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# Analysis on the dynamic responses of a prototype line from iced broken conductors

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ABSTRACT

A full scale transmission line section of three continuous spans was established. With the consideration of the equivalent mass of the accreted ice, steel cables are used to simulate the iced conductors. For different types of conductors and ice thickness, broken conductor experiments were carried out. Under different broken cases, time histories of the tensions and displacements at the middle of conductor spans were measured. The first order damping coefficients of the line section for different broken cases were calculated. The Fourier transform of the experimental time history of the conductor tensions was completed. The dynamic impact factors of the conductor tensions were determined. The experimental results show that the impact effect is more significant for the location nearer to the break point. The dynamic impact factors decrease with the increase of the ice thickness, and the impact factors of conductors without accreted ice are much higher than those of conductors with accreted ice. With the increase of the ice thickness, the initial tensions before break as well as the ratios of the residual static tensions to the initial tensions increase. Nearly all the first peak tensions are close to the initial tensions for the broken cases with accreted ice. The damping coefficients determined by the experimental identification were applied to the finite element analysis (FEA) model. The stiffness of the accreted ice as well as the contact effect between the conductors and the ground are considered in the FEA model. The numerical simulations were performed for different broken cases. Both the residual static tensions and the first peak tensions by the numerical simulations were well agreed with the experimental values. The maximum differences are 5.6% and 12.9% respectively.

## 1. Introduction

Accreted ice, galloping and strong wind can cause break of conductors or ground wires in transmission lines. In the broken process, high longitudinal unbalanced tension will be produced, which can cause transient impact on transmission towers. The stresses and displacements of transmission towers increase significantly. The tower will be collapsed and even a major collapse with cascading effect happens. Many studies have been focused on load values and dynamic responses of the tower-line system by numerical and experimental methods in recent years.

The numerical studies are mainly by two methods. The first is the static calculating program based on the equilibrium conductor length method [1,2], and the impact effect cannot be considered. The second is the dynamic analysis by implicit

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or explicit method [3–17], the dynamic responses from the broken conductors can be calculated by nonlinear transient analysis. Peabody and McClure [11] have modelled the EPRI-Wisconsin line with broken conductors using ADINA. It shows that the first peaks of the insulator tensions were modelled accurately in time and magnitude. The second peaks were modelled accurately in time. However, the magnitudes were larger than those measured during the tests. A damping ratio of 0.5% was used in this study.

Some scale and prototype tests for broken conductors have been carried out. Broken tests of conductors and insulators were completed in the Wisconsin tests line by Peyrot et al. [18]. Longitudinal loads and the impact effect on the transmission line were studied. Mozer et al. [19] carried out a simulating broken test of a three span conductor-ground wire-steel pole system. The broken tensions of the conductors and the ground wires as well as the strains of the steel poles were measured, and the impact coefficients of the support structures from broken wires were determined. Geometrical proportion of the test model to the real 345 kV transmission line is 1:30. The length of the middle span is 9.753 m. The conductors and the ground wires were substituted by copper wires. The wire broken test was initiated by cutting a short length of string which had been inserted in the wire span to be broken. Dynamic responses of the pole-line system as well as the dynamic impact factors were determined.

China Electric Power Research Institute (CEPRI) carried out a simulating broken test for a ±800 kV tangent tower [20]. The span length of the broken span and the unbroken span are 55 m and 103 m respectively. Geometrical proportion of the model tower to the prototype tower is 1:2. The initial tension of the conductors is a quarter of the real tension. Broken of the bundle conductor was simulated by changing the conductor tensions. Displacements and strains of some typical members of the tower were measured. North-East Electric Power Design Institute of China completed a prototype broken test in a transmission line section [21]. The line section has seven continuous span conductors and the span length is 450 m. Dynamic strains and displacements at the suspension points were obtained. It shows that the peak values of the dynamic strains usually occur with the second waves. The second peak values sustains for about 0.5 s to 1.0 s. Ratios of the peak value to the stable value are from 1.95 to 2.74.

Heavily accreted ice is one of the main reasons causing conductor ruptures. After the serious ice disaster in South China in 2008, in order to ensure the anti-bending and anti-torsion capacity of transmission towers, the Technical Code for Designing of Overhead Transmission Line in Medium & Heavy Icing Area [22] was revised, and the icing rates were regulated for the calculation of broken tensions. In the past studies, the effect of the accreted ice was almost not considered in the broken analysis and experiments. Furthermore, the damping coefficients of the conductors were not measured in the experiments and an approximate value was assumed in the dynamic analysis.

In this paper, a full scale transmission line section of three continuous spans was established. For different types of conductors and ice thickness, broken conductor experiments were carried out. Under different broken cases, time histories of the tensions and displacements at the middle of conductor spans were measured. Damping coefficients of the line section for different broken cases were calculated. Dynamic impact factors of the conductor tensions were determined. Damping coefficients by the experimental identification were applied to the FEA model. The numerical simulations were performed for different broken cases. Both the residual static tensions and the first peak tensions by the numerical simulations were calculated and compared with the experimental values. Moreover, according to the equilibrium conductor length theory, A MATLAB program was compiled to calculate the residual static broken tensions. The calculated results by MATLAB program were compared with the FEA values and the experimental results.

## 2. Experimental investigation

### 2.1. Experimental investigation

The broken tests were carried out at the UHV transmission tower test station of CEPRI. A line section with four poles and three span conductors was constructed in south–north direction. The arrangement of the test line section is presented in Fig. 1. The span lengths of the three spans are 95 m, 100 m and 95 m in turn. The initial tensions of conductors can be adjusted by the earth anchor at the north side of the test section.

The broken device in Fig. 2 was set in the middle of the first span. The conductor break can be realized by pulling the trigger extension of the broken device. The tension sensors were installed at the middle of the second span and the third span. The bundle number of the conductor is single. The sampling frequency of the tension sensor is set 30 Hz.

The accreted ice was simulated by steel cables with the equivalent mass. The damping characteristics of iced conductors are affected by conductor type, ice type and ice thickness, etc. It is difficult to determine the damping of iced conductors accurately. So the damping effect of the accreted ice was not considered in this broken test. Before the conductor of the first span is broken, time history of the transversal displacements at the second span conductor was measured by a displacement sensor for the identification of the first order damping coefficient.

The types of test conductors are JL/GIA 240/30 and JL/GIA 400/35. Mechanical parameters of the conductors are listed in Table 1. The rated tension of the insulator is 68.6 kN. The structural length of the insulator is 1.7 m.