WhitePaper

Comparing Advanced Cores: Achieving Maximum Grid Capacity

Assessing steel core conductors against alternatives.

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The Steel Core Advantages

Conductors with steel cores are widely used due to their performance and significant cost advantage. Increasing the capacity of electrical grids is now one of the most pressing topics in the world today, due to the growing realization that renewables development is far exceeding the necessary growth in grid capacity. Grid operators must provide consumers with ever-increasing amounts of power while also focusing on maximizing sustainability and reducing costs. Choosing the right conductor is crucial.

Each type of conductor design can be viewed as being a “tool in the toolbox”. Each has useful applications where its advantages make it the best choice. Aluminum Conductor Steel Reinforced (ACSR) conductors are the industry standard. This is due to their lower cost, superior ruggedness, and design flexibility.

Advanced Aluminum Conductor Steel Supported (ACSS) conductors maximize the capacity of steel core conductors.

Several composite core providers claim that their design is the key to a sustainable, resilient, and efficient grid.

Composite core conductors do have a place in the industry. Their higher strength to weight ratio and lower thermal expansion allow for less thermal sag. This is helpful in cases where thermal sag must be minimized at all costs. In most cases, the savings from thermal sag improvement are not big enough when compared to the total cost of ownership in a given project.

To put this claim to the test, we’ve compared conductors with advanced steel cores against the new generation of conductors. Can conductors reinforced or supported by carbon fiber composite (CFC) cores really outperform advanced ACSS (steel core) conductors?

Ranking Overhead Conductors: Our Criteria

Conductor selection has always involved careful consideration of capacity, resiliency, sustainability, and cost.

Resiliency and sustainability are both subjective and qualitative judgments where the utility needs to reflect on their priorities and assign weighting factors. Cost and capacity are purely quantitative. In this paper, we use objective data to compare how various conductor core designs meet these key criteria.

Resiliency can be seen as the combination of two attributes: survivability after extreme weather events or hostile acts, and the time and expense required to restore service following damage from an extreme event.

Sustainability is defined by Merriam Webster: “of, relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged.” When ranking sustainability, we consider criteria such as resource depletion, monetary cost, and resource recovery by recycling. Cost can also be grouped under sustainability because money is a resource that can be put to beneficial use elsewhere. In this discussion, cost is covered as a separate criterion under the quantitative analysis.

Capacity is the electrical load, in amperes, at the manufacturer-recommended maximum operating temperature. The values used in this paper come from open-source literature with standard default values for ambient temperature, wind speed, and solar heat gain.

Cost encompasses the total lifetime cost of the transmission line for land usage, materials, installation, operation (including the cost of line losses), maintenance, repair, and decommissioning costs. For this paper, we have only focused on the first cost. Analyzing the true total cost can be done only on a project-specific basis.

Overhead Conductor Design Options

The overhead conductor designs compared in this paper are:

- **ACSR (Aluminum Conductor Steel Reinforced): standard galvanized steel core, hard-drawn pure aluminum.**
- **ACSS/TW/MA5 (Aluminum Conductor Steel Supported): steel core coated with high-temperature Bezinal®, with annealed pure aluminum outer strands.**
- **ACCFCS/TW (Aluminum Conductor Carbon Fiber Composite Supported): composite core with pure annealed (soft) aluminum. ACCC® is available with annealed aluminum.**
- **ACCFCR/TW (Aluminum Conductor Carbon Fiber Composite Reinforced): composite core with hard aluminum-zirconium high-temperature alloy. ACCC® is a variant of ACCFCR/TW.**

Please note that "TW" designates trapezoidal wire shaping for the aluminum strands to increase the packing density of the aluminum component. This is not meant to imply that TW is the best choice in all cases.

For example, all other factors being equal, a conductor with round aluminum strands has a greater cooling area, providing both greater capacity and lower line losses.

We have focused on TW conductors simply because some of the designs considered are available only with TW aluminum strands. The ACSR conductor used for reference values has round aluminum strands and represents most of the conductors now in service.

Weighting factors for each criterion are based on utility-specific and project-specific preferences. For example, ACSR seldom competes in reconductor applications due to insufficient capacity to replace an existing ACSR conductor.

Some utilities standardize on a small number of conductor sizes and types. The cost of occasionally using a non-optimal conductor is offset by savings in inventory and tool costs. Since damage recovery time can be reduced if fewer conductor types are in service, this makes sense as a resiliency strategy.

In the following sections, we rank each of the candidate conductors according to the criteria.

Capacity Rankings

1. ACSS/TW/MA5 has a temperature-resistant Bezinal® coating on the steel core, giving it a maximum operating temperature of 250 °C and is resilient when taken to these temperatures. This is higher than any other competing conductor class. This variant also ranks highly in capacity as it uses the most conductive aluminum available (1350-0).[5]

2. ACCFCS/TW (soft aluminum) has a polymer matrix in the core that limits the operating temperature to 180 °C and is not resilient after taken to these temperatures multiple times.[5]

3. ACCFCR/TW (hard aluminum alloy) also has a polymer matrix that limits the maximum operating temperature to 180 °C and is not resilient after taken to these temperatures multiple times. The capacity is lower than alternatives due to the higher resistivity of the aluminum zirconium alloy.[4]

4. ACSR has a metallurgical temperature limit of 100 °C. This limits the capacity to well below the other conductors in this ranking.[5]

Resiliency Rankings

1. ACSR has the highest survivability ranking. This is due to the combination of hard/strong aluminum strands and a tough stranded steel core. In most cases, redundancy for the steel core is provided by multiple strands. As well as having the top rating for survivability, ACSR lines have the shortest restoration times. This is because ACSR has multiple sources of supply, the largest available inventory, and the most available tools, fittings, and trained crews.[1] "ACSR is a better conductor hands down. Reasons being: higher tensile strength, reliability, lack of memory, and ability to form loops easily." – Tim Rhodes, North American Lineman Training Center.[2]

2. ACSS/TW/MA5 has a multi-strand core that provides some structural redundancy. All ACSS variants lack the redundancy of a strong aluminum component. Based upon the tougher core and advantage in restoration time, ACSS/TW is ranked ahead of the composite core options for resiliency.[1]

3. ACCFCR/TW ranks third as only one variant has a single-strand (non-redundant) core. A multi-strand CFC core is available to provide some redundancy in the case of damage affecting the core. The alloy aluminum outer shell will generally support the span in the event of a failure of the composite core. However, because specialized tools and fittings are needed, restoration time is usually longer than for steel core options.

4. ACCFCS/TW ranks last for resiliency. The single-strand core version is non-redundant, and the soft aluminum component will not survive if the core fails.[1] The multi-strand CFC core improves the rating on resiliency, but not enough to change this ranking. Once again, because of the need for specialized tools and fittings, restoration time will generally be longer than for steel core options. "ACCC® doesn't hold the load of trees in storm situations. It also bends, kinks, and breaks easily. Not to mention, the restoration time is far longer due to making repairs." – Tim Rhodes, North American Lineman Training Center.[2]

Sustainability Rankings

1. ACSR and ACSS both tie in terms of sustainability. A long service life and use of abundant materials give conductors with steel cores top ranking. These conductors are less expensive and use less resources to produce. They also have an established value in the recycle stream. A retired conductor can be chopped into short lengths and the steel component is easily separated using magnets. Both steel and aluminum have high value in the recycle stream making them 100% recyclable. Line losses can be reduced if the cost advantage is leveraged to provide a larger conductor with lower electrical resistance.[1]

2. ACCFCS/TW variants rank above conductors with aluminum alloy strands because pure aluminum has a higher value in the recycle stream. If we consider money to be a resource, then the first cost is significantly higher than steel core options. Like fiberglass, the matrix polymer is cross-linked

by an irreversible process which makes recycling problematic. Due to this process, composite cores can only be disposed of in landfills or by incineration.[3]

3. ACCFCR/TW variants have similar qualities to ACCFCS/TW but are ranked lower due to higher line loss and the lower recycling value of alloy aluminum.[4]

Cost Rankings

All variants analyzed in this report were ranked based on the conductor cost alone. Individual attributes of conductors have a significant impact on the cost of structures and right-of-way. Only a project-specific analysis can determine the total integrated least-cost option.

As far as industry standards go, ACSR is still widely used for new structures. This is because of its low first cost and the relatively low cost difference when compared to alternatives.

The composite core options and ACSS/TW/MA5 are highly competitive options for reconductor projects. ACSR cannot compete in this area since an ACSR conductor is being replaced to increase capacity in these scenarios.

Analysis of the Rankings

The rankings for each of the four criteria can be seen below in Table 1. The table provides an overall rating based on the sum of the individual categories. We have assumed that all options have equal weighting factors. Ranking 1 indicates the highest performance, whereas 4 denotes the lowest.

Table 1: (Lowest score denotes best performance)

	ACSS/TW/MA5 annealed aluminum/ steel core	ACSR hard drawn aluminum/steel core (reference conductor)	ACCFCS/TW annealed aluminum/composite core	ACCFCR/TW aluminum alloy/composite core
Capacity	1	4*	2	3
Resiliency	2	1	4	3
Sustainability	1	1	2	3
Cost**	2	1	4	3
Total Score	6	7	12	12
Ranking	**1**	**2**	**3**	**3**

* ACSR is disqualified for most reconductor applications due to low capacity

** a project-specific analysis is needed to determine the integrated least cost

Judging by these rankings, the market seems to be making well-informed decisions. ACSR remains the highest-volume conductor on a conductor-foot basis, followed by ACSS. Composite core options are gradually increasing their market share, but due to their much higher cost, they will likely not achieve significant market penetration. It is only in niches where their premium cost is offset by savings in other areas that conductors with composite cores can compete with ACSS (steel core).

When assessing the above rankings, it is important to bear in mind that resiliency and sustainability are qualitative judgments. Cost and capacity, on the other hand, are quantitative, and so can be accurately computed. We have provided a realistic example that demonstrates the quantitative differences between these advanced conductors in a reconductor scenario.

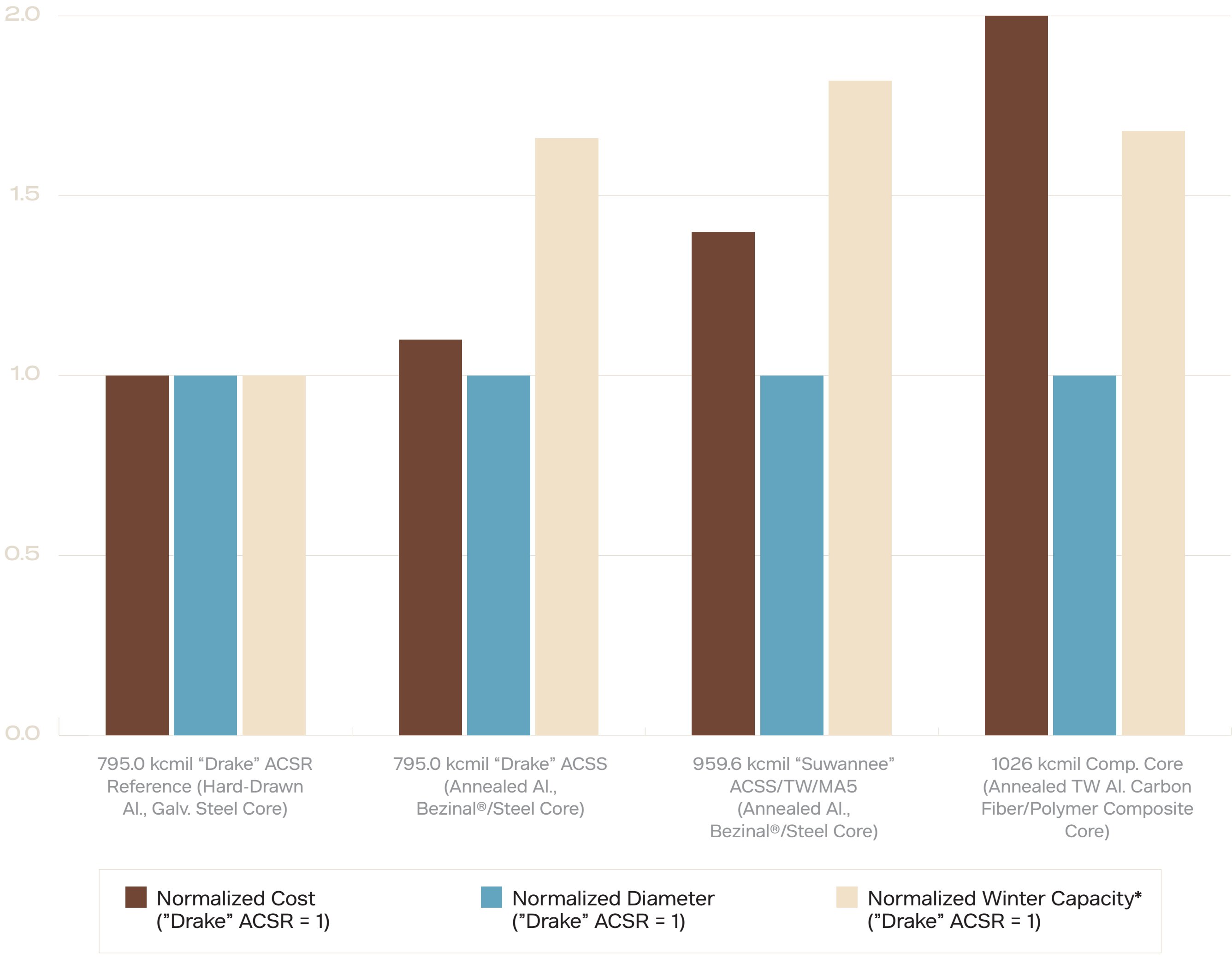
Performance In a Realistic Reconductor Scenario

In our scenario, a 795 kcmil 26/7 "Drake" ACSR conductor has reached its capacity limit. Although there is no margin for increased loads or increased sag compared to the installed ACSR conductor. However, it is possible to remediate the structures at problem locations for a modest cost. The question is what conductor is the optimal choice, based on capacity and total installed cost?

The following analysis was performed using industry-standard methods and industry-standard software. Engineering values were computed, but to avoid scaling issues on the charts and confusion regarding engineering units, the engineering values are normalized by reference to the legacy "Drake" ACSR. Alternatives were evaluated based on equal diameter, and equal cost.

In all three scenarios, a conductor with a steel core delivered both the lowest cost and highest performance.

Figure 1: Cost, diameter, and capacity for conductors of equal diameter (blue bar).



* Capacity computed based upon 25°C ambient, 2 f/s wind, mid-winter sun at 30° north latitude

Key: "Drake" and "Suwannee" are industry designators for two conductor designs. "kcmil" is the industry unit for the conductor's aluminum area. ACSR was introduced in 1909, designates Aluminum Conductor Steel Reinforced. ACSS was introduced in 1973, designates Aluminum Conductor Steel Supported.

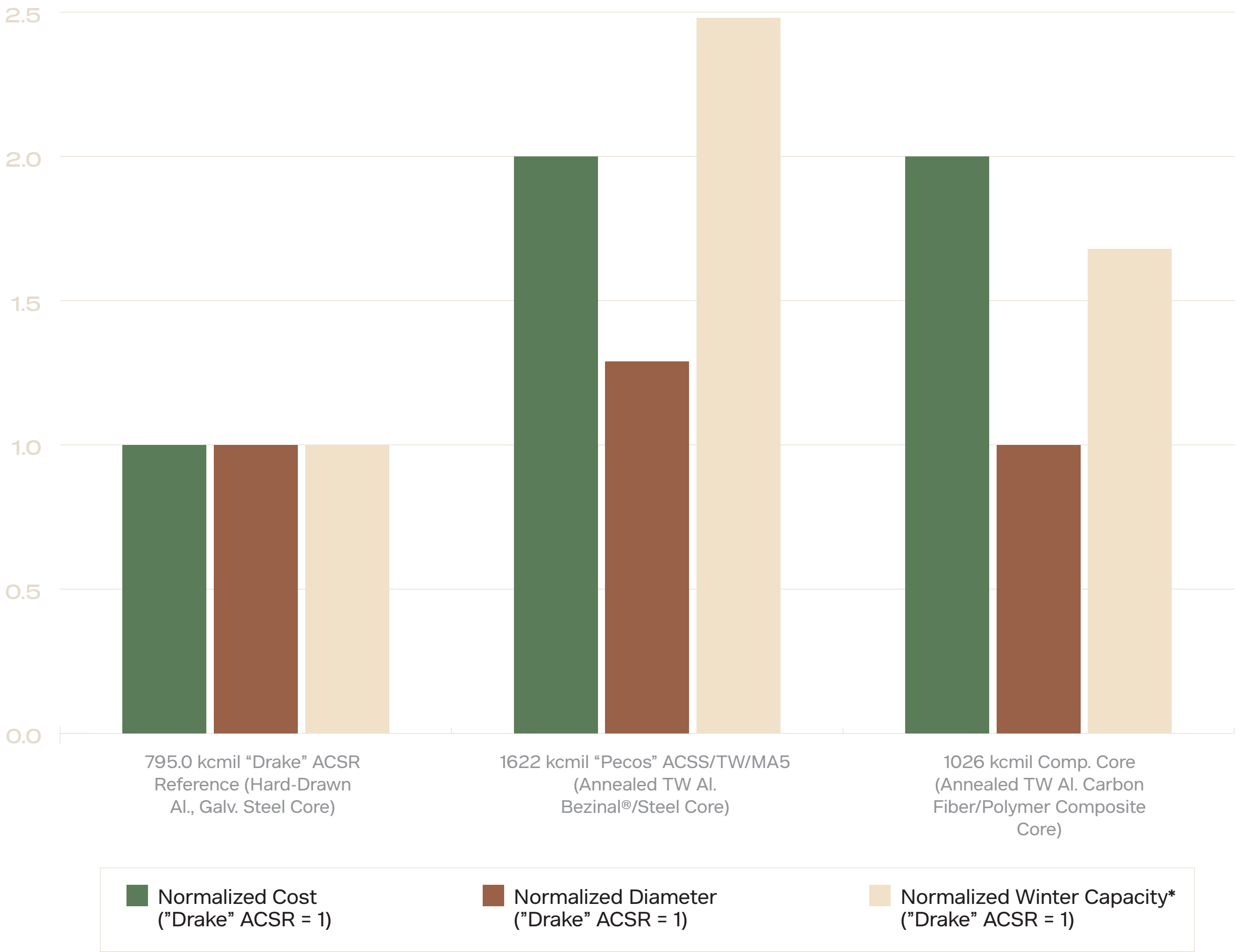
In Figure 1, we can see a comparison with a fixed constraint. In this example, the replacement conductor needs to be of equal diameter to the existing conductor to avoid structure changes or permitting issues.

In many reconductor cases, only a limited number of structures require remediation for sag issues. The ACSS/TW option can improve its competitive position by incorporating an advanced ultra-high-strength steel core protected by a high-temperature Bezinal® coating, designated by the suffix MA5. Savings on the ACSS/TW/MA5 conductor more than cover the structure remediation costs. The composite core option is the best choice when its cost premium is less than the cost for structure changes to use an ACSS (steel core) option.

Figure 1 also shows that the 795 kcmil round-wire ACSS option provides a 66% capacity increase for a 10% cost increase over the ACSR reference conductor. The same-diameter ACSS/TW option increases the aluminum area to 959.6 kcmil for a capacity increase of 82% and a 40% cost increase compared to the ACSR reference. The composite core option has TW stranding to increase the aluminum area to 1026 kcmil. This boosts the capacity increase to 68% but also also doubles the cost. We can see that the composite core option is only competitive where the cost of structure remediation exceeds its premium cost.

In the Figure 2 scenario, comparisons are made based on having approximately the same cost:

Figure 2: Cost, diameter, and capacity for conductors of approximately equal cost (green bar).

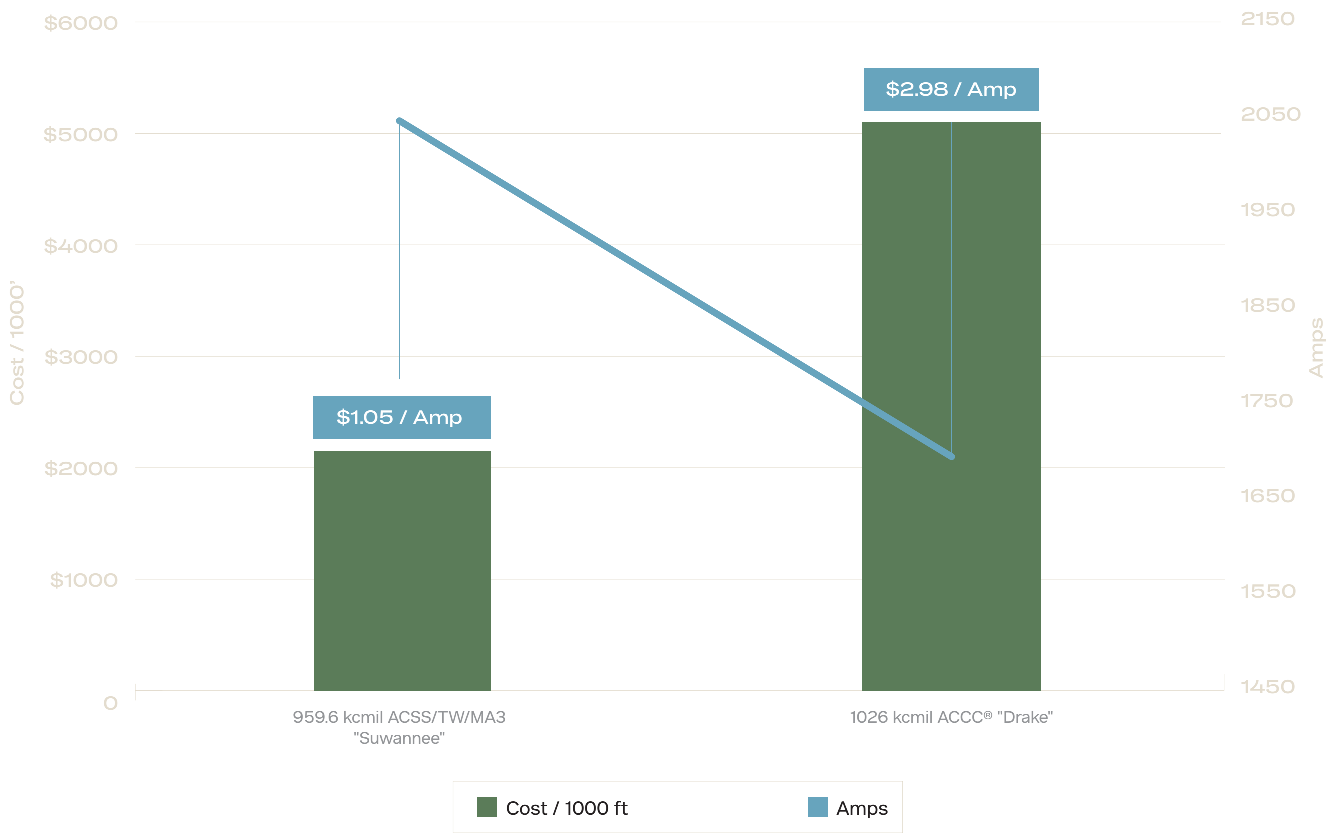


*Capacity computed based upon 25°C ambient, 2 f/s wind, mid-winter sun at 30° north latitude.

Figure 2 shows that the composite core option provides a 68% capacity increase for a 200% cost increase relative to the "Drake" ACSR reference. For the same 200% cost increase, a 1622 kcmil "Pecos" ACSS/TW/MA5 conductor provides a 148% capacity increase relative to the ACSR reference. However, the "Pecos" ACSS/TW/MA5 also has a 29% larger diameter and may also require significant structure remediation.

In Figure 3 below, we show a quick way to visualize the cost per amp of an ACSS/TW/MA3 conductor vs the cost per amp of an ACCC® "Drake" conductor. The ACSS/TW/MA3 conductor provides the transmission line with nearly 3 times cost per amps savings than the ACCC® "Drake" conductor.[6]

Figure 3: Conductor Cost per Amp



Viability of Alternative Conductors

ACAR (aluminum conductor alloy-reinforced) and AAAC (all-aluminum alloy conductor) are not candidates for higher-capacity reconductor projects. These conductors have operating temperature limits equal to ACSR conductors.

ACSR/AW (ACSR with an aluminum-clad steel core) conductors are also not candidates for high-capacity lines. Their capacity is equal to ACSR conductors with the same steel/aluminum ratio. ACSR/AW conductors also have greater thermal sag due to their lower steel content and the higher thermal expansion of an aluminum-clad steel strand.

ACSS/AW (ACSS with an aluminum-clad steel core) are candidates for high-capacity lines. Their thermal limits are identical to ACSS conductors, and their performance is similar to the ACSS conductors shown in the charts. However, the thermal sag is greater due to the higher thermal expansion of aluminum-clad steel strands.

Despite this, aluminum-clad cores are often preferred in locations where steel corrosion is a major concern. Recent improvements such as high-performance coatings such as Bezinal® and Bezinal 2000® provide greater corrosion protection than conventional hot-dip zinc-galvanized coatings.

Our Conclusions

This paper demonstrates that conductors with steel cores will continue to significantly lead the market based on lower cost, far superior ruggedness, and improved design flexibility for most applications.

Conductors with composite cores are a valuable addition to the list of conductor options but only where steel core options exceed the nominal sag limit at the maximum allowable operating temperature, and structure changes to address sag are cost-prohibitive compared to the composite conductor cost.

For new construction, rugged and reliable ACSR is the best option because its cost advantage allows for larger and more efficient conductors.

In reconductor applications, the main driver is capacity increase. In these cases, ACSS and ACSS/TW/MA5 variants perform better and cost only slightly more than ACSR. This cost advantage is generally enough to allow for structure remediation (nips and tucks) to address any locations where the electrical clearance or structure load capacity needs to be increased.

For new construction, ACSR continues to rightfully lead the market due to the combination of high resiliency and low cost. ACSR will also continue to lead the market on efficiency (low line loss). This is simply because a larger conductor is more affordable, will run more efficiently, and operates at cooler temperatures. The low operating temperature also reduces sag for the simple reason that high-temperature operation is not required.

It is possible to use ACSR and ACSS interchangeably, as they use the same grips and end fittings, greatly reducing the stock costs of replacement parts. Where even higher capacity is needed, an ACSS or ACSS/TW option competes well for new construction as the low cost enables high-temperature sag to be addressed with modest structure enhancements.

There is a heated contest occurring in the reconductor market. ACSR is no longer a viable option because it is unlikely to meet the capacity increase requirements. The same-diameter ACSS/TW/MA5 option increases the aluminum area to 959.6 kcmil for a capacity increase of 82% and a 40% cost increase compared to the ACSR alternative.

The leading composite core option only increases the capacity by 68% but at a cost premium of twice the ACSR cost. There are niches where the sag advantages of the composite core provide enough savings on the structure cost to justify the cost premium and capacity penalty. However, steel cores do outperform composite in ballast-induced sag situations (i.e. ice or wind loading). The size of this niche is reflected in conductor sales for reconductor projects.

ACSS/TW/MA5 remains the market leader. It is expected to expand its lead as continued innovation in the steel industry delivers increasingly effective options.

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