Aerial Covered Conductor Systems as a Wildfire Mitigation Tool

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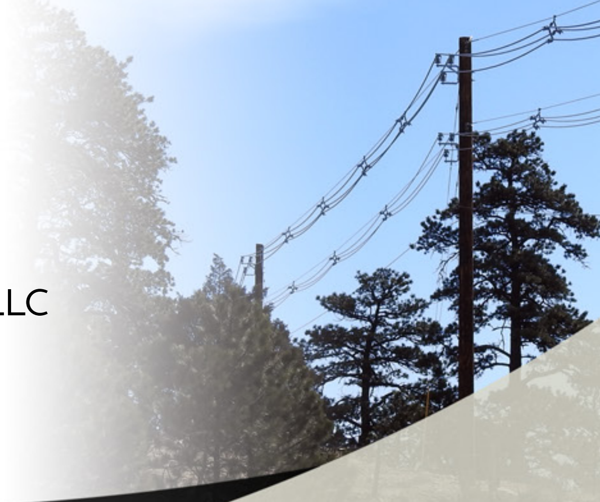


Introduction

Over the past number of years, the western parts of North America have been increasingly under siege from wildfires. There are a number of reasons for the wildfires and, unfortunately, in some cases, powerlines have been a contributing factor. A key objective of constructing power lines in wildfire prone areas is to ensure every measure has been taken to design those lines so as to avoid igniting a wildfire.

This paper is not about powerline wildfire survival, or other tools and processes utilities are using in the fight against wildfires. Some of those are brush clearing (fuel load removal), simulation/modelling/prediction, monitoring, Smart Grid, pole changeouts to steel, or Public Safety Power Shutoff (PSPS). All of these tools are instrumental in the fight against wildfires, but the focus here is mitigation, or avoiding ignition in the first place.

Background

Power lines have coexisted with trees since the first transmission line was built in the late 1800's. Wildfires were significant events throughout history as they consumed large swaths of land and caused widespread destruction. For thousands of years, Indigenous peoples managed their land proactively, setting controlled burns on land to ensure that the fuel load was kept to a minimum, so as to minimize the risk of catastrophic wildfires. This changed in 1944 when the U.S. National Forest Service started the Fire Prevention campaign and proactive policies to minimize fuel load in national forests were terminated. Nevertheless, it is only in the last 20-30 years that wildfires have gained prominent attention due to the devastation caused and lives lost. Wildfires seem to get worse every year, and powerline design is being upended with new and urgent requirements.

How Power Lines Cause Wildfires

While 85-90% of wildfires are caused by human activities, including unattended campfires, discarded cigarettes, arson, and carelessness, some are started by lightning or other natural events. Finally, a small percentage of wildfires are caused by powerlines. We can endeavor to eliminate powerline-initiated fires via proper line design.

The leading cause of powerline related ignition is contact with trees during high wind events. A tree branch spanning two phases of a power line can be problematic. The branch may become ignited and fall to the ground, igniting dry brush or grass on the ground.

High winds can also cause downed lines. In fully 30% of cases when a powerline falls to the ground, there isn't enough current to operate a protective device (recloser/relay/fuse). This is commonly referred to as a high impedance fault. However, if the ground is dry and there is dry brush available, it is possible for the current to cause ignition. By the time someone notices the fire and calls for help, it is often too late as the fire has grown and spread. Similarly, power lines blowing in high winds may blow into one another, a scenario known as "Conductor Clashing or Conductor Slap." In this case, the conductors touching one another produce high energy arcing and expel high temperature plasma particles onto the ground below, which may cause ignition.

Hendrix®

Mylar balloons used for celebrations have been known to cause powerline related fires. The balloons are (intentionally or accidentally) released into the air, occasionally becoming lodged between two energized lines and causing a massive explosion when they fault phase to phase or phase to ground. Mylar balloon caused hundreds if not thousands of wildfires to date and there is currently legislation being debated to ban them or make them nonconductive.

Lastly, while most faults are isolated events, repetitive faults (apparatus failures, bushings, cap banks, switches, etc.) can cause ignition. Aged equipment adds to the possibility of a fault scenario occurring.

Bare Wire Lines

Bare wire lines are intrinsically vulnerable as a source of ignition. They may make contact with trees or fall to the ground energized and cause ignition. They may also fall to the ground de-energized, hit a rock or pebble, throw a spark and cause ignition. There have been protection schemes introduced which anticipate a line falling to the ground and de-energize the line before it hits the ground. If the bare metal hits a rock and throws a spark, that scheme won't work. For energized lines, conductors clashing in high winds can cause ignition.

One strategy to mitigate bare wire wildfire ignition from conductor clashing is the use of interphase spacers. These spacers are installed midspan between the individual phases and ensure that the conductors remain separated. There are several producers of interphase spacers, but the most common configuration is a simple fiberglass rod with hardware on each end positively affixed to the phase conductor at each end. The hardware is either an insulator or a clamp. These spacers ensure that energized conductors will stay separated and not have a chance to engage in conductor clashing.

Another strategy for bare wire lines is to utilize Flame Retardant (FR) insulators. While the ignition temperature for polyethylene (~650°F) is below the temperatures wildfires can reach (1,100°F – 2,000°F), they will still be less prone to ignition. We don't want insulators, or anything on the system, to be fuel for a wildfire. Secondly, if the insulator is ignited, it will self-extinguish after the flame is removed. This will prevent the insulator from depositing flaming drops down onto ignitable material which may be lying on the crossarm. Without dripping, concern is eliminated for bringing fire at the top of the pole (which will extinguish as soon as the wildfire passes) to ignite something on the crossarm or beneath the pole.

Undergrounding of Powerlines

A popular strategy for wildfire mitigation is to simply put the lines underground. Underground lines are aesthetic in that they are "out of sight," they can't throw a spark onto dry brush, and they aren't subject to vegetation contact. Unfortunately, the materials and installation costs for underground lines can be five to ten times the cost of bare wire construction, and even greater in urban areas with legacy infrastructure. This is due not only to the added cost of cable, but the added cost of underground transformers, cabinets, and switches. Undergrounding also poses potential harm to tree roots. Lastly, there are flexibility issues. With load growth, overhead lines can easily be reconductored, while this is more difficult and costly for underground lines. So, while undergrounding is a technically viable and extremely attractive option for wildfire mitigation, it also comes with a cost structure that may be difficult to justify systemwide.

Aerial Covered Conductor – Spacer Cable and Tree Wire Systems

Spacer Cable Systems consist of three heavily covered, but unshielded, phase conductors. The conductors are usually AAC when in a spacer configuration, since there is no tension on the phase conductors, but can be ACSR or AAAC when installed in a self-supported or "Tree Wire" configuration.

In Spacer Cable construction, the phase conductors are attached to a messenger by spacers, installed every 30 ft. (10m.) along the messenger. The messenger is a high strength, alumoweld (AW) or alumoweld-aluminum (AWA) conductor which has several functions. The first is that the messenger is the mechanical strength member, holding the phase conductors up. The messenger can also be used as a system neutral, is a lightning shield, and provides a mechanical protection function by protecting the phase conductors from any items (leaves, branches, trees) which can fall onto the bundle from above. The spacers are made of High Density Polyethylene (HDPE), as are the pin or line post insulators used on the angles, to ensure dielectric compatibility with the phase conductors.

Tree Wire systems, on the other hand, look more like bare wire construction. They utilize the same 3-layer covered conductor design, but the phase conductors are usually either ACSR or AAAC (since it is fully self-supported and tensioned). Tree Wire systems are strung in an open wire configuration on crossarms with polyethylene insulators. The photo below left shows a spacer cable system, while the photo on the right shows a tree wire configuration.

There are many differences in operational effectiveness between Spacer Cable and Tree Wire. Our purposes here are to simply review their efficacy as wildfire mitigation tools. There are three significant advantages to using covered conductor in wildfire prone areas:

1. If a line blows into trees or branches, there is not enough contact current to cause ignition.

2. If a line is impacted physically and falls to the ground, there is not enough current to ignite dry brush or other fuel which may be present.

3. If a line falls to the ground and hits a rock, the polyethylene covering on the covered conductor will not cause a spark to be thrown (unlike a bare wire, where a spark and subsequent ignition of dry brush would be possible.)

There are a few differences between Spacer Cable and Tree Wire Systems with respect to wildfire mitigation effectiveness. If a Tree Wire configuration is used, there is the possibility that an overhead tree could fall onto the line, abrade the conductor covering over time, and result in a failure. That would seem to reduce the attractiveness of Tree Wire in abundantly treed wildfire prone areas, in favor of Spacer Cable.

Additional differences arise in relation to foliage removal and tree trimming since spacer cable uses less Right-Of-Way (ROW) than Tree Wire.

Tree Wire

Spacer Cable

The illustrations above show the differences between Tree Wire and Spacer Cable with respect to tree trimming. For the Spacer Cable configuration, even with the same clearances, much more of the tree remains intact. Note that the additional foliage does not increase the risk of fire. If branches become weighted down with wind or rain and touch the power bundle, they will be supported by the high strength messenger, which is suitably grounded at every pole, or every other pole. This is one function of the overhead messenger: to protect the phase conductors beneath it from objects which may fall on them from above.

Not all powerline related fires initiate with branches falling from above. A significant part of the wildfire prone landscape consists of dense scrub, tangled bushes, and what is more commonly known as chaparral. These plants don't threaten powerlines from up above but are a potent source of fuel for wildfires from below. Further, there are cases of palm fronds being ignited by fire and travelling with the wind hundreds of yards. Should this palm frond fly between two phases of a bare wire system, this can be a concern. Note that fire is plasma, and conducts electricity, since it is essentially an ionized gas consisting of ions and free electrons. If the ignited palm frond gets between the two bare wire phases, a flashover is likely. This could create a new wildfire location beneath the power line. The use of a covered conductor would prevent this scenario.

As such, when there are no trees, it is viable to use covered conductor in a Tree Wire configuration. Conversely, when trees are present, Spacer Cable is recommended since it will prevent ignition and protect the phase conductors from objects which threaten the power line from above and below.

Relative Wildfire Mitigation Effectiveness

In 2019, Southern California Edison (SCE) studied the effectiveness of powerline construction alternatives. Specifically, they compared re-conductoring with bare wire, re-conductoring with covered conductor, and converting to underground. They looked at costs per mile, relative mitigation effectiveness, and tabulated a mitigation-to-cost ratio. Results are shown in the table below.

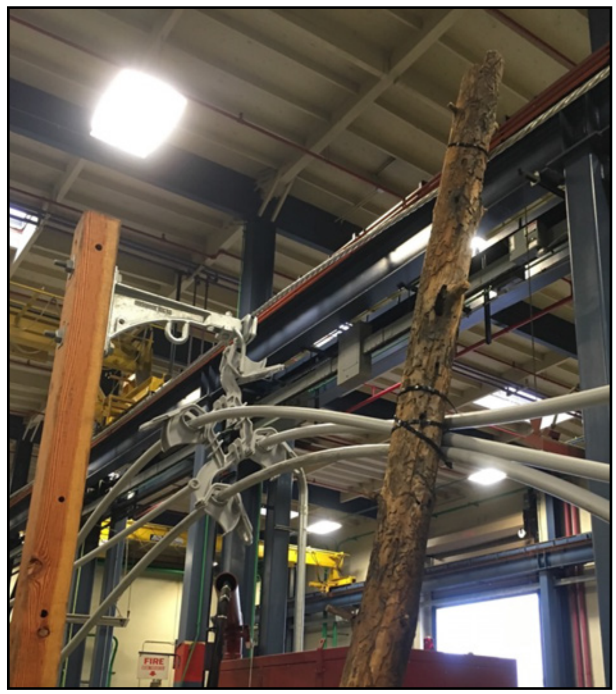
Mitigation Option	Relative Mitigation Effectiveness Factor	Cost per Mile ($ million)	Mitigation Cost Ratio
Re-conductor Bare	0.15	0.30	0.50
Re-conductor Covered	0.60	0.43	1.40
Underground Conversion	1.00	3.00	0.33

The conclusion drawn from the study of Wildfire Mitigation strategy alternatives is that covered conductor is the most viable, cost-effective mitigation tool. Undergrounding, which is an extremely potent mitigation tool, is costly to the point that the mitigation to cost ratio is the lowest of the three alternatives. Utilities are using all three methods studied, depending on the location, fire danger rating, landscape, population density, budget, and other factors.

Testing

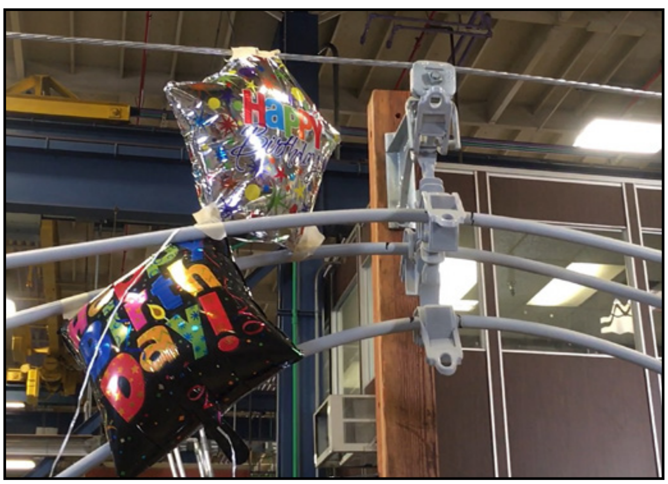
If we select one mitigation strategy, how do we know it will work? The best way is to set up a test protocol and determine what type of contact will be problematic.
Or, set up a test of worst case scenarios and see what happens.

SCE, in crafting a wildfire mitigation strategy, set up numerous tests. The first test was the Tree Contact Test. They constructed a 3-phase line in the lab and fastened all three phases to a tree. Instead of using a dry tree, they wetted the tree with a saline solution to ensure it had maximum conductivity. The covered conductor used was a 15 kV design. The system was energized at 35 kV (3x line voltage), and the test was run for eight hours. The test setup is shown below. When the line was de-energized, there were no signs of burning, tracking, or damage of any kind, so the test demonstrated that covered conductor will not cause ignition for tree or ground contact, even for an extended period.



Similar tests were run at Hendrix labs in the 1990's and published in the IEEE (1). The test setup used wet wood, and energization voltages were up to 7x line voltage. The results demonstrated that a covered conductor in direct contact with a grounded object can last up to a full year without failure. While this is not recommended, and no line design should ever consider the possibility of extended contact between a live line and vegetation, it demonstrates that (properly designed) covered conductor can be in contact with grounded or partially grounded objects for extended periods without concern for a fault, or in this case, wildfire ignition.

SCE also performed two tests using mylar balloons, as shown in the photo below. One test setup placed the mylar balloon phase to ground (between one phase and the grounded messenger), while the other test placed the mylar balloon between two energized phases. The tests were each run for two hours. Instrumentation included monitoring for partial discharge and thermography. At the conclusion of each test, there was no flashover, current, or evidence of burning or tracking. It should be noted that if the mylar balloon were tested on bare wire, there would be an explosion and accompanying fireball within minutes. The tests demonstrate that mylar balloons will not fault when trapped on covered conductor lines.



Covered Conductor and Operational Strategy

Utilities can design power lines with covered conductor to minimize the potential for wildfire ignition. However, can this have ramifications for operational strategies to combat wildfires? Common to wildfire prone areas is the aforementioned PSPS. At least one utility has stated that in addition to its wildfire mitigation benefits, covered conductor has some PSPS benefits as well, raising the threshold for PSPS to higher wind speeds than those used for bare wire systems.

Summary and Conclusions

Powerlines are an inevitable source of risk for wildfire ignition. Bare wire, underground, and covered conductor systems offer mitigating strategies, each having their own costs and efficacy. Covered conductors have been shown to be a viable and cost-effective tool to combat this phenomenon. As has been seen with the horrendous wildfires hammering the western regions and even Hawaii in 2023, this problem is not going away any time soon.

1. Carl Landinger, "Spacer Cable Systems for Rural Electric Cooperatives," Rural Electric Power Conference, Louisville, Kentucky, May 2000.