APPLICATION OF THE COMPOSITE INSULATOR WITH THE OPTIC FIBER SENSORS IN ICING-MONITORING OF OVERHEAD TRANSMISSION LINES

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Abstract: An intelligent monitoring technology of composite insulator with the optic fiber sensors is presented, which can monitor the ice of overhead transmission lines.

1. INTRODUCTION

Many works focus on anti-icing, deicing and icing-monitoring techniques of transmission line in the past decades, but most are not very effective techniques for monitoring and preventing the icing on overhead transmission lines. The existing icing-monitoring technique has many shortcomings, such as the sensitivity to electromagnetic interference (EMI), the unavailability of distribution measurement and a short lifespan. The traditional icing-monitoring sensors are difficult to adapt the snow weather, for the sensitivity of the sensors, power supply and signal transmission are subject to this bad weather. In this work, an intelligent monitoring technology of composite insulator with the optic fiber sensors is presented, which can monitor the ice of overhead transmission lines.

2. THEORY AND CALCULATIONS

The reference [1] gives a comprehensive introduction of the composite insulator with the FBG sensors. Experiment results reveal that the strain of the FBG has good linear relationships with the displacement of the center wavelength of fiber grating, and this means when the icing on overhead transmission lines happen, the FBG insulator can get the change of the strain from the icing condition of transmission line, in other words, this technique may be an effective icing-monitoring in overhead transmission lines. Accurate monitoring on the icing condition of overhead transmission lines should be calculated in the chapters to follow.

The rigidity of transmission lines is usually ignored for engineering purposes [2, 3], then we can use the parabolic equation to calculate the lines. Let S_a', S_b' are the line lengths between the lowest points of lines and Tower A; q_{ice} is the uniform ice thickness of the ice around the split line, and F is the strain along the vertical direction, the following equation is obtained:

$$q_{ice} = \frac{F\cos\theta'\cos\eta - G}{(S_a' + S_b')} \tag{1}$$

The tilt angle (θ') of the insulator strings in the windage plane is the included angle between F and the vertical direction in the windage plane, and η is the angle of wind oscillation for insulator strings. Suppose that the ice around the split line is a cylinder, the equivalent ice thickness (b) around the split line can be obtained using the following equation:

$$b = \frac{1}{2}\left(\sqrt{\frac{4q_{ice}}{9.8\pi\rho} + D^2} - D\right) \tag{2}$$

where ρ is the ice density around the split line, and D is the diameter of the split line. We can get the uniform ice thickness and the equivalent ice thickness around the split lines by calculating equations (1) and (2).

3. CONCLUSION

In this paper, an intelligent monitoring technology of composite insulator with the optic fiber sensors is presented, which can monitor the ice of overhead transmission lines. The intelligence rod structure is by implanting fiber Bragg grating (FBG) into the composite insulator rod, which can online detect the tension change of the composite insulator interior caused by the icing thickness of overhead transmission lines. The relationships between the tension change of the insulator interior and the ice-coating of the transmission lines is studied in this work, which means this technique may be an effective icing-monitoring in overhead transmission lines. The next step is establishment of this icing-monitoring technique according to the practical needs.

4. REFERENCES

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Keywords—composite insulator; icing-monitoring; insulator rod; ice-coating; transmission lines

I. INTRODUCTION

Nowadays, with the great change of world climate, icing on overhead transmission lines is a great threat to the stability of power grid operation. Icing on overhead transmission line is extremely vulnerable to microclimate and topography. If ice thickness of transmission lines accumulates to a certain extent, the regular transmission lines can often lead tosericus accidents endangering the safe operation of the power system, such as the flashover of iced insulators, the breakdown of transmission line, the tower tilt, the tower base settlement or the tower falling [1-4]. In order to keep the transmission line safe and reduce the economic loss, it is a necessity to strengthen online icing-monitoring to get the ice information of transmission line timely, and so the monitoring center can early get the icing condition of transmission line and adopt some measures to protect to avoid substantive economic loss and disastrous accident.

Many works focus on anti-icing, deicing [5-6] and icing-monitoring [7-9] techniques of transmission line in the past decades, but most are not very effective techniques for monitoring and preventing the icing on overhead transmission lines. The existing icing-monitoring technique has many shortcomings, such as the sensitivity to electromagnetic interference (EMI), the unavailability of distribution measurement and a short lifespan. The traditional icing-monitoring sensors are difficult to adapt the snow weather, for the sensitivity of the sensors, power supply and signal transmission are subject to this bad weather.

In this work, an intelligent monitoring technology of composite insulator with the optic fiber sensors is presented, which can monitor the ice of overhead transmission lines. The intelligence rod structure is by implanting fiber Bragg grating (FBG) into the composite insulator rod, which can online detect the tension change of the composite insulator interior caused by the icing thickness of overhead transmission lines. The relationships between the tension change of the insulator interior and the ice-coating of the transmission lines is studied in this work, which means this technique may be an effective icing-monitoring in overhead transmission lines.

II. THEORY

The reference [7] gives a comprehensive introduction of the composite insulator with the FBG sensors. The following correlation is used to get the strain and temperature response of FBG sensors in the composite insulator rod.

$$\Delta\lambda_B = 2\Delta n_{ef}\Lambda + 2n_{ef}\Delta\Lambda \tag{1}$$

where Λ is the period of grating lines, n_{ef} is the refractive index of optical fibers, $\Delta\lambda_B$ is displacement of the center wavelength of fiber grating, $\Delta\Lambda$ and Δn_{ef} is the period of grating lines and the refractive index of optical fibers, respectively. If the strain, temperature or other physical quantities of FBG sensors is expected to change, Λ and n_{ef} would change, affecting the displacement in the center wavelength of fiber grating (λ_B). We can get the change in the physical quantities of FBG sensors for the test, when we measure directly the displacement of the center wavelength of fiber grating.

Strain test experiment has been performed in the lab with Brag fiber sensor implanted into the insulator rod. A tesile testing machine is used to measure the strain of 220 kV FBG insulator with a hypothetical example that the change of the strain is from the icing condition of transmission line. The stain increases from 0 kN to 50kN, and the central wavelength is recorded with keeping the strain for 15 minutes per 10 kN. The results about the strain response of the fiber Brag grating sensor are shown in figure 1.

Experiment results reveal that the strain of the FBG has good linear relationships with the displacement of the center wavelength of fiber grating, and this means when the icing on overhead transmission lines happen, the FBG insulator can get the change of the strain from the icing condition of transmission line, in other words, this technique may be an effective icing-monitoring in overhead transmission lines. Accurate monitoring on the icing condition of overhead transmission lines should be calculated in the chapters to follow.

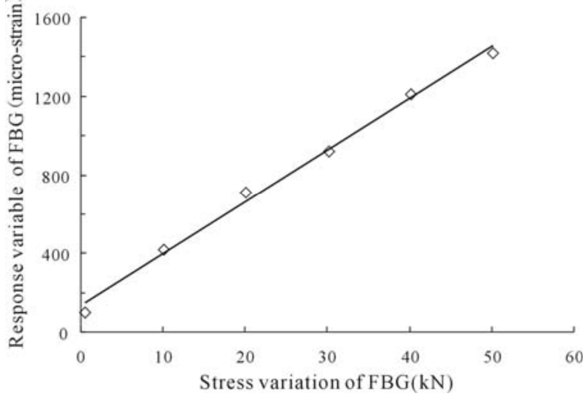

Figure 1. Strain response of fiber Brag grating sensor

III. CALCULATIONS

The rigidity of transmission lines is usually ignored for engineering purposes, then we can use the parabolic equation to calculate the lines [8-9]. Transmission line model without external load in vertical plane of towers is shown in figure 2. The subspans between Tower A and Tower B, Tower C are l_1, l_2, respectively; the subspan lengths of lines are S_1, S_2, respectively; the altitude difference of the line suspension points are h_1, h_2, respectively; the angles of the altitude differences are β_1, β_2, respectively; the lengths between the lowest points of lines and Tower A are l_a, l_b, respectively; and the own load-weight ratio of the lines is γ.

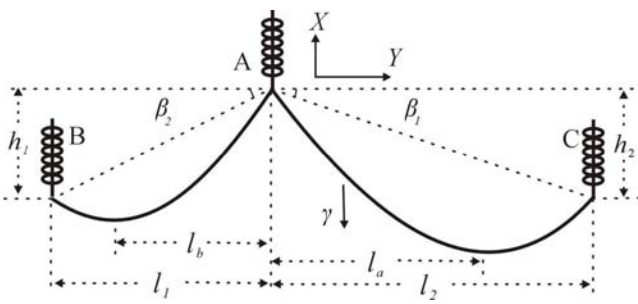

Figure 2. Transmission line model without external load in vertical plane of towers

If the lengths of transmission line model without external load and under icing condition are S, S_t, respectively, the following equation is obtained:

$$S_t = S - S\alpha\Delta t \tag{2}$$

where Δt is the temperature difference between the design temperature and the icing temperature, α is the temperature expansion coefficient. The lengths of transmission line model without external load and under icing condition S_{t1}, S_{t2} can be calculated by equation (2). We can use the parabolic equation to calculate the horizontal strain of the lines σ_0, as follows.

$$\sigma_0 = \sqrt{\frac{\gamma^2 l^3 \cos\beta}{24[S_t - (\frac{l}{\cos\beta})]}} \tag{3}$$

The horizontal strain of the lines σ_{10}, σ_{20} between Tower A and Tower B, Tower C can be obtained by equation (3), Substituting σ_{10}, σ_{20} into equations (4) and (5), we can get the lengths between the lowest points of lines and Tower A l_a, l_b by a calculation using the following equations.

$$l_b = \frac{l_1}{2}(1 + 2\frac{h_1\sigma_{10}}{l_1^2\gamma}\cos\beta_1) \tag{4}$$

$$l_a = \frac{l_2}{2}(1 + 2\frac{h_2\sigma_{20}}{l_2^2\gamma}\cos\beta_2) \tag{5}$$

Substituting equations (3), (4) and (5), into equations (6), (7), the line lengths between the lowest points of lines and Tower A (S_a, S_b), are obtained.

$$S_b = l_b + \frac{l_b^3\gamma^2}{6\sigma_{10}^2\cos^2\beta_1} \tag{6}$$

$$S_a = l_a + \frac{l_a^3\gamma^2}{6\sigma_{20}^2\cos^2\beta_2} \tag{7}$$

In fact, the windage of suspension insulator strings under dynamic wind loads should be taken into account. If the angle of wind oscillation for insulator strings is η, as shown in figure 3, the factors can be obtained according to reference [9], respectively.

$$l' = l\sqrt{1 + (\tan\beta\sin\eta)^2} \tag{3}$$

$$\cos\beta' = \cos\beta\sqrt{1 + (\tan\beta\sin\eta)^2} \tag{4}$$

$$\sigma_0' = \sigma_0\sqrt{1 + (\tan\beta\sin\eta)^2} \tag{5}$$

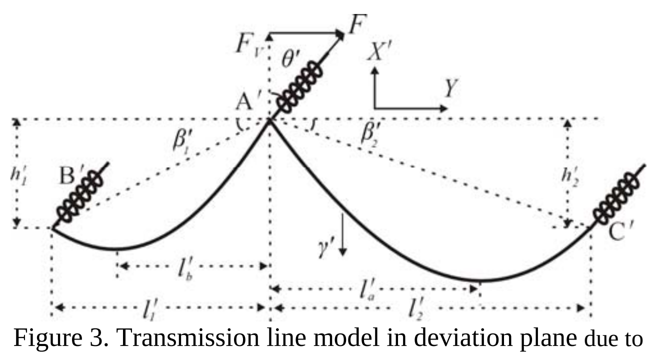

Figure 3. Transmission line model in deviation plane due to wind

The relationship between the load-weight ratio and the own load-weight ratio of the lines (γ) is as follows.

$$\gamma' = \gamma\cos\eta \tag{11}$$

Compared with equations (6) and (7), the line lengths between the lowest points of lines and Tower A (S_a', S_b'), are obtained under dynamic wind loads.

$$S_b = l_b + \frac{l_b^3 \gamma^2}{6\sigma_{10}^2 \cos^2 \beta_1} \quad (12)$$

$$S_a = l_a + \frac{l_a^3 \gamma^2}{6\sigma_{20}^2 \cos^2 \beta_2} \quad (13)$$

The change strains of the transmission lines from the icing bring about the mechanical failure. The axial strains of the insulator strings F can be obtained by the composite insulator with the optic fiber sensors, which was introduced in part II. The tilt angle (θ') of the insulator strings in the windage plane is the included angle between F and the vertical direction in the windage plane, which can be obtained as follows:

$$\cos\theta' = \frac{1}{\cos\eta\sqrt{1+\tan^2\eta+\tan^2\theta}} \quad (14)$$

where θ is the included angle of the insulator strings along the line direction in the vertical plane. Let G be the summation of own weight of the line, the insulator strings and the fitting, and G_i is the summation of own weight of the insulator strings and the fitting. If A is the cross-sectional area and n is the number of split lines, we can get:

$$G = G_i + \gamma A(S_a + S_b)n \quad (15)$$

Let q_{ice} is the uniform ice thickness of the ice around the split line, and F is the strain along the vertical direction, the following equation is obtained:

$$q_{ice} = \frac{F\cos\theta'\cos\eta - G}{(S_a' + S_b')} \quad (16)$$

Suppose that the ice around the split line is a cylinder, the equivalent ice thickness (b) around the split line can be obtained using the following equation:

$$b = \frac{1}{2}\left(\sqrt{\frac{4q_{ice}}{9.8\pi\rho} + D^2} - D\right) \quad (17)$$

where ρ is the ice density around the split line, and D is the diameter of the split line.

We can get the uniform ice thickness and the equivalent ice thickness around the split lines by calculating equations (16) and (17).

IV. CONCLUSION

In this paper, an intelligent monitoring technology of composite insulator with the optic fiber sensors is presented, which can monitor the ice of overhead transmission lines. The intelligence rod structure is by implanting fiber Bragg grating (FBG) into the composite insulator rod, which can online detect the tension change of the composite insulator interior caused by the icing thickness of overhead transmission lines. The relationships between the tension change of the insulator interior and the ice-coating of the transmission lines is studied in this work, which means this technique may be an effective icing-monitoring in overhead transmission lines. The next step is establishment of this icing-monitoring technique according to the practical needs.

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