Seismic-Resistant Switchboards Conforming to New Regulatory Standards Concerning Commercial Nuclear Reactors

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ABSTRACT

Nuclear power plants and other nuclear-related facilities are required to have a certain level of seismic capacity according to the importance of their equipment. After the Great East Japan Earthquake, the nuclear regulatory standards have been revised and demand a greater seismic capacity of related equipment. To meet the demand, Fuji Electric has been developing high-rigidity seismic-resistant switchboards that conform to the new regulatory standards. We evaluated the rigidity with natural frequency analysis and verified that dynamic components can retain their functions with vibration testing. The results show that we would achieve a target natural frequency of 30 Hz or more.

1. Introduction

Switchboards play a major role in ensuring safety in nuclear power plants and other nuclear-related facilities. They are required to prevent the main body from breakage and the internal electrical components from malfunction by ground acceleration during an earthquake. In general, the higher the natural frequency of a switchboard, the more the acceleration caused in the switchboard, and its internal electrical components during an earthquake (response acceleration) can be reduced. Since switchboards are equipment important to safety, they are designed to ensure seismic capacity by having a highly rigid structure with substantially higher natural frequencies than those of the buildings in which they are installed.

After the Great East Japan Earthquake in 2011, switchboards used in commercial nuclear power plants have been required to have higher seismic capacity, and the demand for seismic-resistant switchboards has been escalating. Fuji Electric has a track record of delivering seismic-resistant switchboards for laboratories mainly for the Japan Atomic Energy Agency. We have also been working on the development of seismic-resistant switchboards that can be used in commercial nuclear power plants. The challenges were as follows: For use in laboratories, it was only necessary to design a rigid structure with a natural frequency of 20 Hz or higher. Commercial nuclear power plants, however, may require natural frequencies of 30 Hz or higher and so the structure should be designed to satisfy this.

In the "New Regulatory Requirements for Commercial Nuclear Power Reactors" revised in July 2013 (new regulatory standards), the scale of the earthquake that needs to be assumed at the time of design was reconsidered to require the facilities to have a structure that can endure a stronger seismic force (acceleration applied to the switchboard) than before.

This paper describes the seismic-resistant switchboards that we have developed to conform to the new regulatory standards.

2. Seismic Design

In conventional seismic design, the reference values of the earthquake resistance for seismic-resistant switchboards were specified as a horizontal acceleration of 1 G and vertical acceleration of 0.5 G, which are sufficiently higher than the design seismic force. After the Great East Japan Earthquake, the reference ground motion used for seismic design was changed, and switchboards have been required to have a higher seismic capacity. The maximum values of the design seismic force, which are varies depending on the region because the ground condition of the installation site should be considered, were changed to a horizontal acceleration of 3 G and vertical acceleration of 2 G.

It has been said that 20 Hz or higher is sufficient for the natural frequency of the seismic-resistant switchboard. We, however, set the development target at 30 Hz or higher because this value may be required in some regions.

The seismic design conditions are as follows:

(a) Natural frequency: 30 Hz or higher
(b) Anti-acceleration: 3 G or higher in horizontal direction, 2 G or higher in vertical direction

Figure 1 shows the development process of the seismic-resistant switchboard. The switchboard development process is divided into 3 phases: Rigid structure design, verification of dynamic component ability to re-

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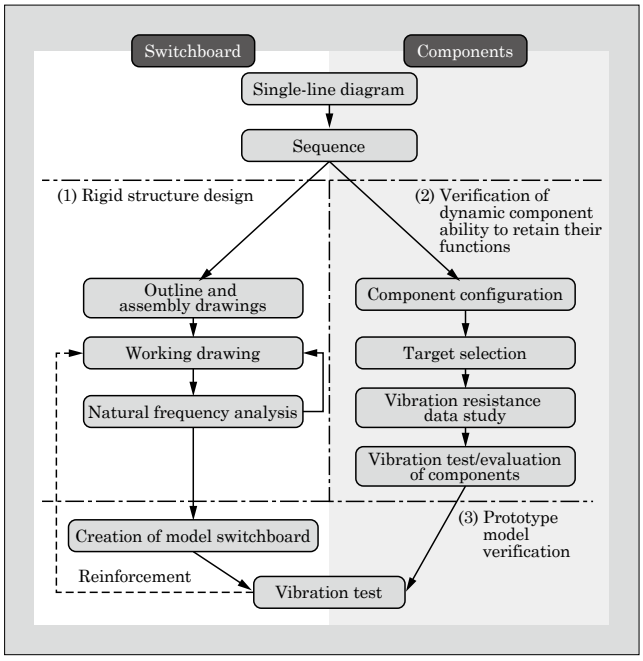


Fig.1 Development process of seismic-resistant switchboards

tain their functions, and prototype model verification.

(1) Rigid structure design

This phase analyzes the natural frequency of the switchboard based on the working drawing. To meet the target of the natural frequency of the panel, the structure design is changed by adding beams, changing the wall thickness, and doing other corrections.

(2) Verification of dynamic component ability to retain their functions

Among the internal components of the switchboard, dynamic components with moving parts (such as circuit breakers, protective relays, auxiliary relays and timers) must retain their functions even in the event of an earthquake. Such ability, however, cannot be verified from structure analysis. Consequently, this phase actually shakes each component separately for evaluation and determines the acceleration up to which the component can retain its functions. As for draw-out type components that are not completely secured, a vibration test is performed under the condition simulating the actual securing method to determine the acceleration up to which the component can retain its functions.

(3) Prototype model verification

To verify the result of structure design obtained in (1), this phase creates an actual-size model of a high-voltage switchboard for seismic resistance verification and performs a vibration test to verify its natural frequency. Then, the internal components evaluated in (2) are mounted in the switchboard, and their health is checked by verifying their functions under vibration.

3. Improving Seismic Capacity of High-Voltage Switchboard

3.1 Design of seismic-resistant switchboards

A high-voltage switchboard is equipment for distributing supplied power according to the specifications of load equipment. It consists of circuit breakers, protective relays, auxiliary relays, transformers, current transformers, and other devices.

The high-voltage switchboard used for the prototype has 2 vacuum circuit breakers (VCBs) stacked vertically and is designed to provide a commonly used rated current of 1,200 A or 2,000 A and breaking capacity of 40 kA. It employs the “F-MPC60B” digital multifunction relay, which is a commonly used protective relay for power applications. Table 1 shows the major specifications.

This high-voltage switchboard is equipped with shutters for the main circuit disconnection sections of draw-out type circuit breakers or other components.

Table 1 Major specifications of high-voltage switchboard

Item		Specification
High-voltage switchboard	Model	JEM-1425 MWG
	Rated voltage, number of phases	7.2 kV, 3-phase 3-wire
	Rated frequency	50/60 Hz
	Rated bus current	3,000 A
	Rated short-time withstand current	40 kA, 2 s
	Rated insulation voltage	Power frequency withstand voltage: 22 kV, 1 minute Lightning impulse withstand voltage: 60 kV
	Dimensions	W1,000 × D2,600 × H2,300 (mm)
Vacuum circuit breaker (VCB)	Rated operating voltage	100/200 V AC, 100/125 V DC
	Rated breaking capacity	40 kA
	Rated current	1,200 A, 2,000 A
	Closing system	Motor-spring stored energy

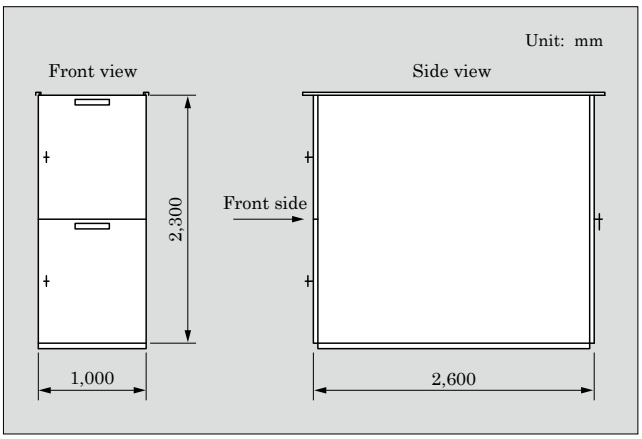


Fig.2 Outline drawing of high-voltage switchboard for seismic resistance verification

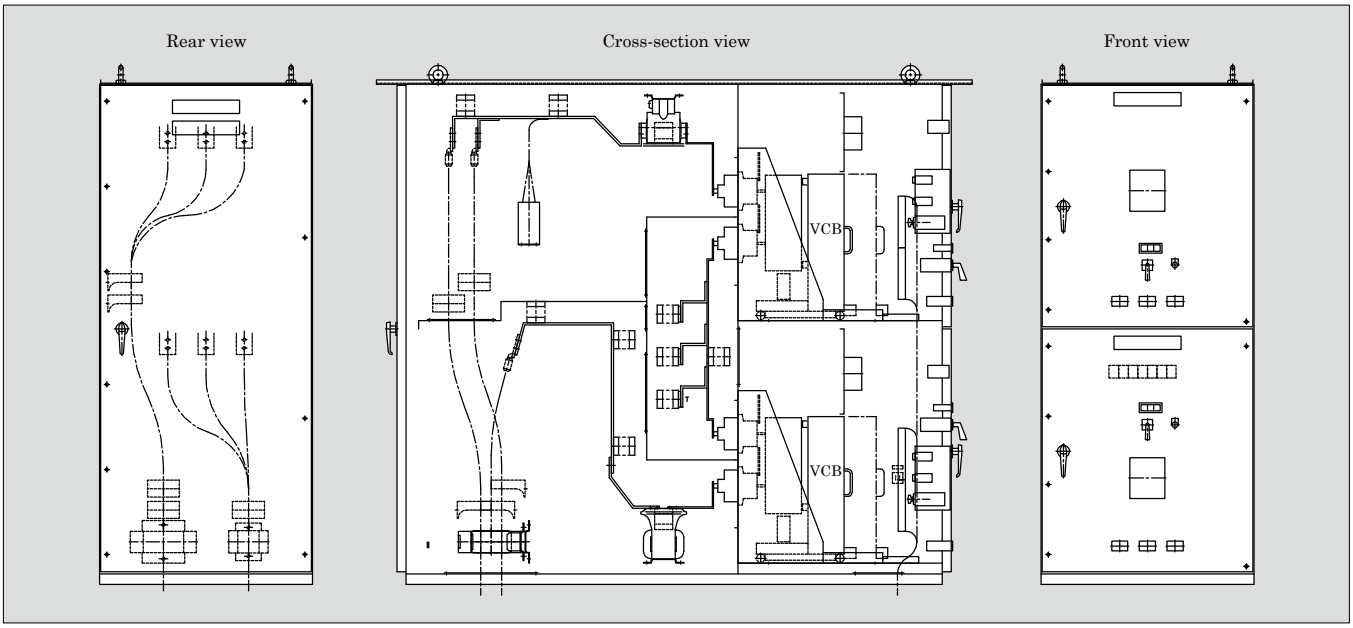


Fig.3 Assembly drawing of high-voltage switchboard for seismic resistance verification

After the circuit is disconnected and the circuit breaker is drawn out to the test position, the shutter closes automatically and covers the main circuit live section to improve safety during inspection. Auxiliary components for the main circuit (voltage transformers, grounded type voltage transformers, arresters) are mounted on transfer wagons, enabling for easy replacement and mounting space saving. On the other hand, some structural measures are needed to ensure that such a structure designed for maintainability to allow easy replacement of a vacuum circuit breaker and other components will not lead to a weakness in terms of seismic capacity. To meet the requirement, the switchboard frames and components are designed to make surface contact so as to suppress the vibration of the components and ensure seismic capacity. A clamp mechanism is adopted to enable easy securing and drawing in/out operation. The vacuum circuit breakers provide sufficient seismic capacity in both the operating position and test position. Figure 2 and Figure 3 respectively show the outline drawing and assembly drawing of the high-voltage switchboard for seismic resistance verification.

3.2 Natural frequency analysis

Based on the design drawing of the seismic design switchboard, the natural frequency was analyzed with NX NASTRAN structure analysis software. Figure 4 shows the analysis results. The result indicated that the entire housing starts shaking at 36.7 Hz, which proves that its natural frequency satisfies the seismic design requirements.

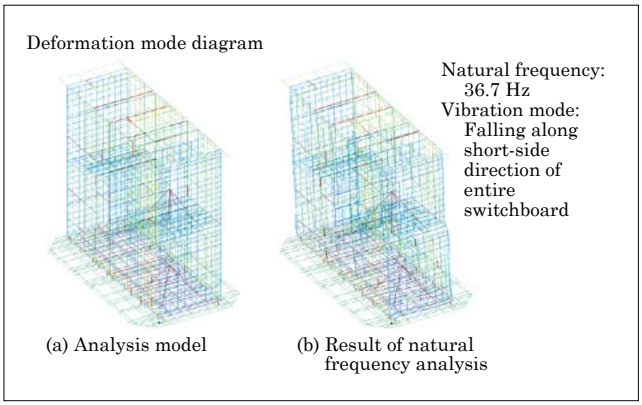


Fig.4 Result of natural frequency analysis

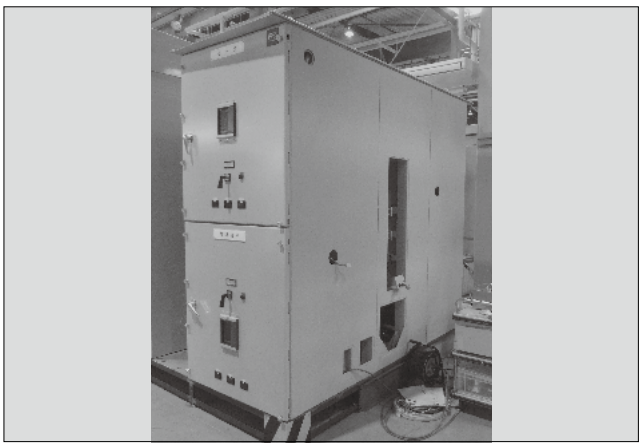


Fig.5 High-voltage switchboard for seismic resistance verification

3.3 Producing high-voltage switchboard for seismic resistance verification

Figure 5 shows the external appearance of the high-voltage switchboard for seismic resistance verification. In order to improve seismic capacity, the framework was built with square pipes (vertical posts

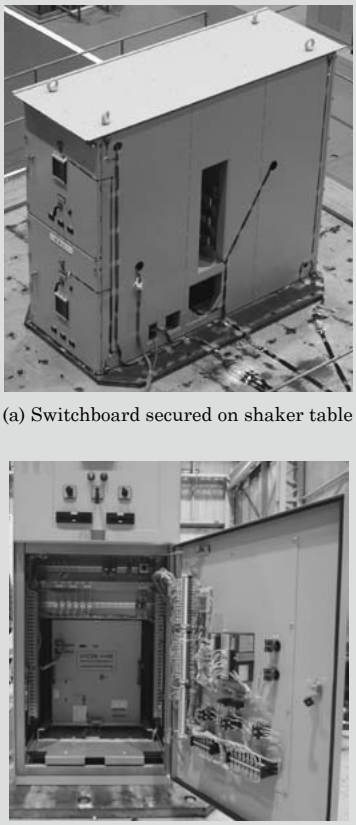
and ceiling, total of 8 frames) that were joined to the side panels to increase rigidity. Moreover, in order to ensure a natural frequency of 30 Hz or higher, the connection between the base frame and switchboard was reinforced.

3.4 Vibration test

We conducted a vibration test for the purpose of verifying the seismic capacity of the high-voltage switchboard. Figure 6 shows the states of the switchboard secured on a shaker table and of the components mounted inside the switchboard.

We attached accelerometers to the switchboard housing and major internal components and measure response acceleration during vibration to determine its natural frequencies and anti-acceleration. At an input acceleration of 100 Gal*1 (sine wave), the range between 5 and 50 Hz was swept at a rate of 0.1 Hz/s and the natural frequency was measured in 3 directions of horizontal and vertical. Figure 7 shows the magnification factor of an accelerometer that was mounted on the switchboard frame plotted against the frequency in the horizontal (depth) direction. They were evaluated using the measured value of the accelerometer mounted on the shaker table as a reference. The frequency at which the magnification factor is highest is the natural frequency. The measured natural frequency of this switchboard housing was approximately 37 Hz, which shows good agreement with the value obtained through analysis.

Furthermore, the natural frequencies were estimated to exceed 30 Hz in all directions.



(a) Switchboard secured on shaker table

(b) Components mounted inside switchboard

Fig.6 States of vibration testing

*1: Gal: Unit of acceleration. 1 Gal = 0.01 m/s²

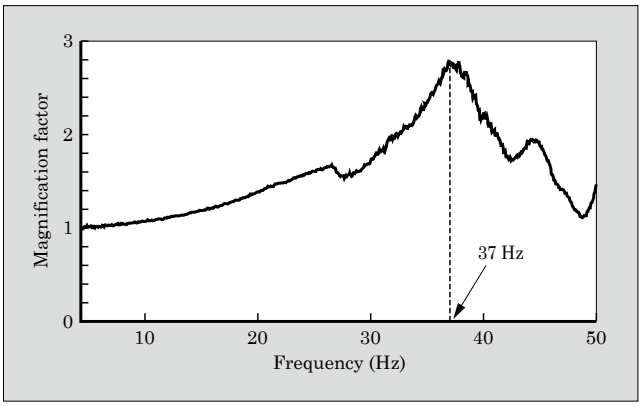
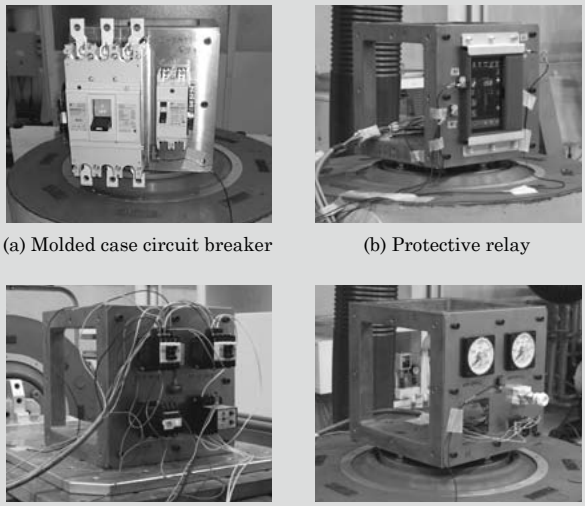


Fig.7 Result of vibration testing

4. Improving Seismic Capacity of Low-Voltage Switchboard and Its Components

The development of low-voltage switchboards, such as power centers and control centers, have also been promoted based on the same design conditions and steps as the high-voltage switchboards to ensure seismic capacity.

In addition, we have determined the acceleration rate up to which each component can retain its functions by conducting vibration tests for each component individually, as well as for components being mounted in a switchboard. Figure 8 shows the states of vibration testing of individual components.



(a) Molded case circuit breaker

(b) Protective relay

(c) Magnetic contactors and switches

(d) Fuses and meters

Fig.8 States of vibration testing of individual components

For some components such as molded case circuit breakers (MCCBs), protective relays and auxiliary relays, the same models are used in both high-voltage and low-voltage switchboards. We designated representative types for such components and evaluated them separately to confirm their seismic capacity.

5. Postscript

This paper described seismic-resistant switchboards conforming to the new regulatory standards concerning commercial nuclear reactors. We started the development of seismic-resistant switchboards conforming to the new regulatory standards with studies concerning high-voltage switchboards, such as internal component evaluation, seismic analysis and stress analysis. This was followed by studies concerning low-voltage switchboards, such as seismic analysis, verification using a model switchboard, and checking the critical acceleration of the components.

We created a prototype high-voltage switchboard in actual size and conducted vibration testing. The result showed there was a prospect of achieving the target natural frequency of 30 Hz. This completed the development of the series of switchboards from high voltage to low voltage that offer the seismic capacity required in the new regulatory standards or other criteria.

Fuji Electric is committed to improving safety in nuclear power plants and other nuclear-related facilities by supplying these seismic-resistant switchboards both now and in the future.

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