SAFETY CONSIDERATIONS OF AERIAL SYSTEMS USING INSULATED AND COVERED WIRE AND CABLE

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I. ABSTRACT

Insulated and covered wires and cables have been used in aerial applications for over fifty years. Their various constructions, characteristics, and applications are discussed in "Design and Application of Aerial Systems Using Insulated and Covered Wire and Cable"[1]. Some have suggested that covered wires and cables should be used in general applications solely for the purpose of providing safety to operating personnel and the general public.

This paper discusses factors leading to the conclusion that nonshielded, covered conductor should not be installed solely to assure personal safety. The National Electrical Safety Code (NESC)[2] treats covered conductors as bare conductors for purposes of clearances to personnel spaces; such a requirement is strongly supported by this paper.

II. INTRODUCTION

Covered conductors do not have an insulation shield. Thus, there is no practical means of calculating charging currents available to an object contacting a covered, non shielded conductor. The amount of current that can flow when a contact occurs is dependent upon the charge available on the covering surface at the point of contact and the current that can be accumulated via tracking across the covering surface. For instance, the charging current for a 795 kCmil conductor 0.260" polyethylene insulated *fully shielded* cable for 25 kV service 0.5 milliamps/ft. This small amount of current would not cause operation of protective devices such as fuses, reclosers or breakers; thus, no outage would occur. In fact, this condition can and often does exist for a substantial period of time in areas where covered conductors are used. Typically, only a few milliamperes will flow when contact is made by an object such as a tree branch/limb or a person, unless the covering of the tree wire or aerial spacer cable has been degraded or damaged. More current would be available from a weatherproof conductor. However, depending on the covering thickness, tracking and covering erosion can occur and create unsafe conditions. If the contact is left as a permanent condition, tracking and erosion would more than likely damage the covering, increasing the current available and eventually could cause cable failure.

If this small amount of charging current was representative of all the current that would be available if contacted by a grounded object or person, some might be prompted to believe that no safety hazard exists. In fact, some have suggested that covered conductors should be required for safety against accidental contact. This paper explores the appropriateness of such a presumption.

This paper also reports the results of a comparison as calculated and tested values of charging current available on the surface of various covered conductor designs at different voltages.

III. CALCULATED CHARGING CURRENTS

Charging currents were calculated for various polyethylene covered weatherproof wires, tree wire and aerial spacer cable and constructions, assuming typical dimension, polyethylene

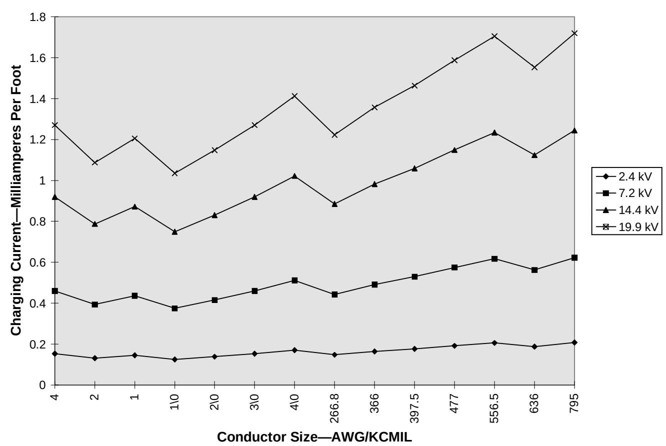

Figure 1. Calculated Charging Currents for Weatherproof Conductors

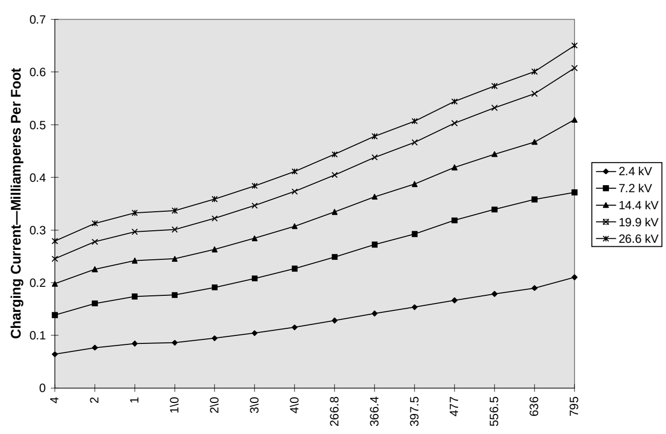

Figure 2. Calculated Charging Currents for Hendrix Spacer Cable and Tree Wire

covering with a dielectric constant of 2.3, and the indicated voltage from conductor to covering out surface (to an "imaginary" shield). The results are shown in graphical form in Figures 1 (weatherproof) and Figure 2 (aerial spacer cable).

Because these constructions can vary between designs and manufacturers, the charging currents shown here cannot be assumed to apply to all wires and cables.

IV. LEAKAGE CURRENT TESTS

Even though coverings described as track resistant are commonly used, an additional charge can accumulate via cable surface tracking if the cable is contacted by a grounded object. Significant tracking can increase actual values well above calculated values. In order to quantify levels of increased charges due to tracking, actual "leakage" measurements were made on samples of *recently manufactured* Type II aerial spacer cable and tree wire when energized and contacted by a grounded object.

A. Test Procedure

A 20 ft. length of sample #4 was prepared for test as shown in Figure 3.

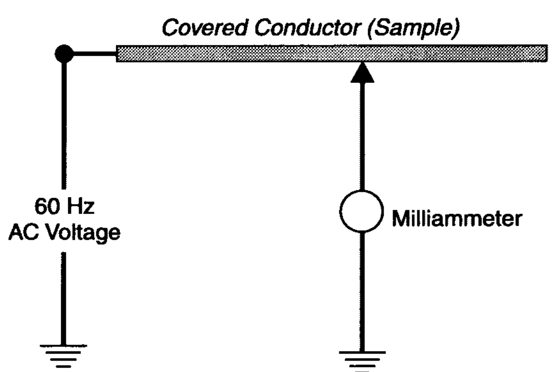

Figure 3. Arrangement of Test Procedure

One loop of bare #14 Awg copper wire was wrapped around the center of the sample and grounded through a milliammeter. A 60 Hz voltage source was used to energize the sample at 2.5 kV, 5.0 kV, 8.0 kV, 14.5 kV, 16 kV and 20 kV to ground. The leakage current at each voltage step was recorded within 15 seconds of energization.

The loop of wire contact was then replaced with tightly lap-wrapped 0.005" X 1.5" copper tape covering the center 1.0 ft. portion of the sample and secured with electrical tape over the ends of the copper tape. The voltage steps and "leakage" readings were repeated. Next, tap water was applied to the sample generously with a cloth and the test repeated. Finally, one hundred (100) grams of table salt was dissolved in 1.0 liter of water and the solution was applied in the same manner as the tap water and the test repeated.

Some fluctuations were noted in the leakage current readings during the wet tests, which were anticipated due to drying. In such cases, the highest stable leakage current was recorded. The sample was then allowed to dry for 1 hour followed by a test for leakage current vs. voltage. The test was repeated at 1.5 hours.

The same 20 ft. sample was then cut to a 10 ft. length, but no significant change in leakage readings was observed, so all subsequent tests were conducted on 10 ft. sample lengths. The subsequent dry contaminated tests were taken after drying 1.5 hours.

B. Test Results

Test results are given in Appendix 1. All tests were made on new cable. Results for older cable can be higher. Since the most common condition in field service would be represented by the dry, uncontaminated case, the 1 ft. copper tape contact leakage current *test results* at 20kV to ground were compared with the *calculated value* (based on the nominal stated sample covering dimensions and a dielectric constant of 2.3 for the sample). The comparisons are shown in Table 1

Table 1. Sample Data

SAMPLE Number	Measured Ma Leakage @ 20Kv	Calculated Ma Charging @ 20Kv
1	0.738	0.7125
2	1.259	1.153
3	0.768	0.7758
4	0.780	0.7242
5	0.843	0.7489
6	0.893	0.7758
7	0. 803	0.7758
8	1.075	1.004
9	0.610	0.500
10	0.801	0.691
11	0.609	0.525
12	0.429	0.4009

Considering the variability in actual dimensions and contact of the copper tape with the sample surface, the comparison is excellent. As anticipated, in every case except sample 3, the measured value exceeds the calculated value by a very small margin. This suggests that minimal leakage current is obtained via surface tracking and that discharges are initially largely due to the charging current developed by the grounded contact.

Thus, for normal dry conditions the probable leakage current due to a contact by a grounded object (or person) can be approximated by calculating the charging current for the contact conditions. The addition of moisture and/or modest contamination to the surface does increase the tracking component of the leakage current, but as anticipated except for very severe (and evident) conditions of moisture and contamination, the increase was less than anticipated.

V. SAFETY

When one compares the charging current values shown in Figures 1 and 2 and the test values shown in Appendix 1 with the widely discussed 5ma, 60Hz contact-current safety level[3], one might initially assume that covered conductors and spacer cable systems preclude the possibility of injury or death due to human contact. While this may be the case in the majority of events involving modern cables, this assumption is not true for all cases. Indeed there have been cases of serious injury involving covered conductors, even at lower voltages.

If the conductor contact is made at a location where there is an uncovered splice or tap, severe covering damage, or unusual conditions of conducting contamination on the covering surface, there does exist the distinct possibility of discharge current in excess of the 5ma. Even if electrocution or serious electrical injuries do not occur, the resulting shock may cause involuntary movement due to muscle reaction or instinctive jerking away due to fright, and an injury can result from a fall or from contacting another energized conductor in the general area.

In the case of contact with the generally thinner-walled "weatherproof" conductor, the possibility of injury or death is greater than for heavy-walled Type II tree wires or aerial spacer cable . Further, since weatherproof conductors commonly consist of a single thin layer of carbon filled material, the possibility of damage sufficient to reduce the electrical integrity or the possibility of a split or pinhole in the covering is much greater.

The identification of an aerial spacer cable system can be reliably accomplished by skilled electrical workers because the design has a distinctive configuration. However, even the most skilled worker cannot readily discern the difference between thin-walled weatherproof wire and heavy-walled tree wire. There also is no industry-wide standard to prohibit, for example, the use of a cable designed for 5kV systems at higher voltage. Also, the general public is not expected to have knowledge of conductor differences. Further, there may be no plainly visible indication that the covering has deteriorated to the point of allowing the outer surface to be at a hazardous voltage.

While it might be said that covered conductors, such as those utilized in the aerial spacer cable system, may well avoid injury or death due to unintentional human contact if the installation is in good condition, at worst it will be similar to a bare conductor.

The NESC, OSHA, and all recognized safety standards require covered conductors to be treated as bare conductors for clearances to areas accessible to the public. The rules of the NESC in regard to the treatment of covered conductors are intended to provide the basic provisions for safety, balancing the expected degree of a problem versus the practicability of constructing the facilities to address the problem in a way that is both reliable and economical.

Provision is made in the NESC for reduced clearances for fully insulated cables from objects or structures such as buildings. While the probability of electrocution due to accidental contact is small if the covering remains intact, should a fault occur at the point of contact, electrocution, flash burns, or burns from hot debris associated with the fault are possible, even on a shielded cable.

The cable used in fully shielded cable installations is factory tested to demonstrate its voltage rating. However, unless specified in a purchase contract, weatherproof wire, covered wire, and aerial spacer cable may not always be tested prior to shipment (there is no requirement to do so).

VI. CONCLUSION

1. Leakage test values on new covered wire and cable reasonably compared with charging current calculations for the same cable.

2. Covered wires and cables meeting NESC Rule 230D are not intended for and cannot be depended upon for absolute personal protection.

3. Contact with any energized conductor carries some risk of death or injury.

VII. REFERENCES

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APPENDIX 1—TEST RESULTS
AERIAL CABLE
CHARGING CURRENT
(ma)

SAMPLE 1

1. 1/0 AWG 7 strand compact, Al, 0.085” nominal, black high molecular weight polyethylene (BHMW) covering.

Cable Setup Test Voltage To Grid	**1 Loop Of Wire**	**1 Ft. Copper Tape Dry**	**1 Ft. Copper Tape Wet**	**1 Ft. Copper Tape Wet Contaminated**	**1 Ft. Copper Tape Dry Contaminated**
2.5kV	.004	.064	.408	.432	.092
5.0 kV	.009	.133	.763	.900	.169
8.0 kV	.020	.244	1.303	1.496	.300
14.5 kV	.074	.517	1.189	1.561	.595
16.0 kV	.091	.580	1.241	1.040	.652
20.0 kV	.157	.738	1.557	1.273	.817

No discharge problems

SAMPLE 2

2. 336.4 Kcmil, 19 strand compact, Al, 0.085” nominal, gray track resistant high density polyethylene (GTRHD) covering.

Cable Setup Test Voltage To Grid	**1 Loop Of Wire**	**1 Ft. Copper Tape Dry**	**1 Ft. Copper Tape Wet**	**1 Ft. Copper Tape Wet Contaminated**	**1 Ft. Copper Tape Dry Contaminated**
2.5 kV	.004	.101	.193	.151	.121
5.0 kV	.011	.227	.423	.319	.265
8.0 kV	.030	.406	.772	.587	.457
14.5 kV	.114	.843	1.296	1.474	.891
16.0 kV	.152	.941	1.359	1.613	1.011
20.0 kV	.247	1.259	1.608	1.671	1.296

SAMPLE 3

3. 397 Kcmil, 19 Str. Compact, Al, 0.150” Black High Molecular Weight Polyethylene (BHMW) covering.

Cable Setup Test Voltage To Grid	**1 Loop Of Wire**	**1 Ft. Copper Tape Dry**	**1 Ft. Copper Tape Wet**	**1 Ft. Copper Tape Wet Contaminated**	**1 Ft. Copper Tape Dry Contaminated**
2.5 kV	.005	.069	.314	.430	.080
5.0 kV	.010	.153	.603	.901	.170
8.0 kV	.026	.242	1.049	1.400	.280
14.5 kV	.093	.534	1.630	1.830	.580
16.0 kV	.115	.612	.773	1.930	.670
20.0 kV	.179	.768	1.020	2.500	.870

SAMPLE 4

4. 336.4 Kcmil, 19 Str. Compact, Al, 0.075” natural HMW (NHMW) overlayed with 0.075” Black Track Resistant High Density Polyethylene (BTRHD)

Cable Setup Test Voltage To Grid	**20 Ft. Length 1 Loop Of Wire**	**20 Ft. Length 1 Ft. Copper Tape Dry**	**20 Ft. Length 1 Ft. Copper Tape Wet**	**20 Ft. Length 1 Ft. Copper Tape Wet Contaminated**	**20 Ft. Length 1 Ft. Copper Tape Dry Contaminated**		**10 Ft. Length**
					1 HR.	1.5 HR.	1.5 HR.
2.5 kV	.005	.076	.095	.113	.087	.085	0.09
5.0 kV	.011	.166	.173	.227	.193	.178	0.178
8.0 kV	.027	.263	.303	.340	.311	.299	0.303
14.5 kV	.075	.523	.629	.667	.615	.598	0.599
16.0 kV	.090	.596	.678	.734	.684	.669	0.662
20.0 kV	.150	.780	.867	1.063	.894	.867	0.865

SAMPLE 5

5. 336.4 Kcmil, 19 Str. Compact, Al, 0.015” semiconducting shield, 0.075” NHMW and 0.075” (GTRHD).

Cable Setup Test Voltage To Grid	**1 Loop Of Wire**	**1 Ft. Copper Tape Dry**	**1 Ft. Copper Tape Wet**	**1 Ft. Copper Tape Wet Contaminated**	**1 Ft. Copper Tape Dry Contaminated**
2.5 kV	.005	.008	.225	.098	.085
5.0 kV	.010	.153	.378	.231	.187
8.0 kV	.021	.282	.688	.448	.325
14.5 kV	.069	.593	1.160	1.062	.635
16.0 kV	.094	.638	1.114	1.185	.714
20.0 kV	.152	.843	1.677	1.677	.908

SAMPLE 6

6. 336.4 Kcmil, 19 Str. Compact, Al, .015” SC, 0.075” NHMW, 0.075” BTRHD.

Cable Setup Test Voltage To Grid	**1 Loop Of Wire**	**1 Ft. Copper Tape Dry**	**1 Ft. Copper Tape Wet**	**1 Ft. Copper Tape Wet Contaminated**	**1 Ft. Copper Tape Dry Contaminated**
2.5 kV	.004	.087	.118	.104	.087
5.0 kV	.010	.191	.260	.215	.193
8.0 kV	.019	.299	.430	.440	.321
14.5 kV	.066	.614	.787	.962	.640
16.0 kV	.088	.693	.824	1.024	.705
20.0 kV	.146	.893	1.071	1.166	.923

AERIAL CABLE
CHARGING CURRENT
(ma)

SAMPLE 7

7. 397 Kcmil, 19 Str. Compact, Al, 0.075" NHMW, 0.075" BTRHD.

Cable Setup Test Voltage To Grid	1 Loop Of Wire	1 Ft. Copper Tape Dry	1 Ft. Copper Tape Wet	1 Ft. Copper Tape Wet Contaminated	1 Ft. Copper Tape Dry Contaminated
2.5 kV	.005	.076	.095	.092	.078
5.0 kV	.011	.169	.200	.182	.172
8.0 kV	.022	.278	.355	.310	.281
14.5 kV	.074	.558	.746	.818	.579
16.0 kV	.095	.637	.807	.810	.641
20.0 kV	.157	.803	1.002	.991	.822

SAMPLE 8

8. 795 Kcmil, 19 Str. Compact, Al, 0.080" NHMW, 0.080" BTRHD.

Cable Setup Test Voltage To Grid	1 Loop Of Wire	1 Ft. Copper Tape Dry	1 Ft. Copper Tape Wet	1 Ft. Copper Tape Wet Contaminated	1 Ft. Copper Tape Dry Contaminated
2.5 kV	.005	.105	.127	.143	.107
5.0 kV	.012	.228	.267	.294	.230
8.0 kV	.025	.365	.536	.509	.369
14.5 kV	.076	.738	1.139	.973	.764
16.0 kV	.100	.840	1.299	1.052	.861
20.0 kV	.169	1.075	1.577	1.265	1.092

SAMPLE 9

9. 336.4 Kcmil, 19 Str. Compact, Al, 0.015" SC, 0.125" NHMW, 0.125" BTRHD.

Cable Setup Test Voltage To Grid	1 Loop Of Wire	1 Ft. Copper Tape Dry	1 Ft. Copper Tape Wet	1 Ft. Copper Tape Wet Contaminated	1 Ft. Copper Tape Dry Contaminated
2.5 kV	.004	.066	.093	.076	.065
5.0 kV	.010	.131	.180	.154	.138
8.0 kV	.016	.206	.292	.262	.223
14.5 kV	.051	.422	.599	.507	.449
16.0 kV	.065	.466	.624	.538	.509
20.0 kV	.105	.610	.768	.706	.632

SAMPLE 10

10. 759 Kcmil, 19 Str. Compact, Al, 0.015" SC, 0.125" NHMW, 0.125" BTRHD.

Cable Setup Test Voltage To Grid	1 Loop Of Wire	1 Ft. Copper Tape Dry	1 Ft. Copper Tape Wet	1 Ft. Copper Tape Wet Contaminated	1 Ft. Copper Tape Dry Contaminated
2.5 kV	.005	.079	.181	.086	.090
5.0 kV	.011	.170	.362	.362	.162
8.0 kV	.019	.279	.580	.580	.298
14.5 kV	.070	.564	1.178	1.178	.566
16.0 kV	.096	.612	1.164	1.164	.637
20.0 kV	.155	.801	1.165	1.165	.822

SAMPLE 11

11. 556 Kcmil, 19 Str. Compact, Al, 0.015" SC, 0.175" NHMW, 0.125" GRTHD.

Cable Setup Test Voltage To Grid	1 Loop Of Wire	1 Ft. Copper Tape Dry	1 Ft. Copper Tape Wet	1 Ft. Copper Tape Wet Contaminated	1 Ft. Copper Tape Dry Contaminated
2.5 kV	.005	.062	.063	.067	.062
5.0 kV	.010	.123	.128	.142	.131
8.0 kV	.017	.207	.222	.223	.223
14.5 kV	.055	.416	.456	.436	.430
16.0 kV	.073	.472	.512	.487	.487
20.0 kV	.128	.609	.672	.646	.643

SAMPLE 12

12. #2 Awg, 7 Str. Compressed, 0.150" thermoplastic rubber.

Cable Setup Test Voltage To Grid	1 Loop Of Wire	1 Ft. Copper Tape Dry	1 Ft. Copper Tape Wet	1 Ft. Copper Tape Wet Contaminated	1 Ft. Copper Tape Dry Contaminated
2.5 kV	.003	.040	.188	.091	.042
5.0 kV	.007	.088	.409	.193	.085
8.0 kV	.013	.147	.699	.353	.153
14.5 kV	.034	.291	1.396	.730	.301
16.0 kV	.043	.330	1.447	.833	.335
20.0 kV	.070	.429	1.675	1.035	.435