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Seismic performance and restraint system of suspended 800 kV thyristor valve

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ABSTRACT

Suspended thyristor valves are widely used in ultra high voltage (UHV) direct current transmission projects all over the world nowadays. However, the seismic performance of the 800 kV thyristor valve, which has longer hangers, larger air clearance requirement and is heavier than its lower voltage counterparts, has not been fully investigated. This study firstly established a finite element (FE) model of an 800 kV thyristor valve and its corresponding hall building to evaluate the seismic response of the valve. Subsequently, a restraint system consisting of rods, springs and viscous dampers was introduced to reduce the seismic response of the valve. Parametric analysis was carried out on a simplified model to determine the optimal design parameters of the restraint system. The FE model of the restrained valve, making use of the optimal parameters, was investigated. The results show that the system with the optimal parameters can effectively reduce the horizontal displacement of the valve. It is proposed to apply the restraint system to the valves, or other types of suspended equipment, to reduce the horizontal displacement and accordingly increase the seismic resiliency of this types of suspended equipment.

1. Introduction

In recent years, ultra high voltage (UHV) direct current transmission projects have experienced a rapid growth in southwest China, where exist abundant hydropower resources. However, earthquakes frequently take place in this region [1]. As the key equipment in a UHV converter station, the thyristor valve needs to avoid structural or functional damage during earthquakes. The seismic performance of floor-mounted valves has been studied thoroughly [2,3] and some performance enhancing technologies have been proposed consequently. For example, Nakagaki et al. [4] experimentally studied the influence of laminated rubber bearings on the seismic responses of floor-mounted 250 kV thyristor valves. The test results shows that the bending moment generated at the root section deceases considerably after the employment of the bearings. Because floor-mounted valves need big converter hall buildings and large cross-sectional areas for porcelain legs, suspended thyristor valves were introduced by Larder et al. [5] in the Intermountain Power Project in 1989 and since then this kind of valve has been widely used in many other projects. Suspension isolation can significantly reduce the seismic load on the valve. However, suspended valves without any restraint system behave like a pendulum and consequently experience large horizontal displacement, vertical acceleration and vertical force response during earthquakes, which may lead to a potential failure of the hangers [6]. For example, one hanger of a suspended 500 kV thyristor valve in the Sylmar substation failed during the Northridge Earthquake in 1994 [7]. Taking the tilt ground motion into consideration, Wei et al. [8] carried out a shaking table test on the scaled model of a hall building with one suspended valve. The spring hanger, which has a smaller stiffness than the typically used steel rod, experiences a smaller tension during the test. Therefore, softer hangers are recommended. Moreover, the horizontal displacement of the suspended valve can be more than one meter according to the numerical simulation by Liu et al. [9]. In order to minimize the interaction between the valve and its adjacent installations, flexible bus was adopted in the Sylmar Substation [10]. However, the large displacement of the valve may lead to insufficient air clearance, especially for the voltage upgrade in an existing converter station.

A well-designed restraint system is indeed necessary for thyristor valves located in seismic regions. Enblom et al. [11] adopted a post hydraulic damper for a 350 kV thyristor valve, which can decrease the displacement from 850 mm to approximate 480 mm at the bottom of the valve and increase the damping ratio of the valve to approximate 12%. The internal forces and displacements of the valve were obtained by a nonlinear time history analysis and verified experimentally.

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Similarly, Mahmoud et al. [12] employed post-tensioned links in parallel with energy dissipation components to reduce the seismic responses of suspended floor slabs in a building, which has similar structure to the thyristor valve. As specified in IEEE 693 [6], supplementary damping devices are recommended for suspended equipment to reduce its horizontal displacement although details are not given. Another path to alleviate the seismic response is the employment of dynamic vibration absorber. Both the transversal and longitudinal dynamic absorbers, which consist of springs and damping devices, can achieve response reduction for pendulum structures [13]. In addition, the introduction of semi-active on–off damping controller can further improve the effectiveness of the dynamic absorber [14].

Compared with the valves with the specified voltage of less than 500 kV as mentioned above, 800 kV thyristor valves used in the UHV direct current transmission projects have longer hangers and larger air clearance requirement. The suspension technology successfully used in the 500 kV thyristor valves is also applied to the 800 kV valves, but whether they can satisfy the displacement limit under strong ground motions has not been reported until now. Thus, it is necessary to quantitatively investigate the seismic performance of the 800 kV UHV valves. As the distance from the valve to the ground increases, the post damper devices become longer, which decreases the seismic resistance of the dampers. Therefore, for the 800 kV thyristor valves, a new restraint system needs to be developed.

In this paper, firstly, a finite element (FE) model including six 800 kV thyristor valves and a hall building was established and the seismic responses of the valves were obtained by time history analyses. Secondly, a new restraint system connecting the valve bottom to the ground by pretensioned damper-spring joints in series with epoxy rods, was proposed. A simplified model was introduced and then a parametric analysis was carried out to study the effects of the four main parameters of the restraint system. Finally, a FE model of the thyristor valve with the restraint system, which was modeled by a user-defined element (UEL), was developed to evaluate the seismic performance of the restrained valves.

2. Seismic performance of thyrister valves

2.1. Modeling of the thyristor valves and the hall building

Fig. 1 shows the side view of a typical converter hall in an 800 kV converter station. The UHV hall building consists of the steel roof, steel portal frames and reinforced concrete fire walls. The width, length and height of the hall building are 36 m, 86 m and 33 m, respectively. Fig. 2 shows three thyristor valves and accessory equipment in a hall building. The thyristor valve is composed of the top and bottom shields, four valve layers, one valve arrester, several bus bars and cooling water pipes (Fig. 3). The 7.58 m high valve, whose layers are connected by six 6.72 m epoxy hangers, can be thought of as a pendulum. The lengths of the hanger segments between adjacent layers vary from 1.11 to 1.7 m. The total mass of the thyristor valve and the arrester is 8.58 t, about

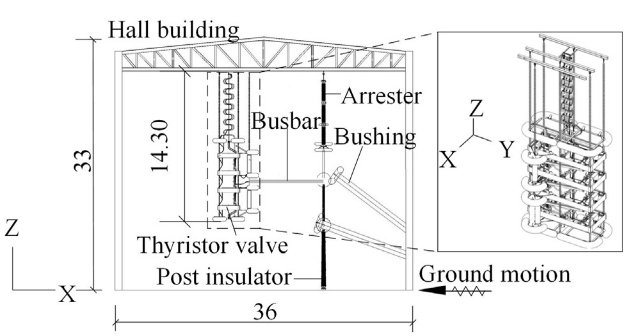

Fig. 1. Side view of an 800 kV converter hall (unit: m).

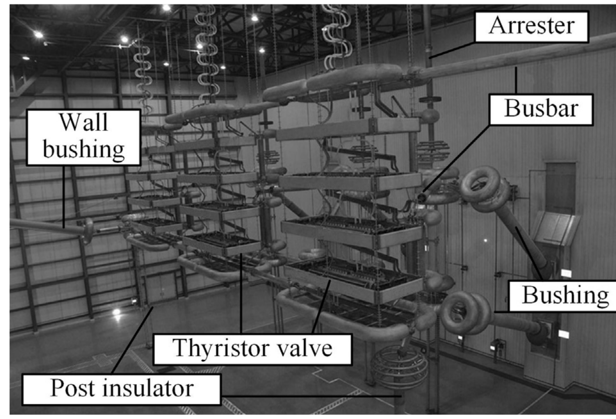

Fig. 2. Electric equipment in a hall building.

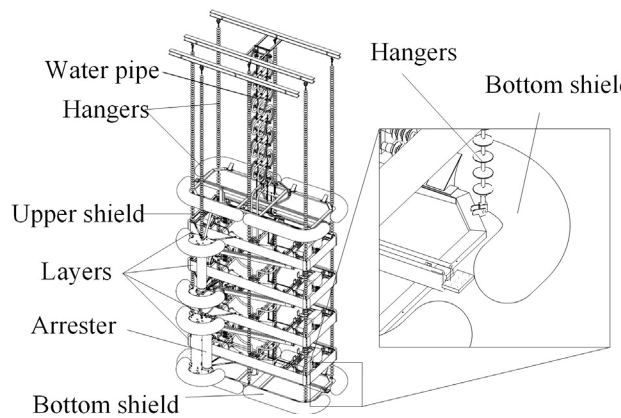

Fig. 3. Components of the thyristor valve.

3.8% of the mass of the hall building.

A FE model comprising the hall building and six thyristor valves was established following Fig. 1. The FE package of ABAQUS [15] was used for the development of the FE model. The modeling of the valve is quite detail to investigate the inner stress distribution of the valve. Only the main structural and mass components were taken into account. The top and bottom shields of the thyristor valve supported by an aluminum frame, were modeled as additional mass on the aluminum frame (Fig. 4). The electronic equipment in each layer, including the thyristor and reactor modules, was modeled by solid element. The composite braces between layers were modeled by linear beam element. The shields of the four intermediate layers, as the main structural component in each layer, were modeled by shell element to accommodate

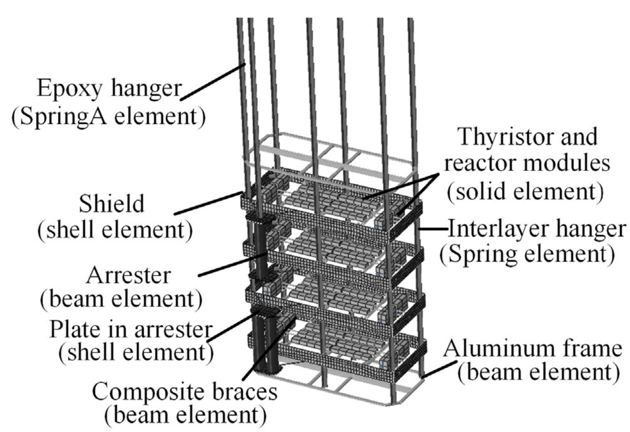

Fig. 4. FE model of the thyristor valve.