# GRID HARDENING, INCREASING RELIABILITY AND REDUCING WILDLIFE-RELATED FIRE RISK

The strategic installation of insulating covers and barriers can be used to minimize the impact of wildlife on power grid assets. If these components are specified correctly, they can minimize costly power outages, while reducing fire risk and safeguarding assets and the environment for 40 years or more.

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FIGURE A

## ABSTRACT

When animals (such as birds, squirrels, raccoons, possums, bats, rats, snakes and more) come into contact with overhead lines and substations, this can cause localized fires and even uncontrolled wildfires on the ground below. This represents an increasingly common problem for electric utilities and industrial power-distribution systems all over the world. Such problems are particularly common in older networks, which were not designed to protect against wildlife-related outages or fires. Up to 25% of fires associated with power-distribution systems are preventable with the appropriate engineering controls, and are most commonly caused by the following:

- Wildlife-related activities, including ignition of nesting materials and other animal-related debris, pole-top fires from electrocuted birds and animals falling to the ground, igniting dry vegetation below.
- Flashover of pollution (such as bird guano and airborne environmental pollutants) that has built up on insulated components. Such contaminants can create a conductive path for the current to flow through, increasing the risk of arcing, tracking and flashover.
- Vegetation-induced fires resulting from live, bare conductors touching dry vegetation.
- Conductor clashing, where two adjacent conductors come into contact with each other, generating sparks, conductor damage and traveling arcs.

Poorly designed insulation material is a less well-known, but equally important fire risk. In order to be fit for purpose, a high quality insulation material formulation should have the following characteristics:

- Perform reliably for 40+ years without deterioration in performance.
- Minimize the risk of fire ignition associated with normal and abnormal utility environments.

No pure polymers will work in a high voltage environment. All materials need a stabilizer package to deliver:

- UV longevity.
- Thermal endurance.
- Prevention of tracking and erosion on new and aged materials.
- Prevention of fire ignition due to power arcs and surface leakage currents from new and aged materials.

## Fire-Related Outages Caused by Wildlife and Vegetation

In general, fire-related outages caused by wildlife and vegetation fall into two categories: phase-to-earth faults and phase-to-phase faults. Both risk types can be mitigated appropriately using insulated Wildlife Asset Protection (WAP) components:

- Phase-to-earth faults. These faults occur when wildlife bridge the gap between phase and earth.
- Phase-to-phase faults. These occur when two adjacent phases collide or are momentarily bridged by wildlife or debris (for example, during wire-clashing incidents), producing hot, molten metal particles that can ignite dry materials nearby.

Selecting the most appropriate material is a critical — and often-overlooked — consideration when upgrading overhead lines and substations with insulating components, to help reduce ignition risks and prevent wildfire propagation. As such, if suitably-formulated engineering polymers are not used, the insulated components may still be susceptible to ignition and fire propagation.

This White Paper discusses a variety of retrofit solutions and the importance of following an engineering design strategy that carefully considers material properties and their impact on component performance.

FIGURE B

In the authors opinion, utility owners and operators who are planning upgrades to reduce wildlife-related risks should keep the following in mind:

A) Any retrofit solution should be designed to match the lifetime expectancy of the asset being protected. For example, substation transformers and switchgears are usually designed for 40+ years of service life.

B) Quality insulating components designed for stable operation over their projected lifetime will help to reduce, or even eliminate, fire threats to the overhead power lines and substations they are connected to.

**Materials that deteriorate prematurely over time will create new and unpredictable problems in the future.**

If product engineering design upgrades are not underpinned by robust material selection, utilities risk undermining their own efforts to safeguard critical assets. Eventually, components which are manufactured from materials that are prone to early degradation will fail, and efforts to ensure the asset is protected over its lifetime will be lost. However, it should be noted that the electrical and mechanical performance of new and aged materials is very different. It is important to test aged samples in order to predict their lifetime. For example in the TERT test, abraded samples should be evaluated as per ASTM D2303 or IEC 60587 STEP test method.

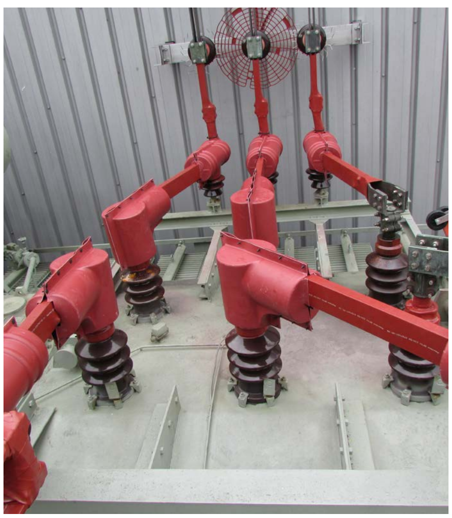


FIGURE C

## Installing the Right Insulation Upgrades

Too often, the investment needed to reduce the risk of wildlife-related fires and wildfire risks is deemed discretionary, and such investments tend to be reactionary. This operating philosophy is dangerously short-sighted, as wildlife interactions with overhead lines and substations are unavoidable, and create consequences that put an enormous toll on companies and surrounding communities.

Utility owners and operators — as well as industrial operators that own and operate captive power-generation systems that include overhead lines and substations — should seriously consider making timely and necessary investments in appropriately formulated insulating components, especially those that focus on prevention.

Efforts to improve fire safety and enhance operational reliability provide tangible payback for utility owners, by helping to avoid the costly and catastrophic implications of wildlife-related fires. These include:

- Damage to (and loss of) power grid assets.
- Service interruptions and power outages, which can threaten not only individual homes and communities, but create potentially hazardous conditions at hospitals, industrial facilities, schools and more.
- Environmental hazards and potentially life-threatening danger to personnel if the wildfires are able to impact nearby industrial facilities and result in a loss of potentially hazardous materials to the environment.
- Catastrophic damage to agricultural and horticultural assets.[6]
- Regulatory repercussions related to penalties, fires and litigation.
- Human injuries and loss of life.
- Negative media and social media attention, creating reputational damage and impacting shareholder value.
- Threats posed to wildlife are both real and pervasive. According to one estimate between 0.9 and 11.6 million birds are electrocuted every year in the USA on energy infrastructure.[1]

FIGURE D

## FIRE IN THE DISTRIBUTION SYSTEM AT A SOLAR FARM IN CALIFORNIA SUFFERS A REVENUE LOSS OF US$8-9 MILLION

In June 2019, a fire in the distribution system at a solar farm in California resulted in 1,127 acres being destroyed due to wildfire, resulting in an 84% reduction in its generating capacity, and a revenue loss of US$8–9 million. The incident was caused by a crow flying between adjacent live phases, bridging the wires and thus creating a circuit. The bird was electrocuted, its wings caught fire and when the carcass dropped to the ground, it ignited the dry grass below.[3]

[1] Loss SR, Will T, Marra PP (2014) Refining Estimates of Bird Collision and Electrocution Mortality at Power Lines in the United States. PLoS ONE 9(7): e101565. doi:10.1371/journal.pone.0101565

[2] https://www.sapowernetworks.com.au/data/303696/animals-and-electricity-supply/

[3] https://www.bloomberg.com/news/articles/2019-06-24/here-s-how-a-bird-started-a-fire-at-a-california-solar-farm

Animals are involved in 6-7% of outages in Australia's distribution network. Birds are responsible for 4%, possums 1% and bats 1%.[2] The remainder is attributed to rats, termites, snakes and lizards. Wildlife-related events can incur significant financial penalties for electric utility owners. For example, under the Migratory Bird Treaty Act, the U.S. Fish and Wildlife Services (FWS) agency, makes it illegal for anyone to kill a protected bird without obtaining a permit. Over the past 20 years, the FWS has fined multiple North American utility companies up to $10 million for killing eagles and other protected birds. In another example, a possum caused a power outage to 12,000 homes and businesses in Sydney, Australia when it came into contact with two live parts of the electricity network near a large substation. According to the utility spokesperson, "there are a lot of possums in Sydney and they use the power lines as their own highway - as a connection between trees or roads".

For most utilities, avoiding even one potential outage would help to underwrite the costs of upgrading their system with appropriate protections.

## A Squirrel Caused a Massive Power Outage in California

FIGURE E

- **45,000 customers without power for 150 min.**
- **Average cost of outage at NAM Utility US$0.12 / min per customer meter.**
- **Total cost of outage US$810k for one event.**
- **This substation was hit twice in one year.**
- **Annual impact >US$1.5M.**

TABLE 1

| In 2019 the California wildfire season generated these results:[6] | |
|---|---|
| **Total Fires** | 7,860 |
| **Total Area** | 259,823 acres |
| **Non-fatal injuries** | 22 |
| **Cost** | $162 Million (suppression costs alone) |

TABLE 2

| The 2019 Australian wildfire season created equally tragic consequences:[7] | |
|---|---|
| **Total Areas** | 18.6 hectares |
| **Total Fatalities** | 34 |
| **Buildings Destroyed** | 6,500 |
| **Cost** | US$4.4 Billion (fire fighting cost) |
| **Pollution** | 306 Million Tons of $CO_2$ emitted |

4 https://www.smh.com.au/environment/conservation/possum-cuts-power-to-12-000-homes-20120209-1rlld.html
5 European Forest Fires Information systems: https://effis.jrc.ec.europa.eu/
6 https://www.citymetric.com/horizons/squirrel-caused-massive-power-outage-california-1123
7 https://en.wikipedia.org/wiki/2019%E2%80%9320_Australian_bushfire_season

Over the past few years, severe weather conditions, unprecedented weather patterns and pervasive wildfires in California, Australia and elsewhere, have produced tragic headlines and had a profound personal and financial impact on communities, businesses, wildlife habitats as well as utility and industrial infrastructures. Weather extremes result in dry vegetation, which increases the risk of localized, spark-induced fires raging out of control. Recent statistics are sobering as illustrated in Tables 1 and 2 which detail fire statistics from California and Australia.

**Aging Electric Utility Infrastructure**

Many privatized utilities have under-invested in their extensive legacy infrastructure for years or even decades. As a result, these aging systems face new challenges every day, from mounting threats posed by severe weather, to aggressive new reliability targets and increased customer demand.

Traditional options for upgrading aging infrastructures to reduce fire risk are not feasible in many locations or would be prohibitively expensive (this includes burying conductors). Similarly, replacing conductors with covered conductors is a relatively costly option.

FIGURE F

Fortunately, today's utility owners have access to several engineering options to install affordable upgrades to overhead lines and substations, particularly in targeted, high-risk areas. For example, installing appropriate insulating solutions can both thwart wildlife interactions with overhead lines and substations, and actively prevent ignition and fire propagation. This offers utility owners a more economical option to mitigate the risk of fire. With strategic engineering investments, the influence of wildlife on outages and fires can be avoided.

Sadly, too many operators still view such investments as discretionary. This short-sighted approach in relation to the design, operation and maintenance of critical power-distribution assets has proven to have costly and catastrophic consequences.

**Equipment Failures**

Most capital equipment installed in a power utility network is designed to have a functional service life of 40+ years. In reality, most utility infrastructure components remain in service until they fail (which could be in excess of 50 years). As equipment components age and come to the end of their useful life, they become harder and more costly to clean, maintain and are often to blame for costly power outages. Thus, upgrades to replace obsolete components becomes a more cost-competitive approach.

Often, the drive to reduce costs is counter-productive as cheaper equipment provides a shorter life span and it costs more to maintain the components safely and reduce the fire risk.

**Material Failures**

As noted above, capital equipment in power-distribution systems is typically designed to last 40 years or more. It therefore follows that any ancillary protective equipment installed to protect capital assets should provide a reliable, functional lifespan for at least the same duration.

Over the years, we have identified many materials in service that over-focused on one or another technical parameters. For example, materials that had excellent TERT (Tracking & Erosion Test, see page 6 for further explanation) and power arc test performance when new, fail the same tests when UV-aged. This UV-aging depleted the pure polymer rich surface, exposing the bulk ingredients.

Utility owners would do well to partner with vendors that have a long, proven track record, a broad product portfolio, and in-depth expertise in electrical, mechanical and materials science (See TABLE 6).

**Whereas insulating components which fulfil specified standards, can help reduce fire risk in overhead lines and substations as well as match the lifespan of the other assets they are designed to protect. Many materials, (i.e. EPDM) have UV degradation autocatalyzed. These materials can look good as new unaged materials, but their performance declines after a certain degree of aging. Understanding the aging performance and long-term accelerated aging is critical. During selection and specification, close consideration must be given to identifying polymeric formulations that can withstand the harsh operating conditions most overhead lines and substations routinely experience. These include high-voltage stress, pollution buildup, pollution, ozone, water and UV-induced arcing, flashover, elevated temperatures and mechanical stress.**

For example, insulated components that are not manufactured from the most appropriate performing polymer, face gradual degradation over time. They have an elevated risk of tracking, embrittlement due to ultraviolet (UV) damage, melting due to poor thermal resistance, and ignition due to poor arc resistance of the aged surface. All these pervasive risks can be reduced or even eliminated with the correct component and material selection.

**Pollution Buildup and Secondary Ignition Sources**

Guano from animals, salt build-up in coastal areas and even airborne pollutants from industrial and environmental activities can wreak havoc on many engineering polymers. Such pollutants routinely accumulate on the surface of insulated components during long, dry periods and then wash away in the rain. However, at the end of any dry period, when temperatures start to drop, dew can form on the insulation. This combination of conductive contamination and moisture causes increased resistance in the leakage current and localized arcing on the insulation surface. If the material is not engineered correctly, this process can degrade the material and lead to tracking over time.

What is more, if the insulated component was not specified in an engineering polymer to withstand pollution build-up, then persistent arcing can degrade the material surface, leading to accelerated degradation, higher arcing currents and the risk of ignition.

**Mechanical Stress, Abrasion and UV Degradation of Critical Components**

Overhead power lines operate for decades and are subject to direct sunlight and polluted environmental conditions. Long-term exposure to UV can lead to the roughening, hardening, thinning, embrittlement and degradation of insulation and critical components, manufactured from engineering polymers. The premature failure of insulated parts and other polymeric components put the entire system at greater risk of ignition, flame propagation and uncontrolled wildfires.

## Material Considerations for Insulating Components

Despite the best intentions, it is impossible to keep wildlife away from the overhead lines and substations that make up a power-distribution network. Instead, strategic investments should be made to install the right mix of standard and customizable insulating covers, barriers and guards. This will help reduce the risk of fire related to wildlife climbing, birds landing, bird nests and other debris, conductor clashing, and vegetation clashing with bare conductors.

As previously discussed, insulating components are manufactured from engineered polymers, but not all polymers are able to guarantee the same type of fire protection — and, importantly, the level of fire prevention that is essential — to effectively mitigate the risk of fire. Utility owners should closely examine material science considerations and formulation options when specifying insulating components to safeguard and fortify their power-distribution systems. Such components must be designed to withstand decades of exposure to electrical stress, UV degradation in outdoor conditions, power arcs, surface arcing, overheating connections and flame tracking, and erosion.

In the authors opinion there are four critical material science performance attributes that all utility owners should consider when specifying insulating components.

**1. Tracking and Erosion Resistance (TERT)**

TERT provides the measure of a material's tracking resistance, which is its ability to withstand surface arcing and ignition in a high stress environment. If the material properties of the insulating component do not have a sufficient TERT rating, arcing can cause the material to deteriorate, which can lead to ignition, increasing the risk of starting a wildfire in dry vegetation on the ground below.

A material's TERT rating can be demonstrated using the ASTM D2303 or IEC 60587 STEP test method (with abrasion). This is a destructive, variable- voltage test method that brings a material to failure in order to demonstrate its ability to withstand erosion, tracking and fire. A polymer's TERT rating and tracking resistance provides a critical indication of the material's ability to maintain its functional and mechanical integrity over time, in the face of voltage incidents, pollution flashover and power arcs.

## Utilities Worldwide Face Insulation and Protection Challenges

**Protecting Assets from Wildlife Interference**

- Preventing equipment damage
- Preventing flashovers
- Interference

**Reducing Ignition Risk Related to Wildlife/Debris**

- Animal or debris that gets stuck in phase to earth position can catch fire
- Overvoltage due to lightning

**Vegetation Related Outages**

- Vegetation clashing
- Fast Growth
- Storm winds
- Can be used as a strategy to reduce trimming frequency

**Reducing Weather Related Outages**

- Snow
- Ice
- Heavy rain
- Wind
- Lightning

FIGURE G

TERT testing was developed to stimulate arcing on the surface of a polymer, and testing an abraded surface simulates a surface aged by UV. This test measures a material's life expectancy under stress, in terms of time to failure (in minutes) at a particular pollution level and kV stress. In TERT testing, every material uses the ASTM D2303 method. Each tested material will eventually fail, with the time to failure dependent on increasing kV stress and exposure to pollution. One very important feature of the ASTM test method is that the sample preparation involves abrading the surface of the test sample to simulate the effects of long-term aging. The abrasion exposes the bulk constituents beneath the polymer rich surface.

**It is widely accepted in the industry that the electrical and mechanical performance of materials can deteriorate over time. The rate of deterioration depends on the formulation and service environment. Performing TERT on an abraded TERT sample (which simulates the roughening of a material due to UV) is an effective method to predict the performance of an aged material.**

In the opinion of the authors, polymeric materials that exhibit insufficient tracking resistance (according to TERT), tend to perform poorly under the harsh operating conditions of high-voltage power lines, and thus present a higher risk of longer-term degradation over time. This leads to insulation breakdown, increased spark production and flame propagation.

### 2) Ultraviolet (UV) Resistance

UV resistance provides a measure of a polymer's ability to withstand damage and failure from prolonged UV exposure in outdoor environments. Polymeric components that have poor UV resistance have an increased fire risk, as sun damage to polymer components can lead to mechanical degradation and surface roughening over time. This makes it easier for environmental pollutants to accumulate, thereby increasing the risk of arcing, tracking and ignition.

UV resistance is demonstrated using the ASTM G154 UVB or UVA test methods. TE recommended that at least 5000 hours* of constant, accelerated UV testing be applied to evaluate materials.

**(Our final 5,000 hour test data for new V0+ materials will be published in June 2023. At the time of writing 1200 hours of testing has been completed).*

### 3) Thermal Endurance

A polymer's thermal endurance rating provides a measure of a material's ability to maintain its mechanical integrity - that is to resist melting and deforming - in the face of sustained elevated temperatures. This functional attribute is an effective predictor of a polymer component's ability to maintain a long service life in elevated temperatures, and withstand melting and dripping (when hot polymer drips on dry vegetation, there is a risk of triggering a wildfire).

Thermal endurance on insulating covers is typically demonstrated using two test methods:

A. Thermal Index IEC 60216/ IEEE 98" at 105°C (221°F), which demonstrates a material's thermal performance for 5,000 hours.

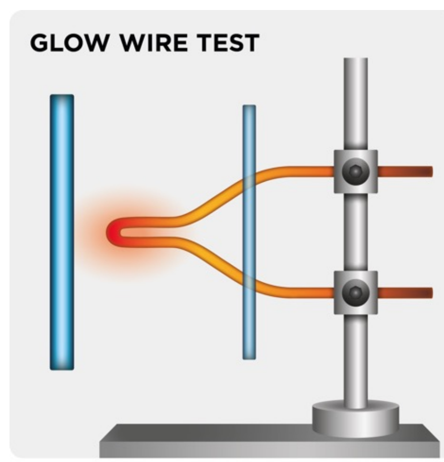
B. Thermal Aging ASTM D2671 168 hours at 150°C (302°F), which is a useful indicator of life expectancy and ties the material's tested performance attributes to a service life of 30 years or more.

It is critical that utility owners looking to select and specify insulating components manufactured from polymers, choose polymers that have been formulated with the most appropriate fillers and additives. This will ensure adequate performance in TERT resistance, UV resistance and thermal endurance. All pure polymers will be susceptible to light surface erosion over time, and this slow, safe and predictive method of aging allows operators to maintain or replace affected parts as required. However, the choice of engineering polymer can drastically improve erosion resistance and this helps to reduce the risk of pollution build-up and fire risk, while extending the life of the insulating component. This design philosophy is particularly critical in the high-voltage environment of overhead power lines and substations.

### 4) Heat Resistance

According to IEC 60696-2-11, a polymer's glow wire rating defines a material's ability to withstand radiant heat. The test is considered passed if a) the specimen does not constitute an ignition risk to the environment and b) any flames or glowing on the test specimen extinguish within 30 seconds after the glow wire (heat source) is removed. This method assesses the flame retardancy of a material and is used to test a potential ignition source in an overheated connection or busbar application.

The glow wire test evaluates a material's behavior when exposed to radiated heat from a super-heated element, which could represent a busbar or any energized overheated connection. The super-heated element simulates a scenario in which the substrate the material is in contact with experiences a significant rise in temperature due to a circuit fault, such as over current. In this case, it is crucial that the material does not pose a fire risk which could result in fire ignition.




Test speciment = finished part
Temperatures of glow wire: 550, 650, 750, 850, 960˚C
Maximum penetration depth: 7mm, pressing force 1N
Application time: 30s

IEC 60695-2-11
Burning or glow time ≤ 30s

FIGURE H

| Ignition source | Ignition Source Description | Root Cause in Problem Materials | Test Used to Measure and Mitigate Risk | Warning Signs May Look Like |
|---|---|---|---|---|
| Primary  | • Insulation material ignites itself.<br>• Normal network service conditions. | • Materials with inadequate antitracking, UV or heat resistance performance.<br>• Material aging, i.e. performance deteriorates over time. | • Thermal & UV accelerated testing (long term durability)<br>• TERT test (resistance to surface arcing)<br>• Glow wire (resistance to contact heat) |  |
| Secondary  | • Insulation breakdown causes damaging arc and/or ignition.<br>• Abnormal network service conditions. | • Flashover induced ignition caused by lightning, or bridging caused by vegetation debris or electrocuted wildlife.<br>• Pollution on the surface of the material induced tracking and pollution withstand.<br>• Radiation heat caused by overheating connections and busbars. | Materials:<br>• GLOW wire test (resistance to radiation heat)<br>• TERT test (resistance to surface arcing)<br>Product:<br>• Insulation withstand testing<br>• Power arc testing (resistance to traveling arcs) |  |
| Other  | • Insulation ignited by other fire source.<br>• Abnormal external factors. | • Passing wild fire<br>• Transformer or other equipment fire.<br>• Wooden pole top fire caused by king pin arcing. | • Standardized burning tests, (UL94, IEC 60695-11-10). |  |

- It is critical that electrical insulation is capable of performing consistently and reliably throughout the lifetime of the asset being protected without deteriorating performance. TE's materials are designed to balance long term performance in typical utility applications, and to reduce risk of primary and secondary ignition.
- Materials optimized to enhance self extinguishing properties only, and sacrifice TERT performance, may create increased risk of ignition during normal utility environments.
- The optimal material performance will cater for all three of the above ignition sources, combining ignition prevention with self-extinguishing capability.

TABLE 3

## Fear Of Fire and Power Network Sources Of Ignition

Before considering the flammability resistance requirements of a material optimized for use in the power grid, let's examine the relevant ignition risks.

It is critical that the electrical insulation is capable of performing consistently and reliably throughout the lifetime of the asset being protected, without deteriorating in performance or creating a new downstream risk.

The authors think that optimal material performance will cater to the three ignition sources outlined below, combining ignition prevention with self-extinguishing capability.

a) Primary ignition represents the risk of the material self-igniting in normal utility service conditions. Poorly formulated materials can lead to failure due to aging. Aging can be caused by UV (embrittlement, surface cracking) or deformation due to excess radiation heat from overheated components (such as loose connections). This can cause or lead to mechanical failure in storms, dielectric breakdown or tracking on these materials.

b) Secondary ignition represents the risk of insulation breakdown leading to a damaged arc and/or ignition during abnormal utility service conditions. Examples of abnormal conditions include:

- Lightning flashover.
- Bridging caused by vegetation debris or electrocuted wildlife.
- Pollution flashover.
- Radiated heat (i.e. from overheated connector or busbar).

TE's materials are designed to balance long-term performance in typical utility applications and reduce the risk of primary and secondary ignition. In addition to the above, some regional geographies are also at risk of ignition from external factors.

c) Another ignition risk is a fire source not related to the wildlife protection insulation, such as:

- Wild fire.
- Transformer fire.
- Pole-top fire.

Some materials that are only optimized to enhance self-extinguishing properties may be subject to an increased risk of ignition during normal utility environments.

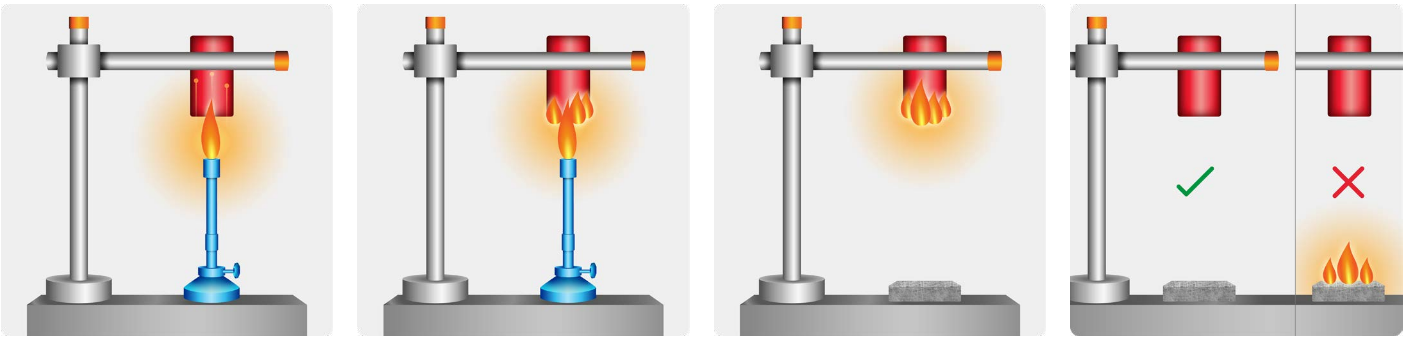
## The Historical Scientific Challenges With Self-Extinguishing Polymers

In recent years, some utilities have chosen to install insulating upgrades that favor polymers with the V0 fire retardancy classification, according to UL94. Polymers with V0 ratings can self-extinguish over time once the ignition source has been removed, as demonstrated by the UL94B test methodology.

Polymers that demonstrate self-extinguishing properties have a valuable role to play in certain industries, such as enclosed environments in automotive, industrial and rail applications. In these applications, the material itself is not usually the fire ignition source.

FIGURE I

## UL94 Test Methodology and V0 Criterion



**A torch with a 50W energy is applied directly under the sample.**

**The torch is applied to the sample for 10 seconds or until the sample ignites.**

**Once ignited, the gas torch is removed and the sample is observed.**

**In a positive test, the flame will self-extinguish in under 10 seconds.**

**Any drips should NOT ignite the cotton below.**

FIGURE J

| Practical use of UL94 | Limitations of UL94 Criterion |
|---|---|
| • Repeatable laboratory test<br>• Evaluates self-extinguishing behaviors of material<br>• Gas torch removed 10 seconds after ignition<br>• No ambient weather influence | • In most real wild fire scenarios, the ignition source will persist for more than 10 seconds |

TABLE 4

*(1) An average surface fire on the forest floor might have flames reaching 1 meter in height and reach temperatures of 800°C (1,472° F) or more. Under extreme conditions a fire can give off 10,000 kilowatts or more per meter of fire front.*

The source is almost always an external factor, however for safety reasons it is important that the materials can self-extinguish and will not emit toxic gases in an enclosed fire zone.

However, the polymer formulation for high voltage utility applications is complex, due to the many stresses that these materials must endure throughout decades of service.

Such materials must withstand degradation in the face of extreme electrical, mechanical and thermal stresses, long-term exposure to UV, heat radiation, pollution and chemicals, and wildlife-related fires. Finding the correct balance of properties to facilitate forty years of service is challenging. Over-emphasizing one or another source of stress can have a negative impact on overall performance and longevity.

**Reliability and resilience are so critical to modern utilities that more effort is required to ensure the materials installed are "fit for purpose" and designed with a lifetime span which matches the assets being protected. To maximize the long-term protection of high-voltage utility assets, system owners and operators should select components (including insulating components) that are engineered from polymers that demonstrate and optimize these essential performance characteristics: anti-tracking resistance, UV resistance, thermal endurance, mechanical and chemical resistance.**

UL94 is a standardized, repeatable laboratory test, but it does not simulate a real-life utility scenario as there are no temporary gas torch ignition sources in utility distribution systems. Rather, in the context of insulating performance under real-world conditions, a product may be subject to flashovers, power arcs, or a nest that may catch fire (igniting nearby polymeric insulating components).

Under real-world operating conditions, whether the material is V0 or non-V0, a nest that has ignited does not suddenly stop burning like in test conditions in which the ignition source can be turned off. Rather, the fire source would continue until the entire nest has been consumed.

In real life, the fuel source cannot be suddenly removed, as is the case in the UL94 test methodology. Thus, in practice, most V0 polymers that are classified as self-extinguishing, will continue to burn until the flame source has been removed. This extends the risk for the power infrastructure, as the longer the fire burns, the greater the opportunity for an uncontrolled wildfire to be triggered in nearby vegetation.

*With this understanding in mind, utilities must now determine which performance attribute is more important when specifying components — the ability to prevent ignition in the first place, or the ability to minimize flame or eliminate flame propagation.*

Given the underlying chemical engineering considerations, these competing sets of performance attributes are very difficult to economically optimize in the same polymer. This means a trade-off is always necessary during material specification.

The biggest challenge facing material scientists is how to achieve the correct balance of properties required for any given application.

In the authors opinion, in this industry the majority of materials successfully optimized to achieve V0 self-extinguishing properties, have failed to maintain the necessary balance of properties required to ensure long service and to protect from primary and secondary ignition sources.

They believe that anti-tracking and thermal performance has been compromised to achieve optimal V0 results, as demonstrated in the graphic below. TE believes that finding the right balance of properties is critical in guaranteeing a reliable and consistent performance of 40-50 years. This belief underpins our legacy of success in developing Raychem materials over the past 50 years.

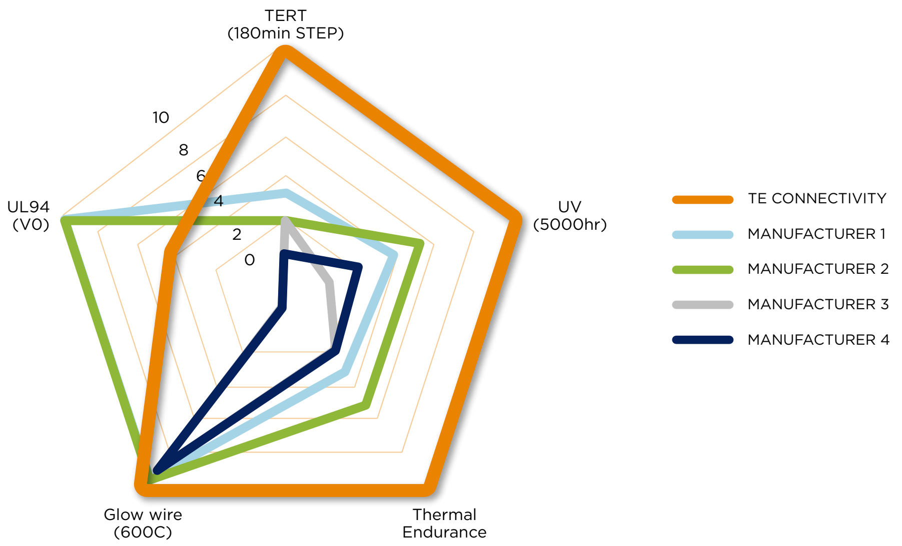



FIGURE K

Data based on testing carried out in TE laboratories or available on public websites

## Critical Materials Specifications Required To Reliably Prevent Primary And Secondary Ignition In Wildlife Covers

Since the 1970s, TE has mitigated primary and secondary ignition risks with polymers designed to define typical application risks and determine an optimal specification.

A series of standardized tests are used to moderate performance. Referring to the table, the following material tests are considered critical to mitigate ignition risk:

- Long term UV testing
- Long term thermal aging
- Glow wire testing to define minimum heat radiation performance
- TERT testing to determine anti-tracking threshold and ignition resistance

Our legacy designs have been in service since the 1970s and have accumulated over 50 years of service.

In addition, TE carries out product testing to demonstrate essential material properties. We use power - arc testing methodology, as recommended in IEEE 1656, to test materials in product form.

This test simulates the challenging conditions of a power arc in service generating high voltage, high energy, high temperatures and hot gases in a short period of time.

**This is shown in the photos in FIGURE L. This test simulates the potential ignition scenarios that could occur in a power-distribution system, where a high-energy burst from a lightning strike, trapped arc root or fault current confronts the system and individual polymeric components.**

**Such a test is deemed successful if the polymeric insulating component remains intact following the arc exposure and does not deform or catch fire.**

## TE's Raychem Next Generation Materials Development V0+ Material

| Wildlife and Asset Protection Material Performance Attributes | TE Raychem Standard | TE Raychem V0+ |
|---|---|---|
| **Tracking and Erosion Resistance (TERT), per ASTM D2303 or IEC 60587 STEP test method (with abrasion)** | | |
| This test predicts behavior under contamination and leakage current stress. The sample is abraded to represent testing on an aged sample. | >300min | >180min |
| **UV Performance, per ASTM G154** | | |
| This test assesses the damage from UV exposure in intense environments. | 5,000hr | 5,000hr* |
| **Thermal Aging Performance** | | |
| **Thermal Index IEC 60216 / IEEE 98** This accelerated aging test predicts long-term product performance and is a key predictor of the material's life-cycle performance. | 105°C (5,000hr) | 105°C (5,000hr)* |
| **Thermal Aging ASTM D2671** This test predicts life expectancy and ties the material's tested values to real-life data from 35+ years of service life in the field. | 150°C, (168hr) | 150°C, (168hr) |
| **Flammability Performance** | | |
| **Flame Retardancy** This tests assesses a material's ability to self-extinguish under strict repeatable laboratory conditions - UL94, IEC 60696-11-10. | HB40 | V0 |
| **Flame Retardancy** Glow wire IEC 60695-2-11 simulates the ignition source associated with overheating busbar or connections ASTM D2303 or IEC 60587 STEP test method (with abrasion). | 650°C 300 minutes | 650°C 180 minutes |
| Halogen free. | Yes | No |
| **Electrical Product Performance Attributes** | | |
| **Wet Withstand IEEE-4-1995 and IEEE 1656-2010 (Guide), Fixed Electrode** | | |
| This test demonstrates a material's ability to remain protected against animal contact up to 35 kV. | Yes | Yes |
| **Wet Power Frequency Flashover & Lightning Impulse Withstand IEEE-4-1995 and IEEE 1656-2010 (Guide)** | | |
| This test demonstrates whether a cover affects the electrical performance of the insulator it is covering. | Yes | Yes |
| **IEEE Compliance** | | |
| IEEE-1656 (Guide for testing wildlife protection devices on overhead equipment up to 38 kV)<br>IEEE-1264-2022 (Guide for Animal Mitigation for Electric Power Supply Substations) | Yes | Yes |

TABLE 5

**Our final 5,000 hours test data for the new V0+ materials will be published in June 2023. At the time of writing, 1200 hours of testing have been completed. Taking into account the increasing regional sensitivities towards external ignition risks in power grid scenarios, TE invested in the development of an advanced, new-to-market material. Our Materials Science Team took on the challenge to develop a material that maintained our impressive legacy performance, without compromising critical performance indicators, and added self-extinguishing properties according to UL94, V0. The result of this development program is summarized in the table above.*

This advanced material development delivers a new-to-market cross-linked material formulation that maintains TE TERT standards with the addition of UL94 V0 self-extinguishing features. End users can now choose between non-halogenated materials with superior anti-tracking performance and a halogenated material with a very good anti tracking performance, combined with V0 self-extinguishing properties.

This new material is unique in the industry in that it combines V0, >180 minutes STEP TERT performance and 5000 hours of UVB capability.

As stated earlier, both materials were tested using the ASTM TERT STEP methodology which best simulates the testing of an aged sample by abrading prior to testing.

## Power Arc Test

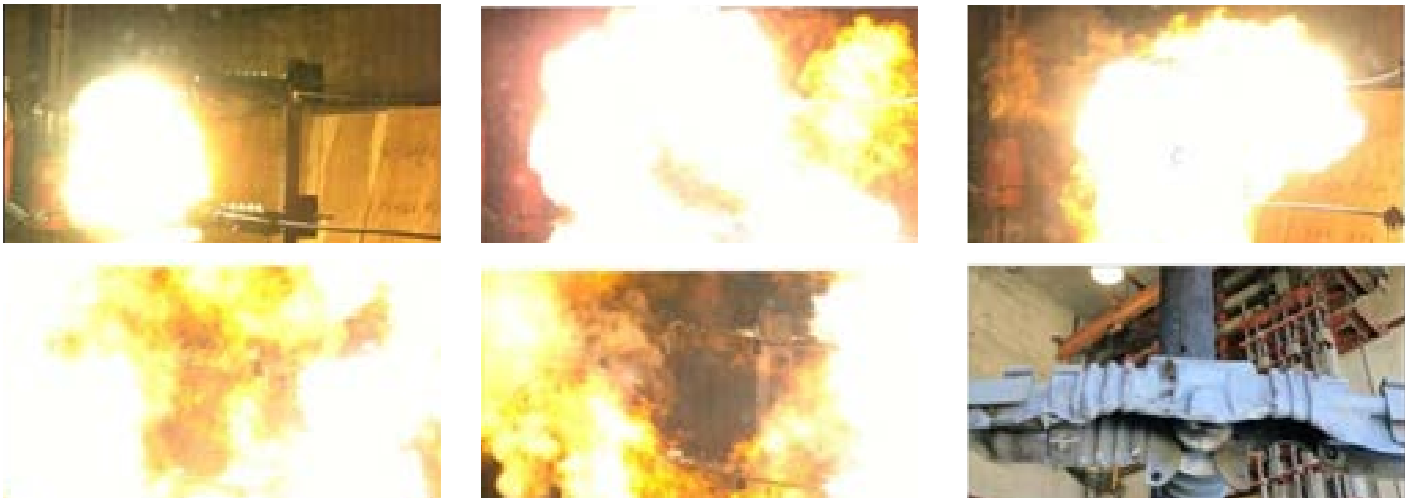


FIGURE L

## Critical Insulating Components To Protect Overhead Lines And Substations

Evaluating the aging infrastructure of an existing power-distribution and transmission system, and identifying its weaknesses with regard to wildlife-related fire risk, gives operators the opportunity to strengthen the overall grid, improving reliability and reducing the risk of flashover events that can create a fire ignition risk. All new wildlife- or fire-risk-mitigation projects begin with a thorough assessment of the problem in hand.

In its most basic form, this assessment starts with a site visit and interviews conducted with the engineers responsible for the problems identified. Gathering statistics, photos and site-incident reports is a valuable process that can help to determine the scale, frequency and root cause of outages. Unfortunately, such detailed information is not always available at the start of the process and cannot be carried out thoroughly by the utility owner alone. Therefore, a site visit conducted by a TE insulating specialist, together with the responsible asset maintenance engineer, provides a good starting point. During the visit, this team will:

- Define the utility operator's view of the problem, in terms of what types of wildlife routinely interact with that particular system and which elements of the system are particularly at risk. This is done with a site visit and reviewing photos of current and legacy issues.
- Define the highest risk areas in the substations, and parts of the station that have the shortest phase-to-phase or phase-to- earth distances.
- Seek evidence of wildlife interactions such as nesting materials, feathers, bones and guano.
- Gather evidence of flashover, corrosion on the support structures, insulator fittings and broken porcelain.

While conducting a site audit, the associated equipment is counted and either videoed or photographed. Armed with this data, the TE Wildlife and Asset Protection Specialist will prepare a risk statement, preliminary engineering proposal and quotation related to the upgrades required to reduce the potential risks associated with wildlife and vegetation in that location.

The particular combination of insulating components needed to fortify each site is customized based on the particular challenges and assets encountered at that location. Typically, the overall solution is created using a portfolio of standard and customizable insulating products, manufactured from proven Raychem polymeric materials.

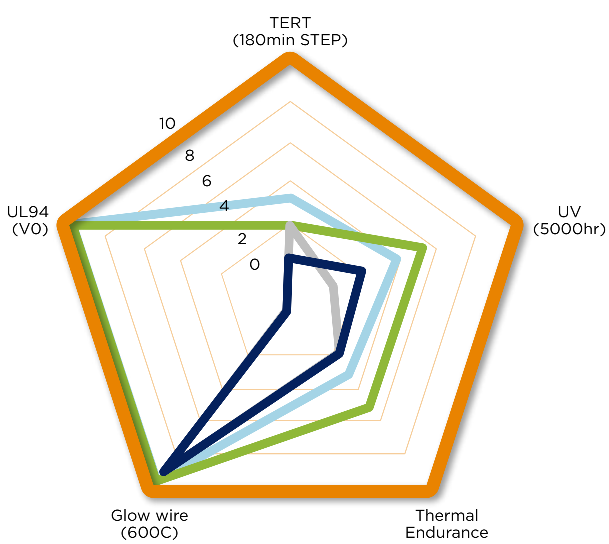



FIGURE M
Data based on testing carried out in TE laboratories or available on public websites

An overview of the most commonly used wildlife and asset protection products can be found in Table 6 below:

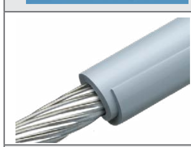
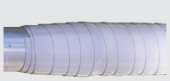
| Photo | Solution Category | Description |
|---|---|---|
|  | Insulating Bushing Covers | • Insulation and barriers to prevent wildlife contact with bushing connections<br>• Some designs enable thermal inspection and are hot stickable |
|  | Fuse Cutout Insulating Covers | • Insulation and barriers to prevent wildlife contact with fuse cutout live connections<br>• Hot stickable |
|  | Arrester Caps | • Insulation and barriers to prevent wildlife contact with arrester live connections |
|  | Animal Guards | • Barrier to increase the straight-line distance between the phase and ground on short insulation units<br>• Protection against climbing animals and birds |
|  | Line Guards | • Barrier to prevent climbing animals traversing a conductor or service line |
|  | Raptor Covers | • Insulation and barrier to prevent birds electrocution on overhead lines |
|  | Guano Shields | • Barrier to protect insulation from guano flashover or guano buildup<br>• Usually used in conjunction with conductor insulation and bushing covers |
|  | Insulation Sheets | • Used to increase insulation in tight spaces<br>• Sometimes used as a barrier |
|  | Creepage Extender | • Customized insulation attached to porcelain sheds to extend creepage or flash over distance<br>• This is always a custom design |
|  | Bird Flight Diverters | • Diverters used to increase visibility of bare conductors to birds to reduce the risk of midflight collision |
|  | Retrofittable Conductor Insulation | • Cold-applied and heat-shrink retrofit insulation to protect bare conductors<br>• Reduces risk of wildlife electrocution or clashing sparks<br>• MVCC, MVLC, MVFT |
|  | Tapes and Tubes | • Bare conductor, busbar insulation. Can be factory-installed<br>• Tapes used to insulate more complex geometry |

TABLE 6

## Closing Thoughts

To safeguard overhead lines and substations from the risk of unplanned outages and wildlife-related fires, utility owners should partner with an experienced vendor and develop a strategic plan to replace, retrofit and/or upgrade the most at-risk assets and enhance insulation throughout the system, based on a structured risk assessment process.

**Trust should be placed in partners with a proven track record of experience in the field, broad expertise in electrical and mechanical component design and material science. Such partners should have fully integrated compounding, supply-chain integration, testing and installation capabilities, and be able to demonstrate their dedication to materials science, reducing installation time and supporting troubleshooting, offering quality-control and customer-service initiatives.**

TE strongly recommends that anti-tracking testing be carried out according to the ASTM D2303 Step test with ASTM D2303 or IEC 60587 STEP test method (with abrasion).

The goal is to select and specify insulating and isolating components and enhanced insulation throughout the overhead lines and substations. This would mitigate active threats and reduce the risk of outage and associated risk of fire related to wildlife interactions with energized components. Such strategic investment will provide a return on investment by protecting assets and communities from costly and potentially catastrophic wildlife interference. It will also reduce the risk of flashovers, interference, equipment damage and uncontrolled wildfires on the ground.

Materials used in such solutions should be designed for 40+ years to match the life expectancy of the expensive assets they protect. The performance specification and testing requirements should be designed to reflect this requirement. Critical to the attainment of this 40+ years life span is providing optimal performance with respect to:

- UV
- Anti-tracking
- Thermal endurance
- Heat resistance

This method performs testing on abraded samples to simulate aging caused by mechanical wear and UV. This is a critical test in predicting reliability over 40+ years.

It is no longer necessary to choose between anti-tracking (TERT) optimized and V0-optimized materials. TE has developed a new, advanced Raychem material which combines both critical properties in one material formulation. This advanced material does not compromise on reliability, thermal, UV or anti-tracking performance.

TE's wildlife and asset protection material formulations are designed:

- To perform reliably for 40+ years without impactful deterioration in performance.
- To minimize the risk of fire ignition associated with normal and abnormal utility environments with our standard materials.
- To extend the performance to add V0 for those customers who require it.

For more detailed information, please visit **TE.com/wap**

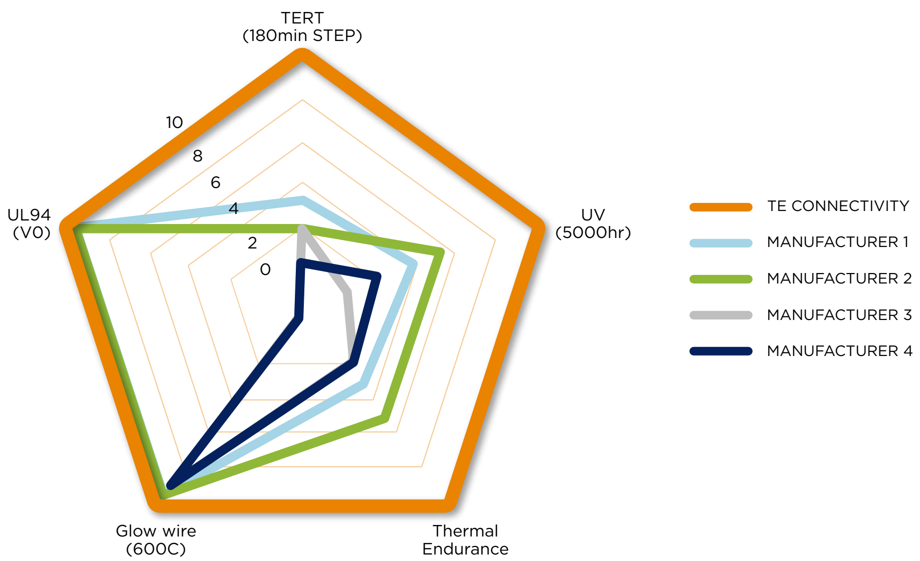



FIGURE M
Data based on testing carried out in TE laboratories or available on public websites

## Broad Expertise And Experience In Polymer Science

The use of strategic engineering upgrades provides an essential solution for utility operators to fortify their power distribution systems. Selecting wildlife asset protection components can reduce the risk of fire and wildfire from interactions with birds and animals, but specification of components with the most appropriate polymer formulation — with a focus on ensuring the most critical performance attributes — is essential.

Underpinning the entire TE Connectivity product portfolio is its use of Raychem polymers and the deep material science and formulation expertise. Raychem invented the first heat-shrink polymer for use in the power-generation and distribution industry. It was also one of the first companies in the world to commercially deploy radiation techniques and cross-linking to facilitate polymerization and the production of materials and components that could be heated, cooled and shaped, as needed.

Over 60 years ago, Raychem's innovative material science and polymerization breakthroughs, eventually led to the development of a broad array of wildlife and asset protection solutions, whose polymer formulations allow them to withstand fault conditions (such as tracking, flashover and power arcs) that are endemic to overhead power lines and substations. Raychem was subsequently acquired by TE Connectivity and the broad technology platform and materials science expertise has continued to grow. Today, TE's Raychem polymer formulations have been in service around the world in countless electric utilities, original equipment manufacturer (OEM) systems, industrial applications and more, demonstrating their reliability and longevity.

### Engineering Polymers with Critical Traits

**As noted in this White Paper, three of the most critical performance attributes — TERT resistance, UV resistance and thermal endurance (these are discussed in detail in the main text) — are needed when selecting and specifying insulating components to reduce the risk of wildlife-related fires and wildfires, and to improve the reliability and endurance of power grid components for decades of useful service life. Proven material science capabilities allow different polymers to be formulated with the most appropriate balance of critical attributes to meet the site-specific aspects of the installation.**

**These include improved:**

- **Electrical stress control**
- **Tensile strength**
- **Elongation**
- **Hydrophobicity**
- **Dielectric strength**
- **Resistance to ignition and flame propagation**
- **Resistance to weathering and erosion**
- **Resistance to chemical and biological attack**
- **Integrity in the face of temperature extremes**
- **Resistance to ultraviolet degradation**
- **Resistance to mechanical, electrical, thermal stress**

Typical additives and fillers that are blended into different polymers to provide desired performance capabilities and functional attributes include the following:

**Iron oxide —** used to provide pigment and improve a polymer's ability to withstand damage from UV exposure and improve tracking resistance and high-temperature performance.

**Thermal stabilizers —** used to help polymers retain their integrity and withstand long-term aging in the face of extreme high temperatures and temperature fluctuations.

**UV stabilizers —** used to help polymers withstand degradation in the face of long-term UV exposure.

**Electrical additives —** help to reduce the effect of electrical arcs.

**Antioxidants —** these additives react with harmful species that could damage the polymer and undermine its long-term integrity.

**Non-wetting additives —** help shed water from the formulated component (to create a hydrophobic surface).

**Chemical cross-linking agents (with irradiation) —** to improve the material's resistance to chemicals, thermal damage, abrasion, elastic memory, improved product stability.

**Carbon black —** used to provide pigment and reinforcement and to improve a polymer's conductivity and UV resistance.

**Other fillers —** selective fillers can also be added to provide added reinforcement, improve a polymer's dielectric strength, modify a polymer's viscosity, improve dispersion of other fillers, improve process ability or surface finish and more.

To fortify their overhead lines and substations against the persistent threat of wildlife-related fires, wildfires and power outages, utility operators would benefit from partnering with a technology provider that has not only a full portfolio of insulating components, but also depth of expertise and experience with polymer science, compounding, product development and manufacturing, coupled with a relentless focus on product optimization and customer service.

## Authors


### Brian McGowan

Brian McGowan is TE Connectivity´s Raychem Global Portfolio Manager for Wildlife and Asset Protection, based in Castlebar, Ireland. He has 25 years' experience in the R&D and Product management supporting the design and development of polymeric insulators, arresters and wildlife and asset protection. He is an expert in design, development, and qualification of outdoor materials, and insulation & protection products, he holds 3 patents and 5 technical papers. He is a member of Raptor research foundation, Birdlife International and Engineers Ireland. He holds a BE (University College Galway), MSc Eng (University College Galway) CDipAF (ACCA), MBA (University College Dublin).

### Luis Puigcerver

Luis Puigcerver is TE Connectivity's Product Manager for Wildlife and Asset Protection in the Americas, based in North Carolina, USA. He has more than 35 years' service at the company. Luis' career includes a tenure in the Telecommunications business as Product Development Engineer with a focus on overhead and terminal systems. For the past 20+ years, he has managed the Wildlife Asset Protection portfolio in both a regional role in the Americas as well as Globally working closely with customers to help improve grid reliability, asset protection, wildlife protection and fire mitigation. Luis is involved in IEEE substation and distribution standards committees and holds 15 US patents in both the Telecom and Energy space.

### Matt James

Matt James is TE Connectivity's Senior Product and Materials Specialist for Wildlife and Asset Protection, based in Swindon, United Kingdom. He has 10 years' experience in materials development, cable accessories product development and wildlife and asset protection. He is currently the EMEA Senior Product Specialist Manager for Wildlife and Asset Protection (WAP). Matt holds an Engineering and Master's degree in Integrated Mechanical and Electrical Engineering.

### Michael Anderson

Michael Anderson is TE Connectivity's North American Business Development Manager for Wildlife and Asset Protection, based in North Carolina, USA. He has more than 14 years' experience, managing business-to-business relationships in many market segments and working closely with clients to help improve the reliability, resiliency and safety of their power-delivery systems. Mike holds committee membership with the IEEE1264 and IEEE 1656. He has worked closely with the utility industry, wildlife resource agencies, conservation groups, and APLIC, creating solutions to help prevent bird mortalities and associated power outages. He holds a BA from The University of Iowa.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