by Y. Ohki

Development of a Low Sag Carbon Fiber Reinforced Aluminum Conductor for Transmission Lines

The demand for electric power in the world is growing steadily, especially in China. Electric power transmission capacity must, therefore, be increased. However, construction of new transmission lines requires time and space and is costly. Towers for overhead transmission lines are expensive, compared with the cost of the cables. It follows that, if possible, the transmission capacity of overhead transmission lines should be increased without changing the tower structures.

Another problem with overhead transmission lines is the limited clearance between the transmission line and the ground, buildings, trees, etc. A heavy transmission conductor forms a catenary because of its weight. The sag increases if the conductor material has low tensile strength and a high thermal expansion coefficient. Increasing the current through an overhead line increases its temperature and its length, and thus the sag, which in turn reduces the ground–line clearance. To alleviate this problem, a new aluminum conductor for overhead transmission lines has been developed by Showa Electric Wire and Cable and Tokyo Rope Manufacturing, Japan [1]. It is called aluminum conductor fiber reinforced (ACFR). A key component of the ACFR is the unique stranded carbon fiber reinforced plastic or carbon fiber composite cable (CFCC), shown in Figure 1.

Table 1 lists some fundamental physical properties of the carbon fiber used in the CFCC, and Table 2 compares the characteristics of CFCC with those of its conventional counterpart, namely aluminum conductor steel reinforced (ACSR), each with a cross-sectional area of 160 mm^2. As listed in Table 2, CFCC has several advantages, contributing to the outstanding performance of ACFR. Compared to ACSR, CFCC has about one-fifth the weight, one-tenth the thermal expansion coefficient, and a higher tensile strength. It contains only nonmagnetic materials and, therefore, does not suffer from magnetic losses. It is highly flexible so that it can be wound around a small drum and is highly resistant to corrosion, unlike iron and steel. Last, its expected creeping deformation level at high temperatures is similar to that of iron.

Table 1. Some important physical properties of carbon fiber

Item	Fundamental physical properties	
	2002	Recent
Raw material	PAN[1] carbon fiber	PAN carbon fiber
Tensile strength (N/mm^2)	3,630	4,900
Elastic modulus (N/mm^2)	235,000	235,000
Elongation at fracture (%)	1.5	2.1

[1]PAN = polyacrylonitrile.

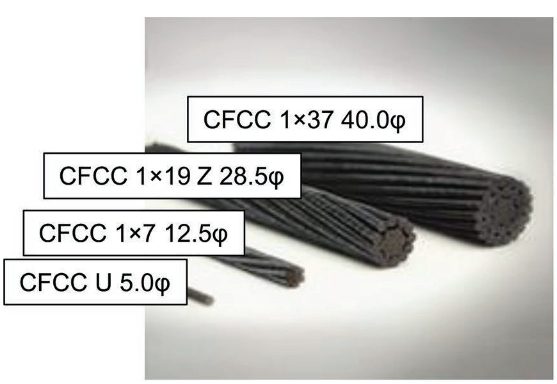

Figure 1. Carbon fiber composite cable (CFCC) component (left side). Flexible CFCC (right side). 1 × 37 40.0φ = one strand with an outer diameter of 40 mm consisting of 37 wires; U = consisting of only one wire; Z = outermost wires are stranded like a letter Z, otherwise they are stranded like a letter S.

Table 2. Comparison of various characteristics of the carbon fiber composite cable (CFCC) core of aluminum conductor fiber reinforced and the steel core of aluminum conductor steel reinforced, both with a cross-sectional area of 160 mm²		
Item	Characteristic	
	CFCC	Steel
Heat resistant grade	Normal/high temperature resistant	—
Cross section (mm^2)	37.2	37.16
Outer diameter (mm)	7.8	7.8
Unit weight (g/m)	61	291.3
Rated tensile strength (kN)	79.5	44.2
Elastic modulus (N/mm^2)	130,000	206,000
Coefficient of thermal expansion ($\times 10^{-6}$/°C)	1.0	11.5

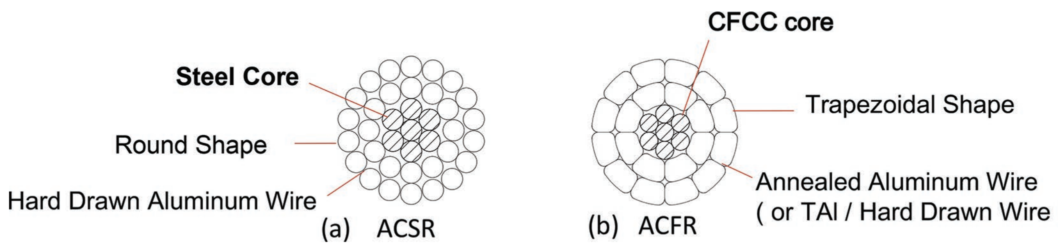

Figure 2. Cross-sectional structures of the conventional aluminum conductor steel reinforced (ACSR; a) and the developed aluminum conductor fiber reinforced (ACFR; b). CFCC = carbon fiber composite cable; TAl = thermally resistant aluminum.

Table 3. Specifications of aluminum conductor fiber reinforced (ACFR) and aluminum conductor steel reinforced (ACSR) for low-loss operation			
Conductor	Unit	ACFR	ACSR
Diameter			
Conductor	mm	28.62	28.62
Core	mm	9.6	9.54
Aluminum cross-sectional area	mm^2	542.4	428.9
Linear mass	kg/m	1.597	1.621
Tensile modulus	GPa	68.6	78.4
Thermal expansion			
Conductor	$\times 10^{-6}$/°C	18.9	19.5
Core	$\times 10^{-6}$/°C	1.0	11.5
Electrical current	A	700	700
Operation temperature	°C	67	73
AC resistance at operating temperature	Ω/km	0.0623	0.0851
Thermal sag at operating temperature	m	20.74	21.29

Table 4. Specifications of aluminum conductor fiber reinforced (ACFR) and aluminum conductor steel reinforced (ACSR) for high-capacity operation			
Conductor	**Unit**	**ACFR**	**ACSR**
Diameter			
Conductor	mm	28.62	28.62
Core	mm	12.5	9.54
Aluminum cross-sectional area	mm^2	494.5	428.9
Linear mass	kg/m	1.517	1.621
Tensile modulus	GPa	71.5	78.4
Thermal expansion			
Conductor	$\times 10^{-6}$/°C	16.9	19.5
Core	$\times 10^{-6}$/°C	1.0	11.5
Electrical current	A	1,571	729
Operation temperature	°C	175	75
AC resistance at operating temperature	Ω/km	0.0923	0.0858
Thermal sag at operating temperature	m	20.74	21.29

CFCC was developed in the 1980s. Initially, it was used for civil engineering applications such as bridge reinforcement because of its anticorrosion properties. Then, after substantial testing by a Japanese electric power utility company, CFCC was first used as the cores of ACFR conductors in 2002. In that role it has now been operating satisfactorily for 15 years.

The structures of ACFR and ACSR are compared in Figures 2 and 3. The ACFR is a composite consisting of a CFCC core and trapezoidal-shaped annealed aluminum wires. It is also available with hard drawn and heat resistant aluminum. The conventional ACSR consists of a steel core and round aluminum wires. The ACFR has lower electrical resistance than the ACSR, since the trapezoidal shape has a larger contact area than the round shape.

Figure 3. External appearance of aluminum conductor steel reinforced (ACSR) with a cross-sectional area of 160 mm^2, and aluminum conductor fiber reinforced (ACFR) with a similar diameter.

Table 3 lists the specifications of ACFR designed for low transmission loss. The lightweight CFCC core allows an increased aluminum content, at constant conductor weight. The transmission loss expected from this design is 27% less than that of similarly sized ACSR because of the increased content of aluminum, zero magnetic loss, and high electrical conductivity resulting from the use of trapezoidal-shaped annealed aluminum.

Table 4 lists the specifications of ACFR designed for high transmission capacity. Since the CFCC core has a small thermal expansion coefficient at temperatures as high as 175°C, its thermal expansion is less than that of ACSR. The transmission capacity expected from this design is more than double that of similarly sized ACSR. According to the company, this format is very popular worldwide because customers can increase transmission capacities using existing towers.

The company has been promoting the installation of ACFR lines for long-term use, as shown in Figure 4. Initially, ACFR would be installed as a low loss conductor. If the electric power demand increased significantly, the ACFR conductor could be switched to a high capacity conductor. Given further increase in power demand, an additional low loss conductor could be installed, and if appropriate, the high capacity ACFR conductor could also be replaced with the original low loss conductor to reduce energy loss.

Figure 5 shows a tension clamp used for ACFR, consisting of three components. It is very similar to those widely used for ACSRs. Since CFCC is stranded, the bendability and flexibility of ACFR are good. ACFR is therefore easily handled by such a clamp, and no special equipment is required, unlike several

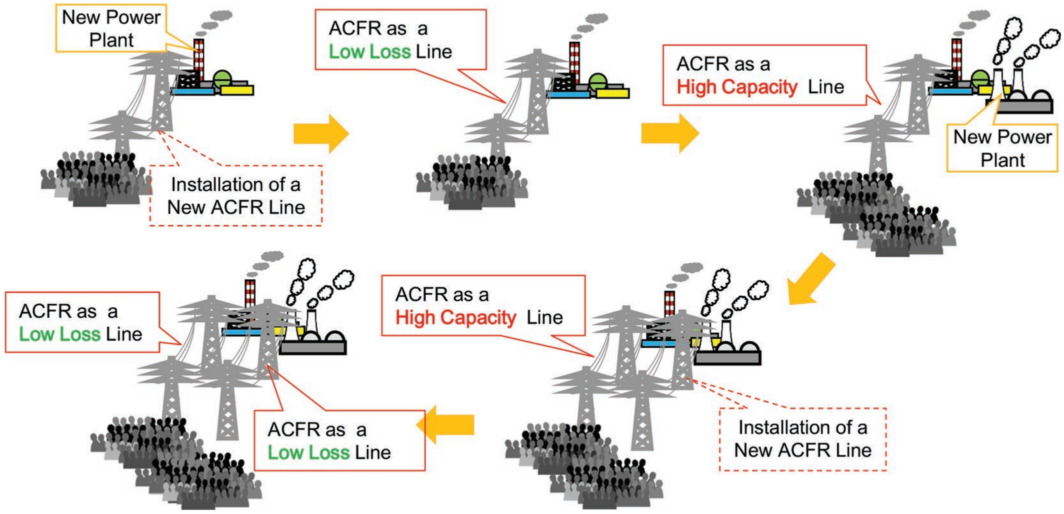

Figure 4. Installation of aluminum conductor fiber reinforced (ACFR) lines for long-term use.

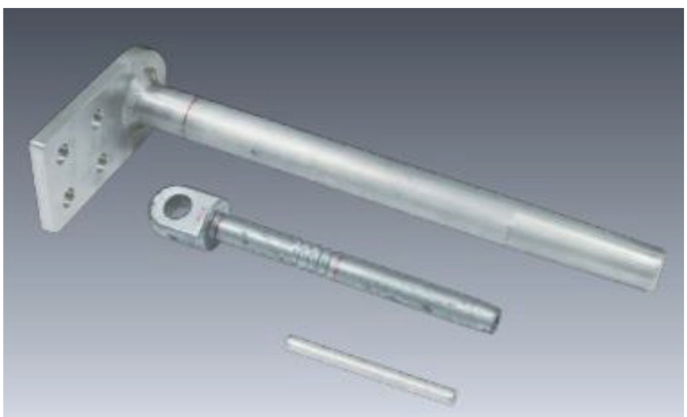

Figure 5. A tension clamp for aluminum conductor fiber reinforced.

other high capacity type conductors, e.g., carbon and glass fiber cores. This makes the installation of ACFR very easy.

Many tests have been conducted to check the performance of every component of ACFR under tensile loads, aeolian vibrations, corrosion resistance, sheave testing, and long-term thermal aging. Satisfactory results were obtained. Recently, the company has described its preferred installation procedures in many forums, e.g., CIGRE workshops, aiming to increase installation safety levels.

It is true that several pultrusion bar types of carbon-fiber-reinforced plastic cores for power transmission lines are available from other companies. However, the most important feature of the products described in this column is the stranded structure of the core. ACFR with a CFCC core is significantly more flexible and bendable than other conductors with a pultrusion-bar-type carbon-fiber-reinforced plastic core.

This article was completed with the help of Tokyo Rope Manufacturing Co. Ltd.

Reference

[1] F. Sato and H. Ebiko, *Development of a Low Sag Aluminum Conductor Carbon Fiber Reinforced for Transmission Lines*. CIGRE 22-203, 2002.