

Development and Installation of a 69kV Aerial Cable System

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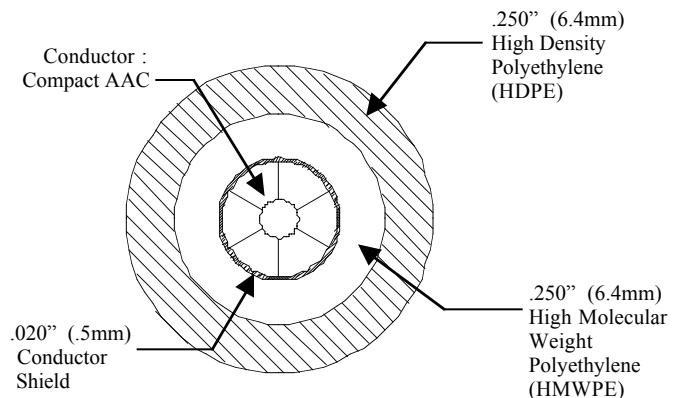
Abstract: Several years ago, the growing demand for higher reliability, concern over the possible effects of magnetic fields and difficulty in obtaining right-of-way resulted in work by the Electric Power Research Institute (EPRI) and several utilities into the feasibility of using covered conductors for transmission voltage applications. The preliminary work suggested the possible use of covered conductors through 138 kV. A 69 kV Aerial Spacer Cable (ASC) system has been developed and tested. By permitting a significant reduction in the phase separation the heavily covered phase conductors reduce right-of-way requirements and magnetic field strength. Reliability is improved due to the ability of the system to tolerate momentary contact with trees or other objects. In cooperation with the Omaha Public Power District the first 69 kV Aerial Spacer Cable system was installed and energized in December of 1996. To date the system has not had any outages and system components have operated without mechanical failure.

Introduction: Properly designed and installed, the close phase spacing of Aerial Spacer Cable conductors minimize the right-of-way required for necessary clearances. Reliability and quality of service are enhanced by precluding fault current flow due to momentary, and to some degree sustained, contact with trees or other objects contacting the heavily covered phase conductors. Despite over 40 years of service with Aerial Spacer Cable circuits in the 5 to 46 kV range, the step to 69 kV presented new challenges.

When covered conductors are used on transmission circuits, wide phase spacing is desirable from the standpoint of electrical tracking, impulse strength and short circuit forces. However, closer phase spacing is desirable to minimize right-of-way, magnetic field strength at ground level, and mechanical demands on the phase spacers. The size of the mold required to produce the spacers also exerts practical constraints on the spacer size and therefore, the phase spacing. Transmission circuits, unlike distribution, are less likely to be installed and operated such that tree contacts will be allowed to exist for months or years before being removed. This makes it possible for a compact spacer design resulting in higher levels of charge current at the cable covering surface. Finally, a strong foundation in 69 kV spacer cable will permit the investigation of higher voltage transmission spacer cable systems.

Electrical Design: Standard design 46 kV Aerial Spacer cables utilize a conductor shield overlaid with two layers of insulating polyethylene totaling .400" (10.2 mm), similar to the 69 kV cable construction detailed in Figure 1. The system has provided excellent service for over ten years. In at least one case, a 46 kV system has withstood continuous tree contact, between two phases, for between four and eight years with no recorded outages. This period of contact is not recommended by the authors and was thought unlikely for transmission circuits. However, this experience does provide a frame of reference that convinces the authors that a 69 kV cable construction consisting of a conductor shield and .500" (12.7 mm) of covering (refer to Figure 1) is adequate to avoid fault in the event of a short duration contact.

Figure 1
Typical 69 kV Spacer Cable Construction



636 kcmil compact and 795 kcmil compact cables, both having a conductor shield and .250" (6.35 mm) of unfilled low density polyethylene (LDPE) and .250" (6.35 mm) of filled, ultraviolet stabilized high density polyethylene (HDPE) for a total of .500" (12.7 mm) of insulating covering were manufactured for test. The following are among the tests conducted:

1.) Increasing AC Voltage in Five Minute Steps to Breakdown

This test, conducted on nominal 50 ft. lengths of cable, were frustrated by the difficulty in fabricating a uniform paint and tape semi-conducting layer with a copper wire shield over the cable for test. Despite this, the average breakdown value for the five samples from the 795 Kcmil production run was

214 kV with a range from 190 kV to 250 kV. The average breakdown value for the five 636 Kcmil samples from the second production run was 218 kV with a range from 190 kV to 250 kV. The ac breakdown results are, at a minimum several times the voltage that the covered conductor would be exposed to if a solid ground were to make contact with the cable surface.

2.) Impulse Tests

The test was conducted using a 1x50 micro-second impulse. Three positive and three negative impulses were generated for each ten percent step increase in voltage. Two samples of cable from each production run were tested. All four samples completed the 962 kV step which was the limit of the test set. Impulse tests were also conducted in spacers using a 1 x 50 micro second voltage pulse. Starting voltage was selected at a level anticipated to be well below flashover. Then, voltage was increased in approximately ten percent steps, maintaining the polarity under test through all steps, 3 impulses at each step, to flashover.

For spacing in excess of 17" (431.8mm), commonly used estimations of impulse strength begin to fail (12). In order to examine the impulse strength of the spacer alone, several preliminary tests were conducted. The first test involved a bare conductor in both the side phase and messenger positions (36 inch spacing - refer to Figure 4). Flashover occurred at 550 kV positive polarity and 522 kV negative polarity. This was followed by bare conductors in the phase to phase position (26 inch spacing - refer to Figures 2 & 4). Flashover occurred at 412 kV for both positive and negative polarity. A 795 kcmil, 69 kV cable was placed in the phase position and the phase to neutral tests were repeated. No cable puncture could be obtained as flashover repeatedly occurred across the spacer and the cable surface to the test ground connector at 880 kV positive and 636 kV negative. Moving the bare cable to an adjacent phase position resulted in flashover at 852 kV positive and 550 kV negative across the spacer and on the cable surface to test ground, as in the previous case.

Since these test levels were below the 963 kV (minimum) impulse strength of the cable, it was decided that a cable with a lower impulse strength should be used to allow an estimate of the higher level of impulse test voltage required to achieve a breakdown. The test setup was modified to increase the distance to test ground. The bare conductor electrode was replaced with a loop of 4/0 Awg, 25 kV covered conductor (250 mils of covering with a conductor shield). No flashover occurred at 935 kV for both positive and negative polarity, which was the upper limit of the test equipment. Further impulse testing was discontinued until such time as a higher impulse voltage test set became available. Only a portion of these additional tests have been conducted to date and will be reported on in a later paper.

3.) "U" Bend Discharge Test

Five covered conductors from one of the manufacturing runs were bent into a "U" shape, with the bottom of the "U" resting on a grounded steel plate and energized at 100 kV. This is a modification of the Insulated Cable Engineers Association "U" bend test. The average time to failure for the five samples was 14.6 hours. The erosion current under the actual conditions of operating voltage would be significantly less and the time to failure would be considerably longer under actual service conditions.

Spacer Design: The spacer is a critical component in the reliable mechanical and electrical performance of the system. A complete spacer is a multi-component assembly, consisting of: the injection molded high density polyethylene structural members that are joined using glass filled nylon bolts, three ethylene propylene dimonomer (EPDM) ring ties for securing the phase conductors in the spacer and an aluminum suspension clamp used to attach the assembled spacer to the messenger (refer to Figure 1). The design of each of the components has expanded on the foundation of the Hendrix Aerial Spacer design(s) for distribution voltage levels which have been in operation since 1951.

The spacer was molded using the same material that was used to extrude the outer aerial cable layer. Using the same compound for both the cable "jacket" and the spacers assures that the dielectric constant (ε) of the contacting surfaces is equal and thereby prevents degradation of the cable covering through corona cutting (1,4,7). Periodic ultraviolet (UV) weathering testing per ASTM G26-90 (test method 1), and liquid contaminant, incline plane tracking and erosion testing per ASTM D2303 assures that this material is well suited for long term outdoor exposure in a high voltage application (4,5,6).

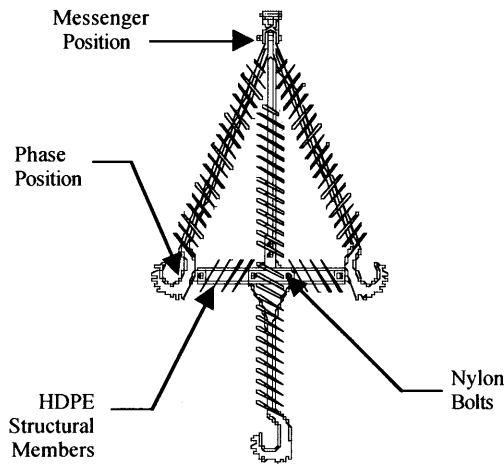
Three 954 kcm compact conductors with .520" (13.2mm) of covering, under NESC heavy loading [.50" (12.7mm) radial ice and 4 psf (191.5 Pa) wind] were used to establish the maximum mechanical design loading criteria. Spacers are typically installed every thirty feet (9.1 meters), therefore each spacer would be required to support a static load of approximately 177 pounds (80.3 kg) in a level span under the maximum design condition.

High Density Polyethylene (HDPE) like all polymers is subject to creep. Because of the long service life required by the users, the spacer was designed to support loads ten times the design maximum of 177 lb (787.3 N). In the test the messenger position was rigidly fixed to the test apparatus and a steadily increasing load (pull rate: approximately 5"/min) was applied to the bottom phase position. Mechanical testing has confirmed that the average vertical tensile load at failure is 1800 lb (refer to Figure 2). A safety factor of ten ensures that

the strain experienced by a spacer, under the maximum design conditions, of 177 lb (787.3 N) will not exceed 1%. At 1% strain the deformation due to creep will be

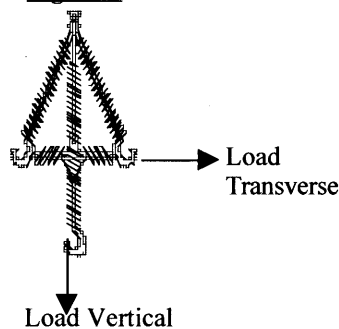
approximately .125 inch per foot (.98 mm/meter) during the normal life expectancy of forty years.

Figure 2



Mechanical testing was also conducted to verify the transverse load capacity of the spacer (refer to Figure 3). One of the side phase positions was rigidly fixed to the test apparatus and a steadily increasing load (pull rate: approximately 5"/min) was applied to the opposite phase position. The average transverse load at failure was 450 lb.

Figure 3



An aluminum suspension clamp is incorporated into the spacer design for attachment to the messenger (refer to Figure 2). The suspension clamp allows the spacer to pivot thereby maintaining a vertical attitude. By keeping the spacer in a vertical orientation, the loads induced by the phase conductors are primarily tensile. Ultimate vertical load testing of the suspension clamp has defined the average tensile strength to be 1825 lb.

The 69 kV aerial spacer has the same triangular phase configuration that has been used at distribution voltages. This configuration offers a significant reduction, over bare overhead conductors, in the magnetic field strength at ground level, provides a rigid mechanical structure to withstand short circuit forces and ensures that all three phases fall within the 30° shield angle provide by the messenger.

An increase in system voltage from distribution levels to 69 kV required an increase in phase separation. The 26 inch phase separation (refer to Figure 4) was selected to balance impulse withstand values, surface charging current, and flashover characteristics with the required mechanical properties.

The long leakage path of the spacer (refer to Figure 4) is achieved by incorporating fins along the structural I-beam sections of the spacer. Fin orientation promotes the washing effect of rain, thereby minimizing the detrimental effects of contamination build-up. A minimum leakage distance was based on severe atmospheric contamination (Class D) using the equation (12):

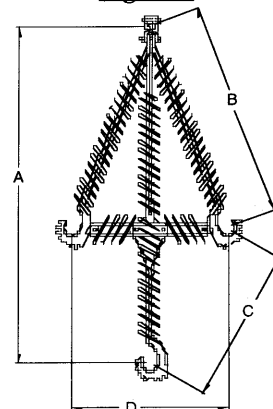
$$\text{Leakage Distance} = (1.74 \text{ in/kV})(\text{line to ground voltage, kV})$$

$$(1.74 \text{ in/kV})(69\text{kV}/1.732) = 69.3 \text{ inches}$$

Short circuit testing has suggested that the spacer has the ability to withstand short circuit loads up to 30kA. During testing the nylon assembly bolts were replaced with steel hardware after shear failure of the polymer bolts used to assemble the spacer components was experienced at 17 kA. With the steel bolts in place the spacer withstood a short circuit load of approximately 20 kA. The next short circuit load was measured at 38 kA test. At this level the test loop of cable pulled loose from the support but the spacer was not damaged at this load level. The authors are confident that larger diameter nylon bolts will increase the short circuit capacity of the spacer.

The final component in the aerial spacer assembly is the ring tie. Compression molded using a UV stabilized EPDM, the ring tie was designed to provide a balance of tensile strength and elongation to handle the 30 kA short circuit forces anticipated at this transmission level. Ring ties were used in all of the aforementioned short circuit testing with no instances of failure.

Figure 4

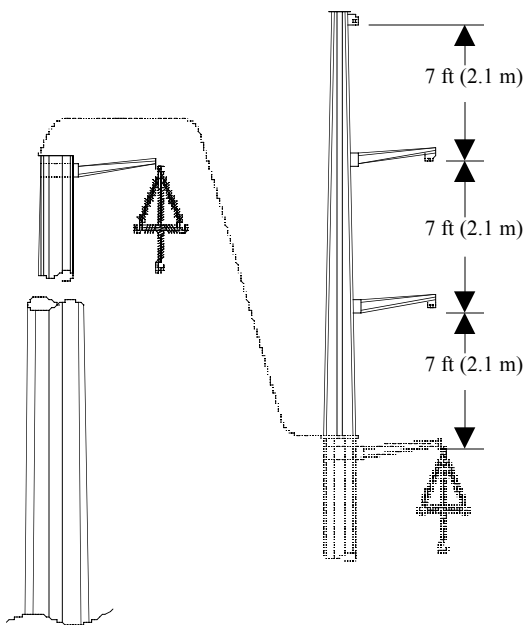


<u>Dimension</u>	<u>Spacing</u>	<u>Leakage Distance</u>
A	56-3/8"	128"
B	36-1/4"	86"
C	26"	87-5/8"
D	26"	80-1/8"

Initial Test Circuit Design: Service reliability requirements resulted in the need for an alternate 69 kV feed to the Paxton-Mitchell foundry substation in Omaha, Nebraska. Line switches were installed at each end of the circuit to provide the ability to transfer load within one half hour. The service area is somewhat congested including a mixture of residential, commercial and industrial establishments. Thus, there was an interest in an overhead design that minimized right of way requirements as well as being capable of momentary contacts by foreign objects without a service interruption.

The Hendrix 69 kV Aerial Spacer cable system offered an opportunity to reduce right of way and structure height requirements as well as increase service quality and reliability. However, understanding the trial nature of the system made its use as an alternate feed an ideal test case. As a further precaution, pole design included provision to add a pole extension to gain an additional 21 ft. in height to accommodate conversion to bare wire vertical construction on the same side of the pole. This was the only bare wire design which could be placed in the approximately eight foot right of way utilized by the spacer cable design (refer to Figure 5).

Figure 5



Immediate load requirements would have suggested a 3/0 Awg ACSR conductor but there is the possibility of extending the line to serve additional load in the future, therefore a larger conductor size was selected. Ampacities (refer to Table 1) were calculated using the Aluminum Association methods (9) with modifications to account for the conductor covering. The following ampacity chart was developed based on an elevation of 0.0 ft., 30° N. Latitude and 83° angle of the sun. The calculations indicated that 636 kcmil all aluminum covered conductors supported by spacers on 30 ft (9.1m) intervals installed on a 19 #8 Alumoweld messenger having a breaking strength of 43,240 lb. met the requirements.

Table 1
636 Kcmil Covered Conductor Ampacities

Ambient Temperature: 20°C				
Conductor Temperature	Sun No Wind	No Sun No Wind	Sun Wind	No Sun Wind
75°C				
2.0 fps wind	553	663	671	753
4.4 fps wind	553	663	758	813
85°C				
2.0 fps wind	622	717	734	807
4.4 fps wind	622	717	822	877
90°C				
2.0 fps wind	663	748	776	842
4.4 fps wind	663	748	857	908
Ambient Temperature: 40°C				
Conductor Temperature	Sun No Wind	No Sun No Wind	Sun Wind	No Sun Wind
75°C				
2.0 fps wind	376	527	501	606
4.4 fps wind	376	527	579	656
85°C				
2.0 fps wind	476	596	589	677
4.4 fps wind	476	596	666	732
90°C				
2.0 fps wind	517	627	627	709
4.4 fps wind	517	627	704	766

The close 26 in. phase spacing resulted in a low 0.535 ohm/mile inductive reactance which is lower than the value for the same conductor size at typical, vertical, bare wire spacing. Voltage regulation also benefits from the close spaced spacer cable system.

Other parameters were:

636 kcmil
ACS

Capacitive Reactance (60Hz)	.123 ohm/mile (.076 ohm/km)
AC Resistance (75°C)	.178 ohm/mile (.111 ohm/km)
AC Resistance (85°C)	.183 ohm/mile (.114 ohm/km)
AC Resistance (90°C)	.186 ohm/mile (.116 ohm/km)

The additional weight due to an increase in conductor size, covering and spacers, as well as the greater ice load due to the increased cable diameter, results in an increase in tension and wind loading to be used in the circuit design. A summary for the heavy and special loading conditions for a typical 400 foot span is given in Table 2.

Table 2

Load Case	Condition	Total Weight		Temperature		Radial Ice		Wind		Messenger Tension	
		(lb/ft)	(kg/m)	(°F)	(°C)	inches	mm	psf	Pa	lb	kg
LC1	NESC Heavy	12.85	19.12	0	-18.8	0.50	12.70	4.0	191.52	18873	8560.6
LC2	NESC Wind	10.75	15.99	60	42.2	0.00	0.00	16.0	766.08	15997	7256.1
LC3	OPPD Wind	10.75	15.99	50	32.2	0.00	0.00	16.0	766.08	15997	7256.1
LC4	Wind/Med. Ice	14.81	22.04	25	-3.9	0.25	6.40	9.0	430.92	20357	9233.7
LC5	Heavy Ice	18.74	27.88	0	-18.8	1.00	25.40	0.0	0.00	24141	10950.1
LC6	Norm. Service	7.13	10.61	0	-18.8	0.00	0.00	6.4	306.43	12214	5540.1
LC7	Pre-camber	5.69	8.47	50	32.2	0.00	0.00	0.0	0.00	10486	4756.3

The most direct route from the tap point to the Paxton-Mitchell substation was to utilize the Union Pacific railroad right of way avoiding adjacent property owner overhang involvement (refer to Figure 6). This resulted in the use of self supporting structures except for 90° corners where guying was available. The pole heights were such that the sag was not a major factor except where the line crossed over the elevated expressway. As a point of reference maximum final sag for the spacer cable system under worst case conditions, Heavy Ice (refer to Table 7, Load Case 5), was calculated as 15.65 ft. for a 400 ft. ruling span.

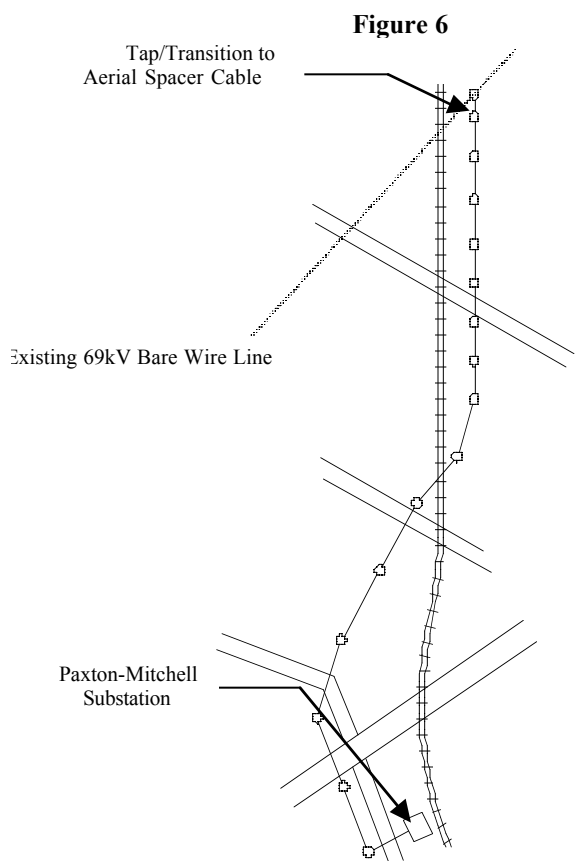
Conclusion: The reliable operation of the Omaha Public Power District circuit coupled with the performance of the cable design and spacers in laboratory testing indicate a viable 69 kV spacer cable system has been developed.

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References:

- 1.) A.L. Clapp, J.B. Daggenghart, C. Landinger, J.W. McAuliffe, W.A. Thue. "Design and Application of Aerial Systems Using Insulated and Covered Wire and Cable" presented at *IEEE T&D Expo, Los Angeles, September 1996*.
- 2.) A.L. Clapp, J.B. Daggenghart, C. Landinger, J.W. McAuliffe, W.A. Thue. "Safety Considerations of Aerial Systems Using Insulated and Covered Wire and Cable" presented at *IEEE T&D Expo, Los Angeles, September 1996*.
- 3.) M.R. Soares, F.R. Britto, F. Nishimura, L.D. Cicarelli. "Spacer Cable and ABC Distribution Lines, A Long Term Analysis" presented at *IEEE T&D Expo, Los Angeles, September 1996*.
- 4.) H.B. Slade "Three Phase Measurements of Charging Currents on Spacer Cable Systems Under Simulated Service Conditions". Paper #CP 62-PWR, presented at *IEEE Winter Power Meeting, New York, January 25-30, 1970*.
- 5.) R.T. Harrold, T.W. Dakin "On Predicting the Life of Polyethylene Spacer Cable Eroded by Surface Discharges in Wet Weather" *IEEE Transactions on Power Apparatus and Systems, PAS-95, pp. 821-828, May/June 1976*.



6.) E.K. Duffy, S. Jovanovetch, I.J. Marwick. "Discharge Resistant Characteristics of Polyethylene for Wire and Cable" *IEEE paper #CP 63-413, presented at IEEE Winter General Meeting, New York, January 27-February 1, 1963.*

7.) R.G. Raymond. "Spacer Type Aerial for Higher Voltages" *paper #DP 63-851, presented at IEEE Northeastern District Meeting, Portsmouth, New Hampshire, May 20-22, 1963.*

8.) Rodick and P. Musser "Evaluation of Measures and Costs to Mitigate Magnetic Fields from Transmission and Distribution Lines" *Missouri Valley Electric Association Engineering Conference, April 7, 1993, Kansas City, Missouri. 1996.*

9.) *Ampacities for Aluminum and ACSR Overhead Electrical Conductors*, Second Edition. The Aluminum Association. July 1986.

10.) *The Effect of Creep and Other Time Related Factors on Plastics*, Volume 1 - Book A. Plastics Design Library, New York, NY. 1991.

11.) F.F. Fowle, A.E. Knowlton. *Standard Handbook for Electrical Engineers, First Edition.* McGraw-Hill, New York, NY. 1993.

12.) J.G.Gill, R.D. Stys, R.V. Seely. *Impulse Characteristics of Spacer Cable.* Paper 31, pages 66-71, presented at the IEEE Winter Power Meeting. New York, NY. Jan/Feb 1966.

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