Seismic Qualification Case Study for a New Inverter

Stephen J. Eder[1] and John O. Dizon[2]

ABSTRACT

The purpose of this paper is to summarize the results of a research effort that reviews and compares some of the available seismic qualification approaches for new equipment at U.S. nuclear power plants. This includes investigation of not only the costs and lead times for each seismic qualification approach, but also the seismic capacity definitions that result from application of each qualification approach. The seismic qualification methods investigated in this paper include IEEE 344 Seismic Simulation Tests [1]; the Seismic Qualification Utility Group (SQUG) New and Replacement Equipment (NARE) guidelines [2]; the updated IEEE 344 Earthquake Experience Data method [1]; and then explores combination of analysis and testing, guided by prior seismic qualification experience. A new static inverter is used as the candidate specimen equipment component in the study.

It is found that the shake table testing process can be costly, but in general it results in relatively high seismic capacity definitions as compared with the other methods. The SQUG NARE guidelines provide a cost effective tool, but have limitations in so far as application scope and low seismic capacity levels. The updated IEEE 344 guidelines for use of seismic experience data for seismic qualification of new equipment are restrictive, relatively difficult to apply, and result in the most conservative (lowest) seismic capacity definitions.

An alternative approach is developed that adheres to the IEEE 344 requirements for seismic qualification by a combination of analysis and testing, and takes advantage of the experience gained through other industry programs related to seismic evaluation and qualification of equipment. This method involves screening of all parts of a new item of equipment to identify potential weak links and subcomponents that require detailed testing and analysis. Then the follow-on testing and analysis efforts are focused on only those critical features. The resulting capacity levels are consistent with those from full scale shake table testing, with lower cost and shorter schedule duration. This streamlined seismic qualification approach can be used at all nuclear power plants.

INTRODUCTION

Seismic qualification is necessary for safety-related equipment in nuclear power plants. In general, all plants perform equipment seismic qualification in accordance with IEEE 344 [1] requirements. Acceptable qualification methods in the current IEEE 344 standard include seismic simulation testing (shake table testing), analysis, and use of earthquake experience data. Shake table testing is the most common method used for seismic qualification of equipment. The most recent version of IEEE 344 includes updated requirements for use of earthquake experience data. As an acceptable alternative, certain older nuclear power plants that resolved Unresolved Safety Issue (USI) A-46 using the SQUG Generic Implementation Procedure (GIP) [3] can use the SQUG NARE [2] guidelines for seismic qualification of new and replacement equipment. The NARE guidelines are consistent with the GIP and involve application of earthquake experience data methods. There are significant differences between the updated IEEE 344 requirements for use of earthquake experience and the SQUG NARE guidelines.

The seismic qualification methods investigated in this paper include IEEE 344 seismic simulation tests; the SQUG NARE guidelines; the updated IEEE 344 earthquake experience data method; and lastly a method involving a combination of analysis and testing, guided by prior seismic qualification experience. As a case study, each method is employed for qualification of a static inverter as the specimen equipment component.

Specifically, the case study equipment is a safety-class ferroresonant type static inverter. The function of the inverter is to generate single-phase continuous and uninterruptible output AC power from any DC source within the operating input range of 200 to 280VDC. The AC output is 120 VAC, 60 Hz, 42 Amps, with a rating of 5kVA. The inverter was manufactured in May 2004. The inverter cabinet is a NEMA-1 (IP-20) free standing enclosure, which has a minimum 2.66 mm thickness (12 GA) framework, 1.90 mm (14 GA) door panels, and 1.21 mm (18 GA) side panels. The inverter stands 1791 mm (70.50 in.) tall and has plan dimensions of 552 mm (21.75 in.) wide by 648 mm (25 in.) deep. The front face of the cabinet has a dual latch door over the upper 2/3 of the height. The weight of the inverter is 499 kg (1,100 lbs.) with center of gravity 594 mm (23.4 in.) above base elevation. The electrical cables enter the top of the candidate inverter via flexible conduit.

The seismic qualification case study centers on determination and then comparison of the seismic capacity of the specimen equipment component using each of the above-mentioned seismic qualification methods. Anchorage design and seismic interaction reviews are excluded from this study, as these are considered to be equal for all methods. Seismic demand is not specifically discussed in so far as it is constant for each method and application. One exception regards IEEE

1. Chief Executive Officer, Facility Risk Consultants, Inc., Huntsville, AL.
2. President, Facility Risk Consultants, Inc., Huntsville, AL

344 earthquake experience which has special provisions regarding seismic-capacity-versus-demand comparisons. For each of the seismic qualification methods, cost and time factors are estimated and compared, including consideration of internal (utility design engineering) and external costs. Conclusions are made for the case study based on the determined seismic capacities, estimated costs, and time frame associated with implementation of each method. The authors acknowledge the support provided by EPRI and SQUG towards this research effort.

SHAKE TABLE TESTING

Seismic simulation shake table testing is a standard method that is commonly used in the nuclear power industry for seismic qualification of equipment. An item of equipment that is identical to the item being installed in the plant is sent to a test lab and it is subject to simulated ground motion based on Test Response Spectra (TRS) that match or exceed the plant's Required Response Spectra (RRS). The mounting of the candidate equipment item to the shake table has to be consistent with the manner in which the item of equipment will be anchored in the plant. IEEE 344 [1] describes in detail how the shake table test program must be conducted and how the results of the testing are to be documented.

The shake table test is most commonly performed as a proof test. The equipment is subjected to the particular response spectrum, time history, or other parameters defined for the mounting location of the equipment. In a proof test, no attempt is made to explore the failure thresholds of the equipment. Therefore, the proof test requires the preparation of a detailed specification. The equipment is tested to the specified performance requirement and not to its ultimate capability. The TRS of the proof test completely defines the seismic capacity of the candidate item of equipment.

The seismic capacity response spectrum for the case study static inverter achieved by use of shake table testing is shown in Figure 1. This has a peak spectral acceleration of about 2.8g, with a relatively narrow frequency band. The frequency band is narrow because the required response spectrum for the test qualification was narrow. The zero period acceleration (ZPA) capacity is 0.50g. It is possible that a higher capacity could have been achieved in the shake table test; the tested capacity is an envelope of the required response spectra.

A standard inverter meeting the functional and quality requirements for a nuclear power plant has a total cost of less than about $15,000. The shake table test seismically qualified static inverter had a total cost of slightly more than about $50,000. Thus the cost associated with obtaining a second inverter, shipping it to the test lab, developing the test plan, performing the shake table test, and documenting results was roughly $35,000.

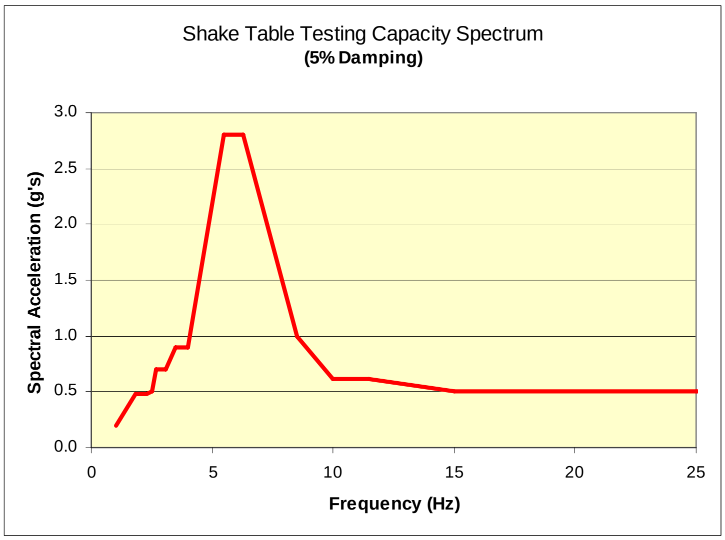

Figure 1: Seismic capacity based on seismic simulation tests

The shake table qualification test method involved minimal time for the utility design engineer, who only had to provide the required response spectra to the test lab and interface with the plant procurement department. The plant procurement department personnel simply checked the "Seismic Class 1 required" box on the procurement form, and the rest of the process became the responsibility of the equipment manufacturer and/or test lab. When the final test report was sent to the utility, the utility design engineer had to review the report for compliance. The overall time involvement for the utility engineer was less than about 8 hours. The total time duration required for procurement and qualification testing was about 6 weeks.

EARTHQUAKE EXPERIENCE DATA

IEEE 344 [1] provides requirements for seismic qualification of equipment through the use of experience data. The specific requirements that are implemented in this inverter case study include characterization of the earthquake experience reference equipment class, characterization of earthquake motions experienced by the reference equipment, and establishment of the earthquake experience-based seismic capacity for the reference equipment class. The reference equipment class is a group of equipment with similar physical, functional, and dynamic response features as the candidate equipment being qualified, and that have performed adequately is past earthquakes. Inclusion rules are used to define the bounds of equipment included in the reference equipment class. Caveats are used to define any prohibited characteristics that have resulted in seismic induced failure of the equipment, addressing both structural integrity and specified function.

The reference equipment inclusion rules were defined to include base mounted free-standing static inverters with cabinet dimensions similar to or bounding the candidate inverter. That is, shorter and squatter database inverters were excluded, but taller and narrower inverters were included. The reference equipment class was defined to have at least 5 kVA rated capacity (rating directly impacts the overall weight of the inverter). Wall mounted inverters and inverters in long line-ups of cabinets bolted together were excluded. The flexible conduits at the top of the candidate inverter provide no top restraint, so the reference equipment class definition excludes inverters with rigid top entry conduit and inverters that are top braced.

In order to establish the caveats for the reference equipment class, The Electric Power Research Institute (EPRI) electronic version of the SQUG database (eSQUG) [4] was considered to be the complete library of all inverters subject to past major earthquakes. No additional earthquake response data were considered. Reference equipment class caveats were established based on review of all seismic effects for all eSQUG battery chargers, inverters, small transformers, and distribution panels. The resulting caveats are that the inverter must have sufficient clearance such that it is free from impact by adjacent structural features and plant commodities, and that the inverter must be free of any loose metal objects.

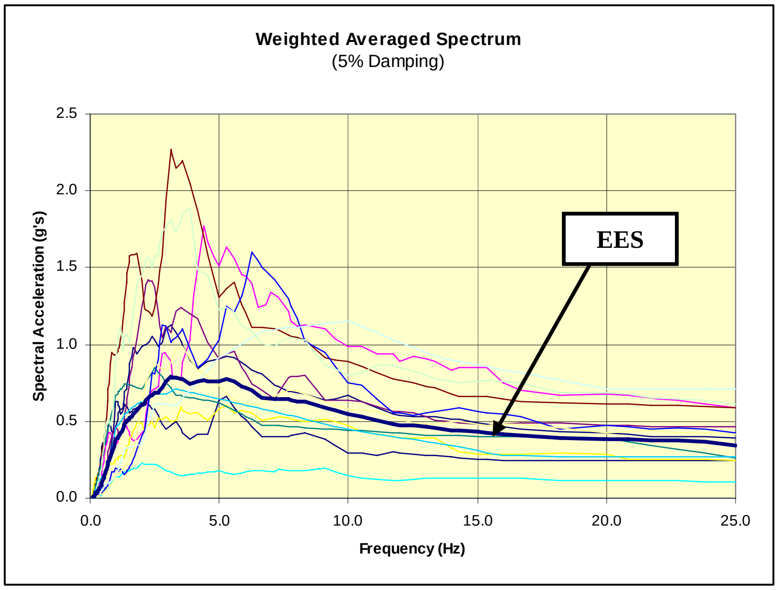

Figure 2: Reference Equipment Class Ground Motion Response Spectra and the Earthquake Experience Spectrum (EES)

Out of a total of eighty-nine (89) datasets included in eSQUG [4] for battery chargers and inverters, only thirty (30) independent items were determined to match the reference equipment class static inverter definitions. Reference equipment class site ground motion response spectra (which are the average of the two orthogonal horizontal components of the 5% critically damped response spectra) were found to be available in eSQUG for only twenty-one (21) of the thirty (30) independent items. New ground motion estimates were made for two (2) other database sites for which data were readily available, following the guidelines provided in IEEE 344 [1] for earthquake experience.

The earthquake experience-based seismic capacity for the reference equipment class was then defined as an earthquake experience spectrum (EES) [1]. This involves determination of a weighted average of the ground motion response spectra from the selected reference sites. Because the number of independent items included in the reference equipment class was less than 30, the EES had to be reduced by a reduction factor. The reduction factor for 23 sites is 0.86. The data base reference site ground motion response spectra and the resulting EES are shown in Figure 2.

This EES defines the seismic capacity of the reference class of equipment for use in the seismic qualification of the candidate equipment using the earthquake experience data method. The seismic capacity of the static inverter was found to have a peak spectral acceleration of 0.75g and a ZPA of 0.35g. It must be noted that this seismic capacity is for comparison with median centered seismic demand (corresponding to roughly an effective 1.25 increase in capacity). The cost was $15,000 for the standard inverter meeting the functional and quality requirements. The utility design engineers had to spend considerable time to establish the reference equipment class and the EES, and prepare the seismic qualification report. In total this was about 120 hours of engineering time for this case study. The total minimum time duration required for procurement and finalization of the qualification report was about 3 weeks.

SQUG NARE GUIDELINES

The Seismic Qualification Utility Group (SQUG) Generic Implementation Procedure (GIP) [3] was developed primarily for the resolution of Unresolved Safety Issue (USI) A-46, i.e., to evaluate the seismic adequacy of as-installed equipment. The GIP also provides guidelines for seismic qualification of new and replacement equipment and parts (NARE) based on seismic experience data methods. Per NRC Generic Letter 87-02 [5], nuclear power plants that were subject to resolution of USI A-46 can adopt the GIP as a licensing basis method for NARE, using the provisions of 10 C.F.R. § 50.59 to add this method to the plant licensing basis. Non-A-46 plants are excluded.

The general SQUG GIP provisions may be applied to new or replacement equipment not identical to the equipment originally installed in the USI A-46 plant, provided the seismic evaluations are performed in a systematic and controlled manner so as to assure that new or replacement equipment are represented in the earthquake experience equipment class and that applicable caveats are met. In particular, each new or replacement item of equipment and part must be evaluated for any design changes that could reduce its seismic capacity from that reflected by the earthquake experience equipment class, and these evaluations must be documented. The SQUG NARE process of identifying design differences in new and replacement equipment and evaluating these differences for their effect on seismic capacity addresses the concern that newly designed equipment may not be as rugged as the older vintage equipment upon which the GIP equipment classes are based. The GIP is primarily based on data collected on the vintage of equipment in use at the time the earthquake occurred.

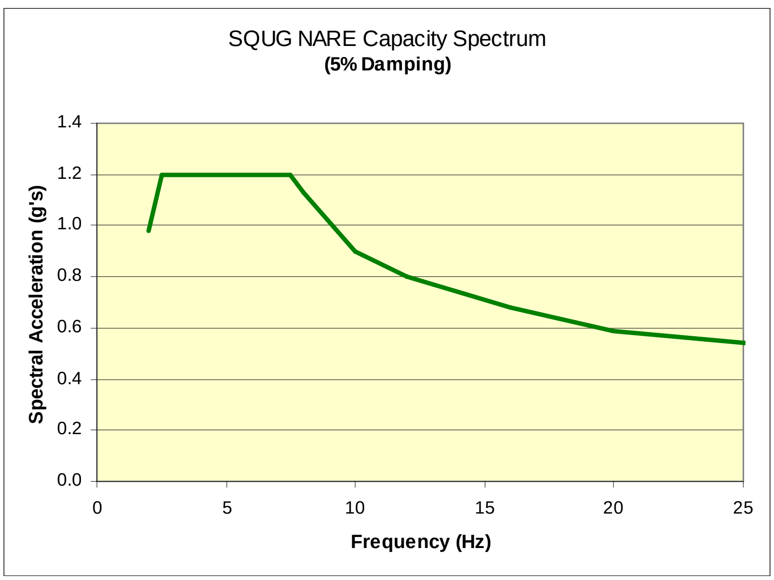

Figure 3: Seismic capacity based on SQUG NARE guidelines

Use of the SQUG NARE guidelines for seismic experience data provides the basis for establishing the SQUG Reference Spectrum as the seismic capacity of a candidate item of equipment. The SQUG Reference Spectrum is shown in Figure 3. As with the IEEE 344 earthquake experience method, the cost was $15,000 for the standard inverter meeting the functional and quality requirements. However, for implementation of the SQUG NARE method, the utility design engineers had to spend only about 12 hours to develop the seismic qualification report. The total minimum time duration required for procurement and finalization of the qualification report was less than about 2 weeks.

COMBINED ANALYSIS AND TESTING (STREAMLINED APPROACH)

The combination of analysis and testing is one of the acceptable seismic qualification methods as provided in IEEE 344 [1]. The method of combined anlaysis and testing is broadly defined in IEEE 344 and this enables implementation of a streamlined approach that remains within the prescribed rules, but takes advantage of the many available generic industry procedures and documents as follows.

STERI and GSTERI

EPRI has developed guidelines for the seismic technical evaluation of replacement items (STERI) [6]. These guidelines provide practical, cost-effective techniques for assuring that replacement items will meet the seismic performance requirements necessary to maintain a plant's seismic design basis. They also provide methods for determining when seismic evaluation is required. The STERI guidelines do not provide methods for seismic qualification. However, the STERI guidelines can provide a framework for guiding the analysis and testing qualification efforts for seismic qualification of new equipment, based on its three levels of screening evaluations: (1) an item is seismically insensitive if its performance is not affected by earthquake loads; (2) an item is seismically rugged if it is shown to maintain its required seismic adequacy under seismic loading in excess of the seismic demands for the application under consideration; and (3) a replacement item may be shown to be seismically adequate by an item-specific equivalency evaluation based on characteristics important to seismic ruggedness and functionality.

EPRI has also developed generic lists of seismically insensitive and seismically rugged items, together with the associated conditions and technical justifications (G-STERI) [7]. These lists can be used to support seismic qualification. For example, if a fuse is defined as a seismically rugged replacement item for a particular plant site, then by similarity it is also a seismically rugged part for a new item of equipment provided that there are no design differences. Therefore the fuse does not have to be addressed by analysis or testing in a new seismic qualification package. The supporting data is the G-STERI report. Insensitive and rugged parts can be screened out from further consideration, and enable the qualification engineer to focus on the parts of the new equipment that may have some seismic vulnerability. There is no need to analyze or test parts that are seismically insensitive or rugged at a particular plant site.

SQUG Relay Procedure

A relay seismic functionality review was required as part of USI A-46 resolution, in order to determine if plant safe shutdown systems could be adversely affected by relay malfunction in the event of a design basis earthquake. This included evaluation of the seismic adequacy of those relays for which malfunction is unacceptable. The SQUG and EPRI procedures [8, 9] include detailed investigation of electrical systems to identify a minimum set of chatter-sensitive relays requiring seismic evaluation. An in-cabinet amplification factor (AF) multiplied by the in-structure response spectrum (IRS) at the base of the cabinet is used to determine the seismic demand requirements for the identified relays. Capacities are based on shake table tests.

The in-cabinet amplification factors are defined for three types of cabinets: (1) low amplification panel, AF = 3.0; (2) medium amplification panel, AF = 4.5; and (3) high amplification panel, AF = 7. For other types of cabinets, an effective broad-based amplification factor can be developed [8]. The USI A-46 in-cabinet amplification factors are based on analysis and testing. These are not based on earthquake experience data. These conservative generic amplification factors can be relied on for seismic qualification. The supporting data are contained in the reference reports [3, 8, 9].

SQURTS Program

The Seismic Qualification Reporting and Testing Standardization (SQURTS) organization was formed by EPRI and interested utilities in 1993 to share seismic qualification data, standardize test procedures and reports, gain testing experience, and decrease seismic qualification testing costs and schedules. SQURTS qualification tests are performed for a bounding required response spectrum (RRS) that envelopes the floor response spectra for all member utility plants. The standard format test reports are entered into a shared library that is used by all member utilities for current and future seismic qualification needs. The SQURTS library provides a well-documented database of shake table tested equipment and parts. This database can be used by members for seismic qualification of potentially seismically sensitive subcomponents in new items of equipment. The database can also be used to strengthen any plant-specific STERI application, to assist in the identification of seismically insensitive or seismically rugged subcomponents.

Other Experience

Essentially all operating nuclear power plants in the U.S. performed seismic IPEEE reviews, and many older plants also had to perform the USI A-46 seismic verification. Much of the screening evaluations and walkdowns were based on seismic experience data, which is outside of the licensing basis for newer plants and cannot be used for new seismic qualification. However, outliers from the screening reviews were qualified using analysis and testing methods. Also, a considerable amount of qualification and fragility test information is presented in the Generic Equipment Ruggedness Spectra report [10]. In addition, many of the plant evaluation of High Confidence Low Probability of Failure (HCLPF) capacities were determined based on analysis and test results as described in the Methodology for Assessment of Nuclear Power Plant Seismic Margin report [11]. The outlier evaluations and the HCLPF capacity evaluation results and procedures provide a solid basis for identifying weak links in equipment components and in the seismic load paths for those components. These can be used as the basis for focusing the analysis and testing for IEEE 344 seismic qualification of new equipment using the streamlined analysis and testing approach.

Description of Combined Analysis and Testing Method

The streamlined approach for seismic qualification of new equipment, developed to be in accordance with the IEEE 344 [1] methods of combined analysis and testing, consists of parts screening, testing, analysis, and documentation. For parts screening, a list of all of the parts of the new equipment component is required, as provided by the equipment manufacturer. STERI and G-STERI [6, 7] are then used as the bases to screen out seismically insensitive and seismically rugged parts. The SQUG / EPRI in-cabinet amplification factors [8, 9] are used to determine the required response spectra for the testing of parts that were not screened out. These parts are tested (if SQURTS data is not available). Weak links in the equipment seismic load path are identified, and evaluated. Results of the combined analysis and testing qualification process are documented in a summary report.

Parts Screening Review for Candidate Inverter

A screening review was performed for all of the parts of the static inverter, following the general guidelines and generic results from STERI [6] and G-STERI [7]. A functional screening was performed for relays and contactors, following the SQUG relay review guidelines [8]. The protective and auxiliary relays and contactors within the static inverter were all determined to be not vulnerable or not affecting equipment operation. The bulk of parts in the static inverter (such capacitors, diodes, circuit transformers, network cards, switches, actuators, fuses, pilot lights, ammeters, voltmeters, resistors, noise suppressors, and printed circuit boards) were determined to be seismically insensitive. Molded case circuit breakers were not screened out and thus identified as requiring seismic simulation testing. Other parts were determined to be seismically rugged, such as wiring harnesses, terminal buses, crimp pins, and the cooling fan assembly.

A qualitative review was performed for the internal structure and base framing. The transformer is the heaviest subcomponent in the inverter, and based on review of GERS [10] and the Seismic Margin Assessment guidelines [11], the transformer load path and attachment bolts were found to be the key features governing seismic capacity. The attachment and support frame member for the internal transformer were judged as the weak link and identified for further evaluation. In addition, analysis is required in order to confirm that the base channel frame, attachment bolts, and stiffener plates have sufficient capacity.

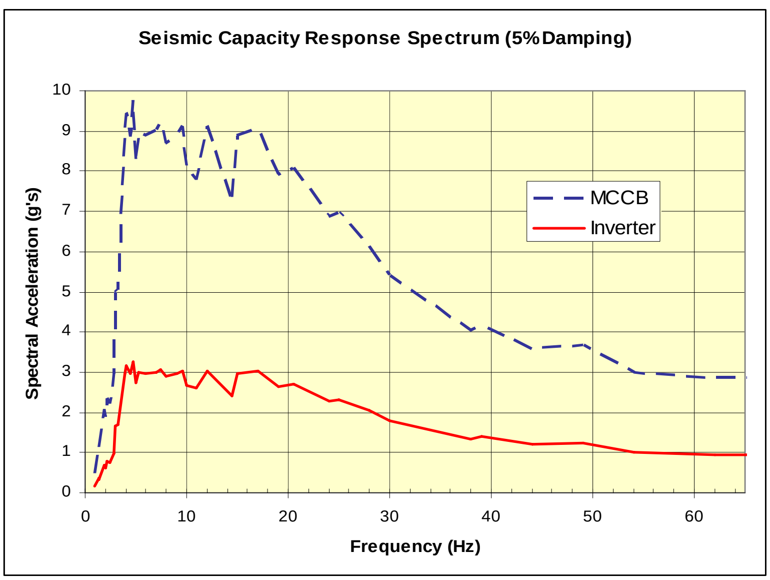

Figure 4: Seismic capacity response spectrum for static inverter derived from the tested seismic capacity of the molded case circuit breaker

Analysis and Testing Results

A trail and error approach was used to find the seismic capacity of the inverted by analysis. Seismic demand was progressively increased until the capacity / demand interaction ratio (I.R.) for the weak link reached 1.0. The analysis of the transformer mount assembly was found to lead to a peak floor spectral acceleration capacity of the static inverter of 4.0g. The analysis for the inverter base connection and framing was found to lead to a capacity of 4.15g. The tested seismic capacity response spectrum of the molded case circuit breaker is shown in Figure 4. This response spectrum was scaled downward by a factor of 3.0, which is the broad band seismic amplification factor for the cabinet [8]. The resulting floor response spectrum capacity for the static inverter is also shown in Figure 4. This has a peak spectral acceleration of about 2.8g, which governs over the analyzed capacities of 4.0g and 4.15g.

The cost was $15,000 for the standard inverter meeting the functional and quality requirements. Implementation requires a total of about 80 hours of utility engineer time for collecting data, screening parts, performing analyses calculations, and developing required response spectra for the necessary parts. The total cost of purchasing a spare molded case circuit breaker (part not screened out for the case study inverter) and conducting a shake table test for it was about $8,500. This required about 4 weeks total time.

COMPARISON AND DISCUSSION

Figure 5 presents the seismic capacity results from the four (4) seismic qualification methods discussed above. As shown, the lowest capacity was obtained by use of the IEEE 344 [1] earthquake experience data (although note that this capacity can be compared with median-centered seismic demand, whereby the other methods cannot, which is equivalent to a 1.25 increase in capacity). The capacity obtained by use of this method is about 25% of the capacity of the inverter as determined by the other IEEE 344 methods. This means that the inherent factor of safety by use of the updated IEEE 344 earthquake experience data method is at least 4.0. Of the 4 methods, the highest seismic capacity was obtained by the use of the combined analysis and testing method. For comparison purposes, the SQUG GERS [10] capacity spectrum for inverters is also shown on Figure 5. The SQUG GERS capacity spectrum is slightly lower and roughly similar in shape to the spectrum from the combined analysis and testing method; the combined analysis and test method spectrum is similar to that of the underlying test database for SQUG GERS inverters [10]. The SQUG GERS inverter test database does not include any fragility test data, and does not include any instances of failure or malfunction. This indicates that the GERS represents a lower bound estimate of the seismic capacity of an inverter.

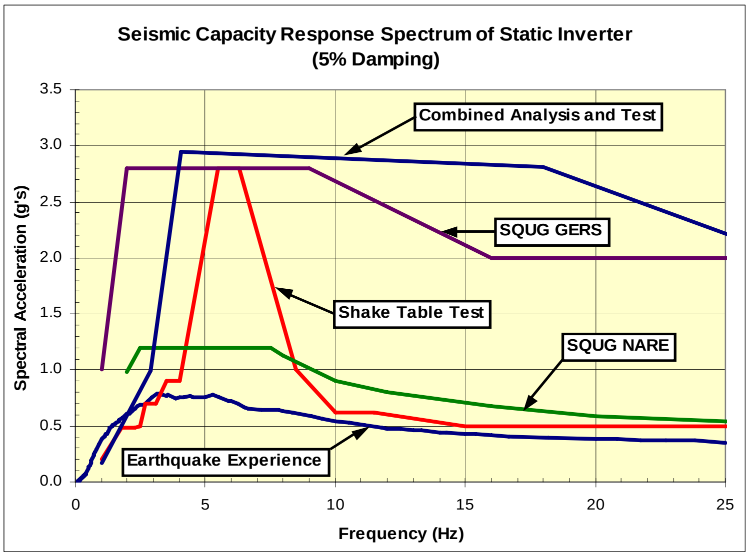

Figure 2-5: Comparison of seismic capacities

Cost and time duration comparisons are presented in Table 1 (cost comparisons use a composite engineering rate of $100/hour). As shown, SQUG NARE [2] is the lowest cost and shortest duration method. However, this method is only applicable to USI A-46 plants. In comparison with SQUG NARE [2], the IEEE 344 earthquake experience data method [1] has lower capacity, higher cost, and longer duration. The highest cost method is seismic simulation testing which also has the longest duration. In comparison, the combined analysis and test method had higher capacity, lower cost, and shorter duration. Based on the comparisons, and in recognition that the combined analysis and test method achieved the highest seismic capacity, the combined analysis and testing method appears to be an attractive alternative method for seismic qualification of equipment.

Table 1: Comparison of Seismic Qualification Methods

Method	Equipment Cost	Utility Engineering Cost	Total Cost	Total Length of Time	Peak Spectral Capacity	Zero Period Capacity
Seismic Simulation Tests	$50,000	$800	$50,800	6 weeks	2.80 g	0.50g
Earthquake Experience Data	$15,000	$12,000	$27,000	3 weeks	0.75g	0.35g
SQUG NARE Guidelines	$15,000	$1,200	$16,200	2 weeks	1.20g	0.50g
Combined Analysis & Testing	$23,500	$8,000	$31,500	4 weeks	2.80g	0.95g

CONCLUSION

A total of four seismic qualification methods were investigated and implemented for a case study inverter, including shake table testing [1], earthquake experience data [1], SQUG NARE [2] guidelines, and the combined analysis and testing method. Of the four methods, the SQUG NARE guidelines have the lowest time and cost, and any risk to the utility is low because the target capacity is known in advance (capacity is the SQUG Reference Spectrum). The shortcoming in the SQUG NARE method is that the use of this method is restricted to only the USI A-46 plants that revised their licensing basis to include use of the SQUG GIP [3] for NARE.

The updated IEEE 344 earthquake experience method [1] is the worst of all four methods investigated. It required the most engineering time and resulted in the lowest seismic capacity. Based on this case study, more code development effort is recommended for the earthquake experience data seismic qualification method. Factors of safety appear to be too high which makes use of the method impractical.

The shake table test per IEEE 344 [1] is the costliest and most time-consuming, but straight forward. The illustrated combined analysis and testing approach for seismic qualification of equipment appears to be an attractive alternative method, especially if coordinated with the EPRI SQURTS program. It is recommended that utilities identify additional industry programs that can be used to further focus future seismic qualification work, and rely on the combined analysis and testing method as summarized in this paper.

REFERENCES

1. IEEE Std. 344-2004, "IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations," 2004.
2. SQUG, "Implementation Guidelines for Seismic Qualification of New and Replacement Equipment/Parts (NARE) Using the Generic Implementation Procedure (GIP)," July 2000, Revision 4.
3. Seismic Qualification Utility Group, "Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment," Revision 3A, December 2001.
4. EPRI, "SQUG Seismic Experience Database," Version 2.2, http://www.epri.com/esqug/main.htm
5. U.S. Nuclear Regulatory Commission, "Verification of Seismic Adequacy of Mechanical and Electrical Equipment in Operating Reactors, Unresolved Safety Issue (USI) A-46," Generic Letter 87-02, Washington, DC, February 19, 1987.
6. EPRI, "Guideline for the Seismic Technical Evaluation of Replacement Items for Nuclear Power Plants," Final Report NP-7484, February 1993
7. EPRI, "Generic Seismic Technical Evaluations of Replacement Items for Nuclear Power Plants," Report TR-104871, May 1995.
8. MPR Associates, Inc., "Procedure for Evaluating Nuclear Power Plant Relay Seismic Functionality," EPRI Report NP-7148, December 1990.
9. Stevenson & Associates, "Development of In-Cabinet Amplified Response Spectra for Electrical Benchboards and Panels," EPRI Report NP-7146, December 1990.
10. ANCO Engineers, Inc., "Generic Seismic Ruggedness of Power Plant Equipment," EPRI Report NP-5223, Revision 1, August 1991.
11. J. R. Benjamin and Associates, NTS Engineering, and RPK Consulting, "A Methodology for Assessment of Nuclear Power Plant Seismic Margin," EPRI Report NP-6041, Revision 1, August 1991.