Study of seismic response and vibration control of High voltage electrical equipment damper based on TMD

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Abstract. Substation high voltage electrical equipment such as mutual inductor, circuit interrupter, disconnecting switch, etc., has played a key role in maintaining the normal operation of the power system. When the earthquake disaster, the electrical equipment of the porcelain in the transformer substation is the most easily to damage, causing great economic losses. In this paper, using the method of numerical analysis, the establishment of a typical high voltage electrical equipment of three dimensional finite element model, to study the seismic response of a typical SF₆ circuit breaker, at the same time, analysis and contrast the installation ring tuned mass damper (TMD damper for short), by changing the damper damping coefficient and the mass block, install annular TMD vibration control effect is studied. The results of the study for guiding the seismic design of high voltage electrical equipment to provide valuable reference.

1. Instruction

China belongs to one of earthquake-prone countries. When the earthquake disaster, there are prone to damage electrical equipment in the composition of ceramic [1, 2]. Install the damping shock absorber is an important way to improve the seismic performance of electrical equipment [3]. TMD damper is mounted on the structure of a device used to reduce the dynamic response of the structure, which consists of two parts, mass and damping blocks. TMD damper full name of the tuned mass damper, as early as 1909 proposed by Frahm [4]. With the development of the industry, the TMD damper also obtained the further research. In 2006, Chenglin Zhang proposes two broadband: Girder Model Tuned Mass Damper – GTMD and Ring - Model Tuned Mass Damper – RTMD [5], these two kinds of Damper can in a wider frequency range effectively suppress the vibration of the structure, which has been widely used. In 2014, Bai Wen, who use multiple loop TMD damper towering cylindrical porcelain electrical equipment for the damping research conclusions show tuned mass damper can be used on electrical substation equipment [6].

Based on previous studies and the seismic design specifications at home and abroad [7, 8], using numerical analysis method, selection of best TMD damper installation position, choosing typical electrical equipment, refining damper parameters, study the structure of the different parameters on the vibration reduction effect.

2. Seismic response analysis of typical SF₆ circuit breaker

This paper chooses LW36-126A/T3150-40 high-pressure sulfur hexafluoride AC breaker, as shown in figure 1. Using ANSYS software simulation circuit breakers, aluminum flange, ceramic column, stent
using SOLID45 unit, a control box with SHELL281 unit. The finite element model of the circuit breaker shown in figure 2. Modal analysis performed first.

Figure 1. SF₆ circuit breaker structure size
Figure 2. Finite element model of SF₆ circuit interrupter

In modal analysis, pre-select the circuit breaker 10 modal vibration mode. Figure 3 shows the front of the breaker modes Figure 4 order. Table 1 shows the 10 modal frequency of each order.

(a) First order            (b) Second order        (c) Third order            (d) Fourth order

Figure 3. Modal figure of SF6 circuit interrupter

| Modal | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Frequency | 3.8753 | 8.5434 | 11.726 | 13.587 | 15.295 | 15.857 | 17.907 | 23.851 | 25.144 | 47.313 |

2.1. Select seismic waves

This paper selects the natural El Eentro and Taft waves recorded to load the input circuit breaker. Figure 4 for EL Centro wave and Taft wave acceleration time history curve.

(a) El Eentro-ew            (b) El Eentro-ns        (c) Taft-ew            (d) Taft-ns

Figure 4. EL Centro wave and Taft wave acceleration time history curve.

2.2. Breaker pole Stress analysis

Circuit breaker pole column is mainly composed of ceramic material, its brittleness is big and bending shear capacity is weak. When the earthquake loads, its root cause greater stress, causing brittle fracture occurs. Table 2 shows the circuit breaker three-phase column under seismic load stress. To stress analysis, a column suffered the biggest, the most prone to brittle failure.

Table 2. The stress of circuit breaker three-phase polar column under the seismic action/Pa
2.3. Breaker top displacement analysis
Circuit breaker top-heavy, the maximum displacement occurs at the top. From table 3 can be concluded that, under seismic load, the three-phase is most prone to column damage fracture was born in column A, C, and A column under strong earthquake are more likely to happen.

Table 3. The top displacement of circuit interrupter three phase column/mm

| Seismic wave | Direction | A   | B   | C   |
|--------------|-----------|-----|-----|-----|
| EL Centro    | X         | -0.696 | 0.587 | 0.505 |
|              | Z         | 17.84  | 15.368 | 12.979 |
| Taft         | X         | 0.69   | 0.43  | 0.7  |
|              | Z         | 11.4   | 11.2  | 11.7 |

3. Vibration Control Analysis

3.1. Breaker - ring TMD system
First, install the circular TMD damper. Then, through the damper for vibration control of circuit breaker, reduce the seismic load to the destruction of the circuit breaker. Formula for equivalent damping system as shown in (1), with $\xi_e$ for equivalent damping system, $\bar{m}$ for TMD damper than with the quality of the circuit breaker, $\xi$ for TMD damping coefficient of dampers, $\xi_d$ as the main body structure damping coefficient [6].

$$\xi_e = \frac{\bar{m}}{2} \sqrt{1 + \left( \frac{\xi_d}{\xi} \right)^2}$$

(1)

3.2. Breaker - ring TMD system finite element model
Choose suitable ring TMD damper, install it in very top three phase. As shown in figure 5 is the damper structure diagrams, figure 6 is the damper installation location.

Figure 5. The structure diagram of circular TMD

Figure 6. The installation drawing of circular TMD

3.3. Vibration damping control impact
From the above analysis, the vibration control effect depends on factors both TMD mass and damping coefficient. This paper set the TMD damper mass block is the main structure of the 7.5%, by changing the damping coefficient of the TMD damper damping effect.
As shown in figure 7, not installed TMD damper, the displacement of structure is very big, after the installation of TMD damper, the maximal displacement obviously reduced, and after the change of damping coefficient, damping effect is also corresponding change, when factor take 0.04, damping effect is better. As shown in figure 8, for the installation of TMD displacement before and after contrast, it can be seen that the damping effect is obvious.

![Figure 7](image1.png) ![Figure 8](image2.png)

**Figure 7.** The displacement time history diagram of without TMD and different damping coefficient of TMD

**Figure 8.** Installation of TMD compared with not installed TMD displacement diagram

Damping ratio is calculated according to the simulated data. Formula is as follows.

\[
\text{Damping ratio} = \frac{\text{No TMD response} - \text{With TMD response}}{\text{No TMD response}}
\]  

(2)

Extracted on the basis of above analysis, the damping ratio under different damping coefficient, as shown in figure 9, from the tendency of the line can be concluded that the displacement of the shock absorption effect of stronger before they are weakened with the increase of damping coefficient, damping effect and stress first changes obviously with the increase of damping coefficient, and then leveled off, acceleration shock absorption effect of the minimum acceleration shock absorption effect increases gently lower, after the first maximum acceleration shock absorption effect increases after the first down. Comprehensive analysis of TMD damping coefficient at around 0.05 vibration control effect is best.

![Figure 9](image3.png)

**Figure 9.** The damping effect of each response

### 3.4. Effect of the mass ratio of vibration control

In addition to the damping coefficient and damper quality will also have influence on TMD damper. Different mass block, vibration effect is also different. This paper set up 7.5% of the mass of the main structure units of quality, TMD damping coefficient is 0.04. Mass ratio calculation formula as shown in (3). Ratio from 25% to 225% in each 0.25 in a group, by changing the parameters of quality than the TMD dampers for structural vibration control effect.

\[
\text{quality ratio} = \frac{\text{quality of the mass}}{\text{unit mass}} \times 100\%
\]  

(3)
Calculate the acceleration damping ratio. As shown in figure 10, analysis of the data found when quality than 1.25 (the main structure TMD mass block quality 9.375%), the structure vibration control effect is better.

![Figure 10. The damping effect of different quality ratio](image)

4. Conclusion
(1) Through the study of the seismic response analysis of a typical circuit breaker, the circuit breaker in three-phase extremely column in the direction perpendicular to the plane (Z) displacement is larger, and with flange binding site in the biggest stress in the root, easy to brittle fracture.
(2) In large part, installing annular TMD damper can reduce the moving of the circuit breaker pole pillars.
(3) Ring TMD damper for vibration control effect of the circuit breaker with the change of the ratio of damping coefficient and quality change, the circuit breaker at the top of the displacement, acceleration and polar column root stress as the parameter change into regular change, and when the damping coefficient of 0.05, quality than 9.375%, the quality of structure of the TMD damper vibration control effect is best.

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