

Comparison of the Mechanical Properties of a New Capacity-expanding and Energy-saving Conductor and Traditional Conductors

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Abstract—The mechanical properties of a traditional steel-cored aluminum strand conductor and a new capacity-expanding and energy-saving conductor for a typical 500 kV transmission line are compared to provide a reference for the conductor lectotype of transmission lines. The study objects are a traditional steel-cored aluminum strand and three new capacity-increasing and energy-saving conductors (a new steel-cored aluminum strand of high conductivity, a new total aluminum alloy aluminum stranded conductor, and a new total aluminum alloy aluminum conductor of medium tenacity). The sag characteristics, icing overload capacity, and load bearing characteristics of these conductors are comprehensively compared and analyzed to obtain the mechanical properties of each conductor. The analytical results show that in the engineering of a 500 kV transmission line, the new steel-cored aluminum strand of high conductivity has the best sag characteristics, icing overload capacity and combined load capacity.

Keywords- *new capacity-expanding and energy-saving conductor; mechanical properties; comparative analysis*

I. INTRODUCTION

As the national economy develops rapidly and continuously, the social demands for power utilization increase each year, coupled with an increasingly large imbalance between the power utilization demand and electricity supply [1]. New capacity-expanding and energy-saving conductors have emerged along with the increasing demands for capacity increases and energy savings in power grids. An overhead power transmission conductor must have a certain mechanical strength to support its deadweight and natural external loads, such as wind load and ice load. Thus, research on the mechanical properties of new capacity -expanding and energy-saving conductors is an important step in conductor lectotype.

Current research on the mechanical properties of conductors mainly focuses on a specific span and specific ice thickness [2-4] or only compares new capacity-expanding and energy-saving conductors [5-8], lacking comparisons between new capacity-expanding and energy-saving conductors and traditional conductors in different representative spans and ice thicknesses.

The paper takes a typical 500 kV typical transmission line as the study subject and selects three representative spans of 400, 500 and 600 m and two ice thicknesses of 10 and 20 mm to compare three new capacity-expanding and energy-saving

conductors (new steel-cored aluminum strand of high conductivity, new total aluminum alloy aluminum strand, and new total aluminum alloy aluminum conductor of medium tenacity) and a traditional steel-cored aluminum strand in terms of their high-temperature sag performance, icing overload capacity, and weight bearing power. The results show that the new steel-cored aluminum strand of high conductivity has the best sag characteristics, icing overload capacity and combined load capacity.

II. CONDUCTOR SAG CHARACTERISTIC

Conductor sag is related to the linear expansion coefficient^[9], structural design, manufacturing process and maximum stress of the conductor. An overhead conductor shrinks due to temperature fluctuations. To adapt to such telescoping, the sag of the conductor increases accordingly. Now, consider the conductor's sag characteristics in high temperature; then, the calculation steps of the conductor's sag are as follows [10]:

First Calculate The Specific Load g_n and stress σ_n under the condition to be calculated according to the state equation of the conductor with the following formulas:

$$\sigma_n^2(\sigma_n + A) = B \quad (1)$$

$$A = \frac{Eg_m^2 l_{re}^2}{24\sigma_m} - \sigma_m + \alpha E(t_n - t_m) \quad (2)$$

$$B = \frac{Eg_n^2 l_{re}^2}{24} \quad (3)$$

where t_m is the temperature under the initial meteorological conditions, °C ; t_n is the temperature under the meteorological conditions to be calculated, °C ; g_m is the specific load under the initial meteorological conditions, (N / m · mm²); g_n is the specific load under the meteorological conditions to be calculated, (N / m · mm²); σ_m is the stress when the temperature is t_m and the specific load is g_m , MPa; σ_n is the stress when the temperature is

t_n and the specific load is g_n , MPa; α is the linear expansion coefficient, $1/^\circ C$; E is the elastic coefficient of the conductor, N/mm^2 ; and l_{re} is the representative span for the strain section, m .

(2) Then, calculate the sag according to the following sag calculation formula:

$$f_x = \frac{g_n}{2\sigma_n} l_a l_b \quad (4)$$

where f_x is the maximal high-temperature sag, m ; g_n is the specific load under the meteorological conditions to be calculated, (N/mm^2); σ_n is the stress when the temperature

is t_n and the specific load is g_n , MPa; and l_a and l_b are the horizontal distances from the scissor crossing to be verified to the tower, m .

Select the representative spans for the strain section l_{re} as 400, 500 and 600 m and the ice thicknesses as 10 and 20 mm. Then, take the average air temperature $15^\circ C$ as the temperature t_m in under the initial meteorological conditions, and take the maximum temperature of the conductor $+80^\circ C$ as the temperature t_n under the meteorological conditions to be calculated. The high-temperature sag characteristics of the four conductors can be obtained by Formulas (1)-(4), and the results are shown in TABLE 1.

TABLE I. CONDUCTOR'S HIGH-TEMPERATURE SAG CHARACTERISTICS

Conductor's span (m) / high-temperature Ice thickness sag characteristics (mm)	400	400	500	500	600	600
	/10	/20	/10	/20	/10	/20
Conductor type						
Traditional steel-cored aluminum strand	12. 423	18. 013	18. 952	28. 029	27. 882	40. 268
New steel-cored aluminum strand of high conductivity	7.2 71	9.9 88	11. 142	15. 819	17. 856	22. 693
New total aluminum alloy aluminum strand	12. 555	18. 626	19. 152	28. 988	27. 242	41. 651
New total aluminum alloy aluminum conductor of medium tenacity	8.0 79	11. 456	12. 316	18. 006	17. 443	26. 018

According to Table 1, except for the fact that the new total aluminum alloy strand and traditional steel-cored aluminum strand have identical sag performances, the other two new conductors both perform better than the traditional steel-cored aluminum strand, with the new steel-cored aluminum strand of high conductivity having the best sag performance.

The new steel-cored aluminum strand of high conductivity also has more significant advantages under large spans, and it can directly lower the nominal height of the tangent tower by 5 m under ideal conditions compared with that of traditional steel-cored aluminum strand.

III. CONDUCTOR'S ICING OVERLOAD CAPACITY

When calculating the icing overload capacity, the maximum tension at the sag nadir should not exceed 60% of the rated breaking force and the maximum tension at the suspension point should not exceed 66% of the rated breaking force. According to the literature [11], the conductor's icing overload capacity can be obtained as follows:

$$g_n = \sqrt{(\sigma_n - \sigma_m + \frac{g_m^2 l_{re}^2 E}{24\sigma_m^2})} \sqrt{\frac{24\sigma_n^2}{l_{re}^2 E}} \quad (5)$$

$$b = -\frac{d}{2} \pm \sqrt{\left(\frac{d}{2}\right)^2 + \frac{(g_n - g_m) \square S}{0.02772}} \quad (6)$$

where g_m is the specific load under the initial meteorological conditions, ($N/m \cdot mm^2$); g_n is the specific load under the meteorological conditions to be calculated, ($N/m \cdot mm^2$); σ_m is the stress when the temperature is t_m and the specific load is g_m , MPa; σ_n is the stress when the temperature is t_n and the specific load is g_n , MPa; α is the linear expansion coefficient, $1/^\circ C$; E is the conductor's elastic coefficient, N/mm^2 ; l_{re} is the representative span of the strain section, m ; d is the diameter of the conductor, m ; and S is the conductor's

cross-sectional area, mm^2

TABLE 2.

The icing overload capacity of the conductor is obtained according to Formulas (5) and (6), and the results are shown in

TABLE II. CONDUCTOR'S ICING OVERLOAD CAPACITY

Conductor's icing overload capacity	span (m)/ ice thickness (mm)	400/10	400/20	500/10	500/20	600/10	600/20
		Conductor type					
	Traditional steel-cored aluminum strand	27.94	37.94	26.29	36.99	25.32	36.46
	New steel-cored aluminum strand of high conductivity	37.27	44.06	33.27	41.27	30.69	39.59
	New total aluminum alloy aluminum strand	26.57	37.18	25.40	36.31	24.63	35.82
	New total aluminum alloy aluminum conductor of medium tenacity	33.83	41.48	30.48	39.28	28.34	37.98

According to TABLE 2, the newly configured steel-cored aluminum strand of high conductivity has the best icing overload capacity under different representative spans and different ice zones, and the newly configured total aluminum alloy strand has the second best performance, 10-30% higher than that of the steel-cored aluminum strand. The new total aluminum alloy aluminum strand of medium tenacity and traditional steel-cored aluminum strand have similar icing overload capacities; however, they can all meet the requirements of 10 mm and 20 mm ice thicknesses with some margin of safety.

IV. CONDUCTOR'S COMBINED LOAD CAPACITY

Under the effect of wind and icing, the combined load for the conductor of overhead transmission lines can be broken up into a horizontal component and a normal component, with the former being the horizontal wind load of the conductor and the latter being the load produced by conductor's deadweight and ice weight ^[12-13] (the influence of pneumatic transverse force produced by the Karman vortex is not considered here). This paper studies the conductor's combined load capacity under meteorological conditions for typical 500 kV transmission lines. The meteorological conditions are as shown in TABLE 3.

TABLE III. METEOROLOGICAL CONDITIONS

Representative condition	Temperature (°C)	Wind speed (m/s)	Ice thickness (mm)
Minimum air temperature	-10	0	0
Average air temperature	15	0	0
Maximal gale	10	27	0

A. Conductor's vertical load capacity

The conductor's vertical load can be computed as

$$G = gS l_v + G_i \quad (7)$$

where G is the vertical load of the conductor, N ; g is the vertical specific load of the conductor, ($N / m \cdot mm^2$);

l_v is the vertical span, m ; and G_i is the total weight of the insulator string, N .

According to Formula (7), the vertical load of the three conductors under the conditions of average temperature and icing is obtained, and the results are shown in TABLE 4.

TABLE IV. CONDUCTOR'S VERTICAL LOAD CAPACITY

Conductor's vertical load capacity Ice thickness (mm) Conductor type	10		20	
	Average temperature	Icing	Average temperature	Icing
Traditional steel-cored aluminum strand	48.94	78.91	48.94	78.91
New steel-cored aluminum strand of high conductivity	48.57	78.51	48.57	78.51
New total aluminum alloy aluminum strand	43.97	73.96	43.97	73.96
New total aluminum alloy aluminum conductor of medium tenacity	48.33	73.87	48.33	73.87

TABLE 4 shows that the vertical loads of the new aluminum alloy cored aluminum strand and new total aluminum alloy conductor of medium tenacity are highly similar and are approximately 10% lower than that of the traditional steel-cored aluminum strand, whereas the vertical load of the new steel-cored aluminum strand of high conductivity is slightly smaller than that of the traditional steel-cored aluminum strand.

B. Conductor's horizontal load capacity

The conductor's wind pressure load can be calculated as

$$P = gsl_h \sin^2 \frac{\theta}{2} + P_i \tag{8}$$

where P is the conductor's wind pressure load, N ; θ is the included angle between the conductor and line direction, ($^\circ$); g is the wind pressure specific load of the conductor, $N / m \cdot mm^2$; l_h is the horizontal span, m ; and P_i is the wind pressure of the insulator string, N .

The load of the conductor under gale and icing is obtained according to Formula (8), and the results are shown in TABLE 5.

TABLE V. CONDUCTOR'S HORIZONTAL WIND LOAD CAPACITY

Conductor's horizontal wind load capacity Ice thickness (mm) Conductor type	10		20	
	Gale	Icing	Gale	Icing
Traditional steel-cored aluminum strand	36.92	8.55	36.92	8.55
New steel-cored aluminum strand of high conductivity	36.86	8.54	36.86	8.54
New total aluminum alloy aluminum strand	36.86	8.54	36.86	8.54
New total aluminum alloy aluminum conductor of medium tenacity	36.86	8.54	36.86	8.54

TABLE 5 shows that the four conductors have highly similar horizontal loads under the same icing thickness.

V. CONCLUSION

This paper calculated and compared the mechanical characteristics of three new capacity-expanding and energy-saving conductors and the traditional steel-cored aluminum strand and found that the new steel-cored aluminum strand of high conductivity has superior sag characteristics and icing overload capacity for a typical 500kV transmission line compared with those of the traditional steel-cored aluminum strands and other new capacity-expanding and energy-saving conductors. The combined load capacity of the new steel-cored aluminum strand of high conductivity is nearly equal to that of the traditional steel-cored aluminum strand and is higher than those of the other two new capacity-increasing

and energy-saving conductors. In summary, the new steel-cored aluminum strand of high conductivity has the best sag characteristics, icing overload capacity and combined load capacity.

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