SEISMIC CAPABILITY OF BUSHINGS MANUFACTURED
BY ABB POWER T&D COMPANY INC., ALAMO, TN

BACKGROUND

Historically, several different methods have been used for the justification of the seismic capability of electrical equipment, including transformer bushings. These methods usually involved some form of static calculations to estimate the forces generated during a seismic event of a given ground acceleration, and then comparing this force to the capability of the equipment, which may have been derived from calculations or from actual measurements. The way the calculations were to be done, what factors to include, how the comparisons were to be made, what was an acceptable margin, and what the specified conditions themselves were could be vastly different from application to application, or from customer to customer. Still other customers required actual shake-table testing to various requirements. All of this led to great difficulty for suppliers of electrical equipment in generating seismic qualification documents, and in getting them approved by the end customers. What was then needed was a more standardized way of specifying seismic requirements, and of qualifying equipment, that could be more universally accepted. Two standards groups have attempted to address these concerns.

SEISMIC STANDARDS

IEEE Std 693-1997

IEEE Std 693-1997 “IEEE Recommended Practice for Seismic Design of Substations” is a newly revised document covering the seismic design and qualification of all types of electrical equipment found in power substations. This document is a revision of the 1984 recommended practice, but it has been greatly expanded and completely reworked, such that it is effectively a new document. It simplifies the process of specifying seismic requirements by providing a single standard set of design recommendations for seismic qualification of each equipment type. This means that the seismic criteria, qualification methods and levels, and performance requirements are standardized for a given equipment type. Three qualification levels are recommended: low, moderate, and high. The user determines which level the equipment is to be qualified to, and includes this as part of their specification. In this way the equipment manufacturer has a very clear understanding of what must be done to obtain the qualification. IEEE 693 does not allow calculations as the only means of qualification of bushings, but requires testing.

IEC Technical Report 1463

IEC 1463: 1996-07 “Bushings-Seismic qualification” is an IEC document covering the seismic qualification of power bushings, and is based on static coefficient calculations to compare the expected forces generated during a seismic event to the cantilever withstand capability of the bushing. While ABB believes this document to be technically sound, it is not widely accepted in the United States, and as such is not the preferred method of seismic qualification of the ABB Power T&D Company, Components Division Inc., Alamo, TN, USA. Also, it should be noted that bushings meeting the requirements of IEEE 693 will, in most cases, meet the requirements of IEC 1463.

ABB COMPONENTS USA PREFERRED APPROACH

Our preferred approach will be to qualify our bushings to the IEEE 693 standard. The reasoning behind this is that the IEEE standard requires actual shake-table tests to be performed on the larger bushings, and while the IEC standard allows for calculations, most customers will be better satisfied with actual tests, or with a combination of tests and calculations. By using this approach, the largest number of customers can be satisfied. Additionally, the approval process is streamlined with this approach, and it allows us to respond to seismic performance questions in a timely fashion.
CUSTOMER SPECIFIC REQUIREMENTS

When users create their own unique set of seismic requirements and qualification methods, it becomes extremely difficult for electrical equipment manufacturers to execute the conditions of these requirements. Consequently, requests for equipment qualification to these unique requirements will be considered extremely special, and are highly discouraged. It is hoped that users with their own unique requirements will consider the adoption of IEEE 693, and if that is not done, that at least they will have enough information about the capability of our bushings to evaluate their suitability for application to the user’s specifications.

BASICS OF IEEE 693 AS IT APPLIES TO BUSHINGS

Seismic Performance Levels

Three performance levels are defined. The low performance level allows for peak ground accelerations up to 0.1g, horizontal, and does not require testing of the equipment at this level. The moderate performance level allows for peak ground accelerations up to 0.5g, horizontal, and requires testing of most categories of equipment. The high performance level allows for peak ground accelerations up to 1.0 g, horizontal, and also requires testing of most categories of equipment. For all performance levels, the vertical accelerations are to be 80% of the horizontal.

Selection of Performance Level

The user of the equipment determines the expected ground accelerations by the earthquake hazard method, or by seismic exposure maps and site conditions. Guidelines for doing this are given in the standard, and exposure maps are referenced for use in the United States, Canada, and Mexico. Once the user determines the expected ground accelerations, the performance level is selected to match the acceleration. The desired performance level then becomes part of the user’s specification, and is passed along to the supplier of the electrical equipment.

Requirements for Bushings in General

As bushings are used as components in larger equipment, there is not a section dedicated just to bushings, but rather they are covered in IEEE 693 in Annex D, Transformers and liquid-filled reactors. The requirements depend upon the nominal system voltage rating of the bushing, and the basics are described in the following sections.

Qualification of Bushings Rated Less Than 161 kV

Bushings rated less than 161 kV nominal system voltage are to be qualified by means of a static pull test (cantilever test), with twice the weight of the bushing applied normal to, and at the top of, the bushing. The bushing must withstand this load for a minimum of two seconds without damage or leaking. The reasons for allowing this simplified test are not given in the standard, but some of them are explained here. Bushings in this size range have historically performed well in real earthquakes, but it was desired that there be some kind of actual test to make sure that they would continue to perform well. It was desired to have as simple a qualification test as possible, and if one were to perform a static coefficient analysis, a bushing that could withstand the application of twice its weight to the top of the bushing would likely perform very well.

Qualification of Bushings Rated 161 kV and Above

Bushings rated for a nominal system voltage of 161 kV or higher require shake-table testing, using the time history method. A time history is a record of motion, usually in terms of acceleration, as a function of time. In this method, the shake-table is configured to simulate the type of shaking that would likely occur in a real earthquake. While every earthquake produces different motions, the input for this test contains accelerations, amplitudes, frequencies and energy levels that occur simultaneously, and envelope a required response spectrum. In many cases, the input signal used is derived from a recording of the ground accelerations experienced during a real earthquake, although artificially generated signals can be used as well. Since no real earthquake will envelope the entire required response spectrum, the signal is then modified such that the output of the shake-table will envelope the required response spectrum. Essentially, the bushing must pass this test without damage.
Because it is not practical to test every individual design, similar equipment may be grouped together for the purpose of qualification, with the most seismically vulnerable piece of equipment being tested. This allows similar equipment to be qualified, based on the testing done on the original equipment, so that the actual test need not be repeated, and is described in 5.7, *Qualifying equipment by group*. In order to use this grouping, it must be demonstrated that the new equipment to be qualified is less seismically vulnerable than the equipment tested. The exact method for grouping is left to agreement between the supplier and the user, and will vary somewhat depending on the equipment.

**ORDERING OF STANDARDS**

**IEEE Std 693-1997**  
IEEE Customer Service  
445 Hoes Lane  
P.O.Box 1331  
Piscataway, NJ 08855-1331  
Tel:- 1-800-678-4333 or 732-981-0060  
Website:- [http://standards.ieee.org](http://standards.ieee.org)

**IEC 1463**  
American National Standards Institute  
11 West 42nd Street  
New York, NY 10036  
Tel:- 212-642-4900  
Website:- [http://web.ansi.org](http://web.ansi.org)

**STATUS**

Our standard line of bushings was designed before seismic considerations were an issue. Even so, every bushing does have a certain strength inherent in the design, and most are able to withstand significant seismic events.

We have been in the process of evaluating our bushings to the requirements of IEEE 693, and have had time history shake-table tests performed on a 196 kV bushing, and on a 550 kV bushing. These tests were performed by the Pacific Earthquake Engineering Research Center at the University of California, Berkeley. The 196 kV bushing tested was our style 196W0800AY. It met all the requirements of the high qualification level, and is used as the basis of comparison for other bushings that are qualified by group. The 550 kV bushing tested was our style 550W2000UW. As this was a standard bushing, designed before seismic considerations were much of an issue, we did not expect that it would pass all the requirements for qualification. What this testing did reveal was the actual performance level of the bushing, which was approximately 0.25g horizontal ground motion. Allowing a margin of approximately 10% yields an acceptable ground motion of 0.22g. Because the desired ground motion must be doubled for the test, this translates into a horizontal motion of 0.45g, as applied to the flange of the bushing. Work is underway to develop a 550 kV bushing with improved strength and seismic withstand capability.

The test for bushings below 161 kV is simpler, and is the static pull test described previously.
The following table lists commonly used bushings by style number and gives the qualification level per IEEE 693 requirements.

<table>
<thead>
<tr>
<th>Style Number</th>
<th>Qualification Level</th>
<th>Equivalent Acceleration at the:</th>
<th>Qualification Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ground</td>
<td>Bushing Flange</td>
</tr>
<tr>
<td>025W0412AT</td>
<td>High</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>025W2000BE</td>
<td>High</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>025W3000BF</td>
<td>High</td>
<td>1.0</td>
<td>2.0</td>
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<td>034W0412AP</td>
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<td>2.0</td>
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<td>2.0</td>
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<td>069W0412AN</td>
<td>High</td>
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<td>2.0</td>
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<tr>
<td>115W0800AA</td>
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<td>2.0</td>
</tr>
<tr>
<td>115W1216AK</td>
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<tr>
<td>138W1620XC</td>
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<td>2.0</td>
</tr>
<tr>
<td>161W0800AA</td>
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<td>2.0</td>
</tr>
<tr>
<td>161W1216AK</td>
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<tr>
<td>196W0800AY</td>
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<tr>
<td>196W0800XA</td>
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<td>2.0</td>
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<tr>
<td>196W1216XP</td>
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<td>2.0</td>
</tr>
<tr>
<td>196W2530XD</td>
<td>High</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>362W1600UM</td>
<td>Moderate</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>362W2000UJ</td>
<td>Moderate</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>362W3000CB</td>
<td>Moderate</td>
<td>0.5</td>
<td>1.0</td>
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<tr>
<td>550W2000UW</td>
<td>---</td>
<td>0.22</td>
<td>0.45</td>
</tr>
</tbody>
</table>

The information given in the above table is meant to give quick answers to questions concerning the seismic capability of ABB Alamo bushings. It is not meant to serve as documentation of qualification. For qualification documents for a specific bushing, contact your ABB customer service representative.
DETAILS OF TIME HISTORY TESTING AS APPLIED TO BUSHINGS

Performance Level

The performance level is a specified level of earthquake ground shaking that is associated with one of the standardized seismic qualification levels (high, moderate, or low), as previously described. It is the level of earthquake ground shaking that a piece of qualified equipment could reasonably be expected to withstand. The high and moderate performance levels are represented by response spectra shown in Figures 4 and 5 within Clause 9.3 of IEEE 693. These spectra were developed to bracket the vast majority of substation site conditions.

Two Options for Testing

For equipment covered by IEEE 693, two options for demonstrating acceptable performance at the specified performance level are allowed. The first option is to perform the test to a required response spectrum that is only 50% of the specified performance level. However, if this method is used, a safety factor of 2.0 against structural damage must be demonstrated through analysis of the data. This safety factor is referred to as a performance factor, and is discussed in Clause 9.4 of IEEE 693. In this way, one can be reasonably certain that the equipment will perform well at the full performance level. This is allowed because it may not always be possible to attain the acceleration levels required to test at the full performance level. Additionally, some yielding of ductile materials at the performance level is considered acceptable, which means that equipment that had some yielding during testing would still function, but would not be considered acceptable for installation as new equipment. This method works best for equipment that responds in a linear fashion, such as steel structures. The required response spectra for the high and moderate qualification levels when using this method are shown in Figures A.1 and A.2 within Annex A of IEEE 693.

The second option is to perform the test at the full performance level. When this method is used, the equipment must remain functional and be undamaged, but it is not required that an additional safety factor of 2.0 be demonstrated, since the test is done at the full performance level. This option is allowed as described in 5.6.7 of IEEE 693. This method provides a greater degree of certainty that the equipment will perform well at the full performance level, particularly for equipment that responds in a non-linear fashion. For many bushings, the first failure mode encountered when performing shake-table testing is likely to be leakage of gaskets, which behaves non-linearly. Using this second option in regard to gasket leakage is specifically suggested in D.5.1.d, and is the method we prefer and use, where possible. Testing at the performance level, rather than the required response spectrum is simply more direct, and is likely to be acceptable to the largest number of customers.

Effects of Mounting

In actual service, bushings are not mounted directly to the ground, but are mounted on a larger piece of equipment, such as a transformer or liquid filled reactor. Because the ground accelerations get amplified through the transformer tank, the accelerations experienced by the bushing will be greater than the ground accelerations. To account for this during the test, where the bushing is mounted on a rigid stand, the time history test has to be performed at a level twice that shown in the appropriate spectra for the options mentioned above. Also, the bushing is to be mounted at no less than its in-service mounting angle, which is taken to be 20°, unless otherwise specified. Both of these requirements are specified in D.4.3 of IEEE 693.

The Test Response Spectrum

The test response spectrum is the spectrum used in the actual testing, with the motion applied directly to the mounting flange of the bushing. It is derived from the performance level, but with the above adjustments included. Since we prefer testing at the performance level, rather than trying to demonstrate safety factors, and because the ground accelerations must be doubled, the test response spectrum will normally be twice the performance level. For example, a bushing qualified to the high qualification level would have to withstand 2.0g horizontal accelerations, as applied to the mounting flange, to be considered good for a 1.0g horizontal ground acceleration.

Acceptance Criteria

Complete acceptance criteria are given in IEEE 693, but basically the bushing must have no evidence of damage, such as broken, shifted or dislodged insulators, visible leakage of oil, or broken support flanges. Bushings must also pass all routine tests as specified in IEEE Std C57.19.00, which are the same tests that all new bushings receive from the factory.
Technical Support
If a technical question arises regarding the product detailed in this Technical Product Literature contact:

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Power Technology Products Division USA
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Alamo, TN 38001-3813 USA

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