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WILDFIRE RISK MITIGATION

FOR ELECTRIC UTILITIES

A compendium of articles from *T&D World* contributors

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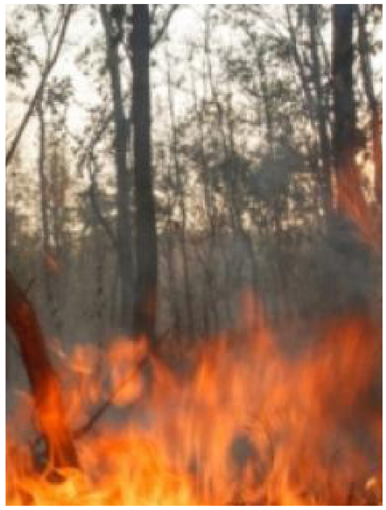

Martha Davis

INTRODUCTION

Wildfire risk mitigation is a complex and never-ending challenge for electric utility companies, especially in areas of the Western United States. These areas see wildfires every year that claim lives and millions of dollars in property. This e-book is a compilation of several resources which will provide useful and practical information to assist utility personnel in addressing these risks. We discuss various tools and practices available to help minimize the occurrence of power equipment caused fires and to help utilities protect their equipment from wildfires.

The coverage spans from fire retardants and vegetation management to various technologies used by utilities. The content also outlines methods utilities should undertake to materially decrease the costs, financial risks and ability to maintain insurance coverage associated with power line initiated wildfires.

Finally, utility personnel will benefit from real-life examples that detail multi-agency responses and the challenges associated with maintaining system reliability during wildfires.

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FIRE RISK MITIGATION IS A NEVER-ENDING CHALLENGE FOR UTILITIES

Are there tools and practices available to help utilities protect their equipment from wildfires and to help minimize the occurrence of power equipment caused fires?

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Fire is as old as time, and while we have conquered it in countless ways, it still has a habit of showing up unannounced and unwanted. Nowhere is this more evident than in areas of the Western United States, which see numerous wildfires every year that claim lives and millions of dollars in property. Unfortunately, fires that can be caused by and/or destroy utility infrastructure occur in other parts of the U.S. as well. So, are there tools and practices available to help utilities protect their equipment from wildfires and to help minimize the occurrence of power equipment caused fires?

The answer is definitely yes. In states with hot, dry periods where long expanses of transmission and distribution lines may cross high-fuel environments containing dry grass, brush and forested areas, utilities are increasingly turning to granular herbicides to create vegetation-free zones that act as a fire-break to protect their equipment. According to Paul Escobar with SSI Maxim Company, a reduced vegetation zone creates a defensible space where heat and flame exposure to equipment is reduced. Moreover, granular herbicides can be applied around structures with a broadcast spreader and they protect an area for months. Creating a reduced vegetation zone in the vicinity of distribution equipment like pole mounted transformers or capacitors also helps minimize the creation of a fire should an errant spark occur.

In recent years, utilities across the country have been taking steps to increase reliability and resiliency after a series of major storm events caused major outages. For example, CenterPoint Energy developed a hazard tree inspection program after Hurricane Ike in 2008 to periodically inspect important circuits thought to be potentially at risk due to the presence of certain danger trees including palm and pine species. Unitel implemented a vegetation storm resiliency program (SRP) after experiencing a series of extreme weather events and realizing that standard vegetation management practices may provide insufficient protection from extreme events. The SRP goes beyond the company's traditional core vegetation management program consisting of cyclical pruning and hazard tree removal by conducting detailed tree risk assessment on critical circuits to remove all failure risks and ensure ground-to-sky clearance. Not surprisingly, the storm hardening practices conducted by both utilities also serve to help minimize the risk of fires resulting from vegetation caused equipment damage.

According to Scott Holmquist with Pursue It Consulting, utility companies are increasingly focusing on developing effective wildfire mitigation, vegetation management and pre-treatment programs to minimize losses. Scott's experience has been that fire retardants in the Long-Term Fire Retardant (LTR) classification have proven to be highly effective for a variety of situations. They can be applied on and around flammable materials to reduce fire intensity, rate of spread and increases safety for those working on a fire line. In addition, LTRs can be applied several days prior to fire passage and remain effective for days and even weeks after application. Wooden poles treated with fire retardants experience greatly minimized damage compared to untreated equipment.

Some observers might argue that the billions of dollars utilities are pouring into smart grid technologies will put an end to electrical equipment related fires. After all, automation technologies can aid in fault location, isolation and restoration and there is no question that system resilience to extreme weather events is improved when equipment has the ability to detect and automatically limit the extent of major outages. However, utilities and researchers are learning that even smart grid enhanced systems are fallible and can be improved upon.

Pedernales Electric Cooperative and other Texas utilities are working with Texas A&M Engineering to address potential sensitivity gaps in some smart grid systems that should further reduce wildfire risks. The team is demonstrating a technology known as distribution fault anticipation (DFA) that was developed at Texas A&M University's College of Engineering. The technology helps utilities detect multiple line issues that could lead to wildfires by utilizing sensitivity triggered, high fidelity waveform recorders positioned at substations on distribution circuits. An extensive database of collected waveform data has helped researchers identify the characteristics of various line events and develop algorithms to recognize and report them. As an example, the DFA system can help identify and isolate a recurrent fault that left uncorrected might lead to permanent damage and, potentially, a fire.

Ever-improving vegetation management practices, fire prevention/mitigation treatments and advanced technologies are contributing to improved electrical system reliability, resiliency and reductions in fire ignition risk. However, we can never drop our guard because nature, careless humans and malfunctioning equipment keep the risk of wildfires alive. Every additional measure we can implement that improves situational awareness and preparation further reduces the chances that a fire will lead to major losses.

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SIG GUGGENMOOS
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RISK TREES & WILDFIRE RISK

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What should you do if you ever have the misfortune of being the defendant in a power line-initiated wildfire case?

Today, approximately 120 megawatts of customer-owned distributed energy resources, almost all rooftop photovoltaic systems, are spread out over 20,000 connections at various customer locations throughout Entergy Corp.'s system. Approximately 83.5 MW of utility-scale solar generation is currently in operation, and additional solar generation is under development.

One of the major causes of power line-initiated wildfires is trees or tree parts falling into electrical conductors. What can a utility reasonably do to reduce this risk?

First, any tree that on failure could contact the electrical equipment is deemed a "risk tree." If you are located in North America this is covered in ANSI A300 Part 9. Internationally Risk Management is covered by ISO 31000:2009. As a utility you should be aware of and responsive to these standards. Should you ever have the misfortune of being the defendant in a hundreds of millions of dollars power line-initiated wildfire case, you can expect the plaintiff lawyers will rigorously measure you against these standards.

So let's go back to that risk tree. Because every tree will fail given enough stress loading, any tree that could contact the electrical equipment is defined as a risk tree. There you have a can of worms. The plaintiff lawyers will want to know the risk assessment made on the tree that initiated the incident. We don't have a conveniently low statistical probability that you can assign to a tree that appears healthy and structurally sound. In fact, we don't have probabilistic failure data for trees in general.

When the courts are evaluating a claim for damages, the key question is what a reasonable person or entity would have done to avert the damages. The first step in this, which was covered in the last issue, is recognizing the risk so that it is covered in policy, procedures, and dedication of resources.

The question then emerges: Would a reasonable person examine every risk tree, to what extent and how often? Conversely, we might ask, is it a reasonable expectation that every risk tree be evaluated and to what extent, how often?

International Society of Arboriculture's Tree Risk Assessment Best Management Practices sets out three levels of tree risk assessment.

- Level 1: Limited visual
- Level 2: Basic
- Level 3: Advanced

Typical utility procedure is to conduct a slow drive by or aerial inspection. These fall under Level 1. This inspection may identify some trees for a more detailed ground inspection. In this case the tree or trees would be viewed from all sides, noting lean, root support, structure and any indications of the tree being affected by pathogens. This would be classified as a Level 2 assessment.

In the aftermath of a power line-initiated wildfire there's a good chance it will be implied that had you made it a policy to undertake a Level 2 tree risk assessment on all risk trees that the fire could have been avoided. You may find yourself in the uncomfortable position of having to concede that may be true.

Your defense to this argument is that it is not reasonable to undertake a Level 2 tree risk assessment on all risk trees. You can make this argument after the fact but I believe you would be much better served by having the justification for your VM practices documented in advance of any legal proceedings.

What should you document? You should know the percent of your system that has treed edge. You should undertake some studies to determine the total number of risk trees on your system. I'm not talking about an order of magnitude guess like we have millions of trees. It will have far more credibility if you can say we 4.3 million ± 5% risk trees at a 95% confidence level.

Once you know your total tree exposure, which you will find to be stunningly large, you will need to determine the operational and cost implications. That will require a two-week trial having two people doing a walking Level 1 tree risk assessment of all risk trees and conducting a Level 2 assessment where and when necessary. From this trial you should be able to determine the productivity. Let's optimistically assume that the test reveals they can do 80 trees per hour. Assuming, for example, the previously stated risk tree exposure of 4.3 million trees yields 53,750 crew hours or 107,500 man hours to cover the system once. If you were to do annual inspections, which you should given the magnitude of the risk, this would necessitate 28 crews. You can also then derive the projected annual inspection cost. If we assume a crew cost of $130/hr you will need $6.99 million to cover this program. Keep in mind I have only stated the tree risk assessment costs. Obviously, such an intense program will lead to a higher number of removals and this increased rate you will also determine and cost from the two week trial. The next step is to apply to the regulator to fund this tree risk assessment process and the resulting actual tree work. If you gain approval your program will be one of the most advanced and therefore, difficult to fault. If you do not get approval then the regulator has effectively determined that drive by or aerial inspections as you have been doing are adequate but more importantly to you, as the regulator acts on behalf of the ratepayer, that such Level 1 inspections are what is considered reasonable to the public.

The process I've outlined should materially decrease the financial risk associated with power line initiated wildfires. In doing so, it will simultaneously help utilities with the cost and ability to maintain insurance coverage..

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SCOTT HOLMQUIST
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RON RALEY
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UTILITIES CAN MITIGATE FIRE DAMAGE WITH LONG-TERM RETARDANT

Fire retardants provide utilities a significant edge when the inevitable wildfire occurs.

Pole and surrounding vegetation pretreated with LTR well in advance of a fire. There was no damage.

Wildfires have become increasingly common, larger, more expensive to fight and deadlier. They are costing billions of dollars in natural resource and property losses. Of significance, wildfires also pose an extreme risk to utility infrastructure. Every year, utilities spend millions of dollars replacing wildfire-damaged wood utility poles and infrastructure. Replacing fire-damaged equipment is extremely expensive, disrupts routine maintenance schedules and, most importantly, reduces the reliability of electric service.

Utilities have tried a variety of ways to prevent damage to utility infrastructure from wildland fires. Approaches range from doing nothing to installing metal poles and all points in between. Utilities face some tough questions when it comes to wildfire mitigation: Is spending more funds for poles made of fire-resistant materials a good approach? Is pretreating wood poles and utility infrastructure with long-term fire retardant (LTR) an equally viable and potentially less costly option?

LTRs have proven to be an effective tool in reducing the damage and destruction of wood utility poles from wildfires. Pretreating utility poles with LTR ahead of a spreading wildfire can increase the odds of their survival.

FIRE RETARDANTS

The same fire chemicals traditionally used by wildland fire agencies can be used by utilities as a treatment method on utility infrastructure. They include Class A foams, gels or water enhancers, and LTRs.

Class A foams are dependent on the water they contain. Foams typically evaporate within one hour to four hours of application.

Pole pretreated with long-term retardants exposed to a flame from a propane burner at more than 2000°F (1093°C) did not ignite or show any damge.

The surfactants in Class A foam significantly reduce the water's surface tension and, when mixed with air, create a superior foam blanket that surrounds fuels with a thick layer of water. This creates a barrier between the fuel and fire, knocking down the fire faster than water alone, and enabling firefighters to see the areas of application. Making the water more effective reduces the amount of water needed to extinguish the fire, reducing water damage and increasing firefighter safety through quicker knockdown as well as reduced time required to locate and extinguish residual hot spots.

Foam limitations include decreased performance in high heat as well as in long periods of exposure to sun and wind, which speed evaporation of water from the foam solution and render it less effective. Also, foams cannot be rehydrated with the application of additional water. Because of these characteristics, Class A foams must be applied immediately prior to flame impingement (within one hour or less), thus requiring application crews to work near the fire area.

Like Class A foams, water enhancers or gels depend on the presence of water to be effective. Gels break the fire triangle by suffocating oxygen from the fuel and cooling the heat source, thus providing a thermal barrier. Gels cling to vertical surfaces, which prevents rekindles—thereby reducing property damage. Because of their increased effectiveness over water alone, gels provide an additional margin of firefighter safety. While gels tend to retain moisture and resist evaporation better than foams, they also lose their effectiveness after periods of exposure to ambient temperature, relative humidity, sun and wind.

Results of a controlled live fire where dry vegetation stacked around the pole burned and ignited an untreated pole. The pole had to be extinguished (left). Results of a controlled live fire where dry vegetation stacked around the pole burned but did not ignite or damage the pole pretreated with long-term retardants (right).

Some manufacturers suggest, once dried, gels can be rehydrated by the application of additional water. This is a myth. Any dried gel remaining on unburned fuel can be rinsed off by a subsequent application of water. Because of these characteristics, gels are best when used within hours of flame impingement. Because of their limited duration of effectiveness, gels also require application crews to work near the fire area.

Foams and gels both rely on the water they contain to be effective; they do not chemically alter the combustion process. Once dry, they are no longer effective. In contrast, LTRs do not depend on the presence of water to be effective. LTRs consist primarily of ammonium phosphates and other functional components. Phosphate-based LTRs chemically modify the combustion process in cellulosic fuels, reducing the rate of spread. This occurs with or without the presence of water. Fuels treated with LTRs result in less combustion. This reduces fire intensity and rate of spread as well as increases safety for those working on the fire line.

From a reaction standpoint, LTRs chemically alter the combustion and decomposition process of fuels as well as reduce flammable gasses and vapors. After fuel coated with LTR is exposed to fire, the chemically modified combustion process results in a graphite-like carbon char that continues to insulate the fuel surface and emits water vapor, which provides cooling. From a safety perspective, this characteristic is highly desirable, as it does not require application crews to work near the fire area. LTRs can be applied several days prior to fire passage, and they will remain effective for days and even weeks after application.

LONG-TERM RETARDANTS

Testing and evaluating the use of fire retardants, by simulating conditions that would typically be encountered during a wildfire, can be conducted on wood utility poles to compare the effectiveness of various fire chemical agents. A series of tests were conducted by Pacific Gas and Electric Co. (PG&E) in which utility poles were treated and exposed to a standardized flame for a specified period. Based on the experience of staff at PG&E and testing conducted by the author, LTR products were determined to provide the best results in this evaluation.

Ground application of LTRs to wood utility poles can prevent ignition and eliminate replacement costs. Application in rights-of-way, perimeter fuels around utility substations, switchyards, valve lots and mountaintop communications sites can prevent a fire from entering the area, resulting in the protection of utility equipment and infrastructure. Further, ground application is not subject to restrictions of weather, inversions, smoke conditions and night operations that may hinder dissemination using air tankers and helicopters. LTRs can be applied with back pumps, utility terrain vehicles with pumps and poly tanks, garden sprayers (highly effective for poles with limited accessibility), water tenders, hydro mixers and fire engines.

In some situations after application, ignition of wood poles or fuel is still possible. This may be a result of improperly mixed solution, improper application of the product, damage or checking of the pole, or heavy fuel loading near poles. The performance of any product depends on proper mixing and mix ratio to achieve the proper viscosity and salt (active ingredient) content.

LTR properties remain effective for weeks to months after application. Because of this characteristic, retardant can be applied well in advance of fire impact, making it unnecessary to expose personnel to potentially more dangerous work situations near an approaching fire. Once LTR is applied, it does not require the additional application of water for rehydration, again preventing the need for employees to work in proximity to dangerous fire areas. LTRs remain effective even months after the water has evaporated, unless they are removed by rain.

Readily available documentation regarding the environmental and safety effects of fire retardants is an important consideration for utilities. For example, all the commercially available Phos-Chek LTRs from Perimeter Solutions have been evaluated and tested extensively by the U.S. Forest Service (USFS) and shown

Before and after scene from 2016 fire in San Luis Obispo County. Area around pad-mounted transformer is pretreated with long-term retardant a day prior to fire burning through the area. After scene shows the effectiveness of the treatment - no damage.

to have no adverse health effects or negative environmental impacts when properly applied. In fact, they are included on the USFS's qualified products listing and approved by the Canadian Interagency Forest Fire Centre. Of note, Phos-Chek products are the only LTRs currently approved by the California Department of Forestry and Fire Protection.

EXAMPLES OF SUCCESSES

During the 2015 California wildfires, significant damage and destruction occurred in the areas of Amador, Butte, Calaveras, Fresno, Lake and Trinity counties. Pretreating poles with LTR by one utility prevented the loss of at least 312 T&D poles. This resulted in a savings of more than US$6 million in infrastructure alone for the utility. The 2015 Asset Protection on Wildland Fires publication included the following quote from Robert Cupp, PG&E's incident commander for the Rough fire in Fresno County: "Without a doubt, pretreatment of PG&E infrastructure with long-term fire retardant on the Rough fire saved thousands of dollars in expensive repair and replacement expenditures. More importantly, our efforts to protect these assets allowed PG&E to restore service more quickly and maintain service reliability for our customers."

Major incidents in 2017 included the Helena fire in Trinity County as well as the fire siege in Sonoma and Napa Counties, which included the Tubbs, Nuns and Atlas fires. One utility pretreated 200-plus transmission poles, 1000-plus distribution poles, a mountaintop communications site, an electric substation and a gas transmission substation with LTR prior to these events. The utility's actions reduced damage and destruction, resulting in significant savings to its infrastructure.

Utilities are increasingly focusing on developing effective wildfire mitigation, vegetation management and pretreatment programs to minimize losses. LTRs have been proven to be the most effective treatment for a variety of fuel types. An efficient and effective pretreatment program generates four extremely important benefits for utilities:

- Enhcancing safety for the public and responders by keeping the electric utility up and energized
- Increasing utility cost savings through avoidance as well as mitigation of damage and destruction to infrastructure
- Improving reliability of service is improved by reducing potential outages to critical community facilities
- Minimizing disruption of normal business activities is minimized as resources are not redirected to perform fire damage repair work.

Utility pole replacement costs can be $20,000 or more per pole. By comparison, the cost of pretreatment amounts to less than $20 per pole. When infrastructure is protected, valuable maintenance crews can focus on their normal duties rather than spending days replacing damaged or destroyed poles and equipment. Pretreatment program benefits and cost savings can be instrumental to utilities focused on achieving their goals of safety, reliability of the electric utility grid, affordability and customer satisfaction.

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The insulators on these wires mark where an untreated pole was before the fire destroyed it.

TRAVIS WEGER
Public Affairs Specialist, WAPA

IN THE HEAT OF THE BLAZE: WAPA POWERS LOCAL COMMUNITIES

The historic Carr Fire may have taken 15 of WAPA's transmission lines out of service, but the agency rapidly responded to help its customers.

A transmission line stands on the water in the smoke.

July 23 marked the beginning of the Carr Fire in northern California. CNN reported that it began as the result of a flat tire on a trailer; the motorist continued driving and the trailer's rim scraped the asphalt, sending sparks into the nearby dry brush.

High temperatures and extreme drought conditions compounded the problem, and the blaze rapidly grew to uncontrollable proportions. It ultimately became the sixth most destructive wildfire in California's history, threatening many transmission lines and customers in the Sierra Nevada region. Once again, WAPA employees responded to disaster.

UNIFIED RESPONSE

The fire quickly reached Trinity County and the southern part of Shasta County. As the disaster response was kicking off for WAPA, an incident management structure was stood up with the emergency operating center at headquarters and the Sierra Nevada regional office in Folsom, California. WAPA crews came together in a unified response consisting of craft, technical and support personnel across WAPA.

"The people on the front lines are in the most stressful situations," said Executive Vice President and Chief Operating Officer Kevin Howard. "Our goal was to establish a support network where we could help them with what they needed. It required a broad team."

The dispatch team in Folsom acted quickly to de-energize the lines, allowing firefighters and WAPA crews in the area to work safely.

"The Carr Fire didn't impact our facilities immediately," said Supervisory Power System Dispatcher Christine Henry. "We started seeing impacts as the fire raged out of control the evening of July 26. We had a dozen or so lines that evening relay out of service."

As the fire grew, fiber on the lines was damaged, leaving dispatch unable to see what was happening to the system. Henry compared the situation to driving on the freeway while blindfolded. With no remote access, the dispatchers' only option was to send personnel to substations to perform manual switching. These employees acted as the eyes, ears and hands of the dispatchers.

Protection and Communications Craftsman Dave Scharton and Foreman II Electrician Larry Torres rushed to Scharton's home to print the documents necessary to perform the switching. On the way back, they noticed one of the power poles next to the road was on fire.

"This thing was about to fall," Torres said. "I stepped on the gas to get through, grabbed the switching and started working our way back. When we got back to that pole, it was laying in the road. We had just missed it landing on us."

Communications needed to be reestablished with the substations to give dispatchers control back over the system.

"I was on leave when I got a call saying they needed me in Redding," said Foreman III Electronic Integrated Systems Mechanic Leader Daryl Rictor. "We got through all the National Guard fire checkpoints to Keswick Substation. When we got there, we saw a lot of alarms and started working right away."

Rictor and two other technicians worked to get three substations back online. They arrived on the scene, analyzed what needed to be done and worked through the night and weekend to get the systems restored. Dispatchers were then finally able to take control.

"We go through the annual exercises, but during the real issue your adrenaline is pumping a lot more," Rictor said. "It was very interesting and surreal, and sad at the same time."

By July 27, WAPA had 15 transmission lines, six substations and 13 Bureau of Reclamation hydroelectric units out of service with fire actively burning in and around the infrastructure.

The destructive power of the Carr Fire forced the evacuations of more than 38,000 residents.

CITY CONNECTIONS

WAPA line crews worked closely with the Bureau of Reclamation to ensure generating units were online and providing power to keep Trinity County energized. WAPA has a radial feed for Trinity County, and if the fire destroyed the 230-kV Trinity-to-Carr line that feeds Trinity Substation, all of Trinity County would lose power. Reclamation worked with WAPA on islanding the 60-kV line to protect Trinity's load, allowing the power to flow while WAPA's lines were affected by the blaze.

"Several of the power restorations have depended on black-starting Trinity Powerplant," said Trinity Public Utilities District General Manager Paul Hauser. "This had never been done prior to this emergency."

WAPA moved a diesel portable generator from Maxwell Substation, which was four hours away, to Weaverville to provide station service to Trinity. While bringing the plant back online, Trinity PUD had to work directly with Reclamation over the phone to add load one half-megawatt at a time to avoid tripping the plant off.

"Having never done this before, it was much more sensitive than we imagined it would be," Hauser said. "But we ran through that routine half a dozen times now and we've gotten pretty good at it."

The fires and various events have caused a total of eight system-wide outages for Trinity PUD, but Hauser explained that residents were incredibly supportive of the efforts to restore power.

"Without the folks at WAPA, I could not imagine what it would be like going through this," Hauser said. "This is just a tremendous partnership."

Scenes of devastation such as this one are now common in the aftermath of the massive Carr Fire.

City of Redding Electric faced its own difficulties, with transmission lines failing faster than the utility could provide generation. The utility contended with overloading, rolling blackouts, low gas pressure preventing them from running generators, and complications from the abundant smoke.

"In the heat of this, we were down to one radial feed from WAPA. We were hanging by a thread," said Redding Electric Utility Director Daniel Beans. "We were essentially islanded. We had to produce all of our power."

Beans explained that City of Redding Electric employees did everything they could to keep the lights on, and WAPA played a big part in that effort. Although so much was going wrong, they kept service going in partnership with WAPA. He used one word to describe the situation: astounding.

Beans said that the transmission lines' rights of way and vegetation management by City of Redding Electric and WAPA played a large part in slowing the fire down, giving residents more time to evacuate.

WAPA power system dispatcher Ray Zeller returns to the remains of his home, which was destroyed in the massive Carr Fire.

TOO CLOSE TO HOME

Many of the Carr Fire responders across agencies have been affected directly by the tragedy. Foreman III Lineman Brian Adams was one of several linemen on the Redding crew to have been evacuated.

"I have to give it to my employees," Adams said. "Even though a lot of them and their families are evacuated, they still show up every day for work. They know the importance of getting this line back up for our customers."

"When you lose your home, you lose everything," said Power System Dispatcher Ray Zeller, who lost his house to the fire. "We had a little time to get some things out. We got some pictures and some family heirlooms, but we ended up losing a lot more important things."

The Zellers' friends, family and coworkers stepped up to help. Dispatchers in the Folsom office collected money for the first day he returned to work. He explained that in Folsom, coworkers take care of one another like a family.

"Volunteers have come out to help us sift through the ash to find some of my wife's jewelry and other things we had in our home," Zeller said. "The community has stepped forward and everyone is trying to do a little bit to help all of us that have lost our homes."

A destroyed tower outside Redding, California.

COMING TOGETHER

As of Aug. 20, the Carr Fire had affected 229,651 acres. It had destroyed more than 1,000 homes and damaged nearly 300 more. Fortunately, though, it was 91% contained by that date. After a long, difficult fight, the end was finally near.

"I have to take my hat off to the crews out in the field," Howard said.

"This experience has confirmed to me once again that we have the best people in all of government, and we are committed always to serving like our lights depend on it." Administrator and CEO Mark A. Gabriel echoed Howard's sentiment. "We cannot predict tragedies such as this one," he says, "but time and again our dedicated crews have proven they will rise to meet them. I could not possibly be more proud of the selflessness and devotion demonstrated by WAPA employees in the most difficult of situations. Their incredible response here and elsewhere has not gone unrecognized."

Signs of support for utility, firefighters and first responders are seen throughout the city.

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JEAN MARIE GEORGE
Scientific Director PhD

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Research Manager

INSULATORS UNDER FIRE

What can be done differently and what needs to be changed in the selection of insulators?

Wildfires can have multiple causes. Overhead lines often just happen to be on the path of a fire, and in this case it is critical to understand what may happen to the line and its components. Besides the risk of having phase ground faults resulting from intense arcing activity in the smoke and heat cloud, resilience is paramount and the amount of damage to lines is a direct consequence of line designs. Distribution overhead lines are obviously much closer to fires than transmission lines and therefore suffer much more of heat damage. Wood poles are clearly identified as a weak link under such circumstances but insulators can also become critical. Even for transmission lines the heat impact can be substantial but not necessarily immediately visible in the short term. Some specific physical characteristics of overhead line insulators need to be clearly identified and taken into consideration either to evaluate the risk of having a line drop during the fire or years later as a result of a weakening of the insulators which survived the fire in the first place.

Another aspect of this problem is to review insulator design features assessing the risk of insulators to be a threat triggering fires on a normal day. Insulator failures can lead to line drops and subsequently trigger fires and catastrophic situations. This is true for either distribution or transmission lines. Hardening the grid means finding more robust line designs and insulators.

In the aftermath of the Californian fires, this contribution is intended to help evaluate what can be done differently and what needs to be changed in the selection of insulators.

INTRODUCTION

The question of insulators under fire conditions can be addressed from many different directions. On one hand it is interesting to understand which parameters can be degraded or become critically deteriorated if an insulator is submitted to heat and fire, which itself depends on exposure time and of course type and design of insulator.

On the other hand, and this is perhaps more tricky, one should consider the potential collateral damage to an insulator, not necessarily directly under a fire, but close enough to suffer of heat. In this case, and besides the direct risk of failure related to heat, it is of paramount importance to be able to evaluate the possible weakness induced in the insulator which could be the root cause for a line drop and a fire later on. Some considerations will be given also to line design, especially for distribution poles and insulation methods. This paper will therefore address the following aspects:

a. Identification of heat and fire sensitivity of the typical insulator designs used on overhead distribution and transmission lines

b. Degradation of insulator performances when subjected to heat while still apparently operational after a fire

c. Suggestion for grid hardening from an insulator point of view in distribution and transmission

Figure 1: Typical designs of composite insulators

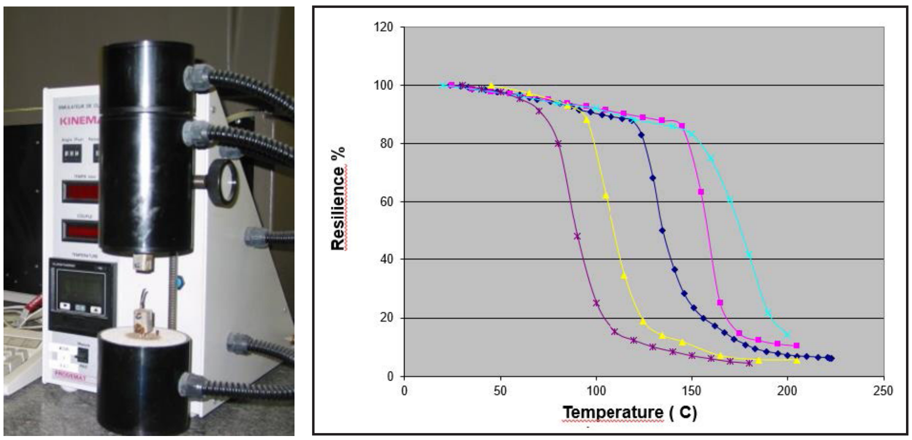

Figure 2: Torsional strength test showing the loss of resilience at the Tg set point

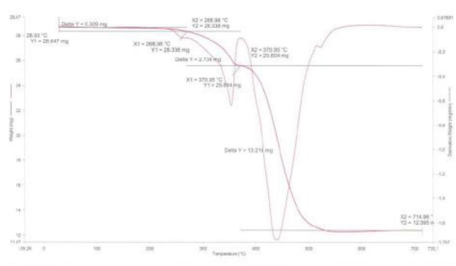

Figure 3: TGA curve of silicone

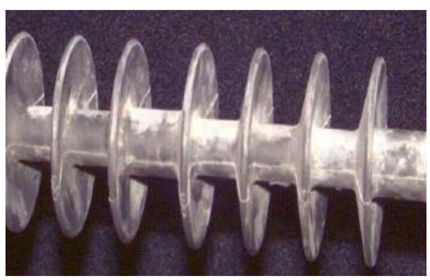

Figure 4: White powderish aspect of heated silicone

1. REVIEW OF KEY DESIGN FEATURES OF OVERHEAD LINE INSULATORS WITH RESPECT TO THERMAL RESILIENCE

While temperatures can fluctuate dramatically during a fire it is difficult to know precisely the direct temperature in contact with a fire as well as the duration of the event. This section will therefore look into the key properties impacted by heat for polymer and ceramic insulators based on their design features.

a. **Composite insulators** exist in a large variety of designs (figure 1) and are made of organic materials which therefore have temperature limitations. The diversity of possible designs and materials used to make these insulators dramatically increases the complexity of their long term evaluation. There are three main design features to look into as described hereafter and checked in detail in section 2.

- The fiberglass rod is made of resin reinforced by glass fibers. Resins used for insulators can be polyester, vinlyester or epoxy. The strongest and best performers are made with epoxy resins. Resins are defined by a thermal set point called Tg (softening point) above which the resin is progressively losing its mechanical strength. This characteristic can be established by DSC (Differential Scanning Calorimetry). The mechanical weakening of the interface between the glass fibers and the resin in the rod (key for mechanical strength) can also be measured through a torsional strength test on a small slice cut from a rod. Figure 2 shows the test equipment and the results obtained from commercially available fiberglass rods used in the manufacturing of composite insulators. The mechanical resilience of the samples is decreasing with temperature. The sensitivity to heat is directly the result of the chemistry of the resin itself.
- The housing, typically silicone rubber, is a material designed to chalk and not burn (in most cases). Silicone rubbers exist in numerous chemistries but the most popular silicone compounds contain a fire retardant filler such as ATH (Alumina TriHydrate). For erosion and electric tracking resistance the amount of this additive in the silicone is usually above 45% and can be measured by Thermo Gravimetric Analyses (TGA). Figure 3 shows the graph obtained by TGA of a silicone rubber. The decrease in weight during the test is typical of the loss of water from the ATH molecule during heating. Normally ATH is decomposing around 250C (482 F). Silicone rubber subjected to excessive heat will display a white powderish surface as shown in figure 4.
- The end fittings of modern composite insulators are normally crimped by compression (like cable joints). The particularity of this process is to ensure enough pressure through the end fitting (made of steel, cast iron or alu-

Figure 5: Crimping process and internal stress distribution on a fiberglass rod/ftting connection

minum) to ensure a sufficient grip on the fiberglass rod which is not a metal. To avoid a thermal relaxation during the molding to the rubber housing onto the core, the end fittings are usually crimped after the housing is in place. Figure 5 shows this process and the compressive stress distribution into the rod which must be preserved from any damage such as cracks during the crimping (this is still a sensitive operation despite the use of compression sensors intended to control the process)

b. **Porcelain insulators**, besides their end fittings (cap in cast iron and pin made of forged steel) are made of mineral materials. The cement is either alumina cement, or (usually) portland cement. The assembly is usually not made with pure cement but with a mortar containing silica (sand) and other minerals. The stability of the cement with temperature is high and the resilience of such an assembly is mostly driven by the design of the head and the coupling of the thermal expansion coefficients between the end fittings, the cement and the porcelain body. Figure 6 shows the linear expansion coefficients of typical porcelain insulator components. The particularity of the porcelain body is related to its heterogeneous structure of porcelain which contains crystals having themselves different properties. This aspect of porcelain is what leads to the inherent ageing of the dielectric with possible punctures of internal crack propagation (figure 7). This parameter needs to be taken into consideration for resilience performance under heat (see section 2).

c. **Toughened glass insulators** are assembled like porcelain insulators with cement (usually alumina cement but sometimes portland) but do not have any microstructure and the coupling of the thermal expansion factors is more homogeneous as seen in figure 6. The glass is toughened for strength purposes and the prestresses built in the bulk thickness of the dielectric are a balance of compressive and extension forces (figure 8). The mechanical shield represented by this toughening operation makes glass immune to any crack propagation or puncture. A toughened glass insulator will either be intact of shatters if any excessive adverse stress is applied. In this case the glass insulator becomes a so called "stub" (figure 9) which electro me-

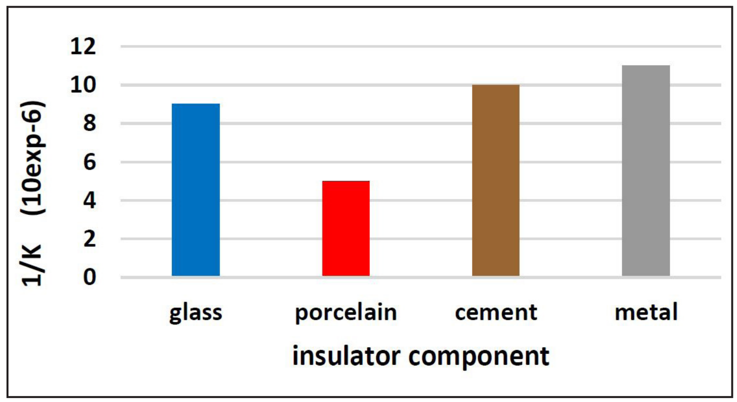

Figure 6: Linear expansion factor coefficient of glass and porcelain insulators and their components

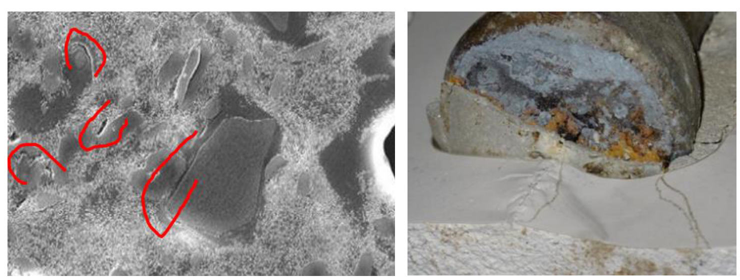

Figure 7: Microstructure of porcelain and internal microcracks leading to punctures of the dielectric

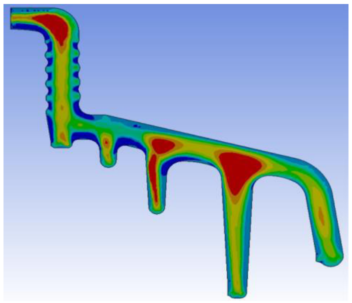

Figure 8: Toughening internal prestresses

Figure 9: Typical aspect of a "stub"

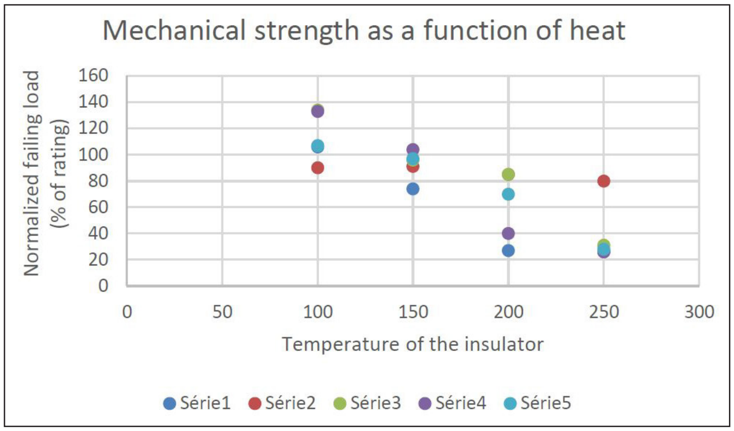

Figure 10: Mechanical resilience of composite insulators at different temperatures (temperature in °C.)

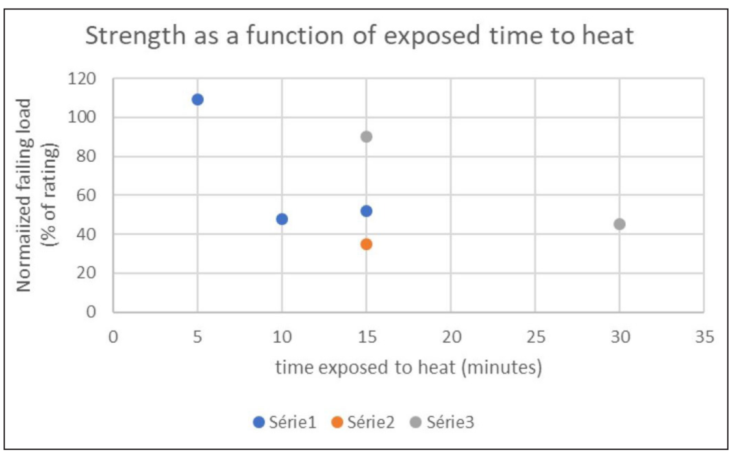

Figure 11: Strength of various composite insulators as a function of time after being exposed to 300°C (572F)

chanical performance remains intact (no internal puncture, and high residual strength).When subjected to heat the glass can suffer of superficial chips or can shatter if exposed to brutal and immediate heat. It is important to understand that the toughening prestress is permanent unless the glass shell is exposed to a permanent temperature of 700°C (1300F) for a duration of 6 hours or more, which will not happen since the insulator will shatter at a temperature of approximately 400F leaving a stub which remains sound. In the next section such properties will be described in detail.

2. RESILIENCE TESTS OF VARIOUS INSULATOR DESIGNS UNDER HEAT

a. **Polymer insulators:** The combination of the crimping compression of the end fitting over the fiberglass rod itself sensitive to heat (see figure 2) can be feared as a weak point under heat conditions. In order to establish this property tests were performed with various composite insulators (mostly distribution dead ends). Samples were introduced in an oven for 3 hours and pull tested while still hot until failure occurs. Figure 10 shows the normalized results with a reference at 100% corresponding to their ratings. It appears clearly that the strength goes rapidly below the everyday load design of the line.

An additional test was performed with insulators exposed at 300°C (572F) for short durations. Figure 11 shows again normalized strength with reference to the rating of the insulators. It appears that very quickly (less than 30 minutes the strength goes down to 30% to 40% with serious risks of line drop whenever such loads are encountered.

In most cases the rod slips outs of the fitting as shown in figure 12. It can be interesting to note that the best values (but still very weak results are obtained with forged steel fittings and fiberglass rods which have a very high Tg. (Tg > 180°C, 360F)

This test sequence shows a major risk for having a line drop with polymers exposed at high temperatures. At some point they will not sustain everyday normal loads.

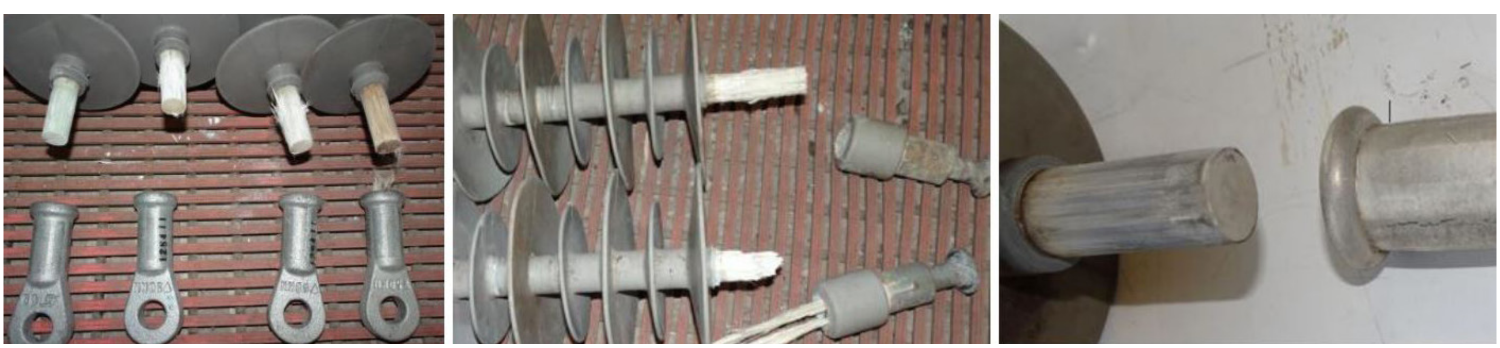

Figure 12: Typical aspect of the tested units after the mechanical pull test

b. **Porcelain insulators** underwent a similar test with various insulators placed in a furnace for 3h before being pull tested. Given the risk for porcelain to puncture the relevant test in this case is the ANSI M&E test. A number of units failed with cracks either visible or not. As expected, the difference in expansion between components favors this type of failure. However, and while most units survived their mechanical stress with no separation below the rating, most failed electrically from internal punctures not visible from the outside. This demonstrate that once porcelain insulators have been directly or not in contact with high heat there is a major risk for having hidden defective units on a power line.Figure 13 shows the M&E test results and figure 14 the typical physical aspects of the units after test.

It can be noted that while these results show only an M&E failure, old porcelain insulators carrying already deeper and older cracks internally might lead to a string separation which could adversely under such conditions drop a conductor. (simulation in a thermo mechanical test as shown in figure 15). The cement itself (in fact a mortar) shows no specific heat sensitivity. The dehydratation of the cement could generate some slight crumbling but by design the head works under compression leading to a wedge effect. The tested units were all assembled with Portland cement. The separation of the head is strictly the result of the porcelain body cracking in two pieces.

c. **Toughened glass insulators** were tested with the same procedure. The insulators were pre heated in an oven for a duration of 3h but in this case up to 400°C (752F) since, as shown in figure 16 not much was happening. (Toughened glass does not puncture, and as per ANSI, the test is a mechanical test only, no use for an M&E combined given the fact that toughened glass does not generate cracks but shatters). The test was carried out to the maximum temperature of the oven.

In a few cases the glass shattered before the mechanical separation, but in all the other cases the failure mode was a breakage of one of the fitting, usually the pin as shown in figure 17. It is also interesting to note that, while all the results seem very stable the lowest performer was assembled with Portland cement. Without enough elements to come to any conclusion on the influence of cement, it can be interesting to remember that Alumina cement is a better thermal refractory than Portland.

Since toughened glass can shatter, an additional test was carried out on stubs which were preheated as well and pull tested. Figure 18 shows the normalized test results. All the failure modes were identical with a pin pull out taking out

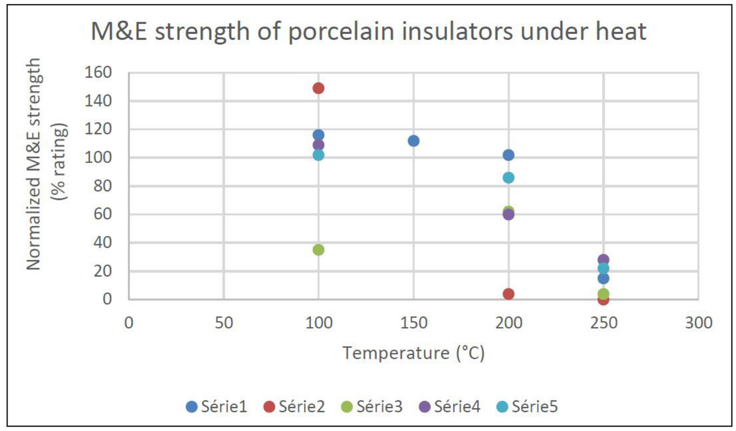

Figure 13: M&E test results of porcelain insulators subjected to heat prior to pull testing

Figure 14: Overall aspect of the insulators after the test

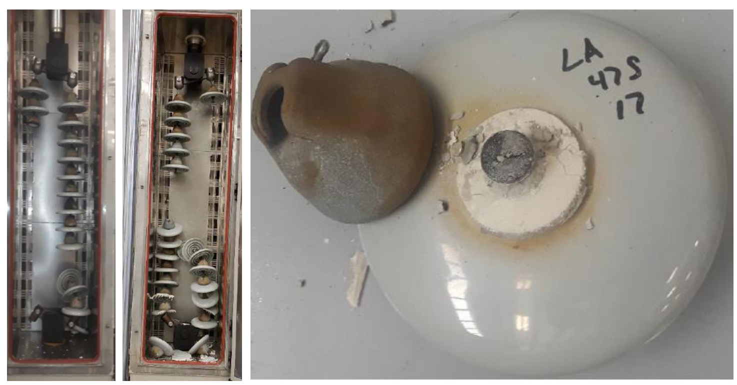

Figure 15: String separation during a thermo mechanical test performed on weak porcelain units containing already cracks from years of aging

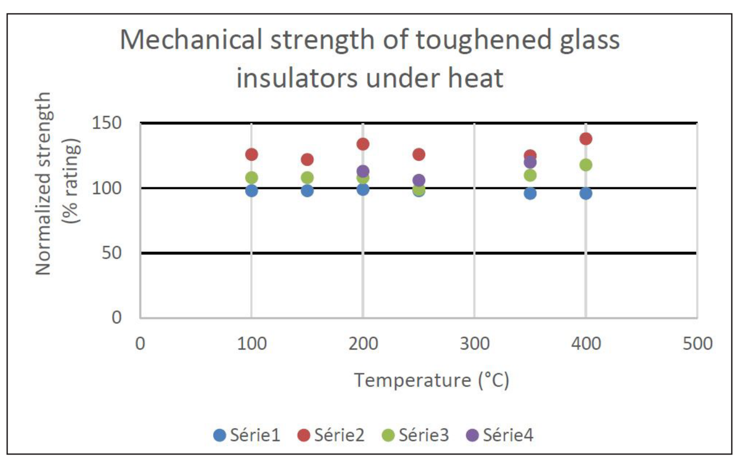

Figure 16: Mechanical test results on toughened glass insulators (normalized to the rating)

Figure 17: Typical aspect of the glass units after the test

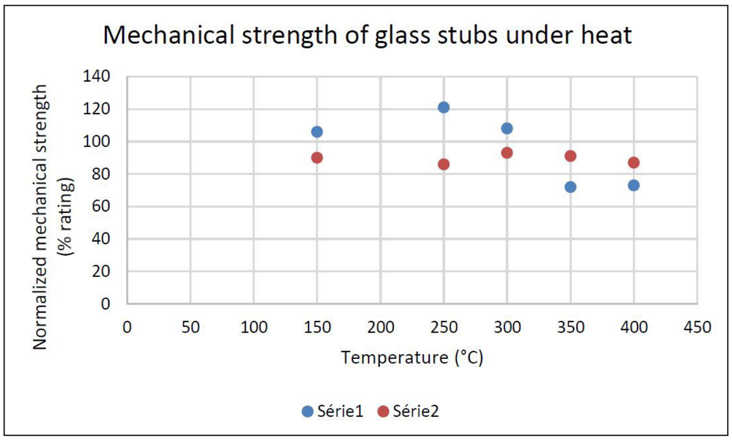

Figure 18: Normalized mechanical strength of stubs preheated and pull tested at different temperatures

Figure 19: Overall aspect of the stubs after the mechanical test under heat conditions

the cement with the pin from the inside of the head of the insulator as shown in figure 19. All the values remain above 65% of their initial rating, which is the requirement in ANSI for new insulators tested for their residual strength.

3. AFTER FIRE CONSIDERATIONS

In the previous section we analyzed the risk factor for having a line drop or a major accident related to an insulator during a fire. At this stage we know that polymer insulator most likely can snap and drop a conductor. Porcelain, less likely unless the insulators are old. Glass present no risk either intact or broken (stub). The next question is related to the management of the lines from a maintenance aspect after the fire is over. Is there a risk to leave some insulators which were previously near a fire source and subjected to heat?

Porcelain insulators, as shown earlier will not recover from their degradation and if punctured they will be a possible liability for the future life of the line. Glass insulators are almost totally immune, and the only change might be a few units shattered. This is easy to spot, and does not constitute a risk (stubs keep their mechanical strength and are not electrically punctured).

Composite insulators are different. Two questions are open:

- What is the mechanical strength of a polymer which survived the heat event after it cooled off?
- What is the condition of the silicone housing and are there risks to leave them on the line?

a. Mechanical strength of polymers after cooling

One question left after investigating the behaviour of polymers under fire is to know their residual strength once they cooled off. Tests were perfomed on insulators which had previously been subjected to heat maintained for 2h at 300°C (572F). The results are shown in figure 20 with a strength between 20% and 30% of the rating. This result can be compared wih the results on broken glass (stubs) largely above the standard requirement for residual strength.

b. Housing permanent degradation and associated risks

In section 1 we described the chemical mechanism of protection offered by ATH in silicone compounds. The main target is not to be a fire retardant, even if the chemical used is classified as such. The main attribute of the addition of this filler is to slow down the erosion of the silicone during dry band arcing or pollution related activity. At some point in time the rubber will fail leading to cracks on the core (figure 21). Of course the rubber does not burn, and many compounds used in the overhead line industry are classified HB and V0 in IEC60695, but once cracks appear the insulator is doomed to fail either electrically (internal tracking) or mechanically

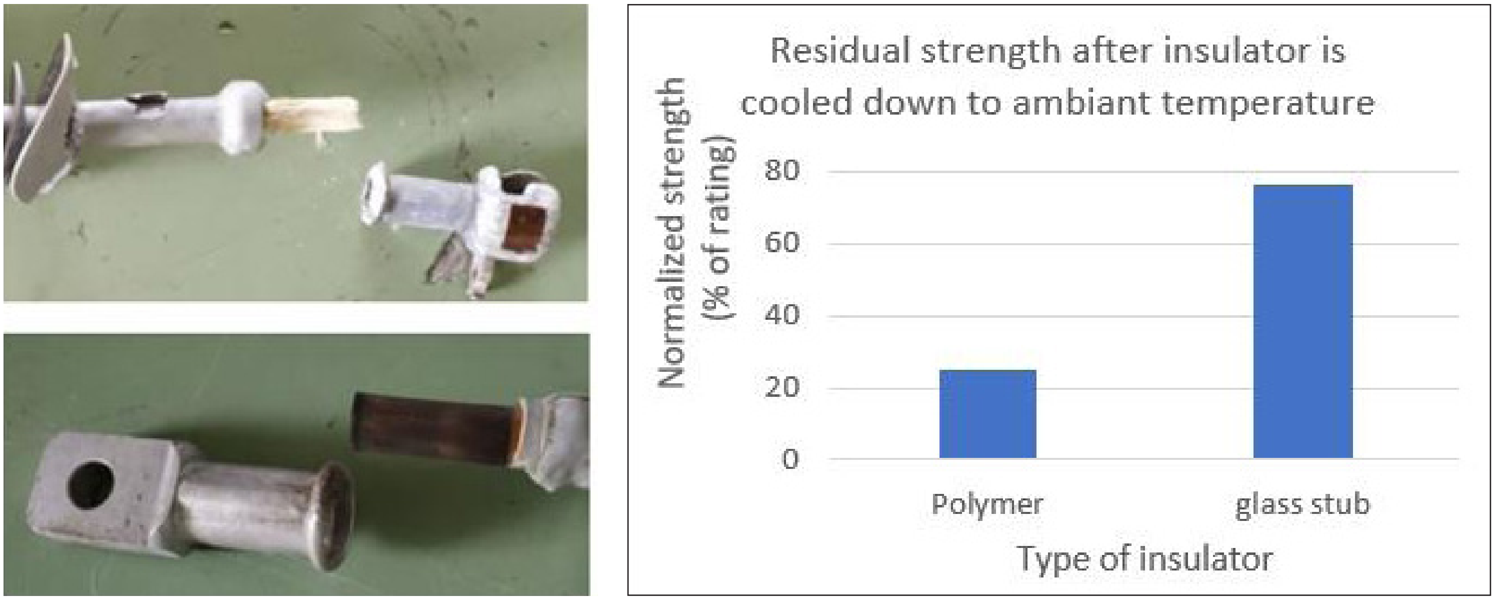

Figure 20: Fitting pull out after the insulators were cooled down after a heat cycle at 300°C and comparison with results on glass stubs tested in the same conditions

Figure 21: Cracks in silicone housing left after being subjected to heat for a few hours

(brittle fracture,decay fracture...). It is important also to consider the existence of sulfuric acid and other fire related acids which will destroy progressively the core of the insulator. In most cases these degradations are not easy to spot visually as shown in several cases presented in figure 21.

4.POSSIBLE RECOMMENDATIONS FOR GRID HARDENING

Starting from a basic concept that any type of equipment capable to burn should be banned, wood poles should no longer be used especially on distribution lines; replacing those with steel, or concrete poles would be the most effective choice

Strengthening the pole brings the weak link on the insulators especially if they are pin or post types working under cantilever which limits are driven by stubs, bolts and the intrinsic strength of the pin or post itself.

It appears also that a tensile load is easier to secure consistently than bending loads. Therefore a line design where deadends are strictly made of glass with tangent structures made of concrete with suspension glass cap and pins would offer the best resilience. The grid hardening would result from insulators immune to heat and a mechanical structure where heavy duty strings working systematically in tension with ratings which could go up to 20kips or 30 kips or more are being used. Figure 22 gives examples of such systems using glass insulators for their strong resilience to adverse environments such as those encountered in fire driven environments or areas where conductors ar not allowed to touch ground under any circumstances.

Figure 22: examples of resilient distribution lines using concrete poles and toughened glass insulators in suspension and tension.

CONCLUSION

The findings of this program are pointing out typical weaknesses and strengths of the different insulator designs:

- Composite insulators mechanical strength drops quickly leading to major risks of line drop under heat or signficant reduction of strength after the fire is over
- The degradation of the housing of composite insulators uder heat and fire can breach the inegrity of the housing leading to moisture and acid ingress. Future failures and line drops after the fire is out could occur if these small cracks are not spotted and the insulators replaced.
- Porcelain insulators would not drop a conductor unless already old and aged in their microstructure. However the large gap between the thermal expansion factors of the components of porcelain insulators will lead to punctures or internal cracks not visible from a visual inspection.
- Toughened glass insulators do not lose their performance.if a thermal shock breaks the glass the stub left remains mechanically safe even at hgh temperature. Visual inspection is obvious after the fire with no urgency to be replaced.

The grid hardening can benefit of these results with the following recommendations:

- Use glass especially for deadends but also for tangent structures
- Modify the design of the distribution lines design replacing pin and post types by suspension strings working only in tension and installed on concrete poles.
- Transmission lines should use glass only.

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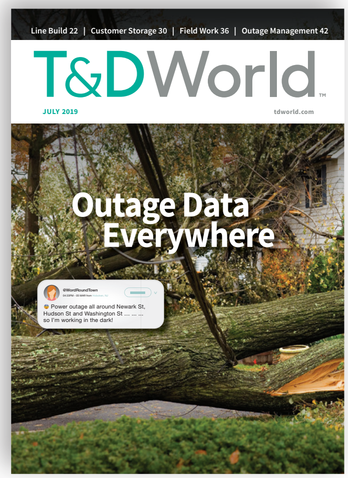

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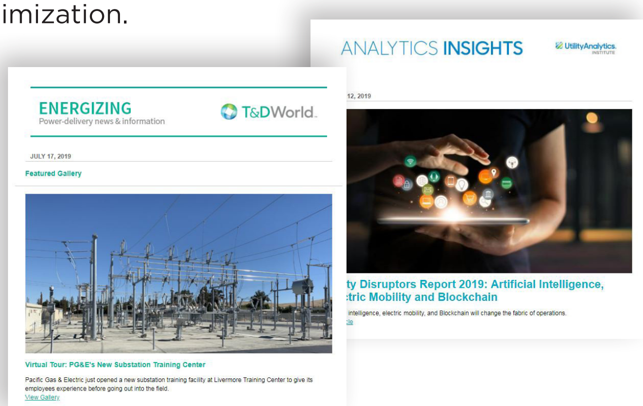

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