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U.S. Senate Energy and Natural Resources

"Impacts of Wildfire on Electric Grid Reliability"

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Introduction

Chairwoman Murkowski, Ranking Member Manchin, and distinguished members of the Committee, thank you for the opportunity to testify before you today on this hearing to examine the impacts of wildfire on electric grid reliability and efforts to mitigate wildfire risk and increase grid resiliency.

My name is B. Don Russell and I am a Distinguished Professor and hold the Engineering Research Chair in Texas A&M University's Department of Electric and Computer Engineering, Director of Texas A&M's Power System Automation Laboratory, and Principal Investigator of the Texas Power-line Caused Wildfire Mitigation Project. I will offer my personal perspective and insights on this important topic based on my over 45 years working on electric power transmission and distribution including power system protection, safety, reliability, and security. As discussed below, years of research and field demonstrations have shown that certain events which can cause ignition of wildfires can often be detected, identified, found, and fixed before catastrophic failure results in a line down or arcing condition that may cause a wildfire.

The electric power system in the United States is the largest built infrastructure on our planet, providing millions of citizens the highest electric service reliability of any country, with the average customer receiving electric power 99.98% of the time.

The typical utility responsible for distributing electricity to customers has high voltage transmission lines - the big wires on the big towers, and low voltage distribution circuits - the lines on wooden poles along your street near your house. A neighborhood electric substation receives power from overhead high voltage transmission lines, transforms the high voltage to a lower voltage, and then distributes that low voltage power to customers. These low voltage circuits may serve several hundred rural customers or several thousand urban customers. About 10% of all power lines are transmission circuits that are rigorously built on large steel towers with heavy conductors and cleared right-of-way. By contrast, 90% of utility power-lines are lower voltage lines that run along city streets or along rural roads. Because most power-lines are lower voltage distribution circuits and because transmission lines at high voltage must be built with a far more rigorous construction, it is the numerous distribution circuits that most often experience faults, tear downs, or failures of components.

An electric utility may have tens of thousands of miles of electrical conductor in the air and cable under the ground, a system that is supported by millions of components including poles, insulators, clamps, connectors, switches, transformers, and capacitors. Power components are designed to last for many decades, most without requiring scheduled maintenance or inspection. But, sooner or later, all manmade systems and devices fail! On any given day, on any given electric circuit, a connector or clamp may fail causing an outage, dropping a line to the ground, and on rare occasions starting a fire. The failure rate of components is extremely low, but the consequences of a single failure can be devastating if a major fire is ignited or a person is electrocuted.

A distribution circuit may go years without a single failure or may experience multiple failures in a short period of time. Failures cannot be predicted statistically because components that are designed to last 40 years in service very rarely fail. Additionally, most outages and damage to circuits are caused by external forces such as high winds, ice storms, and trees tearing down lines. Failures on distribution circuits are rare, but power-lines are the cause of some wildfires.

Work by the Texas A&M Forest Service found that in a three-year study period, over 4,000 wildfires were caused by power-lines in Texas. While many of these fires were small, some had devastating economic effects and caused loss of life. A fire in an urban area that cannot spread may have little consequence, but often power-line caused fires occur in rural areas and therefore go unnoticed, spreading in high wind conditions until they are uncontrollable causing significant damage.

Following the devastating 2011 wildfires in Texas, some of which were caused by power distribution circuits, the legislature in the state of Texas authorized the Texas Power-line Caused Wildfire Mitigation Project to study the causes and possible solutions to wildfires. Principal investigators Dr. B. Don Russell and Research Professor Carl Benner of the Power System Automation Laboratory at Texas A&M University began a four-year study with seven participating utilities. During this study, 60 electrical circuits were instrumented to capture all naturally occurring failures of devices and mis-operations of equipment that could affect power system reliability or potentially be fire ignition causes.

Outside of Texas, in response to the increased number and intensity of wildfires, utilities in high fire risk areas have proposed numerous physical infrastructure upgrades and operating changes. These include the following:

- Harden physical structures, including better poles, covered wire, non-expulsion fuses, and increased conductor spacing.
- Increase vegetation inspection, pruning, and clearing.
- Further explore and exploit smart meter capabilities.
- Expand deployments of weather stations and high-definition cameras.
- Use monitored reclosers, sensitive protection settings, and fallen wire detection.

In general, the concept is to harden distribution circuits so that they fail less often and exhibit more rigor in response to adverse weather conditions such as high winds. Increasing the strength of circuit lines and poles and increasing inspection and maintenance will have a positive effect. However, research has shown that many fires in recent years would not have been prevented by these upgrades.

What is notable about the above list of upgrades is that it emphasizes stronger structures and better response to high current faults as they occur, but none of these upgrades address the issue of circuit health monitoring, fault prediction, or real-time diagnostics to identify degrading electrical conditions and device failures. Stronger circuits still leave utilities in a reactive mode – wait until the catastrophic failure occurs, then react. Texas A&M research has found an effective, proactive approach to device failures and mis-operations – find and fix before catastrophic failure!

Electric Utility State of the Art

Most utilities today use state-of-the-art protection and monitoring systems to operate electric distribution circuits. It is common to find modern, digital protection devices (i.e. protective relays) that can rapidly detect the presence of a high current fault and de-energize the affected portion of the circuit. Sophisticated systems have been developed that allow for the automatic sectionalizing of circuits to reconnect as many customers as possible following the isolation of a faulted section. Smart meters assist in identifying outage areas. Supervisory control and data acquisition systems (i.e. SCADA) provide operators important information such as which protective devices have operated.

All the above systems have a common operating feature. Today protection devices and fault monitoring systems are “reactive” in nature. They activate, operate, or document the presence of a high current fault on a distribution circuit. The systems available to utilities and commonly used today are not predictive or diagnostic about the health of the power system. They do not “see” developing failure mechanisms; they react to the ultimate catastrophic failure.

Figure 1 graphically shows the current operating paradigm for electric utilities. Utility operators must assume that an electric circuit that is successfully delivering energy to customers is “normal and healthy” until it is known that an outage or a major electrical fault has occurred. In other words, the system is by definition “normal” until it is known to be “broken.” Most often, a circuit that has faulted is only known to operators when customers call to report “lights out.”

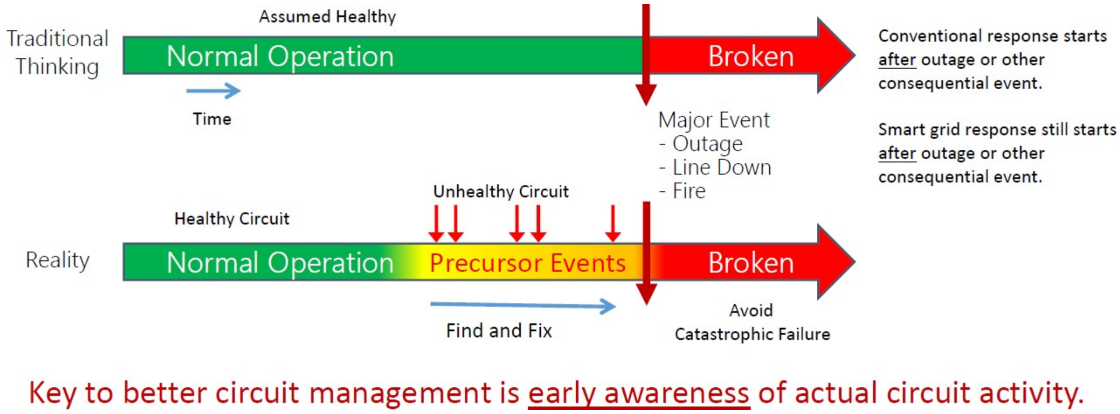


Figure 1: Distribution Circuit Operating Paradigms

Our research has shown that the current operating assumptions of utilities is incorrect. Many of the failures on a distribution circuit do not occur precipitously, but rather have a relatively long period of degradation leading up to catastrophic failure. The reality is that circuits are healthy until the initial, incipient stages of a failing device begins. The initial unhealthy period is often characterized by very subtle, low magnitude electrical signals that can occur with many precursor events leading up to final failure. If during this incipient failure period the failing device or failing component can be found, repaired, or replaced, then catastrophic circuit failure can be avoided. Clearly, this means that an outage, a downed line, or a fire can be prevented.

Power-line Caused Fires

To properly understand power-line caused fires, we must understand the common causes of electric circuit wildfire ignition. It should be first noted that if we take all causes of wildfires into consideration, electric power circuits are not among the most common causes. Yet certain conditions and events on electric circuits do represent possible fire ignition mechanisms. These include the following.

- Conductors slapping together with arcing, resulting in the emission of heated or combusting metal particles
- Failing devices or apparatus in a melting or arcing condition
- Downed conductors caused by mechanical or electrical failures
- Arcing conditions and combustion because of intrusion of vegetation or other foreign objects.

The Power System Automation Laboratory at Texas A&M conducted a 15-year longitudinal study of electric circuit failure mechanisms. The study, involving over 100 circuits on a dozen utilities, has captured high fidelity recordings, documenting hundreds of thousands of circuit events. This largest database of its kind coupled with the findings of the Texas wildfire mitigation study has enabled researchers to study how, why, and under what conditions circuits fail and when these failures cause fires. A few examples related to wildfire ignition follow; the cases cited are composite simplifications taken from naturally occurring events recorded on operating utility circuits.

Case 1: Arcing downed conductor
A downed line can be a competent ignition mechanism as shown in the arcing downed conductor in Figure 2. Lines can fall due to device failures such as component overheating and arcing connections or due to trees tearing lines down.

Figure 2: Downed line arcing Figure 3: Arcing clamp

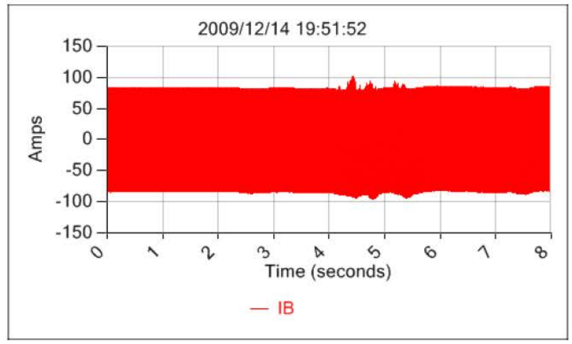
An arcing clamp can cause erosion of a conductor, causing it to be severed. Figure 3 shows the damage in the jaws of a clamp that can erode a conductor causing it to break, fall, and arc to ground. A failing clamp can be in an incipient failure mode for hours, days or even weeks. The failure mechanism is often gradual, progressive, and accelerating. The eroding and melting clamp is most often undetectable and unidentifiable by traditional protection and monitoring systems used today by utilities.

Identifying and replacing the failing clamp before a high-risk day can prevent a fallen conductor which can start a fire.

Case 2: Failing devices – falling melted metal
Melted metal can fall from the jaws of a clamp or switch due to resistive heating and/or arcing, as seen in Figure 3. This burning or heated metal represents a competent ignition mechanism. What is not known by a utility is that the clamp failure mechanism may have existed for weeks without any notice to operators.

In its incipient stage, a few seconds of arcing may be followed by hours of quiescence, with no abnormal electrical behavior. The deteriorating condition is likely undetectable by even ground crew visual inspection, except possibly during active flareup. The electrical waveform presented in Figure 4 reveals the very subtle electrical signals from a failing clamp. This signal cannot be detected by protection equipment commonly used today by utilities. Research has now shown that this signature can be detected by advanced waveform analytics.

Clamp heating/melting



Electrical failure signature

Figure 4: Failing line clamp electrical signature

Case 3: Conductors clashing and emitting ignition particles

The arcing caused by contact between two phase conductors or phase to neutral can cause a fire if significant metal is ejected in a burning or sustained heated condition. Figure 5 shows heated metal particles showered from an extreme example of an arcing conductor.

What is not often known is that similar conductor clash events may have occurred multiple times in the same pole span, often months or even years apart. After a fire, investigators may see arc damaged lines but cannot know the full context that the damage they see was created cumulatively by many events, which, on previous occasions, did not start a fire. Many conductor clash events do not even cause an outage.

Figure 5 – Incandescent particles emitted from an arcing electric conductor.

Figure 6 documents an actual utility event sequence that was conductors clashing and arcing five times in four years – same fault, same location. The root cause of this fault was never identified by the utility even with inspections. Texas A&M researchers were conducting a blind test of waveform diagnostic analytics and showed that the very first fault was detectible, identifiable, and could be found and fixed. Repairs made after the first occurrence would have prevented four subsequent faults including the loss of power to hundreds of customers on Christmas day.

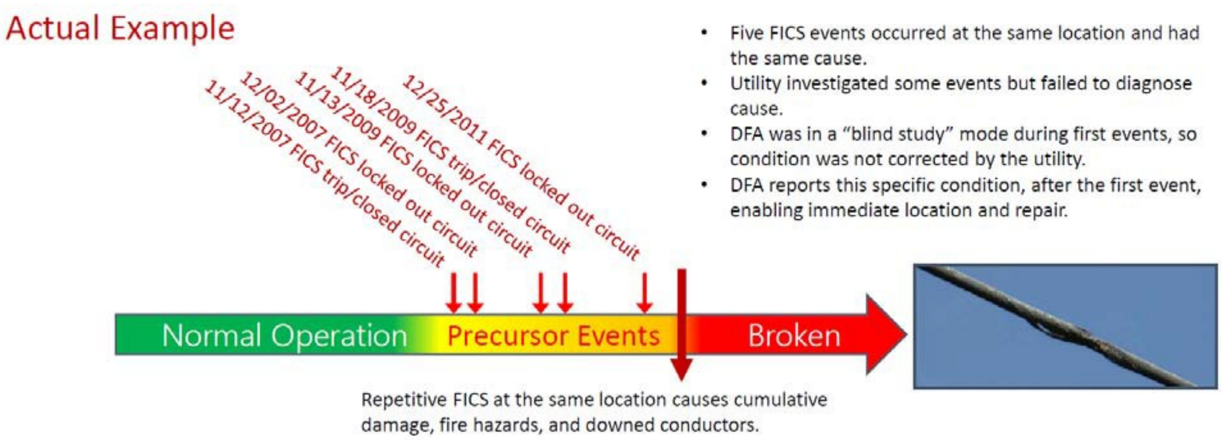


Figure 6: Repetitive Conductor Slap

Common Threads

What do these three failure mechanisms have in common.

- All of these "failure" mechanisms may exist for days, weeks, or months before fire ignition occurs!

- None of these failure mechanisms can be reliably detected, identified, or found by commonly used protection, monitoring, or AMI (e.g. smart meter) systems used today by utilities.

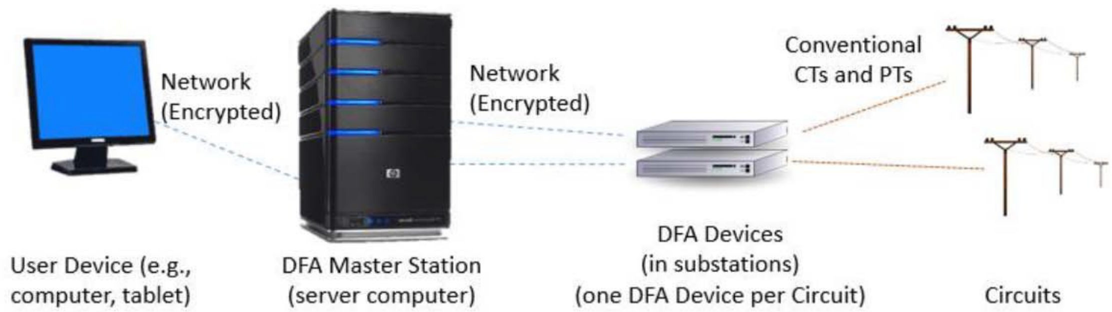
- If operators are informed in real-time about the existence and periodic reoccurrence of any of these ignition mechanisms on a circuit, they can initiate repairs before a red flag day, before fire ignition or an outage occurs.

- Knowledge of active failure conditions on a circuit may justify de-energizing the circuit on high fire risk days to power down an unhealthy circuit.

Operators need to be aware of and act on ignition mechanisms when high fire risk conditions exist, but they must not be overwhelmed by more data that must be studied, interpreted, and evaluated. They do not have the time or the expertise to analyze complex "waveforms." Operators need real-time, actionable information that points to a clear plan of action. Technology now exists to provide operators continuous, real-time situational awareness of circuit health and activity.

Distribution Fault Anticipation Technology

Working in close cooperation with the Electric Power Research Institute and numerous utility companies, Texas A&M Engineering developed Distribution Fault Anticipation (DFA) technology. High-fidelity current and voltage event signatures of naturally occurring device failures and circuit mis-operations were recorded over a 15-year period. Waveform data from more than 1000 circuit-years of monitoring of in-service, medium-voltage distribution circuits at 20+ electric utilities was archived, enabling research into failure detection methods.



Each substation-installed DFA Device monitors an entire circuit 24x7 by analyzing conventional CT and PT waveforms with advanced software and sending results to a central DFA Master Station. Personnel access DFA results via DFA Web.

Figure 7: DFA Monitoring Topology

DFA technology detects circuit events, including early-stage incipient arcing failures of apparatus as well as line failure events that have the potential to ignite wildfires. DFA is practiced with software algorithms – in substation-based hardware that continuously monitors conventional current and voltage sensors (CTs and PTs). No special sensors are needed. Sophisticated proprietary software analyzes those signals to detect normal and abnormal line events, and a central master station server provides event reports to utility personnel. The components of the DFA technology system are illustrated in Figure 5 and described in more detail in references 1-8. Although neither DFA nor any other technology will detect all failures, extensive field demonstration of DFA with multiple utilities has demonstrated that it can provide the sole notice of many events capable of igniting wildfires and events which may affect safe, reliable delivery of electric service.

DFA real-time waveform analytics, developed by Texas A&M Engineering researchers, will enable utilities to better manage circuits to improve reliability, shorten and reduce outages, and prevent certain unsafe conditions such as downed lines and wildfires. Benefits include the following:

- Continuous health monitoring of circuits (24/7/365).
- Advanced waveform analytics for early detection of failing devices.
- Automated diagnostics and device identification – what is breaking or broken?

- Actionable information to operators in real-time to enable condition-based maintenance.

Example 1: A clamp that arced repetitively and failed after a 21-day period, ultimately dropping a line to ground, was detected and identified as it began on the first day. Arcing events toward the end of the 21-day period represent competent fire ignition mechanisms. See Figure 8.

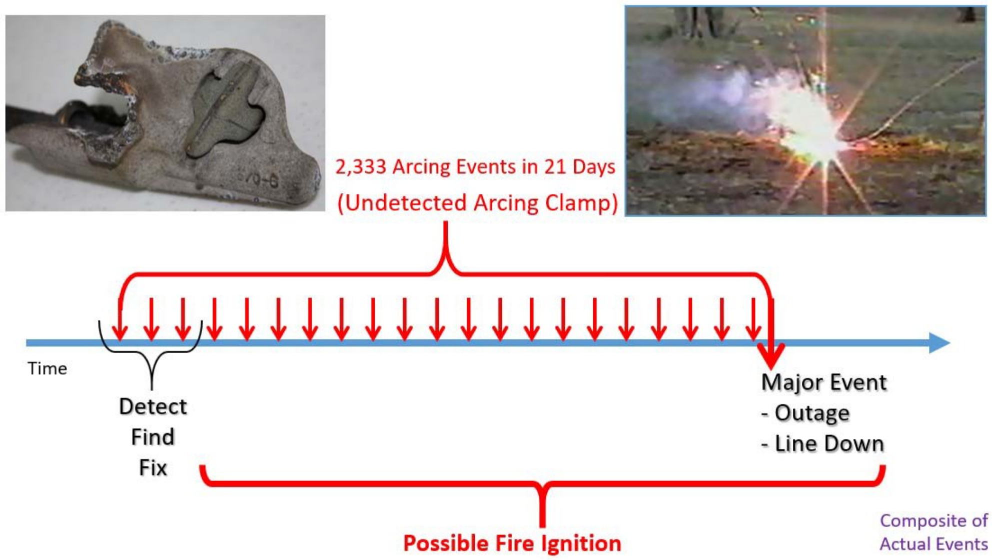


Figure 8: Powerline Clamp Failure

Example 2: A repetitive tree branch intrusion on a circuit caused 17 faults in 24 hours and was detected as it first began. If operational, DFA information would assist in location and repair, avoiding numerous faults and preventing the burn down of a line that will arc to the ground, possibly causing a fire.

Date	Time	Trips
11/02/2004	06:57:47	1
	07:58:33	2
11/03/2004	00:09:06	1
	00:16:48	1
	00:40:38	1
	00:40:53	1
	01:10:51	1
	01:12:37	1
	01:15:30	1
	03:24:47	1
	04:19:39	1
	04:30:36	1
	05:51:01	1
Line burns down →	06:19:45	3
	Total Faults:	**17**

16 hours – no arcing

Figure 9: Repetitive fault from tree limb

Diagnostics and Prevention vs. Waiting to React

Research and years of field demonstrations on 20 utility systems has shown that failing devices and conductor clashing events that can cause ignition of wildfires can often be detected, identified, found, and fixed before catastrophic failure results in a line down or arcing condition that may cause a wildfire. Distribution Fault Anticipation technology is a new tool providing utilities a 24/7 health assessment of circuits. With DFA, utility operators are knowledgeable and informed of circuit conditions and have situational awareness of failing devices and all circuit operations, all day-everyday, but most importantly under high fire risk conditions. This will prevent many power-line caused fires!

Conclusion

Digital technology is broadly used today to improve our quality of life and make us safer. My 1950 Chevrolet had no diagnostic systems. I knew it was broken when it stopped running! Today our cars have a computer under the hood that monitors everything: when the tire pressure is low or the brake system needs work. Automatic warnings that the car is not in perfect health may come days or weeks before a failure actually stops the car.

In medicine, we have come to depend on diagnostics to warn us so that we can find and fix problems long before catastrophic results. Digital/electronic diagnostic systems allow us to find cancer early, when it is much easier to address the condition.

The digital technology applied to cars and medicine has a direct analogy in the electric utility system. It is long overdue that we use advanced digital technologies to diagnose problems in our electric utility system, at the earliest possible stage, so that operators can take actions in real-time to address developing conditions and so that failing devices can be found and fixed before devasting consequences, like fires, result from catastrophic failure.

A rigorous, resilient power system is critical to our economy and way of life. Strengthening and hardening the physical systems is an important tool. But there are insufficient funds and physical resources to rebuild the entire aging infrastructure of our utility system. We can save lives and stop some fires by using advanced digital diagnostic technology that is now available.

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