Application of Digital Image Monitoring System to Detecting a High Voltage Icing Conductor

LI Penghui  ZHAO Wenguang  WEN Yinping  CHEN Yong  HU Wei

Abstract  A real-time system of numeral image manipulation technology is employed to inspect the dynamic displacement of an engineering structure. First, the CCD vidicon aims at the fixed point. The image of the fixed point on the structure is gathered by a picture gathering card. By processing pictures with a self-programmed software, the real-time space coordinate of the calibration device can be obtained. Finally, the data is dealt with to get the movement curve, and the dynamic displacement is carried out. The system is applied to the test of a high voltage icing conductor. The result indicates that the dynamic data of the ice shedding conductor includes jumping amplitude, displacement-time curve and attenuation process.

Keywords  icing conductor; ice-shedding jump; dynamic displacement; image processing

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Introduction

In winter, high voltage conductors often suffer from icing hazards in the north and mid-west China. Especially last winter, in Guangdong, Hunan, and Guizhou provinces, the freezing rain disaster in a large area caused a large number of power transmission towers to collapse, which caused harm to the security of state property and safety of people’s lives. The ice shedding of the conductor will induce a strenuous movement of the conductor, which causes great dynamic pulling force to the insulating string, the electric substation fitting and the power transmission tower. It could also possibly cause destruction. When the conductor is jumping, reduced air gap between the conductors may cause flashover between phases. Therefore, transmission line design in heavy ice area must take into account the problems of ice shedding. Small conductor spacing is prone to phase flashover and big conductor spacing is a large wastage. A dynamic displacement monitoring system applied for high voltage power line’s ice shedding provides reasonable basis for the transmission tower conductor spacing.

Since the 1950s, conductor icing research has made significant progress. In the theory and observation of conductor icing, and de-icing and anti-icing technology, many countries in the world have accumulated a wealth of information and experience. Conductor icing research is mainly in the following five areas: (1) the establishment of mathematical models, (2) the ground observation of icing, (3) simulation tests and outdoor tests of icing process, (4) probability and statistics charts of icing, and (5) anti-icing, de-icing the-
ory and the corresponding technology.

According to the relevant theoretical research at home and abroad, the empirical formula is given. However, for more than 750 kV extra high voltage (EHV) lines, there is no precedent to follow. The domestic study of icing has assumed the conductor to be a hinged flexible chain, and that the forces along the length of the conductor are evenly distributed. The analysis of the force is considered as a catenary model. Through dynamics simulation, a domestic group has calculated a displacement amplitude of 2.8 meters, and the result measured by a dynamic displacement monitoring system is 4.3 meters. It is easily calculated that the measured value and the numerical simulation value has a difference of 53.6%.

Thus, obtaining correlative parameters through outdoor simulation tests is extremely important work to verify the theoretical analysis. At the large outdoor testing ground of Wuhan High Voltage Research Institute of the State Grid Corporation of China, a series of large-span conductor simulation tests were carried out. Dynamic displacement data of the jumping conductors is obtained by the use of image processing technology, including the largest jump range, displacement-time curve, cycle, attenuation process, insulation string dynamics, adjacent span dynamic parameters, etc. Such data is extremely valuable [1-4]. Fig.1 shows the schematic diagram of dynamic image monitoring.

![Fig.1 Schematic diagram of dynamic image monitoring](image)

1 Working principle

1.1 Test scheme

The jumping of the conductor is at high speed, and the displacement amplitudes are more than a few meters. Accordingly, the monitoring goal is difficult to achieve by using conventional equipment and methods. By studying the test, the group has decided to adopt the “Dynamic displacement monitoring system based on image processing technology” for testing. The design idea of the system uses image acquisition equipment to acquire images of the dynamic target and a self-programmed processing software to obtain two-dimensional dynamic displacement data, real-time output of dynamic curves, displacement amplitude and structural vibration frequency. It is a non-contact direct measurement of dynamic displacement at a distance. It has unparalleled advantages to traditional measurement techniques, with independent intellectual property. The frequency of image acquisition depends on the limitation of technology and hardware. The available distance is from a few meters to several hundred meters, and the measurement precision is from sub millimeters to millimeters. A large number of comparative tests have been done in the laboratory by using the image processing system, whose reliability is fully proved. Also, by the construction monitoring of many bridges and structures, the expected technical indicators and good engineering adaptability are verified.

The system is for the monitoring of large-scale displacement of the structure, and the range of dynamic displacement is only several hundred millimeters. Nevertheless, the test range of the jumping conductor is more than 4 000 millimeters, and its range expands to several times. Consequently for the jumping conductor test, the range is not enough. Hence, a special study has been conducted by using the appropriate hardware devices.

The test has been carried out at the outdoor test site of Wuhan High Voltage Research Institute. The condition of the first test is isolated span test, and the second is continuous span test. The first test only requires the biggest jump amplitude. In order to give full advantage to the image monitoring system, the dynamic image of each working condition was collected for more than 20 seconds. By dealing with the data, the vibration curve, jump amplitude, frequency, and attenuation process of the conductor’s middle span are obtained. These parameters provide the original data to the theoretical analysis and simulation.

For comparison, the group has used laser tracking electronic total station measurements to test the reli-
ability of the image monitoring system at the same time. It is worth noting that the electronic total station is the static measurement instrument. It is difficult for dynamic observation; only the object (in this test, it is the erection of a cross-ruler behind the conductor) is used as a reference for manual visual tracking. The artificial visual response speed is limited, and the conductor jumping movement is soon, so the observation precision is limited. By the outside rough test, the reliability of the system was gained, thus the ultimate measurement results of test depend on the image monitoring system[5-7].

1.2 Test equipment

Two sets of monitoring equipment used by this test are listed as follows.

1.2.1 Dynamic displacement monitoring system

The system consists of three parts, image acquisition equipment, calibration device of space coordinates and the self-programmed processing software. The data collection frequency is 25Hz, measurements of dynamic point are the two-dimensional coordinates, and the output is displacement-time curve, jump amplitude and the cycle. The measurement distance is from a few meters to 100 meters, and the accuracy of the system is in millimeters[8,9].

1.2.2 Laser electronic total station

Main technical indicators of Switzerland Leica-TC (R)-402 are ranging accuracy of 2 mm +2 ppm and angle measuring accuracy of 2".

2 Icing conductor test

2.1 Isolated span monitoring

In monitoring of the isolated span, the 320-meter-span vibration conductors of six conditions are tracked. The working conditions are non-uniform unloading at 30%, non-uniform unloading at 50%, non-uniform unloading at 70%, non-uniform unloading at 100%, uniform unloading at 70% and uniform unloading at 50%. The displacement-time curves of three conditions are shown in Fig.2 to Fig.4. The vibration cycle and leap amplitude of the conductor in various conditions are listed in Table 1.

![Fig.2 Vertical displacement-time curve of non-uniform unloading at 50% in isolated span condition](image)

![Fig.3 Vertical displacement-time curve of non-uniform unloading at 100% in isolated span condition](image)

![Fig.4 Vertical displacement-time curve of uniform unloading at 70% in isolated span condition](image)

In the isolated span condition, for the jumping conductor there is greater impact of non-uniform unloading than the uniform unloading. In the non-uniform or uniform unloading conditions, there is greater impact of the conductor when the load is larger.

2.2 Consecutive span monitoring

In the monitoring of consecutive span, the two 160-meter-span vibration conductors of the three conditions are tracked. The working conditions are unloading of two consecutive spans at 100%, unloading of one span at 100% and unloading of two
Table 1 Vibration cycle and leap amplitude in various isolated span conditions

| Working conditions | Non-uniform unloading at 30% | Non-uniform unloading at 50% | Non-uniform unloading at 70% | Non-uniform unloading at 100% | Uniform unloading at 70% | Uniform unloading at 50% |
|--------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|--------------------------|--------------------------|
| Average cycle/s    | 2.32                          | 2.31                          | 2.36                          | 2.33                          | 2.41                     | 2.47                     |
| Amplitude/mm       | 1 268.6                        | 1 961.9                        | 2 936.7                        | 4 063.2                        | 2 042.4                   | 1 250.9                   |

consecutive spans at 50%\textsuperscript{[10]}. The displacement-time curves of three conditions are shown in Fig.5 to Fig.7. The vibration cycle and leap amplitude of the conductor in various conditions are listed in Table 2.

In the continuous span condition, there is more impact of the conductor jump when unloading two spans at the same time than unloading of a span. Like the isolated span condition either in the non-uniform or uniform unloading conditions, there is greater impact of the conductor when the load is larger.

Table 2 Vibration cycle and leap amplitude in various consecutive span conditions

| Working conditions | Unloading at 100% in two consecutive spans | Unloading at 100% in one span | Unloading at 50% in two consecutive spans |
|--------------------|--------------------------------------------|-------------------------------|------------------------------------------|
| Average cycle/s    | 1.56                                       | 1.76                          | 1.74                                     |
| Amplitude/mm       | 1 794.4                                    | 1 650.2                       | 897.2                                    |

3 Conclusion

The ice shedding jump of a conductor is a complex process; the traditional dynamics formula cannot give precise answers to the questions. By the test of an independent span and continuous spans we draw the following conclusions:

(1) When there is larger unloading load, the conductor jump is more serious;

(2) With the same unloading load, it is more serious in non-uniform unloading than uniform unloading;

(3) The ice shedding of a conductor is a process of low-frequency vibration;

(4) There is more jump height in continuous spans than in an isolated span.

In the actual weather conditions, the ice thickness of a conductor is non-uniform, and the site and amount of ice shedding are random, thus these conditions are not easy to estimate. On the other hand, the conductors of actual power transmission towers are continuous spans. Therefore, the actual ice shedding of conductors should be more serious than that in the tests. In engineering applications, for strict control of the ice shedding conductors, it is suitable to use isolated spans, which can greatly reduce the jump height.

Conductor jumping is a complicated dynamic problem. The establishment of an ideal model must be based on dynamics theory, taking into account the actual situations in a variety of complicated factors.
and carrying through an in-depth study on a “theory→experiment→amendment→perfect the experiment” process. This recycling process can achieve these objectives. “Dynamic displacement monitoring system based on image processing technology” can be measured to obtain the conductor leap value. It can provide the detailed and reliable data for theoretical calculation formula, and lay the foundation for conductor jumping research in order to further establish a dynamic model.

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Notes to Contributors

Contributions are welcomed on one of the following subjects or in related areas:

- GIS
- GPS
- RS
- Cartology
- Geodynamic
- Geo-surveying
- Photogrammetry
- Graphics
- Physical geo-surveying
- Engineering surveying
- Mapping apparatus

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