Earthquake-Resistant Technology for Uninterruptible Power Systems

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ABSTRACT

Uninterruptible power systems (UPSs) need to have adequate earthquake resistance because they are used as backup power during blackouts at data centers, financial institutions, hospitals and other places requiring a stable supply of power. After the Great East Japan Earthquake, the guidelines on the earthquake resistance of transformers have been established. Fuji Electric thus tested the earthquake resistance of its UPSs using seismic waves, for which the acceleration response of the building was considered, and confirmed their stable operation. On the basis of the analysis on the deformation of transformers by the finite element method, we took anti-sway measures and revised the housing frame of the transformer panel to improve earthquake resistance.

1. Introduction

Uninterruptible power systems (UPSs) are used for backup power at data centers, financial institutions, hospitals and other places requiring a stable supply of power even during blackouts and earthquake disasters.

This paper describes technology for improving the earthquake resistance of UPSs that have been made capable of continued operation even during earthquake disasters.

2. Need for Improving Earthquake Resistance in the Wake of the Great East Japan Earthquake

In the Great East Japan Earthquake that occurred in 2011, transformers shook, causing many short circuits and ground faults. Repeated heavy shaking of transformers for a long time led to fractures of the primary-side terminals and burnout due to the secondary-side conductors coming into contact with the housing and multi-layered conductors. Examples of accidents of seismic snubbers coming off have been reported.

Earthquake-proofing of transformer panels has been regarded as important and, in September 2013, the Guide for Movement of Distribution Transformers JEM-TR252[(1)] was established. In response, relevant companies are working on earthquake-proofing of transformer panels and development of aseismic devices for transformers.

With a large-capacity UPS system, the input transformer panel uses a molded transformer to step down three-phase 6,600 V to 400 V to distribute to the individual UPSs, for example, as shown in Fig. 1. The output branch panel uses a dry-type transformer or other device to step down to 400 V or 200 V according to the load. For that reason, the earthquake resistance of transformers and panels must be improved so that they can operate stably.

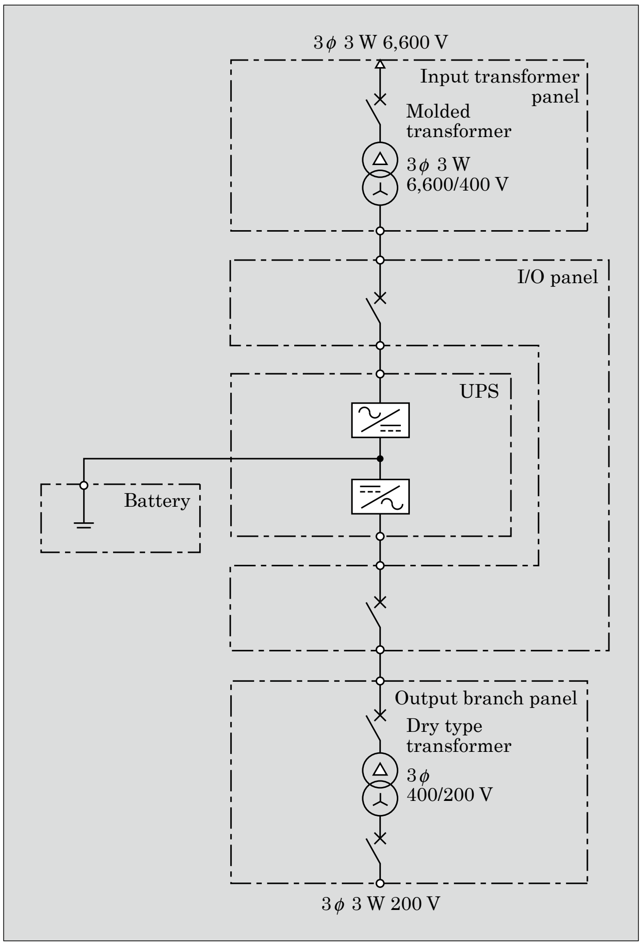

Fig.1 Example of UPS system

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3. Vibration Test of UPS Equipment

3.1 Guideline for Aseismic Design and Construction of Building Equipment

The Guideline for Aseismic Design and Construction of Building Equipment presents aseismic designs and calculations for aseismic supports in view of the mechanism of action of seismic force on equipment. A force resulting from multiplying the seismic force of the base of a building by the response factor of each floor is applied to the building and equipment, and the force must be supported by anchor bolts that secure the equipment. The seismic force used in the Guidelines is not specified assuming any specific earthquake but is based on average properties of seismic forces generated on rare occasions. For the input seismic waves for vibration tests, the Guidelines are used as a reference to take the response factor of the building into account to carry out the tests.

3.2 Vibration test

To evaluate the earthquake resistance of equipment, vibration testing, in which actual seismic waves are applied, may be used apart from static analysis that uses the finite element method. In a vibration test, the equipment is directly installed on a vibration table, to which seismic waves with the response factor taken into account are applied.

Electrical equipment is installed on the vibration table to conduct a resonance point search test, input seismic wave vibration test and resonance point search test in this order. The resonance point search test applies random waves with a frequency of 2 to 50 Hz respectively in the X, Y and Z (lateral, depth and vertical) directions with one-tenth of the design acceleration as the maximum acceleration. A delay of 90° with reference to the phase of the vibration applied by the vibrator is judged as a resonance state and the natural frequency is found.

To study the earthquake resistance against seismic motion, we applied reproductions of the actual seismic waves. Because the acceleration response spectrum varies depending on the seismic wave, we selected seismic waves from the Southern Hyogo Earthquake (occurred on January 17, 1995) and Niigata Chuetsu Earthquake (occurred on October 23, 2004), and the El Centro seismic wave (occurred on May 18, 1940).

We mounted an accelerometer to measure the maximum acceleration of the housing and a strain gauge to measure the stress on the housing. As the mounting locations, we selected points where large stress was observed by static analysis. In the UPS, devices such as the inverter transformer and reactor are secured only in the lower part and we mounted an accelerometer in the upper part of the devices, which shows a larger amplitude.

After the vibration test, another resonance point search test was conducted. Any difference of the resonance point between before and after application of the vibration suggests plastic deformation, which requires detailed investigation of deformation of the housing and internal devices.

3.3 Vibration test results

Figure 2 shows a row of the UPS and peripheral panels installed on the vibration table. The configuration includes four panels, which are an input transformer panel, UPS panel, input transformer panel and UPS panel from the left.

The maximum acceleration of the El Centro seismic wave is 0.341 G. Considering the response factor based on the building structure and the height of the floor of installation, we specified a maximum acceleration of 1.0 G for the test.

The following presents the results of the vibration test:

(a) The characteristic vibration and acceleration response of the UPS panels were approximately 17 Hz and 1.5 times respectively in the X direction, and 11 Hz and 1.6 times respectively in the Y direction. The characteristic vibration and acceleration response of the peripheral panels were approximately 15 Hz and twice respectively in the X direction. In the Y direction, the characteristic vibration and acceleration response were approximately 14 Hz and 1.7 times respectively. The acceleration response can be large in either case and housing design is required to take earthquake resistance into account sufficiently.

(b) The characteristic vibration and acceleration response of the transformer were about 30 Hz and 1.5 times respectively in the X direction, and about 15 Hz and 2 to 3 times respectively in the Y direction. With the transformers, the characteristic vibration in the X direction was found to be high and the acceleration response in the Y direction to be large. Accordingly, we designed earthquake resistance reflecting these results.

(c) With all of the panels, we confirmed that there

Fig.2 UPS equipment installed on vibration table

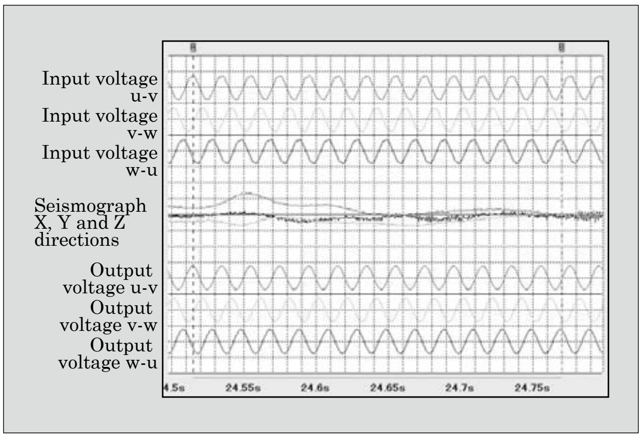


Fig.3 Input voltage and output voltage waveforms during vibration

was no problem in the stress applied during vibration, with the maximum stress at less than one-tenth of the allowable stress for temporary loading.

(d) Figure 3 shows the input and output voltage waveforms of the UPS during vibration. Operation continued with no abnormality in the AC output voltage.

(e) We confirmed that there was no variation in the characteristic vibration after vibration and no plastic deformation occurred in the housing.

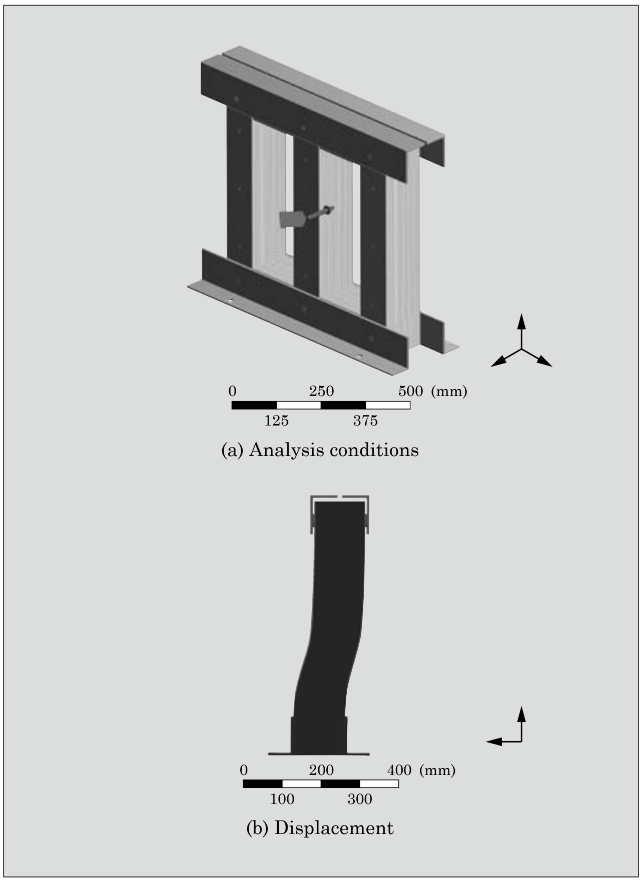


Fig.4 Results of static analysis of transformer

4. Improvement in Earthquake Resistance of Transformers

4.1 Displacement of dry-type transformers

For UPSs, a molded type is used as the input transformer, and a low-voltage dry type of Class H is used as the output transformer. The iron core of these molded and dry-type transformers doubles as a strength member. However, an iron core consists of layers of steel sheets with a thickness of 1 mm or less and has some uncertainty in terms of strength. Accordingly, we conducted static analysis on the displacement of transformers by the finite element method.

We took a 100-kVA dry-type transformer with a total mass of 427 kg as an example to analyze the displacement. The iron core consists of 357 layers of silicon steel strips with a width of 620 (legs: 100 mm × 3) × height of 650 × thickness of 0.35 (mm) and the top and bottom parts are held down with angle steel bars (L-bars), which are secured with bolts. The three legs are secured with bolts. The restraint condition is the bolts for securing the bottom angle steel bars on the floor. As with the local seismic coefficient method used for equipment design, we applied a force equivalent to acceleration of 2.0 G to the center of gravity. Figure 4 shows the analysis results. The maximum displacement was found to be 20.5 mm. In this case, we took measures with steady rests for the transformer because there was a danger of damage to cables and contact with the panel.

4.2 Aseismic design of molded transformers

Recently, data centers have been getting increasingly larger in capacity. Generally, a molded transformer of 550 kVA is used for a UPS with a single-unit capacity of 500 kVA. This section describes earthquake proofing of Top Runner MOLTRA used for UPS systems.

Figure 5 shows the structure of a molded transformer. The iron core is secured with the top and bottom frames and the windings are prevented from un-

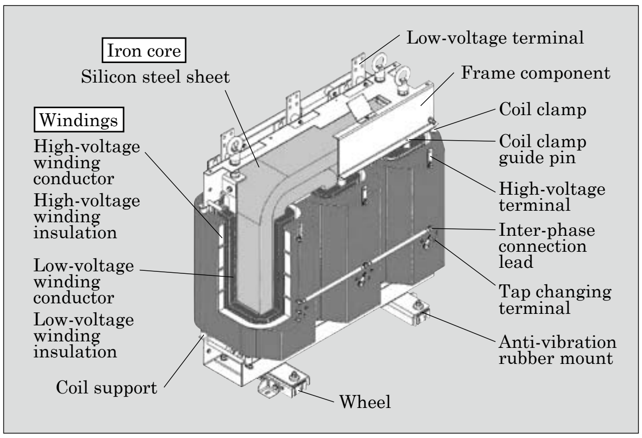


Fig.5 Structure of molded transformer

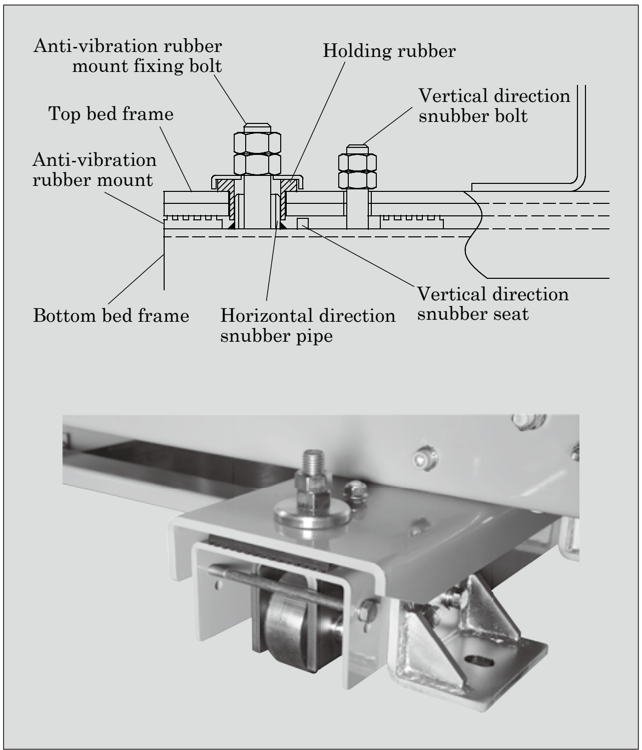


Fig.6 Structure of seismic snubber of molded transformer

dergoing displacement by providing guide pins of the coil clamps and supports between the top and bottom frames and coils. The guide pins do not come off easily due to the large diameter and the long length.

Once a seismic force is applied to this transformer, the anti-vibration rubber mounts shrink to the seismic snubbers in the horizontal and vertical directions and the transformer is displaced. Flexure of the transformer itself is also added to increase the displacement. Figure 6 shows the structure of a seismic snubber. The transformer is provided with anti-vibration rubber mounts between the top and bottom bed frames in order to reduce vibration transmission to approximately 3%. Conventionally, seismic snubber bolts were used for securing to reduce vibration in the vertical direction. Vibration in the upward vertical direction is reduced by the vertical direction snubber bolts and in the downward vertical direction by the vertical direction snubber seats. To reduce vibration in the horizontal direction, we have used a horizontal direction snubber structure since 2014.

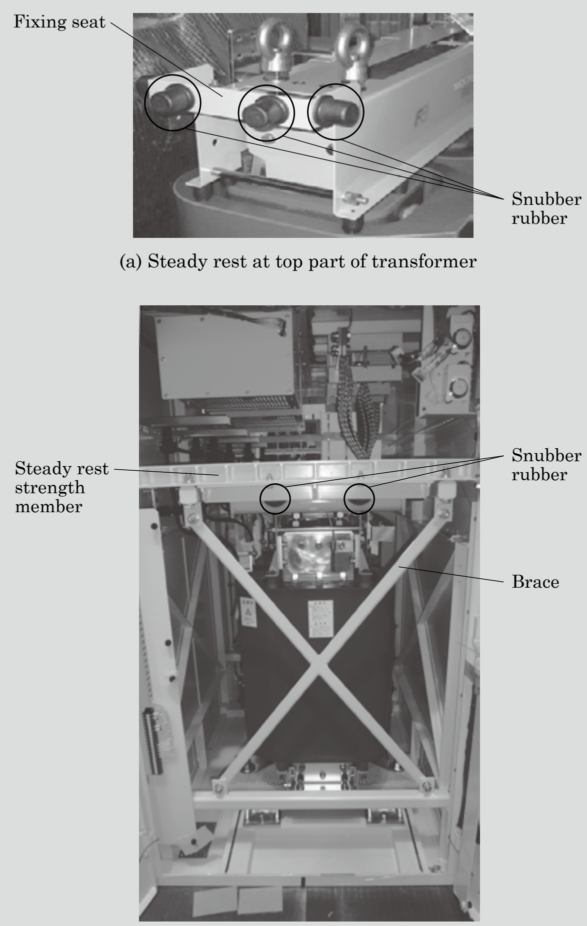
The transformer is secured by the snubber pipes welded to the bottom frame and the bolts welded to the wheels.

5. Aseismic Design of Transformer Panels

The Guide for Movement of distribution transformers JEM-TR252 specifies the displacements of terminal sections during earthquakes. The standard design seismic coefficient is determined by the applicable floor on which the device is installed and the seismic class required for the device. The displacement of molded transformers with a rated capacity of 1,000 kVA or less is specified as 50 mm for up to 1.0 G. Accordingly, no guideline is given for the condition of design seismic coefficients 1.5 G and 2.0 G and the respective companies are required to improve earthquake-resistance independently.

If a value of 1.0 G or larger is specified for the design seismic coefficient, which is the ratio of acceleration in the horizontal direction to that of gravity, to ensure earthquake resistance while reducing introduction costs, it is more appropriate to improve the earthquake resistance of the transformer panel than of the transformer. JEM-TR252 presents a method of connecting the top part of a seismic transformer with a seismic frame and cushioning[1]. This method allows the transformer to reduce not only the vibration of the top part but also the shock resulted from seismic motion. However, solid propagation of the vibration generated when the transformer is operating must be taken into account because the transformer and seismic frame are fixed.

Figure 7 shows the steady rest at the top part of the transformer. The transformer panel receives the



(a) Steady rest at top part of transformer

(b) Transformer panel stored

Fig.7 Steady-rest structure at top part of transformer vibration of an earthquake with the structure that has fixing seats provided at the top part of the transformer and snubber rubbers for vibrations in the lateral and depth directions. On the panel housing side, steady rest strength members are provided where the transformer snubber rubbers comes into contact with the housing. A gap of approximately 5 mm is provided to prevent vibration of the transformer from being transmitted to the panel.

In order to reduce the force applied to steady rests of the transformer panel to less than the allowable stress for temporary loading of strength members, we have adopted a structure in which the housing frame is integrated with the seismic frame. The seismic frame has been provided with an angle structure and earthquake-proofed by using a brace. In addition, we have used square pipes for the housing frame.

6. Postscript

This paper relates to technology for improving the earthquake resistance of UPSs and has described the need for this and methods of applying it on the basis of examples of accidents from the Great East Japan Earthquake.

In the future, we intend to strive to improve earthquake resistance to meet customer demands in addition to enhancing the reliability of power supply from UPS systems.

References

(1) JEM-TR252: 2014. Guide for Movement of Distribution Transformers. The Japan Electrical Manufacturers' Association. (Japanease).

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