STUDY ON IMBALANCE TENSILE FORCES WITH TOWER FOR NON-CONTEMPORANEOUS ICE SHEDDING

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Abstract—Based on analysis of a mass of references, this paper summarizes and analyzes the formative causes of ice shedding, its factors, and damages are summarized. According to the characteristics of the non-contemporaneous ice shedding, the imbalance tensile forces of conductors in the same dead-end section are analyzed. As to the non-contemporaneous ice shedding, the results show that, the location for ice-shedding span will affect the maximum uneven tension and the maximum sag variation. When the ice-shedding span is close to the strain segment, the straight-line tower will withstand the maximum imbalanced-tension. While the ice-shedding span is the middle of the strain segment, it will produce maximum sag variation. Therefore, the key positions of new established transmission towers should be reinforced according to the meteorological conditions.

I. INTRODUCTION

Icing of overhead transmission lines is the most important parameter influencing the safe and stable operation of power grid [1]. In recent years, as each year there are thousands of transmission line failures worldwide caused by excessive ice loadings.

II.CAUDES AND DAMAGES OF ICE SHEDDING

Sudden ice shedding from the conductors may result in high-amplitude vibrations leading to the reduction of phase spacing, and the application of excessive dynamic forces to support structures, which may cause flashover between conductors or damage to structures.

III. MODEL, UNEVEN TENSION, DISPLACEMENT OF INSULATOR STRIN AND THE SAG VARIATION

If the conductors of the adjacent span are of non-contemporaneous ice shedding, it will result in tension difference, which will produce the conductors and ground-lines' sliding in clamp, in severe cases, full-scaled fracture of the outer layer of aluminum wire on the outlet of clamp and the twitch of steel core. Therefore, it is necessary to research the uneven tension of the towers caused by non-contemporaneous ice shedding.

IV. CONCLUTIONS

The ice shedding mechanism is affected by a number of factors and parameters, such as ice morphology, meteorological conditions, and structural design of lines, as well as wire and conductor characteristics.

The location for ice-shedding span will affect the maximum uneven tension for asynchronous ice shedding. The ice-shedding span is close to the strain segment, the straight-line tower will withstand the maximum imbalanced-tension. Moreover, the insulator string deflection angle is also max.

The location for ice-shedding span will affect the maximum sag variation for asynchronous ice shedding. While the ice-shedding span is the middle of the strain segment, it will produce the maximum sag variation.

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Study on Imbalance Tensile Forces with Tower for Non-contemporaneous Ice Shedding

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Abstract—**Based on analysis of a mass of references, this paper summarizes and analyzes the formative causes of ice shedding, its factors, and damages are summarized. According to the characteristics of the non-contemporaneous ice shedding, the imbalance tensile forces of conductors in the same dead-end section are analyzed. As to the non-contemporaneous ice shedding, the results show that, the location for ice-shedding span will affect the maximum uneven tension and the maximum sag variation. When the ice-shedding span is close to the strain segment, the straight-line tower will withstand the maximum imbalanced-tension. While the ice-shedding span is the middle of the strain segment, it will produce maximum sag variation. Therefore, the key positions of new established transmission towers should be reinforced according to the meteorological conditions.**

Keywords-transmission line; ice shedding; tower; conductor; mechanical property

VI. Introdution

Icing of overhead transmission lines is the most important parameter influencing the safe and stable operation of power grid[1]. In recent years, as each year there are thousands of transmission line failures worldwide caused by excessive ice loadings. The extreme weather hit Eastern Canada (Ontario, Quebec and New Brunswick) and the North-eastern United States, in January 1998[6].The storm caused widespread damage to the power system. Over two million people were without electric power for weeks. 1,300 transmission towers and 35,000 power equipments were destroyed by excessive ice loads. Restoration costs in only Quebec were over 5 billion dollars. While 1954 the first record to transmission line icing disaster happened in our country[3].In early 2008, many provinces of Southern China encounter the rare sleet and freezing weather[4,5], which results in the serious transmission line icing, and cause the frequent occurrences of many serious accidence. The stable operation of power systems and reliable power supply are faced with huge challenges[1,2].

After a large number of phase-to-phase flashover faults caused by ice shedding on the 132 kV and 275 kV in England, both at home and abroad, a lot of research work about the mechanism of the non-contemporaneous ice shedding for conductor has been done[7-10]. In the 1970s, experiments and analytical simulations were conducted to study the effects of ice shedding on compact lines in the USA. As it is useful to study the mechanism of the uneven tension during ice shedding, in recent years a number of analytical models have been developed, and considerable work has been done to simulate line behavior after ice shedding. However, a general practical method that can be easily used by designers is still not available due to the complexity of the problem and vast number of parameters that influence line behavior.

Non-contemporaneous ice shedding is of great danger to the safe operation of the transmission system. Based on the research results of the experts both at home and abroad, the mechanism of non-contemporaneous ice shedding and the adverse impact on the transmission tower and conductors are analyzed[8, 10-12]. The research work in this paper will be helpful to the in-depth understanding of the mechanism of the conductor non-contemporaneous ice shedding and the influence on the transmission lines. It is also of great reference values to the "West-to-East Power Transmission, South-and-North Transaction and Nationwide Electricity Interconnection "and the construction and operation of UHV and EHV transmission lines.

VII. CAUDES AND DAMAGES OF ICE SHEDDING

A. The damages of ice shedding[6]

Sudden ice shedding from the conductors may result in high-amplitude vibrations leading to the reduction of phase spacing, and the application of excessive dynamic forces to support structures, which may cause flashover between conductors or damage to structures.

(1) It induces high dynamic loads on the lines that might be responsible for tower arm failures or even a cascade failure of several towers in a transmission line.

(2) It may provoke flashovers when the conductor rebound brings it close to an adjacent phase, ground wire or parts of the towers.

(3) Ice shedding over road crossings constitutes another hazard since big chunks of ice may fall on the vehicles below.

B. The causes of ice shedding[6]

Ice shedding is the physical phenomenon that occurs when ice accumulated on overhead ground wires and conductors is removed naturally or by other means. The ice shedding mechanism is affected by a number of factors and parameters, such as ice morphology, meteorological conditions, and structural design of lines, as well as wire and conductor characteristics.

It is not a continuous phenomenon, however, once the ice drops begin, the conductors may be excited for many cycles with a slow decrease of amplitude where the damping is mainly due to the air resistance over the conductor displacement. Ice shedding is a difficult phenomenon to observe since it happens suddenly and is not repetitive contrarily to conductor galloping. When the transmission lines occur ice shedding which will cause the frequent occurrences of many serious accidence such as tower collapse, transmission line disconnection, galloping, ice flashover and even large area blackout accidents.

VIII. MODEL

The above analysis shows that, non-contemporaneous ice shedding on overhead transmission lines is a familiar phenomenon, which is resulted in the uneven distribution of ice thickness, wind velocity and other parameters along the wire axis due to the terrain along the transmission system and the difference of altitude. The velocity of Ice-shedding is slower for the place of thicker ice on the conductor, or larger wind velocity, on the contrary, Ice-shedding is more quickly.

If the conductors of the adjacent span are of non-contemporaneous ice shedding, it will result in tension difference, which will produce the conductors and ground-lines' sliding in clamp, in severe cases, full-scaled fracture of the outer layer of aluminum wire on the outlet of clamp and the twitch of steel core. Therefore, it is necessary to research the uneven tension of the towers caused by non-contemporaneous ice shedding. Figure 1 shows a strain segment of an overhead line with asynchronous ice shedding. It contains the less ice-load (γ_n) in the center of the strain segment, while the rest are γ_m ($\gamma_m > \gamma_n$)

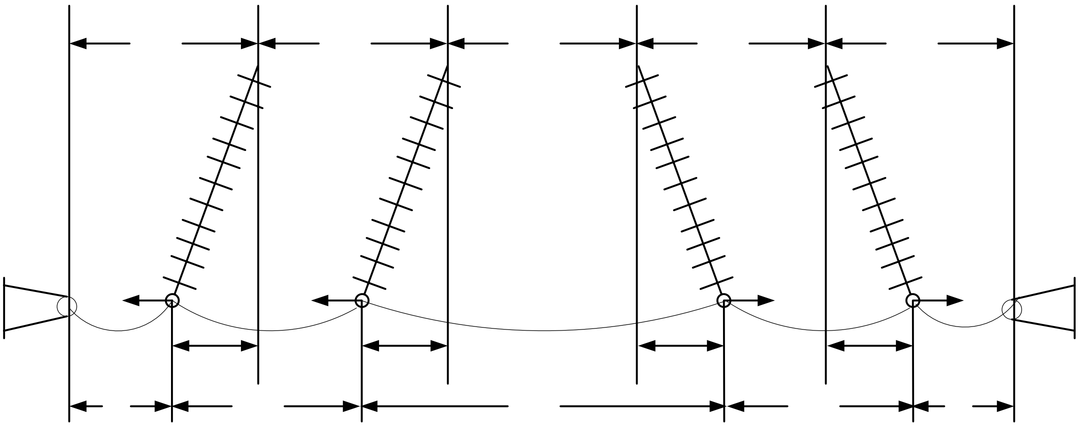

Figure 1. Sketch map of a strain segment of an overhead line with asynchronous ice shedding

（1）The relationship between the tension of the span for heavy icing and the reduction of the span length can be expressed as follows[14-15]:

$$T = A\sqrt{\frac{(l_0 - \Delta l)^3 \gamma_m^2}{24\Delta l + l_0^3 \gamma_m / \sigma_m^2}} \tag{1}$$

Where: T is conductor tension, N; A is cross-sectional area for the conductor, mm^2; l_0 is the initial span length, m; Δl is the reduction of the span length, m; γm is the sum ice-load on the heavy ice-area, N·m^{-1}·mm^{-2}; σ_m is the initial stress for the conductor, N·mm^{-2}.

（2）The relationship between the tension of the span for light icing and the reduction of the span length can be expressed as follows[14-15]:

$$T = A\sqrt{\frac{(l_0+\Delta l)^3\gamma_n^2}{l_0^3\gamma_n/\sigma_n^2 - 24\Delta l}} \tag{2}$$

Where: T is conductor tension, N; A is cross-sectional area for the conductor, mm^2; l_0 is the initial span length, m; Δl is the increment of the span length m; γ_n is the sum ice-load on the light ice-area, N·m^{-1}·mm^{-2}; σ_n is the initial stress for the conductor, N·mm^{-2}.

（3）If both sides of the ice loads are light, the relationship between displacement of the insulator string and the tension difference of the dead-end section can be expressed as follows[14-15]:

$$\delta_n = \frac{\lambda\Delta T}{\sqrt{(\gamma_n A l_0 + G_J/2)^2 + \Delta T^2}} \tag{3}$$

Where: δn is the displacement of the insulator string, m; γn is the sum ice-load for the span contained the conductors, N·m-1·mm-2; ΔT is the tension difference of the dead-end section of the insulator string, N; λ is the length of insulator string, m; GJ is the weight of insulator string, N; other notations as above.

（4）If both sides of the span containing the ice loads are not equal, the relationship between displacement of the insulator string and the tension difference of the dead-end section can be expressed as follows[14-15]:

$$\delta = \frac{\lambda\Delta T}{\sqrt{[(\gamma_m+\gamma_n)Al_0/2 + G_J/2]^2 + \Delta T^2}} \tag{4}$$

Where: δn is the displacement of the insulator string, m

In addition, the relationship between displacement of the insulator string and the variation of the span length can be expressed as follows:

$$\delta_{i-1} = \delta_i + \Delta l_i \tag{5}$$

Furthermore, the relationship between the tension of the dead-end section of the insulator string can be expressed as follows:

$$T_{i-1} = T_i + \Delta T_{(i-1)i} \tag{6}$$

According to equation (1)~(6), we can calculate the conductor tension, sag, variation of the span length, displacement and uneven tension of insulator string for the uneven ice accumulation and the non-contemporaneous ice shedding.

For example, strain segment contains 5 span lengths (210m) for a 110kV transmission line. The transmission line parameters are as follows: cross-sectional area: A=216.76mm2, diameter: D=19.02mm, elastic modulus: E=7.84×107N/ mm2, self-icing load: γ0=0.035N.m.mm, the length of insulator string: λ = 1.45m, the weight of insulator string: GJ=49N. If the icing for the overhead line is 100% designed ice-load, we can know that conductor stress is 98N/mm2 and the sum ice-load is 142.03 N·m-1·mm-2.

IX. UNEVEN TENSION, DISPLACEMENT OF INSULATOR STRIN AND THE SAG VARIATION

Case 1: The span close to the strain segment (span l1 on Figure 1) is only 25% of the designed ice load after asynchronous ice shedding. The rest of spans are still 100% of the designed ice load. At this point the calculated conductor strain, conductor sag and variation amount of the span of the dead-end section with asynchronous ice shedding as shown in Table 1, while the displacement of the insulator string and the tension difference of the dead-end section as shown in Table 2.

Table 1. Conductor strain, conductor sag and variation amount of the span of the dead-end section with asynchronous ice shedding

Span number	**Conductor strain T_i(N)**	**Variation amount of the span of the dead-end section Δl_i(m)**	**Maximum sag f_M(m)**	**Sag variation Δf_i(m)**
l_1	17422	0.4229	4.476	3.513
l_2	18935	0.2067	8.963	-0.973
l_3	19947	0.1074	8.508	-0.519
l_4	20452	0.0632	8.298	-0.308
l_5	20664	0.0456	8.213	-0.224

Table 2. Displacement of the insulator string and the tension difference of the dead-end section with asynchronous ice shedding

Tower number	**Displacement of the insulator string δ_i (m)**	**Uneven tension $\Delta T_{i(i+1)}$ (N)**
1#	-0.4229	1513
2#	-0.2162	1012
3#	-0.1088	505
4#	-0.0463	211

Table 3. Conductor strain, conductor sag and variation amount of the span of the dead-end section with asynchronous ice shedding

Span number	**Conductor strain T_i(N)**	**variation amount of the span of the dead-end section Δl_i(m)**	**Maximum sag f_M(m)**	**Sag variation Δf_i(m)**
l_1	19233	0.1759	8.824	-0.835
l_2	18626	0.4548	4.187	3.802
l_3	19599	0.1399	8.659	-0.670
l_4	20245	0.0810	8.383	-0.393
l_5	20514	0.0580	8.273	-0.284

Table 4. Displacement of the insulator string and the tension difference of the dead-end section with asynchronous ice shedding

Tower number	**Displacement of the insulator string δ_i (m)**	**Uneven tension $\Delta T_{i(i+1)}$ (N)**
1#	0.1760	607
2#	-0.2789	-973
3#	-0.1390	-646
4#	-0.0580	-269

Table 5. Conductor strain, conductor sag and variation amount of the span of the dead-end section with asynchronous ice shedding

Span number	**Conductor strain T_i(N)**	**Variation amount of the span of the dead-end section Δl_i(m)**	**Maximum sag f_M(m)**	**Sag variation Δf_i(m)**
l_1	20087	0.0948	8.449	-0.459
l_2	19648	0.1352	8.638	-0.649
l_3	18850	0.4601	4.137	3.852
l_4	19648	0.1352	8.638	-0.649
l_5	20087	0.0948	8.449	-0.459

Table 6. Displacement of the insulator string and the tension difference of the dead-end section with asynchronous ice shedding

Tower number	**Displacement of the insulator string** δ_i **(m)**	**Uneven tension** $\Delta T_{i(i+1)}$ **(N)**
1#	0.0948	440
2#	0.2301	797
3#	-0.2301	797
4#	-0.0948	440

Case 2: The ice-shedding span (span l2) is only 25% of the designed ice load for asynchronous ice shedding, the rest of spans are still 100% of the designed ice load. Consequently, conductor strain, conductor sag and variation amount of the span of the dead-end section with asynchronous ice shedding as shown in Table 3, while, displacement of the insulator string and the tension difference of the dead-end section with asynchronous ice shedding as shown in Table 4.

Case 3: The intermediate span among the strain segment (span l3) is only 25% of the designed ice load for asynchronous ice shedding. The rest of spans are still 100% of the designed ice load. So, the calculated Conductor strain, conductor sag and variation amount of the span of the dead-end section with asynchronous ice shedding as shown in Table 5, while Displacement of the insulator string and the tension difference of the dead-end section with asynchronous ice shedding as shown in Table 6.

(1) Based on analysis of Table 2, Table 4 and Table 6, this paper can summarize that: if the span near the strain segment (span l1) is ice-shedding span, so, the maximum uneven tension is 1513N. The maximum displacement of insulator string is 0.4229m. While the span l2 is ice-shedding span, the maximum uneven tension is 973N. The maximum displacement of insulator string is 0.2789m. However, the intermediate span among the strain segment (span l3) is ice-shedding span, the maximum uneven tension is 797N. The maximum displacement of insulator string is 0.2301 m. That is, the location for ice-shedding span will affect the maximum uneven tension for asynchronous ice shedding. If the ice-shedding span is close to the strain segment, the straight-line tower will withstand the maximum imbalanced-tension. Moreover, the insulator string deflection angle is also max.

(2) Based on analysis of Table 1, Table 3 and Table 5, we can know that: when the span near the strain segment (span l1) is ice-shedding span, the maximum sag variation is 3.513m. While the span l2 is ice-shedding span, the maximum sag variation is 3.802m. However, the intermediate span among the strain segment (span l3) is ice-shedding span, the maximum sag variation is 3.852m. That is, the location for ice-shedding span will affect the maximum sag variation for asynchronous ice shedding. While the ice-shedding span is the middle of the strain segment, it will produce maximum sag variation.

X. CONCLUTIONS

(1) The ice shedding mechanism is affected by a number of factors and parameters, such as ice morphology, meteorological conditions, and structural design of lines, as well as wire and conductor characteristics.

(2) The location for ice-shedding span will affect the maximum uneven tension for asynchronous ice shedding. The ice-shedding span is close to the strain segment, the straight-line tower will withstand the maximum imbalanced-tension. Moreover, the insulator string deflection angle is also max.

(3) The location for ice-shedding span will affect the maximum sag variation for asynchronous ice shedding. While the ice-shedding span is the middle of the strain segment, it will produce the maximum sag variation.

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