Final Project Summary — PEER Lifelines Program

Project Title—**ID Number**	*Seismic Qualification Requirements for Transformer Bushings*—**406**		
Start/End Dates	10/1/01 – 9/30/03	Budget/ Funding Source	$120,000 / PG&E/CEC
Project Leader (boldface) and Other Team Members	**Filiatrault (UCSD)**		

1. Project goals and objectives

This research task investigates the factors that most greatly influence the dynamic response of high voltage bushings as well as attempts to quantify the ground motion amplification for various high voltage transformers. Numerical models of four different high voltage transformers were developed and used for modal and dynamic time-history analyses. In addition, system identification and seismic shake table tests were performed on a full-scale 525 kV transformer-mock bushing system, as shown in Fig. 1. A numerical model of the test configuration was created to predict the seismic test results through dynamic time-history analyses.

Figure 1.

2. Benefits of the results of this project to develop technologies and protocols to mitigate the vulnerability of electric systems and other lifelines to damage directly and indirectly caused by earthquakes. Also, benefits to develop assessment techniques to evaluate damage to electric systems caused by earthquakes and to assess fiscal impacts due to the loss of electric service to the community.

The IEEE-693 standard, which provides seismic design recommendations for substation equipment, states that bushings with voltage ratings exceeding 161kV must be seismically qualified by shake table testing. Since placing a full-scale transformer-bushing system on a shake table is not economically feasible on a routine basis, bushing qualification tests are generally performed by placing the bushing on a rigid frame in lieu of the transformer body itself. Although the transformer body is assumed to be fairly rigid, it is acknowledged that the supporting structure of the bushing, consisting of the turret and transformer tank, amplifies the ground acceleration. For this purpose, the IEEE-693 standard assumes that the motion at the base of the bushing is equal to the ground motion multiplied by a factor of 2. Shake table testing of porcelain bushings on a rigid base using the IEEE-693 seismic qualification procedure has demonstrated a generally good performance of these components. This good experimental performance is contrary to the failure of bushings observed in the field following past earthquakes. It is believed that the actual seismic vulnerability of porcelain bushings might be caused by the flexibility of transformer tanks and of bushing attachments, which amplify their dynamic response. To clarify this issue, this study investigated numerically the dynamic response of porcelain bushings mounted on transformer tanks.

3. Brief description of the accomplishments of the project

The numerical experimental results obtained in this study have provided several insights into the seismic response of high voltage transformer-bushing systems. The main conclusions that can be drawn from this study are summarized below:

- The flexibility of the top plate of the transformer tank greatly reduces significantly the fundamental frequency of a bushing compared to that of the same bushing rigidly mounted.
- The top plate flexibility of the transformer tank provides the largest influence on the amplification between the ground and the base of the bushing.
- In a given direction, the ground motion amplification occurs at two predominant frequencies: the fundamental frequency of the transformer tank and the fundamental frequency of the bushing.
- The lower fundamental frequency transverse direction of the transformer tank consistently results in larger ground motion amplifications than the higher frequency longitudinal direction.
- The ground motion amplification factor of 2.0 specified in the IEEE-693 standard may not be conservative for transformer-bushing systems for which the bushing fundamental frequency is tuned to the fundamental frequency of the transformer tank.

- Bracing members attached near the turret of the bushing effectively reduce the ground motion amplification as well as improve the overall bushing response.

4. Describe any instances where you are aware that your results have been used in industry

The results generated in this study are being considered by the IEEE-693 Committee for future editions of their standard.

5. Methodology employed

In the numerical study, linear dynamic time-history analyses on three-dimensional finite element models of four different high voltage transformers were performed using the commercially available structural analysis software SAP 2000 (Computers and Structures 2003). The finite element mesh for each of these 4 models is shown in Fig. 2. The analyses were performed in each principal direction of the transformers under 20 different historical strong ground motion time-histories scaled to the 2% damped high required level response spectrum specified in the seismic qualification procedure of the IEEE-693 standard.

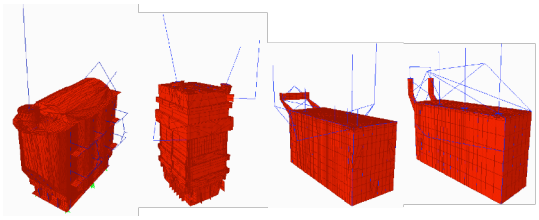

Figure 2.

The ground motion amplification was then quantified in two different ways. First, a frequency dependent spectral amplification was computed by taking the ratio of the 2% damped absolute acceleration response spectrum of the horizontal acceleration time-history obtained at the base of the bushing to that of the horizontal ground acceleration. Second, for three of the four transformer-bushing systems, the ground motion amplification was also computed by taking the ratio of the maximum bending moment obtained at the base of the bushing mounted on the transformer to that of the same bushing rigidly mounted.

The numerical study was complemented by system identification and seismic shake table tests on a full-scale 525 kV transformer-mock bushing system.

6. Other related work conducted within and/or outside PEER

Complementary experimental and numerical studies on bushing-transformer systems have been carried out by researchers from the Multidisciplinary Center for Earthquake Engineering Research (MCEER).

7. Recommendations for the future work: what do you think should be done next?

Further numerical and experimental studies on the influence of various transformer tank top plates may have on the dynamic response of transformer-bushing systems should be conducted. Isolation systems to decouple the fundamental frequency of bushing from that of transformer tank should be investigated.

8. Author(s), Title, and Date for the final report for this project

Matt, H. and Filiatrault, A. “Seismic Qualification Requirements for Transformer Bushings,” April 2004.