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Revamped High Ampacity Low Sag Stranded Carbon Fiber Composite Core – Aluminium Conductor Fiber Reinforced Conductor (ACFR)

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SUMMARY

Globally ACSR and AAAC conductors are commonly used as overhead conductors for energy delivery application. High density transmission corridors are the need of energy utilities to optimise the right of way. So the use of High Ampacity Low Sag conductors (HALS) has been increased to address the increasing congestions in the existing transmission network. There are several types of HALS conductor technology are tested and deployed by all major global power transmission utilities. The selection of suitable HALS technology considering the requirements with respect to increase in power transfer capacity, exiting ground clearance, existing tower loadings and cost of capital investment is not only the deciding factor but also the operational efficiency (ohmic losses) over a period of its life time and installation of those conductors in the existing terrain are the major parameters needs to be considered for the right technology adoption.

Now a day, the carbon fiber composite core conductor technology has been preferred by the utilities among the HALS conductor technology because of high strength to weight ratio, lower thermal expansion and no creep (almost zero creep). The popular composite core technology are mostly a single core or several number of single wires bunched together. But the challenges of this popular carbon fiber composite core conductor technology is flexibility, which needs careful handling and care needs to be taken during installation. After several years of research to address the challenges in the carbon fiber composite technology we developed a technology to strand the carbon fiber composite material to form a stranded carbon fiber composite core (just like stranded steel core used in ACSR conductors) to make it flexible and easy to handle during installation. This paper describes about the development, testing, deployment and applications of the revamped carbon fiber composite core conductor technology named as Aluminium Conductor Fiber Reinforced Conductor (ACFR)

KEYWORDS

HTLS Conductor, Carbon fiber composite core, ACFR, Reconductoring transmission line, Carbon composite core conductor, High ampacity conductor, High performance conductor

1. INTRODUCTION

The research and development to strand the carbon fiber composite material to make it more flexible started in the year 1980’s . The stranded carbon fiber composite material is named as Carbon Fiber Composite Cable (CFCC).The CFCC was first tested for civil construction application mainly focusing to replace the steel reinforcement with CFCC to enhance corrosion resistance. The first deployment of CFCC for civil construction application was PC bridge project in Japan in the year 1986. In the year 2002 the CFCC was used instead of steel core in the overhead conductor application, the new conductor with carbon fiber composite core named ACFR was introduced, tested and deployed in one of the transmission line project in Japan. The ACFR conductor was analysed to be the best fit for overhead line which doesn’t have magnetic effect in the AC resistance (where as steel core has its magnetic effect in the AC resistance), light weight, high strength, low thermal expansion and increase in corrosion resistance.

The ACFR conductor construction is as simple as ACSR conductor where the stranded steel core is replaced with stranded carbon fiber composite core. The outer conductive layer is a either a EC grade hard drawn aluminium wires used in ACSR conductor or thermal resistance aluminium wires of either of Al-Zr alloy (Thermal resistance aluminium alloy) or EC grade thermal resistance annealed aluminium wires. The selection of outer conductive layer depends on application and the preference of the energy delivery utilities. The annealed aluminium wires having little higher electrical conductivity than the hard-drawn aluminium wires used in ACSR conductors, but annealed aluminium wires are softer and are more prone to abrasive resistance and needs more care during installation. Thermal resistance aluminium alloy (Al-Zr) having marginally lesser or equal conductivity as that of hard drawn aluminium wire and easy to handle as that of hard drawn aluminium wires used in ACSR conductor. The conductive layer of ACFR can be of round wire or shaped wire (Trapezoidal, Z Shape etc) to increase the conductive area. The trapezoidal wire shaped construction of ACFR conductor is shown in the Figure -1

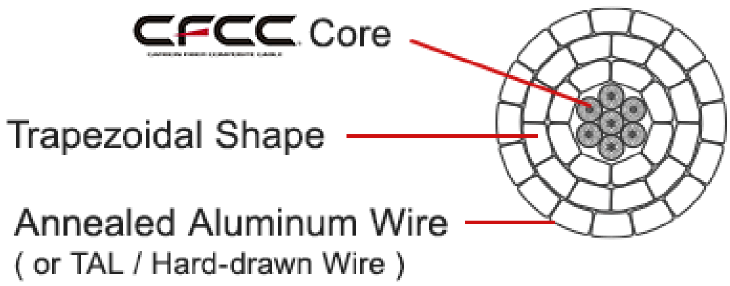

Figure-1 Construction of ACFR conductor

2. CFCC CORE

The raw material carbon fiber and epoxy resin matrix are bunched together to form a composite wire and are coated with organic layer act as galvanic protection and thus formed single carbon fiber composite wires are stranded together to form a stranded Carbon Fiber Composite Cable (CFCC). The single strand size can be chosen to match the final CFCC diameter suitable for ACFR conductor that replaces the existing conventional 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 address the challenge of flexibility and handling issues in the single strand carbon fiber composite core. The table-1 compares the steel core and CFCC properties

Table–I Compression of CFCC and Steel core used in ACSR conductor

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 ^{o}C)	1	11.5

3. ACFR CONDUCTOR

The maximum continuous operating temperature of ACSR conductor is between 70^{o}c to 90^{o}c. The limit of maximum operating temperature is considering the loss of strength of EC grade hard drawn aluminium wires. So the current carrying capacity of ACSR is limited because of joules effect. The sag of ACSR is higher because of higher steel weight and higher thermal expansion of steel.

The ACFR conductor uses high thermal resistance aluminium alloy or high thermal resistance EC grade annealed wires, so the maximum operating temperature of ACFR is 180^{o}c. The maximum operating temperature of ACFR is restricted considering the resin matrix used in CFCC. The sag of ACFR is lesser than the ACSR from the installation temperature and up to maximum operating temperature (after knee point the core will take the entire mechanical load and thus the conductor mechanical characteristic behave similar to core after knee point).

The comparison of ACSR and ACFR conductor for a 132 kv transmission line is shown in the Table-II.

Table-II Comparison of ACSR and ACFR for 132 kv transmission line

Properties	ACSR Panther	ACFR Himalaya
Construction (No./mm)		
Conductor Diameter (mm)	21	21
Core Diameter (mm)	9	7.8
Cross sectional area (mm2)	261	312
Ultimate Tensile Load (kN)	89.7	95.3
Weight (kg/km)	974	820
DC Resistance at 20 ^{o}c (ohm/km)	0.1390	0.1018
Current Carrying Capacity (Amperes) (Ambient 45^{o}c)		
Operating temperature – 75^{o}C	366	464
Operating temperature – 85^{o}C	466	537
Operating temperature – 180^{o}C	--	1061
Sag and Tension for 320-meter span		
Tension at 32 ^{o}C Full wind (52 kg/mm2) Kg	3324	2739
Sag at 75^{o}C and Nil Wind	6.90	5.99
Sag at 85^{o}C and Nil Wind	7.09	6.39
Sag at 180^{o}C and Nil Wind		6.66

The ACFR conductor is not only chosen for enhancing the power transfer capacity of the exiting transmission lines by replacing the existing ACSR conductor with ACFR conductor.

ACFR conductor has lesser AC resistance when compared to ACSR conductor, so it can be deployed in new power transmission line to reduce the ohmic losses and thus reduce the carbon foot print

4. TESTING

In the recent days CFCC and ACFR conductor has been tested for Design test, Installation test and In-service test and the outcome of each test is discussed in detailed

4.1 STRESS STRAIN TEST

Stress Strain test on ACFR 315 mm2 was performed to room temperature and the data was collected to support for the calculations of sag tension.

The procedure two stress strain tests were conducted, first test was conducted on ACFR conductor and the other test was on the CFCC. Practically it is not possible to perform the test on the conductive layer annealed aluminium. So the stress strain characteristic of aluminium is developed by subtraction CFCC core stress from the total ACFR conductor stress at common strain.

The results from the stress strain data were used to obtain the fourth quadrant polynomials and are used to compute the sag tension results using PLS CADD software.

4.2 CREEP TEST

The creep test was performed holding the ACFR 315 mm2 at constant tension for 1000 hours. To obtain a perfect fourth quadrant polynomial, the creep tests were performed at different constant tension levels from 15% to 30% of RTS of the ACFR 315 mm2.

The strain due to creep will lead to increase in sag over a period of time, so the final sag needs to be considered including creep strain.

It is observed from the test that ACFR conductor exhibits creep because of the conductive layer and carbon composite core has almost zero creep. So the creep behaviour of aluminium has been considered by the separation from the stress strain data.

4.3 SHEAVE TEST

The objective of the test is to observe the mechanical performance of ACFR 320 Sq.mm conductor when subjected to simulated action of being pulled over a sheaves during installation. This test is to show the conductor is robust for installation over stringing pulleys.
The ACFR 320 Sq.mm conductor was tensioned to 15% of the conductors RTS, the conductor is passed 30 times over a pulley of diameter 20 times the diameter of the conductor, After completion of the sheave test the ACFR conductor was subjected to an ultimate tensile test.

The ACFR conductor reached 128% of the conductor RTS as against the minimum requirement of 95% of the conductor RTS. Furthermore the conductor doesn’t have any broken strands or fretting on completion of the sheave test.

4.4 BENDING TEST ON CFCC

Bending test on CFCC diameter of 7.8 mm was performed to find the mechanical performance of the CFCC when subjected to combined bending and tensile stress.

CFCC sample was passed through the bending mandrel of diameter not higher than 50 times of the core diameter and the sample was tensioned to 15% of the RTS of CFCC Core and kept for one minute and 30% RTS of CFCC core for 2 minutes. The UTS test was performed after bending test to find out the remaining tensile strength of CFCC, dye penetration test was also performed to find any cracks on the CFCC sample

CFCC core attained 125% of the RTS of core against the requirement of 95% of the RTS of the core. In the die penetration, CFCC has not shown any kind of cracks or flaws.

4.5 HIGH TEMPERATURE TENSILE TEST ON CFCC

The purpose of the test is to measure the tensile stress of CFCC core at the short term emergency operating temperature of 200^{o}c.

The CFCC core was heated to 200^{o}c, the sample was allowed to reach thermal equilibrium before the tensile test, once the temperature is stabilised the CFCC was tensioned until failure to determine its tensile strength.

The CFCC broke at 104% of the RTS of CFCC core against the requirement of 95% of the RTS of CFCC.

4.6 SALT SPRAY TEST

ACFR 320 Sq.mm conductor was performed for salt spray test to investigate the effect of ACFR conductor under a controlled salt atmosphere. The salt atmosphere is considered typically the most corrosive environment the conductor will experience.

Samples of ACFR 320 Sq.mm were placed on the slat spray chamber the PH of the solution was maintained between 6.68 to 7.04 at 25^{o}c through out the test. The mass of the each sample was measured prior to the test. The test was performed as per ASTM B117 for 1000 hours

The mass of each sample was measured after completion of the test and it was recorded to find the loss of cross sectional area. After completion of test aluminium wires and CFCC were tensile tested to find the loss of strength due to corrosive atmosphere.

There was no significant signs of pitting, corrosion or detoriation noted on aluminium wires as well on CFCC

4.7 HEAT STRESS TEST ON CFCC

The CFCC core size of 7.8mm was performed for heat stress test to verify the mechanical performance of CFCC when exposed to combined mechanical and thermal stresses at its short term emergency operating temperature of 200^{o}c.

CFCC core was heated to 200^{o}c and allowed for thermal equilibrium, the tensile load of 25% of RTS of core was applied to CFCC core and held for 1000 hrs. After completion of 1000 hrs the sample was tested for tensile load.

The CFCC attained 120% of RTS of core against the requirement of 95% of the RTS of the core. No damage, cracks or breaks were observed on the CFCC sample.

4.8 THERMAL AGING TEST ON CFCC

CFCC size of 7.8 mm was performed for thermal aging test to find the loss of strength of CFCC while exposed to continuous operating temperature for long time.

CFCC sample was placed in the inside the tube furnace and temperature was raised to 180^{o}c after attained the thermal equilibrium, the sample was exposed to 8736 hours (52 weeks). The samples were collected at an interval of 400, 1500, 2500, 5000 and 8736 hours. After completion of 52 weeks the sample was tensile tested

CFCC tensile value achieved was 116% RTS as against the requirement of 95% of the RTS. From the collected data and using logarithmic formula CFCC will degrade its UTS to 95% of RTS after 15 million years of service

5. TESTS AND RESULTS

ACFR Conductor and CFCC core samples were tested for all the needed relevant test as per the test requirement specified in international standards and guidelines for High Temperature Low Sag conductors the test results shows that the ACFR and CFCC core exceeds the expectations of the acceptance criteria required for all the tests.

From the test results, ACFR conductor is proved to be robust in design, installation and in-service operation

6. HARDWARE

The important hardware fitting is tension clamp and mid span joint, because for any composite core overhead conductors the challenge is to hold the composite core. The remaining other hardware and accessories can be designed considering other HALS type conductor

6.1 TENSION CLAMP

The tension clamp of ACFR is same as ACSR conductor. ACFR tension clamps are compression type as like ACSR. It has major three components composite core compression unit, Aluminium tube as a buffer and Outer aluminium compression unit. The aluminium buffer is used to reduce the crushing of composite core during compression of the core potion. Figure 2 and Figure 3 shows the components of tension clamp for ACSR and ACFR conductor respectively

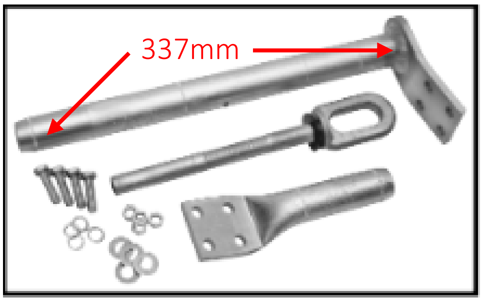

Figure 2 ACSR Tension Clamp

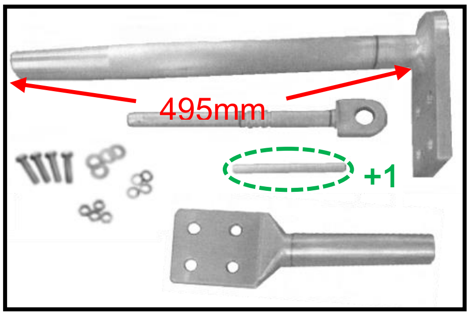

Figure 3 ACFR Tension Clamp

The tension clamp of ACFR is little longer than the ACSR conductor which supports secured current density and grip strength.

6.2 MIDSPAN COMPRESSION JOINT (MSCJ)

Figure 4 and Figure 5 shows the diagram and component of ACSR MSCJ and ACFR MSCJ respectively

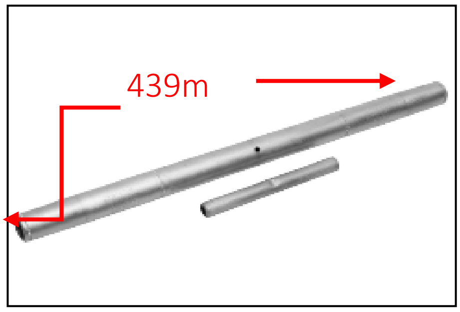

Figure 4 ACSR MSCJ

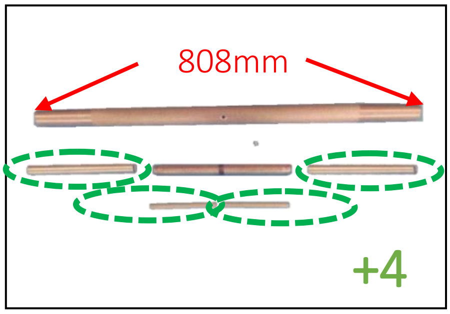

Figure 5 ACFR MSCJ

7. INSTALLATION

ACFR uses a stranded carbon fiber composite core CFCC, so ACFR conductor is more flexible. Thanks to the flexibility of ACFR, the installation method of ACFR is similar to ACSR. The tolls and tackles used for ACFR is same as that of ACSR. So the stringing method as conventional as ACSR.

The Table – 3 shows the requirement for ACSR and ACFR during installation, It should be noted that if ACFR uses outer conductive layer as annealed aluminium then the only exception is recommended pulling angle is 60 degrees considering annealed aluminium may get loose and bird cage may occur.

Table 3 Installation Requirement for ACSR and ACFR

Description	ACSR	ACFR	
Outer Conductive Layer	HAL	Annealed Al	TAL
Bull Wheels	40 X D	40 X D	
Sheave Wheels	20 x D	20 X D	
Recommended pulling angle	60 degrees	45 degrees	60 degrees
Dead End Installation time	15 minutes	15 minutes	
MSCJ Installation time	30 minutes	30 minutes	

D – Diameter of Conductor

8. Conclusion

ACFR conductor has the following advantages and the best choice for power transmission overhead lines.

8.1 Stranded Carbon Fiber Composite Cable (CFCC) is having lesser weight. High strength and lower thermal expansion

8.2 CFCC is more flexible than the single carbon composite core

8.3 Aluminium Conductor Fiber Reinforce (ACFR) can be produced by any one of thermal resistance alloy wire, annealed aluminium wire or hard drawn aluminium wire.

8.4 The outer conductive layer used in ACFR conductor can be produced by either round wire or shaped wire depends on application need.

8.5 ACFR is the best choice for reconductoring line to increase the transmission capacity by more than 2 times of the existing capacity without any reinforcement of tower and maintaining the same ground clearance

8.6 The new transmission line using ACFR will reduce the ohmic losses thus towards green solution for energy delivery utilities

8.7 ACFR conductor has been tested for all the test requirements considering design, installation and in-service operation

8.8 Test results exceeds the expectation and acceptance criteria specified for all the tests

8.9 The dead end clamp and midspan joint of ACFR conductor is same as that of ACSR conductor

8.10 Due to the more flexibility of ACFR conductor, the installation is same as that of ACSR conductor

8.11 Quicker installation and easy to handle than any other composite core conductor used in power transmission line

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