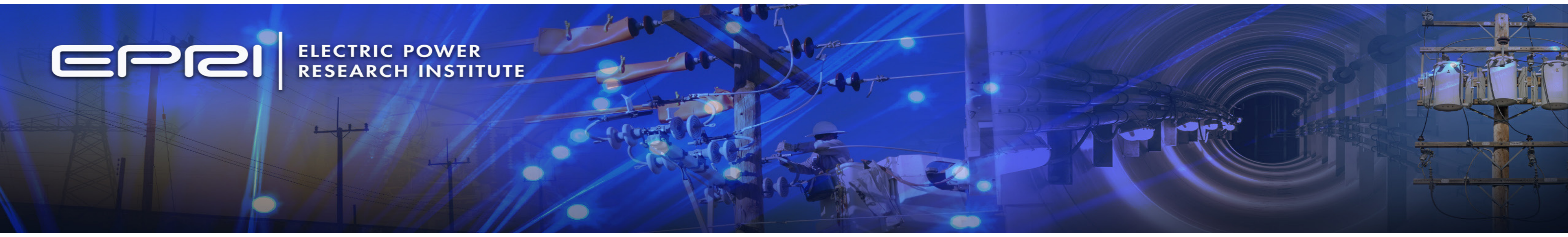

COVERED CONDUCTORS TO REDUCE WILDFIRE RISKS FROM OVERHEAD DISTRIBUTION

An Executive Summary

EPRI Distribution Systems

Contents of Document

Introduction

Using covered conductors instead of bare conductors is one way to reduce risks of energized distribution circuits from initiating wildfires. The insulated covering is not rated for a full conductor line-to-ground voltage, but it is thick enough to reduce the chance of flashover and ignition when a tree branch falls between conductors. A covered conductor is also called tree wire or weatherproof wire. Utilities in the Northeast US widely use covered conductors, primarily to reduce tree-caused outages. Covered conductors are used on open-wire style distribution circuits at traditional spacings and also for compact spacings. Spacer cable systems use three covered phase conductors bundled into a diamond-shaped configuration and suspended from high-strength messenger wire.

Covered conductors are available with a variety of covering types. The insulation materials such as polyethylene, XLPE, and EPR are common. For modern-vintage material, insulation thicknesses typically range from 30 to 150 mils (1 mil = 0.001 in. = 0.00254 cm).

From a design and operating viewpoint, covered conductors must be treated as bare conductors according to the National Electrical Safety Code (NESC) (IEEE C2-2017), with the only difference that tighter conductor spacings are allowed. There are various grades of insulation used for the covering.

Wildfires can be initiated in several ways. Use of a covered conductor can reduce risks of wildfire initiation by reducing many of the modes of ignition, including:

- Tree branches igniting
- Live, downed conductors
- Conductor slap
- Faults from animals and other external sources

Tree-branches into or across live, bare conductors are a significant source of ignition. See Figure 1 for an example. Covered conductors should prevent ignition in most cases of vegetation contact. Covered conductors limit current flow and arcing currents. Ignition tests performed in Australia found that for a conductor in contact with a tree, the probability of ignition is strongly a function of current. For a current of 2 A, the fire probability was 50% based on test results, and for a current of 0.5 A, the fire probability was 8% (Marxen, 2015). With intact conductor coverings, currents for contacts to tree branches (or other objects) is mainly just the charging current of the covered-conductor system. Landinger et al. (1997) measured currents on various covered conductors with different contact types (wire loop, copper tape, and others) and found that currents were normally less than 1 mA, much less than that needed to ignite vegetation.

Figure 1
Vegetation ignition from a contact to a conductor at 7.62 kVLG

Source: EPRI 1016219 (2007); test current was between 400 and 800 mA for the eight-minute duration of the test.

Covered conductors may also reduce the probability of ignition when energized conductors fall on the ground. Figure 2 compares staged tests of bare and covered conductors in downed-conductor scenarios. In these two scenarios, the line-to-ground voltage was 13.1 kV. In cases tested with the covered conductor, the current was low enough to be unmeasurable, and there was never any visible arcing at any point where the insulated covering touched the earth. If an exposed part of the aluminum conductor touched the earth, then arcing would occur, but the contact area is less than with a bare conductor. While ignition is still possible, the conductor covering may reduce that probability.

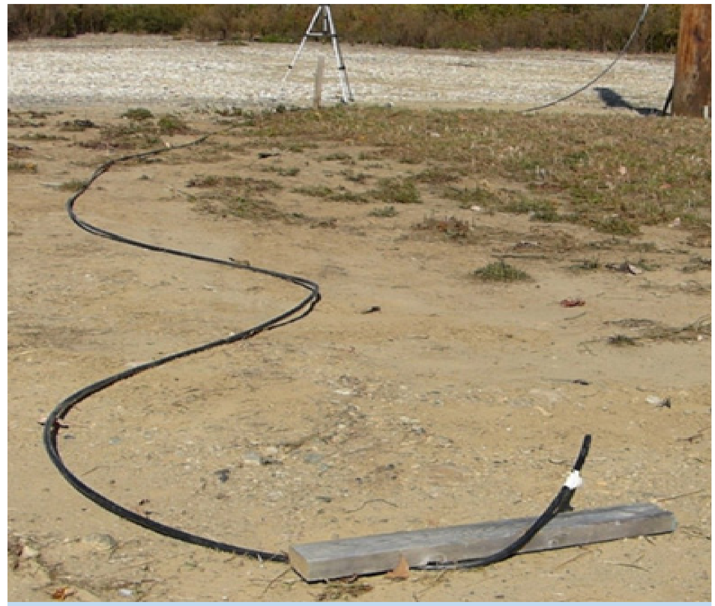

Figure 2
Comparison of live, downed conductors with bare and covered conductors

Source: EPRI 3002010163 (2017)

Industry Use

In the northeast US, covered conductors are widely used and have been in service for decades. Covered conductors are applied mainly to reduce vegetation faults in heavily treed areas. Based on anecdotal feedback, utilities are happy with the performance of the covered-conductor systems. Outside of the northeast US, covered conductors have not been used widely, and they have not been used to target wildfire risks in the US.

However, many Australian utilities have begun to use covered conductors for the purpose of reducing wildfire risks. The Australian state of Victoria has enacted regulations in 2016 that requires use of covered conductors for any new or rebuilt overhead circuits (State of Victoria, 2016). The state of Victoria has also established a AUS$200 million program for bare-wire powerline replacement over a ten-year period (State of Victoria, 2018).

Estimating Improvement

EPRI is unaware of any published data on the relative performance of bare and covered conductors as it relates to wildfire initiation specifically. Because outage events are a source of many potential wildfire initiations, outage data can approximate the benefits of using covered conductors.

Good fault data comparing fault rates of a bare wire with a covered wire is hard to find. European experience with covered conductors suggests that covered-wire fault rates are about 75% less than bare-wire fault rates. In Finland, fault rates on bare lines are about 3 per 100 km/year on a bare wire and 1 per 100 km/year on a covered wire (Hart, 1994).

Table 1 compares the relative rate of fault events for bare and covered conductor for Eversource Energy in New England. These are based on data from major event days. These are events per mile normalized for mainlines with bare conductors. For Eversource Energy, the performance rates on the mainline are comparable. For laterals, there is a stronger difference between bare and covered conductors. Eversource Energy uses enhanced tree maintenance with wider clearances on mainlines but not laterals. That might explain the sizeable difference between conductor types on laterals: with standard tree maintenance more branches are likely to fall on laterals, and the covered conductors are more immune to electrical flashovers when this happens.

	Mainline	Laterals
Bare	1.00	2.47
Covered	0.97	1.67

Table 1
Comparison of the relative outage performance of bare and covered conductors for Eversource Energy (2008 – 2015)

Source: EPRI 3002006780 (2015)

Another way to estimate the impact of using covered conductors is to examine failure modes. Falling trees and limbs can cause outages in two main ways:

- Electrical (no damage)—Trees or limbs cause an electrical fault, but do not damage the system. Crews only have to remove the trees and limbs from the line before reclosing. Trees can push conductors together, or a branch can create a bridge across conductors that provides a flashover path.
- Mechanical damage—Falling trees or limbs can damage distribution infrastructure, requiring crews to repair the damaged equipment.

Each of these events is a possible fire-initiation event. Covered conductors mainly protect against electrical events, so knowing the portion of events on a system can provide an estimate of the reduction in fire-risk events. Table 2 shows data from Duke Energy and Xcel Energy on the portion of vegetation events that are electrical (no damage). These utilities both included the mode of failure in outage data, and both reviewed these outage events in the field. Both utilities mainly use bare conductors (not covered). Given this data, it's expected that covered conductors will eliminate wildfire risks from 29 to 47% of vegetation events.

Utility	Criteria	Portion of events with no mechanical damage
Duke Energy	Non-MED days	31%
Duke Energy	MED days	29%
Xcel Energy	Non-MED days	47%
Xcel Energy	MED days	42%

Table 2
Portion of vegetation events without mechanical damage

MED = major event day

Source: EPRI 3002006780 (2015)

Engineering Issues

Covered conductors have several engineering challenges that are discussed in following sections. Covered conductors are a mature technology, and covered conductors are widely used, so these issues do not need to block use, but they should be considered for applications.

Ratings

Covered conductors are heavier, have a larger diameter, and have a lower-strength rating. Relative to the same size of a bare conductor, a 477-kcmil all-aluminum conductor with an 80-mil XLPE conductor covering weighs 20% more, has a 17% larger outside diameter, and has a 10% lower-strength rating.

The ice and wind loading of a covered conductor is also higher than a comparable bare conductor. Both increase with increasing diameter.

Burndowns

A covered conductor is susceptible to burndowns because when a fault current arc develops, the covering prevents the arc from moving.

The heat from the arc is what causes the damage. Although ionized air is a fairly good conductor, it is not as good as the conductor itself, so the arc gets very hot.

On bare conductors, the arc is free to move, and the magnetic forces from the fault cause the arc to move (in the direction away from the substation; this is called motoring). The covering constricts the arc to one location, so the heating and melting is concentrated on one part of the conductor. If the covering is stripped at the insulators and a fault arcs across an insulator, the arc motors until it reaches the covering, stops, and burns the conductor apart at the junction. See the example in Figure 3. A party balloon, lightning, a tree branch, a squirrel—any of these can initiate the arc that burns the conductor down. Burndowns are most associated with lightning-caused faults, but it is the fault current arc, not the lightning, that burns most of the conductor.

Figure 3
Example of burndown damage on covered 336-kcmil Al conductors

Source: EPRI 1017839 (2009)

Conductor damage is a function of the duration of the fault and the current magnitude. For the same fault current, a bare conductor will survive damage at least three times longer than a covered conductor. Relays and fusing must be coordinated to clear before conductors are damaged. To coordinate relays and fuses with a conductor size and type, the protection curve can be plotted against the conductor damage curve. See Short (2014) and EPRI 1017839 (2009).

To achieve coordination and prevent burndowns, relay and recloser settings can be changed, and faster fuses can be used. If these are not options, larger conductors should be used to prevent conductor damage.

Arc protective devices (APDs) are another option to consider to reduce burndowns on covered conductors. These are sacrificial masses of metal attached to the ends where the covering is stripped (Figure 4). The arc end attaches to the mass of metal, which has a large enough volume to withstand much more arcing than the conductor itself. EPRI testing showed that arc protective devices are effective at eliminating conductor damage if they are applied right where the covering is stripped (EPRI 1017839, 2009); the arc anchors on the device and protects the conductor. If there is a gap between the device and the covering, the arc will motor past the device and burn down the wire where the arc attaches in the gap. Crews should place these on the downstream side of the exposed conductor, or place them on both ends for scenarios where the line could be fed from either end.

Figure 4
Application of an arc protective device where the covering is stripped

Source: EPRI 1017839 (2009)

Insulator Capability

Pole structures with covered conductors can generate RFI if the insulator wire tie is not compatible with the covering. Power-line noise can be generated by conducting insulator ties separated by insulation from the line conductor. These scenarios include the following combinations:

- Bare conductor tie on a covered line conductor that is not stripped at the insulator
- Insulated conductor tie on a bare or covered line conductor

A conducting insulator tie in close proximity to the phase conductors creates a prime arcing scenario that can cause power-line noise. A voltage can develop between the conducting insulator tie and the line conductor. The capacitance between the two is on the order of 30 to 50 pF, which is enough to charge the conducting tie relative to the line conductor (Vincent et al., 2007). The line covering may hold this voltage, but the covering may deteriorate or lightning may puncture it. Once the insulation has been bridged, repetitive arcing can occur across the air gap as the tie wire charges and then discharges into the line conductor. Arcing will further deteriorate the conductor insulation, possibly causing more arcing. Vincent et al. (2007) also document a second cause of RFI from incompatible insulator ties: if the insulation deteriorates enough so that the tie touches or nearly touches the line conductor, then an insulating oxide layer can build between the two, leading to microsparking noise from breakdowns across this small gap.

Mechanical Coordination and Resilient Design

Research into overhead distribution structures and resiliency has found that the insulator-conductor interface is important for the mechanical performance of a distribution line. This area is a subject of past research (EPRI 3002006780, 2015) and ongoing research (EPRI 3002008783, 2016). In a resilient design, the mechanical strengths of components are coordinated to limit damage to that which has the least impacts.

The application of covered conductors affects the choice of insulator and insulator tie systems used with covered conductors (particularly if the covering is not stripped). Consider the case where a tree falls into a line. If the insulator attaches too rigidly to the conductor, the conductor will transfer the impact forces to the nearest poles. That may cause more downed conductors from broken poles or from broken conductors or splices. If the insulator attachment allows some slip, the forces on the conductor and the nearest poles may reduce, leading to less downed conductors.

Reliability

Modern, multi-layer covered-conductor systems from reputable manufacturers are thought to be reliable. They have been in use for decades in the US. There is a history of failure of conductor coverings that is insightful and provides lessons that can help with selection of insulating systems.

Electrical tracking along coverings has occurred with some materials. Eduful and Asante (2012) document the result of covered conductors in Ghana. Outage rates were 35% higher on circuits where covered conductors were in use. The coverings had problems with tracking, particularly when in contact with trees or bamboo. Problems were especially apparent on their 33-kV circuits.

Tracking problems were also found with XLPE material with high levels of carbon black added to limit ultraviolet degradation (Wareing, 2005). HDPE uses a different UV inhibitor that has less issues with tracking. Modern multi-layer designs are thought to be resistant to tracking, abrasions, and ultraviolet degradation.

Spacer Cables

Spacer cables are a compact design that uses covered conductors along with a high-strength messenger. See Figure 5 for an example. Spacer-cable systems have many of the same wildfire advantages and the same application issues as covered-conductor systems. In addition to preventing electrical failures, properly applied spacer cables can be less susceptible to mechanical damage and downed conductors.

Figure 5
Spacer-cable system

Mechanical coordination of spacer cables is especially important. If mechanical coordination is not considered, falling trees can damage multiple poles and equipment. EPRI tested spacer cables in setups designed to replicate impacts from falling trees (EPRI 3002006780, 2015). A flexible spacer-cable bracket was also tested to evaluate the impacts on mechanical coordination. Overall, these tests showed that spacer cable performs well when applied as follows:

- *High tensions* — Tension helps spread the force among multiple structures.
- *Strong poles* — Class 2 or higher poles may be needed to avoid pole damage.
- *Good guying* — With higher tensions, the guying and supports along the whole length of the line are important. If one guy fails, cascading failures are more likely. Measures to insure good guying include selection of guy anchors and use of suitable guy angles.

If these measures are not used and spacer cables are used on Class 4 and smaller poles, pole failures are more likely because the high-strength spacer cable transfers considerable force to nearby poles. Also, structures with multiple spacer cables may be likely to have more issues with pole breakage.

Note that spacer-cable systems are not immune to causing ignitions. At least one fire was started on a spacer-cable system in Victoria, Australia (State of Victoria, 2010).

Estimating performance improvements in wildfire risks and fault rates for spacer cable has similar challenges as for standard covered-conductor systems. For electrical events that would typically cause no damage, the estimates based on use of covered conductors should apply (for example, a 40% reduction in tree-caused events). Avoidance of mechanical damage is more difficult to quantify. If the spacer cable is robustly applied to limit pole breakage, spacer cables should reduce equipment damage and downed conductors.

Summary

Overall, it is expected that covered conductors will reduce wildfire risks. Application of covered conductors should include analysis to mitigate the issues that come with the use of covered conductors. For wildfire application, preventing burndowns is a critical issue.
The best overall application approach will involve many choices, including:

- Covering selection
- Conductor sizes
- Compatible fusing and relay settings
- Selection of insulators and conductor ties
- Mechanical coordination of structures
- Span lengths and loadings
- Use of arc-protective devices

Staged tests with mock structures could help determine the best setup for reducing wildfire risks.

One unknown issue is how well insulated covering performs during wildfires. If coverings are easily damaged by fires, it may degrade future performance (if not replaced), or it may extend restoration times as conductors need to be replaced. Testing could evaluate this issue.

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