21, rue d'Artois, F-75008 PARIS
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How Aerospace Technology is Improving the Efficiency, Capacity and Reliability of the Smart Grid

D.C. BRYANT[1]
CTC Global Corporation
United States

OVERVIEW

For several decades utilities, regulators and ratepayers have all recognized the importance of having access to reliable and affordable electric power. Without it, no economy in the world can possibly flourish. Electricity is used to pump water, process food, create products, light homes and power our information based society. While the demand for electricity continues to grow and new sources of generation are being built, the de-commissioning of older power plants and increased environmental concerns are adding to the challenge and increasing project costs. To help offset many of these challenges, efforts are underway to increase the efficiency of generators, demand side appliances and, most recently, the electric grid itself where a substantial percentage of power is lost, and delivered energy costs and reliability are impacted by congested or constrained transmission lines.

Though the industry is aggressively working to improve the efficiency, capacity and reliability of the grid using several novel technologies, new technologies are generally not widely deployed until they are substantially proven and well understood. This paper will explore how extensive lab testing, field experience and a few hard-learned lessons has helped over 100 international utilities deploy more than 22,000 km of a new overhead conductor technology to more than 260 project sites in 28 countries since the product was first commercialized in 2005.

KEYWORDS

Advanced Conductors; HTLS Conductors; Smart Grid; Transmission Efficiency; ACCC

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[1] dbryant@ctcglobal.com

BACKGROUND

During the Western Energy Crisis of 2000-2001 in the United States, where deregulation set the stage for market manipulation, which, in California, due to consumer rate freezes financially strained several major utilities, Composite Technology Corporation (now CTC Global), recognized the need to develop a new bare overhead conductor that could be used to increase the capacity of existing transmission lines that were constrained due to thermal sag. Constrained transmission lines in many cases (such as Path 15) prevented utilities from accessing the least expensive sources of generation which caused prices to skyrocket by as much as 800%.[i]

CTC leveraged its composite materials expertise and developed an overhead conductor that replaced a conventional conductor's steel core with a novel carbon and glass fiber composite core. The composite core offered increased strength, reduced weight and most importantly, a coefficient of thermal expansion about one-tenth that of steel. The lower coefficient of thermal expansion allowed the new conductor to carry increased levels of current under high load conditions without experiencing excessive conductor sag that limited the current carrying capabilities of conventional conductors such as ACSR. While other high-temperature, low-sag conductors were also introduced in the 1970's 1980's and 1990's, several entities such as EPRI, Ontario Hydro, American Electric Power, China State Grid and many others began extensive laboratory testing and field trials.

LAB TESTING

While a number of industry standard tests were performed on many of the new conductors to assess electrical and mechanical performance, a number of new test protocols were also developed to assess the new conductors under high-load, high-temperature conditions. In 2005, Hydro One, for instance, devised a sag comparison test using ACSR as a basis for comparison. Hydro One selected a number of Drake size conductors, placed them in a 215 foot (65 meter) indoor test span at Kinectrics lab and applied a 1,600 amp current.[ii]

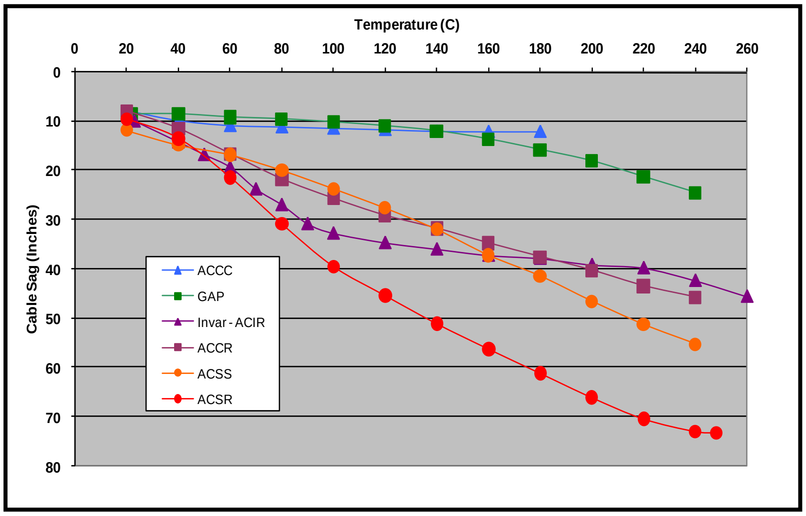
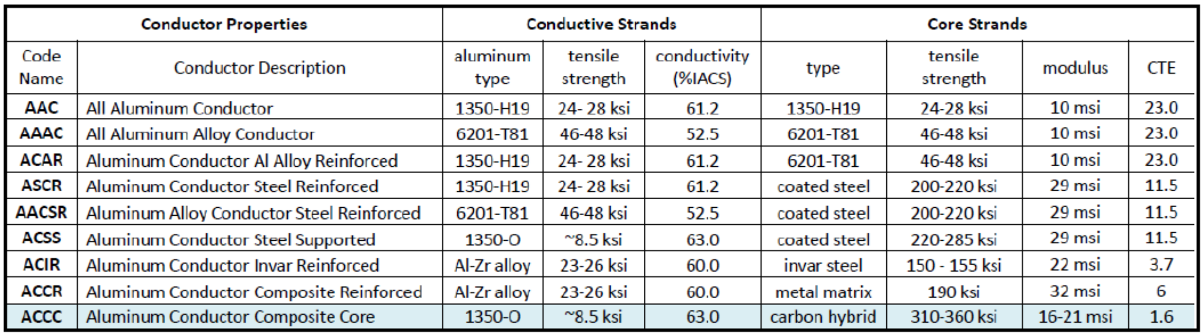


Figure 1 – Sag comparison data (Hydro One test span at Kinectrics Lab)

While Figure 1 shows the differences in thermal sag measured on the relatively short test span, it is noteworthy that in addition to decreased thermal sag the temperature of the ACCC conductor was substantially cooler due to its use of compact trapezoidal strands that increased the aluminum content by approximately 28 percent compared to the other round wire conductors tested. The ACCC conductor's composite core is about 70 percent lighter than steel which allows it to include the added aluminum content without a weight penalty that would otherwise contribute to additional conductor sag and increased mechanical loads on supporting structures. Figure 2 offers some basic electrical and mechanical comparative data of many commonly used conductor types.[iii]



Conductor Properties		Conductive Strands			Core Strands			
Code Name	Conductor Description	aluminum type	tensile strength	conductivity (%IACS)	type	tensile strength	modulus	CTE
AAC	All Aluminum Conductor	1350-H19	24- 28 ksi	61.2	1350-H19	24-28 ksi	10 msi	23.0
AAAC	All Aluminum Alloy Conductor	6201-T81	46-48 ksi	52.5	6201-T81	46-48 ksi	10 msi	23.0
ACAR	Aluminum Conductor Al Alloy Reinforced	1350-H19	24- 28 ksi	61.2	6201-T81	46-48 ksi	10 msi	23.0
ASCR	Aluminum Conductor Steel Reinforced	1350-H19	24- 28 ksi	61.2	coated steel	200-220 ksi	29 msi	11.5
AACSR	Aluminum Alloy Conductor Steel Reinforced	6201-T81	46-48 ksi	52.5	coated steel	200-220 ksi	29 msi	11.5
ACSS	Aluminum Conductor Steel Supported	1350-O	~8.5 ksi	63.0	coated steel	220-285 ksi	29 msi	11.5
ACIR	Aluminum Conductor Invar Reinforced	Al-Zr alloy	23-26 ksi	60.0	invar steel	150 - 155 ksi	22 msi	3.7
ACCR	Aluminum Conductor Composite Reinforced	Al-Zr alloy	23-26 ksi	60.0	metal matrix	190 ksi	32 msi	6
ACCC	Aluminum Conductor Composite Core	1350-O	~8.5 ksi	63.0	carbon hybrid	310-360 ksi	16-21 msi	1.6

Figure 2 – Common conductor types showing various electrical and mechanical properties

Another novel test protocol was developed by American Electric Power to assess longevity based on anticipated mechanical stresses that included bending encountered during installation, cyclic tensile loads that are a function of wind, ice and thermal loads, as well as galloping and vibration which are also functions of wind and other environmental conditions. The test protocol required that the conductors be subjected to 100,000 cycles of galloping and 100,000,000 cycles of vibration after being mounted in a test span that included a suspension clamp. While ACSR and ACSS conductors experienced strand fatigue failure, initiated by fretting, the increased surface area of the ACCC conductor's trapezoidal strands coupled with the improved self-damping of the composite core mitigated fatigue failure during this test protocol.[iv]

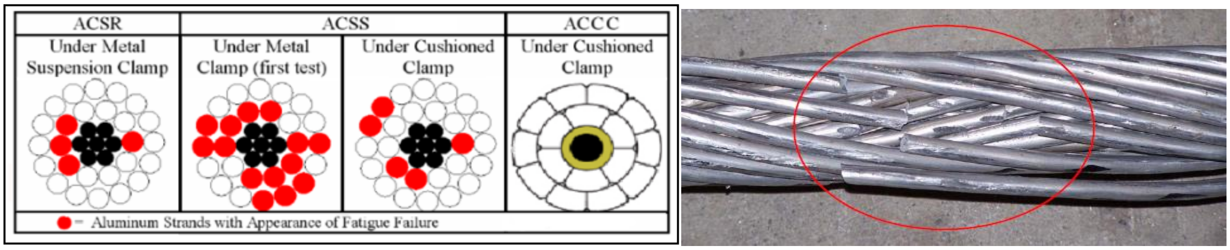


Figure 3 – Strand fatigue failure observed in AEP's Sequential Mechanical Test

While literally hundreds of tests have been performed on the ACCC conductor and several other HTLS conductor types, one of the biggest concerns about the polymer matrix ACCC conductor composite core was its resistance to thermal fatigue. To assess the ACCC conductor's upper limits EPRI and EDF developed a thermo-mechanical test which subjected the conductor to five-hundred thermal cycles along with five 24 hour holds at 70 percent of the conductor's rated tensile strength.

During the development of the new test protocol a number of test set up conditions prevented the successful completion of the initial tests. One example was that after a number of thermal cycles and cyclic tensile loads, the thermocouples that controled the test became loose which caused temperature spikes. After these and other test set up problems were resolved (a non-tensioned dummy conductor was added to the protocol) the ACCC conductor completed the tests at the 180°C and 200°C temperatures selected for the tests. After the 200°C test series was completed (in August, 2013), test specimins, which included dead-end assemblies, pulled to failure at over 110 percent RTS suggesting that the ACCC conductor could withstand this degree of exposure without a loss of performance. [v]

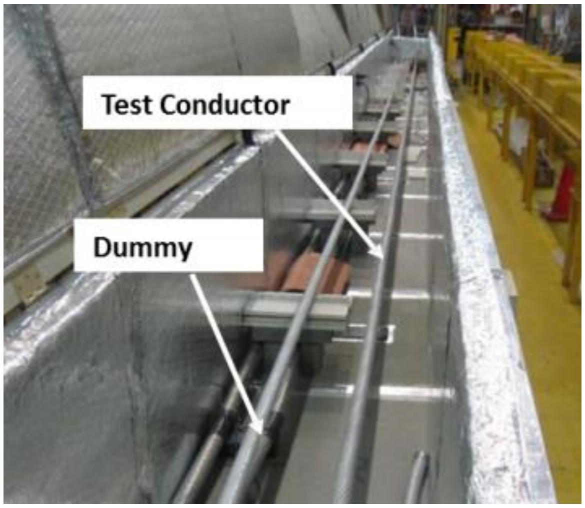


Figure 4 – Thermo-mechanical test developed by EPRI & EDF

National Grid UK also evaluated ACCC conductor prior to its initial installation in the UK. As N-1 conditions suggested that the ACCC conductor could see temperatures as high as 215°C for as many as 8 continuous hours per year over an anticipated 40 year service life, testing was conducted at USC's composite materials lab and at Kinectric's Lab in Canada. Core samples retained well over 100 percent RTS while the conductor and dead-ends tested retained 96.3 and 97.8 percent RTS.[vi]

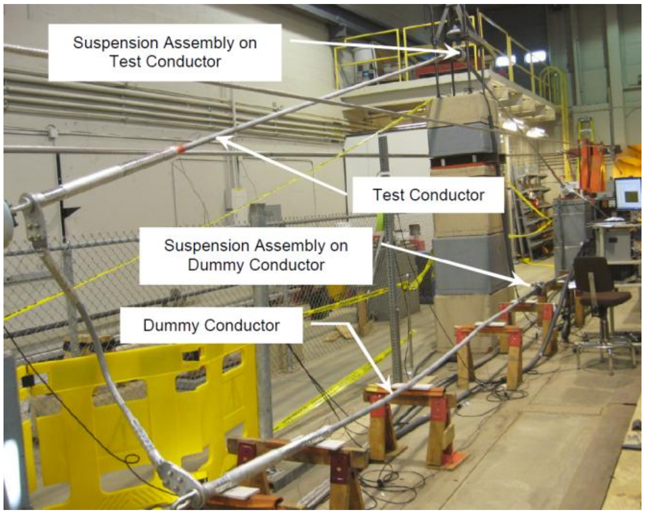


Figure 5 – National Grid UK test of ACCC conductor through a suspension clamp at 215°C

Core samples “cooked” at higher temperatures in various labs showed some surface oxidation but excellent strength retention.

Figure 6 – Composite core sample after 12 month exposure to 220°C

FIELD EXPERIENCE

While much has been learned in the lab over the last ten years, a number of field incidents have also shown the ACCC conductor’s attributes and limitations. In 2009, ACCC conductor was selected to increase the capacity of a 220 kV 100 km circuit feeding Warsaw, Poland, during a very short 30 day outage. One of the 16 crews (from 6 independent contractors) fell behind schedule. A new crew was brought in to pick up the pace. Unfortunately excessive pulling speed coupled with dozens of repair sleeves on the old conductor used to pull the new conductor in caused jerking and excessive bending that damaged the core, leading to conductor failure after the line was energized. Experiences such as these are unfortunate but do provide valuable insight as to ‘what not to do’ during installation. These experiences have helped dozens of other utilities avoid making the same mistakes.

In January, 2011, an ACCC transmission line installed by NV Energy between Reno and Carson City, Nevada, experienced a fire storm that downed several wood H-Frame structures. The very small Linnet size ACCC conductor fell to the ground. After careful inspection, it was determined that the conductor was undamaged. The wood H-frames and insulators were replaced and the conductor was lifted back into position and re-energized very quickly.

Figure 7 – ACCC conductor undamaged after support structures burned to the ground

In May, 2013, what quickly developed into an EF-5 tornado in Moore, Oklahoma ran directly across a one mile section of ACCC conductor as it ran north from a power plant.

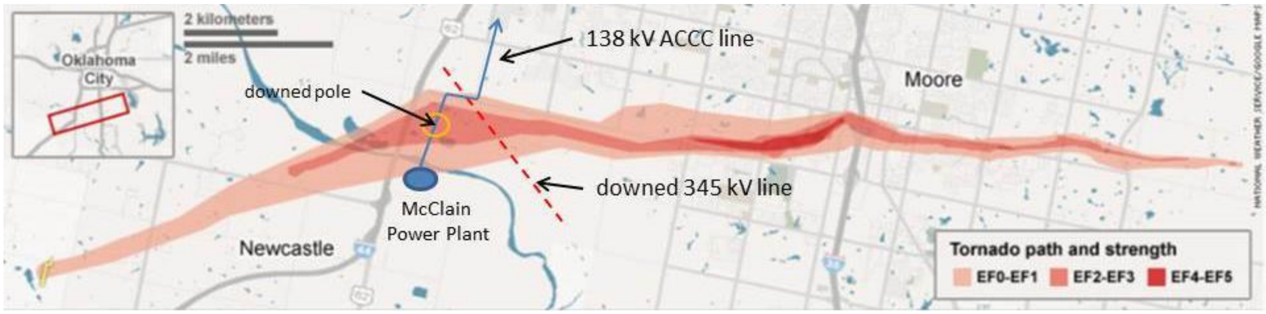


Figure 8 – Path of EF5 tornado in Moore, Oklahoma crossing 138 kV ACCC line

A 40 foot shipping container slammed into a 125 foot steel monopole as it flew over a road and several trees. After impact, the pole was bent by ~45 degrees. While the tension carried by the ACCC conductor was substantial enough to pull adjacent poles over by about 10 degrees, it probably also prevented the pole from falling completely to the ground. While the aluminum strands of the ACCC conductor in one location were completely severed, surprisingly, the composite core was intact.

Figure 9 – ACCC conductor damaged by EF5 tornado

While 30 feet of new conductor had to be spliced in to replace the damaged section, the fact that it didn’t fall completely to the ground allowed repairs to be made relatively quickly.

In another section of the line, during the same storm, a steel lattice structure that carried two overbuilt double-circuit, double-bundled lines was damaged by a flying mobile home chassis. The lattice structure was knocked over, dropping its wires onto the ACCC conductor below. The ACCC conductor did not appear to be damaged, but armor rod repair sleeves were installed over the impacted areas as a precautionary measure.

Figure 10 – downed lattice structure that dropped its double circuits lines onto an underbuilt ACCC circuit without damaging the ACCC wires

While hundreds of indoor and outdoor lab tests have been performed on ACCC and other new conductor technologies, worldwide, the experiences gained in the field have also given a number of major utilities such as American Electric Power increased confidence and the knowledge of proper installation techniques that have allowed them to utilize new technologies as needed. Currently AEP is replacing 240 circuit miles of a double-bundled 345 kV line with ACCC conductor in Texas, while the line remains energized. Experiences such as these will help utilities worldwide benefit from the shared knowledge base.

Figure 11 – AEP / Quanta live line 345 kV reconductoring project using ACCC conductor

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