ACSS/TW - An Improved Conductor for Upgrading Existing Lines or New Construction

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Abstract: This paper describes the properties and performance characteristics of an improved overhead conductor, ACSS/TW. ACSS/TW is constructed of fully annealed aluminum wires formed into a trapezoidal shape. The aluminum wires are stranded around a steel core of seven or more wires as described in ASTM B-857. The improved conductor can operate continuously at temperatures up to 250°C without loss of strength; its sag is less than that of conventional composite conductors; final sags are not affected by creep; it has excellent self-damping characteristics. ACSS/TW can be designed with both equal area or equal diameter, compared to conventional round stranded conductors, to optimize line design options.

Keywords: Overhead Conductors, Sag, Reconductoring, Uprating, Upgrading, Transmission Lines, Distribution Lines, SSAC, ACSS

I. INTRODUCTION

The electric utility industry is undergoing a changing competitive environment. These changes are affecting how electricity is generated, transmitted and sold throughout the US. and North America. Deregulation of the electric power industry means more than just new business models and acronyms. Utilities face an abundance of technical hurdles to maintain a competitive and reliable power system. Not the least of these is the transmission and distribution infrastructure. Most agree that the nation's transmission capacity has reached or is nearing the critical limit. The additional power transactions that deregulation will bring may be more than the existing system can reliably handle.

Because of the increased uncertainty in future electrical loads in a competitive deregulated environment, utilities are less willing to make large investments. Increasing competition is requiring them to squeeze as much capacity as possible from the existing lines. As these lines become overloaded the thermal limit of the conductor is exceeded causing loss of strength in the conductor and sags exceeding predicted limits.

Reviewing the needs of the utility industry, it became apparent that the existing conductor designs had definite limitations. A review of the design elements of existing conductors provides options for the development of an improved conductor design.

1. <u>Annealed Aluminum Strand</u>:

One design option originated with a conductor developed in the early 1970's, formerly known as SSAC, using fully annealed aluminum wires [1]. This conductor is presently referred to as ACSS [5]. The steel core provided the entire support for the conductor. The aluminum wires contribute virtually no mechanical strength to the conductor. Operating temperature is limited not by the aluminum but by the galvanized coating on the steel core.

2. <u>Coated Steel Core Wire</u>:

A new coating for steel was developed as a suitable replacement for galvanized coatings on steel core wire in the late 1980's. The coating, identified as a zinc-5% aluminum-mischmetal alloy, herein referred to as mischmetal, provides increased corrosion resistance and improved thermal stability. ASTM standards B-802 and B-803 were developed in 1989 defining the requirements of core wire using the new coating.

3. <u>Trapezoidal Shaped Aluminum Wires</u>:

In the early to mid 1980's a conductor construction was introduced replacing the round wires in conventional stranded conductors with trapezoidal shaped wires. Replacing the round wires with wires of a trapezoidal shape created a more compact conductor of equal metal area having a smaller overall diameter and less void space at the strand interstices. The smaller conductor diameter reduced ice and wind loading on the conductor. The shaped wire conductor has a lower drag coefficient, increased resistance to vibration and improved fatigue resistance. A second construction was introduced with equal diameters to that of conventional stranded conductors. The equal diameter design provides a conductor with all the advantages of the equal area design, but with increased aluminum area. With only a modest increase in weight, the cable exhibits reduced resistance, increased current carrying capacity, and increased strength.

A shaped wire, compact concentric-lay-stranded aluminum conductor, steel supported, ACSS/TW, was developed. This conductor combines the concept of fully annealed aluminum wires, in a trapezoidal shape, concentric-lay-stranded around a mischmetal coated steel core. The conductor can be designed in constructions with either equal area, or equal diameter, to the corresponding conventional round ACSS. Some of the performance advantages exhibited by this new conductor construction:

- ACSS/TW can operate continuously at temperatures up to 250°C without any detriment to mechanical properties.
- ACSS/TW will sag significantly less at high temperatures than other conductors when the installed tensions under ice and wind loading are approximately the same.
- The final sag of ACSS/TW is not affected by long term creep in the aluminum.
- ACSS/TW has improved self damping characteristics and exhibits a high degree of resistance to vibration fatigue.
- The aluminum wires of the ACSS/TW conductor have an increased conductivity of 63% IACS.
- The mischmetal coated core provides improved corrosion resistance and thermal stability.

II. DISCUSSION OF CONDUCTOR PROPERTIES

ASTM Standard B-857 "Shaped Wire Compact Concentric-Lay-Stranded Aluminum Conductors, Coated-Steel Supported (ACSS/TW)" defines the basic conductor properties and construction requirements for ACSS/TW. A more in depth discussion of these properties is presented here.

1. Annealed Aluminum Strand:

ACSS/TW, develops most of its performance advantages from the fact that the aluminum wires are fully annealed during the manufacturing process and have very low yield strength [1]. Because of the low yield strength, rapid permanent or inelastic elongation occurs in the aluminum when tension is applied to the composite conductor transferring the load to the steel core. The trapezoidal shape has no effect on the ductility of the aluminum in the fully annealed, "O" temper. Typical properties of the shaped ACSS aluminum as compared to conventional hard drawn, 1350 aluminum, are listed in TABLE 1.

TABLE 1
Typical Properties of
Annealed ACSS Aluminum Wires vs. HD Aluminum Wires

Property	ACSS Aluminum	Hard Drawn Aluminum
Tensile Str., Min, Avg., ksi (MPa)	8.5 - 11.0* (59 - 76)	23.5 - 29.0 (160.0 - 200.0)
Elongation in 10 in., Min., %	20 - 30	1.2 to 2.0
Conductivity, Min., % IACS	63 **	61.2

* 8.5 - 14 ksi (59 - 76 MPa) required by ASTM.
** 61.8% IACS minimum conductivity required by ASTM.

2. Mischmetal Coated Steel Core Wire:

The maximum operating temperature of ACSS/TW conductor is limited only by the temperature at which damage will occur to the coating on the steel core. Conventional galvanized coatings deteriorate rapidly at temperatures above 245°C. Mischmetal coated steel core exhibits improved thermal stability and corrosion resistance over galvanized core wire. Samples of the class "A" mischmetal coated core were exposed to temperatures up to 343°C (650°F) for 32 hours without physical damage to the coating. Samples of the core wire, aged for 32 hours, were also subjected to a Salt Spray Corrosion test performed in accordance with ASTM B-117. Results indicate that after aging for 32 hours at 343°C (650°F), the time to formation of red rust was in excess of three times (3x) that required for standard class "A" zinc galvanized core wire. Results of the corrosion test are indicated in TABLE 2 below.

3. Rated Strength:

The rated strength of ACSS/TW is calculated using the aggregate tensile strengths of the aluminum and steel components [5]. The strength is based on 96% of the aggregate strengths of the equivalent round aluminum wires at a minimum average tensile strength of 8.5 ksi (59 MPa) and the minimum average tensile strength for the core wire as specified by ASTM. Because the elongation of the fully annealed aluminum wires is several times that of the steel core wire, the full rated strength of the steel may be utilized.

The rated strength of ACSS/TW is primarily dependent upon

TABLE 2
Salt Spray Corrosion Test Results

Sample	Hours to 5% Red Rust per ounce of coating
.094 in. (2.39 mm) Mischmetal coated (from stranded core wire without aging)	1019
.094 in. (2.39 mm) Mischmetal coated (from core wire after aging @ 343°C for 32 hr.)	1285
12 Ga. hot-dip-galvanized class "A" coated steel wire	310
12 Ga. electro-galvanized class "A" coated steel wire	394

TABLE 3 Strength Comparison ACSR vs. ACSS/TW Constructions			
ACSR Construction	ACSR Strength lbs. (N)	ACSS/TW Eq. Area lbs. (N)	ACSS/TW Eq. Dia. lbs. (N)
477 kcmil 26/7 Str.	19,500 (86,740)	15,600 (69,392)	18,400 (81,847)
795 kcmil 26/7 Str.	31,500 (153,464)	25,900 (115,209)	30,700 (136,560)
954 kcmil 45/7 Str.	25,900 (115,209)	16,700 (74,285)	20,500 (91,189)
954 kcmil 54/7 str.	33,800 (150,350)	26,000 (115,654)	31,100 (138,340)
1272 kcmil 54/19 Str.	43,600 (193,942)	34,100 (151,684)	41,200 (183,267)
1590 kcmil 45/7 Str.	42,200 (187,715)	27,900 (124,105)	34,300 (152,574)

the grade and content of steel core wire and may be less than conventional ACSR of the same area and/or diameter. TABLE 3 gives a comparison for a series of area and/or

diameter equivalent ACSS/TW constructions as compared to standard 795 kcmil (402.9 mm²) ACSR constructions.

The strandings of ACSS/TW are defined in terms of Type numbers like ACSR/TW. The Type number indicates the steel to aluminum area ratio in percent, i.e., a Type 16 indicates 16% steel area ratio, the same steel area ratio contained in a 26/7 stranding for conventional ACSR. A listing of Type vs. stranding is given in TABLE 4 below.

4. *<u>High temperature Capability</u>*:

The maximum continuous operating temperature for ACSS/TW conductors is 250°C. Because the aluminum wires are fully annealed, the conductor can operate at this temperature continuously with no loss of strength. The mischmetal coating on the steel core wire experiences no adverse effects until exposed to temperatures well above the suggested maximum operating temperature of 250°C.

5. *<u>Current Carrying Capacity</u>*:

TABLE 4 Comparison of ACSS/TW Type Numbers with Equivalent Strandings of ACSR.	
ACSS/TW Type Number	Conventional ACSR Stranding
3	36/1
5	42/7
6	18/1
7	45/7
8	84/19
10	22/7
13	54/7
13	54/19
13	24/7
16	26/7

The maximum continuous operating temperature normally observed for conventional conductors is 75°C with a maximum emergency overload temperature of 100°C. Typically when lines are designed the conductor size is determined, not only for the daily load to be transmitted, but
also to allow increased emergency loads for a contingency ratings. With ACSS/TW more emphasis can be placed on present and projected growth loads rather than emergency contingency loads. Also, when reconductoring a line, the increased current carrying capacity combined with reduced sag at higher operating temperatures can increase the line's overload current capacity by up to 50%, without reducing required clearances.

As seen in TABLE 5 below, the current carrying capacity of Suwannee/ACSS/TW, the diameter equivalent of 795 kcmil (402.9 mm²) - 26/7 ACSR "Drake", is 2000 amps at 250°C. This is double the current carrying capacity of standard 795 kcmil (402.9 mm²) - 26/7 ACSR at 100°C.

6. <u>Self-Damping Characteristic</u>:

Conventional types of conductors inherently have some degree of capability for damping aeolian vibration [1]. The degree of resistance to aeolian vibration is dependent upon many factors, including metal temper, strand configuration, conductor construction, internal friction, etc. Lower radial compressive forces between conductor strand layers leads to increased strand movement and higher self damping capability. ACSS/TW exhibits lower compressive forces between the aluminum strand layers and the steel core than conventional ACSR because of the increased ductility of the aluminum in the fully annealed state. When stressed, the aluminum elongates and transfers all the tensile load to the steel core. This increases the self-damping capability of the ACSS/TW conductor construction well beyond that of conventional conductors.

To verify that ACSS/TW exhibited improved self-damping properties, a series of self-damping tests were performed. The test consisted of four constructions of 795 (402.9 mm²) kcmil-26/7 ACSR equivalent conductors. The four conductors, each

TABLE 5 Current Carrying Capacity* 795 kcmil (402.9mm²) - 26/7 ACSR "Drake" vs. ACSS/TW Conductors of Equal Area & Equal Diameter			
Conductor Temp. °C	Standard 795 ACSR	ACSS/TW Equal Area	ACSS/TW Equal OD
75	730	720	820
100	990	980	1110
150	------	1320	1490
200	------	1560	1770
250	------	1740	2000

*Ampacities calculated assuming an ambient temperature of 40°C, .61 m/sec wind, sun, .5 coefficient of emissivity and absorptivity having a mischmetal coated steel core, were conventional ACSR, ACSR/TW, ACSS and ACSS/TW.

The conductor was tested at 15%, 20% and 30% of its Rated Tensile Strength (RTS). Upon completion of the 30% level, the conductor was loaded to 50% RTS and held for one hour. The conductors were tested again at final stress levels of 30%,
20%, and 15% RTS.

The conductors were tested using the "Inverse Standing Wave Ratio" (ISWR) test method. The anti-node displacement (double) amplitudes selected for the test were 33/f, 67/f, and 100/f which correspond approximately to the transverse loop velocities of (100 $^{mm}/_{sec}$), (200 $^{mm}/_{sec}$) and (300 $^{mm}/_{sec}$) respectively. Previous investigators have reported that loop velocity correlates directly to maximum strain. The fatigue limit for aluminum is considered to be approximately 150 microstrain which corresponds to the anti-nodal amplitude of 67/f. The values of anti-nodal displacement amplitude selected correspond to 0.5, 1.0, and 1.5 times the fatigue limits for aluminum, respectively.

A minimum of five different modes (loop lengths) per tension level were tested for each conductor. Modes 4, 8, 12, 16, and 20 were chosen since they were within the ranges of the frequencies and wind speeds classified as causing aeolian vibrations on overhead conductors.

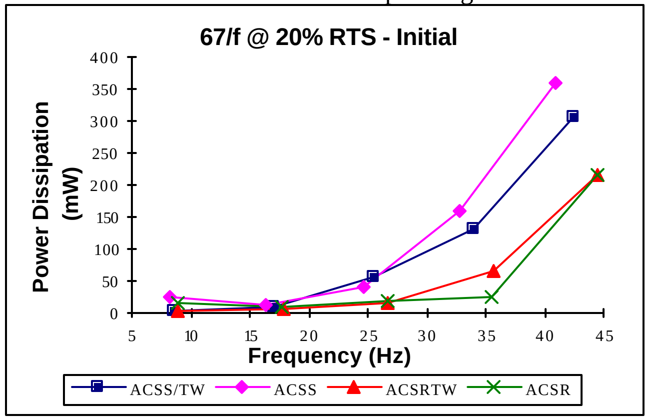
Comparison of the data indicate that the ACSS and ACSS/TW constructions have a higher degree of self-damping capabilities compared to the ACSR and ACSR/TW constructions. With respect to the conductors in their initial states, all four constructions possess relatively similar damping characteristics below 20 Hertz. The power dissipated by each conductor is generally very low--often less than 50 mW. The power dissipation typically increases by as much as two to four times on average at 20 Hertz and higher for the ACSS and ACSS/TW constructions compared to the ACSR and ACSR/TW constructions.

The damping performance of the four constructions varied considerably after stretching the conductors to their final states. The power dissipated by the ACSS and ACSS/TW constructions compared to the ACSR and ACSR/TW constructions increases by as much as 5-20 times throughout the entire frequency spectrum.

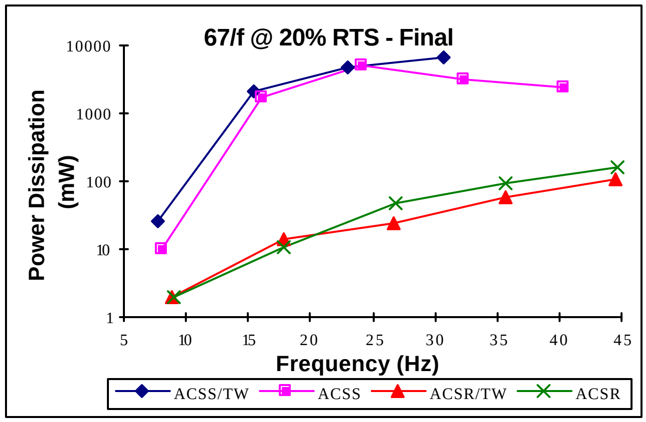
Fig. 1 shows the power dissipation characteristic for all four conductor constructions at a tension of 20% Rated Breaking Strength (RBS) and an antinode displacement of 67/f ($200^{mm}/_{sec}$). Fig. 1(a) shows the power dissipation without prestressing (initial) and Fig. 1(b) after prestressing to 50% RBS (final).

7. Long Term Creep:

Conventional conductors experience permanent elongation, long term creep, due to the high tensile stresses in the aluminum strands. Creep is not a factor in ACSS/TW conductors. In service, all stress in the aluminum is rapidly transferred to the steel core under operating conditions.



(a)



(b)

Fig. 1 Power Dissipation Characteristic

Therefore, creep of the aluminum does not affect the final sags of ACSS/TW conductors. The long term creep rate of steel is very small and can be neglected for the normal allowable operating stresses.

8. Sag-Tension Performance:

Sag and tension for ACSS/TW can be generated using the stress-strain characteristics for standard ACSS conductors with a stranding equivalent to the Type classification for the ACSS/TW conductors.

When tension is applied to the ACSS/TW conductor, permanent elongation of the aluminum wires occurs rapidly. As the aluminum stretches, the tensile load is transferred to the steel. Once stressed in service or prestressed at time of installation, the sag of the conductor is only dependent upon the changing length of the steel with temperature. The

TABLE 6 Designing with lower Thermal Elongation of ACSS/TW			
Conductor Temp. °C	"Drake" ACSR Sag- ft (m)	"Suwannee" ACSS/TW Sag - ft (m)	Ampacity
15	31.0 (9.45)	31.0 (9.45)	-----
100	37.6 (11.46)	35.3 (10.76)	990 / 1110
150	-----	37.8 (11.52)	1490

Final sags based on 1000 foot (305 meter) span.
Ampacities based on 40°C ambient, .61 m/sec wind, sun.

coefficient of thermal expansion for steel is 11.5 x 10^{-6} /°C. This is approximately half that of conventional ACSR conductors. Therefore, the sag of ACSS/TW conductors is much less than that of ACSR. TABLE 6 shows a comparison in sags of 795 (402.9 mm²) kcmil 26/7 ACSR "Drake" and equivalent diameter 959.6 kcmil (486.4 mm²) Type-16

"Suwannee/ACSS/TW" when installed to the same final sags at 15°C (60°F).

III. LINE UPGRAGE EXAMPLE

ACSS/TW conductors provide the transmission engineer with more design options than any other conductor. One example of reconductoring using ACSS/TW conductors is presented below.

Example:
The line to be upgraded is a 138 kV transmission line installed on light duty wood pole H-frame construction. No cross-braces between poles or knee braces for cross-arms were installed. The wood pole structures are in good condition although the line has been in service between 30 and 40 years. The line was constructed with 477 kcmil (241.7 mm²) - 26/7 ACSR "Hawk" at a maximum NESC heavy loaded tension of 7350 lb. (3334 kg). The average ruling span was 600 feet. At the maximum conductor temperature of 100°C the sag is 15.3 feet (4.85 meters). Rated current carrying capacity of the conductor is 710 amps at the 100°C thermal limit.

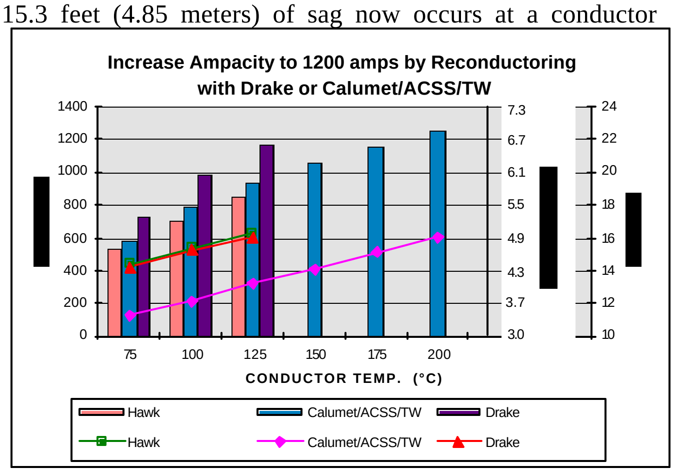
TABLE 7 Comparative Conductor Properties			
	477 kcmil-26/7ACSR "Hawk"	795 kcmil-26/7 ACSR "Drake"	565.3 kcmil, T-16 ACSS/TW
Size, kcmil (mm²)	477 (241.7)	795 (402.9)	565.3 (286.5)
Diameter, in. (mm)	0.858 (21.8)	1.108 (28.1)	0.858 (21.8)
Weight, lb/1000 ft (kg/km)	655.8 (975.9)	1093.4 (1627.1)	714.8 (1063.7)
Weight Increase, %	-----	67	9
Breaking Str., lbs. (N)	19,500 (86,740)	31,500 (140,119)	18,400 (81,847)
Strength Change, %	-----	+ 62	-6

Requirement:
Increase thermal capacity by at least 30%, without exceeding the maximum sag clearance of 15.3 feet (4.85 meters). Upgrade must be completed with absolute minimum capital investment.

Considerations:
Two alternatives are considered for the upgrade. One is conventional 795 kcmil (402.9 mm²) - 26/7 "Drake" ACSR conductor, with a current carrying capacity of 990 at 100°C. A second alternative is a 565.3 kcmil (286.5 mm²) Type-16 "Calumet/ACSS/TW", diameter equivalent to the existing 477 kcmil (241.7 mm²) ACSR. The Calumet/ACSS/TW has a current carrying capacity of 790 amps at 100°C and 1160 at 175°C. TABLE 7 shows a comparison of the conductors.

Option 1:
If conventional 795 kcmil (402.9 mm²)- 26/7 "Drake" ACSR is used for the reconductoring, the maximum conductor tension under loaded conditions must be increased to 11,050 lb. (5012 kg) to maintain the maximum sag of 15.3 ft. (4.85 meters). Therefore, the maximum tension on the angle and dead-end structures will increase by approximately 50%. The suspension structure and foundation transverse loads will increase by approximately 30%. This increase in tension will require the strain structures to be replaced or reinforced with cross bracing for the H-frame structures and knee bracing for the cross arms. Most suspension structures will also need to be reinforced or replaced. The current carrying capacity of the Drake ACSR is 990 amps at 100°C, a 39% increase.

Option 2:
If the 565.3 kcmil (286.5 mm²) Type-16 Calumet/ACSS/TW conductor is selected, it can be installed at the same ice and wind loaded tension as the original Hawk conductor. It can also be installed to the same sag as the Hawk ACSR but the 15.3 feet (4.85 meters) of sag now occurs at a conductor



*Sag of the 795 kcmil (402.9 mm²) - 26/7 ACSR "Drake" is based on a 50% higher tension than the 477 kcmil (241.7 mm²) - 26/7 ACSR "Hawk"

Fig.2 Ampacity and Sag vs. Temperature

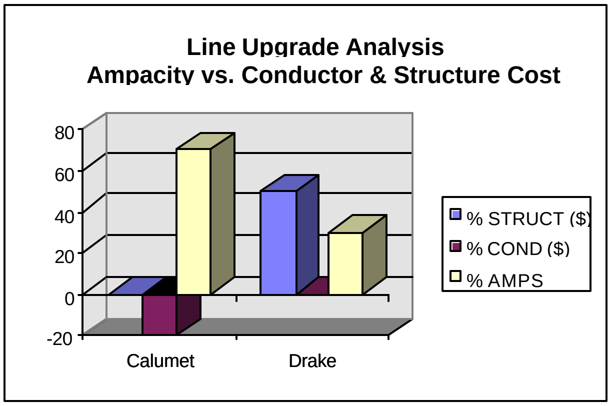


Fig. 3 Line Upgrade Analysis

temperature of 180°C. No reinforcement is required for the strain or suspension structures. The ampacity of the Calumet/ACSS/TW at 180°C is 1200 amps. This is an increase of 70% in current carrying capacity. More than two (2) times the initial upgrade requirement for current increase has been achieved with no structure modifications and no increase in sag.

A comparison of the current carrying capacity versus the temperature and sag for the conductors considered is shown in Fig. 2. The shaded bars represent the current carrying capacity of the conductors at the reference temperatures and the lines indicate the comparative conductor sag vs. temperature.

Using 795 kcmil (402.9 mm²) ACSR "Drake" as the benchmark for conductor costs and referencing the original 477 kcmil "Hawk" ACSR as the benchmark for line upgrade, the comparative cost are summarized in Fig. 3. Reconductoring with 565.3 kcmil (286.5 mm²) Type-16 "Calumet/ACSS/TW", saved the total cost of structure modifications, reduced conductor cost by 20% and increased the contingency current carrying capacity by 70%.

IV. CONCLUSIONS

ACSS/TW is a new conductor which provides increased design options to an engineer when upgrading existing lines or designing new lines. Some of the options are:

- ACSS/TW can operate continuously at temperatures up to 250°C without any detriment to mechanical properties.
- ACSS/TW will sag significantly less at high temperatures than other conductors when the installed tensions under ice and wind loading are approximately the same.
- The final sag of ACSS/TW is not affected by long tern creep in the aluminum.
- ACSS/TW has improved self damping characteristics and exhibits a high degree of resistance to vibration fatigue.
- The aluminum wires of the ACSS/TW conductor have an increased conductivity of 63% IACS.
- The mischmetal coated core provides improved corrosion resistance and thermal stability.
- ACSS/TW is available in conductor constructions of both equal area and equal diameter to optimize line design options.

V. ACKNOWLEDGEMENTS

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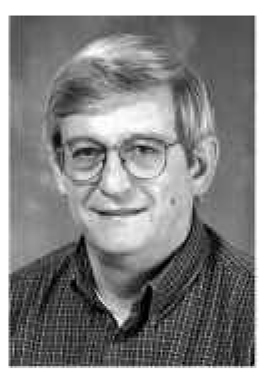

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