To insulate or not insulate. That is the question.

Insulated high voltage cables may have reliability challenges of their own compared to traditional bare conductors

Introduction:

Over the past 25 years, utilities have been ramping up their use of covered, or insulated, cables to reduce the risk of accidental contact with energized lines, mitigate outages caused by wildlife or vegetation, improve system reliability, and reduce the risk of wildfire. However, these conductors present unique challenges, particularly when small insulation defects occur or conductor deterioration or damage is hidden under the insulation. This paper outlines how such defects can lead to more reliability challenges than those associated with bare conductors, especially when no proactive monitoring systems or predictive analytics are employed to monitor the condition of the grid.

Covered Conductors vs. Bare Conductors

Bare conductors are widely used in high-voltage transmission and distribution systems. They rely on "air insulation", i.e., physical separation, for safety. If a fault occurs, it is often a direct short circuit, triggering protective devices quickly.

In contrast, covered conductors utilize one or more thin layers of insulation (sometimes including cross-linked polyethylene, XLPE) that provides dielectric protection, but usually not as robust, nor rated, as cables installed underground. They are not typically used in high-voltage transmission systems (69 kV and above), due to the thermal limits of their insulation, difficulty in dissipating heat, risk of insulation breakdown over long spans, and cost/weight penalties.

Although insulated cables have been slowly integrated into power distribution systems since the 1960's, it wasn't until the 2000's that utilities began deploying them in earnest as part of their fire risk mitigation strategy. Although this is considered a positive step to reducing the risk of wildfire, it can create the perception of lower *overall* risk. Consequently, attention to *actual* risk and potential failures is reduced, which could ultimately lead to faults of greater impact.

From a safety standpoint, EPRI Distribution's paper on *Covered Overhead Conductors*[1] highlights a critical concern: *"Safety is sometimes cited as a reason for using covered conductor, but these systems do not necessarily offer safety advantages, and in some ways the covering is a disadvantage."* The report concedes that while covered conductors *"may reduce the chance of death from contact in some cases,"* they ultimately do not provide a reliable safety barrier for utility workers or the public.

This conclusion aligns with the National Electrical Safety Code (NESC) Rule 155, which mandates that, from both a design and operational perspective, covered conductors must be treated as if they are bare. The rationale is that covered conductors behave differently than bare ones when energized and in contact with the ground. As explained in TD Systems' March 2006 technical paper[2], *"If a covered wire does contact the ground, it is less likely to show visible signs that it is energized, such as arcing or jumping, which would help keep bystanders away*." One research project reports test results that indicate a broken covered conductor on the ground may produce a greater fire risk that an equivalent fallen bare conductor[3].

The False Sense of Security

When utilities, maintenance crews, and the public assume that covered conductors significantly reduce the likelihood of faults, it sometimes leads to less frequent inspections and relaxed maintenance schedules. This false sense of security is unconsciously embraced, as decision-makers prioritize short-term budget savings over proactive condition monitoring and associated predictive maintenance - underestimating the long-term risks posed by insulation degradation. Consequently, the urgency to inspect these assets diminishes, leaving emerging defects undetected until they escalate to become a full network fault.

Even when utilities implement proactive visual inspection programs, the insulation on covered conductors inherently limits conductor defect detection. Issues such as cuts, abrasions, UV degradation, or moisture ingress

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[1] https://distribution.epri.com/wildfire/public/wildfire-tech-database/fault-count-freq-reduction/covered-oh-conductors/

[2] T&D System Design and Construction for Enhanced Reliability and Power Quality. EPRI, Palo Alto, CA: 2006. 1010192

[3] https://www.researchgate.net, Probability of ignition in 'wire down' earth faults with covered conductor, 2015.

with consequential conductor corrosion are easily masked, allowing failure points to remain hidden. Recent analyses have shown that over 70% of field failures in covered conductor powerlines involved insulation breakdown from UV exposure, mechanical wear, or animal contact - all of which would have been more visible and repairable on bare conductors. Minor insulation breaches can evolve into high-impedance faults, tracking, or flashovers - potentially triggering large-scale outages or fires, the very risks covered conductors are intended to prevent. In contrast, defects on bare conductors, like corrosion or mechanical wear, are usually immediately visible and more likely to prompt timely intervention.

Insulated systems also introduce failure modes that can often be overlooked. Compromised insulation may harbor small voids or cracks that initiate partial discharge (PD) - a localized breakdown of the insulation material. Though not immediately catastrophic, undetected PD weakens insulation over time and can lead to full dielectric failure. Similarly, moisture ingress through minor breaches or insulation removal to accommodate conductor clamps, splices, etc., can lead to conductor corrosion, surface tracking, carbonization, and eventual arcing. Thermal buildup is another factor. In bundled configurations or hot climates, unnoticed defects can lead to localized overheating, further increasing the risk of failure with consequential ignition and supply outages.

When faults occur, the consequences with covered conductors are often more severe. Unlike bare conductors, which typically trigger immediate disconnection through direct short circuits, damaged covered conductors may generate high-impedance faults that persist undetected. These draw insufficient current to trip protective devices, allowing prolonged arcing and progressive system degradation. A single insulation failure can even compromise adjacent conductors, creating a cascading effect that leads to broader system outages.

The perceived safety of covered conductors can lead to less frequent inspections or reliance on old techniques that don't reveal hidden damage. While advanced diagnostic tools - such as partial discharge monitoring, infrared thermography, and ultrasonic detection - are available, they may not be widely used due to cost, resource limitations, or lack of skills or awareness. This gap highlights the growing importance of continuous, high-fidelity condition monitoring solutions like IND Technology's Early Fault Detection (EFD) system. By identifying faults at the earliest stages - before insulation defects evolve into critical failures - utilities can make the transition from reactive response to predictive maintenance, improving safety, reliability, and wildfire resilience across the grid.

A false sense of security results from the classic "Perception vs. Reality Problem": While insulated conductors reduce immediate risks like accidental contact or wildlife-related faults, they introduce new failure mechanisms that require different mitigation strategies. If utilities and maintenance teams rely too heavily on the *perceived* safety of covered conductors without accounting for *actual* hidden risks, failures can escalate into more severe outages, costly repairs, or even fire hazards.

The key is not to assume covered conductors eliminate risk, but to shift attention toward proactive monitoring, predictive maintenance, and advanced fault detection techniques to prevent insulation failures from turning into major system disruptions.

Figure 2: Cracked Spacer Cable

Small Defects and Their Consequences

In practice, several major wildfires and outages have been linked to problems with covered conductors, at least in part due to the “false sense of security” driven by their design. For example, the 2018 Woolsey Fire, which broke out in Ventura County, California, is a notable example of a wildfire attributed to covered conductors. Investigations by the California Public Utilities Commission (CPUC) determined that a steel guy wire contacted an energized 16kV covered conductor during high wind conditions. Despite the insulation, the contact eventually led to arcing and ultimately ignition. The Woolsey Fire burned nearly 97,000 acres, destroyed over 1,600 structures, and resulted in three fatalities[4]. This example is not meant to imply that bare conductors would have prevented the incident, only that the risk may have produced a quickly cleared fault at a time of low fire-risk. A better solution is predictive analytics to detect the degradation of the insulation before the fault occurs.

Insulated conductors can introduce unique challenges despite their intended protective benefits. One such issue is capacitive charging effects, where charge accumulates along the surface of the insulation. Even minor breaches in the insulation can result in localized high-voltage stress points, accelerating the degradation of the insulation material.[5]

Insulation defects and compromise discovered via Early Fault Detection (EFD)

How Can Covered Conductors Result in Worse Faults?

Covered conductors, while designed to reduce faults from incidental contact with vegetation or wildlife, can introduce failure modes that are more difficult to detect and control, such as undetected fault propagation. In bare conductors, a fault typically results in immediate arcing, which triggers protective devices and isolates the problem. However, when a covered conductor develops a small defect - such as a pinhole or crack in the insulation - it can allow a fault to persist. These faults generate localized heating and conductor damage. They may continue to erode the insulation without drawing enough current to trip protective relays. Over time, the defect can worsen, leading to a more catastrophic failure with much greater energy release.

A critical issue is no or slow protection response. High-impedance faults, such as those involving intermittent arcing through degraded insulation, often produce currents that remain below the trip threshold of traditional overcurrent protection devices. The conductor and surrounding materials may be subjected to prolonged thermal and electrical stress, which can degrade system reliability and increase the risk of fire. In wildfire-prone areas, these persistent faults can be especially hazardous, as the arcing and overheating may ignite nearby dry vegetation.

Furthermore, defect detection and maintenance of covered conductors is inherently more challenging. Unlike bare wires, where surface damage or wear is visible during inspections, defects in covered conductors are

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[4] A redacted CPUC investigation report detailing the incident is available here. The utility’s public submission can be found here.

[5] J. Lewis, "High Voltage Insulation: Materials and Systems", IET Power and Energy Series 27, Institution of Engineering and Technology (IET), 1999.

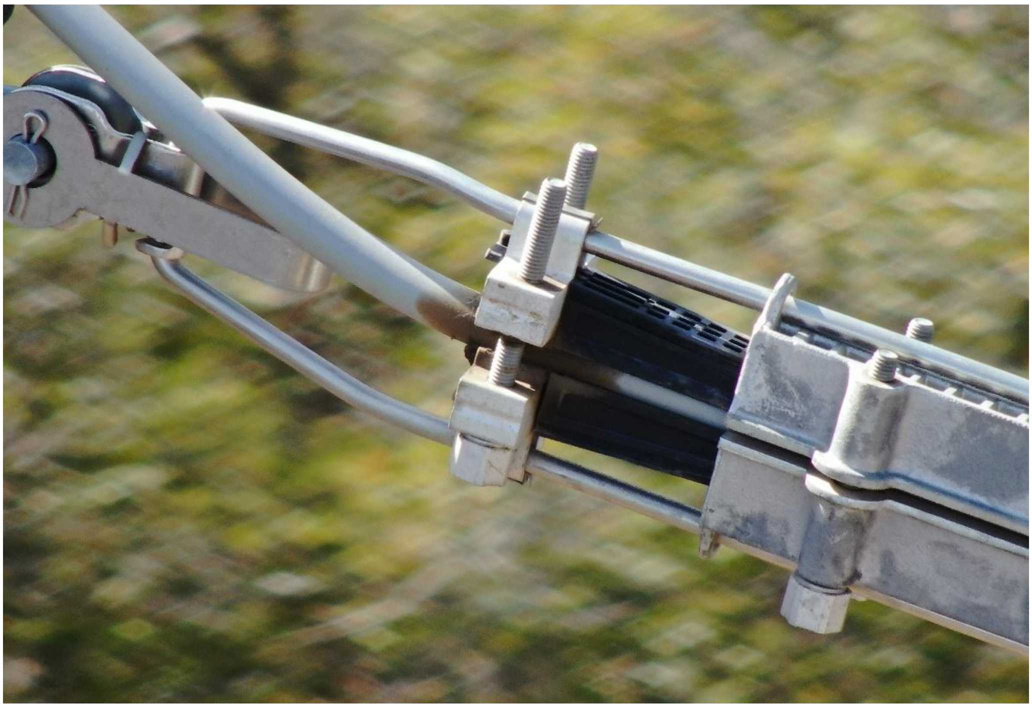
hidden beneath the insulation. Identifying these faults requires advanced diagnostic methods such as partial discharge (PD) sensing through Early Fault Detection (EFD), infrared thermography, or high-resolution corona cameras during line patrols. Without such tools, utilities risk missing early warning signs of conductor deterioration - potentially leading to unmitigated fault escalation.

Implementing the Digital Threat Barrier

Traditional risk mitigation strategies in electrical distribution systems involving covered conductors have several limitations that compromise their effectiveness:

- The invisibility of conductor defects because damage is hidden beneath the covering. Routine visual inspections and scheduled maintenance often fail to detect early-stage deterioration.
- High-impedance faults when insulation begins to break down or are compromised by vegetation contact, may not draw enough current to trigger protective devices, allowing these faults to persist and generate localized heating and electric field stress.
- Intermittent arcing caused by moisture or partial discharge may come and go undetected, further complicating defect identification as the insulation progressively degrades.
- The presence of covered conductors can create a false sense of security, leading utilities to reduce inspection frequency or delay asset replacement, even as inner conductors degrade.
- Traditional approaches also lack real-time visibility, relying instead on periodic assessments that can miss emerging threats. This often results in slow response times and inefficient use of resources, as utilities are forced to patrol large areas to locate faults or respond to failures under high-cost emergency conditions.

To address the limitations of traditional risk mitigation strategies for covered conductors, utilities should adopt more proactive, condition-based and data-driven approaches. Rather than simply reducing the consequence of failure, IND Technology’s Early Fault Detection (EFD) system serves as a threat barrier - actively identifying emerging issues before they escalate into faults. EFD continuously monitors the network for signs of partial discharge, detecting incipient anomalies the instant they begin to develop. It pinpoints the location of potential failures to within 30 feet, allowing maintenance teams to intervene long before a fault or insulation breach evolves into a fire or outage. EFD shifts the operational paradigm from reactive risk mitigation to proactive threat prevention, significantly enhancing grid resilience and safety.



Partial discharge through compromised insulation discovered via Early Fault Detection (EFD)

IND Technology's Early Fault Detection (EFD)

IND's EFD uses passive listening devices, reporting the condition of the grid infrastructure every second of every hour of every day, using patented high-frequency monitoring technology. It pinpoints physical weakness with an accuracy of 30 feet over a three-to-six-mile stretch of distribution and transmission lines with two pole-mounted units.

Tony Marxsen, Chairman of IND Technology recently noted, "The key difference between EFD technology and many other technologies such as line sensors and sensitive earth fault protection systems is that it predicts a failure rather than simply recording it. In risk assessment terms, this makes it a threat barrier rather than a risk mitigator. In other words, it is proactive rather than reactive." [6]

Simply put, a fault-event doesn't have to happen for IND's EFD system to find it and report on it. The early fault detection report allows the utility time to plan and schedule the repair that they would otherwise have to address as an emergency, redirecting valuable resources to correct something that is not planned nor scheduled to occur. This inflates the OPEX cost of the event to many times the cost for proactive planned maintenance. The Society of Maintenance and Reliability Professionals estimates that reactive maintenance can cost 8-16 times more than planned scheduled maintenance. If the maintenance need is "predicted" through Early Fault Detection, rather than discovered through routine field-based manual preventive inspection, the cost is still lower.

EFD's OPEX reduction benefit can be substantial. In the case depicted below, the covered conductors were not immediately damaged by the tree falling on them, but IND.T's EFD was able to instantly detect the contact and notify the utility before the tree could damage or degrade the conductors.

Immediate EFD detection and location of a vegetation strike on covered conductors

Conclusion

While covered conductors offer tangible benefits in reducing direct contact-related faults, they introduce hidden risks that can escalate into severe failures if not detected by proper monitor and promptly remedied. The insulation conceals degradation, enabling high-impedance faults that evade traditional protection systems and can lead to widespread outages or fires. To address these challenges, utilities should move beyond conventional risk mitigation and adopt proactive, data-driven approaches. Early Fault Detection (EFD) technology provides the necessary visibility, precision, and *prescience*, to identify emerging threats before they evolve into high-impact failures, transforming the maintenance paradigm from reactive to preventive and enhancing overall grid resilience.

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[6] Preventing Powerline Faults and Fires | T&D World (tdworld.com)

About the author

James (Jim) Haw is a seasoned electrical engineer with over 37 years of diverse experience across the paper, plastics, electrical utility, and oil & gas industries. He serves as the Director of Business Development for North America at IND Technology where he is focused on promoting IND's Early Fault Detection system to increase awareness within the U.S. power transmission and distribution utilities sector.

Jim is recognized for his career in automation and for pioneering the groundbreaking concept of the "born digital" industrial facility. His "born digital" concept led to several published articles and recognition from the International Society of Automation (ISA), which awarded him the 2023 Excellence in Technical Achievement Award for his contributions to a new plastics recycling facility. He has served ISA at the local, regional, and national levels, aiming to support the industry and share his knowledge wherever possible.

Jim holds a Bachelor of Science in Electrical Engineering (BSEE) from the University of Arkansas at Fayetteville and is a licensed Professional Engineer (PE) in Texas. In addition to his engineering background, Jim is a Certified Maintenance and Reliability Professional (CMRP) and a Project Management Professional (PMP)