Journal of Constructional Steel Research 78 (2012) 173–182

Contents lists available at SciVerse ScienceDirect

Journal of Constructional Steel Research

Dynamic properties of substation support structures

R. Karami Mohammadi [a,*], V. Akrami [b], F. Nikfar [c]

[a] Civil Eng. Dep., K.N. Toosi University of Technology, Tehran, Iran
[b] Amirkabir University of Technology, Tehran, Iran
[c] McMaster University, Hamilton, Canada

ARTICLE INFO

Article history:
Received 20 July 2011
Accepted 29 June 2012
Available online 3 August 2012

Keywords:
Dynamic amplification factor (DAF)
Substation structures
Finite element method (FEM)
Fundamental natural frequency
Spectral shape

ABSTRACT

Substation electrical equipment is usually mounted on different kinds of structures, which can have a very significant effect on the motion that the supported equipment will experience during an earthquake. In this paper, a parametric study is implemented in order to assess dynamic properties of substation support structures.

In the first phase of this study, a simplified Four Degrees-of-Freedom (4-DOF) system is proposed in order to model different support-equipment systems and is verified through finite element method (FEM). Based on the proposed model, a practical equation is proposed to calculate the fundamental natural frequency of support-equipment systems and compared to the one proposed by ASCE (substation structure design guide, 2008). Furthermore, dynamic amplification factor (DAF) of substation support structures is calculated, and effect of different parameters (e.g. support mass, height and stiffness) is discussed. Finally, a new criterion is developed to restrict maximum acceleration at support-equipment intersection.

Results of this paper can be utilized in order to design more proper support structures to preserve substation electrical equipment from seismic induced damages.

1. Introduction

Experiences obtained from previous earthquakes have demonstrated that the substation equipment is seismically vulnerable and is not in the safe state [1]. In the USA, during the 1989 Loma Prieta Earthquake, some 230 kV and 550 kV high voltage substation equipment items were destroyed severely. In 1994 Northridge Earthquake destruction on 230 kV and 550 kV transformer bushings was serious [2]. Direct cost for repair and replacement of earthquake damage to power system facilities of the USA from some well-known earthquakes is displayed in Table 1.

In 1995 Kobe Earthquake in Japan, 275 kV and 770 kV substation equipment suffered severe damages [3]. In 1990 Manjil Earthquake in Iran, 159 substations were destroyed completely [4]. During this earthquake and only in Loshan substation (230 kV), 23 disconnect switches, 11 circuit breakers, 11 current transformers and 5 post insulators were destroyed severely [5]. Some damages to substation equipment induced by the 2003 Bam Earthquake in Iran ($M_w = 6.5$), are presented in Fig. 1 [6].

Many different parameters can affect seismic behavior of substation equipment. However, performance is strongly influenced by specific equipment design and installation practice. One of the important parameters affecting seismic performance of any substation equipment is the dynamic properties of supporting structure [7,8]. The necessity of considering dynamic effects of supporting structure on seismic behavior of such interconnected systems is confirmed in some studies [9–11].

Dynamic properties of support-equipment sets have been studied by different researchers. Among the rest, Gilani et al. [12] studied the effects of various supports with distinctive heights and stiffness on the seismic behavior of 230 kV disconnect switches (DS). Amplification factors of 2–3 were reported for structures studied in this report. However, the amplification factor for one of the studied structures was in excess of 3. In a similar research Takhirov et al. [13], studied the seismic behavior of 550 kV disconnect switches through fragility testing. Another work has been done by Matt and Filiatrault, [14], which studied the spectral amplification of different transformer tanks and their effects on seismic behavior of bushings.

In this research, a parametric study is implemented in order to assess dynamic properties of substation support structures. In the first part of the study, the support-equipment system is modeled as a Four Degrees-of-Freedom (4-DOF) system and its accuracy is verified by the finite element method (FEM). Using the simplified 4-DOF model, fundamental natural frequency of different support-equipment systems is calculated through modal analysis, and a new equation is proposed to calculate fundamental natural frequency of different support-equipment sets with various top and bottom masses. The proposed equation is compared then to the approximate equation presented in the ASCE design guide [15].

In the second part, dynamic amplification of different support-equipment sets is calculated at support-equipment intersection and

* Corresponding author. Tel.: +98 21 88770006.
E-mail address: rkarami@kntu.ac.ir (R.K. Mohammadi).

0143-974X/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jcsr.2012.06.016