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## IEEE 693 SEISMIC QUALIFICATION OF COMPOSITES FOR SUBSTATION HIGH-VOLTAGE EQUIPMENT

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### SUMMARY

This paper discusses research on the application of IEEE Standard 693 seismic qualification requirements for hollow-core composite insulators used on high-voltage instrument transformer substation equipment. The IEEE 693 qualification procedure of time history shake-table and static-pull tests as well as the acceptance criteria is evaluated. Failure modes for composite insulators are discussed. Experimental observations show that the acceptance criteria are invalid for qualifying hollow-core composites. The need for a static-pull test following vibration qualification tests is presented. The need for post-vibration-test measurement of damping is discussed. Changes to the IEEE standard and potential research are recommended.

### INTRODUCTION

IEEE Standard 693-1997, "IEEE Recommended Practice for Seismic Design of Substations" [1], is a major improvement in the way the power industry seismically qualifies substation high-voltage equipment. The standard has established discrete qualification levels with associated controlling response spectra, and well-defined qualification procedures and acceptance criteria. In addition to general procedures for analysis and testing, special procedures and criteria are developed for individual classes of equipment that reflect their unique characteristics and earthquake performance.

The standard provides two seismic qualification performance levels that are defined by excitation response spectra. Acceptance criteria are established so that equipment shake table-tests qualification need only be subjected to an excitation half of those defined by the performance response spectra. While not explicitly stated in the standard, it is the view of the authors that testing to half of the performance level requires that the failure modes of the equipment are understood and that associated critical variables, such as a strain, can be measured. The acceptance

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natural disasters such as earthquakes Thus in order to build standard methods of providing and validating the seismic capability of electrical substation equipment to sustain the high demands detailed testing and analysis methods are needed Although current standards specify the required capacities of various types of substation equipment and the method for evaluating these capacities discrepancies between the required capacities and the real behavior observed in seismic events were questioned by recent research studies Electrical substation equipment includes a variety of complex components made of multiple mechanical parts and structures which when subjected to earthquakes may fail and impair the electrical functionality Among those some of the most complex and vulnerable components are i disconnect switches and ii high power transformers Each of these components has vulnerable parts which should be studied evaluated and possibly protected in order to ensure continuous operation after earthquakes This dissertation focuses on the two systems indicated above A disconnect switch used in substations of large electrical grids is an important component that supports the functionality of the electrical network Such a switch is a combination of a support structure and the switching mechanism which in turn is made of fixed and moving metal parts and of ceramic or composite electrical insulators In order to determine if this equipment is acceptable in seismic areas the static and dynamic characteristics of these high voltage three phases disconnect switches and their capacity to withstand severe vibrations testing has to be performed Due to the complexity of such systems and uncertainties in the construction and behavior of components such determination cannot be done computationally In an attempt to determine contributions of components to the global response of the disconnect switch DS systems this work proceeds with a methodical experimental and computational study Tests to find the characteristics of each component were performed first followed by tests of various subassemblies Moreover the entire assembly was also tested while observing the contributions of the individual components and sub assemblies When weak components were identified a solution for protecting the components through modification of the response of the global system was attempted The test results and the numerical evaluations showed several important characteristics in the behavior of the disconnect switches and issues in their acceptance testing qualifications The adequacy and acceptance of transformers and transformer bushings is of great concern in the electrical industry The current practice such as the IEEE 693 2005 recommends the following about the qualification tests of a transformer bushing i using a rigid frame to hold the bushing on a shake table instead of using a real transformer tank and ii doubling input ground motions to consider the amplification of the ground motion caused by the flexibility of the transformer tank The rigid frame lacks the capability to simulate the dominant effects of the local connectivity of the bushing to the transformer s cover while the base motion recommended by the current code underestimates the effects of the influence of the tank walls and cover plate on the motion transmitted to the bushing at its connection to the tank While a bushing is mounted on the roof cover of a transformer tank the excitation transmitted to the bushing is not identical to the ground motion below the transformer tank The roof motion is amplified or attenuated differently in the horizontal and

vertical directions due to the dynamics of the tank This study identifies the issues related to the acceptance testing and proposes designs develops and evaluates experimentally and numerically a support frame simulating transformer behavior Due to limitations in reproducing simulated earthquake ground motions seismic qualification testing is often limited to lower levels of shaking In this study the possibility of using a modulated sine sweep that can be implemented in smaller laboratories as an input base motion for qualification purposes is investigated The sine sweep proposed is modulated to match an arbitrary required response spectrum for electrical equipment such as required by IEEE 693 RRS In addition to the existing methods to identify system frequencies and damping values specified in testing standards an alternative method i e a table impulse test is developed and evaluated by analyzing testing results A table impulse test can share most of advantages which can be found from the existing resonant frequency search test methods while each existing method shares only one or some of those advantages This dissertation focuses on the evaluation of current practice and proposes develops and verifies experimentally and numerically where feasible new techniques of evaluation and improvement of the adequacy of electrical equipment

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