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Operator Justification for De-energizing Electric Circuits for Wildfire Prevention – Utilization of Objective Electrical Criteria

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SUMMARY

The year 2018 was the deadliest wildfire season in the history of the United States. In California alone, more than 8000 fires burned nearly two million acres, resulting in loss of life and hundreds of millions of dollars in suppression costs. Property losses are measured in the billions of dollars. In response to this growing threat, the California legislature has directed electric utilities to develop plans and implement mitigation means to reduce wildfire risk. One proposal includes intentional public power outages when circuits are operating on "red flag" days in high risk wildfire areas.

The subject paper summarizes the decision process operators use and the information needed to determine when to de-energize circuits. Commonly used circuit monitoring technology does not provide operators with situational awareness on the electrical health of circuits to assist them in knowing if a fire ignition mechanism is ongoing. Distribution Fault Anticipation (DFA) technology, developed by Texas A&M Engineering, is presented as a new tool for operators to help them make defensible decisions to de-energize powerlines to prevent wildfires. Examples of avoided fire ignition mechanisms are given.

KEYWORDS

Wildfire risk mitigation, DFA technology, Powerline-caused wildfires

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De-energize or not de-energize–that is the question!
The holy grail and prime directive of the electric utility industry in the United States can be summed up in the word "Reliability!" Outstanding reliability is the hallmark of the US electric power industry.

The idea that a utility would turn off a properly functioning electric circuit, thereby interrupting service to customers, without an electrical justification, is a highly unusual consideration for utility operators. Yet the extreme consequences of fires have resulted in many changes, or changes under consideration, in utility operations and planning. In response to increasingly dangerous wildfires at the wildland-urban interface, California's state government has asked utilities to consider what has been called the "nuclear option." When environmental conditions are at their worst and fire spread predictions indicate extreme danger, preemptive de-energization of powerlines, known as public safety power shutoffs (PSPS), may in the future be considered acceptable practice.

De-energizing circuits and causing power loss for customers can have serious consequences, sometimes directly affecting the health and welfare of the public. The need for continual electric power delivery has long been incorporated in state tariff rules that govern electric utility operations, because public safety issues are often linked to electric power availability. As an example, the Texas utility tariff rules and state law states:

"Continuous service by a public utility is essential to the life, health, and safety of the public. A person's willful interruption of that service is a public calamity that cannot be endured… The primary duty of a public utility… is to maintain continuous service at all times to protect the safety and health of the public against the danger inherent in the interruption of service." (see Texas Utilities Code Title 4.B. Chapter 186)

Some would argue that the decision to initiate a public power outage places a utility in a "catch 22" situation, between a "rock and a hard place" with only two bad options. If the utility leaves the power on when environmental conditions are deteriorating and wildfire risk is high, and a fire is then ignited by utility assets, the result may be the loss of life or extreme loss of property. Conversely, however, turning off power to customers also may cause loss of life from such events as traffic accidents and health related conditions. Power is needed for emergency communications and to facilitate evacuation efforts during fires. Since most wildfires are <u>not</u> <u>caused</u> by electric power lines, a given instance of turning off power may have been, in retrospect, the exact wrong thing to do!

How do utility operators decide when to de-energize an electric circuit?

What are the qualitative and quantitative factors that must be considered by operators?

Do objective criteria exist that can be used to minimize the risk of a wrong decision?

What post-outage criteria will be applied to demonstrate that a decision was correct?

The Rules of Engagement
Governmental authorities may declare "red flag" days based on extreme conditions, or long-term general conditions may persist, causing high fire risk, even if a red flag day has not been declared. Current plans of most utilities related to preemptive de-energization of a

circuit primarily consider only ground and environmental conditions. These include the following.

- Atmospheric humidity and temperature levels
- Wind speed and direction
- Fuel load – how long since the last burn
- Ground fuel moisture levels

It is notable that the above criteria, which are often used to define "red flag," high fire risk conditions, do not include an "electrical" metric. In other words, the current electrical condition and health of the electric circuits in a geographic area defined to have high fire risk are not considered in the decision tree for deciding whether to execute public-safety power shutoffs (PSPS). Obviously, dry fuel loads in areas with low humidity and high winds represent a tinder box condition with a high probability of rapid fire spread if ignition occurs. But before we decide to de-energize circuits, should we not also consider the condition of the electric circuits and whether they exhibit ongoing, competent ignition mechanisms for the anticipated fire?

To properly understand this issue, we need to revisit 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.

- Conductor slap resulting in 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 object

Even under red flag conditions with adverse environmental and geographic conditions, if none of the above powerline ignition methods are likely or actively occurring, turning off power to a circuit may not be justified. Conversely, if a red flag day has been declared and it is known that any of the above ignition mechanisms have been detected on a specific circuit, an absolute justification for preemptive de-energization may be evident.

Hypothetical Test Case

Assume under red flag warnings, conductors begin arcing over an area of dry fuel with high winds blowing toward populated areas. With knowledge of such a condition, an operator would be fully justified to immediately de-energize a circuit to prevent ignition and avoid a rapidly spreading wildfire. Yet today, operators are "flying blind" concerning the condition of electric circuits, including those in high fire risk areas. Devices on the powerline may be in the process of failing and melting, or low-level arcing may be occurring intermittently, but, because of limitations of monitoring and protection systems in common use today, operators have no knowledge of these conditions.

A new approach is needed to provide in-depth, real-time situational awareness of the health and condition of electric circuits, not only under adverse fire risk conditions, but at all times, to ensure public safety.

Uncommon Knowledge

The Power System Automation Laboratory at Texas A&M has conducted a fifteen-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 has enabled researchers to study how, why, and under what conditions circuits fail. A few examples related to wildfire ignition follow; the cases cited are composite simplifications taken from actual events.

Case 1: Arcing downed conductor

A downed line can be a competent ignition mechanism as shown in the arcing downed conductor in Figure 1. But, why did the line fail and fall?

Figure 1 – Downed line arcing

Figure 2 – Arcing clamp

Utility responders to an outage have no way of knowing that an arcing device that caused erosion of a conductor, resulting in its fall, had been in an incipient failure mode for several days to weeks. The failure mechanism was gradual, progressive, and accelerating. Yet, this failure is undetectable and unidentifiable by protection and monitoring systems used today.

Figure 2 shows the damage in the jaws of a clamp that can erode a conductor causing it to break. Clamp degradation can occur for days, weeks, or longer before a line falls. Identifying and replacing the failing clamp before a red flag day can prevent a fire.

Case 2: 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. There is a low probability of ground fault ignition by this means, but it can occur.

What is not often known is that similar conductor clash events may have occurred in the same span multiple times, often months or even years apart. After the fire, investigators may see damaged lines but without the full context that the damage they see was created cumulatively by many events, none of which previously started a fire. Many conductor clash events do not cause an outage. An example is instructive.

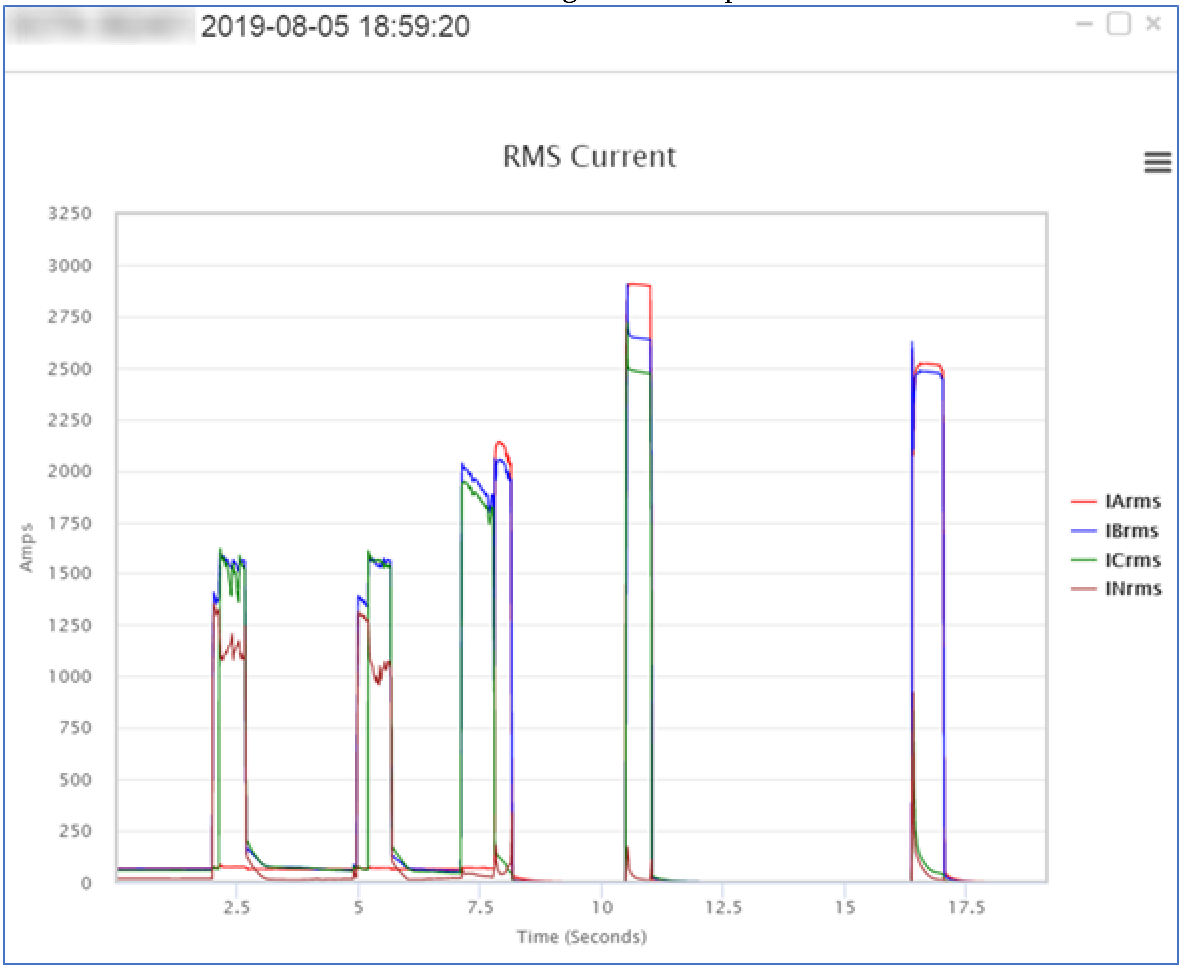


Figure 3 – Current waveforms during naturally occurring fault-induced conductor slap

The waveform shown in Figure 3 was recorded during a conductor clash event on a circuit. The authors have documented that multiple clash event can occur over time in the same span of a circuit, in one case five events over a period of four years.

Case 3: Failing devices – falling melted metal

Melted metal can fall from the jaws of a clamp due to resistive heating and/or arcing, as seen in Figure 2. This burning or heated metal represents a competent ignition mechanism. What is not known by an investigator or utility operators is that the clamp failure mechanism may have existed for weeks.

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 during active flareup. However, electrical series arcing is a definitive indicator of this condition. The electrical waveform presented in Figure 4 reveals the very subtle electrical signal from a failing clamp. This signal cannot be detected by common equipment used by utilities today.

Common Threads

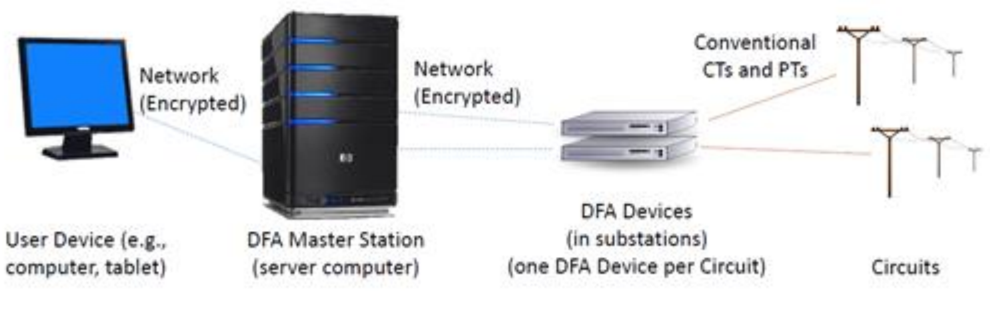
What do these three failure mechanisms have in common.

- All of the failure mechanisms may exist for days, weeks, or months before fire ignition occurs!
- None of these failure mechanisms can be reliably automatically detected, identified, or found by commonly used protection, monitoring, PQ, or AMI systems.
- If operators were informed and knowledgeable about the existence and periodic occurrence of any of these ignition mechanisms on a circuit, they could
    - Initiate repairs before a red flag day, before ignition or an outage could occur.
    - Justify de-energizing a circuit on high risk days.

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

DFA Technology

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. Working in close cooperation with the Electric Power Research Institute and utility companies, Texas A&M developed DFA technology based on high-fidelity line current and voltage event waveform data recorded from more than 1000 circuit-years of monitoring of in-service, medium-voltage distribution circuits at 20+ electric utilities. DFA is practiced with a hardware/software system – substation-based hardware that continuously monitors conventional current and voltage sensors (CTs and PTs), sophisticated proprietary software platform that analyzes those signals to detect normal and abnormal line events, and a central master station server that provides event reports to personnel. The components of the DFA technology system are illustrated below and described in more detail in references 1-5. 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 otherwise affecting safe, reliable delivery of electric service.



Each substation-installed DFA Device runs waveform analysis and classification software and then sends results to a central DFA Master Station. Personnel access DFA results via DFA Web, a browser-based website provided by the DFA Master Station.

Preventable Fire Ignition Event – Arcing Switch

Recall, our objective is to detect electrical ignition events that provide justification for a public safety power shutoff, intentionally de-energizing a circuit on a high fire risk, red-flag day. The following event started a fire! The event occurred on a 12kV circuit and was detected, identified, and recorded by a DFA device located on the substation bus. Only the DFA system captured this event.

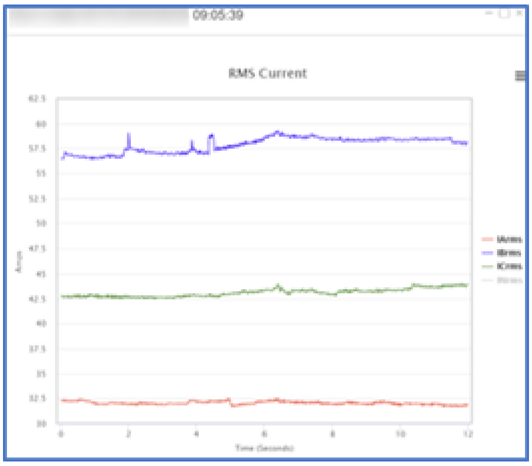


Figure 4a

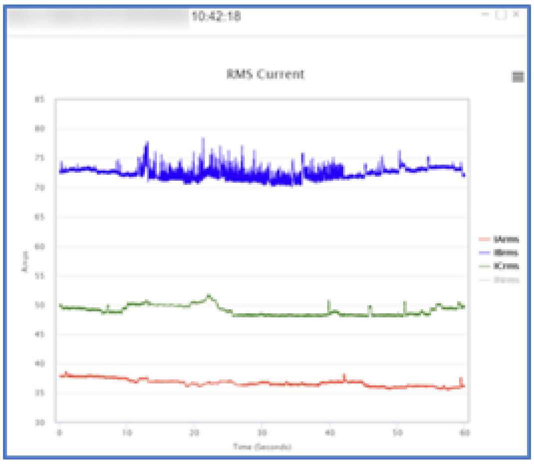


Figure 4b

The waveforms shown in Figure 4a and b were from a failing fused cutout that exhibited low-amplitude arcing over a period of 101 minutes. The cutout barrel ultimately burned in two with half dropping to the ground, stopping the event. A ground fire was ignited.

DFA detected the series arcing event early in its development when the incipient arcing activity was small and sporadic as shown in Figure 4a. Over the next 101 minutes, arcing activity accelerated as shown in Figure 4b. Final failure caused the fire.

A summary of the arcing switch progression and DFA response follows.

Time	Event Progression	DFA Action
T=0	Fused cutout begins to arc	•
T=1-100 min.	Sporadic arcing/low magnitude Arcing activity accelerates over time Fuse barrel suffers progressive damage	DFA detects and identifies arcing switch; operators are informed initially and repeatedly
T=101 min.	Fuse barrel separates and falls Arcing stops Fire starts in ground fuels	DFA records that arcing has ceased

If this arcing event caused a fire on a utility circuit today, post-event investigators likely would conclude that an arcing cutout caused the fire. Only if operators had preventively de-energized the circuit would the fire have been avoided.

Timely de-energization would reduce or eliminate the risk of ignition from this switch failure. The problem today is that a utility system has many switches and other apparatus, and the utility does not know their precise current condition. Operators, at the earliest stages of a device failure, such as an arcing switch, could de-energize the circuit based on DFA alerts. In the subject case, one hundred minutes of arcing and the final fire ignition would have been avoided. An outage would be fully justified. The key limitation today is that operators do not have the means to be informed when the device arcing begins.

Conclusions

Utility operators need better information to enable them to make better decisions. DFA technology, developed by Texas A&M Engineering, is a new tool that can provide them a real-time health assessment of circuits, including warnings of failing devices, arcing conditions, and clashing lines. Armed with this actionable information, they can make informed decisions, including decisions to take outages to avoid fire ignition.

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