EPRI



2025 White Paper

Advanced Conductors Status, Applications and Opportunities

A GET SET White Paper



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FOREWORD

What is GET SET?

Energy companies are seeking all options for increasing delivery capacity to support energy transition objectives and large demand increases from AI and manufacturing growth. EPRI's GET SET (Grid-Enhancing Technologies for a Smart Energy Transition) initiative aims to support the deployment of a subset of technologies to respond to the rapid load growth, changing generation mix, and extreme weather that energy companies are facing today. These solutions can potentially maximize the capacity of existing assets now, while working to build new capacity in the long term. For example, the differing speed of construction of new loads compared to transmission is one driver for increased grid congestion. The resultant increased electrical loading can push transmission lines to or beyond their safe operating limits. While deploying Grid-Enhancing Technologies (GETs) is seen as a potential method to increase capacity from transmission lines and satisfy load growth, deployments must also ensure system stability, asset health and public safety are maintained.

The GET SET initiative is committed to assimilating and disseminating existing GETs knowledge to support utilities in assessing and deploying GETs now, as well as leveraging those deployments and additional research to answer remaining questions and provide the tools that utilities need to evaluate and deploy more broadly.

GET SET White Paper Series

The GET SET white paper series is a collection of papers that describe four promising GETs: Dynamic Line Ratings (DLR), Advanced Conductors, Advanced Power Flow Controllers (APFC) and Transmission Topology Optimization (TTO). This white paper series aims to document the current state of the science regarding GETs, their potential applications and identify opportunities for greater research and collaboration.

INTRODUCTION

The term advanced conductors refers to conductors designed to operate at elevated temperatures (typically above 150°C). In recent years, conductor manufacturers have begun to produce new overhead line conductors that can operate at these higher temperatures while respecting critical safety considerations, such as managing sag to reduce electrical clearances to ground and other objects.

These are relatively new products developed to meet the need to increase the transmission capacity of existing corridors. Currently, all advanced conductors allow for additional current capacity by allowing for higher operating temperatures than traditional conductors. Advanced conductors, in addition to higher allowable operating temperatures, also generally exhibit lower sags for the same conductor temperature when compared to the traditional conductors. New materials have entered the transmission conductor market to enable this low-sag capability, such as carbon fiber and ceramic composites that are used in the conductor core for mechanical strength. The general evaluation of overhead conductors is shown in Figure 1.

TRADITIONAL CONDUCTORS

More than 80% of bare stranded overhead conductors used in transmission lines today consist of a combination of 1350-H19 (nearly pure aluminum, 1350, drawn to the highest temperature possible, H19) wires, stranded in one or more helical layers around a core consisting of one or more steel strands. The steel strands are coated to resist corrosion. These traditional conductors are typically rated for relatively low operating temperatures around 90°C.

The mechanical and electrical properties of traditional conductors (ACSR and all-aluminum conductor [AAC], all- aluminum alloy conductor [AAAC], and aluminum conductor alloy reinforced [ACAR]) are quite stable with time, if the temperature of the aluminum strands remains less than 100°C. Above 100°C, the work-hardened aluminum strands lose tensile strength over time at increasing rates as temperature increases. The steel core strands, however, are unaffected by operation at temperatures up to at least 300°C (although conventional hot-dip galvanizing may be damaged by prolonged exposure to temperatures above 200°C).

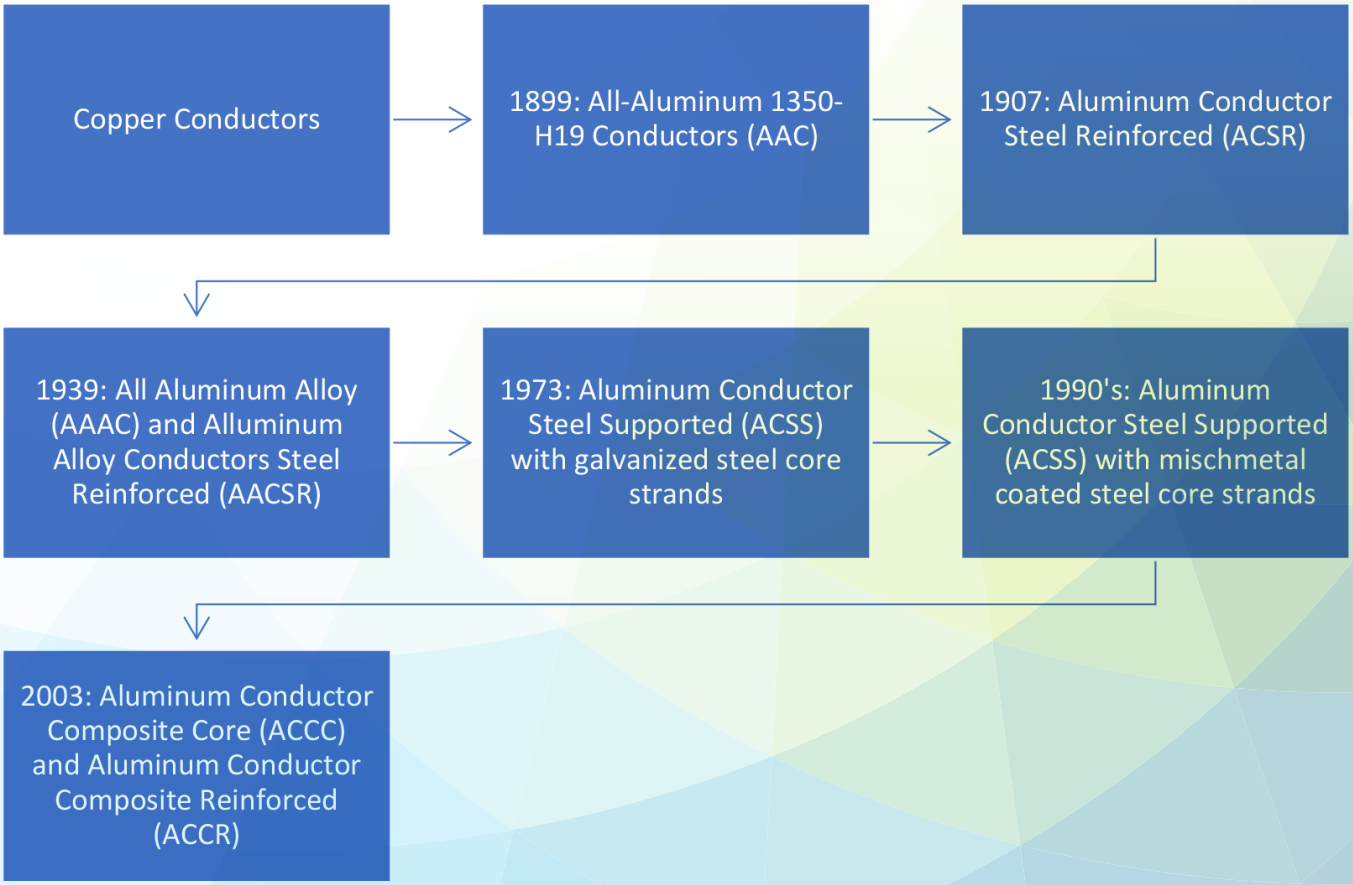


Figure 1. *Overhead conductor evolution timeline*

The sag-temperature behavior of ACSR is also dependent on the size of the steel core. At moderate to low conductor temperatures (25-70C), the thermal elongation rate of ACSR is between that of steel (11.5 micro strain per °C) and that of aluminum (23 micro strain per °C). For example, with Drake ACSR, the thermal elongation is 18.9 micro strain per °C up to a temperature of about 70°C, and it decreases to the thermal elongation rate of the steel core alone (11.5 micro strain per °C) at higher temperatures.

ADVANCED CONDUCTORS

Advanced conductors are designed to operate continuously at temperatures above 100°C without a reduction in mechanical strength. Advanced conductors generally exhibit thermal elongation rates that are less than traditional conductors. This is mainly due to advanced conductor core materials which how lower coefficients of thermal expansion, compared to traditional conductors (see in table 2.2). This characteristic allows the conductor to sag less than a conventional ACSR conductor at any temperature, especially elevated temperatures.

In addition to these properties, which are related to the maximum conductor temperature, advanced conductors can also display the following desirable properties associated with conventional transmission conductors:

- **Mechanical properties.** Low weight per unit length, high elastic modulus, and low plastic elongation under high mechanical loading so that existing lines can be reconductored with minimal structure modification yet remain mechanically dependable.
- **Chemical properties**. Resistant to corrosion over a lifetime of 40 years or more; insensitive to ultraviolet aging in the presence of sunlight and ozone.
- **Electrical properties.** Exhibits conductor resistance less than or equal to traditional conductors with the same diameter.

Available Advanced Conductors

Table 1. *Examples of advanced conductors currently available*

NAME	DESCRIPTION	TECHNOLOGY PROVIDER
Aluminum Conductor Composite Reinforced (ACCR)	Metal matrix stranded core Aluminum-Zirconium outer strands.	3M
Aluminum Conductor Composite Core (ACCC)	Mono carbon core enclosed in glass fiber Fully annealed aluminum or Aluminum-Zirconium outer strands.	CTC Global
Aluminum Conductor Steel Supported (ACSS)	Mischmetal coated steel stranded core Fully annealed aluminum outer strands	Various
C⁷	Stranded carbon core Fully annealed aluminum or Aluminum-Zirconium outer strands.	Southwire
TS	Mono carbon core encapsulated in an aluminum sheathe. Fully annealed aluminum outer strands	TS Conductor

Other advanced conductor providers include:

1. LS Cable
2. De Angeli Prodotti
3. NEXANS
4. Tratos Cavi
5. La Farga
6. J-Power

Advanced Conductor Wire Materials

As with ACSR, advanced conductors normally consist of two component wire materials. The highly conducting aluminum wires in the outer layers carry most of the electrical current and have conductivity of 61–63% relative to the International Annealed Copper Standard (IACS; annealed copper is 100% IACS), which is comparable to the 1350-H19 aluminum wires used in ACSR. The core wires of advanced conductors provide mechanical reinforcement, limiting the elongation of the conductor under high ice and wind loads and at elevated temperatures. Depending on the design of the advanced conductor, the outer layers of aluminum wires may contribute to the mechanical behavior of the conductor and the core may carry some portion of the electrical current, but these are not their primary functions.

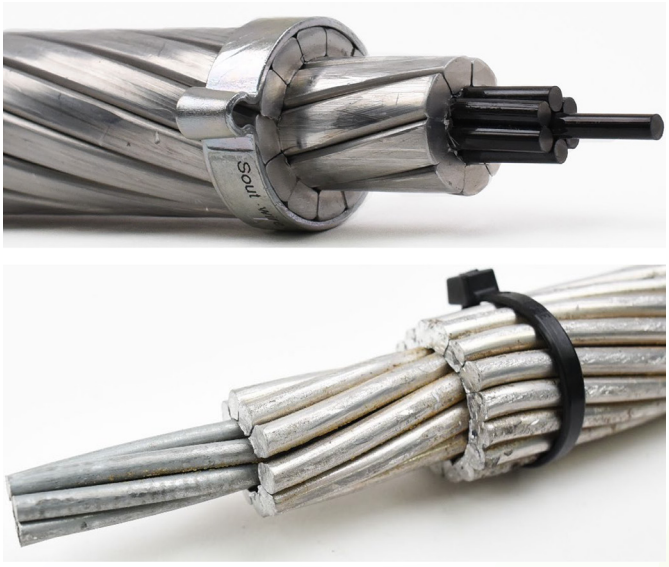


Figure 2. *C7 carbon core conductor (top) versus ACSS conductor (bottom)*

For advanced conductors with annealed aluminum strands, the conductor stiffness and breaking strength are largely determined by the core. For advanced conductors with aluminum zirconium (Al-Zr) outer strands, the composite conductor strength and stiffness depend on the reinforcing core and the aluminum strand layers.

Except for the carbon fiber composite core (CFCC) conductors, the various aluminum alloys and the reinforcing materials are normally in wire form, with a wire diameter of the order of 0.1–0.2 in. (2.5–5 mm). In certain designs, the aluminum wires are provided with a trapezoidal cross section to maximize the aluminum area for a given conductor diameter. The reinforcing core wires are typically round. The properties of the wires vary with wire diameter. Generally, the smaller the diameter to which the wire is drawn, the more work hardening is done, and the higher its tensile strength (although such variations with wire diameter are typically modest).

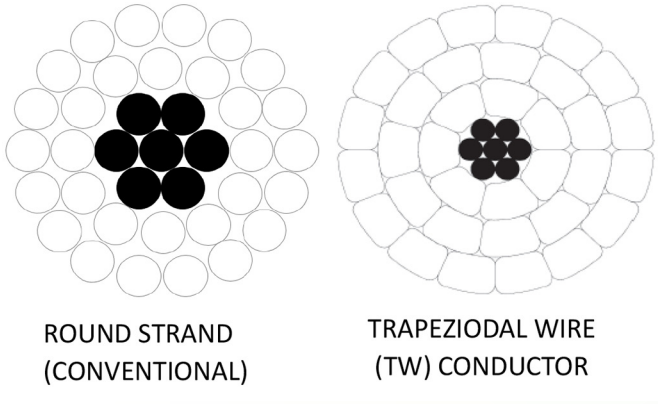


Figure 3. *Diagram showing round aluminum strands versus trapezoidal aluminum strands (steel core wire is round in both cases)*

Current-Carrying Wires

As shown in Table 2, the current-carrying wires used in advanced conductors are capable of continuous operation at temperatures exceeding 100°C with stable electrical and mechanical properties. For example, annealed aluminum strands can be operated continuously at 300°C without any deterioration in conductivity or changing tensile properties.

In contrast to ordinary 1350-H19 aluminum, TAL and ZTAL aluminum can be operated continuously at 150°C and 210°C, respectively, without any loss of tensile strength. These aluminum wires have approximately the same electrical conductivity and thermal elongation as 1350-H19 aluminum strands.

Mechanically, the fully annealed aluminum wires in Table 2 are dramatically different from the non-annealed types. The yield strength of 1350-H19 and the zirconium alloy wires is about 15,000 psi (103 MPa), whereas the yield strength of annealed aluminum wire is about 5,000 psi (34 MPa). Therefore, high-tension loading events cause relatively large permanent elongation of annealed aluminum wires and result in loose strands in advanced conductors that use annealed aluminum wires.

Table 2. *Characteristics of aluminum and aluminum alloy wires*

TYPE OF ALUMINUM	MINIMUM CONDUCTIVITY (%IACS)		TENSILE STRENGTH (MPA) (KPSI)	ALLOWABLE OPERATING TEMPERATURE (°C)	
				CONTINUOUS	EMERGENCY
Hard-drawn 1350 aluminum	1350-H19 (HAL)	61.2	159–200 23–29	90*	125*
Thermal-resistant zirconium aluminum	TAL	60	159–176 23–26	150	180
Extra-thermal-resistant zirconium aluminum	ZTAL	60	159–176 23–26	210	240
Fully annealed 1350 aluminum	1350-0	61.8**	59–97 8.5–14	350	350

* Manufacturers often suggest performing rating calculations at 75°C/100°C.
** Typical conductivity for annealed aluminum is 63.0%.

Table 3. *Characteristics of reinforcing core materials*

CORE MATERIAL	MIN. TENSILE STRENGTH (KPSI)	MODULUS OF ELASTICITY (MPSI)	MIN. ELONGATION AT TENSILE FAILURE %	COEF. OF LINEAR ELONGATION ($\times 10^{-6}$) PER °C	ALLOWABLE OPERATING TEMPERATURE (°C)	
					CONTINUOUS	EMERGENCY
A Galv. Steel **Zn-5Al Steel (B802)**	200–210	30	3.0–4.0	11.5	180 250	200 350
A Galv. HS (B606) **Zn-5Al EHS (B803)**	220–235	30	3.0–3.5	11.5	180 250	200 350
A Galv. UHS **Zn-5Al UHS**	265–285	30	3.0–3.5	11.5	180 250	200 350
CTC Carbon fiber composite core	310–360	16.5	2.0	1.6	180	200
3M Ceramic fiber-reinforced aluminum	200	32	0.64	6	210	240
Alum Clad (AW) 20.3% IACS	149–195	22	3	13.0	150	200
Galv./AW Invar Alloy	149–157	22	3	3.2/3.7	180/210	200/240

1 kpsi = 6.895 MPa; 1 Mpsi = 6.895 GPa

Reinforcing Core Wires

A variety of reinforcing core wires are used in advanced conductors. The core wire materials shown in Table 3 include high-strength carbon steel, nickel-alloy Invar steel, aluminum-clad steel, carbon-fiber-reinforced resin composite, and ceramic-fiber-reinforced aluminum. The three-reinforcing core steel wire types described in Table 3 have a similar modulus, but the tensile strength of extra-high-strength and ultra-high-strength steel core wires is 10% and 30% higher, respectively, than high-strength steel. All have the same thermal elongation coefficient of 11.5 $\times 10^{-6}$.

The aluminum conductor composite core (ACCC) has a very high tensile strength (60% higher than galvanized high-strength steel) but a relatively low modulus (about half that of galvanized high-strength steel). It also has the lowest thermal elongation rate at 1.6×10^{-6}. Its minimum elongation at tensile failure (2%) is less than that of steel (3%). The aluminum conductor composite reinforced (ACCR) composite core has nearly the tensile strength of steel, but it breaks at a much lower elongation (0.64%). Its thermal elongation rate is 6×10^{-6}, about half that of galvanized steel wire. Invar steel wire has the lowest tensile strength in Table 3, but it also has the second lowest rate of thermal elongation (3×10^{-6}).

APPLICATION OF ADVANCED CONDUCTORS

The application of advanced conductors has opportunities in new and upgraded constructions (to date, most applications have been in reconductoring lines). The obvious advantages are the manageable sag and tension considerations for projects that have limited clearances. Consideration, however, must be given to the mechanical strength of the core and annealed aluminum stranding of many advanced conductors where long spans and/or high mechanical loads associated with ice loading or extreme high winds must be factored into the design These are the primary considerations when evaluating advanced conductors for upgrading and uprating existing transmission lines. Increased capacity, using higher operating temperatures rather than a larger diameter, and increased area in the conductor also minimize the need to modify or replace structural supports.

Reconductoring Using Advanced Conductors

Advanced conductors incorporate several aspects that enable increased power flow:

- Ability of conductor materials to operate at higher temperatures
- Reduced thermal expansion characteristics
- Reduced conductor weight and installed tension (in carbon core and ceramic composite core conductors)

While these conductors have been on the market for several years, there are still knowledge gaps regarding the installation, long-term performance, and inspection methods for these conductors and their associated hardware. Many of these advanced conductors have different installation requirements when compared to traditional steel core conductors. Most failures experienced by advanced conductors to date have been attributed to improper installation.

Despite being significantly more expensive (typically between 2.5 to 5 times the cost of equivalent ACSR), most proprietary advanced conductors' options offer capacity increases that would otherwise not be achievable with conventional or non-propriety conductors.

Where a carbon core is used, the expansion coefficient becomes negligible, allowing maximum operating temperatures of 180–200°C.

Reconductoring an existing line with a new advanced conductor is typically done when rebuilding the line is prohibitive from a network constraint perspective. In some cases, the cost of proprietary advanced conductor options may be comparable with the cost of building a new line.

In addition, experience has shown that additional care needs to be exercised when installing composite core conductors, which are more readily damaged than conventional steel core options. While composite-core conductors are quite strong in tension, the core material of some of the conductors can be brittle, making it susceptible to damage from bending. For this reason, older generation, non-proprietary options may also be a cost-effective option.

Implementation Challenges and Maturity

Non-proprietary advanced conductors are mature technologies with a relatively low installation risk, however there are currently no standards for advanced conductors.

The low elastic modulus of carbon core conductors may lead to excessive sag during icing and extreme wind events. In some cases, this may be solved by selecting a larger carbon core.

Experience with installation of both composite ceramic and carbon core conductors has revealed that care to prevent damage during installation is critical, as damage to such conductors has been experienced where the bending radii limits have been exceeded. Recent iterations in some carbon core Advanced Conductor options have introduced multiple strand carbon cores to reduce the allowable bending radius, while other variants offer increased protection to the carbon core.

R&D OPPORTUNITIES TO SCALE AND GROW

EPRI is continuing research on advanced conductors, with a focus on the activities that de-risk and optimize the use of advanced conductors:

- Installation
  - Improved installation procedures for newer generation conductors to prevent installation damage.
  - Safe installation tensions for ACSS conductors, which have improved, and yet, unleveraged, self-damping characteristics.
- Inspection
  - Inspection of conductors, including determination of carbon core integrity,
  - Assessment of conductor condition and determination of end-of-life criteria.
- Long Term Performance
  - Incorporation of testing procedures and methods into standards, such as incorporation of EPRI's thermal-mechanical test protocol into ANSI C119.7 – "Connectors for Use Between Aluminum-to-Aluminum Conductors Designed for Normal Operation Above 93°C"; and Continued laboratory and field evaluations, with technology providers partners as well as national labs to increase understanding of icing, vibration and other unknowns.

EPRI EFFORTS UNDERWAY

To increase confidence in advanced conductors' performance, utilities requested a deeper understanding of life expectancy and requirements to include in specifications when procuring advanced conductors. EPRI has developed a draft specification, including new tests, that utilities can use to inform procurement of advanced conductor systems and has been implementing accelerated aging tests for over a decade.

In the GET SET initiative, EPRI will be formulating training to assist utilities in better understanding advanced conductor technologies as well as providing guidance on installation, inspection, and assessment, and the expected long-term performance of these conductors. The training and previous work undertaken by EPRI (including the collection of utility case studies) will be consolidated into a comprehensive reference book.

Installation

Vibration Testing

A 197-foot-long span with integrated vibration coil enables the testing of conductors and conductor bundles. One of the potential features of advanced conductors is that they are self-damping, reducing the need for dampers to be installed. Testing is planned to confirm this and identify any other learnings.

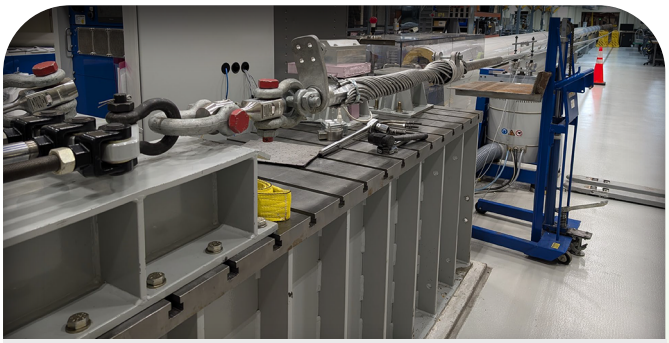


Figure 4. *Conductor vibration rig showing one tensioner mount and the shaker device*

Advanced Conductor Test Specification Testing

EPRI has developed a draft specification which includes tests which can be performed in a range of laboratories around the world. Criteria for pass and fail are provided. EPRI has evaluated most of the advanced conductors available today using the draft specification.

Inspection

Conductor System Tensile Tester

Failure testing of conductor connector systems is implemented by applying mechanical loads of up to 220,000 lbs. Conductor systems removed from the field and from accelerated aging testing are evaluated.



Figure 5. *Conductor tensile tester*



Figure 6. *Strand and core tensile tester*

Strand and Core Tensile Tester

A 67,500 lbs tensile tester evaluates the strength of individual strands and solid cores.

Evaluation of Various Inspection Tools and Technologies

EPRI is evaluating the use of existing inspection tools and technologies for advanced conductors. Technologies currently being assessed includes radiography and guided-waves.

Long-Term Performance

Accelerated Aging Thermal Mechanical Testing

Advanced conductor-connector systems are aged by applying simultaneous thermal and mechanical cyclical stresses. EPRI's test rig can simultaneously age up to 24 X 90-foot-long conductor spans under mechanical loads of up to 30,000 lbs and temperatures of up to 250°C.

Connector and conductor temperatures and mechanical loads are monitored, and resistance measurements are taken periodically. Connector X-rays are taken at the start as well as at the end of the test. When thermal and mechanical anomalies are measured, outages are taken to take X-rays and measure connector resistance. At the end of the cycling test destructive tests are performed on the conductor and connectors to evaluate the loss of life.

A normal 1500 cycle test takes 18 months and simulates 40 years of a conductor system's life. To date five advanced conductors have successfully met the test criteria. More information on the EPRI laboratories can be found by clicking on this link.

Advanced Conductor-Connector Testing Standard

Results from the EPRI testing of advanced conductors have been used as the basis for a new test standard document. ANSI C119.7 – "Connectors for Use Between Aluminum-to-Aluminum Conductors Designed for Normal Operation Above 93°C". The standard, currently in draft format, has adopted the EPRI developed thermal-mechanical test protocol to evaluating advanced conductor connectors.

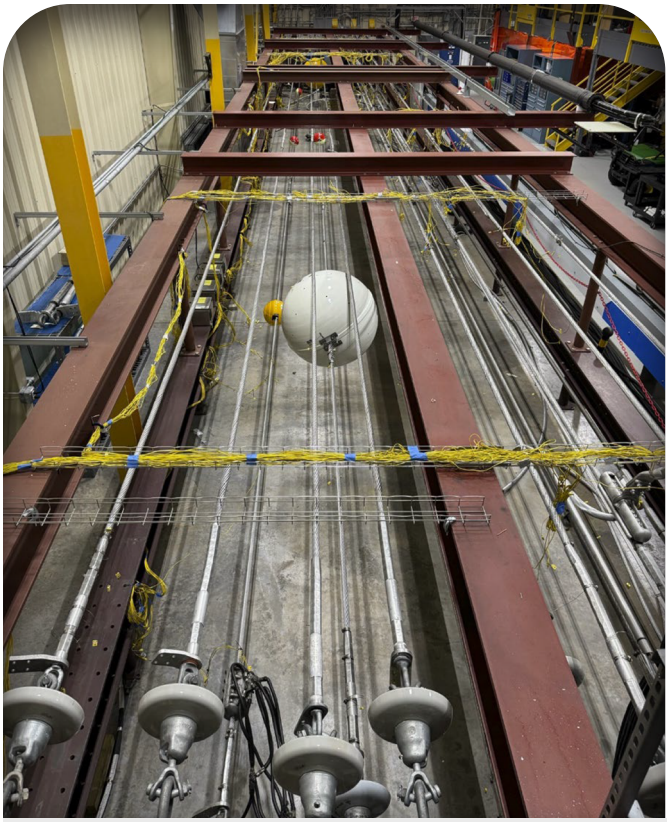


Figure 7. *EPRI Charlotte Laboratory conductor test rig*

Field Monitoring Sites

Over the years EPRI has monitored completed advanced conductor installations at member sites. A new monitoring project was commissioned in the second half of 2024 in the northwest U.S., an environment which is known for icing. Two monitoring sites will continuously measure the tension, vibration and galloping of the conductors as well as the local weather conditions.



Figure 8. *Conductor monitor being installed on an ACCC conductor*

SUMMARY

EPRI's GET SET initiative is committed to assimilating and disseminating existing GETs knowledge to support utilities in assessing and deploying GETs now, as well as leveraging those deployments and additional research to answer remaining questions and provide the tools that utilities need to evaluate and deploy more broadly.

This whitepaper details Advanced Conductors (what they are, and materials used) and how they differ from the traditional conductors used. The most significant difference between advanced conductors and traditional conductors is the ability of the advanced conductors to continuously operate at elevated temperatures (typically above 150°C).

While advanced conductors can be used for new builds as well as for reconductoring, most applications have been reconductoring projects. Since advanced conductors are a relatively new development in the industry, there are certain topics that require further work and understanding, these include:

- Installation
- Inspection and assessment
- Long-term performance

EPRI through the GET SET initiative will provide training and reference material on these topics, to help utilities better understand the technology and application and to derisk the application and use of these conductors.

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3002031441 **January 2025**

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