FP_C.1_LEADER_HIGH TEMPERATURE LOW SAG (HTLS) OVERHEAD TRANSMISSION LINE CONDUCTOR

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ABSTRACT

Overhead conductor is the key component of power transmission to ensure efficient, reliable and sustainable power network system. Brisk increase of electricity demand imply the need of more power to be generated and transmitted. Building a new power transmission network is an obvious solution but it is also involves costly and lengthy processes. It takes in several major issues such as high construction cost, delay from right of way matters and gloomy impact on natural environment. The best alternative solution is reconductoring the overhead power transmission lines with High Temperature Low Sag (HTLS) conductor which able to cater double the Ampacity requirement. This initiative could accommodate the higher power requirement which in return provide a cheaper and faster solution to utilities by maintaining the usage of existing towers. The prevailing conventional Aluminium Conductor Steel Reinforced (ACSR) conductor has several weak points which include large thermal expansion and heavy steel core with higher corrosion rate. On the contrary, the eccentric conductor of HTLS could operates at higher temperature and double the Ampacity with lower Differential Ohmic Loss operation cost. It offers a higher transmission capacity with low transmission loss due to its unique trapezoidal shaped aluminium conductor wires. HTLS conductor core is also made from a special stranded carbon fibre composite cable which is lighter, low expansion, higher strength, non-magnetic, high flexibility, high corrosion resistance, high tensile, low creep elongation and high modulus compared to the steel core of standard ACSR. In conclusion, the insistent needs to increase the transmission network Ampacity on the existing power transmission line towers which also could offers lesser conductor sags made possible with the application of the exceptional attributes of HTLS overhead conductor.

KEYWORDS ***HTLS, ACSR, RECONDUCTORING, AMPACITY, SAG,***

1. INTRODUCTION

High Temperature Low Sag (HTLS) conductor is the preferable latest technology conductor particularly for reconductoring transmission line to accommodate the rapid increase of demand to transmit more power. HTLS helps to bring the best out of reconducturing transmission line activities through it exceptional technical attributes. It offers double the Ampacity and lower sag at fundamentally similar weight of conventional Aluminium Conductor Steel Reinforced (ACSR), hence it makes possible to do reconductoring on existing transmission lines towers while having same conductor to earth clearance. Overtime, HTLS conductor also has progressed with an improved core construction that eventually enhanced its mechanical characteristics. By using stranded carbon fiber composite cable (CFCC) as the core, it has made HTLS becoming more advance under the design of Aluminium Conductor Fibre Reinforced (ACFR). HTLS conductor also offer an effective solution for transmission line issues such as high construction cost, delay from right of way matters and gloomy impact on natural environment.

2. MAIN CONTENTS

2.1 CONSTRUCTION

HTLS made of two components, trapezoidal shaped aluminum conductor wires and fiber core. ACFR offered Carbon Fiber Composite Cable (CFCC) as the stranded shape core. Figure 1 shows the cross sectional drawing of ACFR HTLS conductor. Figure 2 shows the telescopic sample of ACFR HTLS conductor.

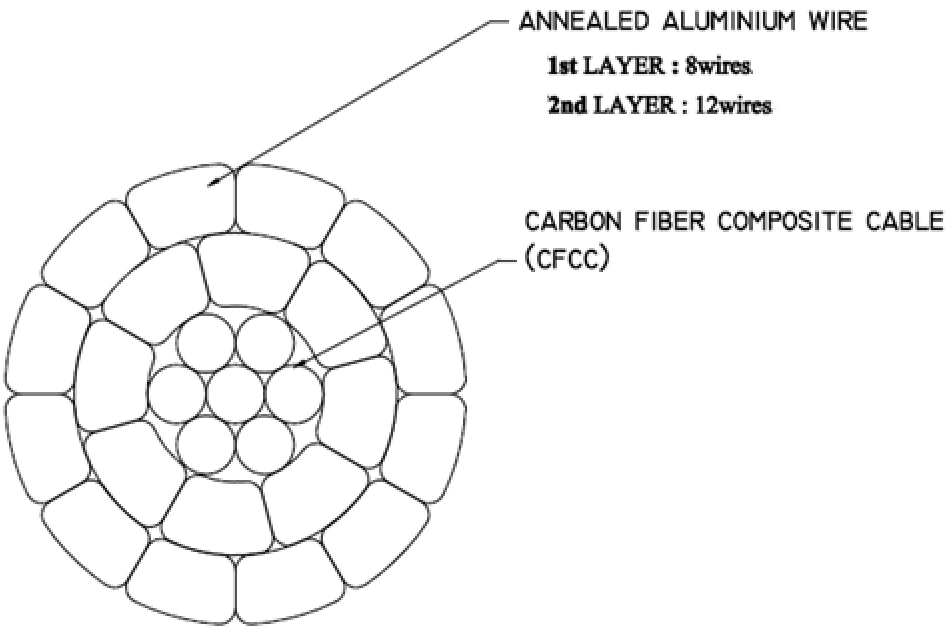

Figure 1. Conductor Cross Sectional Area Structural Drawing of Aluminium Conductor Fibre Reinforced (ACFR) type of HTLS

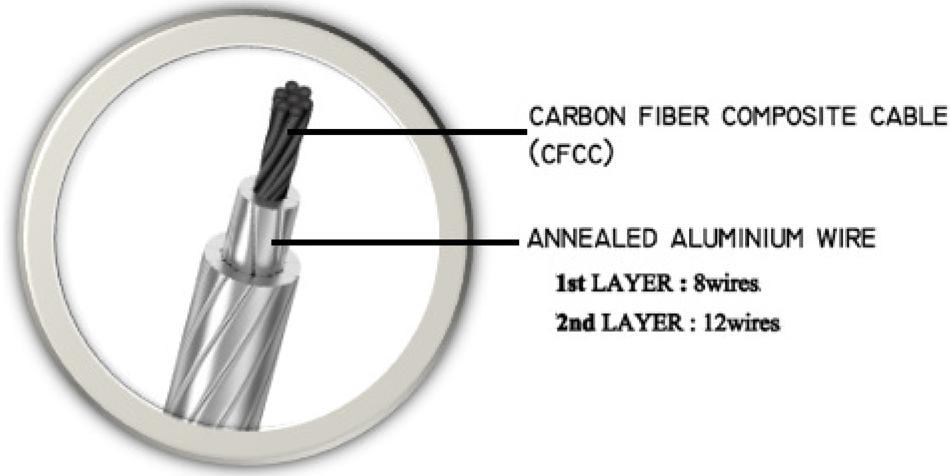

Figure 2. ***Aluminium Conductor Fibre Reinforced (ACFR) type of HTLS***

2.12 Trapezoidal Shaped Aluminium Conductor

The conductor is made of trapezoidal shaped of annealed aluminium wire by stranding pre-shaped annealed aluminium wires into wedges-like to fit tightly to each other to reduce the interstice between strands and have smaller conductor diameter but larger cross section area.

2.13 Carbon Fiber Composite Cable (CFCC) Core

The raw material carbon fiber and epoxy resin matrix are bunched together to form a composite wire and are stranded Carbon Fiber Composite Cable (CFCC coated with organic layer act as galvanic protection and thus formed single carbon fiber composite wires are stranded together to form a). The single strand size can be chosen to match the final CFCC diameter suitable for ACFR conductor that replaces the existing conventional ACSR conductor. CFCC has the same advantage as that of the single carbon fiber composite core like higher strength, lower weight, lower thermal expansion and higher corrosion resistance. But the unique stranded carbon fiber composite core CFCC accommodate the challenge of flexibility and handling issues in the single strand carbon fiber composite core.

2.2 MANUFACTURING

Manufacturing of ACFR HTLS conductor starts with pulling of annealed aluminium rod through a series of drawing dies to obtain trapezoidal aluminium wires of desired dimension, this process is called wire Drawing. The aluminium rod is pulled through a series of dies to reduce the cross section and to obtain a certain size. This drawing of trapezoidal wires are precise and delicate in order to handle the aspects of draw down ratio, friction and elongation. Hence proper control of payoff tension, correct sizing of guide rollers and precise sizing of dies position in the correct sequence are needed. While it is being drawn, the wire continuously undergone natural annealing process through the stages of shaping rollers and drawing dies. At the end of the wire drawing line, there is a take up where output wire is rolled into a processing bobbin and would be ready for the next stage of process called Stranding.

At a time, 20 bobbins containing drawn aluminium trapezoidal shape wires are prepared (first layer x 8wires + second layer x 12 wires). After that it goes to the main manufacturing process of Stranding by applying trapezoidal aluminium wires concentrically around/over the CFCC core to form the complete ACFR conductor. The stranding machine includes a core feeder, a first stranding cage, first two-set of shaping rollers, a first die set, a second stranding cage, second two-set shaping rollers, a second die set, a length counter, a capstan and a drum take up. 8 bobbins are loaded in the first stranding cage representing the first layer of conductor. While rotating, the first stranding cage strands on top of the fiber core. It is highly crucial to set and control the payoff tension of each bobbin of the first cage so that the first layer of wire conductor that stranded around the fed carbon core has a firm contact and grip but just enough, without putting too much compression to avoid crushing the fiber core. After first layer of trapezoidal stranded over the fiber core and gone through the first die set, it fed to the second stranding cage. Second layer that consist of 12 trapezoidal wires stranded over the first layer of the conductor and fed through the second die set to produces a complete conductor. The length counter measures the lengths of the completed conductor by a wheel form. The capstan pulls the completed conductor with a certain tension and twisted at a predetermined angle to prevent the displacement of the conductor. Finally the conductor pulled by the drum take up and rolled the complete conductor in to a drum. The drum take up is equipped with a traverse device to achieve winding alignment. In addition to the in-process inspection, electrical & non-electrical test are performed on the completed products before final packaging and delivery.

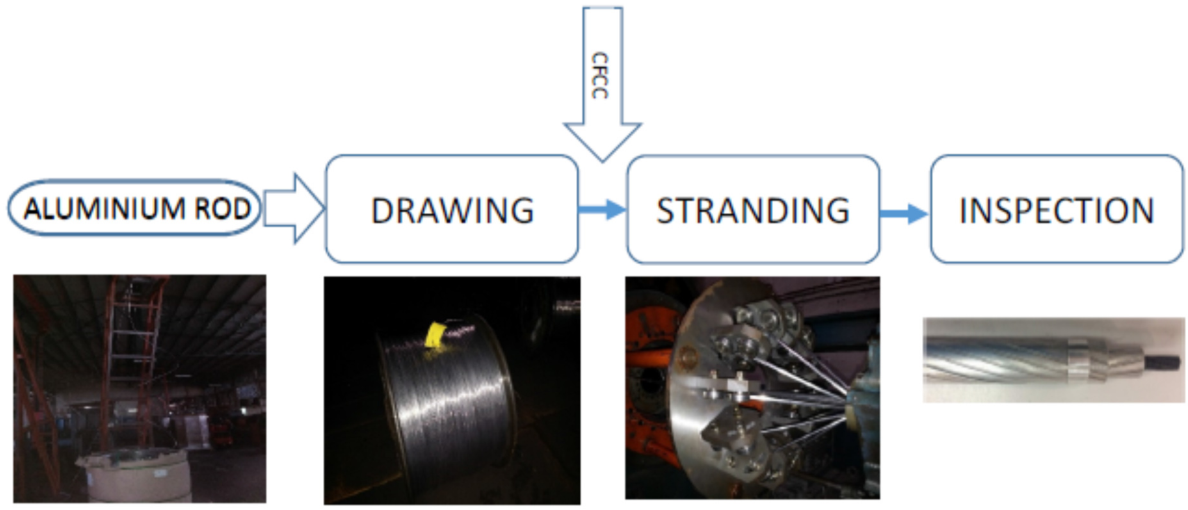

Figure 3. ACFR HTLS Conductor Manufacturing Process

2.3 CHARACTERISTIC ADVANTAGES

2.31 Larger Transmission Capacity - Double Ampacity:

The selection of materials for transmission conductor design depends on the combination of both conductor and its core electrical and mechanical attributes. ACSR conductor is made of aluminium alloy to achieve higher tensile strength. For that, stranded galvanised steel wire core is sufficient for ACSR conductor to comply certain limit of conductor sagging to maintain the clearance between the conductor and earth at certain high temperature. Aluminium alloy conductor however has lower current carrying capacity due to high resistance caused by impurities of aluminium. Operating at higher current will increase the conductor temperature. Operating ACSR that having aluminium alloy as its conductor beyond its normal operating temperature of between 70ºc to 90ºc will start to anneal the aluminium to become soften. The annealing will deteriorates the tensile strength and potentially could cause the conductor to break especially under high wind condition. Thus, the normal operating temperature for ACSR is usually limited to 75ºc to avoid the problem which eventually will also limit the current carrying capacity. It is vice versa to limit the current carrying capacity to avoid the increase of conductor temperature beyond its normal operating temperature that could cause conductor breakage. The objective of reconductoring is to increase up to double the transmission line ampacity using the same existing towers while complying the conductor sagging limitation. This could be achieved by replacing the conventional ACSR conductor with ACFR HTLS conductor. HTLS uses trapezoidal shape conductor of soften aluminium also known as annealed or 'O' temper aluminium. The conductivity of annealed aluminium is higher than aluminium alloy conductor. It is clearly more efficient in transmitting power. On top of that, operating HTLS conductor that uses annealed aluminium at higher temperature virtually resulted no further effect on the aluminium's tensile strength. As HTLS conductor depends on the CFCC as the tensile strength member would able to sustain higher operating temperature, eventually it increase its capability to transmit more current. Unlike ACSR, predictable installation parameters could be determined for HTLS when taking into account of sagging and tension performance at higher temperature. On the other hand, though it is known that the tensile strength of ACSR's aluminium alloy conductor is approximately three times more compared to HTLS's annealed aluminium conductor, ACFR HTLS annealed aluminium conductor is supported by higher tensile and strength core of stranded Carbon Fiber Composite Cable (CFCC). Table 1 shows the comparison between ACSR Batang and ACFR HTLS Hen conductor construction and capabilities.

Table 1. Comparison between ACSR Batang and ACFR Hen of Construction and Capabilities

Item	Characteristic	Unit	ACSR Batang	ACFR HEN
				7.8φ core Annealed
Aluminium	Material	-	Hard-drawn Aluminum	Annealed Aluminum
	Construction	No./mm	18/4.78	8/(4.6), 12/(4.6)
	Shape of Aluminum	-	Round	Trapezoid
	Area	mm2	323.0	332.4
	Weight	kg/m	0.889	0.916
Core	Material	-	Galvanised steel wire	CFCC
	Construction	No./mm	7/1.68	7/2.6
Overall	Area	mm2	338.5	369.6
	Diameter	mm	24.16	22.42
	Weight	kg/m	1.014	0.977
	*Rated Breaking Load	kN	69.7	93.7
	Calculated DC resistant at 20°C	Ohm/km	0.0892	0.0836
** Current Capacity	Continuous	A	617	1235
			(at 75°C)	(at 180°C)
	Emergency	A	N/A	1308
			(at 200°C)	(at 200°C)
***Sagging @ span of 300m				
- 32 degC Still Air (Sag)		m	7.19	6.96
(Tension)		kN	15.49	15.49
			(at 32°C)	(at 32°C)
- 75 degC Still Air (Sag)		m	8.89	8.45
			(at 75°C)	(at 75°C)
- 90 degC Still Air (Sag)		m	9.43	8.78
			(at 90°C)	(at 90°C)

2.311 Higher Maximum Operating Temperature

The maximum operating temperature for conventional ACSR is 70ºc to 90ºc. On the other hand, HTLS conductor uses high thermal resistance EC grade annealed aluminium wires that could withstand temperature up to 180ºc. If compare to ACSR, HTLS could endure double the maximum operating temperature. Hence, HTLS conductor could transmit virtually double the ampacity having this higher thermal limit of conductor on top of another two following factors of lower conductor resistance and larger conductor cross sectional area that contributes to higher current carrying capacity.

2.312 Large Conductor Cross Sectional Area

HTLS with its trapezoidal conductor shape has a larger area compared to stranded round wires of ACSR conductor. HTLS's trapezoidal-shaped annealed aluminium conductor made by stranding pre-shaped annealed aluminium wires into wedges-like to fit tightly to each other and reduce the gap between strands and maximised the conductor cross sectional area. Unlike ASCR conductor that uses aluminium alloy round wires that stranded in typical round shape, the conductor left with significant interstice between aluminium wires. This reflect to higher conductivity for HTLS conductor and contributes to higher current carrying capacity.

2.313 Lower Transmission Loss

The transmission loss expected from HTLS is 27% less than that of similarly sized ACSR because of the increased content of pure aluminium, effectively zero magnetic loss and high electrical conductivity.

2.32 Low Sag:

2.321 Light Weight, High Strength & High Tensile Fatigue

The second important characteristic for HTLS conductor is its low sag attribute. Sagging is a very important parameter to be considered in network design as it is related to safety concerns. Sagging aspect is the clearance of the conductor to the ground is an intrinsic property requirement of the overhead conductor. Hence, correct selection of material and design to be used as the tensile member in the conductor would be the ultimate requirement. ACSR has a stranded steel wire material for its core but HTLS uses lighter and higher strength carbon fiber composite instead. This advantages enhance in ACFR HTLS conductor as the core uses Carbon Fiber Composite Cable (CFCC) which consist of 7 stranded carbon fiber composite wires instead of one single solid carbon fiber for its core. Table 1 shows the comparison of conductor sagging between ACSR Batang and ACFR HTLS Hen at 32ºC, 75ºC and 90ºC where ACFR HTLS Hen sagging reading are the lowest for all set temperature. Table 2 shows the properties comparison between CFCC core and Galvanised Steel Wire core. Table 2 shows the comparison between CFCC core for ACFR HTLS and Galvanised Steel Wire Core for ACSR construction and performance.

Table 2. Comparison between CFCC core for ACFR HTLS and Galvanised Steel Wire Core for ACSR

Properties	CFCC	Galvanised Steel (IEC)
Construction (No./mm)	7/3.2	7/3.2
Type	CFCC	Regular
Diameter (mm)	9.6	9.6
Cross sectional area (Sq.mm)	56.27	56.27
Ultimate Tensile Load (kN)	121	69
Weight (kg/km)	93	441
Thermal expansion ($x10^{-6}$ per ºC)	1	11.5

2.322 Low Linear Expansion

Another ACFR HTLS attribute that contribute to its low sag characteristic is its lower density and low coefficient of thermal expansion (CTE). Compared to galvanised steel wire core of ACSR, CFCC core for ACFR HTLS has only one-tenth the thermal expansion coefficient with only one-fifth the weight but higher tensile strength.

2.323 Low Creep Elongation

HTLS has a low tendency to deform though exposed to a long-term high levels of stress. Figure 2 shows the result of Creep Test for Type Test on ACFR HTLS 320mm² Hen ACFR/TW HEN Conductor conducted at

Kinectrics Lab, Canada, a log-log plot of conductor strain versus elapsed time. The long-term tensile creep of a conductor under constant tension is taken to be the permanent strain occurring between one (1) hour and the specified test time. The specified test time for the Creep Test was 1,000 hours. This trend-line was then extrapolated to ten(10) years (87,600 hours). The equation of the line is:

Strain = A x (Hours)B
where A = Y- Intercept = 1.2069E-02 %
B = Slope = 0.19650
The initial creep value (defined at 1 hour) using the fitted line is:
(Strain at 1 hr) = 1.207E-02 %
The creep during the test using the fitted line is:
(Strain at 1000 hr) - (Strain at 1 hr) = 4.690E-02 - 1.207E-02 = 3.483E-02 %
The 10-year (87,600 hrs) creep using the fitted line is:
(Strain at 87,600 hr) - (Strain at 1 hr) = 1.129E-01 - 1.207E-02 = 1.009E-01 %

The calculated creep after ten (10) years (87,600 hours) is 0.1009 % or 1009 mm/km.

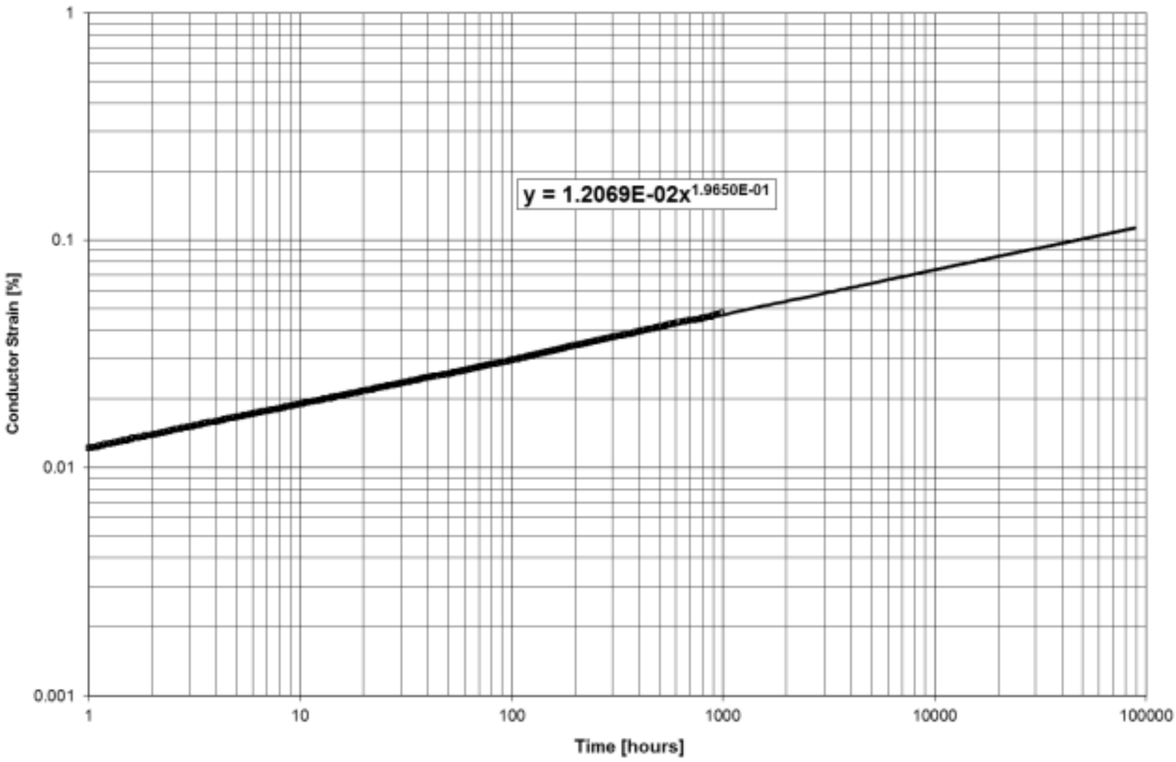

Figure3. Conductor Strain versus Time

2.33 High Corrosion Resistance

HTLS Conductor core is made from carbon composite fiber that has high corrosion resistance compare to galvanised steel wire core for the conventional ACSR. Although the steel core is galvanized to prevent corrosion, the conductor is subject to degradation. When the conductor is penetrated by a contaminant, it causes corrosion of the galvanizing, and then exposes the steel strands to form a galvanic couple with the aluminum. The aluminum begins to degrade rapidly, reducing its current carrying capability and eventually leading to the mechanical failure of the conductor. Atmospheric conditions also affect corrosion on the steel strands and in severe cases, the deterioration in the steel core strands performance will lead to strand breakage and line failure. Over time, the steel strands core that support the mechanical load of the transmission line also can cause permanent elongation and reduce the mechanical performance of the lines. With stranded CFCC core for ACFR HTLS conductor, this potential failure could be highly reduced. Table 4 and 5 show the result of Tensile Strength Test after Salt-Spray Exposure for Type Test on ACFR HTLS 320mm² Hen ACFR/TW HEN Conductor conducted at Kinectrics Lab, Canada. The measured tensile strength of the stranded CFCC core and aluminum wire samples should not be less than 95% of RTS after completing the 1,000 hour salt spray exposure.

Table 4. Mass of Samples during Salt Spray Test

Sample ID	Mass prior to Salt Spray (g)	Mass after Salt Spray (g)	Net Change (g)
1	879.61	882.16	2.55
2	872.60	874.80	2.20
3	858.13	860.12	1.99

Table 5. Tensile Strength Test Results after Salt-Spray Exposure

Test Result after 1,000 hour Exposure	Sample ID		
	Sample #1	Sample #2	Sample #3
Average Tensile Strength of Aluminum Wires (Outer Layer)	67.37 MPa	67.48 MPa	68.01 MPa
Average Tensile Strength of Aluminum Wires (Inner Layer)	67.59 MPa	67.68 MPa	67.88 MPa
Tensile Strength of CFCC Core	93.59 kN (120.1% RTS)	93.85 kN (120.5% RTS)	98.77 kN (126.8% RTS)

2.34 High Flexibility

ACFR HTLS conductor with a stranded carbon fibres core is highly flexible so that it can be wound around a smaller drum for easy packaging, transporting and handling. It has high bending angle with smaller diameter of stringing sheave which contributes to less number of stringing works. Table 3 shows the result of Sheave Test for Type Test on ACFR HTLS 320mm² Hen ACFR/TW HEN Conductor conducted at Kinectrics Lab, Canada.

Table 3. Diameter Measurements during Sheave Test

Cycle Number	Conductor Diameter [mm]						Deflection Angle
	North end		Center		South end		
	Max	Min	Max	Min	Max	Min	Degrees
Before 1st pass	22.35	22.2	22.62	22.13	22.49	22.32	30.4
After 2 passes	22.59	22.08	22.56	22.12	22.41	22.08	
After 14 passes	23.01	22.5	23.03	22.45	22.91	22.34	
After 30 passes	23.33	22.59	23.3	22.65	23.32	22.64	

2.35 Low Differential Ohmic Loss & Reduction of Cost

HTLS conductor has a low differential ohmic loss when in operation. This contributed by low resistance of the annealed aluminium conductor even at double the ampacity compare to ACSR. The usage of non-magnetic stranded Carbon Fiber Composite Cable (CFCC) core in ACFR HTLS conductor instead of galvanised steel wire core in the conventional ACSR also further reduce the differential ohmic loss. The reduction of differential ohmic lost value could be added and justified as a cost saving projection in a long run to the total overall project and operating cost. This is on top of cost saving on eliminating or reducing the requirement of new towers, right of way process and manpower by using ACFR HTLS conductor for reconductoring.

3.CONCLUSION

HTLS conductor has many advantages and is the best choice for power transmission overhead lines be it on new overhead system network or specially when involving reconductoring activities. HTLS offer double the ampacity through it trapezoidal annealed aluminium conductor design that could sustain virtually double the maximum operating temperature of the same size of the conventional ACSR conductor. On top of that, HTLS is having larger conductor cross sectional area and eventually lower transmission loss. HTLS low sag characteristic enhance through the design of ACFR HTLS conductor that uses stranded Carbon Fiber Composite Cable (CFCC) for its core. It is lighter, lower thermal expansion, high strength but in fact more flexible than the single carbon composite core. Thus, by using ACFR HTLS conductor for reconductoring, the objective of obtaining double ampacity in power transmission overhead lines by using existing power transmission line towers while maintaining the same good ground clearance is achievable.

4. RECOMMENDATION

We highly recommend the usage of HTLS conductor especially the ACFR HTLS conductor with stranded Carbon Fiber Composite Cable (CFCC) core that has more advance characteristics for reconductoring existing transmission lines or even for erecting new grid projects. The high technology of stranded Carbon Fiber Composite Cable (CFCC) core contributes for the ACFR HTLS conductor to have superior long term performance, cost effective, durability and reliability to accommodate double ampacity for transmission lines compare to conventional ACSR conductor. ACFR HTLS conductor also contributes to project cost reduction and fast completion through its attributes that make the usage of existing towers possible. In due course, it minimizes the cost from right of way matters and avoid the negative impact on natural environment. As for erecting new transmission lines, with the high ampacity and low sag capabilities, ACFR HTLS conductor is greatly relevant for decades in term of current carrying capacity and mechanical reliability.

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