Citation: INL, "Corona Testing" in Advanced Conductor Testing: Compilation of Test Results and Summaries, Idaho National Laboratory with Electric Power Research Institute, pp. 216-227, 2025. https://inl.gov/national-security/advanced-grid-solutions/

9 CORONA TESTING

This section presents the results of laboratory tests conducted on Suwannee ACSS/TW conductors manufactured by Southwire Company. The tests were performed by the EPRI Engineering and Test Center in Lenox, which is owned by the Electric Power Research Institute (EPRI).

Background

A utility needed to upgrade two existing 345 kV transmission lines from an existing capacity of 1088 MVA at 90ºC with 2-795 kcmil Drake ACSR conductors per phase at 18” horizontal spacing: to a required capacity of 2000 MVA. The alternatives considered were:

1. Rebuild the line with new structures and larger conventional ACSR conductors.
2. Modify some existing structures, replace some angle structures, and replace the conductor with 3 - 959.6 kcmil ACSS/TW conductors per phase at 18” conductor spacing operating up to 180ºC.

The utility preferred alternative 2. However, information on and experience with corona, radio interference and audible noise performance of the ACSS/TW conductor were very limited at the time. Therefore, the utility requested EPRI to perform tests to assess corona, radio interference and audible noise performance of the Suwannee/ACSS/TW conductor.

Testing Objectives

The objectives of the test program, developed in cooperation with EPRI, were to:

- Determine if the Suwannee/ACSS/TW conductor will have acceptable audible and radio noise level performance at high temperatures for application on 345 kV transmission lines.

High Voltage Tests at the Lenox Laboratory

The corona performance of the Suwannee/ACSS/TW conductor was evaluated at the Lenox Laboratory. The corona tests focused on the audible noise and radio noise that could be produced by a two-conductor bundle or three conductor bundle in a typical application as part of a double circuit three phase line at 345 kV. Audible noise and radio noise are produced by corona activity on a conductor due to the high voltage gradient (electric field) on its surface. The corona activity is affected by the conductor size, bundle configuration, surface condition of the conductor, weather (raindrops on the conductor) and relative air density (RAD). RAD is dependent on the altitude and to a lesser extent the temperature of the air around the conductor. RAD becomes a consideration in this project due to the high operating temperature (250°C) of the Suwannee/ACSS/TW conductor.

The tests at Lenox Center investigated the effect of conductor surface condition, RAD, and bundle configuration. To investigate the effect of the surface state of the Suwannee/ACSS/TW conductor, both “new” and “stressed” or bird-caged conductors were used for the tests, and tests were also performed under dry and rain conditions. The effect of temperature (i.e., of the RAD) was investigated by testing both heated and unheated conductors. The effects of hardware and insulator configuration were investigated by testing open span bundles, and bundles with V-string insulator and hardware assemblies and with armor rod attachments. All the tests were performed on both two conductor bundles and three conductor bundles. The tests were performed using a test voltage that produced a voltage gradient on the surface of the conductors that was equivalent to what they would experience in an actual double circuit application at the typical 5% overvoltage (362 kV three-phase voltage).

Test Results

The purpose of the high voltage tests at the Lenox Center was to confirm, but tests at operating voltage, that the corona performance of the Suwannee/ACSS/TW conductor is satisfactory. The following steps were taken to achieve this purpose:

AN From Boiling of Water Droplets

The results of tests are summarized in Table 9-1.

Table 9-1. Audible Noise (AN) from Boiling Water Droplets

Bundle	AN at the edge of the right-of-way (dB-A)
Two conductor	59
Three conductor	Not important

Cooling Rate

The Suwannee/ACSS/TW conductor cools rapidly when the source of heat is removed, i.e., the current is reduced to zero, especially under rain conditions. The amount of time available for RIV and AN measurements during the high voltage test at the Lenox Center is, therefore, short (about 5 min).

RIV Measurement Results

Measured radio influence voltage (RIV) was due to corona at any point along the entire conductor bundle. The radio noise produced on the Suwannee/ACSS/TW conductor bundle and any associated hardware was coupled to the radio noise meter through a high voltage capacitor.

The measured RIV levels must be adjusted for variations in the temperature, barometric pressure, and test voltage and then converted into radio noise generation levels that can be compared to the radio noise generation of other conductor bundles. The radio noise generation levels were also used to calculate the RI levels at the edge of the right-of-way (55') from the double circuit line configuration of interest.

Since the tests were performed in a test cage and not on an actual overhead transmission line, many adjustment and correction factors need to be applied to derive the final RIV (or RI) level for meaningful comparisons. For example, due to slight unavoidable differences between the actual voltage applied to the cage and the desired test voltage in various tests, the measured RIV needs to be adjusted back to the desired voltage level. The dB adjustment of the measured RIV level for the two Suwannee/ACSS/TW conductor bundle with the desired conductor surface voltage gradient of 17.7 kV/cm is given in (8-1). The dB adjustment factor for the three Suwannee/ACSS/TW conductor bundle with the desired conductor surface voltage gradient of 14.1 kV/cm is given in (8-2).

$$\boldsymbol{db = 580 * \left[\frac{1}{0.094847 * Voltage} - \frac{1}{17.7}\right]} \qquad \text{8-1}$$

$$\boldsymbol{db = 580 * \left[\frac{1}{0.077173 * Voltage} - \frac{1}{14.1}\right]} \qquad \text{8-2}$$

Where: 0.094847 is the cage factor for Suwannee/ACSS/TW twin bundle

17.7 kV/cm is the desired voltage gradient for the Suwannee twin bundle

0.077173 is the cage factor for Suwannee triple bundle

14.1 kV/cm is the desired voltage gradient for the Suwannee triple bundle

A further adjustment of the measured RIV is necessary to account for variation of conductor temperature and barometric pressure from test to test [3]. This adjustment is given by (7-3).

$$\boldsymbol{db = 40 * \left[1 - \frac{273.13}{760} * \frac{Barometric\ Pressure}{273.13 + Temperature}\right]} \qquad \textbf{\textit{9-3}}$$

Where barometric pressure is in millibars, and temperature is in °C.

Table 9-2. lists the measured RIV levels from the cage tests on the bundles of "stressed" Suwannee/ACSS/TW conductor. It also gives the RN generation levels after the measured RIV had been adjusted for variation in temperature, barometric pressure, and cage voltage and has been converted to a radio noise generation level.

The measured RIV levels and the resulting RN generation levels from tests on new (unstressed) Suwannee/ACSS/TW conductor bundles, adjusted for cage voltage, temperature and pressure, are listed in Table 9-3.

Table 9-2. RIV and RN Levels From "Stressed" Suwannee/ACSS/TW Bundle Tests

Test #	Date	Cond Bundle	Cage Volts	V-String Hardware	Temp	Rain	Baro Press	Measured RIV dB(1μV)	RN Generation dB(A/m)1/2
17	2/28	3	184	No	Amb 5°C	No	750	-5	5.1
18	2/28	3	184	No	Amb 5°C	Yes	750	16	26.1
19	2/29	3	184	No	Hot 17°C	No	742	-10	-1.9
20	2/29	3	184	No	Hot 18°C	Yes	742	18	25.9
21	3/2	2	188	No	Amb 5°C	No	732	-7	4.0
22	3/2	2	189	No	Amb 3°C	Yes	731	23	34.0
23	3/3	2	189	No	Hot 20°C	No	733	7	15.9
24	3/2	2	189	No	Hot 35°C	Yes	731	24	31.1
25	3/1	2	190	Yes	Amb 9°C	No	733	-3	7.1
26	3/1	2	190	Yes	Amb 9°C	Yes	733	23	33.1
27	3/1	2	190	Yes	Hot 31°C	No	733	-4	3.4
28	3/1	2	188	Yes	Hot 25°C	Yes	733	24	32.5
29	2/29	3	183	Yes	Amb 5°C	No	742	-5	4.9
30	2/29	3	183	Yes	Amb 5°C	Yes	742	11	20.9
31	3/1	3	184	Yes	Hot 17°C	No	734	-10	-2.4
32	3/1	3	185	Yes	Hot 21°C	Yes	733	15	21.9

Table 9-3. RIV and RN Levels From "New" (Unstressed) Suwannee/ACSS/TW Bundle Tests

Test #	Date	Cond Bundle	Cage Volts	V-String Hardware	Temp	Rain	Baro Press	Measured RIV dB(1μV)	RN Generation dB(A/m)$^{1/2}$
1	2/22	2	189	No	Amb 5°C	No	752	12	23.8
2	2/22	2	189	No	Amb 5°C	Yes	752	31	42.8
3	2/22	2	189	No	Hot 33°C	No	751	13	21.2
3	2/22	2	189	No	Hot 35°C	Yes	751	32	40.0
5	2/28	2	189	Yes	Amb 5°C	No	750	-3	8.4
6	2/25	2	189	Yes	Amb 5°C	Yes	748	29	40.6
7	2/28	2	189	Yes	Hot 40°C	No	750	2	9.2
8	2/25	2	189	Yes	Hot 20°C	Yes	749	27	36.7
9	2/24	3	182	No	Amb 20°C	No	745	-9	-0.7
10	2/24	3	182	No	Amb 19°C	Yes	745	17	25.5
11	2/24	3	182	No	Hot 39°C	No	745	-5	1.1
12	2/24	3	182	No	Hot 29°C	Yes	745	23	30.2
13	2/23	3	186	Yes	Amb 14°C	No	749	10	18.4
14	2/23	3	186	Yes	Amb 14°C	Yes	748	19	27.4
15	2/24	3	185	Yes	Hot 38°C	No	747	-3	2.6
16	2/24	3	186	Yes	Hot 24°C	Yes	747	12	19.0

AN Measurement Results

The audible noise levels from the middle of the conductor bundle for the various test conditions measured by the AN meter are listed in Table 9-4. . The A-weighted AN measure is reported since the A-weighted audible noise scale most closely matches the response of the human ear. The reported A-weighted AN level for these cases is based on the 4 and 8 kHz octave band AN measurements since the spectrum of the audible noise due to corona is in the higher frequencies, and the higher frequency levels tend to be free of ambient noise intrusions.

Table 9-4. AN From "Stressed" Suwannee/ACSS/TW Bundles

Test #	Date	Conductor Bundle	Cage Voltage	V-String Hardware	Temperature	Rain	Barometric Pressure	AN dB(A)
17	2/28	3	184	No	Ambient 5°C	No	750	25.3
18	2/28	3	184	No	Ambient 5°C	Yes	750	55.1
19	2/29	3	184	No	Hot 10°C	No	742	27.7
20	2/29	3	184	No	Hot 15°C	Yes	742	49.8
21	3/2	2	188	No	Ambient 5°C	No	732	29.1
22	3/2	2	189	No	Ambient 3°C	Yes	731	61.7
23	3/3	2	189	No	Hot 22°C	No	733	41.5
24	3/2	2	189	No	Hot 35°C	Yes	731	63.9
25	3/1	2	190	Yes	Ambient 9°C	No	733	28.1
26	3/1	2	190	Yes	Ambient 9°C	Yes	733	57.4
27	3/1	2	190	Yes	Hot 31°C	No	733	31.2
28	3/1	2	188	Yes	Hot 25°C	Yes	733	56.8
29	2/29	3	183	Yes	Ambient 5°C	No	742	25.2
30	2/29	3	183	Yes	Ambient 5°C	Yes	742	50.9
31	3/1	3	184	Yes	Hot 17°C	No	734	27.9
32	3/1	3	185	Yes	Hot 21°C	Yes	733	53.3

The measured AN levels must be corrected for variations in test voltage, temperature, and barometric pressure to allow meaningful comparisons with data for standard temperature pressure conditions. The same standard temperature and pressure conditions of 25°C and 760 millibar pressure are the default conditions used in the ACDCLINE module of the EPRI TLWorkstation. In addition to accounting test voltage, temperature, and pressure, the AN data are converted to an AN generation function that describes the AN produced by corona per unit length of conductor bundle. This AN generation function can then be compared directly to the generation function for any other conductor bundle in a similar line geometry. The AN generation function can also be used to calculate the AN from a transmission line at an arbitrary point such as 55', i.e., at the edge of the right-of-way for the double circuit 345kV line of interest. The formula for calculation of the AN generation level from a measured AN level is given by (8-4).

$$AN\ generation\ level = AN - 114.3\ dB + 10 * LOG(R) \qquad 8\text{-}4$$

Where: AN is the measured audible noise

R is the distance in meters from the conductor bundle to the measurement

point which was approximately 15' (4.75 meters) for the cage tests.

Since the tests were performed in a test cage and not on an actual overhead transmission line, many adjustment and correction factors need to be applied to derive the final AN level for meaningful comparisons. For example, due to slight unavoidable differences between the actual voltage applied to the cage and the desired test voltage in various tests, the measured AN needs to be adjusted back to the desired voltage level. The dB adjustment [3] of the measured AN level for the two Suwannee/ACSS/TW conductor bundle with the desired conductor surface voltage gradient of 17.7 kV/cm is given in (8-5). The dB adjustment factor for the three Suwannee/ACSS/TW conductor bundle with the desired conductor surface voltage gradient of 14.1 kV/cm is given in (8-6).

$$\boldsymbol{db = 665 * \left[\frac{1}{0.094847 * Voltage} - \frac{1}{17.7}\right]} \qquad \text{8-5}$$

$$\boldsymbol{db = 665 * \left[\frac{1}{0.077173 * Voltage} - \frac{1}{14.1}\right]} \qquad \text{8-6}$$

Where: 0.094847 is the cage factor for Suwannee/ACSS/TW twin bundle

17.7 kV/cm is the desired voltage gradient for the Suwannee twin bundle

0.077173 is the cage factor for Suwannee triple bundle

14.1 kV/cm is the desired voltage gradient for the Suwannee triple bundle

A further adjustment of the measured RIV is necessary to account for variation of conductor temperature and barometric pressure from test to test. This adjustment is given by (8-7).

$$\boldsymbol{db = 40 * \left[1 - \frac{273.13}{760} * \frac{Barometric\ Pressure}{273.13 + Temperature}\right]} \qquad \textbf{\textit{8-7}}$$

Where barometric pressure is in millibars, and temperature is in °C.

Table 9-5. lists the measured AN levels from the cage tests on the bundles of “stressed” Suwannee/ACSS/TW conductor. It also gives the AN generation levels after the measured AN had been adjusted for variation in temperature, barometric pressure, and cage voltage and has been converted to a radio noise generation level.

The measured AN levels and the resulting AN generation levels from tests on new (unstressed) Suwannee/ACSS/TW conductor bundles, adjusted for cage voltage, temperature and pressure, are listed in

Table 9-6.

Table 9-5. AN Levels From "Stressed" Suwannee/ACSS/TW Bundle Tests

Test #	Date	Cond Bundle	Cage Volts	V-String Hardware	Temp	Rain	Baro Press	Measured AN dB(A)	AN Generation dB(A)/m
17	2/28	3	184	No	Amb 5°C	No	750	25.3	-86.2
18	2/28	3	184	No	Amb 5°C	Yes	750	55.1	-56.2
19	2/29	3	184	No	Hot 10°C	No	742	27.7	-84.8
20	2/29	3	184	No	Hot 15°C	Yes	742	56.8	-56.3
21	3/2	2	188	No	Amb 5°C	No	732	29.1	-82.6
22	3/2	2	189	No	Amb 3°C	Yes	731	61.7	-50.1
23	3/3	2	189	No	Hot 22°C	No	733	41.5	-72.4
24	3/2	2	189	No	Hot 35°C	Yes	731	63.9	-51.5
25	3/1	2	190	Yes	Amb 9°C	No	733	28.1	-84.5
26	3/1	2	190	Yes	Amb 9°C	Yes	733	57.4	-55.2
27	3/1	2	190	Yes	Hot 31°C	No	733	31.2	-83.9
28	3/1	2	188	Yes	Hot 25°C	Yes	733	56.8	-57.2
29	2/29	3	183	Yes	Amb 5°C	No	742	25.2	-86.4
30	2/29	3	183	Yes	Amb 5°C	Yes	742	50.9	-60.7
31	3/1	3	184	Yes	Hot 17°C	No	734	27.9	-85.8
32	3/1	3	185	Yes	Hot 21°C	Yes	733	53.3	-61.1

Table 9-6. AN Levels From "New" Suwannee/ACSS/TW Bundle Tests

Test #	Date	Cond Bundle	Cage Volts	V-String Hardware	Temp	Rain	Baro Press	Measured AN dB(A)	AN Generation dB(A)/m
1	2/22	2	189	No	Amb 5°C	No	752	39.1	-72.0
2	2/22	2	189	No	Amb 5°C	Yes	752	60.0	-51.1
3	2/22	2	189	No	Hot 33°C	No	751	34.0	-80.4
3	2/22	2	189	No	Hot 35°C	Yes	751	60.8	-53.8
5	2/28	2	189	Yes	Amb 5°C	No	750	37.0	-74.1
6	2/25	2	189	Yes	Amb 5°C	Yes	748	58.6	-52.6
7	2/28	2	189	Yes	Hot 40°C	No	750	36.6	-78.6
8	2/25	2	189	Yes	Hot 20°C	Yes	749	58.7	-54.3
9	2/24	3	182	No	Amb 20°C	No	745	26.2	-86.8
10	2/24	3	182	No	Amb 19°C	Yes	745	53.5	-59.3
11	2/24	3	182	No	Hot 39°C	No	745	31.4	-83.7
12	2/24	3	182	No	Hot 29°C	Yes	745	58.2	-55.8
13	2/23	3	186	Yes	Amb 14°C	No	749	25.0	-88.1
14	2/23	3	186	Yes	Amb 14°C	Yes	748	52.3	-60.8
15	2/24	3	185	Yes	Hot 38°C	No	747	31.1	-84.6
16	2/24	3	186	Yes	Hot 24°C	Yes	747	50.7	-63.7

Summary of Calculated Case Results

The RI and AN generation levels were used to calculate the levels at the edge of the right-of-way. Calculations were performed for a base case of a double circuit 345 kV line, using the TLW-Gen2 software. The base case parameters were obtained from utility.

The basic application of interest for the Suwannee/ACSS/TW conductor is on a double circuit 345 kV transmission line with a vertical phase configuration of ABC-CBA. The span length is 750' and the conductor sag is 24 ft. The right-of-way (ROW) is 110 ft, and the line is at sea level. The tower attachment points of the conductors are 51.5ft, 77.5 ft, and 103.5 ft. The horizontal separation between the phases is 35 ft and the vertical separation is 26 ft.

Two base cases of the double circuit line design are of interest:

- Two conductor bundle with “stressed” Suwannee/ACSS/TW conductors
- Three conductor bundle with “stressed” Suwannee/ACSS/TW conductors

The conductor separation within the bundle for both cases is 18 inches. The line data for the two base cases are summarized in Table 9-7. .

Information on the RI and AN levels at midspan along the edge of the right-of-way (ROW ±55 ft) is used to evaluate the corona performance of the Suwannee conductor. The base case data does not include the effects of hardware and insulators.

Table 9-7. Base Case Geometry Parameters

Parameter	Conductor bundle
Bundle Configuration	2 or 3 Bundle Suwannee
Line Voltage	345kV
Phasing	A C B B C A
Horizontal Separation	35 ft
Vertical Separation	26 ft
Lowest Height at Tower	51.5 ft
Conductor Spacing	18 inches

Using TLW-Gen2, the RN and AN levels at midspan along the edge of the Right-of-Way (ROW), 55' from the center line, are listed in Table 9-8 for the base cases with the two conductor and the three conductor bundles using the Suwannee/ACSS/TW conductor. The calculated RN and AN levels are listed for both fair weather and heavy rain conditions. Fair weather RN values are 17dB below the heavy rain RN level.

Table 9-8. Base Case RN and AN at Edge of ROW (55ft)

Conductor Bundle	Fair Weather Audible Noise dB(A)	Heavy Rain Audible Noise dB(A)	Fair Weather Radio Noise dB(1μV/m)	Heavy Rain Radio Noise dB(1μV/m)
2 x Suwannee Bundle	40.6	57.2	53.5	70.5
3 x Suwannee Bundle	20.2	43.1	45.5	62.5

Conclusions

Comparisons of test data clearly indicate that corona performance of the Suwannee/ACSS/TW conductor in general matches and somewhat exceeds that of the Drake conductor. The RN level of the Suwannee/ACSS/TW conductor in heavy rain is close to that of the much larger (and heavier) Kiwi conductor. Also, as expected, the three-conductor bundle performs significantly better than the two-conductor bundle, see Table 9-9.

A new feature discovered in this project is the possibility of additional AN from boiling of water droplets when the Suwannee/ACSS/TW conductors operate at temperatures above 100°C. This source of AN is in addition to the corona generated AN and can be important for two conductor bundles, but most likely not significant for three conductor bundles. For a typical double circuit 345kV tower configuration, AN at the edge of the right-of-way due to water droplet boiling on a two-conductor bundle is 59 dB-A. However, this source of AN is more likely to persist during light rain, not during heavy rain when conductor cooling is very significant. At the same time, corona generated AN is lower in light rain than in heavy rain. Consequently, considering the actual AN values due to boiling of water drops in light rain on one hand, and due to corona in heavy rain on the other hand, the audible noise performance of the Suwannee conductor is relatively independent of rain intensity. Again, however, the Suwannee/ACSS/TW three conductor bundle (which will not experience water boiling noise) performs better than the two-conductor bundle.

Table 9-9. Calculated Base Case RN and AN at Edge of ROW (±55 ft) for Suwannee/ACSS/TW Bundles

Conductor Bundle	Fair Weather Audible Noise dB(A)	Heavy Rain Audible Noise dB(A)	Fair Weather Radio Noise dB(1μV/m)	Heavy Rain Radio Noise dB(1μV/m)
2 Bundle	40.6	57.2	53.5	70.5
3 Bundle	20.2	43.1	45.5	62.5

As summarized in Table 9-9, the RN of a new Suwannee/ACSS/TW conductor is approximately 6dB (1μV/m) higher than for a stressed conductor while the AN is relatively independent of conductor age. RN of a heated Suwannee/ACSS/TW bundle is approximately 2 dB 1μV/m) higher and AN is about 1 dB-A higher relative to unheated conductor. The addition of corona free V-string hardware produces some reduction of the conductor surface voltage gradient on the Suwannee/ACSS/TW conductor around the V-string hardware, and results in changes in RN and AN summarized in Table 9-10. .

Table 9-10. Effects of Conductor Condition, Temperature and Hardware on RN and AN

Condition	Radio Noise	Audible Noise
New Conductor	~ + 6 dB	~ no change
Heated Conductor	+ 2 dB	+ 1dB
V-String Hardware (3 conductor bundle)	- 4 dB	- 6 dB
V-String Hardware (2 conductor bundle)	~ no change	- 4 dB