Journal of Constructional Steel Research 132 (2017) 151–163

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Considering seismic interaction effects in designing steel supporting structure for surge arrester

Sheng Li [a,*], Hing-Ho Tsang [b], Yongfeng Cheng [a], Zhicheng Lu [a]

[a] China Electric Power Research Institute, Beijing, China
[b] Department of Civil and Construction Engineering, Swinburne University of Technology, Melbourne, Australia

ARTICLE INFO

Article history:
Received 16 August 2016
Received in revised form 4 January 2017
Accepted 6 January 2017

Keywords:
Seismic interaction
Surge arrester
Steel supporting structure
Flexural rigidity
Design procedure

ABSTRACT

Porcelain surge arrester is common in electrical substation and is vulnerable in earthquakes. In most cases, surge arrester needs to be mounted on the top of a steel supporting structure. The seismic response behaviors and failure modes of a steel supporting structure – surge arrester system are critical for the safety and reliability of substations. This paper aims at investigating such interaction effects on the seismic responses of surge arrester. Porcelain surge arresters in 220 kV, 500 kV, 750 kV and 1000 kV are considered in this study. Earthquake induced flexural stress and displacement are identified as key response parameters of a steel supporting structure – surge arrester system based on a full-scale test of 1000 kV porcelain surge arrester. Analytical model of the system was then developed and verified by full-scale shaking table test. The effects of supporting structure on the bending moment and displacement responses are then investigated through time history analysis, modal analysis and a parametric study. Finally, a structural design procedure is proposed for selecting suitable value of flexural rigidity of the steel supporting structure.

1. Introduction

Earthquake damage to electrical grid system has serious impact on community resilience and rebuilding efforts. Electrical substation, as the node of an electrical grid, can be vulnerable to earthquake, rendering it extremely important for reliable service of an electrical grid system [1].

As an electrical substation is a complex system with large number of equipment, various levels of earthquake engineering research of substation has been carried out, from a whole substation [2] to an interconnected equipment system [3], and from whole equipment [4] to a critical component of equipment [5,6].

Porcelain surge arrester is a common type of equipment in substations of any voltage levels around the world. Porcelain surge arrester is an assembly of porcelain insulators and other components, as seen in Fig. 1.

Due to the brittleness of porcelain [7], slenderness in shape and relatively large mass, porcelain surge arrester becomes a weak link in seismic performance of substation. It has been observed in post-earthquake investigations that porcelain surge arresters have failed due to brittle fracture of porcelain components [8–10]. Fig. 2 shows the typical failure mode of a 220 kV porcelain surge arrester in the 2008 Wenchuan Earthquake [8].

In order to connect with the conductor at the top, most surge arresters need to be mounted on steel supporting structure (Fig. 1). The seismic interaction behavior between a surge arrester and its supporting structure is different from that between non-structural component and the supporting building floor. For a light component attached to a building, the interaction effect between them is negligible,

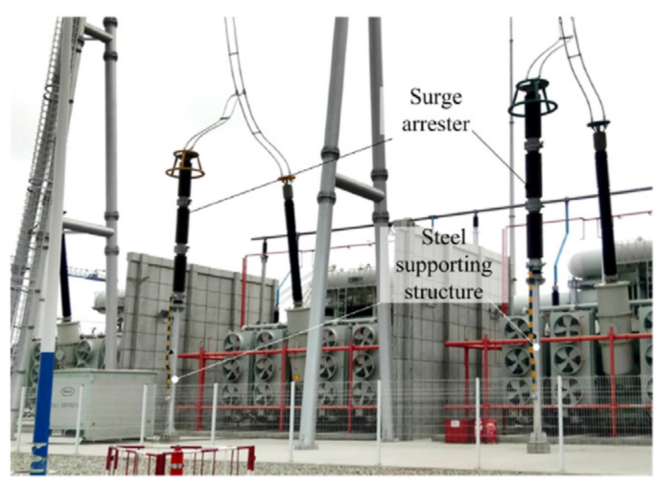

Fig. 1. Porcelain surge arresters and steel supporting structures.

* Corresponding author.
E-mail address: lisheng@epri.sgcc.com.cn (S. Li).

http://dx.doi.org/10.1016/j.jcsr.2017.01.012

Fig. 2. Failure of 220 kV porcelain surge arresters in 2008 Wenchuan Earthquake [8].

as in [11,12]. However, both the mass and stiffness of a surge arrester are of similar order of magnitude as the supporting structure, the interaction effect becomes more significant. In high voltage level substation, the scale of surge arrester is significantly larger. Fig. 3 and Table 1 show the four voltage classes of porcelain surge arresters, including 220 kV, 500 kV, 750 kV and 1000 kV which are considered in this study. The selected configurations and heights are common for surge arresters installed in countries where electrical grids are operated in such voltage levels. When the scale and weight of surge arrester increase, the earthquake-induced inertia forces also increase correspondingly. However, the maximum bending strength of porcelain insulator is very limited, with a typical value of 40–60 MPa, which results in a dramatically high fragility of surge arresters in higher voltage class.

However, seismic performance tests of surge arresters are typically carried out on surge arrester without supporting structure, partly because the structural parameters of supporting structure are unavailable at the equipment design stage [13]. Hence, it is important to study the seismic interaction effects between the supporting structure and surge arrester.

This interaction effect between supporting structure and electrical equipment has been considered in previous research. Mohammadi et al. [14,15] studied the influence of lateral stiffness of the supporting structure on the dynamic response amplification effect based on a 4-DOF simplified model. Whittaker et al. [16] carried out shaking table test of a 230 kV disconnected switch with supporting structure.

Table 1
Key parameters of the porcelain surge arresters adopted in this study.

Voltage class	220 kV	500 kV	750 kV	1000 kV
Mass, kg	688	1100	3129	10,100
Height[a], m	3.26	5.63	8.09	11.32
No. of units	2	3	4	4

[a] Height of the surge arrester alone, excluding the supporting structure.

Displacement responses of the equipment mounted on supporting frames with different flexibility were studied through numerical analysis. Kong [4] tested a transformer bushing on rigid frame and studied the amplification effect of flexible transformer tank. The ASCE Substation Structure Design Guide [17] recommends an equation for estimating the fundamental natural frequency of a support-equipment system, which is $w_{sys}^2 = w_{sp}^2 + w_{eq}^2$, in which w_{sp}, w_{eq} and w_{sys} are fundamental frequencies of support structure, equipment and the mounted system respectively. Filiatrault and Matt [18] investigated numerically the dynamic response of porcelain bushings mounted on transformer tanks and the results showed an amplification factor greater than 2.0 when the fundamental frequency of the porcelain bushing was tuned to the fundamental frequency of the transformer tank. Thuries et al. [19], Enblom et al. [20] and Li et al. [21] installed anti-seismic energy absorbers or dampers to cylindrical porcelain equipment as a seismic retrofitting strategy. Clearly, the cost could be lower if appropriate design of supporting structure carried out at the initial design stage can reduce the seismic response of equipment to an allowable level.

Although the previous research has examined the interaction effect on system frequencies and acceleration amplification factor, limited research has been carried out on the influence of supporting structure on the seismic responses which is directly relevant to the failure mode and its implication on the design of supporting structure. Moreover, very few research works have concentrated on porcelain surge arrester. This paper aims to fill in this knowledge gap.

A full scale shaking table test of a 1000 kV surge arrester was conducted to examine its response behavior under severe earthquake shaking and also to identify the key response parameters. The 1000 kV surge arrester is among the highest voltage level surge arresters tested on shaking table around the world up to date. Numerical model of surge arrester – supporting structure system was then developed with test verification. After that, the effects of supporting structure on the bending moment and displacement responses of porcelain surge arrester were studied numerically. Finally, a design procedure is put forward for selecting a suitable value of flexural rigidity of the supporting structure.

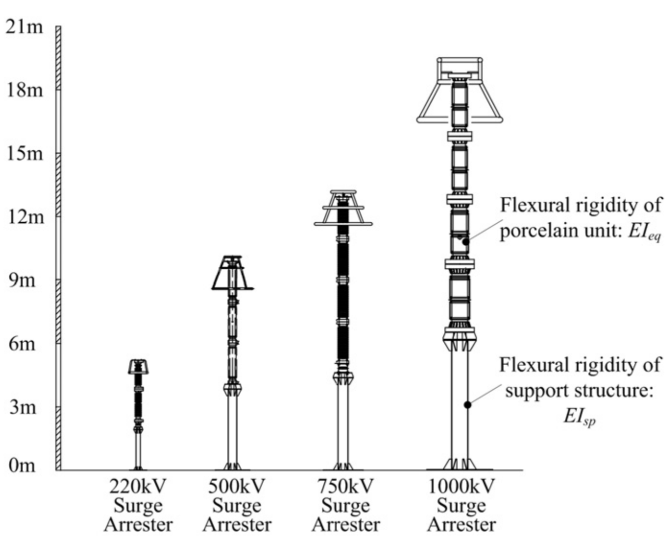

Fig. 3. Schematic diagrams of the porcelain surge arresters adopted in this study.

Fig. 4. Shaking table test of a 1000 kV surge arrester.