Cost Savings for Ratepayers

The Role of Advanced Transmission Technologies and High-Performance Conductors

White Paper

Contents

Executive Summary

Steel core conductors are better than polymer (plastic) composite core conductors for capacity, efficiency, reliability, cost and sustainability.This paper explains how conductor-related costs are passed along to the ratepayers. The accounting method for accurately determining the total annual owning cost is described and used to find the annual cost for three (3) reconductor options described in the Bekaert White Paper entitled "Connecting Renewable Energy with Giga-Strength Steel". This prior paper covers the technical aspects of three (3) reconductor alternatives for increasing the capacity of an existing 795 kcmil ACSR "Drake" transmission line.

The findings of this study describe how the utility industry sees line losses as an unavoidable cost shared by all ratepayers. Line loss is significant, and rate commissions work to prevent unfair rate burdens on ratepayers.

Line energy loss costs (costs related to long term operation) have the greatest impact on ratepayers for lines with an average annual load exceeding 13% of their maximum capacity. Conductor first cost (the cost of the system at installation) is the largest ratepayer impact for lines with average annual load below 13% of the maximum capacity.

Conductors operating at high temperatures significantly impact ratepayers due to high line energy losses. Therefore, conductors should be sized for low-temperature operation, reserving high-temperature capacity for rare events.

Conductors operated at low to moderate temperature have lower ratepayer impact because line loss is a much smaller fraction of the power delivered.

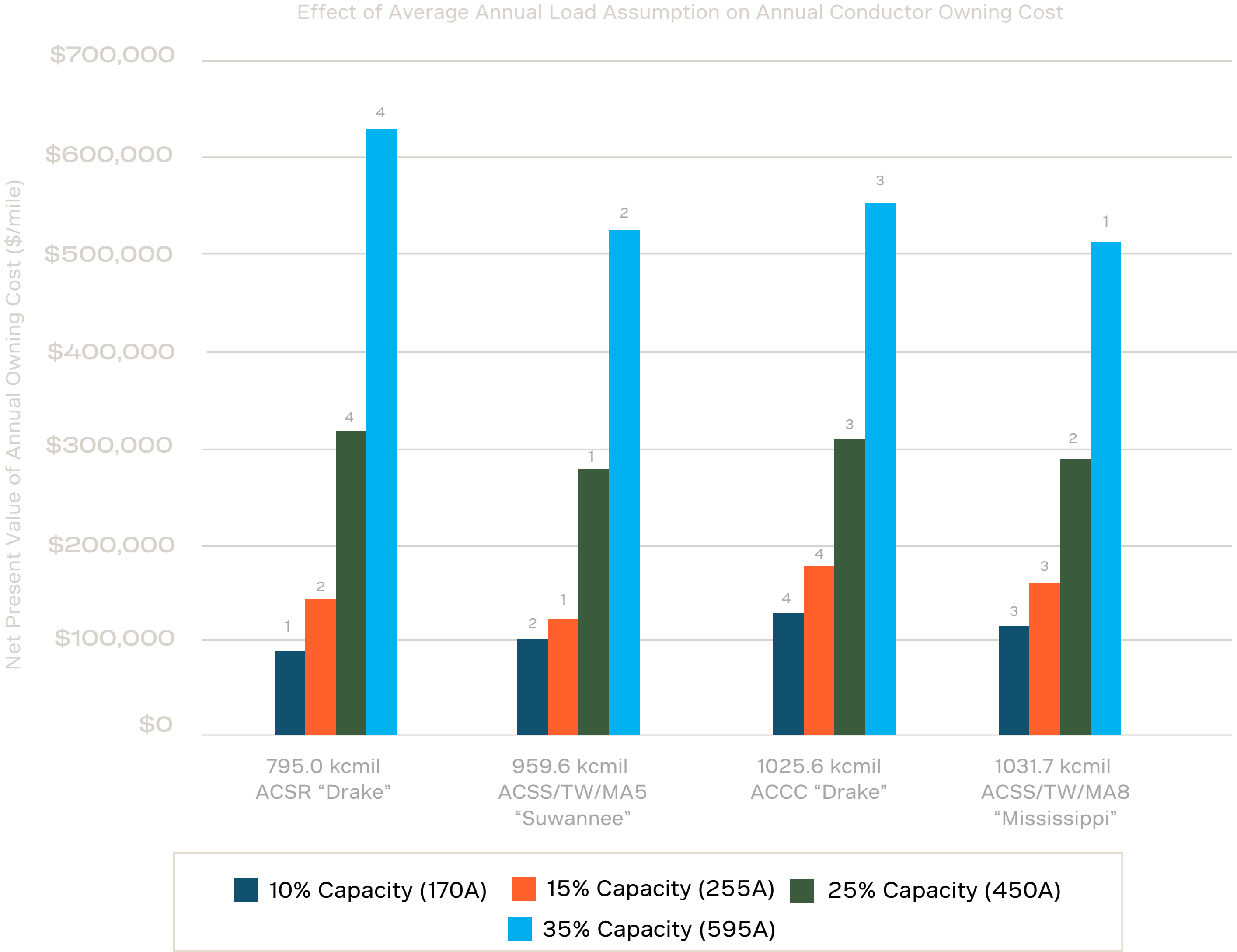
Polymer (plastic) composite core conductors cost more, have lower capacity, and higher line loss than properly sized steel core conductors like ACSR, ACSS, or ACSS/TW conductors. Polymer (plastic) composite core conductors are only advantageous when thermal sag solves a more costly problem.

Figure 1 shows the net present value (NPV) of the annual owning cost of four conductors previously evaluated. The number above each bar is the conductor's rank by ratepayer benefit for each of the four assumed average annual line loads.

The lower the NPV, the less impact or cost it has to the ratepayer which gives it the better ranking.

Figure 1 also demonstrates that the least-cost option depends upon what is assumed for the average annual load. The owning cost analysis shows "Drake" ACSR is the lowest cost for average annual load assumptions below 13% of the 1700A target capacity (less than 221A). This observation confirms that the original "Drake" ACSR investment was prudent for the loads that likely existed 40 years ago when the line was first designed. This also confirms that an appropriately sized ACSR may also be the lowest-cost option for new lines even today. However, there are now high-temperature low-sag (HTLS) options that offer double the capacity and reduced line losses at only slightly greater conductor first cost. The value of the capacity and loss reduction can easily justify an ACSS/TW option over ACSR even for new lines. A ranking of 1 indicates the least cost of ownership, whereas 4 denotes the highest cost of ownership.

Figure 1: Net Present Values of Conductor Owning Cost for Four Different Average Line Loads Over the Life of the Conductor (50 Years)



Note: the number above each bar is the ranking of that conductor for the assumed average annual load designated by that bar.

Increasing the assumed annual load from 170A to 255A (orange bars) shows the effect of the "current squared" term on the line loss. At 255A, "Drake" is no longer the most economical option because the cost of losses has increased enough to overcome its advantage in lower first cost. 959.6 kcmil ACSS/TW "Suwannee" is the least cost option for assumed average loads of 15% and 25% of peak capacity. "Suwannee" combines modest first cost and moderate cost of line losses. At 33% of capacity and above, the 1031.7 kcmil ACSS/TW/MA8 "Mississippi" conductor is the least cost option due to its lowest-in-class line loss and moderate first cost. Regardless of loading assumptions, the 1025.6 kcmil "Drake/ACCC" is not the least cost solution at any load because of its high first cost and lack of an advantage in line loss.

These rankings change in scenarios where the cost of structure modifications is significant. In this scenario, all candidates meet the capacity requirement without exceeding the maximum thermal sag for the "Drake" ACSR being replaced.

The rankings will also change if there is a value assigned to capacity above the 1700A nominal capacity target. 1025.6 kcmil "Drake/ACCC" meets the capacity target with a capacity increase of nearly 70% compared to the original 795.0 ACSR "Drake". The ACSS/TW options exceed the capacity of "Drake" by 99% for 959.6 kcmil "Suwannee", and by 105% for 1031.7 kcmil "Mississippi".

Background

In the utility accounting process, the conductor costs are divided into fixed costs and variable costs: Fixed costs include operation and maintenance costs, and the cost of repaying the bonds or other financing instruments. There is also a fixed charge for the required investment in the generation capacity for the energy consumed by line losses.

The variable cost is the cost of the energy (fuel) plus a "demand charge" for the required investment in generation capacity.

1. Line Loss and Current
The energy lost (line loss) in the conductors increases with the square of the line current. So, if the current doubles, the loss increases by four times.

2. Energy Delivered
The energy delivered to the customer (ratepayer) increases directly with the line current. If the current doubles, the energy delivered also doubles.

3. Fraction of Energy Lost
Because line loss increases faster (squared) than the energy delivered (linear), the fraction of energy lost compared to the energy delivered gets larger as the current (and thus the load) increases.

In simpler terms, as you use more electricity, the efficiency of the delivery system decreases, causing a higher percentage of energy to be lost in the process.

Costs of all types are accounted for using standard accounting practices. Rates are proposed by utilities based on cost recovery and, in the case of investor-owned utilities, a fair return on investment. Profits, if there are any, are returned to the shareholders as dividends, or to members of electric membership corporations (EMC). Rates are typically regulated by a rate commission responsible for ensuring reliable service and fairness to all stakeholders, especially the ratepayers.

Conductor Technical Factors

The important properties of ACSR "Drake" and its reconductor candidates are summarized in Table 1, in the order of increasing aluminum area. Cost values are based on the MISO cost study referenced in the bibliography. The first three conductors in the table are commercially available.

1031.7 kcmil ACSS/TW/MA8 "Mississippi" is a new design enabled by the introduction of advanced Giga-strength steel core. Giga steel allows for a smaller core and larger aluminum outer shell, which allows for both highest-in-class capacity and lowest-in-class line losses. All these conductors have the identical 1.108" outer diameter of "Drake" ACSR.

Table 1: Properties for ACSR "Drake" and Reconductor Options for a Minimum 70% Capacity Increase

Conductor Size & Designation	Rated Breaking Strength (lb)	Weight (lb/1000ft)	Core Size (# x Diameter) (in)	60 Hz AC Resistance @ Temp (Ω/mi @°C)		Maximum Operating Temperature (°C)	Installed Cost ($/mile)
795.0 kcmil ACSR "Drake"	31,500	1,093	7 x 0.1360	0.1166 @ 25	0.1503 @ 100	100	$21,874
959.6 kcmil ACSS/TW/MA5 "Suwannee"	38,600	1,317	7 x 0.1493	0.0941 @ 25	0.1517 @ 180	250	$28,079
1025.6 kcmil ACCC "Drake"	41,200	1,052	1 x 0.3750	0.0903 @ 25	0.1454 @ 180	180	$44,723
1031.7 kcmil ACSS/TW/MA8 "Mississippi"	31,900	1,246	7 x 0.1221	0.0888 @ 25	0.1426 @ 180	250	$36,070

Conductor Economic Factors

Aluminum Association Publication 54, "The Evaluation of Losses in Conductors" describes the accounting methods used for computing the owning costs of conductors. Table 2 below lists the factors from Publication 54 for setting fair rates for electric service. The publication date of 1998 means many of the default values are not current. The suggested values differ from the suggestions in Publication 54 only for these values:

Load Factor

The suggested value is 50%. A range of load factors was assumed to show the sensitivity of the cost to the assumed average annual load (load factor).

Future Growth Factor

The suggested value is zero. This was changed to 2%, which is still a low-growth value.

Present Cost of Energy

The suggested value is $0.02/kWh. This was changed to $0.04/kWh to reflect current costs.

Conductor Service Life

The suggested value is 30 years. This was changed to 50 years to reflect the expected service life for modern conductors.

Table 2: Cost Factors Related to Overhead Conductors

Transmission Conductor Cost Factors per Aluminum Association Publication 54	Suggested Value	Definition
Fixed charge rate on conductor (Ft)	19%	Annual charge as percentage of total installed cost, for operation and maintenance of conductors.
Cost of installed generating capacity (Cg)	$1,000	Cost ($/kW) of generation capacity, used to account for the capital cost of generation needed to cover line losses.
Fixed charge rate on generation capacity (Fg)	17%	Annual charge as a percentage of capital investment, for operation and maintenance of generation assets needed to cover the line losses.
Reserve factor (RF)	1.2	Ratio of generation capacity to total demand including losses.
Peak responsibility factor (PRF)	95%	Probability that the peak load on the line will correlate to peak load on generation.
Loss allowance factor (LAF)	1	A factor to account for losses incurred delivering power to a line. Unit (1) is used for transmission that is connected to the generator.
Load factor (LF)	25%	Ratio of average annual load to peak capacity (for computing annual line loss).
Growth factor (GF)	1.02	A factor to account for future generation costs as the load on the line increases over time. 2% is a low-growth scenario, but note this is not a major cost factor.
Present cost of energy	0.04	Average wholesale cost for electricity ($/kWh).
Equivalent annual cost of energy (EAC)	0.0721	Average electricity cost adjusted for inflation over the life of the line ($/kWh).
Conductor service life	50	Expected service life of new conductor (years).
Inflation Rate (r)	4%	Expected general inflation rate.
Interest Rate (I)	8%	Cost of capital for financing transmission projects.
Required Peak Capacity (A)	1700	Minimum target capacity after reconductor (A)

Conductor Cost Computed per Aluminum Association Publication 54

The equations and data from Publication 54 were coded in an Excel® spreadsheet for detailed accounting analysis of the reconductor options listed in Table 1. The fixed cost of any given conductor is an annual charge based on the first cost and remains the same for the life of the conductor regardless of the assumptions for average annual load. The variable conductor costs vary considerably depending on the assumption for the average annual load.

The cost for line loss increases as I^2R, where “I” is the current in amperes, and “R” is the conductor resistance. The “I^2” term makes the cost of losses highly sensitive to the assumption used for the average annual load in amperes “I”. The following section shows the sensitivity of the owning cost depending on the assumed future line loading.

Sensitivity Analysis for the Average Annual Load Assumption

1. Cost Analysis for 170 A Average Annual Load (10% of Maximum Capacity)

170A is a reasonable assumption for the average annual load on a “Drake” ACSR line designed 40 years ago. Table 3 shows the values computed for “Drake” ACSR and the three reconductor candidates. The color coding in the table identifies the fixed annual costs, the annual cost of losses, and the total annual cost.

The colors correspond to the colors used in the respective load analysis Figure to summarize the annual owning cost data.

At 170A average annual load, ACSR "Drake" is the most economical solution.

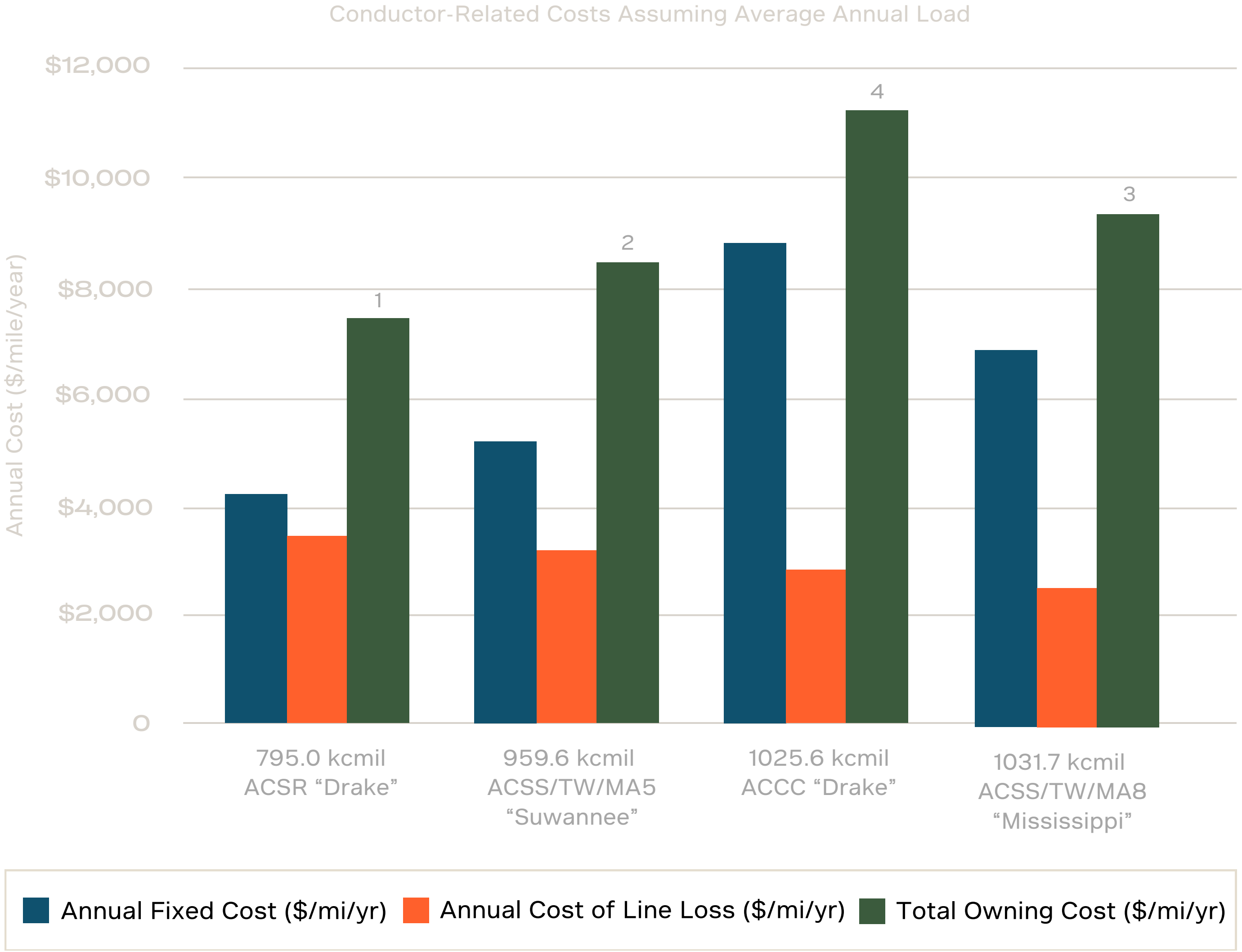
Table 3: Cost Values for Conductor Candidates Assuming 10% Load Factor (170A)

Economic Parameters	795.0 kcmil ACSR “Drake”	959.6 kcmil ACSS/TW/MA5 “Suwannee”	1025.6 kcmil ACCC “Drake”	031.7 kcmil ACSS/TW/MA8 “Mississippi”
I (Average annual current, A)	170	170	170	170
Tc (Conductor Temperature, ℃)	49.9	49.6	49.6	49.6
R (AC Resistance at Tc, Ω/mi)	0.1278	0.1033	0.990	0.0973
PL (Power Loss, kW/mi)	3.69	2.99	2.86	2.81
APL (Adj. Power Loss, kW/mi)	4.29	3.47	3.33	3.27
Fg x Cg (Demand Cost for Line Loss, $/mi/yr)	$730.10	$590.14	$565.57	$555.86
Pe (Annual Energy Losses, kWh/mi/yr)	37,600	30,400	29,100	28,600
Conductor Installed Cost ($/mi)	$21,874	$28,079	$44,723	$36,070
Cc (Fixed Annual Cost, $/mi/yr)	$4,156	$5,335	$8,497	$6,853
Ce (Annual Energy Loss Cost, $/mi/yr)	$3,440	$2,780	$2,660	$2,620
C (Total Annual Cost, $/mi/yr)	$7.596	$8,115	$11,157	$9,473

Figure 2 below is a graphic of the color-coded data from Table 3, the low-load scenario. Line losses are relatively small, and the fixed annual cost (blue bars) is a significant fraction of the total annual owning cost. The number above the total owning cost bar is the ratepayer benefit ranking of that conductor relative to the peer group.

795 kcmil ACSR “Drake” is the least total cost but note that 959.7 kcmil ACSS/TW/MA5 is in close second place and would be the compelling choice if value is assigned for its 99% capacity increase and reduced high-temperature sag compared to ACSR. Regardless of cost, ACSR might not qualify due to a thermal limit that is only 60% of the required capacity assumed for the reconductor scenario. A ranking of 1 indicates the least cost of ownership, whereas 4 denotes the highest cost of ownership.

Figure 2: Conductor Costs Based on Average Annual Load of 170 A (10% Capacity)



Note: The number above bar is the conductor's ranking for ratepayer benefit

2. Cost Analysis for 255 A Average Annual Load (15% of Maximum Capacity)

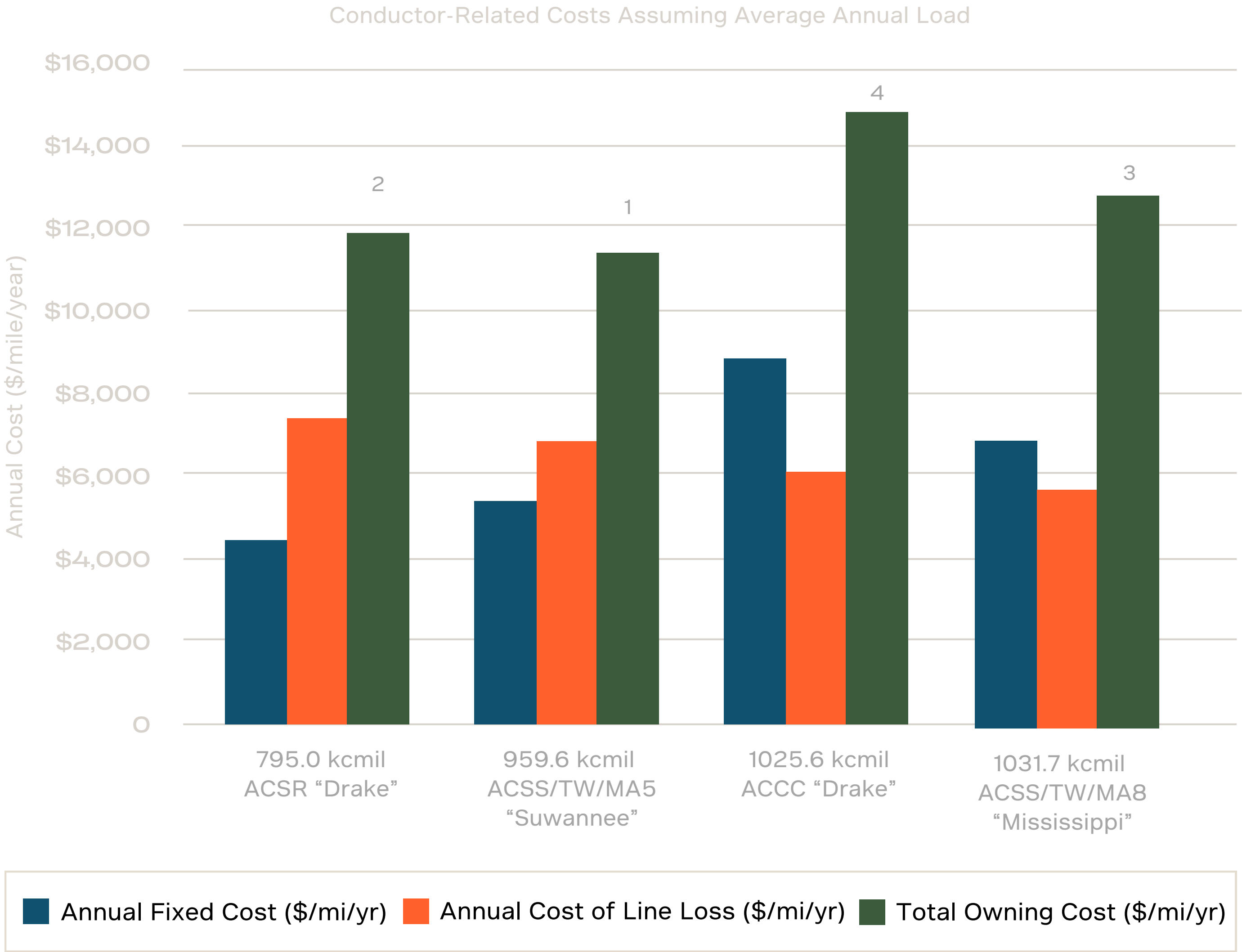
Table 4 shows the values computed for the average annual load of 15% of capacity. The computations show the effect of the current squared (I^2) term in the line loss.

For ACSR "Drake", the cost of line loss now exceeds the first cost. As a result "Drake" has moved from lowest annual cost to second place. 959.6 kcmil ACSS/TW/MA5 is now the lowest annual cost.

Table 4: Cost Values for Conductor Candidates Assuming 15% Load Factor (255 A)

Economic Parameters	795.0 kcmil ACSR “Drake”	959.6 kcmil ACSS/TW/MA5 “Suwannee”	1025.6 kcmil ACCC “Drake”	031.7 kcmil ACSS/TW/MA8 “Mississippi”
I (Average annual current, A)	255	255	255	255
Tc (Conductor Temperature, °C)	51.6	51.0	50.9	50.8
R (AC Resistance at Tc, Ω/mi)	0.1285	0.1037	0.0995	0.0997
PL (Power Loss, kW/mi)	8.36	6.74	6.47	6.35
APL (Adj. Power Loss, kW/mi)	9.72	7.84	7.52	7.39
Fg x Cg (Demand Cost for Line Loss, $/mi/yr)	$1,652	$1,333	$1,279	$1,256
Pe (Annual Energy Losses, kWh/mi/yr)	85,100	68,700	65,900	64,700
Conductor Installed Cost ($/mi)	$21,874	$28,079	$44,723	$36,070
Cc (Fixed Annual Cost, $/mi/yr)	$4,156	$5,335	$8,497	$6,853
Ce (Annual Energy Loss Cost, $/mi/yr)	$7,790	$6,290	$6,030	$5,920
C (Total Annual Cost, $/mi/yr)	$11,946	$11,625	$14,527	$12,773

Figure 3: Conductor Annual Cost for Average Annual Load of 255 A (15% of Capacity)



Note: The number above bar is the conductor’s ranking for ratepayer benefit

3. Cost Analysis for 425 A Average Annual Load (25% of Maximum Capacity)

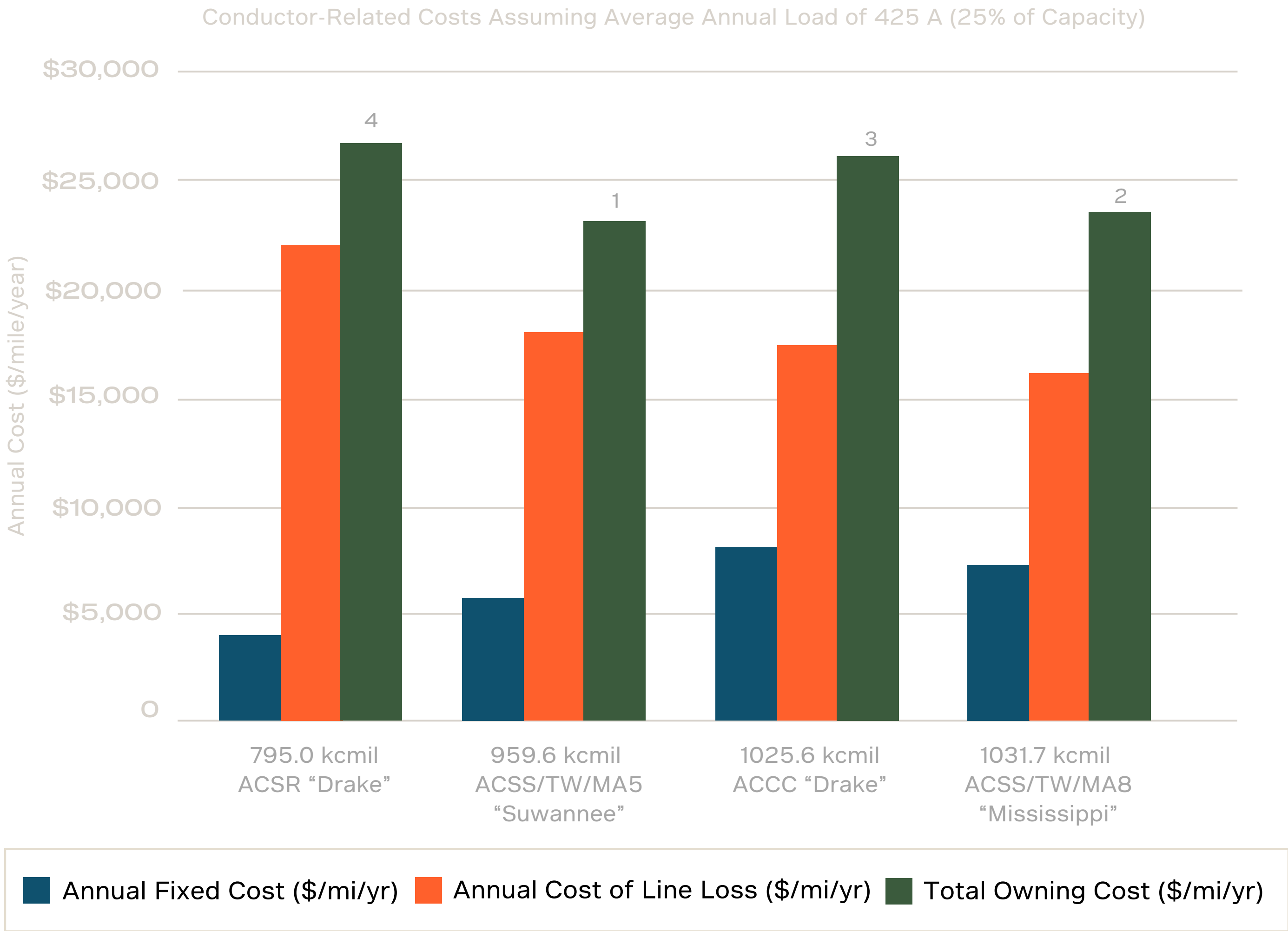
Table 5 shows the values computed for the average annual load of 25% of capacity. Again, the numbers above the total cost bars designate the "ratepayer friendly" ranking for that conductor. The computations show the large effect of the current squared ("I²" term) in the energy loss. The cost of line loss now exceeds the first cost by a large margin.

ACSR "Drake" has moved from lowest annual cost to highest annual cost, simply due to the large increase in the line loss. The rankings of the reconductor candidates have also changed. 959 kcmil ACSS/TW/MA5 is again the lowest annual cost. 1031.7 kcmil ACSS/TW/MA8 has approximately equal cost and would be the compelling choice if credit were given for its significant capacity advantage. A ranking of 1 indicates the least cost of ownership, whereas 4 denotes the highest cost of ownership.

Table 5: Conductor Costs for Average Annual Load of 425 A (25% of Capacity)

Economic Parameters	795.0 kcmil ACSR "Drake"	959.6 kcmil ACSS/TW/MA5 "Suwannee"	1025.6 kcmil ACCC "Drake"	031.7 kcmil ACSS/TW/MA8 "Mississippi"
I (Average annual current, A)	425	425	425	425
Tc (Conductor Temperature, ℃)	57.1	55.4	55.2	55.0
R (AC Resistance at Tc, Ω/mi)	0.1310	0.1054	0.1010	0.0991
PL (Power Loss, kW/mi)	23.66	19.04	18.24	17.90
APL (Adj. Power Loss, kW/mi)	27.51	22.14	21.21	20.81
Fg x Cg (Demand Cost for Line Loss, $/mi/yr)	$4,680	$3,760	$3,610	$3,540
Pe (Annual Energy Losses, kWh/mi/yr)	241,000	193,900	185,800	182,300
Conductor Installed Cost ($/mi)	$21,874	$28,079	$44,723	$36,070
Cc (Fixed Annual Cost, $/mi/yr)	$4,156	$5,335	$8,497	$6,853
Ce (Annual Energy Loss Cost, $/mi/yr)	$22,060	$17,750	$17,010	$16,690
C (Total Annual Cost, $/mi/yr)	$26,216	$23,085	$25,507	$23,543

Figure 4: Conductor Costs Based on Average Annual Load of 425 A (25% of Capacity)



Note: The number above green bars are the ranking by ratepayer benefit

4. Cost Analysis for 595 A Average Annual Load (35% of Maximum Capacity)

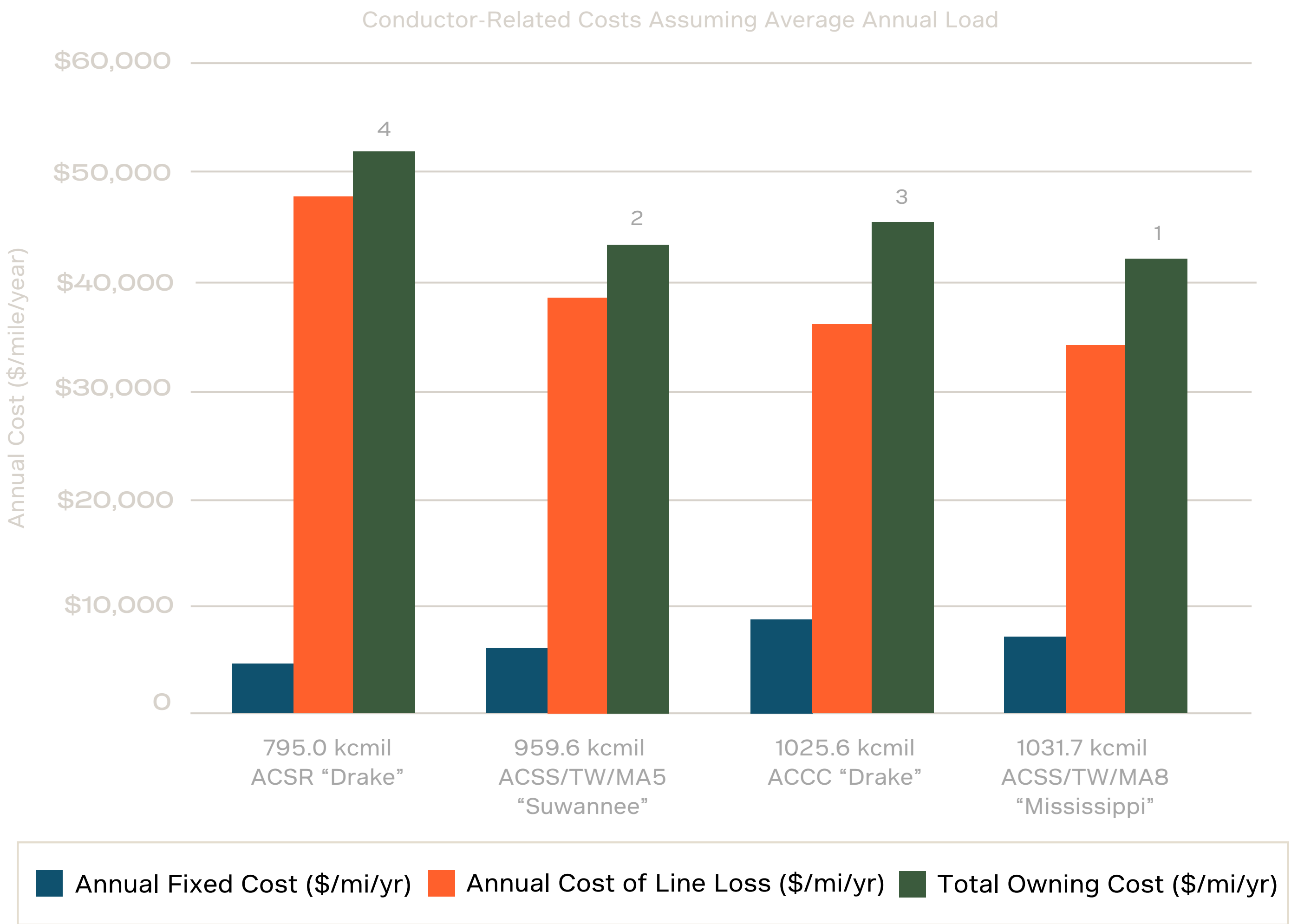
The data in Table 5 below shows one reason the average annual load for HTLS conductors seldom approaches 35% of maximum capacity: the conductor temperature exceeds 75 ˚C (167 ˚F). The cost of line losses becomes prohibitive. A second reason is that utilities are required to maintain continuity of service even after the failure of one or more major assets. Most transmission lines need more than 50% reserve capacity to keep the lights on at the hospital if another major system component fails unexpectedly.

At 595A, 1031.7 kcmil ACSS/TW/MA8 has the lowest cost, the lowest line loss, and the highest capacity. The cost advantage increases as the load increases. All the "Drake" diameter conductors are too small for the assumed 595A average annual load. A larger conductor is more economical and will have lower rate payer impact despite higher first cost. As a back up for an efficient EHV or UHV line, the extended capacity and excellent overload tolerance, low cost, and low line loss make ACSS/TW with a giga steel core the best conductor for this scenario. A ranking of 1 indicates the least cost of ownership, whereas 4 denotes the highest cost of ownership.

Table 5: Conductor Costs for Average Annual Load of 595 A (35% of Capacity)

Economic Parameters	795.0 kcmil ACSR "Drake"	959.6 kcmil ACSS/TW/MA5 "Suwannee"	1025.6 kcmil ACCC "Drake"	031.7 kcmil ACSS/TW/MA8 "Mississippi"
I (Average annual current, A)	595	595	595	595
Tc (Conductor Temperature, ℃)	85.1	77.6	76.4	75.9
R (AC Resistance at Tc, Ω/mi)	0.1436	0.1136	0.1085	0.1063
PL (Power Loss, kW/mi)	50.80	40.20	38.40	37.6
APL (Adj. Power Loss, kW/mi)	59.10	46.80	44.70	43.80
Fg x Cg (Demand Cost for Line Loss, $/mi/yr)	$10,050	$7,950	$7,590	$7,440
Pe (Annual Energy Losses, kWh/mi/yr)	517,800	409.700	391,300	383,300
Conductor Installed Cost ($/mi)	$21,874	$28,079	$44,723	$36,070
Cc (Fixed Annual Cost, $/mi/yr)	$4,156	$5,335	$8,497	$6,853
Ce (Annual Energy Loss Cost, $/mi/yr)	$47,400	$37,500	$35,810	$35,090
C (Total Annual Cost, $/mi/yr)	$51,556	$42,835	$44,307	$41,943

Figure 5: Conductor Costs Based on Average Annual Load of 595 A (35% of Capacity)



Note: The number above bar is the conductor's ranking for ratepayer benefit

Conclusions

Conductor selection is a multi-variable optimization process. Regulatory commissions play a large role, as they protect the ratepayers by ensuring investments in electrical infrastructure are prudent. The ratepayer is best protected if the conductor with the lowest annual ownership cost is selected.

In this analysis, **the ACSS/TW steel core conductors have the lowest annual ownership cost over all load scenarios.** Conductors are expected to last 50 years. The fixed annual cost charges for conductors affect rates for the service life of the line, which is expected to be 50 years into the future.

Bibliography

Ref 1 Aluminum Association Publication 54.
"The evaluation of losses in conductors", Second Edition, 1998.

Ref 2 UK website Energy Sanity.
“How Much Energy Is Lost in Power Transmission Lines?”

Ref 3 Idaho National Laboratory. (December 2023).
“Advanced Conductor Scan Report (Report No. INL/RPT-23-75873 R10).” Department of Energy. 23-50856_R10_-AdvConductorszScanProjectReport-1.pdf (inl.gov)

Ref 4 IEEE 738-2012.
“IEEE Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors.”

Ref 5 Midcontinent Independent System Operator (MISO) 2024 Transmission Cost Estimation Guide.

Ref 6 ASTM 609-2021.
“Aluminum 1350 Round Wire, Annealed and Intermediate Temper, for Electrical Purposes”.

Ref 7 ASTM B857-2022.
“Shaped-Wire Compact Concentric-Lay Stranded Aluminum Conductors, Coated-Steel Supported (ACSS/TW)”.

Ref 8 ASTM B958-2023.
“Extra High Strength and Ultra-High-strength Class A Zinc-5% Aluminum Mischmetal Alloy-Coated Steel Core Wire for Use in Overhead Electrical Conductors”.

Ref 9 ASTM B987.
“Carbon Fiber Thermoset Polymer Matrix Composite Core (CFC) for use in Overhead Electrical Conductors”.

Ref 10 CIGRE Paper ID 10963 Session 2022
“World longest span with ACSR Conductor – Design challenges”.

Ref 11 IEC 63248 ED1.
“Conductors for overhead lines - Coated or cladded metallic wire for concentric lay stranded conductors”

Modifications reserved

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