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Overview of new heat-resistant multi-capacity wire

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Abstract: *With the rapid development of the country's economy, the demand for electricity is becoming greater and greater. In order to achieve increased capacity of power lines, the use of new heat-resistant capacitance conductors has become an inevitable trend. Capacity-enhancing conductors are conductors that increase the line's power transmission capacity by raising the conductor's operating temperature or increasing its cross-sectional area. This review discusses new heat-resistant aluminum stranded wires, mainly heat-resistant aluminum stranded wires and composite core wires, and describes the mechanism for increasing the capacity of these wires.*

Keywords: *aluminum alloy stranded wires; yin steel core*

1. Introduction

Electricity is one of the important bases on which economic and social development can be rapid. With the rapid development of the national economy, the demand for electricity is also growing. In order to meet the growing demand for electricity, it is necessary to improve the transmission capacity of the power grid lines under the premise of ensuring safety and establishing a stable and strong power grid with high transmission capacity. At present. China's transmission lines mainly use ordinary steel-core aluminum stranded wire, but its general conductivity, line losses are high, and the allowable operating temperature is greatly restricted, can not carry long distances, large-capacity power transport, in order to improve the transmission capacity of transmission lines, the use of new capacitance wire has become an inevitable trend. New capacitance conductor not only can enhance the load capacity, but also has excellent wire performance, heat resistance and other advantages, which has played a good role in promoting and safeguarding the capacitance transformation of high-voltage transmission lines in China. This paper introduces the new heat-resistant aluminum alloy strand, soft aluminum strand and composite core wire as the main conductor, and describes the mechanism of these conductors to increase capacity.

2. The principle of wire capacity increase

To carry more power than the original conductor, the capacity of the conductor is increased by increasing the capacity to carry current and increasing the temperature rise of the conductor[1]. However, as the temperature of the conductor rises, the arc sag of the line becomes progressively larger, creating a safety hazard when the arc sag of the conductor exceeds the safety limits for which it was designed. To solve this problem, heat resistant conductors have been designed and developed.

3. New heat resistant conductors overview

China's most widely used wire is steel-core aluminum strand, ordinary steel-core aluminum strand long-term maximum allowable operating temperature of 9o c(engineering design to take 80 °C), if its operating temperature, will deteriorate the overall performance of the wire, in particular, significantly reduce its comprehensive breaking force and increase the amount of thermal elongation and increase the arc sag of the wire, to the safe operation of the line has a greater impact, thereby limiting the line to increase the transmission capacity . In order to solve the problem of wire operating temperature, heat-resistant aluminum alloy conductor wire, the use of soft aluminum wire, composite materials for the core of the wire came into being[2].

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3.1 Heat-resistant aluminum alloy conductors

Heat resistant aluminum alloy conductors are made by adding zirconium and yttrium to the aluminum so that the strength of the heat resistant aluminum alloy is reduced within a permissible range when the conductor is raised to a higher temperature [3]. As an overhead transmission conductor, to determine its permissible operating temperature, the wire is generally heated for a certain period of time to return to room temperature when the mechanical strength of the residual rate of 90% to be considered as the basis, the mechanical strength of the residual rate and heating temperature and time relationship is known as the softening characteristics of the material Figure 1 shows the softening characteristics of the wire using heat-resistant aluminum alloy and ordinary aluminum wire.

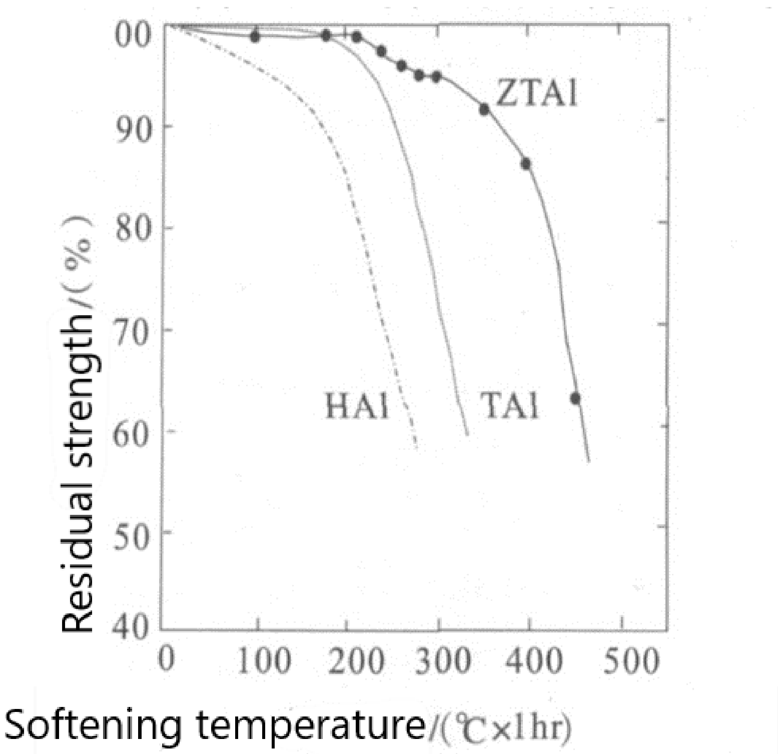

Figure 1: Comparison of softening character

3.1.1 Steel-core heat-resistant aluminum alloy stranded wires

The most common type of conductor using heat-resistant aluminum alloys is the steel-core heat-resistant aluminum alloy strand, which was first developed in Japan in the 1960s.The softening characteristics of heat-resistant aluminum alloys have been shown to be superior to those of ordinary hard aluminum wires, with continuous operating temperatures and short-time allowable temperatures 60°C higher than those of ordinary steel-core aluminum strands. In comparison with other properties of heat-resistant aluminum alloy and ordinary hard aluminum wire, they have similar creep characteristics and corrosion resistance. Therefore, in the line capacity increase renovation project, only similar specification wires need to be replaced, while basically no tower replacement is required to meet the strength and arc sag requirements [4]. But unfortunately, the steel core heat-resistant aluminum alloy stranded wire conductivity is low, in the line transmission increased loss, and because it has the same specifications with the steel core aluminum stranded wire has the same arc sag characteristics, making the wire to improve the temperature rise, increase the transmission capacity, the amount of arc sag will often exceed the allowable safety range, resulting in the wire and cannot improve the ideal temperature rise, the increase in transmission capacity will also be reduced as a result.

3.1.2 Heat-resistant aluminum alloy stranded wire with Yin steel core

In order to solve the problem of not allowing a large temperature rise and transmission capacity due to the characteristics of the arc sag, heat-resistant aluminum alloy strand with a Yin steel core was developed. The aluminum alloy strand with Yin steel core was born in the early 1980s and the steel cores of these wires are either galvanized Yin steel cores or aluminum clad Yin steel cores. Yin steel is an iron-nickel (about 36% to 40% nickel) alloy material. The coefficient of linear expansion of this material is

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much lower than that of ordinary steel cores and has the characteristic that the length basically does not change with temperature. The coefficient of linear expansion of ordinary steel cores is 11.5 x 10-6/ °C,the coefficient of expansion of aluminum wires 23 x 10-6/ °C; while the coefficient of expansion of Yin steel cores is only 3.7 x 10-6/°C, which is 1/3 of ordinary steel cores and1/5 of aluminum wires[5] . In operation, as the expansion elongation of the outer heat-resistant aluminum alloy is greater than that of Yin steel cores, the tension of the heat-resistant aluminum alloy is gradually transferred to the inner Yin steel cores as the working temperature rises. When a certain temperature is reached, all the tension of the outer heat resistant aluminum alloy is transferred to the inner core and the outer layer no longer bears the tension of the wire, this temperature is called the inflection point. At this point, the coefficient of linear expansion of the Yin steel core is 3.7 x 10-6/ °C. The coefficient of linear expansion of the Yin steel core heat-resistant aluminum alloy strand is 3.7x10-6/ °C. Therefore, when the heat-resistant aluminum alloy strand with Yin steel core reaches the inflection point temperature, the characteristics of the wire are characterized by the Yin steel core, i.e. it has high temperature and low arc sag characteristics. The arc sag temperature rise curve for one model of this wire is shown in Figure 2.

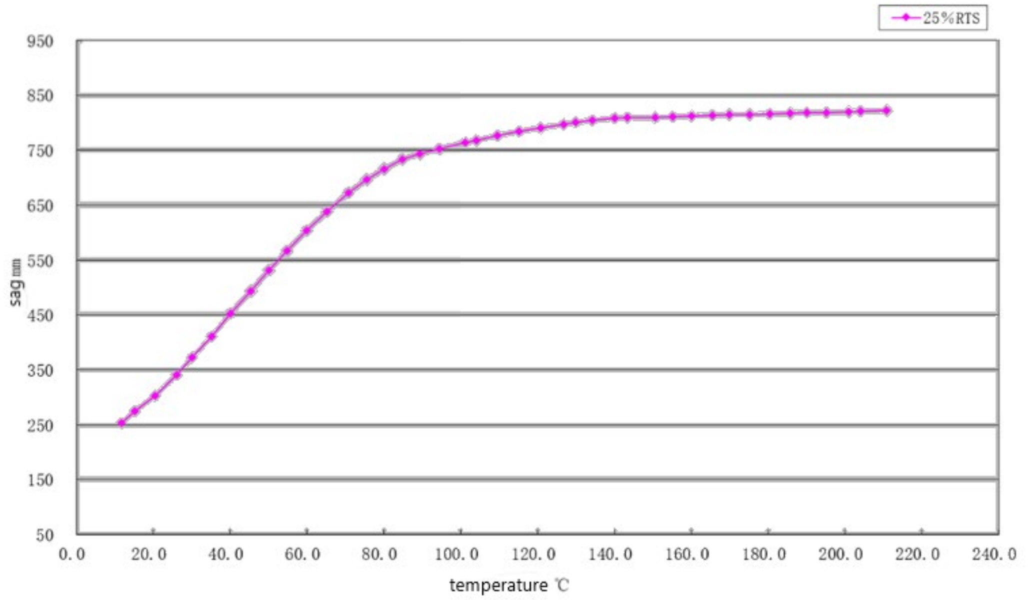

Figure 2: Arc Pitch - Temperature Rise Cu

Table 1: Performance comparison

Wire species	Designator	Continuous			Short term			Resistance temperature coefficient
		Permissible working temperature /°C	Allowable current/A	Ratio*	Permissible working temperature/°C	Allowable current/A	Ratio*	/°C- 1
Aluminum stranded wire with steel core	ACSR	90	829	1.0	120	1115	1.0	0.0040
Extra heat resistant aluminum alloy stranded wire with Yin steel core	XTACSR	230	1715	2.1	310	2004	1.8	0.0038

A comparative performance analysis with ordinary steel-core aluminum stranded wire was carried out and the performance is shown in Table 1.

When the operating temperature reaches 230°C, its ultimate transmission capacity is about twice that of ordinary wires. Not only that, its arc sag characteristics and ice-overload capacity are better than ordinary wires, but it is expensive, 7 to 8 times more expensive than ordinary steel-core aluminum

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stranded wires[6].

3.1.3 Gap-type heat-resistant aluminum alloy strands

The difference is that the gap between the steel core and the heat-resistant aluminum alloy layer is filled with heat-resistant grease to reduce the friction between the steel core and the heat-resistant aluminum alloy layer [7]. This conductor will be installed with a special erection method, so that all the tension borne by the steel core when the conductor is running, the heat-resistant aluminum alloy layer of the line expansion of the conductor does not playa role in the change of chord, the coefficient of linear expansion of the steel core is 11.5×10-6/°C, is generally one-half of the coefficient of linear expansion of the steel core heat-resistant aluminum alloy strand, therefore, the gap type steel core heat-resistant aluminum alloy strand can also be at high temperatures with a better Therefore, the gap type steel core heat resistant aluminum alloy strand can also have a good arc sag characteristics at high temperature, its arc sag characteristics with ordinary wire as shown in Figure 3.

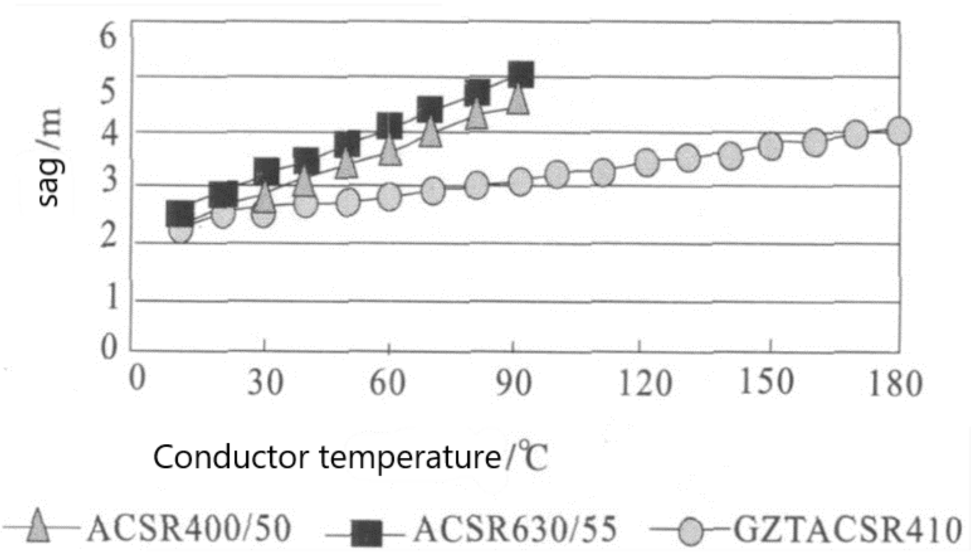

Figure 3: Arc Pitch - Temperature Charact

3.1.4 Summary

According to the above introduction and analysis, steel-core heat-resistant aluminum alloy strand compared to ordinary steel-core aluminum strand allows the working temperature to increase, due to its and ordinary steel-core aluminum strand has similar arcsag characteristics, so that it can replace ordinary steel-core aluminum strand in the actual capacity transformation process, and basically do not need to replace the tower, but at the same time, this arc sag characteristics also make it can not have a large working temperature increase, otherwise the arc sag will exceed the safety range. In order to solve this problem. Yin steel-core heat-resistant aluminum alloy strand and gap-type steel-core heat-resistant aluminum alloy strand were developed, the former as the operating temperature rises, by gradually transferring the tension of the wire to Yin steel core to achieve high temperature and low arc sag characteristics, but this wire is expensive, the latter through the use of special methods in the erection of the line, mandatory transfer of all the tension of the wire to the wire expansion coefficient of the steel core, so as to The latter achieves a better arc sag characteristic, but due to its unique capacity increase mechanism, it increases the difficulty of construction operation and maintenance in the capacity increase renovation project.

3.2 Flexible aluminum stranded wire

Soft aluminum wire is a type of aluminum wire made of 1350-0 electrical aluminum by thermal annealing treatment, because by high temperature annealing treatment, when the wire temperature does not exceed 200 °C, the strength of soft aluminum wire will not be reduced[6].

3.2.1 Steel-core flexible aluminum stranded wires

In order to improve the transmission capacity of power lines, the steel-core soft aluminum strand was developed in the USA and Canada in the 1970s. Unlike the steel-core aluminum strand, which uses hard

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aluminum, the soft aluminum wire used in the steel-core soft aluminum strand is made of a fully annealed aluminum with an electrical conductivity of 63% IACS, about 2% IACS higher than the ordinary hard aluminum wire, which can reduce the line loss of the transmission line and increase the load capacity[8] . In addition, due to the lower mechanical strength of soft aluminum wire, much lower than the mechanical strength of ordinary hard aluminum wire, and its high elongation， so that when the operating temperature reaches the migration point temperature of the steel-core soft aluminum strand, the mechanical load of the wire is fully borne by the steel core, which has good softening characteristics, so this wire has better arc droop characteristics, and can withstand higher operating temperatures. 1980s In the 1980s, a new generation of steel-core soft aluminum strand ACSS/Tw with a round cross-section of the steel strand and a trapezoidal cross-section at the interface of the soft aluminum wire was developed, which has a more compact structure than the original steel-core soft aluminum strand with a round cross-section [9]. The smaller diameter of the new steel-core soft aluminum strand with the same aluminum cross-section reduces the impact of ice and wind loads on the conductor, and the smaller diameter and smoother outer surface reduces the aerodynamic coefficient and the risk of breeze vibrations and dances. With the same diameter, the new steel-core flexible aluminum strand has a larger aluminum cross-sectional area, which increases the load capacity and can reduce line losses; in addition, the smoother outer surface of the conductor reduces the level of corona and radio interference. Due to its better arc sag characteristics, the new steel-core soft aluminum strand can be operated for a long time at an allowable operating temperature of 250°C without reducing its mechanical strength, comparing it with steel-core aluminum strand, as shown in Table 2.

Table 2: Comparison of load capacity

Operating temperature of conductors/°C	Load capacity/A		
	ACSR 795 Kcmil(402.9mm)	ACSS/TW (aluminum equivalent area)	ACSS(equal diameter)
75	730	720	820
100		980	1110
150		1320	1490
200		1560	1770
250		1740	2000

As the new steel-core soft aluminum strand works mainly by the steel core to bear the mechanical load of the wire, it is necessary to configure different strength levels of steel cores according to the actual situation when carrying out capacity enhancement projects[10].

3.2.2 Summary

As a kind of capacitive conductor for overhead transmission lines, the steel-core flexible aluminum strand has the advantages of high electrical conductivity, good thermal stability, low chirality and good self damping performance, and has a broad application prospect.

3.3 Composite core conductors

With the continuous development of the field of materials science, people began to try to replace metal materials with composite materials as the bearing body of the wire, at present, the main composite material core aluminum strand: carbon fiber core soft aluminum strand, aluminum-based ceramic fiber core aluminum strand, etc.

3.3.1 Carbon fiber-core flexible aluminum stranded wires

In the 1990s, Japan and the United States began to research composite synthetic core wire, the early 21st century, the United States CTC company through the synthetic core of the material and structure of the larger improvements, and absorb the structural characteristics of the steel core soft aluminum strand, developed a carbon fiber core soft aluminum strand, the core of this wire is made of carbon fiber as the central layer and glass fiber wrapped in a single core rod. The outer layer and the adjacent outer layer of aluminum strands with a trapezoidal cross section[11]. By testing the carbon fiber core soft aluminum strand, analyzing its density, stress-strain curve and arc sag characteristics, it was concluded that the mechanical strength of the carbon fiber core greatly exceeds that of an ordinary steel core, and that the coefficient of thermal expansion of the carbon fiber composite core is much smaller than that of the aluminum strand, with a coefficient of thermal expansion of 1.6 × 10°/°C, compared with 2.3 × 103/ C for aluminum, so that the arc sag of the wire at a temperature increase to A certain value of the arc sag of

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the wire basically no longer increases, thus allowing the operating temperature of the wire to increase to more than 160 ℃[12], to improve the transmission capacity of the wire JRLX/T-185 /28 type of capacity as shown in Table 3, plus the outer layer of the trapezoidal section of the soft aluminum wire, so it has both the characteristics of the steel-core aluminum strand[13].

Table 3: Comparison of load capacity

Line temperature	LGJ-185/30	JRLX/T-185/28
70 °c	387	388
80 °c		471
90 °c		543
100 °c		609
105 °c		631
110 °c		669
120°c		725
130 °c		779

3.3.2 Aluminum clad carbon fiber core conductors

Although the above-mentioned carbon fiber-core soft aluminum stranded wire has excellent performance in terms of load capacity, arc sag characteristics and ice-covering overload capacity, but due to the less experience of domestic research on carbon fiber, the structural characteristics of the carbon fiber-core soft aluminum stranded wire itself and the brittleness of the inner core, there are shortcomings in its supporting fixtures and construction process. To solve this problem, a new type of carbon fiber composite core conductor has been developed in China. This new type of carbon fiber composite core conductor uses aluminum cladding technology, i.e. by cladding a seamless aluminum tube with a wall of not less than 2.5 mm outside the carbon fiber composite core, the axial pressure of the carbon fiber is converted into pre-tension, thus greatly improving the bending resistance of the core bar to axial compression[14] as shown in Figure 4.

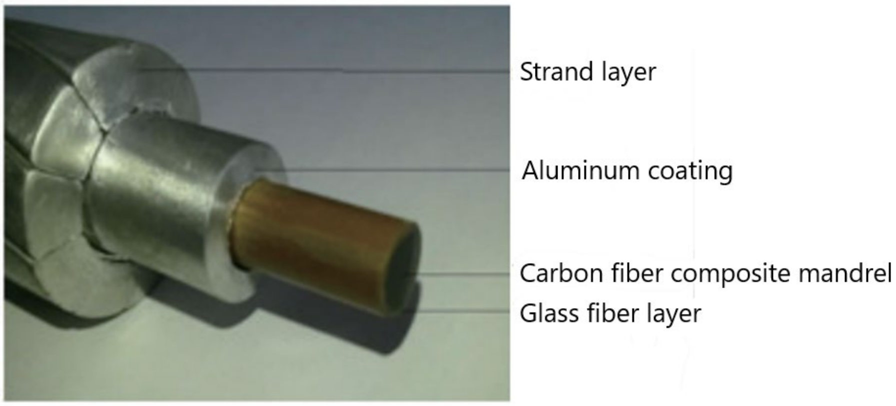

Figure 4: Aluminum clad carbon fiber core

Through the establishment of three-dimensional model, using finite element analysis of this new carbon fiber conductor for compressive performance, tensile performance analysis, and will be compared with the traditional carbon fiber composite core wire, it can be concluded that: when fixed two wires at one end and the same radial pressure applied at the other end, the maximum stress value of the new aluminum-clad carbon fiber composite core wire is significantly smaller than the traditional wire, the stress gradient changes are also smaller The stress gradient is also smaller and more evenly distributed[15]. At the same time, the total deformation of the two is basically the same, indicating that the new wire has better compressive properties than the traditional carbon fiber wire. When the same axial tension is applied, the maximum stress value and total deformation of the new carbon fiber composite core wire are smaller than those of the traditional carbon fiber wire. At the same time, the former stress distribution is more uniform, less stress concentration phenomenon occurs, indicating that the new carbon fiber conductor tensile performance is better than the traditional carbon fiber conductor. In summary, the mechanical properties of the new carbon fiber conductor are better than those of the traditional carbon fiber conductor under different working conditions. In addition, the new carbon fiber conductor also reduces the line loss through aluminum cladding technology, the use of new hydraulic fittings, new crimping technology to reduce construction difficulties and additional costs, and because of its good corrosion resistance to extend the service life of the wire"5. As the new carbon fiber composite core conductor retains the advantages of traditional carbon fiber core conductor, but also solves the shortcomings of the traditional carbon fiber core conductor, therefore, has a broad application prospects.

3.3.3 Aluminum stranded wire with aluminum-based ceramic fiber core

Aluminum-based ceramic fiber-core aluminum strand was developed by 3M in the USA. This new wire has basically the same structure as ordinary steel-core aluminum strand, but the inner steel core is replaced by an aluminum- based ceramic fiber core and the outer and adjacent outer hard aluminum wires are replaced by heat-resistant aluminum alloys. The aluminum-based ceramic fiber-core wire has superior properties such as light weight, high tensile strength at high temperatures and low relaxation[16]. This is due to the increased rigidity of this synthetic fiber material, which is similar in quality to aluminum, but achieves a lower coefficient of linear expansion than steel and a higher tensile strength at high temperatures[17]. As a result, the conductor simultaneously has low creep, high electrical conductivity and a strong corrosion resistance similar to that of aluminum, increasing the conductor's transport capacity.

3.3.4 Summary

According to the above introduction and analysis of composite core conductors, carbon fiber core soft aluminum stranded wire inherits the advantages of steel core soft aluminum stranded wire, at the same time, through the use of composite materials with a low coefficient of thermal expansion, high mechanical strength, the use of trapezoidal cross-section of the aluminum wire， so that the wire has a good arc droop characteristics， improve the transmission capacity, but due to its material characteristics and structural features, there is a certain degree of difficulty in the construction process. The aluminum clad carbon fiber core conductor reduces the difficulty of construction and installation of carbon fiber core conductors through the use of aluminum cladding technology, new hydraulic type fittings and new crimping technology, and inherits the advantages of traditional carbon fiber core conductors. The aluminum-based ceramic fiber-core aluminum strand also improves the conductor's transport capacity by using a core wire with good mechanical and electrical characteristics.

4. Conclusion

This review summaries the literature on new types of conductors, separating out the new capacity-enhancing conductors using heat-resistant aluminum alloy strand, soft aluminum strand and composite cores, describing the mechanisms by which these new conductors achieve capacity increase, and combining them with reality.

References

[1] Huang Haoshi. Transmission Line Energy-saving Type Upgrading Conductor Characteristics [J]. Power Construction, 2010, 31(02); 29-34.
[2] Han Xiaoyan. Brief analysis of the application and current situation of capacity enhancement technology in power grid system [J]. Times Automotive, 2018(10):186-187.
[3] Xie Guangbin, Li Lin, Liu Fangfang. Application of Gap Conductor in Line Reconstruction, 2011. 27(01):70-73,
[4] Qi Donghui. The Energy-saving Application of Heat-resistant Conductors [D]. South China University of Technology, 2012.
[5] You Chuanyong. Research on the application of capacitance-enhancing conductors onoverhead transmission lines [U]. Power Equipment, 2006(10); 1-7.
[6] Cai Hong, Zhu Benyu, Lu Xiuxue. Research on the performance and application of two types of capacitance-enhancing conductors [J]. Jiangxi Electric Power, 2021. 45(08):25-29.
[7] Miao Yaojun, Wu Mingjin. Cai Zhengquan. Discussion of Gap Type Up-Rating Conductor Construction Technology [J]. Wire and cable, 2014(01):44-46.DOl:10.16105/j.cnki.dxdl.2014.01.014.
[8] Xiao Yuanbo. Research on Heat-resisting Wire in Capacity Increase and Modification Project [J]. Jilin Electric Power, 2021, 49(01):33-36.DOI:10.16109/j.cnki.jldl.2021.01.010.
[9] Xie Dongsheng. The Application of Extra Strong ACSS (Aluminum Conductor Steel Supported) in Transmission Line [J]. Science and technology information development andeconomy, 2010, 20(04):217-218.
[10] You Chuanyong. Study on Application of Aluminum Conductor Steel Supported/Trapezoidal Wire

ISSN 2706-655X Vol.5, Issue 1: 25-32, DOI: 10.25236/IJFET.2023.050105

for Overhead Transmission Lines [J]. Power Construction, 2006(05):1-4+30.
[11] Wei Hanxing, Zhu Bo, Chen Yuan, Lu Yi. Investigation on the characteristics of a new aluminum conductor with carbon fiber reinforced composite core [J]. Functional Materials, 2009, 40(12):1993-1995
[12] Lu Qingqing. Application of New Heat-resisting Conductors in the High Voltage Transmission Line capacity improvement [J]. Fujian construction science andtechnology, 2015(01):69-71.
[13] Wei Hanxing. The preparation and investigation of carbon fiber reinforced composites core [D]. Shandong University, 2010.
[14] Dong Gang, Song Zhuoyan, He Chunhui. Yang Bo. Application Analysis of New Carbon Fiber Composite Conductor in Transmission Line [J]. SyntheticFibers, 2019, 48(08):35-38.DOl: 10.16090lj. cnki.hcxw.20190813.001.
[15] Dong Gang, Wei Tong. Analysis and Research on Mechanical Properties of ACCC with Aluminum Coating [J]. Shandong Electric Power Technology, 2020, 47(04):10-14.
[16] Yang Q.H. Liu X. P. Xie S. S. S. Application of novel heat-resistant aluminum conductor composite reinforced [J]. East China ElectricPower, 2008(04):103-105.
[17] Wang Congmin. Deeping Experiment and Study of the Aluminum Conductor Composite Core [D]. North China University of Electric Power, 2015