Research on Seismic Performance of Switches with Different Types of Supporting Structure

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Abstract. As an important type of porcelain-type electrical equipment, switches have been seriously damaged in many earthquake disasters. Studies have shown that different types of supporting structure of switches have significant impact on their seismic performance. This paper takes the medium-voltage and the high-voltage switches in a substation in the high-intensity area as the structural prototype, proposes six different types of supporting structure of switches, and explores the influence of the supporting structure on their seismic performance under different seismic intensities. In addition, the single column supporting high-voltage switch was found to have large displacement under 0.4 g earthquake input, and optimization design is needed for this kind of supporting structure. Seven different optimization schemes were proposed in this paper. It was found that single column supporting high-voltage switch with four bracing and single column supporting high-voltage switch with six bracing have excellent seismic performance in high intensity areas, which can be adopted in the optimization design of single column supporting high-voltage switch.

1. Introduction
As a lifeline project, the power grid facilities have been seriously damaged by the earthquakes [1-2], in Haicheng 7.3 magnitude earthquake, 9 porcelain columns of a circuit breaker were totally broken in Hongqi Bao substation. A porcelain column of switch fractured, ceramic insulator of the also cracked [3]. In Tangshan 7.8 magnitude earthquake in 1976, the damage rate of the switches reached 30% [4]; Wenchuan 8.0 earthquake in China caused damage to 91 switches [5-6].

The main reasons are: the upper structure of the switch is made of ceramic material, which is brittle, small damping, low strength, easily bending and poor energy dissipation ability; the natural frequency of the switch is generally in the range of 1-10Hz, which is close to the excellent frequency of the earthquake; the slender shape of the switch, the large mass of the superstructure and the high center of gravity of the structure will amplify the acceleration from the ground, which will cause the equipment to generate large bending moment and stress, resulting in the structural damage. Therefore, in addition to the impact of the porcelain insulator material on the damage of the switch under seismic action, the supporting structure also plays a decisive role in the anti-seismic performance of the switch.

Based on the structural prototypes the medium-voltage switch and high-voltage switch in a substation in the high intensity region, different supporting structures of switch were proposed in this paper, meanwhile the seismic response patterns of switch with different supporting structures under different
seismic intensities were studied. Moreover optimization design schemes were applied for the switch of poor anti-seismic [7].

2. Seismic Response Analysis of Switches with Different Types of Supporting Structure

Based on the prototypes of the structure forms of the medium-voltage and high-voltage switches in a substation, three column supporting, two column supporting and single column supporting medium-voltage switches and high-voltage switches are proposed, and the numerical simulation study of the switches with six supporting structure forms is carried out in this paper (figure 1).

(a) Single column supporting medium-voltage switch (ZD).
(b) Single column supporting high-voltage switch (GD).
(c) Two column supporting medium-voltage switch (ZL).
(d) Two column supporting high-voltage switch (GL).
(e) Three column supporting medium-voltage switch (ZS).
(f) Three column supporting high-voltage switch (GS).

Figure 1. Switches with different types of supporting structure.

2.1. Modeling and Modal Analysis

In this paper, the switch bracket and steel beam were simulated by beam element. Meanwhile, the connection structure between the porcelain insulator and the flanges is more complicated, the connection stiffness calculation uses the connection stiffness formula deduced by Li, et al [8] through experiments.

Based on the established medium-voltage switches with different types of supporting structure (ZD, ZL, ZS) and high-voltage switches with different types of supporting structure (GD, GL, GS), the
modal analysis was performed using finite element software. The results are shown in the following table 1:

| Equipment | First order | Amplitude of vibration | Second order | Amplitude of vibration |
|-----------|-------------|------------------------|--------------|------------------------|
| ZD        | 2.81        | The whole structure twists around the z-axis. | 3.17         | The whole structure bends in the y-direction. |
| ZL        | 7.64        | The whole structure twists around the x-axis. | 7.78         | The whole structure bends in the x-direction. |
| ZS        | 14.37       | Bending of porcelain sleeves in the x-direction | 15.80        | Ceramic sleeves bend inward in the x-direction |
| GD        | 1.57        | The whole structure bends in the x-direction. | 1.97         | The whole structure twists around the z-axis. |
| GL        | 3.97        | The whole structure bends in the y-direction. | 4.17         | The whole structure bends around x-axis |
| GS        | 6.51        | Bending of porcelain sleeves in the x-direction | 6.89         | Ceramic sleeves bend inward in the x-direction |

The calculation results of the first two order frequencies of structures are shown in the above table. The vibration patterns of switches are all deformed along the horizontal direction.

2.2. Dynamic Time History Analysis

According to the GB 50260-2013 “Seismic Design Code for Electric Power Facilities” [9], when the seismic intensity is 7, 8 and 9 degrees, the design basic seismic acceleration values selected in this paper are 0.1 g, 0.2 g, 0.3 g and 0.4 g accordingly. This paper selects three types of seismic wave of GB, NGA-55 and NGA-7 in time history analysis (figure 2). GB wave is artificial waves in the specification, NGA-55 wave is a numbered 55 earthquake-time record selected from the PEER database, and NGA-7 wave is a numbered 7 earthquake-time record selected from the PEER database.

![GB seismic wave.](image)

![NGA-55 seismic wave.](image)

![NGA-7 seismic wave.](image)

(a) GB seismic wave. (b) NGA-55 seismic wave. (c) NGA-7 seismic wave.

**Figure 2.** Seismic waves.

During the seismic time history analysis, the porcelain insulator is prone to brittle fracture damage under the action of earthquakes. At the same time, the top displacement of the structure is also the key for the seismic design of the structure, so this paper focuses on the stress and top displacement of the porcelain insulator of the switch. The calculation results are shown in the following figure 3.
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Figure 3. Maximum stresses and displacements of switches.

(a) Maximum stress in the X-direction of switches.

(b) Maximum stress in the Y-direction of switches.

(c) Maximum displacement of switches in the X-direction.

(d) Maximum displacement of switches in the Y-direction.

The X-direction and Y-direction stresses of medium-voltage switches with different supporting structure forms are much smaller than those of high-voltage switches. Moreover, the maximum stress value of medium-voltage switches is 4.14 MPa of ZL in the X-direction at 0.4 g load case; the maximum stresses of the high-voltage switch are 19.01 MPa of GL at 0.4 g load case. The maximum displacement value of the high-voltage switch is 64.94 mm for the structure GD in the Y-direction under the load case of 0.4 g, and the X-direction displacement of structure GD is 48.98 mm under the load case of 0.4 g, and the Y-direction displacement of structure GD is 48.70 mm under 0.3 g load case. In order to reduce the displacement response when using the single column supporting structure, optimization design is needed to control the displacement response.

3. Optimization Design

In this section, it is proposed to use the angle section steel beam with a size of ∟ 150×150×10 for the single column support. Seven optimization design schemes are shown in the below figure 4:
Under the conditions of 0.1 g, 0.2 g, 0.3 g and 0.4 g, the three seismic waves selected above are used to seismic response analyze of GD, GD2C, GD4C, GD2T, GD2TY, GD4T, GD4TD and GD6TD. The seismic response results are shown in the following figures 5.

![Figure 4. GD model with different optimization design.](image)

(a) Maximum stress in the X-direction of GD.
(b) Maximum stress in the Y direction of GD.
(c) Maximum displacements in the X-direction of GD.
(d) Maximum displacement in the Y-direction of GD.

**Figure 5.** Maximum stresses and displacements of GD with different optimization schemes.
As seen in figure 5, the maximum stress of the structure with different optimization design schemes is 16.21 MPa of GD6TD in the X-direction under 0.4 g.

4. Conclusion
This paper studies the effects on the seismic performance of the switches with different types of supporting structure. The seismic performance of medium-voltage switches is better than that of high-voltage switches. However, the seismic performance of single column supporting high-voltage switch is poor. Different optimization design was proposed for the single column supporting high-voltage switch. Single column supporting high-voltage switch with four bracing and single column supporting high-voltage switch with six bracing have excellent seismic performance in high intensity areas, which can be adopted in the optimization design of single column supporting high-voltage switch. Moreover, provides references for the anti-seismic performance optimization design of the porcelain-type electrical equipment.

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