTER

Two types of cabinets were tested (rectifier type Profitec 2000S D400 G216/500 BWLrug-Kpx and inverter type Transokraft 80 kVA G220 D400/116 2rfg-P80+EUE). The rectifiers to be mounted, and later mounted, in the electrical and I&C rooms on elevation 9.60 in Unit 3&4 of NPP Kozloduy are 6 pieces and are absolutely identical in dimensions and weight, also including the inside mounted components, location and operability. The inverters are 12 pieces and are

also absolutely identical. Thus, the selection of two types of cabinets for the tests was clearly defined. The dimensions of rectifier and inverter are:

- Rectifier (height x width x depth): 2200 x 1200 x 800 mm
- Inverter (height x width x depth): 2200 x 900 x 800 mm

The weight of the two cabinets is 1800 kg for the rectifier and 1000 kg for the inverter.

The basic function of the system of rectifiers and inverters is the safety related power supply of the 1-st category consumers 0.4kV AC и 220 V DC of Units 3&4 of Kozloduy NPP. Consumers are divided in three independent one from another safety related power supply systems (SRPSS) for each Unit. Each SRPSS supplies only one system of 1-st category consumers. Modernization of SRPSS includes division of section 0.4kV AC – 1-st category into two parts, thus dividing the load consumers and limiting the electromagnetic disturbances. Power supply of sections 0.4kV AC – 1-st category is done by two inverters and power supply of DC consumers and AB by one rectifier. For each section (totally six sections – three for Unit 3 and three for Unit 4) are necessary one rectifier, two inverters and one accumulator battery.

The rectifier has the following functions and characteristics:

- Works in parallel with AB according to IU-characteristics. Supplies the direct current consumers. Supplies trickle charge to the AB, as it reaches its fully charged state;
- Operates with nominal DC current 500 A and rated frequency 50 Hz;
- Allows manual adjustment of the output voltage in the 80 to 320 V range;
- Possesses a device for smoothing the variation of DC-voltage;
- Operates in several modes of operation: idle mode, trickle charge mode, boost charge mode; equalizing charge mode, start-up charge mode. The rectifier controller supplies control during all modes of operation;
- Possesses an informative-controlling block, containing contemporary elements and all the necessary protections against short-circuits, overloads, voltage overloads, loss of phase conditions, switched phases and poles etc.;
- Has ability for control of local and distant indication.

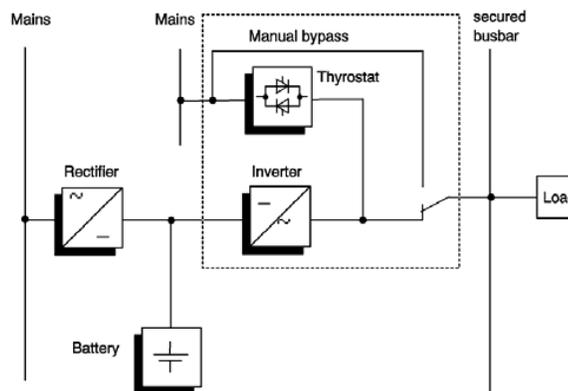
The inverter has the following functions and characteristics:

- Supplies the alternating current consumers;
- Possesses built in electronic system with thyristor switch for quick switching from inverter supply to internal bypass switch – reserve power supply starts at loss of inverter supply (failure of the inverter). The switch over time is 20 ms;
- Possesses three-pole switch for manual switch to reserve power supply in case of diagnostic or repair of the inverter. The purpose is not to have supply breakdown of the DC consumers;
- Operates with nominal power 80 kVA and rated frequency 50 Hz;
- Allows manual control of the output voltage in the 320 to 440 V range;
- Operates in several modes of operation: idle mode, normal mode, emergency mode, synchronous mode, autonomous mode. The inverter controller supplies control during all modes of operation;
- Possesses an informative-controlling block, containing contemporary elements and all the necessary protections against short-circuits, overloads, voltage overloads, loss of phase conditions, switched phases and poles etc.;
- Has ability for control of local and distant indication.

The accumulator battery has the following functions and characteristics:

- Works in parallel with rectifier according to IU-characteristics. Supplies the direct current consumers and the inverter in case of mains failure supplying the rectifier, or failure in the rectifier itself;
- Designed for breakdown discharge of 2 hours.

On Figure 1 below is shown the principle of operation of the system of rectifier, inverter and accumulator battery. Components of the inverter are enclosed on the figure.



**Figure 1. Principle of operation of the system rectifier, inverter and accumulator battery**

## DATA FOR SHAKING TABLE AND SEISMIC TEST INSTRUMENTATION

The seismic qualification tests were performed in the laboratory of University of Architecture, Civil Engineering and Geodesy in Sofia. The seismic excitation in horizontal direction was performed by means of a shaking table with a mounting surface of 1.5 by 1.5 m. This is a uniaxial shaking table (horizontal translation in one direction and rotation about a vertical axis). It is used for a single axis testing in both horizontal axes (X and Y respectively).

For vertical axis tests, one of the actuators was mounted in a vertical position. A platform with a mounting surface of 1.0 by 1.0 m was attached to the piston.

The drive mechanisms for both shaking tables are servo-controlled, electro-hydraulic actuators, manufactured by INSTRON Ltd, England. They have the following capabilities given in Table 1.

**Table 1. Characteristics of shaking table facility**

Frequency Range	0-100 Hz
Dynamic Load Capacity	± 50 kN
Maximum Stroke	± 50 mm
Maximum Velocity	270 mm/sec
Maximum Acceleration	10 g

For registration of accelerations for selected points at height of the cabinets, as well as on the shaking table sufficient instrumentation was provided. The testing equipment included accelerometers [7], amplifiers [8], low-pass filters [9], Analogue to Digital (A/D) and Digital to Analogue (D/A) converters [10], computers and software [11]. The measuring system has an accuracy class of the amplifiers 0.1. Data acquisition and control system has a resolution of 12 bits for both the A/D and D/A converters.

All equipment items used to monitor the tests were checked and calibrated in accordance with an established quality control program. The accuracy of the measurements performed to monitor the parameters was in accordance with the requirements of [5]:

- the measured acceleration values were within 5% of the true value;
- the Test Response Spectrum (TRS) generation equipment produced a plot within 10% of the true plot.

## MOUNTING OF THE RECTIFIER AND INVERTER ON THE SHAKING TABLE

During the tests the cabinets were mounted in their normal service position by four bolts to an intermediate steel frame, produced in the Steel Structures Research Laboratory according to the project specification. The intermediate frame was formed by U14 profiles and welded to the shaking table surface. Additional oval openings (two openings 100/50 mm for the rectifier frame and one opening for the inverter frame) were formed in the front side of the frames for the power supply cables installation during the tests.

Cabinets were mounted on the shaking table for horizontal excitation - first in X direction (X was the horizontal axis perpendicular to the plane of the cabinets' door). Then they were rotated around vertical axis by 90 degrees for testing in Y direction.

For testing in Z direction the supporting frames were mounted on the platform for vertical seismic excitation. For prevention of unwanted dynamic effects (heavy weight of the cabinets, especially the rectifier) that might influence over the dynamic response of the cabinets in the course of the seismic tests and unwanted damage of the shaking table (damage of the actuator), an upgrade of the cabinets to existing stand was designed.

A frame of U profiles was mounted on the top of the cabinets by 4 bolts M16. These bolts were installed on the place of the provided hooks for crane lifting. Four boxes 100/50/5 mm were attached to the frame in the corners of the cabinets. Two horizontal profiles U14 were attached perpendicularly to the existing stand and extended to the front side of the cabinets on both sides. These profiles were upgraded by two vertical inclined profiles U12 attached to the stand and two horizontal profiles U12 also attached to the stand in angle ~55°. Perpendicularly to the horizontal U14 profiles were welded four vertical short profiles U14. The four boxes were interposed between the four vertical short profiles but not in direct contact to them. Between the boxes and the profiles were installed teflon plates in order to have free sliding during the vertical translations of the shaking table.

On Figure 2 below is shown drawing of the upgrading structure for the rectifier (the structure for the inverter is almost the same) and on Figure 3 are shown pictures from this upgrading of the rectifier and the inverter during the seismic qualification tests in vertical direction.

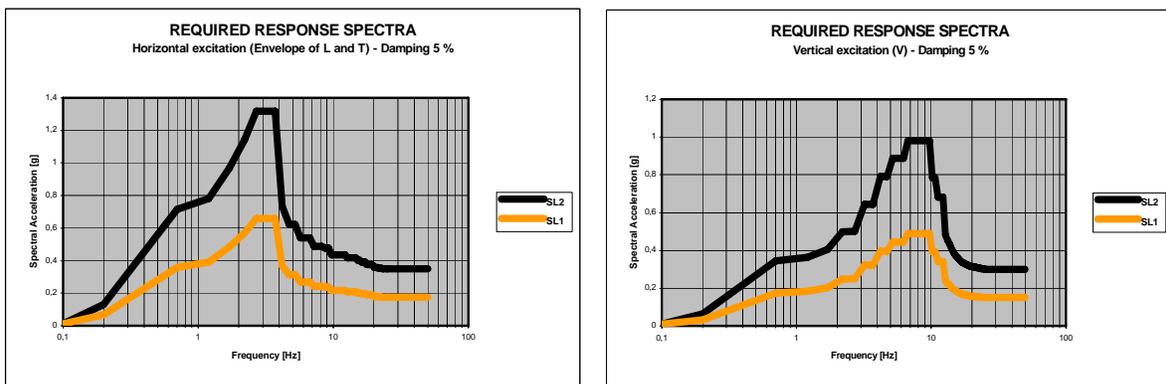




**Figure 3. Pictures of the upgrading structure for the rectifier and inverter testing in vertical direction**

**SEISMIC TEST EXCITATION**

Seismic qualification of the cabinets was performed for two levels of excitation – Operating basis earthquake (OBE) and Safe shutdown earthquake (SSE) with respect to defined RRS. RRS were specified as an envelope of floor response spectra from Review level earthquake (RLE) and Local earthquake (LE) [12] for the mounting elevation of rectifiers and inverters and increasing of the enveloped floor response spectra for the three directions with coefficient of 1.5 which accounts for the influence of unprovided factors and imperfections at mounting of the equipment. On excitation level OBE (low level) and excitation level SSE (high level), the tests were performed in the three directions – X, Y, Z sequentially. During all seismic excitations the cabinets were electrically powered and put in normal operating conditions. The rectifier was tested consequently 5 times with low and once with high level of seismic excitation (as required per [3], [6]) in each of the three directions. In this manner the seismic aging was simulated as per requirements of the applicable standard [3]. As it was necessary to be measured the voltage on the input and output of the inverter at normal mode of operation and mode of operation with switch to power supply from accumulator battery (registration of voltage on the input and output can not be made simultaneously, because of the lack of such registering equipment), the inverter was tested consequently six times with low and three times with high level of seismic excitation in each of the three directions. At the beginning of the tests one preliminary OBE level test in X direction was done in order to demonstrate the proper function of the excitation, measuring and data acquisition equipment. On Figure 4 below are presented RRS spectra for both seismic levels of excitation (horizontal – left side of figure and vertical component of the seismic excitation – right side of figure). The spectra are generated for 5% damping.



**Figure 4 Required Response Spectra for SSE (SL1) and OBE (SL2) levels of horizontal seismic excitation – envelope of directions L and T; RRS for SSE (SL1) & OBE (SL2) levels of vertical seismic excitation – direction V**

The seismic excitation to the shaking table was assigned through generated acceleration time histories. They were derived from the RRS scaled to relevant Zero period accelerations (ZPA) for OBE (SL1) and SSE (SL2) level earthquake respectively. Seismic motions of the shaking table were recorded and the corresponding TRS was generated.

Tests were performed with multi-frequency random waveform with 55 sec duration and strong motion part 21 sec. The SIMQKE program [11] for artificial motion generation was used to obtain multi-frequency random waveforms.

Before starting the seismic qualification tests, resonance search tests were performed by sinusoidal base excitation in the corresponding direction.

### RESONANCE SEARCH TESTS AND SEISMIC QUALIFICATION TESTS

The resonance search tests were performed by sinusoidal base excitation. Low level sinusoidal vibration was applied in the frequency range from 1 to 50 Hz at acceleration level of 0.1 g in each principle axis with frequency sweep rate of one octave per minute [3], [6]. Six accelerometers (recording channels) were used for acceleration registration at different points of the cabinets during tests. The accelerometers for measurement of the vibrations were arranged in different schemes for each one of the testing directions of the cabinets. All accelerometers were mounted on the cabinets in direction parallel to the direction of excitation, but it is possible some accelerometers to be mounted in direction perpendicular to the direction of excitation. Channel 0 was always mounted on the shaking table itself. For each of the exciting frequencies a record with 5 sec duration for all accelerometers / channels was made. At the established resonance frequencies, additional record of the response was made after the excitation was switched off. As a result of the resonance search tests, for selected points at height of the cabinets were generated diagrams of transfer functions. Diagrams show the resonance frequencies and values of magnification in dB. Magnification Q was defined using Eq. (1).

$$Q = 20 * \log a_n/a_0 \tag{1}$$

In Eq. (1)  $a_n$  is the registered response acceleration for selected points(channel) for uniaxial sine-sweep and  $a_0$  is the registered acceleration on seismic platform for the same sine-sweep (in this specific case  $a_0= 0.1g$ ).

Damping coefficients in rectifier and inverter are defined for each resonance frequency, for each channel, for the three directions of excitation. They are defined using Eq. (2).

$$D_{coef.} = (a_0/2*a_n)*100 [\%] \tag{2}$$

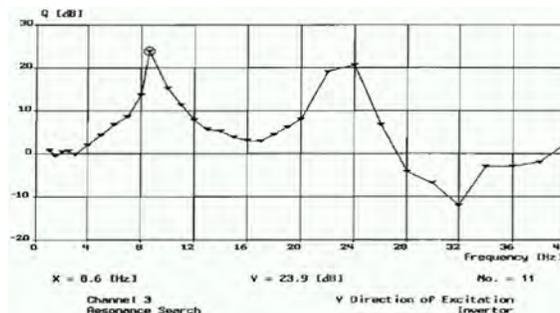
In Eq. (2)  $a_0$  and  $a_n$  have the same values as in Eq. (1).

In Table 2 below are given the values of the resonance frequencies, magnification and damping of the inverter in the Y direction of excitation for the five channels.

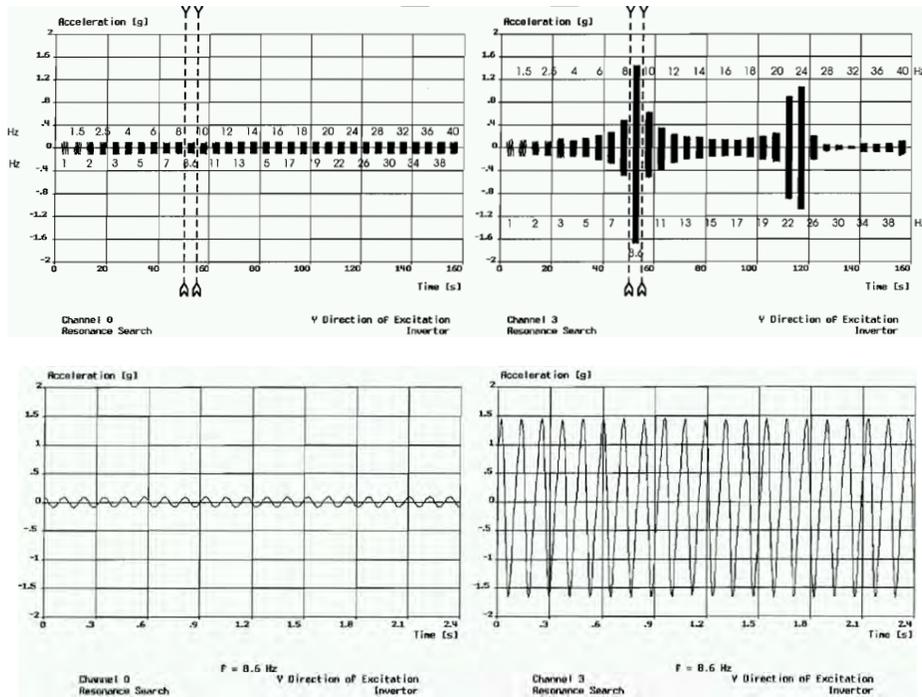
On Figure 5 below is given the diagram of the calculated magnification for channel 3 of the inverter in the Y direction of excitation and on Figure 6 is given a diagram of the recorded resonance search test for channels 0 and 3 in the range from 0 to 40 Hz and part of the data in large scale with one of the resonance frequencies.

**Table 2. Resonance frequency values, magnification and damping of inverter in Y direction of excitation**

Type of cabinet	Direction of excitation	Channel No	Resonance frequency [Hz]	Magnification Q [dB]	Damping [%]
INVERTER	Y	1	8.6	22.6	3.7
			22.0	18.3	6.1
		2	8.6	22.1	3.9
			22.0	17.0	7.1
		3	8.6	23.9	3.2
			24.0	20.7	4.6
		4	8.6	22.1	3.9
			24.0	10.5	14.9
		5	8.6	24.6	2.9
			24.0	12.7	11.6

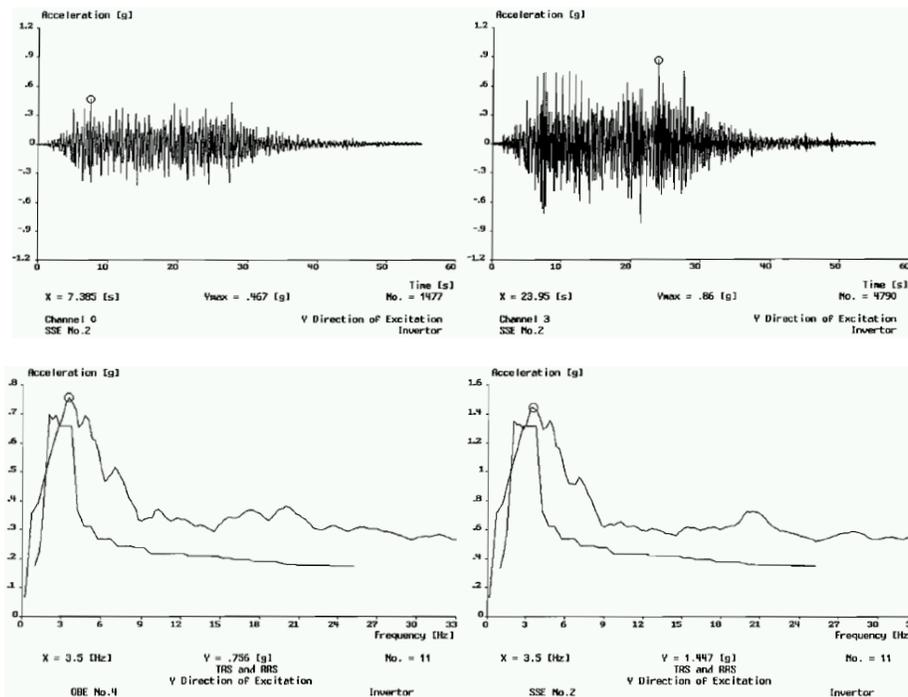


**Figure 5 Diagram of calculated magnification for channel 3 of the inverter in the Y direction of excitation**



**Figure 6** Diagram of recorded resonance search test for channels 0 and 3 in the range from 0 to 40 Hz and part of the data in large scale with one of the resonance frequencies

The seismic qualification tests were performed in the way described in the point „Seismic test excitation” above. On Figure 7 below are presented the time history excitation and response (channel 0 and 3) for the second test with SSE for Y direction of testing of the inverter as well as the RRS and TRS for the fourth test with OBE and the second test with SSE for the same direction of testing. It is shown that the TRS fully enveloped the RRS above 3 Hz (should be enveloped above 3.5 Hz according to [3], [6] as the resonance frequencies were found above 5 Hz). Excitation in the range 1 to 3 Hz was maintained in accordance with the capability of the shaking table as required in [3], [6].



**Figure 7** Time history excitation and response for the second test with SSE for Y direction of testing of inverter; RRS and TRS for the fourth test with OBE and the second test with SSE for the same direction of testing

## FUNCTIONAL TESTS

The rectifier and the inverter were functionally checked before, during and after the seismic qualification tests.

Before the seismic qualification tests the two cabinets were checked for: Cabinets identification and tagging; Correspondence of the cabinets and the components inside them with these listed in input data of the supply; Visual inspection for damages during transportation and handling; Check of the door locks and handles; Individual functional testing to check the adequate performance of the specific functions for each one of the cabinets.

During the seismic qualification tests the rectifier was checked whether it operates properly (namely whether the inverter is power supplied from the rectifier) and whether it charges the accumulator battery. Oscillations and interruptions in DC voltage were observed at the output of the rectifier. The inverter was checked whether it operates properly through power supply from the rectifier and supplies the AC consumers and whether it operates properly through switch to reserve power supply from accumulator battery and supplies the AC consumers. Voltage and current values were measured at the output of the inverter. Deviations in voltage and current were observed.

After the seismic qualification tests the rectifier and the inverter were checked for: Visual inspection for damages (external and internal) and broken el. connections as a result of seismic excitation; Repetition of individual functional testing to check the adequate performance of the specific functions for each one of the cabinets.

Tracing and registration of functional state of the rectifier / inverter during seismic tests was carried out by four-channel digital registering oscilloscope with scanning rate of 1000 accounts per second of a channel. Additionally were used voltmeters and amperimeters for DC and AC current measurements. It was provided single-phase power supply of 220V AC and three phase 380V AC, as well as 220V DC power supply by accumulator battery.

## CONCLUSIONS

The performed seismic qualification tests on the rectifier and the inverter lead to the following conclusions:

- The tested rectifier and inverter preserved their structural integrity;
- The fixing of the cabinets to the intermediate steel frames by bolt connections as well as the fixing of the frames to the seismic platform were reliable;
- The tested equipment functioned reliably and there was no evidence of improper behavior of the rectifier and the inverter as a whole, as well as of the individual components in them, during and after the seismic excitations.

The performed seismic tests certify that the rectifier type Profitec 2000S D400 G216/500 BWLrug-Kpx and the inverter type Transokraft 80kVA G220 D400/116 2rfg-P80+EUE presented for seismic qualification, passed the seismic qualification tests successfully and later devices of this type were installed on Units 3&4 at Kozloduy NPP.

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