Spacer Cable and Tree Wire Issues in Environments Containing Airborne Contaminants

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Introduction

Covered Conductor Systems (Spacer Cable and Tree wire) have been installed in a variety of environments over the last 70 years. It has been used to great advantage in numerous applications on seven continents and in over sixty countries. It is in the last 20+ years, however, that spacer cable usage has expanded to so-called “contaminated environments” and climates more severe than were originally anticipated. In certain cases this has led to system failures.

The purpose of this paper is to categorize contaminants and the environments in which they arise, to review spacer cable performance in such environments, and to analyze lessons learned. Ultimately, the objective of this analysis was to create a design blueprint for the specification of aerial covered conductor systems and system components, along with preventative maintenance requirements, which will withstand these various contaminated environment challenges. That design guideline is contained in Appendix 2.

Historical Background

Comparison of Spacer Cable to Bare Wire Systems

Seacoast salt salinity which becomes airborne, which is also sometimes referred to as salt fog, is a potent source of contamination, as it has the potential to convert insulators into conductors. If there is sufficient rain to wash the salt off the insulators (or insulating "system" as in the case of spacer cable), they will generally return to their original state. Most of the spacer cable installed along the Atlantic coast of the USA has operated with this condition for 70 years, and many Caribbean island installations have been in service for 45 years without any negative effects. It could be argued that these environments have been, for the most part, rather benign when considering the effects of contamination.

Where salt fog is present, and there is sufficient rain, spacer cable performs admirably in comparison to bare wire systems. The increased leakage distance, low charging current on the surface due to the insulation layer, and natural hydrophobic qualities of the polymeric materials used provide advantages over the normally flashover prone bare wire systems, and the polyethylene conductor covering prevents corrosion of the metallic conductor as well. The messenger wire performs well in this environment, as it is Alumoweld conductor, which contains a heavy EC Grade aluminum coating over steel.

First Spacer Cable Contamination Environment Field Trial

A windy, saline environment without appreciable amounts of rain, or with an extended dry season, presents a different type of challenge to insulation systems. The system needs to withstand the contamination accumulation until it is washed off, whether by natural or artificial means, and the total amount or rate of contamination buildup is played off against the period between washings.

A field trial was run in Corpus Christi, Texas, from 1991 to 2000. A spacer cable system was installed at the salt-water sluice for the Barney Davis Power Plant. A sluice is a type of spillway, which is basically a set of stairs constructed so that the water runs down them. In this case, a heavy froth or mist of salt continually bubbled up into the air. It is above this spillway that the spacer cable system was built. The environment surrounding the plant is semi-desert, and also close to the seacoast. There is moderate annual rainfall (around 30 inches/76 cm), but the dry season (less than 2 inch rain/month) is unpredictable. Contamination from the sluice spume, proximity to the sea, and paucity of rain to wash the insulating surfaces, is where the concern arises.

The distribution system was 15kV, and was constructed with 15kV cable installed with 25kV insulators on the angle poles and 46kV spacers to provide added leakage distance. At this time and for years after the standard recommendation was to use one additional class of insulation for spacers and insulators when building in a contaminated zone.

The system was monitored off and on for nine years before it was de-energized and left in place with the possibility of reenergizing at a later date. Inspections revealed that the hardware showed modest corrosion but appeared in acceptable condition, the insulators and spacers showed no surface erosion or discoloration. Furthermore, no failures had been reported throughout the nine-year trial. The trial exhibited exceptionally good results for a spacer cable system in an moderately dry environment with exaggerated contamination from airborne salinity.

Defining and Quantifying Contamination

In order to better understand the challenges presented to aerial covered conductor systems (messenger supported spacer cable and selfsupported tree wire systems), it is helpful to catalog the individual contaminants that may be present in the surrounding environment. Some of these are naturally occurring, such as salt fog or certain mineral compounds, while some are introduced to the environment by man, as is evident in industrial applications. Contaminants may present hazards to spacer cable systems either by themselves or after combining with other compounds or with moisture.

Standards Relating to Contaminated Environments

IEC 1109 – *Composite Insulators For a.c. Overhead Lines With a Nominal Voltage Greater than 1,000 V – Definitions, Test Methods, and Acceptance Criteria:* This universally recognized standard defines insulator compliance for salt fog environments. Hendrix HPI insulators have been tested in accordance with this standard, and have passed not only the 1000-hour test, but the 5000-hour test as well. The latter is recommended for contaminated environment application. The caveat here is that this is a test on insulators only, and does not consider the system (covered conductor or spacer cable) as a whole.

ASTM D2303 – *Standard Test Methods for LiquidContaminant, Inclined-Plane Tracking and Erosion of Insulating Materials:* This is a test for raw materials rather than finished components. It basically requires a material, formed into baseball card sized plaques and resting at a 45 degree angle, energized on one end and grounded on the other, and subjected to a continuous application of liquid contaminant, to “survive” a pre-set time period without succumbing to tracking. It can be argued that this test is not reflective of the composition, severity, or combination of individual contaminants, and, thus, may not be an adequate indicator of whether a component made of this raw material is rigorous enough for a given contaminated environment. The test is valuable, however, and fundamental to not only testing raw materials for all components for incoming inspection, but is valuable for comparatively testing different materials.

IEC 60815 – *Guide for the Selection of Insulators in Respect of Polluted Condition:* This is a comprehensive set of recommendations for the application of insulators and insulating systems in contaminated areas. This guide attempts to assign categories to application environments as a function of annual ambient conditions. It further attempts to recommend leakage distance values as a function of kV class for insulators. While it is helpful and universally recognized, it is exceedingly general in that it avoids either quantifying or defining what "pollution" is and, hence, the severity of one (Pollution Category Zone designation) versus the other as regards insulation systems. IEC 60815 is summarized in Appendix I.

Sources of Contamination

With a moderate amount of rain, and the absence of severely contaminating factors, spacer cable and tree wire will both fare well. Should the contamination be severe, the rain scarce, or the drought long in duration, however, installations may require consideration on a case-by-case basis. An attempt is made here to categorize and list the more familiar sources of contamination and the environments in which they are present. This list is by no means comprehensive, nor does it delve into the larger issues of multiple contaminants.

Proximity to the Sea

Salt, the principal ingredient in seacoast environments, is not inherently a chemical enemy of polyethylene. That is to say, it is not corrosive. It only becomes a problem when it forms a conductive layer and transforms the surface from an insulating one, to one which is prone to conduct electricity. This problem can be exacerbated with the presence of minimal amounts of moisture, such as condensation or morning dew. The moisture acts to make the surface contaminant layer more conductive. There are numerous salts available to form conductive compounds. The most common are Sodium (Na), Potassium (K), and Magnesium (Mg).

Also present near saltwater environments are Silicate (SiOx) compounds, or what is commonly recognized as sand. While silica is acidic in nature, it is not really a problem in itself. However, Silica crystals and associated compounds often contain salts (Sodium, Potasium, Calcium) and metals (Aluminum, Iron, Magnesium), which are highly ionic in nature and inherently conducting.

After a contamination related failure at a high voltage line on the Pacific coast of Central America, it was noted that there were several combining factors which contributed. The argument that followed, however, was whether one seacoast environment is inherently more risk prone than another. Certainly spacer cable systems have existed seaside in the Atlantic and Caribbean for decades, without problems, so why would Pacific Central America be different?

What was theorized is that water temperature combined with climate aridity plays a role. That is, when the ocean is very warm, and the air is very dry and hot, there is a greater tendency for waves crashing on the shore to absorb the water foam into the air in the form of a vapor, which is carried into the air. The vapor contains the troublesome salts. This phenomenon was also exhibited in climates with high temperatures and high humidity.

Refuse Incineration

Localities that practice or allow burning of refuse in close proximity to power lines contribute airborne particulate matter that will deposit itself on insulating surfaces. This material is carbonaceous in nature, but may contain other ionic material that may increase the surface conductivity. A secondary effect is that the deposit of these foreign materials on the insulating surface reduces the hydrophobicity by creating surface roughness areas where other airborne particles will be more likely to become lodged and collect rather than blow away or wash off.

Road and Highway Surface Particulate Matter

If a road is unpaved and in close proximity to the sea, it is likely to contain high concentrations of silica. Problems may arise when high-speed traffic causes these particles to be sent into the air and onto the insulating surfaces.

On paved surfaces in colder regions, state or local authorities may use road salt to prevent icing. This salt remains on the road after everything else melts, and it is not uncommon for the salt to be whipped up into the air and settle on insulating surfaces. It is generally true that climates which have a cold winter also usually have spring rains; these spring rains naturally wash the residual road salts off the insulating surfaces. This airborne road salt has not traditionally been a source of concern for covered conductor systems, although it potentially could be a source for concern in an environment with multiple factors.

Utilities in the north central USA and Canada which use heavy road salt have had issues with insulators on bare wire systems, which have led to pole fires. They have commonly referred to IEC 60815 as a guide in selecting insulators. A guide for covered conductor systems not unlike this standard was heretofore an unmet need.

Agriculture-Related Factors

Agricultural environments, depending on the use and method of spreading chemicals, can contain compounds, which are inherently corrosive to polyethylene. Others are inherently ionic and stick to the insulating surface.

Fertilizers which are spread via aerial spraying in close proximity to power lines, such as Potassium Nitrate, Magnesium Sulfate, and Zinc Sulfate, which are water soluble, can be highly conductive when mixed with water. Pesticides, if sprayed aerially, are another source of corrosive chemicals. Pesticides are made of phosphorous compounds which, when mixed with water or air, can become acids, which are corrosive. Herbicides may be another source, although they have not yet been encountered with spacer cable applications since spacer cable is normally used in environmentally sensitive areas where herbicides would normally be prohibited.

The presence of corrosive chemicals on polyethylene insulating surfaces may lead to what is known as "Environmental Stress Cracking," which opens up microscopic cracks in the material's surface and invites the trapping of contamination particles. This then becomes a more attractive surface for the settling of still more contamination particles, thereby reducing the material's hydrophobicity and selfcleaning abilities.

Minerals, salts, and metals are, depending on their chemical state, ionic and therefore inherently conducting. Some materials, which are inherently corrosive, can come from agricultural or industrial contamination sources, or, be produced in the local environment when mixed with water, depending on the temperature, pH, or concentration. For example, the introduction of sulfates into the air creates the opportunity to mix with moisture (H_20), to create Hydrogen Sulfide gas (H_2S), Sulfuric Acid (H_2SO_4), or other derivatives, which, depending on quantity or concentration may be conductive or corrosive in nature.

Crop Burning

Sugar cane as well as other crops is sometimes burned at a certain point in its annual cycle. This sends carbonaceous material into the atmosphere, which may deposit itself on the insulating surfaces.

Industrial Sources of Contamination

Concrete facilities are perpetually emitting dust, sand, silicone, and cement (glue) from the processing areas, as well as from the exhaust stacks. This dust settles on the conducting surfaces. With a tiny bit of morning dew, the ionic material in the dust mixes with the ionic material, creating a kind of sludge where material is afforded the opportunity to move, or at least change alignment. This allows ionic and thus conductive material on the surface to align with the electric field around the cable, thus creating conductive paths for current to flow, which facilitates tracking. With a bit more moisture, the cement actually cures on top of the conducting surfaces, forming an extremely hard and rigid crust.

Potash mines have similar characteristics. Potash is made up of numerous salts which contain potassium, problematically in water-soluble form. These include, but are not limited to Potassiumsulfate, -nitrate, -chloride, and –carbonate. When airborne potash dust settles on insulating surfaces, the water-solubility is activated by morning dew, which allows realignment of ions and invited tracking on the insulating surfaces. Some potash mines are conveniently located in zones with lots of rain which washes off the contaminants, while others are located in pure desert envinronments.

Petroleum based products, normally taking the form of diesel fumes in locations where exhaust regulations are lax, are natural enemies of polyethylene. Petroleum is a hydrocarbon with components intended to cause oxidation. Oxidation is also caused, to some extent, by sunlight exposure.

The HDPE used in spacer cable is materially blended with anti-oxidants and UV inhibitors to minimize this attack, and this form of contamination is not suspected in having contributed to failures due to oxidation. What is possible, however, is that airborne diesel fumes collecting on conducting surfaces act like glue, which trap other airborne particles on the surface.

Naturally Occurring Sources of Contamination

In rare cases environments may contain sulfur. Hydrogen Sulfide (H_2S) is a naturally occurring gas found near the mouth of some volcanoes and other active geothermal spots. The presence of sulfur also opens the possibility for combination with moisture to create Sulfuric Acid (H_2SO_4), which is corrosive and attacks metals and polyethylenes alike. For locations such as these, the key to predicting potential damage would be the amount of annual rainfall and the duration of the dry season.

Multiple or Combination of Factors

The contamination related effects which can be experienced from multiple sources could be significant. Should a location be close to the sea, with a long dry season, agricultural spraying, refuse burning, etc., special precautions would be recommended to avoid problems.

Contamination-Related Failure Mode of Covered Conductor and Spacer Cable Systems

For a contamination-related failure to occur in a spacer cable system, the first thing required is the buildup of airborne contamination particles. Leakage current increases with the presence of moisture. The moisture referred to here is not rain, because even light rains provide washing of insulating surfaces, thereby improving the situation and averting failure. The moisture which is problematic is condensation or morning dew. Just enough liquid is introduced to react with the contamination particles to form conductive compounds suspended in a liquid film on the surface. The ionic material in the liquid material is then able to align itself with the electric field and facilitate surface tracking.

At some point there is sufficient contamination on the surface that one of two things begins to happen. The first is, depending on voltage level, a partial discharge. The partial discharge is a result of highly concentrated electric fields created by miniature and non-uniform contamination particles resting on the surface. This can create “pitting” of the cable surface, reducing its hydrophobicity, and creating a surface roughness, which invites further buildup of contamination.

The second possibility is that the contamination creates a path for current to flow. This current is known as tracking current. It is possible to have arcs with a temperature of over 1,000 F with just a milliamp of current. These temperatures produce melting of the cable covering as well as any polyethylene support member that lies in its path to ground. Candidates for the latter would be the spacer, insulator, or antisway bracket, if one was utilized.

A related phenomenon that is observed in extremely contaminated and insufficiently designed systems is Dry Band Arcing (DBA). This occurs when an accumulation of contaminants on the insulating surface reduces the surface resistance to a point where current begins to flow, which then eventually results in surface tracking along predetermined paths. It is possible to have a system suffer DBA and minor surface electrical erosion during an extremely prolonged dry season and not progress to a failure stage. Once significant damage has occurred, in terms of melting or pitting, the situation is usually progressive. That is, even with surface washing, the buildup of contaminants will likely take a shorter time to track, melt, and reach failure during the next dry season.

In general, all distribution systems will exhibit corona to some degree, depending on the voltage level, amount of contamination, presence of moisture, etc. This phenomenon is audible, and can be visible as well, depending on its severity and the amount of ambient light available. Without permanent contamination, however, the corona will mostly disappear when the system dries out. Permanent contamination, however, will also lead to tracking, which also makes an audible "buzz," and which is much more likely to cause high temperature arcs and more serious and rapid damage, as demonstrated in ***Photo 1***.

Photo 1: Silica Coated Spacer in Dry, Multiple-Contaminant Environment Exhibiting Dry Band Arcing Prior to Failure

A phenomenon related to premature failures of spacer cable systems but unrelated to the covered conductor relates to the selection of messenger. Alumoweld or Alumoweld-Aluminum messenger was selected for its combined properties of high strength, ampacity (use as a system neutral as well as lightning shield), and corrosion resistance. The use of galvanized wire invites corrosion, loss of strength, and premature failure due to inability to support the system either mechanically or withstand the electrical damage from a lightning strike.

Photo 2: Galvanized Messenger in Dry Pacific Seacoast Environment after Only 9 Months

Responses to Contamination - Mitigating Factors & Strategies

Contamination is present, at least to some extent, in all operating environments. It is possible to build and operate spacer cable systems in even the most extreme environments, as long as the ambient conditions are taken into consideration when initially designing and later, maintaining the system.

Environmental

Natural washing from rain is the best and cheapest form of environmental assistance for covered conductor systems. Strong and frequent rains provide excellent results in washing of properly design insulating surfaces. Another favorable situation, ironically, is an environment that is almost completely without humidity. Spacer cable systems have been operating in certain desert environments for years, and this has been attributed to the absence of the problematic morning condensation.

When working up a profile on possible contamination affected installation sites, one is interested not only in the contaminants present, but also the rain. How much is necessary to properly wash insulating surfaces? This topic is addressed in the design guideline in Appendix 2.

Artificial Washing

Utilities which operate in contaminated environments are accustomed to artificially washing their transmission, and sometimes distribution lines as well. Methods and equipment vary, although the common factors are to apply a fine stream of high pressure de-ionized water to rinse or force off contamination particles residing on the insulation surfaces.

The use of spacer cable and/or tree wire in certain contaminated areas will reduce the required frequency of washing, although not necessarily eliminate it, depending on the ambient contamination. The cost savings of reduced washing cycles needs to be compared to the material cost differential required for these constructions when compared to other construction options. That is, is it cheaper to install bare wire and wash twice per year, or install a covered conductor system and wash once per year, or avoid washing entirely? Also, what are the ramifications for reliability?

Design

The single most effective tool for avoiding system failures or reduction of useful service life is to design the system so as to avoid problems which can be reasonably predicted to result from ambient contamination. The most important items to consider are listed on the next page:

CABLE DESIGN

It is important to ensure that the flow of charging current is kept reasonably low. It has been the experience that designing a cable covering to allow a maximum charging current of a few hundred microamperes will promote a long useful service life. While the bulk of experience supporting this conclusion is based on installations in relatively non- or mildly-contaminated sites, this design objective is still considered to be fundamental. However, it is not simply the control of available charging current which is important, but control of leakage current (i.e., that current which will flow towards ground and possibly initiate tracking) as well.

SPACERS AND INSULATORS

Tests have shown that the use of longer leakage distance components has reduced the level of leakage current. Note that it is the leakage current that results in tracking, eventual arcing, high temperatures, and which lead to failures. Hence, the use of spacers as well as insulators which are rated one or more Kv class ratings above the applied system voltage will help reduce and manage leakage current.

INCREASE TOTAL LEAKAGE DISTANCE

It is possible to use support structures which are non-metallic and have good track resistant characteristics in order to increase total leakage distance at structures which require insulator support of conductors. As an example, the use of fiberglass brackets both at tangent as well as angle structures can help manage leakage current.

ACCESSORIES:

- **Tie Wire:** it is important to use non-tracking ties, both on spacers as well as insulators. Some products, such as preformed ties made of polyethylene are not only ill-designed for sufficient track resistance, but the manufacturing process used to mix the UV inhibition adders is insufficient to get a uniform mix throughout the component. This leads to premature aging, cracking, and rough surfaces which invite contaminant buildup and subsequent tracking.

- **Antisway Brackets:** It is possible that an antisway bracket used at a tangent pole can, by virtue of it being in a continuous horizontal position, be more prone to contamination particle accumulation. It is also possible that the leakage distance of the unit is less than any other path to ground found in the system. If either of these conditions exists, the bracket should either be eliminated, or an antisway bracket with higher leakage value selected.

DEADEND STRUCTURES

This is simply a restatement of the item above. Namely, that the use of higher leakage distance insulators is fundamental for contaminated environments, whether the insulators be pin type, line post, or deadend suspension insulators.

ALTERNATIVE SYSTEM DESIGN OPTIONS

Suffice it say, there are some environments where any type of aerial construction is not cost effective, either due to the need to excessively overdesign, wash too frequently, or both. In this case, the use of underground cable is the next likely candidate.

Silicone Sprays or Hydrocarbons

Numerous products are commercially available to increase and restore the hydrophobicity of insulating surfaces. They are very effective. Drawbacks are that they are also expensive, require reapplication in periods up to several years (this reapplication requires cleaning prior to application), and the quality of the coating may be degraded by heavy rains or other severe weather, indicating that periodic checks are required for the system. While these products hold promise, they have not yet been introduced into or tested with, covered conductor systems.

Monitoring

There are three major monitoring strategies which exist to date. They are reviewed below:

PARTIAL DISCHARGE DETECTORS

These are also known as Acoustic Emission or "Corona Phone" detectors. In varying models available on the commercial market the electrical noise is picked up with a parabolic dish pointed at the location of interest (in this case, the spacer, insulator, deadend, or cable section). The reading is given either on an LCD display in db or with a set of headphones.

Due to the inability to completely eliminate noise components from background sources, this method has not yet been accepted as conclusive for determining whether a system is at the pointof problem inception. Furthermore, no correlation studies have been done to date on partial discharge (PD) testing for spacer cable systems as a function of time-to failure, at least as far as the writer knows. However, audible and certainly visible partial discharge or corona can logically be interpreted as undesirable.

Hendrix started using PD testing a few years ago, employing a company which leads the industry in this technology. More on this topic will be discussed in the future.

THERMOGRAPHY

This method has been used to look for trouble spots. At one utility in Florida, it was used to try to predict trouble spots. One location showed a temperature elevation where Spanish moss had short circuited the three phases. The temperature rise was minimal (less than 8°F) however, and was deemed not useful as a predictor. However, from a preventive maintenance standpoint, it certainly provided a quick indicator of where moss should be removed from the line.

In general, however, when a real hot spot arises which is a result of severe tracking and which may cause arcing at temperatures reaching 1,000°F, it is usually already too late, as the polyethylene will melt rapidly. It is, therefore, desirable to avoid situations which will lead to severe tracking.

PERIODIC VISUAL INSPECTION

Any spacer cable or covered conductor system installed in a nominally contaminated environment should be periodically inspected visually. Things to look for are obvious tracking, Dry Band Arcing, and pitting on the cable surface.

Case Studies

Four case studies are included below to illustrate failures in different locations, how they were influenced by environmental conditions, how their time-to-failure and failure mode were affected by system design, and conclusions and recommendations that were taken away by the study of these failures.

Case Study #1 – North Coastal Florida 25kV Line

This approximately ten mile line suffered 3 failures, all within a short distance of one another. The line was assumed to be a Class II Pollution category, similar to what would be experienced in coastal New England. The minimal nominal leakage distances recommended by IEC 815 are shown in the table below for a 25kV system. Note again that these are recommendations assuming that the conductor is bare and the insulators are porcelain. Covered conductors and polymeric insulating components should be expected to perform better with less leakage.

Pollution Category	Min. Leakage ("/kV)	Min. Leakage (")*
I - Light	0.63	16.5
II - Medium	0.79	20.7
III - Heavy	0.98	25.7

**Allow for 5% voltage rise*

Below are listed, in addition to standard 25kV 3-layer construction cable, the components used at this site:

Pole Type/Material	Leakage Dist. (")	Percent of Class II recommendation
Angle/HPI25	14.6	70.5%
Tangent/BAS-24F	24.1	116.0%
Midspan/RTL46	17.5	84.5%
Deadend/DEINS25	26.0	126.0%

The failures occurred mid-span at what was believed to be sites where seacoast salt laden Spanish moss bridged the 3 phase conductors at a spacer assembly. The system was repaired without improvements and is currently operating without incident. The line was installed in the 90's, and was really the first case of contamination related tracking experienced in the US.

Case Study #2 – Central Coastal Chile 15 kV Line

This line was built in June 2004, and is in an IEC Class IV zone, with high contamination and almost zero rain. The standard utility practice in this location is to artificially wash bare wire lines multiple times per year.

The utility ran a field test trial of spacer cable and formally monitored results on a continuous basis, with visual inspections and data collection on a monthly basis. Instead of using 15kV cable, they utilized 25kV 3-layer cable. For spacers, they utilized the 46kV spacer, and for insulators at angle poles, the 35kV HPI. IEC 815 (bare line, porcelain insulator) minimum leakage distance recommendations are shown below for the 15kV voltage class.

Pollution Category	Min. Leakage ("/kV)	Min. Leakage (")*
I - Light	0.63	9.92
II - Medium	0.79	12.44
III - Heavy	0.98	15.44
IV - Very Heavy	1.22	19.2

**Allow for 5% voltage rise*

Below are listed the leakage distances of the components used, and how they compare with Category IV recommendations.

Pole Type/Material	Leakage Dist. (")	Percent of Class IV recommendation
Angle/HPI35	21.0	109%
Tangent/BAS-24F	24.1	126%
Midspan/RTL46	17.5	91%
Deadend/DEINS25	26.0	135%

After 9 months, the system began to shows signs of Dry Band Arcing, partial discharge, and electrical erosion on the cable surface. After 10 months, the system failed. Failure took place mid-span, where avalanche tracking between phases along a spacer melted a spacer and severed the conductor. From the chart above, this location would appear to be the lowest leakage distance of any construction type. One design step that would mitigate againstthis occurring was the fact that 25kV cable was used instead of 15kV cable, effectively reducing the available charging current. What worked against this location is the fact that the spacer, although designed to be self washing with rain, had no natural rains to clean the surfaces of contaminants. What is interesting and perhaps counterintuitive, is that the Antisway bracket sites, which would seem to capture more contamination due to their pure horizontal orientation, suffered no problems at all. This may be credited to the fact that there was quite a bit more leakage distance compared with the mid-span spacer location.

Recommendations which came forth after the trial were that spacer cable built with standard class components should not be used in IEC 815 Category IV contamination zones. They added that tree wire (covered conductor on croassarms with polyethylene insulators) installations in this same zone which were washed (although not as frequently as bare wire installations) suffered no problems whatsoever and are in satisfactory operation at this time.

This utility concluded that for severe IEC 60815 Category IV contamination zones, tree wire performs better than spacer cable. While this may be a viable conclusion for this isolated case, it is not necessarily a conclusion shared by the author, in that additional design and preventative maintenance strategies are available to accommodate a spacer cable configuration.

Case Study #3 – Central (non-coastal) Brazil 15 kV Line

The line in question here is 15kV class built with 15kV components. Contamination Class is assumed between light and medium, according to IEC 815. To the right is shown a thermographic photo of temperature elevations on a mid-span spacer assembly. The temperature rise is due to the use of substandard components. The cable covering is of insufficient thickness. Suffice it to say, this is NOT a Hendrix system. What is interesting, however, is that the preformed ties used for connecting the spacer to the phase conductors, rather than being track resistant, are collection points for attracting tracking current to the spacer and towards the ground via the messenger.

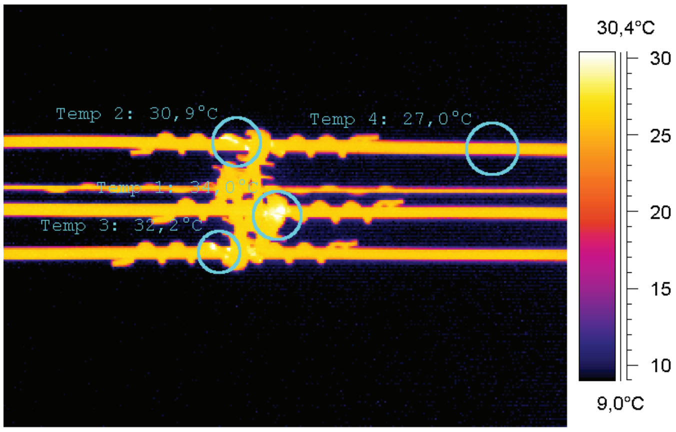

Photo 3: Thermographic Photo of Temperature Elevations on a Mid-Span Spacer Assembly

While this particular case study provides no conclusions regarding properly designed and built spacer cable systems, it is included for completeness, as the market availability of aerial covered conductor and components intended to mimic Hendrix systems increases.

Case Study #4 – Pacific Central American 46kV (delta) Line

This line was built during the dry season and suffered problems soon after energization. It is assumed that if it had been energized in a clean condition rather than with accumulated contamination, results might have been different. Furthermore, the IEC 815 contamination class used for design and component selection was not properly considered. Leakage distances as a function of IEC class are as follows:

Pollution Category	Min. Leakage ("/kV)	Min. Leakage (")*
I - Light	0.63	30.4
II - Medium	0.79	38.0
III - Heavy	0.98	46.0
IV - Very Heavy	1.22	59.0

**Allow for 5% voltage rise*

Below are listed, in addition to standard 46kV 3-layer construction cable, the components used at this site (originally selected and in place at time of failure), as well as the components recommended to repair the line.

Pole Type/Material	Original Leakage (")	Proposed Change	Leakage Dist. after Change (")	Change (%)
Angle/HPI35	21.0	Add "18 fiber-glass bracket	39	86
Tangent/BAS-24F	24.1	Remove	N/A	N/A
Midspan/RTL46	17.5	RTL-GO95	28	60
Deadend/DEINS25	34.8	Add DEINS25	60.8	75

The below chart shows the proposed changes, per construction type, and how the leakage distances compare with IEC 815 recommendations, assuming a Class IV contamination category.

Pole Type/Material	Leakage Dist. After Change (")	Percent of Class IV recommendation
Angle/HPI35	39	66 %
Tangent	N/A	N/A
Midspan/RTL-GO95	28	47 %
Deadend/DEINS35 + DEINS25	60.8	103 %

The IEC recommendations for Class IV are very significant in terms of leakage distance additions. The requirements are almost 200% of the standard, or Class I category. For a 46kV system, the minimum leakage distance requirement of this takes the leakage distances for insulators and spacers to 59”. This is of course, for bare wire systems with porcelain insulators.

When the system failed, it was at the tangent pole. It was surmised that the accumulation of contamination on the horizontal antisway brackets was the cause of the failure. Recommendations include complete removal of all antisway brackets, increasing the spacers to a larger size, higher leakage model, increasing leakage at the angle poles by adding fiberglass brackets, increasing leakage at the deadends with additional deadend strain insulators, and increasing leakage at the transitions with a combination angle pole and deadend construction.

Initial tests have shown that this increase in leakage distance in combination with at least some periodic washing was an adequate solution. Tests were done with the mid-span construction having been changed, which is shown as the lowest leakage distance of any construction type in the table above. It should be noted that this site exhibits high salinity, an extended dry season, and multiple contamination sources (cooking and garbage fires directly under the line, fertilizers, pesticides, and diesel fumes), and artificial washing is key to the line’s survival.

Summary

This paper attempted to review general causes and effects of contamination on spacer cable and covered conductor systems, as well as history, monitoring, mitigation recommendations, and case studies for some of the more trying applications. It should be noted that results for Weatherproof Wire (i.e., 60 to 80 mil single layer BPE covering), or medium voltage covered conductor from non-Hendrix manufacturing facilities may be decidedly different.

The effects of contamination on spacer cable and covered conductor system are a result of complex interactions between contamination factors, time at exposure, the availability of washing, and whether that washing be natural or artificial. In a given application, it can be seen that while one system or location may be operationally fine, another location may not survive, yet the difference between the two sites may appear to be minimal. Steps can be taken to mitigate the risks of ambient contamination.

Finally, it is also relevant to mention that the industry is still learning. One would logically expect that as additional high voltage (i.e., 46 and 69kV) spacer cable and covered conductor systems are installed, and more diverse and challenging locations are selected for application sites, the industry will have more experience to draw from for further knowledge.

Appendix 1: IEC 60815 Recommendation for Polluted Conditions (Porcelain)

Pollution Category	Environment description	MNSL* mm/kV	MNSL* in./kV
I - Light	• Areas without industries and with low density of houses equipped with heating plants • Areas with low density of industries or houses but subjected to frequent wind and/or rainfall • Agricultural areas • Mountainous areas • All areas situated 10 – 20 km from sea and not exposed to winds directly from the sea.	16	0.63
II - Medium	• Areas with industries not producing particularly polluting smoke and/or with average density of houses equipped with heating plants. • Areas with high density of houses and/or but subjected to frequent winds and/or rainfall • Areas exposed to winds from the sea but not too close to the coast (at least several km distance)	20	0.79
III - Heavy	• Areas with high density of industries and suburbs of large cities with high density of heating plants producing pollution • Areas close to the sea or in any case exposed to relatively strong winds from the sea	25	0.98
IV - Very Heavy	• Areas generally of moderate extent, subjected to conductive dusts and to industrial smoke producing particularly thick conductive deposits • Areas generally of moderate extent, very close to the coast and exposed to sea-spray or to very strong and polluting winds from the sea • Desert areas, characterized by no rain for long periods, exposed to strong winds carrying sand and salt, and subjected to regular condensation	31	1.22

** MNSL = Minimum Nominal Specific Leakage*

Table 1: Lorem ipsum dolor sit amet

Appendix 2: Design Guide for Specifying Spacer Cable Components in Consideration of Contaminated Environments

Zone 1 – Light Contamination

For all system voltage classes, Hendrix Spacer Cable Systems have performed well in IEC 60815 Zone 1 conditions for close to 70 years; therefore, no system component selection modifications are recommended.

Zone 2 – Medium Contamination

For 15kV and 25 to 46kV Systems, the Hendrix Space Cable Systems normally work well in medium contamination zones, and, as such, no modifications to the specified material will normally be recommended. However, the classification of a contamination zone as either Zone 1 or Zone 2 is sometimes subjective. Depending on the contamination components, as well as length of annual dry spell and dependability of rain, these options are reflected in options available in Table 2 on the next page. It should be noted that some locations which have the advantage of abundant rains, may also have extended drought periods in certain years.

Experience has shown that precipitation in excess of 40 inches per year, with no or very few dry months (less than 2 inches rain per month), is sufficient to properly clean insulating surfaces for a coastal (saline) environment.

Consult your regional sales contact or email sales@marmonutility.com for assistance with specific designs.

Voltage Class (kV)	15	25	35	46
Conductor Rating (kV)	15	25	35	46
Spacer	RTL15 or 46	RTL46	RTL-GO95	RTL-GO95
Pin insulator	HPI15 or 25	HPI25 or 35	HPI-35 or HPI-35 w/ fiberglass bracket(1)	HPI35 w/fiberglass bracket(1)
Dead-end insulator (kV class)	25	35	35 + 25	35 + 25
Anti-Sway bracket	BAS-15F or BAS-24F	BAS-24F	BAS-24F	Not Recommended(2)

(1) Refer to factory drawings in Appendix 1 for this design

(2) Horizontal surfaces which collect contaminants and are connected to ground are not recommended.

Table 2: IEC 60815 Zone 2 Component Selection

Zone 3 – Heavy Contamination

In zones of heavy contamination, the recommendation is to use components from the next size larger insulation class to increase the leakage distance. Component selection recommendations are shown in Table 3 below.

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Voltage Class (kV)	15	25	35	46
Conductor Rating (kV)	15	25	35	46
Spacer	RTL46	RTL46	RTL-GO95	RTL-GO95
Pin insulator	HPI25	HPI35	HPI-35 w/fiberglass bracket(1)	HPI35 w/fiberglass bracket(1)
Dead-end insulator (kV class)	25	35	35 + 25	35 + 25
Anti-Sway bracket	BAS-24F	BAS-24F	Not Recommended(2)	Not Recommended(2)

(1) Refer to factory drawings in Appendix 1 for this design

(2) Horizontal surfaces which collect contaminants and are connected to ground are not recommended.

Table 3: IEC 60815 Zone 3 Component Selection

Zone 4 – Very Heavy Contamination

In zones of heavy contamination, there are several options, each depending on the severity of contamination, the composition of the individual contaminants themselves, and the amount of natural washing in the form of rain. The options recommended, in order of increased severity of contamination, are listed below:

1. If contaminants are not corrosive (acidic, etc.), and at least some natural washing occurs for several months of the year, components may be selected from Table 3 in the previous section.

2. If contaminants are not corrosive, but little to no natural washing is afforded by nature, then a two part solution is recommended. The first is that components be selected from Table 3, but this is if and only if a line washing program also accompanies this strategy. The frequency of washing recommended would be similar to that used for bare open construction in the same zone.

3. Utilize a different construction option, such as bare wire or underground.

In any case, planning for construction in an IEC 60815 Zone 4 location should be accompanied by consulting with your regional sales contact or email sales@marmonutility.com.